Jeanine Townsend
Clerk to the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, California 95812
RE: Bay-Delta Workshop 3: Analytical Tools

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SWRCB Clerk

October 26, 2012

Dear Ms. Townsend:

American Rivers is providing comments in response to the State Water Resources Control Board's ("Board's") notice dated June 22, 2012, in which the Board presented the schedule for a series of workshops on particular topics associated with its review and potential revision of the 2006 Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). This letter addresses the topics to be discussed in the third workshop, Analytical Tools for evaluating the water supply, hydrodynamic, hydropower Effects of the Bay-Delta Plan, and responds to the two questions the Board posed in the June 22, 2012 notice.

Question one: what types of analyses should be completed to estimate the water supply, hydrodynamic, and hydropower effects of potential changes to the Bay-Delta Plan?

1. The Board should take utilize the logic chain approach as a framework for organizing adaptive management of the Bay-Delta Plan. The logic chain is an approach developed by American Rivers and the Bay Institute for the Bay Delta Conservation Plan (Attachment 1). The approach was reviewed and validated by an independent scientific panel convened by the Delta Science Program for BDCP (DSC Panel, 2010). The Board should require that the BDCP use the logic-chain to structure the BDCP adaptive management framework.

2. The Board should use the Delta Regional Ecosystem Restoration Implementation Plan process (DRERIP) for evaluating and testing proposed adaptive management measures. The DRERIP approach and DRERIP conceptual models were developed over the course of several years by the CALFED Science program and later the Ecosystem Restoration program with extensive input from the fish and wildlife agencies (DRERIP, 2008). http://www.dfg.ca.gov/ERP/DRERIP.asp

3. The adaptive management element of the Bay-Delta Plan should adopt an iterative approach for testing, assessing, and revising conservation measures designed to protect public trust resources. Adaptive management is an iterative approach as illustrated by the circular adaptive management diagram described in the Delta Stewardship Council's Draft Delta Plan, which has been presented to you by previous expert panelists in workshops number one and two.

Adaptive management will be much more effective if it is practiced deliberately and strategically using the logic-chain and the DRERIP evaluation process. American Rivers recommends the boards utilize the following ten step approach on a periodic basis to continuously refine and revise conservation measures, including flow measures.

4. The Board should consider the availability of alternative water supplies and water transfers in determining water supply impacts of potential changes to the Bay-Delta plan. The Board should specifically model reservoir reoperation, including change in the flood reservation and conjunctive management of surface and groundwater supplies. Previous studies have demonstrated that conjunctive management can improve water supply yields for both consumptive and environmental flows (NHI et. al, 2011; NHI, 1998) In conducting these analyses, the Board should build on the modeling approach in certain BDCP alternatives (CS5, Alternative 7a, and Alternative 8 proposed by SWRCB staff) that shows that it is possible to substantially increase winter/spring outflow without adversely or significantly affecting reservoir storage and upstream protections for salmonids.

5. The Board should conduct an integrated water management analysis to determine how expanded floodways could enable changes in the flood reservation rules for upstream reservoirs in a manner that improves water supply reliability without compromising public safety. American Rivers has already conducted a pilot analysis of this approach for the San Joaquin Basin. A draft report describing this method and results from our pilot study are attached as Appendix B to this comment letter.

6. The Board should compare flow alternatives, including alternatives based on a percentage of unimpaired flows approach, to the flow needs of key species. Similar to what the Board did in 2010, we recommend that they first aggregate the flow needs of key species and then compare those needs with other alternatives to see how well they meet the duration, frequency, magnitude, and timing of flow needs of species. In addition to the unimpaired flows approach, the Board should develop alternatives that mimic the natural spring hydrograph while avoiding the potential for severe declines in reservoir storage that could harm public trust resources. See paragraphs 8 and 9 below for more detail on how to develop alternative flow regimes that mimic the natural flow regime.

7. To the extent that the beneficial uses may conflict, or the Board is otherwise required to balance the needs of public trust resources and consumptive uses in revising water quality objectives, the Board should first identify the ecological flow needs of public trust resources. If reservoir releases for ecological flow needs result in undesirable impacts to other beneficial needs, the board should then consider reservoir and water management strategies such as conservation to mitigate impacts to other beneficial uses. If the board eventually determines that innovative reservoir and water management strategies do not sufficiently mitigate impacts to other beneficial uses, the board should only then consider balancing the ecological flow needs of

public trust resources against other beneficial uses using the approach identified in recommendation number 9 below.

8. To the extent that the Board determines that limiting ecological flows may be necessary to minimize the conflict between beneficial uses, the Board should then identify the most important ecological needs (i.e. instream temperature regulation, flood plain inundation, or spring pulse flows), develop measurable objectives that specify timing, duration, magnitude, and frequency of flows necessary to achieve these objectives, and then develop a revised flow regime designed to meet these objectives with less impact on other beneficial uses. American Rivers recommends the following approach to developing flow regimes that best balance the needs of ecological flow regimes and other beneficial uses: Develop ecological flow budgets for five or six year classes (wet, above normal, below normal, dry, critical high, and critical low)[1] and then shape the ecological flow budget into daily or weekly environmental hydrographs for each year type that are designed to best achieve the most important ecological objectives within the ecological flow budget for each year class. These environmental hydrographs should then be modeled as instream flow requirements on a monthly time step for the period of record. If the demand imposed from the environmental flow hydrographs still results in undesirable reservoir level declines in some years, the model should then be constrained to limit irrigation deliveries and environmental flow releases when reservoir levels drop below a specified threshold on March 1. This analysis should be run iteratively to identify an optimal balance between environmental flow releases, reservoir levels, and other beneficial uses.

9. The optimized environmental flow hydrographs developed for each year class should then be converted into a “continuous line hydrograph” using the procedure described in Draft Operation Guidelines for Implementing Restoration Flows that was developed for the San Joaquin River Restoration Program (SJRRP, 2008).

10. The Board should conduct an analysis of the frequency, timing, and area of floodplain inundation for various alternatives. To conduct this analysis, the Board should use an approach developed by American Rivers that quantifies the area and annual frequency of inundated habitat for various flow regime alternatives. This approach generates area-duration-frequency curves for various flow regimes and compares estimated annual habitat curves (EAH) for different flow regime scenarios. This approach is described in Appendix B to this comment letter.

Question two: What analytical tools should be used to evaluate these effects? What are the advantages, disadvantages, and limitations of these tools?

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[1] Year classes should be divided according to exceedance values roughly as follows (wet - 80 percent exceedance, above normal – 50 to 80 percent, dry – 20 to 50 percent, critical high – 5 to 20 percent, and critical low – less than 5 percent exceedance.

1. The Board should use a hydraulic model to evaluate the frequency and area of floodplain inundation, particularly for the lower San Joaquin River. American Rivers recommends the HEC-RAS model developed by the USACE for the lower San Joaquin and modified by Newfields River Basin Services for DWR.

2. Environmental Flows Model (EFM) developed by the USACE to calculate the frequency, duration, and timing of specific flow objectives for varying hydrologies.

3. The Board should use models like the Water Evaluation and Planning (WEAP), CALVIN or another approach. The Board should not simply rely on CALSIM due to its inability to consider demand reduction strategies such as conjunctive use, water conservation, and water transfers. Water supply models such as WEAP should be utilized first to identify the best strategies for balancing water supply and public trust resources and then identify the economic impacts various environmental flow scenarios utilizing and economic optimization such as CALVIN.

Thank you for this opportunity to provide written comments. I have attached a list of references and submitted the new document referenced above in form requested by the Board. American Rivers looks forward to the upcoming workshops. If you have any questions about our comments or about the material attached, please contact me at (510) 388-8930.

Sincerely,

John Cain
Conservation Director
Bay-Delta and Flood Management

References Cited

American Rivers, The Bay Institute, Environmental Defense Fund, Natural Heritage Institute, Natural Resources Defense Council, The Nature Conservancy [AR et al. 2010 exhibit 1] Written Testimony of John R. Cain, Dr. Jeff Opperman, and Dr. Mark Tompkins Before the State Water Resources Control Board, Exhibit 1

Bay Delta Conservation Plan. March 2010. Delta Science Program Panel Review of the “Logic Chain” Approach.

DRERIP Adaptive Management Planning Team. March 2008. Scientific Evaluation Worksheet (DRERIP Tool). Developed for the Department of Fish and Game Ecosystem Restoration Program. http://www.dfg.ca.gov/ERP/DRERIP.asp

Natural Heritage Institute and Glen Colusa Irrigation District. December 2011. Feasibility Study of Re-operation of Shasta and Oroville Reservoirs in Conjunction with Sacramento Valley Groundwater Systems to Augment Water Supply and Environmental Flows in the Sacramento and Feather Rivers: Northern Sacramento Valley Conjunctive Water Management Investigation.

Natural Heritage Institute. December 1998. Feasibility study of a maximal program of groundwater banking.

San Joaquin River Restoration Program. 2008. Draft Technical Memorandum: Operation Guidelines for Implementing Restoration Flows.

Appendix A: Eightfold Path to Adaptive Management for a Bay-Delta Plan

1. Develop and/or refine SMART objectives identify assumed stressors that presently limit attainment of the objectives (hypotheses re: what's causing fish decline in the Delta). Develop stressor reduction targets that would be sufficient to significantly reduce the assumed stressor. Identify specific conservation measures, including changes in the flow regime, to achieve stressor reduction targets.

2. Utilize the DRERIP evaluation process to determine the magnitude and certainty of positive and negative stressor reduction *outcomes* associated with conservation measures. Evaluate risk, reversibility, and opportunity to learn from each action as well as an estimated timeline from project initiation to development of outcomes. Use quantitative models as appropriate to quantify outcomes and inform the DRERIP evaluation.

3. Complete the DRERIP evaluation process by inputting information from step two into DRERIP vetting process. This sorts conservation measures into four bins:
    a. Full scale implementation (Tier 1 actions)
    b. Pilot project (Tier 2 actions)
    c. Targeted research (Tier 3 - low certainty/high to medium magnitude)
    d. Discard. Note that discarded measures can be substantially revised and reevaluated.
4. Compare magnitude and certainty of Tier 1 measure *outcomes* to total stressors reduction targets in step 1, identify gaps, and then refine or develop new conservation measures to fill those gaps.

5. Run new or modified conservation measures through the DRERIP vetting process and revise Tier 1 action plan as appropriate.

6. Assemble all Tier 1 projects into an "Implementation Action Plan" and then sum-up the projected outcomes into a credible estimate of the overall impact in short-term, mid-term, and long-term (this may be a numerical estimate, but will more likely have a qualitative aspect to it). This will be the plans estimated contribution to ecosystem recovery.

7. Assemble all Tier 2 and Tier 3 measures and develop an "Uncertainty Reduction Plan" by which lessons learned from these can contribute to full-scale implementation or abandonment of Tier 2 and 3 conservation measures. Identify how information gained from these projects will be useful in developing/refining life cycle analysis or other models to help reduce uncertainty over time.

8. Revise objectives and develop performance metrics based on information developed from previous 7 steps. Repeat steps 1-8 for revised objectives.

9. Based on collective learning from previous eight steps – design scientific decision-making process (“Adaptive Management Plan”) for moving forward.

10. Compile Tier 1 Implementation Action Plan, “Uncertainty Reduction Plan,” and “Adaptive Management Plan” into the Bay-Delta plan and the BDCP permit application.

Appendix B: American Rivers Comments to SWRCB Workshop #3

Quantifying the Benefits of Expanded Floodways

An approach to multi-benefit river corridor evaluation
informed by a pilot study on the San Joaquin River

Problem Statement

Integrated water management planning to achieve multiple objectives with new investments is the official policy of the state of California and the underlying premise of several major planning efforts including the Central Valley Flood Management Plan (CVFMP), the Bay Delta Conservation Plan (BDCP), and the Delta Plan. Each of these planning efforts identifies the creation of floodplain habitat as a critical element of success. Floodplain creation for these efforts will require expansion and/or reorganization of the physical footprints of the San Joaquin River, Sacramento River, and Delta corridors. Despite the fact that each of these efforts (among others with significant floodplain habitat goals) is well underway, a clear and widely-applicable approach to 1) defining necessary modifications to existing river corridor footprints, and 2) systematically evaluating the three primary benefits (water supply, flood management, and ecosystem) of the modified system has remained elusive. Without such an approach, it will be difficult, if not impossible, to plan and design projects to systematically achieve these multiple benefits.

This study proposes an approach to evaluating these three benefits and demonstrates its use through a pilot study of an expanded footprint on the lower San Joaquin River, where we hypothesized that an expanded river corridor footprint could measurably improve flood management, increase water supply reliability, and improve ecosystem conditions. Our approach requires three primary inputs (peak flow hydrology, daily hydrology, and a modifiable river corridor footprint) and includes three types of analyses (flood management evaluation, water supply evaluation, and ecosystem benefit evaluation). We combined widely-accepted data and methods in this study, all of which are described in the following sections and illustrated in Figure 2.

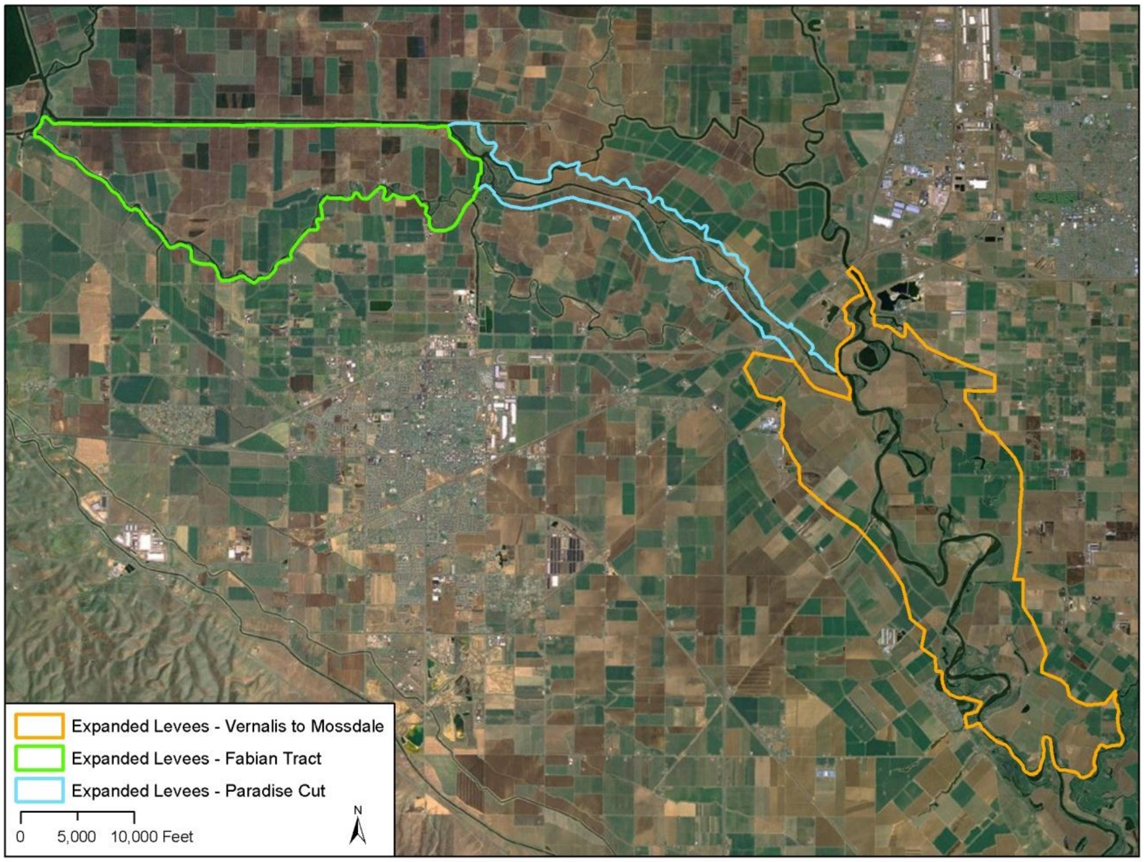

Figure 1. Expanded Flood Corridor

Study Objectives

The objective of the study is to develop and demonstrate an approach for quantifying the flood risk reduction, water supply, and ecosystem restoration benefits of expanding floodways along leveed river channels.

Pilot Study Area Selection

We selected a reach of the lower San Joaquin River between Vernalis and Old River as a test case for evaluating the benefits of an expanded river corridor footprint for the following reasons:

1. It is a known bottleneck for the San Joaquin River flood management system and has failed repeatedly during the last half century;
2. It is increasingly constrained due to recent and ongoing urbanization in levee-protected floodplains in Manteca, Lathrop, and Stockton;
3. It is in a region shown by the USGS (Dettinger et al 2011) as likely to experience significantly larger floods in the future as a result of climate change, particularly rising temperatures;
4. Hydrology and flow routing in this area are relatively simple compared to the Sacramento basin due to the relatively small number of tributaries and unregulated run-off.

5. It is easier to model reservoir management change in the San Joaquin basin relative to the Sacramento basin, because the areas reservoirs are not relied upon to meet Delta outflow objectives.

Methods

We developed several different scenarios to illustrate the range of potential benefits possible with an expanded flood corridor and altered hydrology along the lower San Joaquin River and then used an integrated set of analyses using existing analytical tools to evaluate the flood risk reduction, water supply, and ecosystem benefits of each scenario.

We developed four distinct hydraulic scenarios including an expanded floodway and three different reservoir reoperation scenarios. The expanded floodway scenarios enable reservoirs to safely release larger flows prior to a forecasted flood and therefor justify reservoir reoperation scenarios with reduced flood reservation requirements

Floodway and Hydraulic Scenarios:

1. Existing conditions: Existing channel and levee configuration combined with existing hydrology and reservoir operations.
2. Existing floodway configuration with altered hydrology: Existing channel and levee configuration with an altered hydrology and reservoir operation regime (described in the reservoir reoperation scenario #3 below) designed to increase the frequency of floodplain inundation without significantly disrupting water supply deliveries or reservoir reoperation.
3. Expanded floodway configuration (Figure 1) with existing hydrology: Setback or removed levees along the San Joaquin between Vernalis and Mossdale, create a new flood bypass along Paradise Cut, and setback levees on Fabian Tract. The assumed configuration routes more water over the Paradise Weir and out to Grant Line Canal and the Old River, and creates flood storage in Fabian Tract.
4. Expanded floodway configuration and altered hydrology: Floodway configuration identical to scenario 3 and altered hydrologic regime as described in scenario 2.

Reservoir Re-operation Scenarios:

1. Existing conditions modeled (1950-2001).
2. Reservoir reoperation modeled (1950-2001): Assumes both reducing the flood reservation and conjunctive use to transfer reservoir storage into groundwater storage. We justify the reduction in the flood reservation by expanding the downstream floodway so that it can safely accommodate larger objective releases[2]. The model assumes that the size of the minimum flood reservation starting November 1st and extending through the flood season is half of what is required under existing rules for New Melones, New Exchequer, and New Don Pedro. In addition, the model establishes a lower maximum storage on November 1st and transfers any

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[2] Objective releases are the target reservoir release prior to and during a large flood.

water in excess of this maximum into a groundwater bank. This effectively increases flood reservation on November 1st, but the reservoir is allowed to immediately fill to the new minimum flood reservation rule described above.

3. Reservoir reoperation with increased instream flows: Assumes scenario two but with a downstream flow target designed to create 14 days or more of inundated floodplain habitat in all but the driest 20% of years.

The purpose of the three reservoir reoperation scenarios is to compare the water supply outcomes of different reservoir reoperation scenarios that could be logically paired with floodway scenarios described above. Either scenario two or three, which both decrease the flood reservation requirement, can be paired with the expanded floodway scenarios because the expanded floodways allow reservoirs to safely release higher flows before a forecasted flood, obviating the need for a larger flood reservation.

Integrated Approach with Existing Analytical Tools

We developed an integrated "flow" of analyses (Figure 2) using available and widely accepted tools that allowed us to iteratively evaluate the multiple benefits of an expanded flood corridor and altered daily hydrology in the lower San Joaquin River. The inputs to this flow of analyses include flood corridor geometry using best available topographic information (LiDAR data), flood hydrology (the CVFMP 50-year hydrograph and the 1997 flood hydrograph), and daily hydrology (USGS records). We used daily hydrology from the Vernalis gauge for the post Dam period (1979-present) to characterize existing conditions and synthesized daily hydrology from monthly reservoir model outputs to describe an altered hydrologic regime designed to increase the frequency of floodplain inundation. Using these inputs, we applied a one-dimensional hydraulic model based on the Comprehensive Study (USACE 2002) HEC-RAS model to measure both inundated floodplain area for a wide range of flow and flood stage for extreme events.

We used the Water Evaluation and Planning (WEAP) model (SEI 2011) to predict how the different reservoir reoperation scenarios change reservoir storage, water supply deliveries, and monthly reservoir releases. We analyzed daily hydrology with the ecosystem functions model (HEC-EFM) (USACE 2011) developed by the USACE to define the frequency and magnitude of duration events (1-day, 7-day, 14-day, etc.) under the various hydrologic scenarios, and then correlated these flow magnitudes with output from the hydraulic model to calculate the frequency and area of inundated habitat for various duration events.

To quantify flood risk, we developed estimates of annualized levee failure probability. While annualized expected damage is typically used in this type of analysis, we lacked reasonable economic data for the reach and chose instead to examine failure probability for the reach which can then easily be used if flood damage functions become available in the future. We defined the probability of levee failure using levee fragility curves which relate the probability of failure, due to both overtopping and geotechnical instability, to freeboard. The fragility curves were published by DWR in the most recent version of the Central Valley Flood Protection Plan (CVFPP) (DWR 2012). Using the correlations defined by the fragility curves for the lower reach of the San Joaquin River, we mapped the probability of failure for each 10-foot segment of levee in both the existing and levee removal scenario. We then calculated the average failure probability for the reach for each modeled flow and correlated this probability of failure with the probability that the given flow may occur. By integrating the failure curves, we were able to calculate annualized failure probabilities.

Performance Metrics

We evaluated performance using the metrics described in Table 1. We used fairly standard metrics for flood risk reduction and water supply enhancement but we developed two new metrics for floodplain inundation habitat – the area-duration-frequency (ADF) curve and the annualized expected habitat (AEH). The ADF is a calculation of the area of inundated floodplain habitat wetted for a minimum duration during the ecologically appropriate season (e.g. 14 days in the spring) as well as the annual frequency at which the inundation occurs. The AEH values are the amount of floodplain habitat that occurs in any given year and are calculated by integrating each ADF curve over the recurrence interval (f=0 to f=1) . The ADF and AEH could be used to predict habitat availability for a number of terrestrial and aquatic plan and animal species, but we have constrained this analysis to estimating expected habitat for rearing juvenile salmon and reproducing Sacramento splittail.

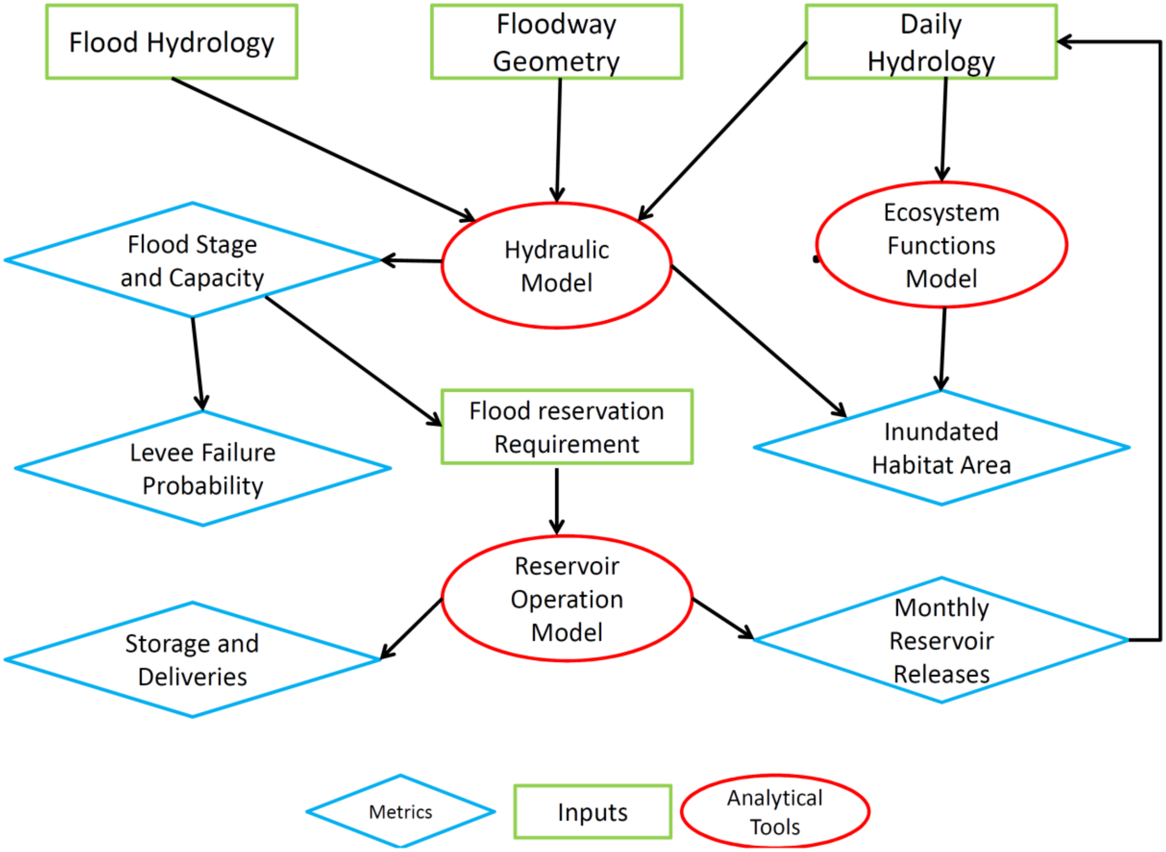


Figure 2. Schematic depicting the analysis flow

TABLE 1: Evaluation Criteria for Expanded Floodway Analysis

Performance Metrics	Rationale
Flood Risk Reduction	
Reduced Stage in Urban Areas • Mossdale • Head of Old River • Brandt Bridge	Reducing stage in urban reaches far more important than reducing stages in other reaches.
Reduced Stage in Rural Areas • Paradise Cut at I5 • Paradise Cut at Paradise Rd. • Old River at Middle River • Old River at Tracy Blvd. • Grant Line Canal at Tracy Blvd.	Provides information on how the hydraulics of the system change with different scenarios. Not particularly useful as measure of flood risk because surrounding areas are relatively undeveloped .
Reduced Failure Probability in urban reach between Mossdale and Stockton	Levee fragility is used as surrogate for risk, since flood damage functions for this reach are not currently available.
Percent Increased Capacity	Surrogate for resiliency to characterize system performance in large events that cannot be modeled without making extraordinary assumptions.
Water Supply Reliability	
Total Annual Deliveries (from Stanislaus, Tuolumne, Merced, Fresno Chowchilla Rivers, and new groundwater bank))	Ultimate measure of water supply performance.
Total Carryover Storage (six existing terminal reservoirs plus a new 1 MAF groundwater bank)	Surrogate for water supply reliability with implications for hydro-power generation.
Vernalis Flow: Feb-May volume (TAF)	Ecological water supply reliability during critical period.
Ecosystem Function	
Floodplain Inundation • Maximum Potential Area • Area Duration Frequency (ADF) Curve • Annualized Expected Habitat for various duration events	Defines the relationships between three critical ecosystem variables for the entire suite of possible combinations. Maximum potential area refers to the hydrologically connected floodplain.
Juvenile Salmon Habitat • ADF for 14 days Dec.-May	Minimum inundation duration necessary to generate food and habitat for juvenile salmon. Timing needs correction: should be adjusted to February thru May, but we don't expect significant change in results.
Sacramento Splittail Reproduction • ADF for 30 days Feb-June	Inundation duration necessary for spawning and juvenile rearing.
Other Ecosystem Functions not evaluated • Channel migration • Channel complexity • Hyporheic flow • Riparian recruitment • Other species	Channel migration, complexity, and subsurface flow cannot be evaluated with study approach, but would clearly benefit from expanded floodway and increased flood flow frequency. Riparian recruitment and habitat potential for other species could be tested with study approach, but were not evaluated as part of this study.

Results

The results for each of the metrics identified in Table 1 are presented below.

Peak Flow Stage Reduction

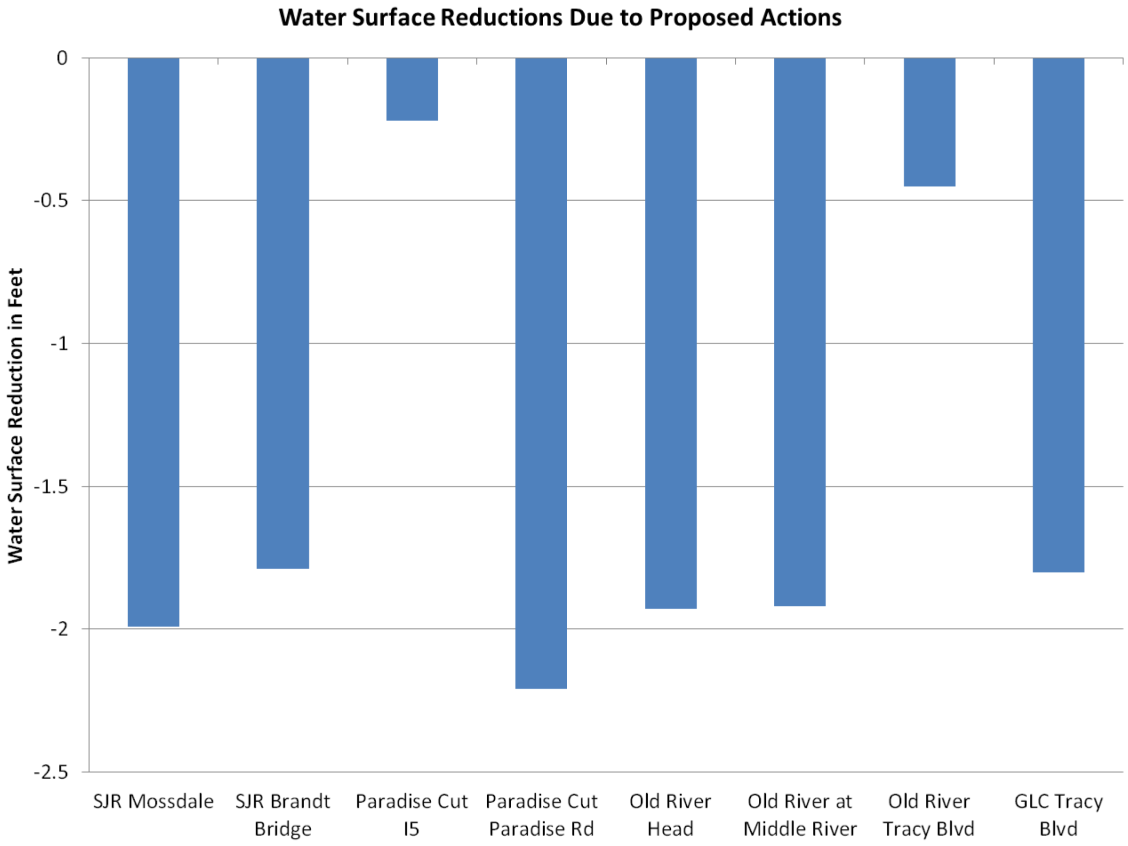
Figures 3-5 compare peak flood stage under existing and expanded floodway scenarios throughout the study area. Figure 3 shows the water surface elevation reductions at eight locations for the 50 year recurrence interval flow. Flood stage along the urbanized mainstem of the San Joaquin River between Manteca and Stockton declined nearly 2 feet at Mossdale, Head of Old River, and Brandt Bridge. Flood stage is also reduced nearly 2 feet at the confluence of Middle River and the head of Old River. In addition to reducing flood risk for the urbanizing areas, these stage reductions also reduce risk for Robert's Tract, which is home to numerous farmers who grow perennial crops. Stage reduction in these areas is due to lower flood volumes resulting from the increased diversion of mainstem flows away from the mainstem and into the expanded Paradise Cut bypass and eventually Grant Line Canal and lower Old River.

Figures 4a-4d show water surface profiles for the 50-year flood along several different flow paths including the mainstem, Paradise Cut, Old River, and Grant Line Canal. Figure 2a shows stage reductions of up to 5 feet in the rural reach downstream of Vernalis and upstream of Highway 5 (station 9,000) where major setbacks are implemented.

Because of the assumed modifications to the Paradise Weir, Paradise Cut receives a greater portion of the total San Joaquin River flow under the proposed conditions. Due to levee setbacks and the general widening of Paradise Cut, however, water surface elevations in Paradise Cut are generally lower under the proposed conditions scenario. This is most dramatic in the vicinity of Paradise Road, where the water surface reduction is over 2 feet. Near the Interstate 5 bridge, the reduction is negligible.

Despite the fact that more flow is routed into Grant Line Canal and Old River from Paradise Cut, flood stages are generally lower in Grant Line Canal (Figure 4b), because all of Fabian Tract has been converted into a floodplain and attenuation basin as part of the expanded floodway scenario. In lower Old River, however, stage during the 50-year recurrence interval flow is increased by 5 feet. This appears to be an artifact of how an altered Fabian Tract is represented in the model: the model geometry results in floodwaters being routed out of Grant Line Canal across Fabian Tract and into the constrained Old River channel. Results for both Grant Line Canal and lower Old River are less reliable due to their relative proximity to the model boundary.

Figure 3: Water Surface Reductions at Eight Key Locations



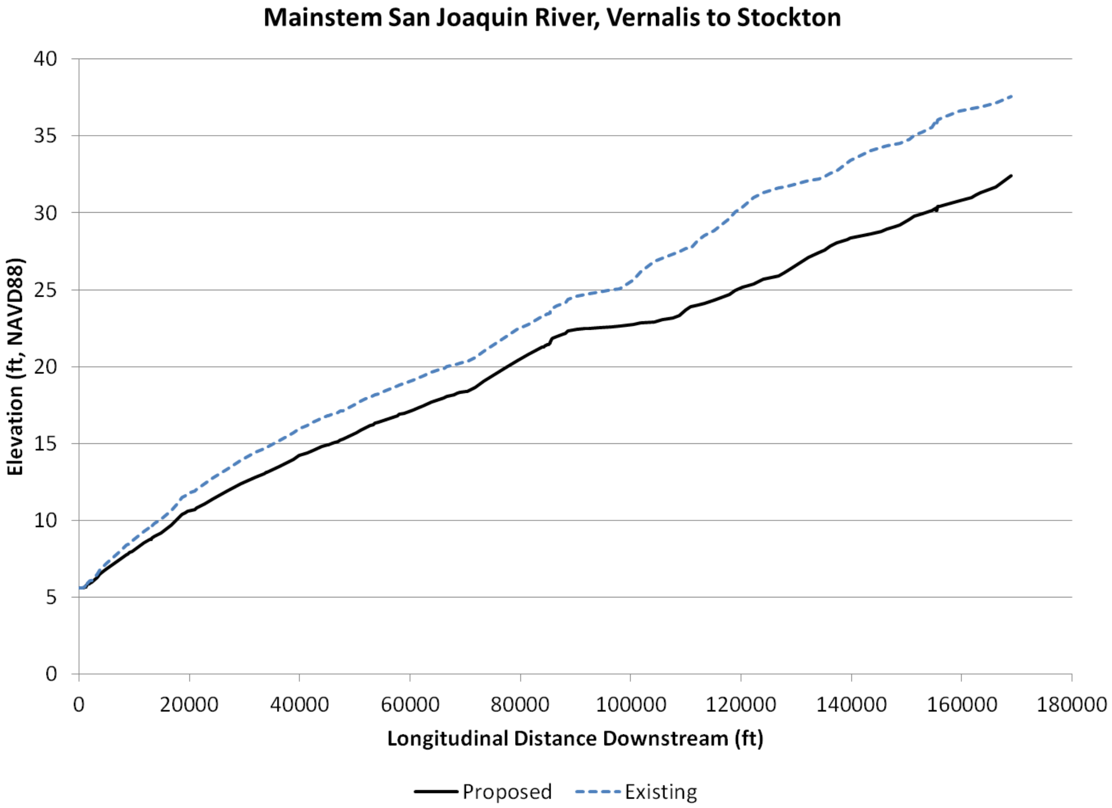


Figure 4a: Longitudinal Profiles of Water Surface Elevation, Mainstem San Joaquin River.

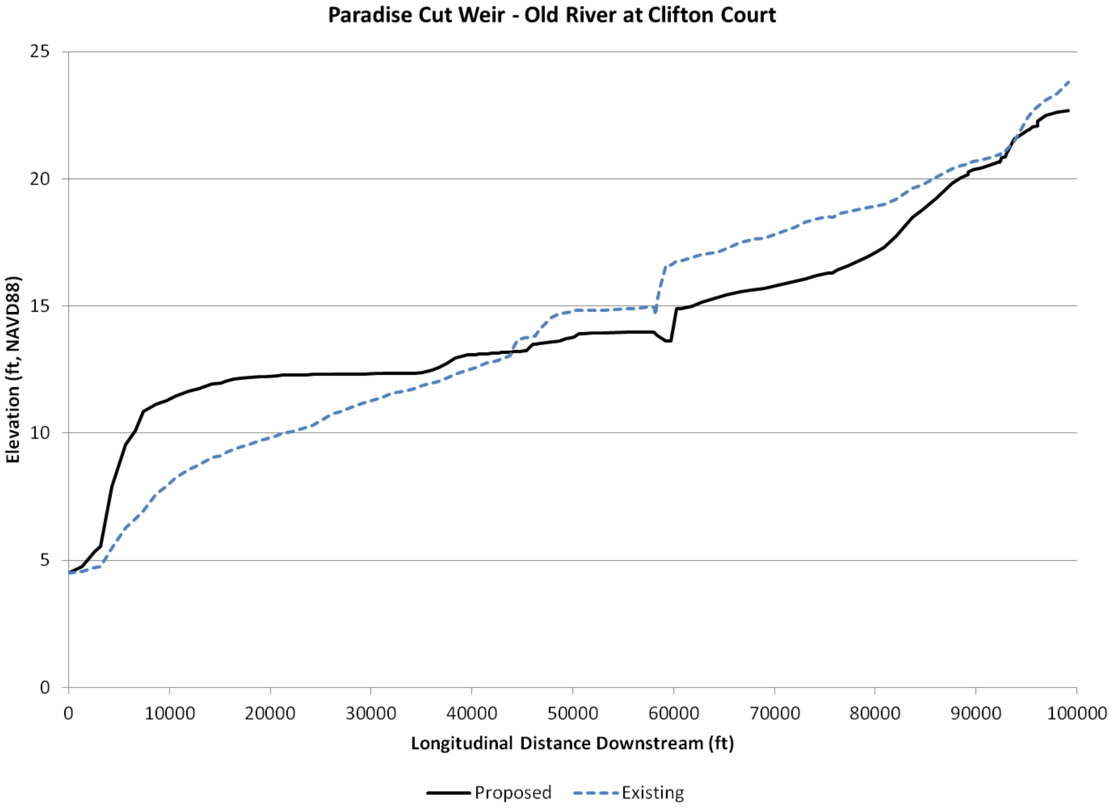


Figure 4b: Longitudinal Profiles of Water Surface Elevation, Paradise Cut through Old River

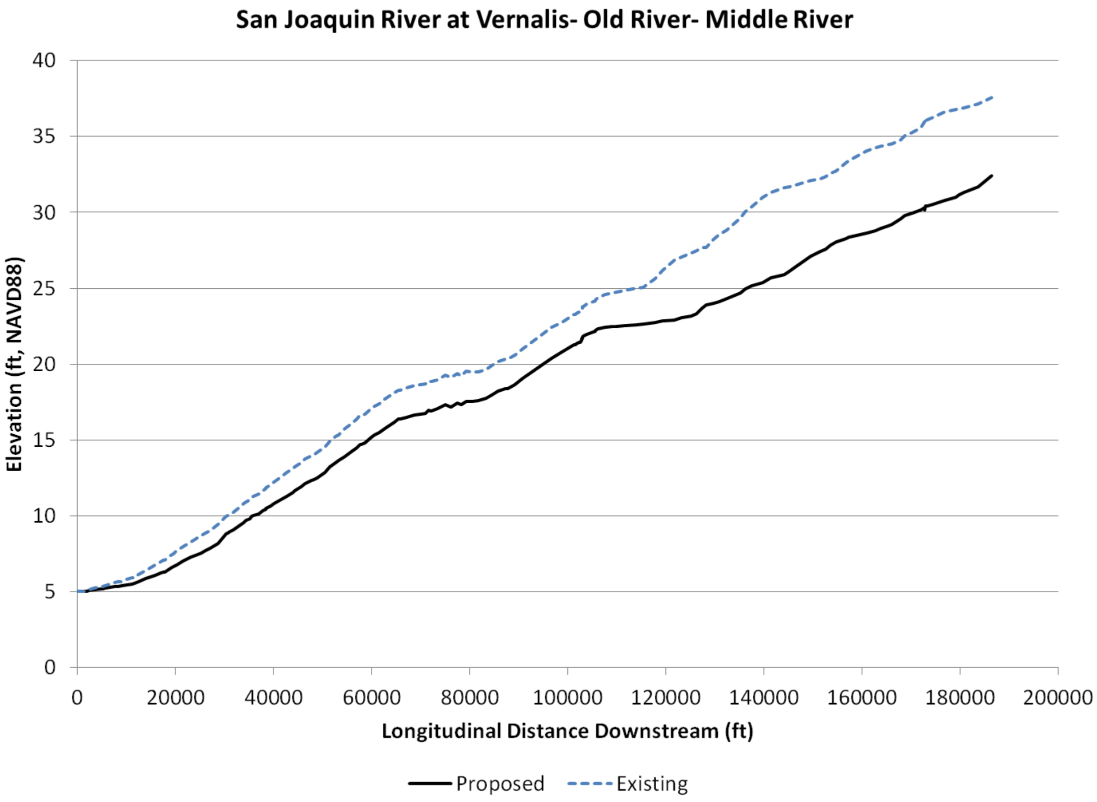


Figure 4c: Longitudinal Profiles of Water Surface Elevation, Mainstem San Joaquin River through Old River through Middle River

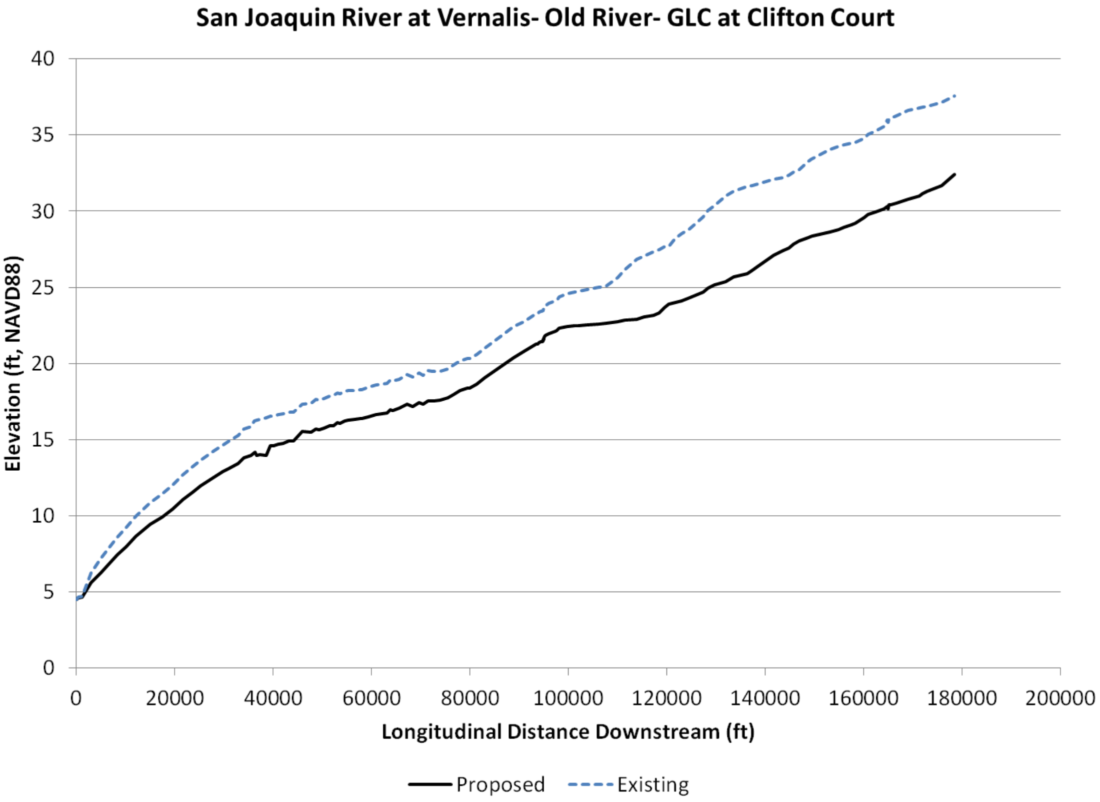


Figure 4d: Longitudinal Profiles of Water Surface Elevation, Mainstem San Joaquin River through Old River through Grant Line Canal

Percent Increase in Flood Conveyance Capacity

Figure 5 compares existing and proposed peak stage conditions for the 50-year flow at Brandt Bridge on the urbanizing mainstem San Joaquin River. The expanded lower San Joaquin River corridor can convey 28 percent more flow (13,600 cfs) than the existing conditions scenario without exceeding the 50-year flow stage at Brandt Bridge. This is not an increase in hydraulic capacity at Brandt Bridge itself, but rather an increase in the total system conveyance capacity associated with re-routing more of the peak flow away from the urbanizing mainstem between Lathrop and Stockton and into Paradise Cut, resulting in lower flows at Brandt Bridge for the 50-year peak flow. It is important to note that the flow at Vernalis represents the entire flow in the San Joaquin River prior to routing through flow splits down the four major distributary channels (Old River, Middle River, Grant Line Canal, and mainstem San Joaquin River).

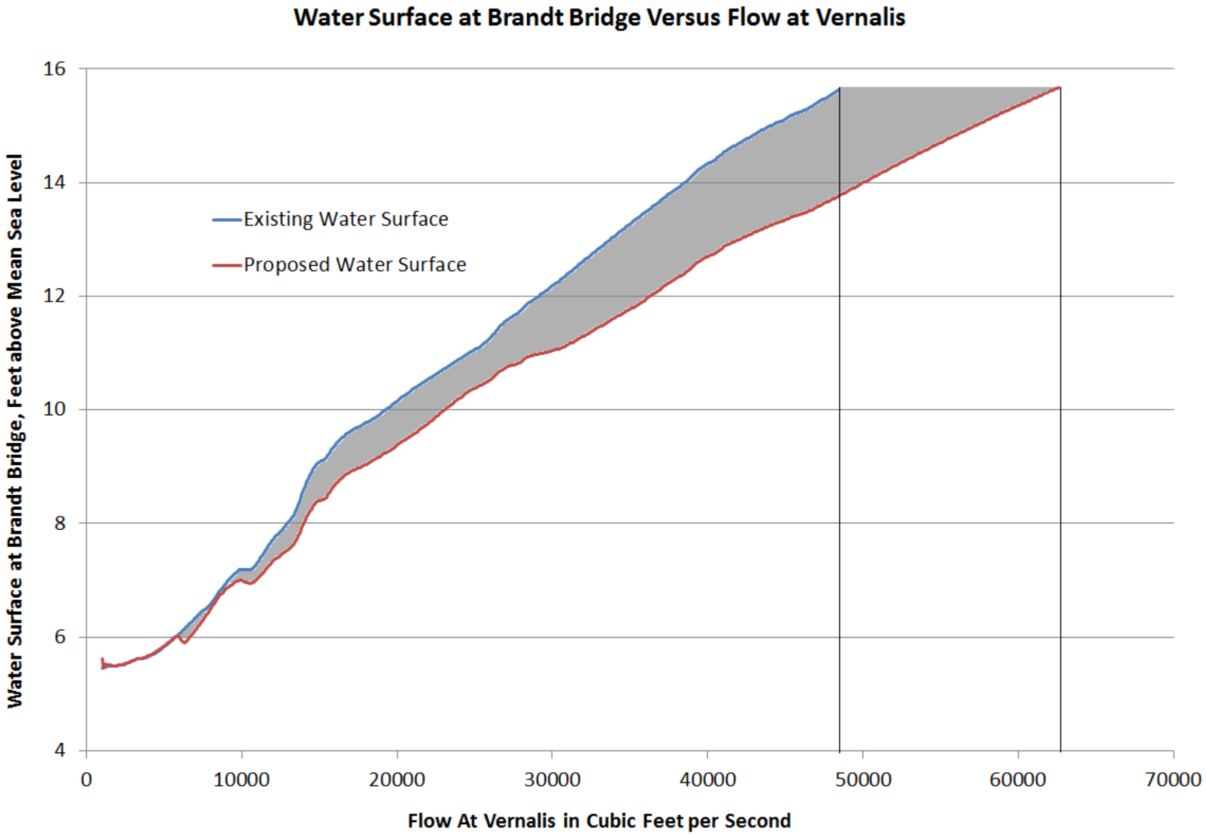


Figure 5: Water Surface Elevation at Brandt Bridge vs. Flow at Vernalis. The grey shading represents the increased total capacity for flow at Vernalis for a given water surface elevation at Brandt Bridge.

Reduced Failure Probability (function of the increase in freeboard)

Table 2 below shows the annualized probability of failure for the right bank levee protecting the urbanized reach of the Lower San Joaquin River between Mossdale and Stockton. The reduction in levee failure probability is a function of the increase in freeboard that results from expanded conveyance capacity. Corridor expansion provides a significant reduction in the annualized probability of failure of the levee through the reach. Looking at the combined effects of corridor expansion and a reservoir reoperation scenario, the annualized probability of a levee failure in the reach is reduced from 9.2 to 2.3 percent, or a 75 percent change. It is important to realize that the right bank levee, which protects the urbanizing areas in Reclamation District 17, is much stronger then the left bank levee for which results are not shown.

The recommended changes in hydrology, however, significantly increase the probability of failure when the configuration of the flood system is held constant and only the hydrology is varied. The levee fragility results in table 2 take into consideration both the expanded floodway and the altered hydrology. The expanded floodway reduces levee failure probability by lowering flood stage for all flood events. The recommended hydrology, however, intentionally increases the frequency of moderate flood events to create inundated floodplain habitat. Although these moderate flood events are well below the design flow for this reach, the increase in the frequency of these events under the recommended flow regime combined with a slight probability of levee failure at low flood stages, increases the probability of failure slightly. Although the levee fragility analysis considers changes in probability of failure due to intentional changes in the hydrology, it assumes that the frequency of unintentional and uncontrolled releases during extreme floods does not change despite the fact that the flood reservation in upstream reservoirs is halved.

Table 2: Percent probability of levee failure between Mossdale and Brandt Bridge.

	Existing Hydrograph	**Recommended Hydrograph**	**Percent Change due to reservoir reoperation**
Existing Floodway	9.2%	14.6%	37%
Expanded Floodway	1.7%	2.3%	25%
Percent Change from Floodway Expansion	-81%	-84%	

Water Supply Reliability: Deliveries, Carryover Storage, and Vernalis Flows

Figures 6 and 7 show changes in combined annual carryover storage and combined annual deliveries as well as changes in average annual carryover storage and average annual deliveries for the six reservoirs and the new groundwater bank assumed in the reservoir reoperation scenarios. The results are preliminary, but they indicate a fifteen percent decline in end of year carryover storage and, surprisingly, a ten percent increase in average annual deliveries between existing conditions and hydrologic scenario number three (reservoir reoperation with increased instream flows downstream). The reduction of carryover storage is the result of both intentional drawdown for groundwater banking at the end of the year as well as increased releases to meet spring flow targets at Vernalis. The surprising increase in average annual deliveries is presumably the result of both increased storage and the reduced flood reservation requirement.

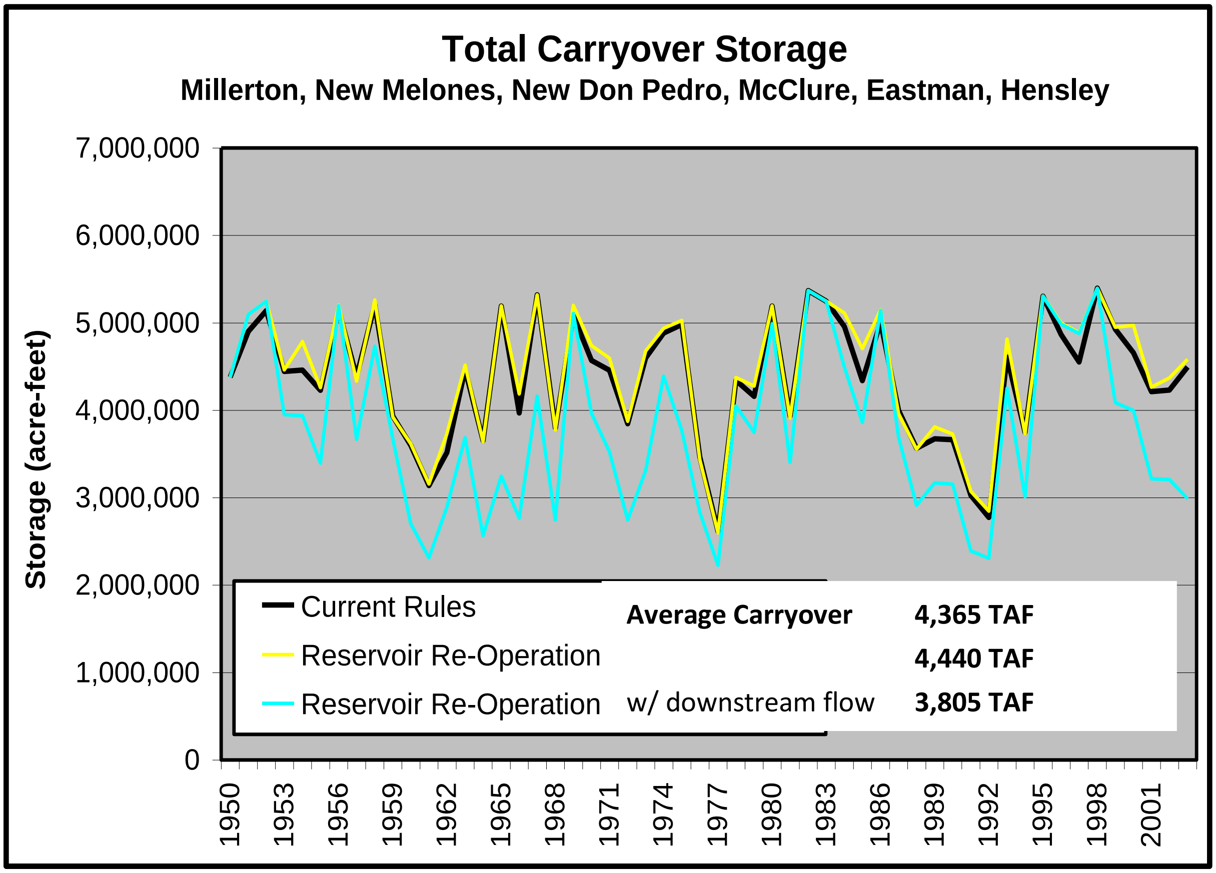


Figure 6: Average annual carryover storage for reservoirs and new groundwater storage

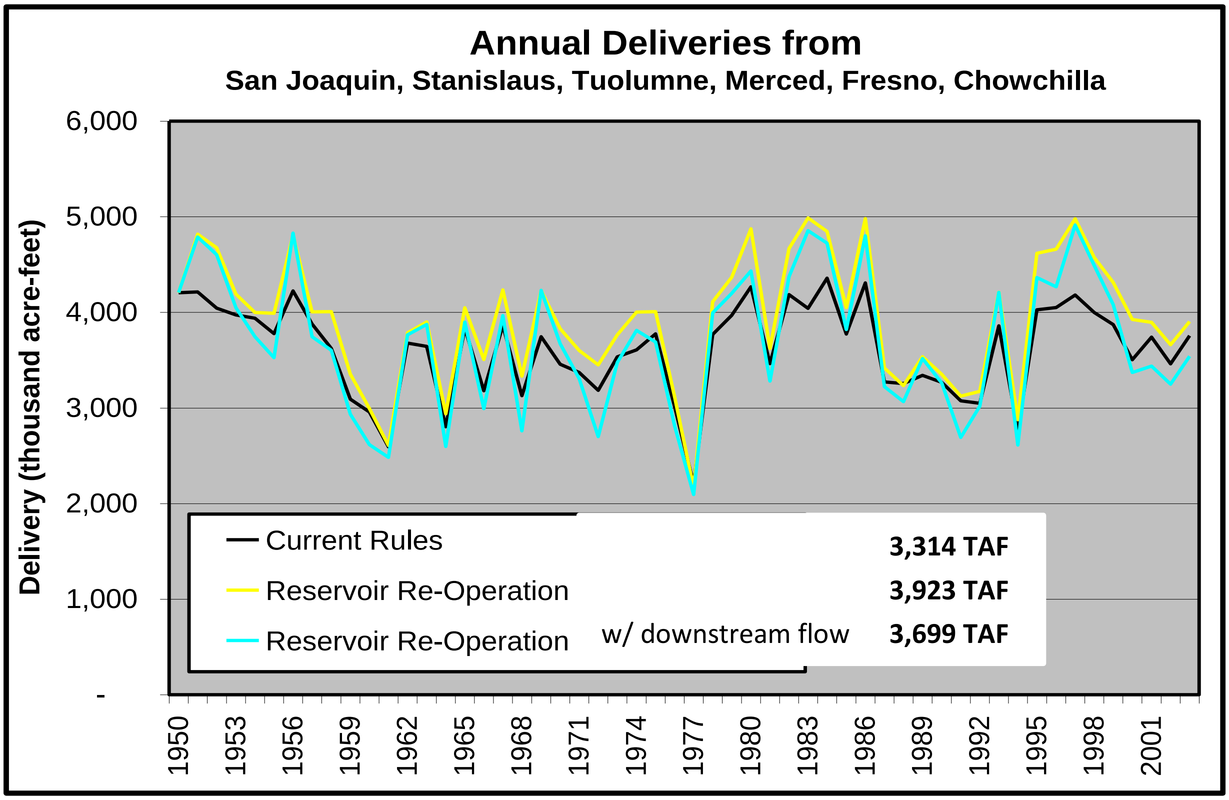


Figure 7: Average annual deliveries from reservoirs and new groundwater storage

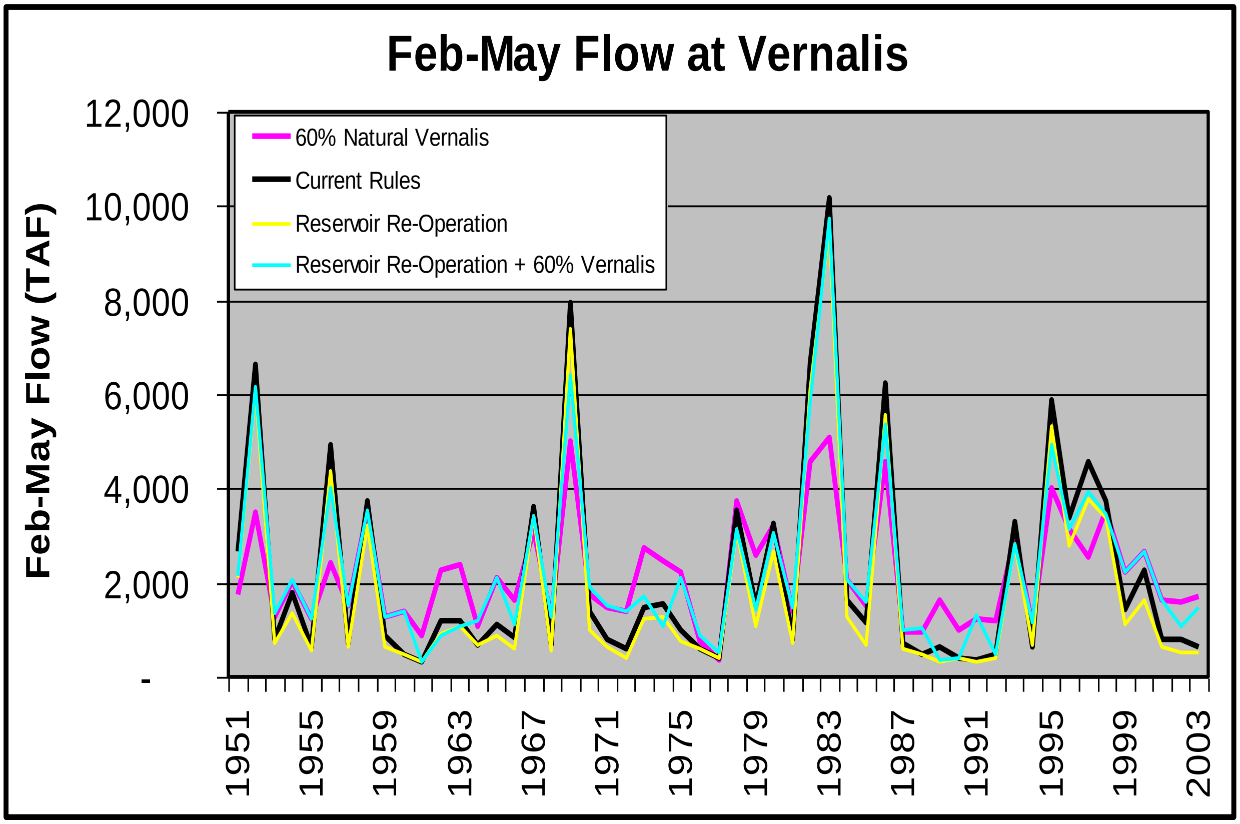


Figure 8: Feb.-May flow volume

Figure 8 shows changes in the Vernalis flow regime during the February-May target period for the three hydrologic scenarios relative to 60% unimpaired flows – the flows that the State Water Resources Control Board concluded were necessary to fully protect public trust resources in the lower San Joaquin River and Delta in the absence of other conservation measures.

Floodplain Inundation Potential

Figure 8 shows changes in maximum inundated floodplain potential between the existing and expanded floodway configuration. Not surprisingly, set-back levees in the expanded floodway scenario increase maximum potential inundation by 500 percent. The existing configuration in each hydrologic scenario has a maximum value for inundated floodplain habitat of approximately 4,700 acres; the corridor expansion increases the maximum potential to approximately 21,000 acres.

In both physical scenarios we see that the main channel overtops and inundates the land adjacent to the river at flows between 10,000 and 15,000 cfs. The existing condition quickly inundated all the area between the levees and at approximately 27,000 cfs. There are no further gains in inundated floodplain as the entire system of less than 5,000 acres is already underwater. The corridor expansion curve rises steeper and faster and does not begin to level off until after 35,000 cfs, at which time the maximum potential floodplain habitat has reached approximately 21,000 acres. The inflection point for the levee removal curve sits at approximately 22,000 cfs and represents the flow that produces the highest marginal habitat benefit to the system: in this range of flow, to increase potential habitat by one acre, an additional flow of 1.2 cfs is required. The highest marginal increase in habitat for the existing physical system occurs around 15,000 cfs and requires an additional 5.0 cfs for each addition acre of floodplain habitat.

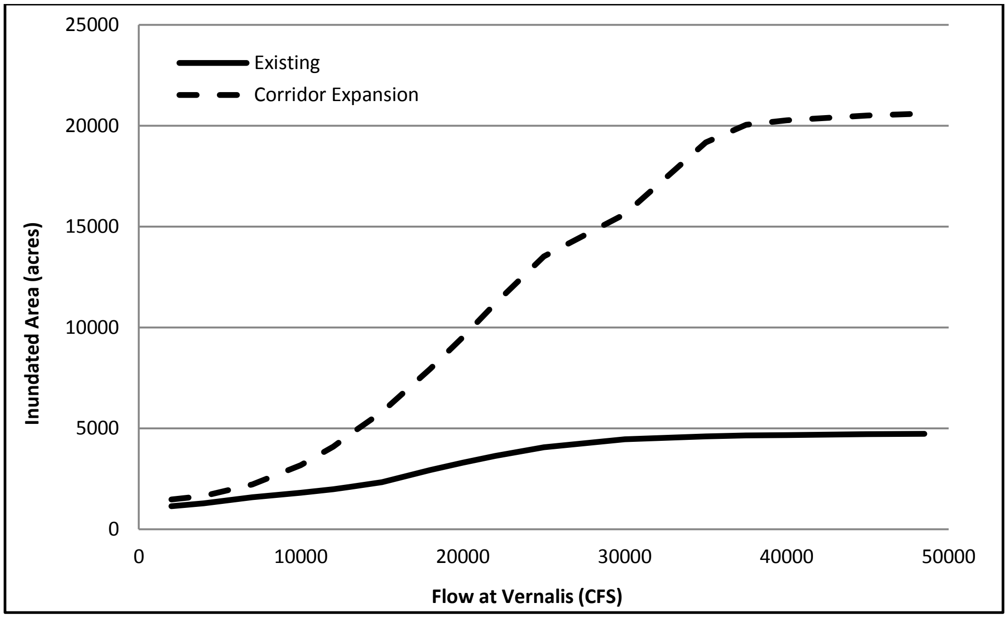


Figure 8: Floodplain inundation potential - Inundated Area vs. Flow at Vernalis.

Area-Frequency-Duration Curves

Figure 9 provides the best visual comparison of changes in area-frequency-duration (ADF) curves of all four scenarios. The ADF is a calculation of the area of inundated floodplain habitat wetted for a minimum duration during the ecologically appropriate season (e.g. 14 days in the spring) as well as the annual frequency at which the inundation occurs. Figure 9 compares the frequency of available 14-day habitat, which we assume is the minimum inundation duration threshold necessary to provide significant benefits to rearing juvenile salmon. Corridor expansion alone is capable of providing only marginal increases in habitat benefits for high frequency events (i.e. flows with recurrence intervals less than 4 years). It is only with hydrologic modifications that these benefits can be amplified to truly significant levels. Corridor expansion combined with a modified flow scenario, however, increases significantly the amount of available floodplain habitat. It increases habitat by a factor of three for every two year event, a factor of four for every three year event, and by a factor of five for every four year event.

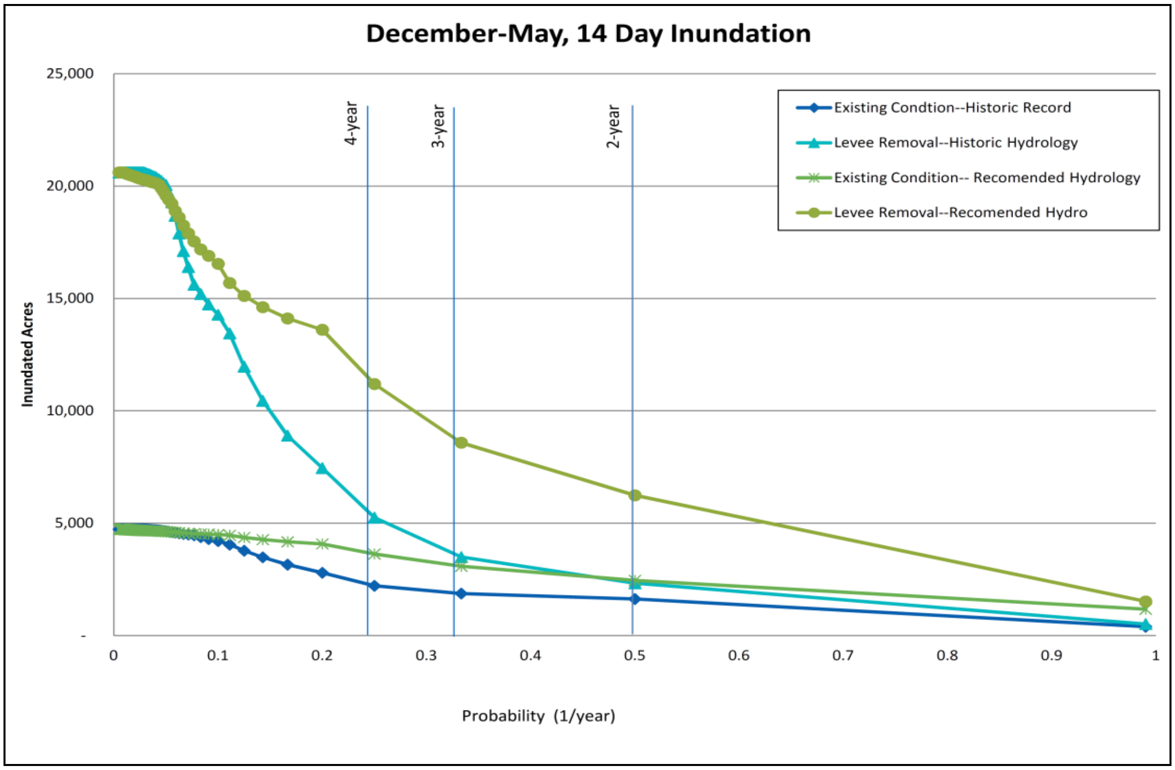


Figure 9: Area-Frequency-Duration Curve for 14-day events that occur between December and May

Figures 10 and 11 show the ADF curves for existing and proposed floodway and hydrology scenarios for various inundation durations (1-day, 7-days, 14-days, etc.). Figure 10 compares the frequency of inundated area events for the existing and expanded floodway scenarios under ***existing*** hydrologic conditions, while Figure 11 compares the two floodway scenarios with reservoir reoperation. The inundated area does not change significantly for frequent events (2-year recurrence or less) under existing hydrology for either floodway scenario, because the frequency of large events on the San Joaquin River is highly regulated and extremely low under existing conditions. The inundated area for less frequent events (5-year recurrence) expands dramatically from a maximum of 5,000 acres to a maximum of 20,000 acres in the expanded floodway scenario. Changes in hydrology, on the other hand, yield significant increases in the area of frequently inundated floodplain habitat for both the existing and expanded floodway scenarios, but the gains are much larger on the expanded floodway.

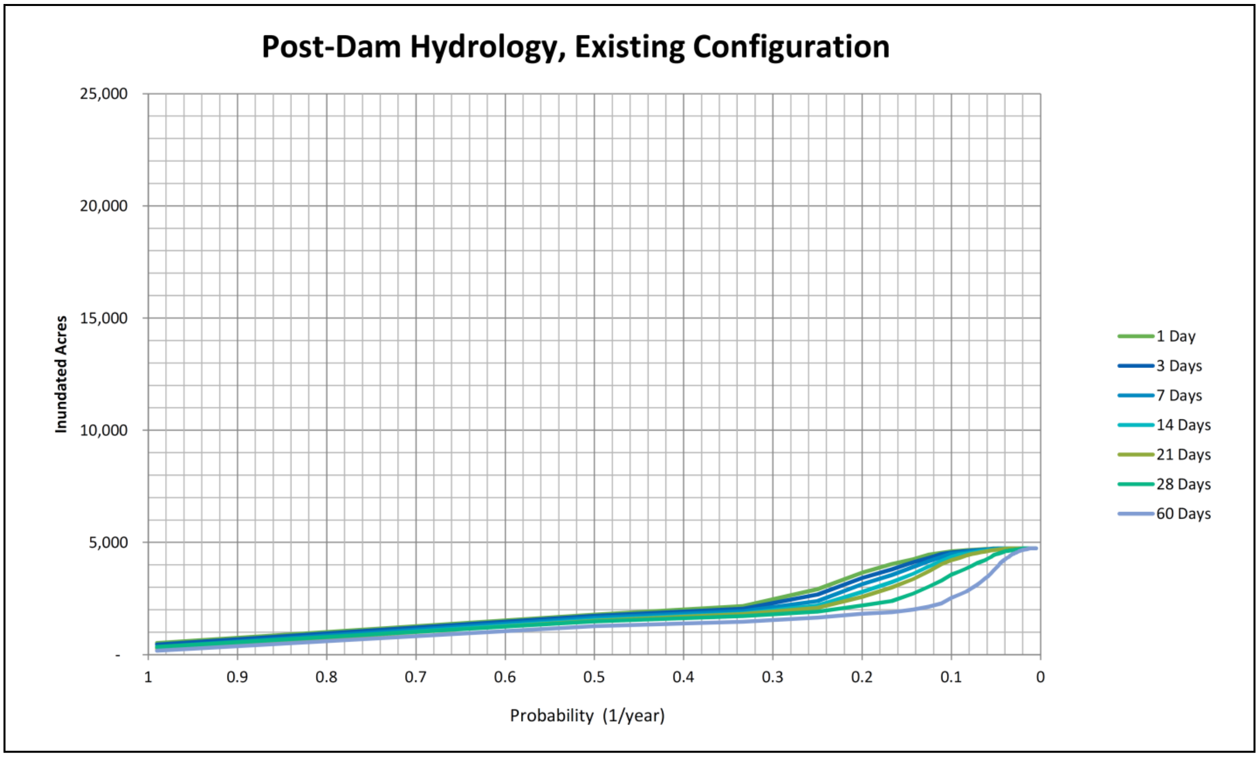
Annualized-Expected-Habitat

Table 3 compares the annualized-expected-habitat curves for the four scenarios. The AEH values are the average amount of floodplain habitat that statistically occurs in any given year and are calculated by integrating each ADF curve over all frequencies (f=0 to f=1) . Expanding the floodway combined with the reservoir reoperation scenario increases the annual average amount of floodplain habitat by 3.5 or 4.5 times over existing conditions. The AEH provides a measure of floodplain habitat over time, but the annual *average* values may not be particularly relevant to species that require regular inundation events.

Table 3: Annualized-Expected-Habitat (AEH) values

Recommended Flow		
	Annualized Inundation Area (acres)	
Duration	Status Quo	No Levee
1	3266	9743
3	2742	9006
7	2665	8676
14	2224	6530
21	1926	4987
28	1810	4464
60	1364	2672

Post-New Melones hydrologic record		
	Annualized Inundation Area (acres)	
Duration	Status Quo	No Levee
1	2233	5920
3	2046	5544
7	1929	5098
14	1822	4644
21	1764	4361
28	1675	4027
60	1356	2711



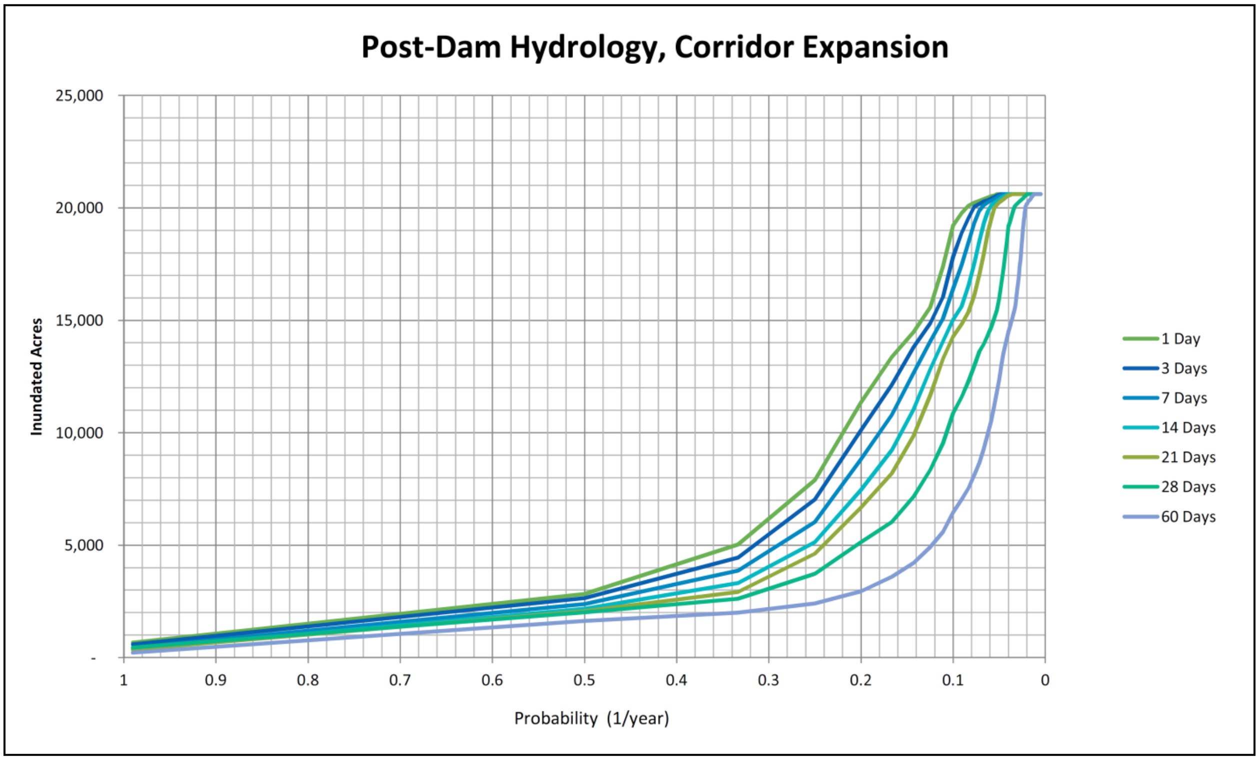
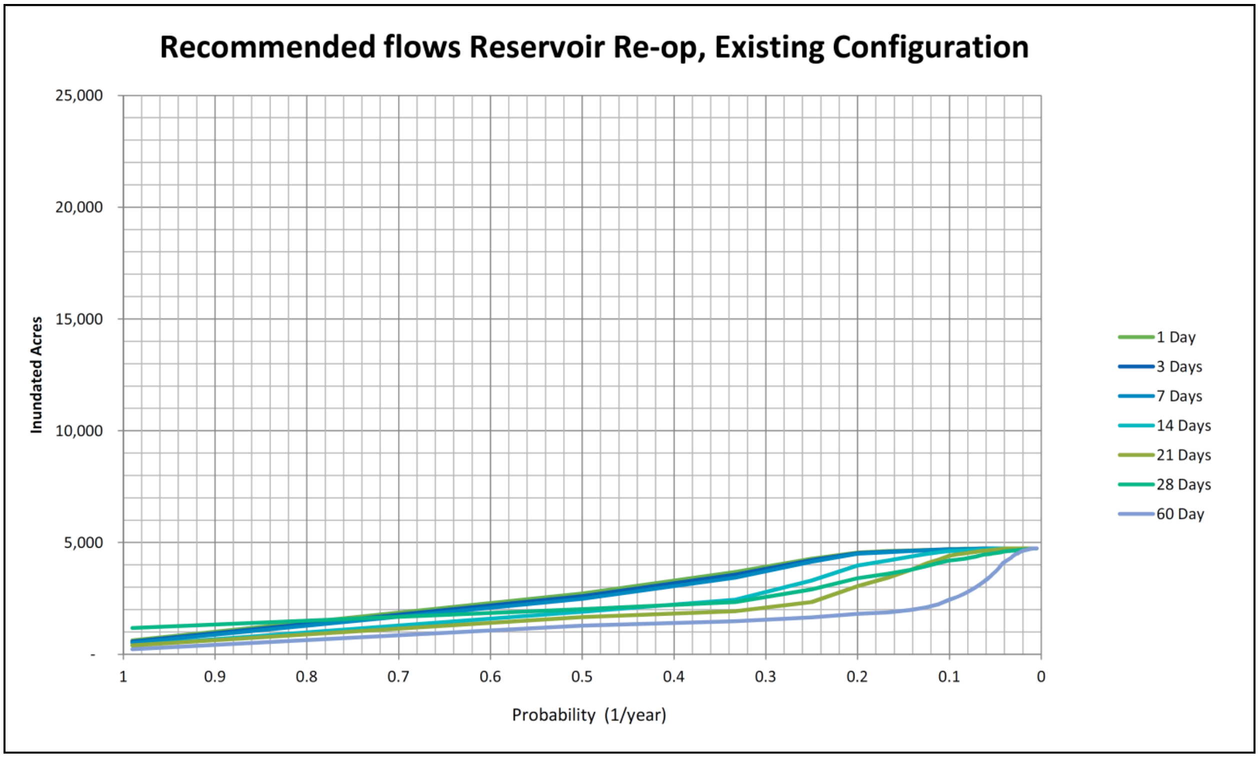


Figure 10: Area-Frequency-Duration (ADF) curves for existing hydrology.



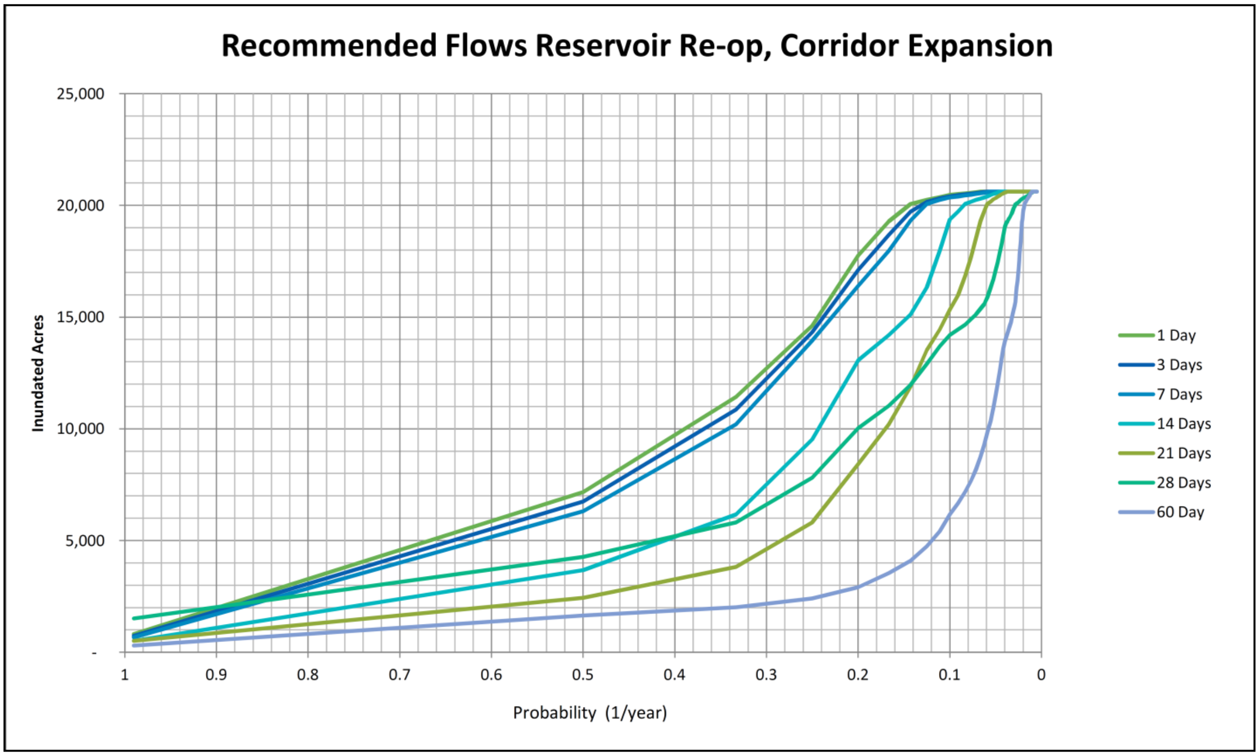


Figure 10: Area-Frequency-Duration (ADF) curves for reservoir reoperation designed to achive increased frequency of inundation events.

Appendix C: American Rivers Comments to SWRCB Workshop #3

Expected Annual Floodplain Habitat Method: A new approach and planning metric for measuring the floodplain habitat benefits of proposed flood management projects

John Cain, American Rivers
Katie Jagt, P.E., American Rivers
Mary Matella, UC Berkeley
Mark Tompkins, P.E. Ph.D., Newfields

Floodplain habitat and processes are critical to several species including threatened and endangered runs of Chinook salmon (*Oncorhynchus tshawytscha*) and are valuable for splittail (*Pogonichthys macrolepidotus*) as well as aquatic food web productivity. Ecosystem restoration, and more specifically the creation of floodplain habitat, is currently a major objective of several state and federal planning efforts including the Bay-Delta Conservation Plan and the Central Valley Flood Protection Plan, but efforts to plan and evaluate potential floodplain restoration projects, or even measure the existing extent and quality of floodplain habitat, have been frustrated by both the ephemeral nature of floodplain habitats and the lack of a readily available and easily useable quantification method. The function of a floodplain depends not just on the extent of inundated area with suitable characteristics (temperature, velocity, depth) for a particular species, but equally important, the frequency, timing, and duration of inundation. For example, ten thousand acres of floodplain that are inundated every ten years may provide less functional habitat to juvenile salmon then 1,000 acres of floodplain that are inundated every year. Similarly, inundated habitat for one objective may provide no value for another floodplain dependent objective: fourteen days of inundation may be sufficient to provide rearing habitat for juvenile salmon, but not for reproducing Sacramento splittail – a species that requires a minimum of 20-30 days of inundation. These complexities, numerous defining variables, and occasionally overlapping objectives have proven difficult for planners, engineers, and decision makers to sort out. Faced with this same dilemma and a lack of language or metrics to succinctly describe floodplain habitat benefits, we developed a method that transparently integrates critical ecosystem variables and quantifies floodplain habitat using existing tools and generally readily available data.

The expected annual floodplain habitat (EAH) method generates a metric that integrates both the spatial and temporal parameters that determine the value of inundated habitat for any given species. It generates area-duration-frequency (ADF) curves (figure 1) that quantify the area inundated for a specified duration, timing, and frequency. For example, ADF curves can tell you how much area gets inundated between March and May for 14 days in at least 50% of all years. Mathematically, the area under each of the area-duration-curves represents the average expected annual habitat benefit for a flow of a given duration. EAH is a metric for quantifying existing or future conditions and is particularly useful for comparing the habitat benefits of alternative river and flood management scenarios. It can be effectively used as screening metric with minimal costs and only superficial knowledge of species needs, or it can be refined to measure and design very detailed floodplain habitats using high resolution models.

ADF curves and EAH values can be generated with standard flood management planning tools and data using an easily replicable process. Figure 1 provides a schematic of the protocol used to calculate EAH vales. Daily hydrology data and floodplain topography provide input into a hydraulic model to generate stage-discharge curves that are then filtered in GIS to calculate flow versus inundated area curves (figure 2). Daily hydrology processed with the ecosystem function model (EFM) (USACE 2002) defines the frequency at which a flow occurs for a given duration during a specific season (figure 3). The primary innovation of the EAH method is to combine the separate inundated area-flow and flow frequency curves into ADF curves (figure3). EAH values reflect the area under the ADF curve (figure 4).

The EAH approach can be easily adopted by all flood management agencies that use GIS based hydraulic models and have access to daily hydrologic data for a reasonably long period of record[3]. EAH values are very similar to expected annual damage (EAD) values that are regularly developed in planning studies by the USACE and other flood management agencies but instead of providing a measure of average annual damages, they provide a measure of the average annual floodplain habitat ***benefits*** a project may provide. One dimensional hydraulic models can generate useful inputs for EAH analysis in planning level studies, but two dimensional models may be necessary to develop detailed designs for specific species. In all cases, detailed topographic data is necessary to develop reliable stage-discharge curves for the range of flows extending from the 1-year event to the 10-year event, the most ecologically relevant frequencies.

ADF curves and EAH values can be used to quantitatively evaluate project performance for a variety of objectives. Where species specific needs have not been identified, total inundated area can be used as a surrogate for many species in planning studies while specific suitability curves can be generated for a variety of habitats, including agricultural cover types. In situations with multiple species objectives, planners can utilize EAH values for various species to inform and optimize design of river management projects.

Aside from the data and hydraulic modeling issues that arise in any flood management study, the calculation of EAH is transparent and replicable. Calculation of inundated area and frequency of inundation is based solely on stage discharge relationships and standard frequency analysis statistics. Calculation of inundated area that is “suitable” for a particular species requires input based on professional judgment or empirical data to generate a habitat suitability curve, but the conversion of this curve into an EAH is a clear process that is not distorted by weighting factors or professional opinion.

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[3] Flow frequency relationships can be generated to augment insufficient hydrologic data sets in areas without a sufficiently long period of record to accurately characterize the frequency of ecologically relevant pulse flow events.

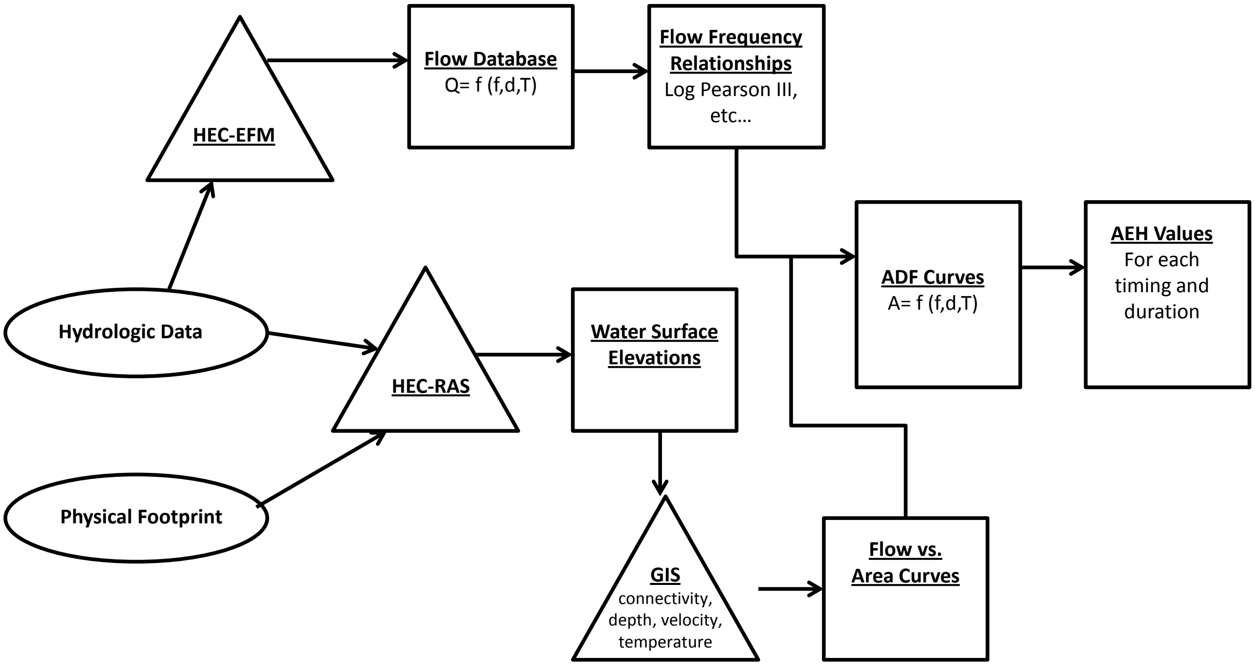


Figure 1: Analytical process. Ovals designate inputs, triangles designate analytical tools, and squares designate quantitative outputs.

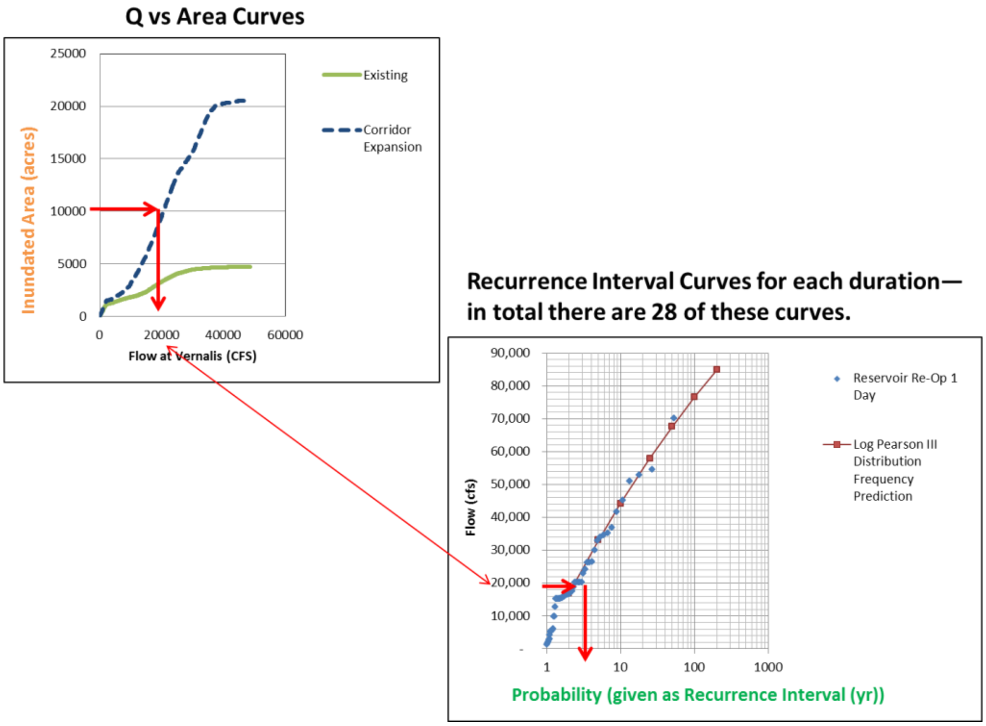


Figure 2: Correlate each value of habitat area with the probability of its occurrence for each duration, timing, and hydrologic scenario via the flow at which that inundated area is produced.

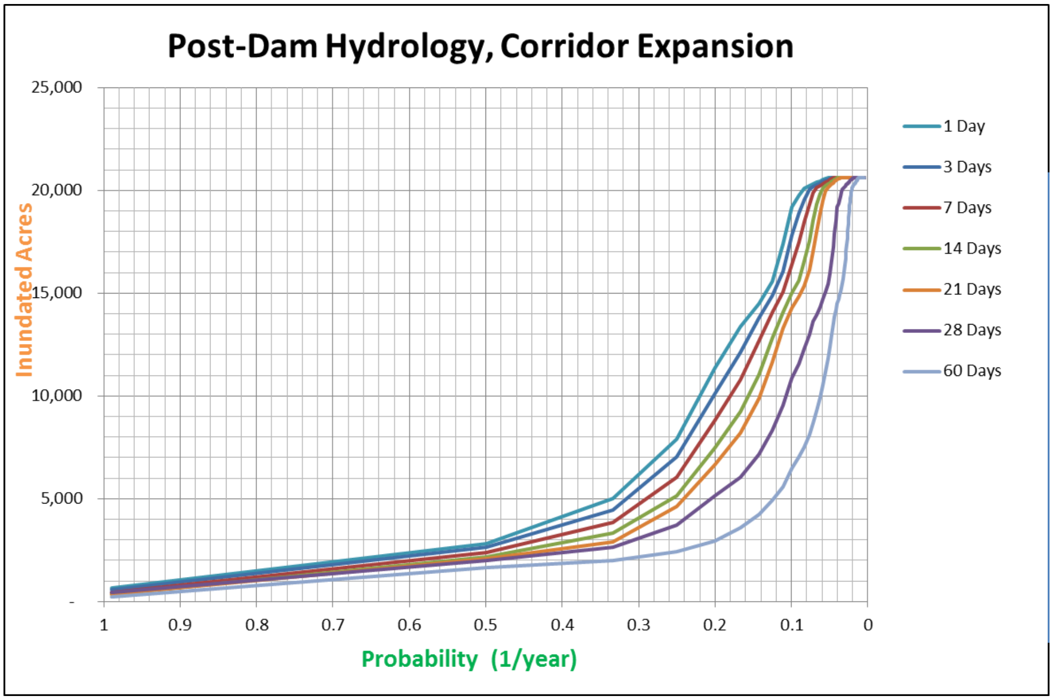


Figure 3: Each of the above correlations creates one point on the ADF (Area-duration-frequency) plot.

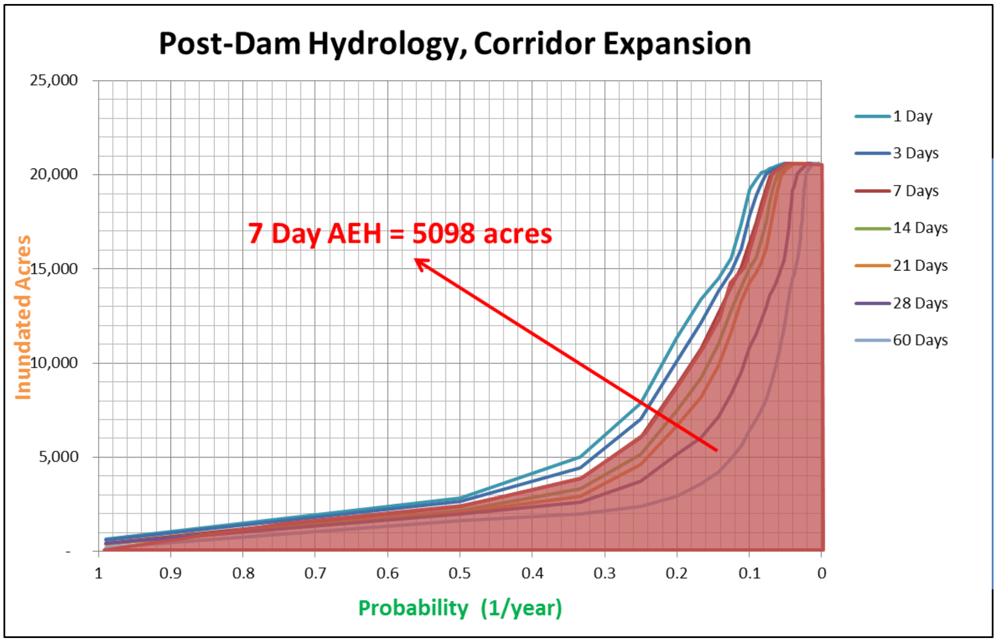


Figure 4: The area under each of the lines represents the average annual habitat area for each duration event. We are calling this the AEH (annual expected habitat).

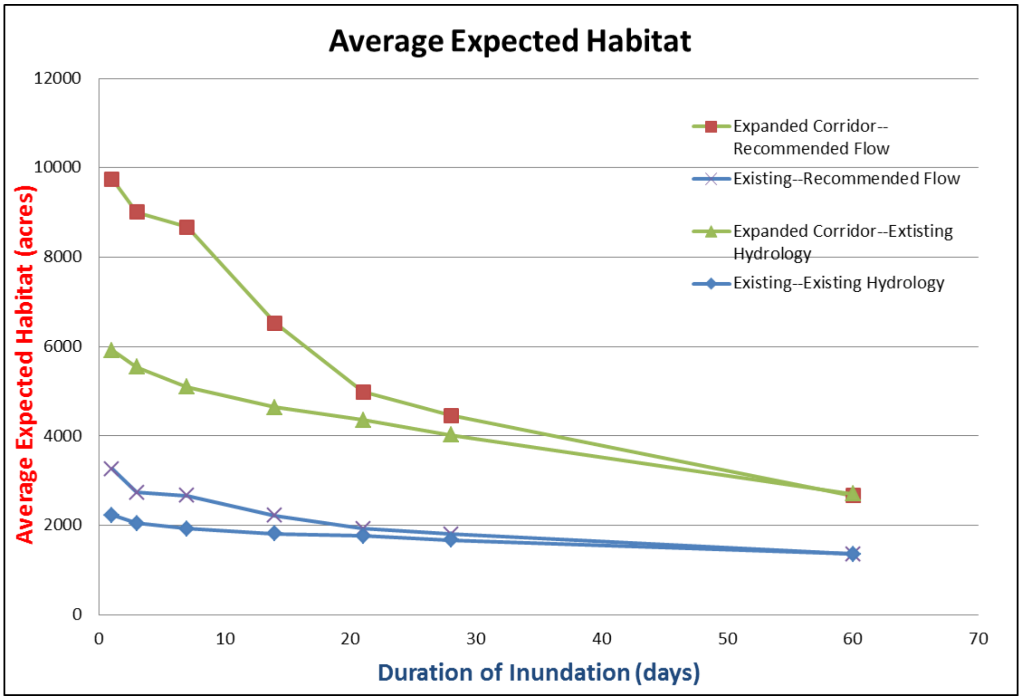


Figure 5: This graph shows the AEH values for four different scenarios we evaluated in a pilot study on the lower San Joaquin River. The AEH values calculated for each duration from figures 4 and 5 for each of the four scenarios is plotted on one graph to show the average expected habitat as a function of duration.

Attachment 1: American Rivers Comments to the SWRCB Workshop #3

October 26, 2012

Description and Graphical Depiction of the Logic Chain Approach

Prepared by John Cain, American Rivers and Jon Rosenfield Ph.D, The Bay Institute

LOGIC CHAIN TERMINOLOGY

(Revised October 25, 2012)

1. Problem Statement: As the name implies, this is a broad, concise statement of the issues BDCP is trying to address for each species and the ecosystem as a whole. It implies the goals and should identify the general hypotheses regarding the main causes of the problem. It does *not* adopt one of the hypotheses as the "preferred" hypothesis.

2. Goals and Objectives: Goals are ultimate outcomes regarding recovery of the ecosystem/covered species*;* these are statements that describe what is needed to achieve the goal. Objectives are the answers to "we will know we have succeeded when _____". Objectives should be "S.M.A.R.T" – that is, specific, measurable, achievable, relevant (to the goal), and time-bound. Neither Goals nor Objectives should specify how we get to the goal nor adopt a particular hypothesis about what prevents us from getting there.

2.a. BDCP Objectives: Objectives do not necessarily identify BDCP's level of responsibility for attaining the desired conditions; "BDCP objectives" are some fraction of the overall recovery objectives.

3. Conceptual Model: Conceptual models are detailed descriptions of how we believe the ecosystem or species populations function. Because of the complexity and high degree of uncertainty regarding how ecosystems function, conceptual models are generally built upon a web of assumptions regarding the factors that drive and limit the ecosystems, key ecosystem processes, or particular species or habitats. These assumptions are *potential* hypotheses for what prevents us (Chinook salmon) from attaining the Goals and Objectives currently. The adaptive management plan will implement "tests" of these hypotheses via the Conservation Measures. Prioritization and scale of implementation rely on information in the Conceptual Models (e.g. the strength of support for various hypotheses).

Various conceptual models are relevant to attaining any given Goal/Objective. As we learn more about the ecosystem through adaptive management, we update the conceptual model (see dashed arrow in the attached figure), and in some cases, that may lead us to change or refine assumptions and desired changes (targets) as described below.

4. Assumed Stressor: This step is an explicit description of the stressor that is hypothesized to limit progress toward the objective. The conceptual models (above) contain numerous assumptions or hypotheses; the desired changes (below) address specific assumptions (i.e. they are tests of specific hypotheses).

5. Desired Changes: Desired changes are stressor reduction targets. Like objectives, desired changes are S.M.A.R.T. The desired changes should be sufficient to significantly alleviate any limits that the assumed stressor places on attaining species, community, or ecosystem goals/objectives. Desired changes can be a combination of physical, biological, financial, or research outcomes (i.e. we may desire a change in the strength of our conceptual model or knowledge base). Like goals and objectives, desired changes can change as we revise the conceptual model, but only within the BDCP governance framework and pre-determined adaptive management range.

6. Conservation Measures: Conservation Measures are both restoration actions and tests of one or more assumptions embedded in the conceptual models. If the assumptions that lead to "desired changes" and to "projected outcomes" are verified (see dashed arrows in the attached figure), then the Conservation Measure will contribute to the Goal . ***Note****: Implementation of the Conservation Measure is neither a desired change, objective, or goal because the Conservation Measure's benefits are hypothetical – desired change targets, objectives, and goals are always outcomes; conservation measures are means to those ends*.

6a. Hypotheses re: Conservation Measures: The Conservation Measures are based upon conceptual models as well. These may be formal conceptual models (e.g. DRERIP) or internal conceptual models. Conservation measures should state why they are expected to produce beneficial outcomes. In many cases, these can be written in the form of an equation that shows the contribution of different factors to the projected outcome. Thus, these "Conservation Measure-specific" hypotheses are used to develop projected outcomes.

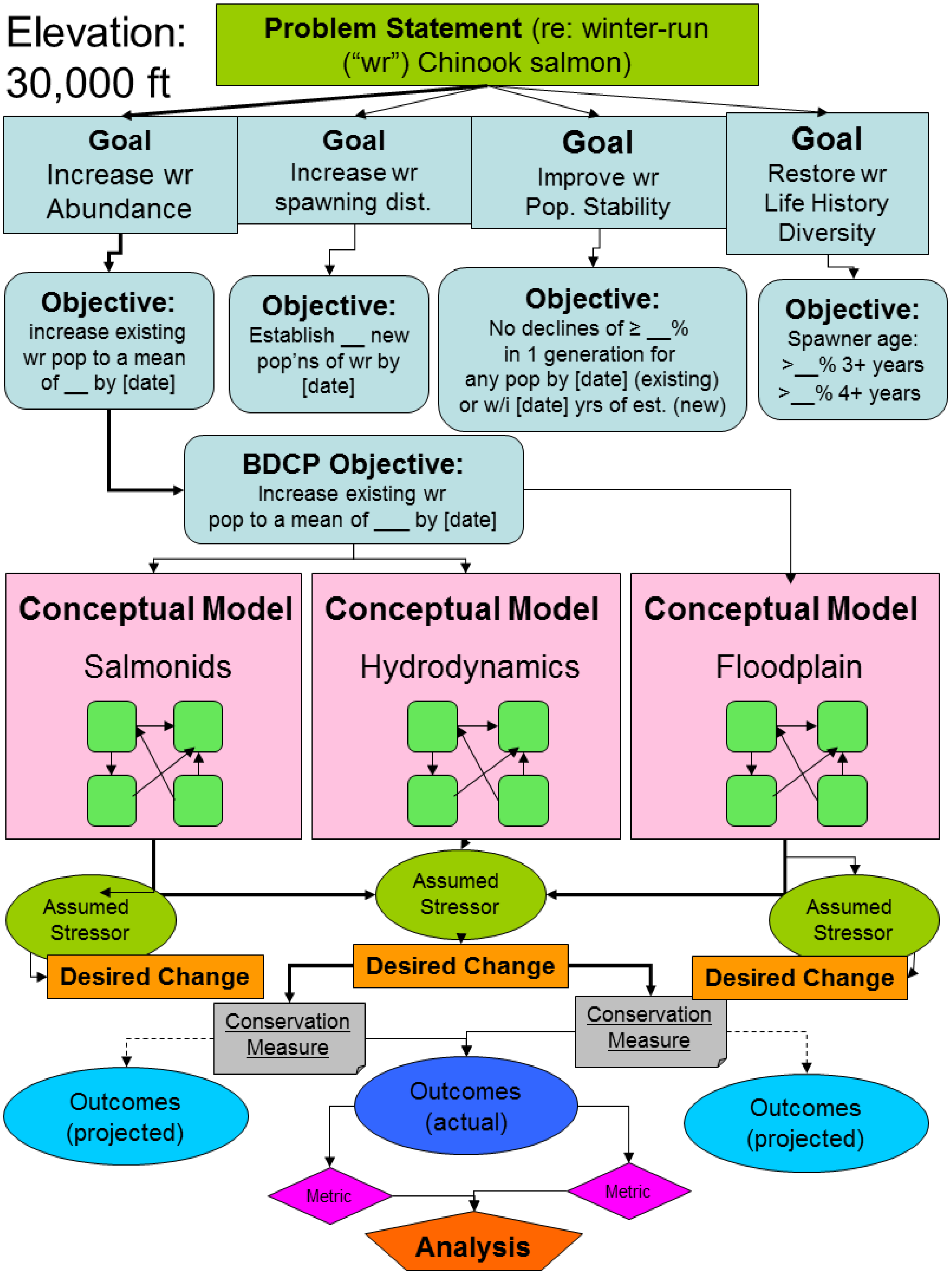
7. Projected Outcomes: Conservation Measures are designed to achieve one or more outcomes. Clear articulation of how the conservation measure will produce projected outcomes (both positive and negative) allows decision-makers to understand how the Conservation Plan as a whole intends to achieve its objectives and allows analysts and decision-makers to assess whether a conservation measure has contributed to its associated target(s). Identifying negative potential outcomes is critical to transparency and allows development of metrics to capture these potential impacts.

8. Actual (+ and -) Outcomes: Actions produce outcomes. We suspect some of these will be positive and some will be negative (detracting from attainment of the goal). We must measure both the positive and negative outcomes in order to understand if, on the whole, the conservation measure is successful (and to refine implementation of subsequent conservation measures).

9. Metrics: Metrics define environmental/biological/ecological variables that will be measured to determine whether (a) the conservation measure is contributing towards the objective/target (hypothesis 1) **AND** (b) whether the objective/target is contributing towards attainment of the goal (hypothesis 2). Measuring only one of these two outcomes is not sufficient as we must know both that implementation of the Conservation Measure leads to the desired targets (e.g. that restored tidal marsh produces food and habitat) and that the targets actually contribute to the relevant Goal/Objective (e.g. more food results in more Chinook salmon).

10. Analysis: Adaptive management does not function unless results of monitoring and targeted studies ("metrics") are analyzed to determine effectiveness of conservation actions and veracity of Conceptual Model (Desired Changes to Objectives) – these are two separate sets of hypothesis evaluation. The Independent Science Advisor's report (2009) stressed that this was missing from early drafts of the Conservation Strategy and it is still missing from the most recent version of Chapter 3.

Elevation: 30,000 ft



Problem Statement (re: winter-run (“wr”) Chinook salmon)

Goal
Increase wr Abundance

Goal
Increase wr spawning dist.

Goal
Improve wr Pop. Stability

Goal
Restore wr Life History Diversity

Objective:
increase existing wr pop to a mean of __ by [date]

Objective:
Establish __ new pop’ns of wr by [date]

Objective:
No declines of ≥ __%
in 1 generation for any pop by [date] (existing) or w/i [date] yrs of est. (new)

Objective:
Spawner age:
>__% 3+ years
>__% 4+ years

BDCP Objective:
Increase existing wr pop to a mean of ___ by [date]

Conceptual Model
Salmonids

Conceptual Model
Hydrodynamics

Conceptual Model
Floodplain

Assumed Stressor

Assumed Stressor

Assumed Stressor

Desired Change

Desired Change

Desired Change

Conservation Measure

Conservation Measure

Outcomes (projected)

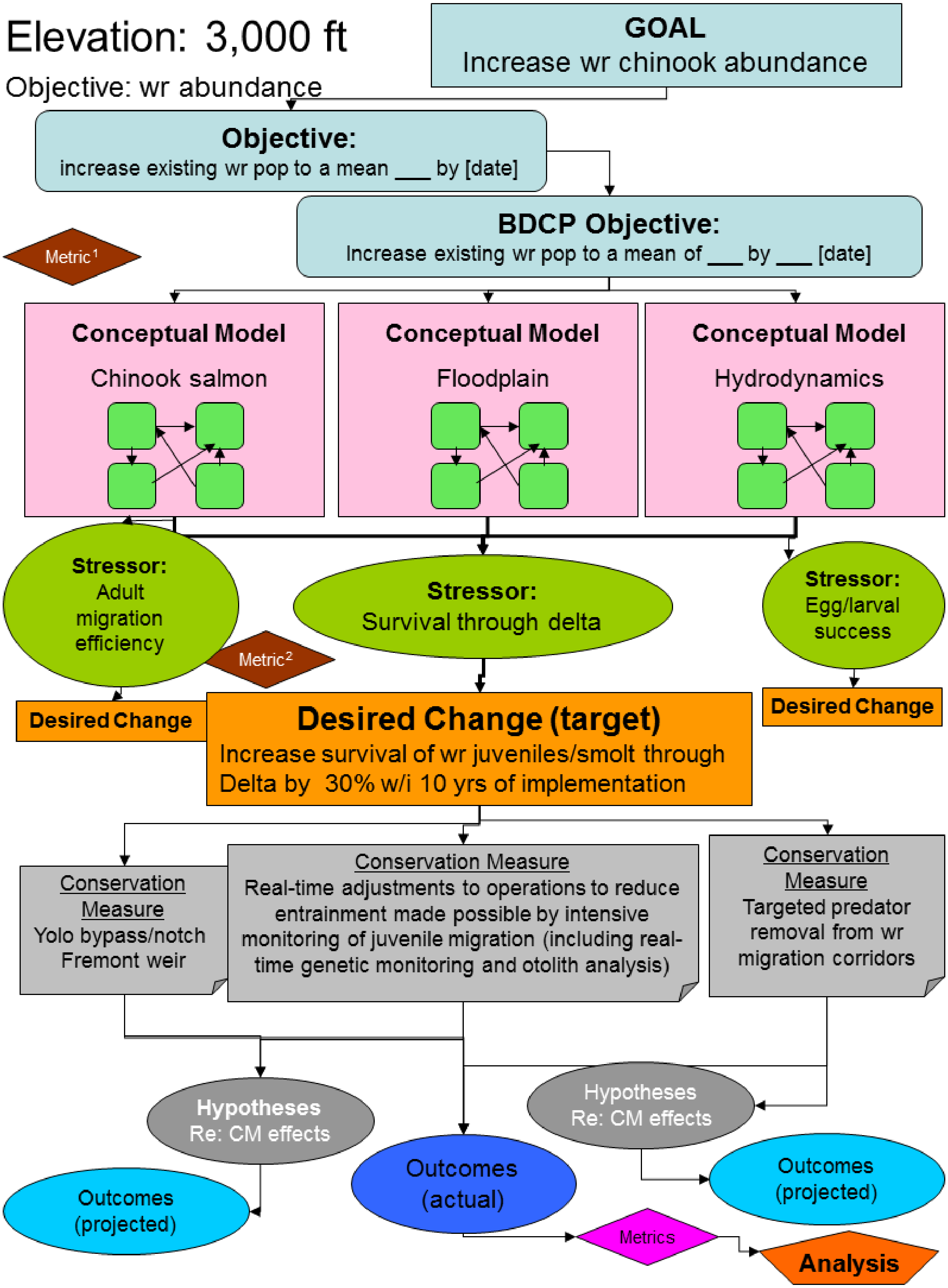
Outcomes (actual)

Outcomes (projected)

Metric

Metric

Analysis



Elevation: 3,000 ft

Objective: wr abundance

GOAL
Increase wr chinook abundance

Objective:
increase existing wr pop to a mean ___ by [date]

BDCP Objective:
Increase existing wr pop to a mean of ___ by ___ [date]

Metric[1]

Conceptual Model
Chinook salmon

Conceptual Model
Floodplain

Conceptual Model
Hydrodynamics

Stressor:
Adult migration efficiency

Stressor:
Survival through delta

Stressor:
Egg/larval success

Metric[2]

Desired Change

Desired Change (target)
Increase survival of wr juveniles/smolt through Delta by 30% w/i 10 yrs of implementation

Desired Change

Conservation Measure
Yolo bypass/notch Fremont weir

Conservation Measure
Real-time adjustments to operations to reduce entrainment made possible by intensive monitoring of juvenile migration (including real-time genetic monitoring and otolith analysis)

Conservation Measure
Targeted predator removal from wr migration corridors

Hypotheses
Re: CM effects

Hypotheses
Re: CM effects

Outcomes
(projected)

Outcomes
(actual)

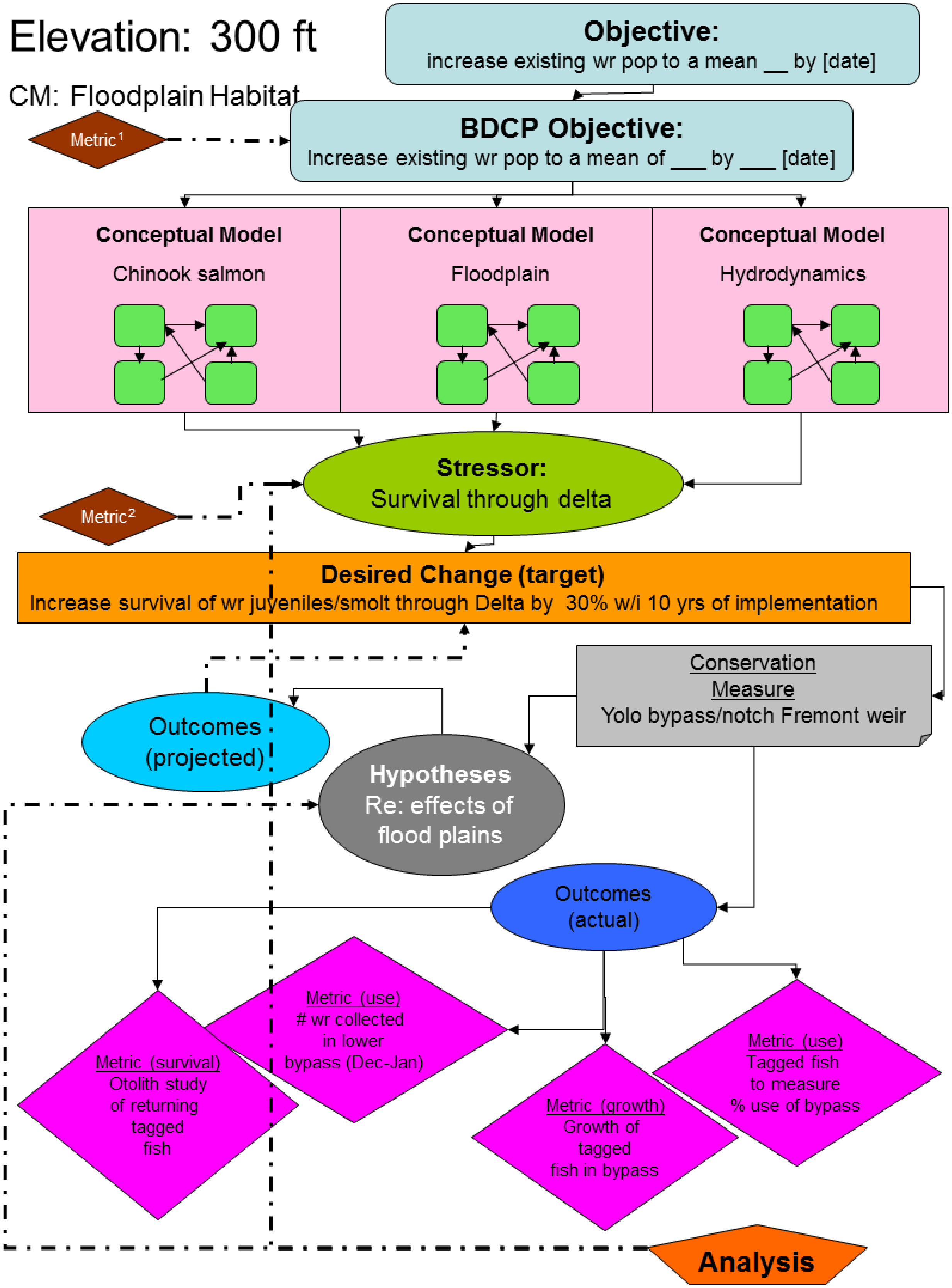
Outcomes
(projected)

Metrics

Analysis

Elevation: 300 ft

CM: Floodplain Habitat



Objective:
increase existing wr pop to a mean __ by [date]

BDCP Objective:
Increase existing wr pop to a mean of ___ by ___ [date]

Metric¹

Conceptual Model
Chinook salmon

Conceptual Model
Floodplain

Conceptual Model
Hydrodynamics

Stressor:
Survival through delta

Metric²

Desired Change (target)
Increase survival of wr juveniles/smolt through Delta by 30% w/i 10 yrs of implementation

Conservation Measure
Yolo bypass/notch Fremont weir

Outcomes (projected)

Hypotheses
Re: effects of flood plains

Outcomes (actual)

Metric (survival)
Otolith study of returning tagged fish

Metric (use)
wr collected in lower bypass (Dec-Jan)

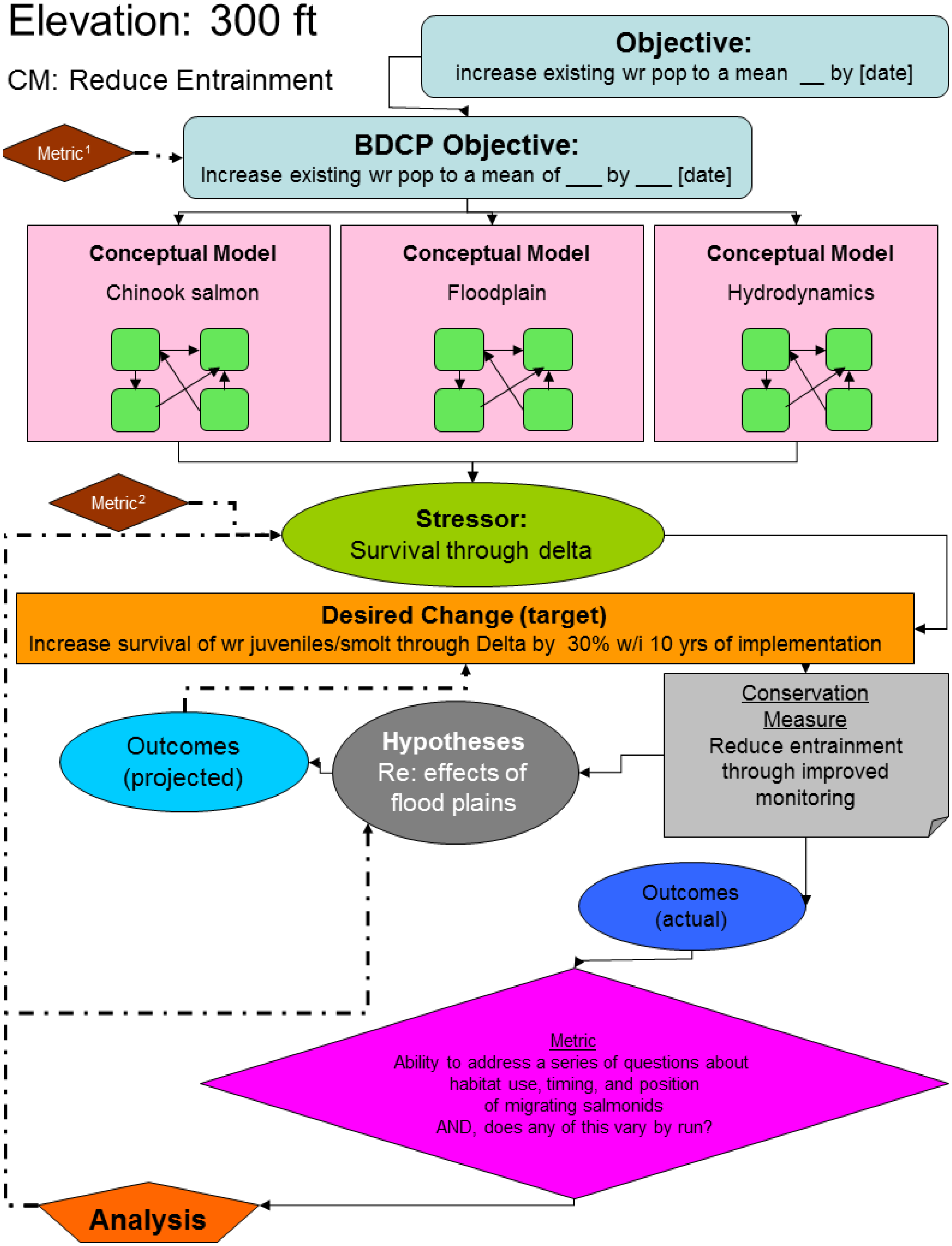
Metric (growth)
Growth of tagged fish in bypass

Metric (use)
Tagged fish to measure % use of bypass

Analysis

Elevation: 300 ft

CM: Reduce Entrainment



Objective:
increase existing wr pop to a mean __ by [date]

Metric[1]

BDCP Objective:
Increase existing wr pop to a mean of ___ by ___ [date]

Conceptual Model
Chinook salmon

Conceptual Model
Floodplain

Conceptual Model
Hydrodynamics

Metric[2]

Stressor:
Survival through delta

Desired Change (target)
Increase survival of wr juveniles/smolt through Delta by 30% w/i 10 yrs of implementation

Outcomes
(projected)

Hypotheses
Re: effects of
flood plains

Conservation
Measure
Reduce entrainment
through improved
monitoring

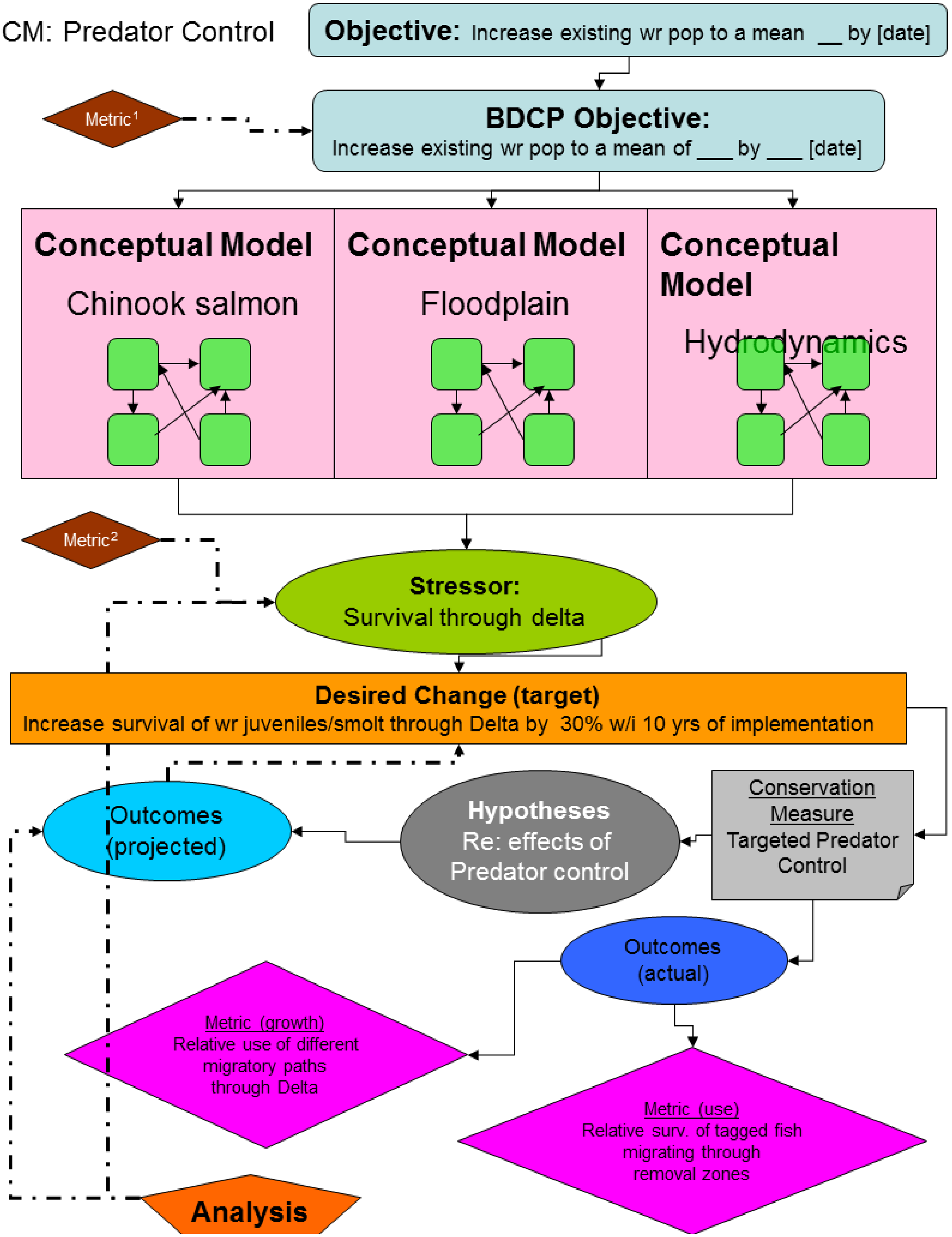
Outcomes
(actual)

Metric
Ability to address a series of questions about
habitat use, timing, and position
of migrating salmonids
AND, does any of this vary by run?

Analysis

Elevation: 300 ft

CM: Predator Control



Objective: Increase existing wr pop to a mean __ by [date]

Metric¹

BDCP Objective:
Increase existing wr pop to a mean of ___ by ___ [date]

Conceptual Model
Chinook salmon

Conceptual Model
Floodplain

Conceptual Model
Hydrodynamics

Metric²

Stressor:
Survival through delta

Desired Change (target)
Increase survival of wr juveniles/smolt through Delta by 30% w/i 10 yrs of implementation

Outcomes
(projected)

Hypotheses
Re: effects of
Predator control

Conservation
Measure
Targeted Predator
Control

Outcomes
(actual)

Metric (growth)
Relative use of different
migratory paths
through Delta

Metric (use)
Relative surv. of tagged fish
migrating through
removal zones

Analysis

BAY-DELTA CONSERVATION PLAN

DELTA SCIENCE PROGRAM PANEL

REVIEW OF THE "LOGIC CHAIN" APPROACH

Prepared for
BDCP Steering Committee

Prepared by
Cliff Dahm, Delta Science Program
Denise Reed, University of New Orleans
Elizabeth Soderstrom, American Rivers
John Wiens, PRBO Conservation Science (Chair)

19 March 2010

Background

The Bay-Delta Conservation Plan (BDCP) is being prepared through collaboration among several government, non-government, and private-sector entities. The goal of BDCP is to identify actions that will contribute to the recovery and protection of endangered and sensitive species and their habitats in the Sacramento-San Joaquin Delta of California while maintaining or improving water supplies to a diversity of users. To this end, a "logic chain" has been proposed as a framework for linking recovery goals for covered fish species with BDCP goals, objectives, conservation measures, monitoring, and adaptive management.

The review panel convened by the Delta Science Program met in Sacramento on March 2-4, 2010, to evaluate this approach. In this review, we drew heavily from the following documents: Logic Chain Status Report, Chapters 3.3 and 3.4 of the draft BDCP, SAIC Draft Effectiveness Monitoring for Conservation Measures document, Summary Report of the DRERIP Evaluations of BDCP Draft Conservation Measures, Independent Science Advisors' Report on Adaptive Management, and examples of logic chains provided by American Rivers and The Bay Institute.

The Charge

The charge to the review team had three elements. The first was to address whether the logic chain framework is a useful tool for refinement of BDCP goals and objectives. The second was an assessment of the logic chain framework with a focus on determining if the internal logic was sound and if there were critical gaps. The third element was to recommend next steps for populating key logic chains and to consider where additional science was needed in the BDCP process. This report addresses these three elements of the charge to the review team.

Recommendations

Adequacy of the logic chain framework

- The general logic-chain approach should continue to be developed and then applied, as it has the potential to clearly articulate and link goals, objectives, actions, and outcomes.
- The logic chain should be first applied to the covered fish species.
- The revisions to the logic chain structure developed by the review panel should be incorporated, as appropriate, to reduce areas of ambiguity and refine the logic chain.

Assessment of the logic chain framework

- BDCP should distinguish between order-of-magnitude approximations of BDCP goals and objectives that are acceptable in the early planning phase and the more detailed descriptions that will be necessary as the plan is finalized and ready for implementation.
- The projected outcomes should be framed as testable hypotheses linked to specific conservation measures and evaluated against actual outcomes. Outcomes must be quantified, with specified and measurable parameters and appropriate metrics. The analytical methodology to be employed should also be specified. It is important to know with clarity whether a conservation measure is working as intended.
- Use metrics to evaluate the success of outcomes that clearly link to biological functions; consider the judicious use of surrogate metrics. For example, accurate quantification of rare and endangered fish species may not be possible but overall community structure that characterizes native and non-native groups could serve as a surrogate measure.
- Constraints to implementation of the conservation measures (e.g., financial, environmental, logistical) should be considered as part of the planning process rather than as factors to be included only when one comes to implementing conservation measures. This will ensure that expectations about implementation are commonly understood. For example, budgetary requirements to make the necessary monitoring measurements and analyze the resulting data should be developed as soon as possible so that this information can be used in the prioritization of conservation measures.
- The potential impacts of system dynamics, variation, and change (especially those associated with climate variability, climate change, and sea-level rise) on the effectiveness of conservation measures should be explicitly addressed in the logic chain. A steady-state equilibrium, in which the system varies around some stable long-term state (i.e., stationarity), cannot be assumed.
- The adaptive management framework should be developed in greater detail, recognizing that analysis is *not* the endpoint of adaptive management. Adaptive management

approaches should be incorporated into the body of the logic chain rather than relegated to something that is done at the end, after measures have been implemented.

Next steps and science needs

- Rather than developing all logic chains at the same pace, logic chains should be developed in detail for 2-3 species and then evaluated as a proof of concept. These logic chains should be for species for which understanding is high (e.g., splittail). A user-friendly version of the logic chain that describes the approach and its uses in readily understandable terms should be developed now.

- The upper section of the logic chain (problem, recovery/species goals, and recovery/species objectives) should be developed and populated by the responsible regulatory and permitting agencies. This needs to be done immediately, because the application of logic chains to BDCP goals and objectives and the evaluation of hypotheses that feed into adaptive management depend on a clear statement of the problem to be addressed and well-defined recovery/species goals and objectives.

- The middle section of the logic chain (BDCP goals and BDCP objectives) should be developed through collaborative efforts. A limited number of experts from the permitting agencies, non-governmental organizations, and the potentially regulated entities should participate in developing this section of the logic chains.

- A science expert workshop should be convened to populate the lower part of the logic chain, focusing on the conservation measures, outcomes, monitoring, metrics, and the form of an adaptive management process once the upper and middle sections of the logic chains have been completed.

- Simulation models and scenario analysis should be used to explore the potential consequences and cost-effectiveness of conservation measures as part of the planning process, before measures are actually implemented.

- The formalisms of other approaches such as cost-benefit analysis, return-on-investment, or ecological risk analysis should be used to help set priorities and evaluate outcomes. Such tools should be used to inform decision making and negotiations, to consider tradeoffs, and to establish priorities among conservation measures.

General Comments

Before dealing with the details of the logic-chain, we offer several general comments as broad guidance for further development of the approach. First, our ability to recover or manage covered species depends on a clear understanding of what factors are limiting or creating stress to populations. These are the factors that must be removed or mitigated by the conservation measures. Such factors may be identified in recovery plans or may require additional information obtained from the scientific literature and/or expert opinion, and should be refined through the adaptive management process.

Second, there is an underlying (but unstated) assumption of stationarity that runs through the logic chain approach, the draft BDCP documents, and recovery plans. This assumption leads to the expectation that there is a stable “baseline” condition for the Bay-Delta ecosystem and the populations it supports. Given the massive changes in this ecosystem over the past century, this is almost certainly not true now. The potential effects of climate change on sea level, tidal fluxes, Sierra snowfall, and the timing of freshwater runoff make it even less likely to hold in the future. The logic chain and BDCP should explicitly incorporate non-stationary dynamics into the framework.

Third, it is important to incorporate study designs, monitoring protocols, and metrics as part of the logic chain. In particular, consideration of the statistical power required for detecting the effects of conservation measures, coupled with a determination of acceptable levels of response of covered species or other targets to conservation measures, may help to determine the feasibility or priority of particular measures.

Fourth, although it is important to have a clear and logical structure for developing hypotheses about the consequences of conservation measures and the efficacy of these measures in addressing BDCP goals and objectives, the framework should not be so highly structured and prescriptive that it constrains thought or resists the exercising of dynamic adaptive management. The Bay-Delta ecosystem is complex. The responses of covered species to conservation measures will always be clouded by uncertainty – did a species respond to a measure or to something else? Dealing with such uncertainties requires flexibility in planning and implementation.

Evaluation of the Logic Chain

In order to understand the logic and function of the logic chain, the review team chose to delve into the logic chain example for the Delta Smelt (Appendix 2). We reviewed and assessed this example from top to bottom; here are our observations and comments, utilizing the terminology of the example provided.

Problem statement, goals and objectives

The problem statement, goals, and objectives need to match or encompass those in the recovery plan(s). Broad statements for the species/populations as a whole are acceptable at this level.

Conceptual models

This part of the logic chain only references *conceptual* models. Various types of models -- conceptual, statistical, process, simulation, etc. – can be used to identify factors that limit the population as a whole, and different models and types of models consider factors such as population dynamics, hydrology, predation, or habitat availability. These models (or perhaps a nested set of increasingly more specific models) can be used to identify what limiting factors or stressors (if any) occur within the planning area and, therefore, would be addressed by BDCP actions. In addition, when these models are used, they relate to what has caused the problem, as articulated in the problem statement.

Hypotheses

The "hypotheses" (which as stated in the logic chain are actually assumptions rather than hypotheses) can better be characterized as specific "BDCP goals" with each goal statement articulating how a limiting factor might be addressed *within the BDCP planning area*. One goal statement for each limiting factor (e.g., increase food in the pelagic zone by 15 percent to improve sub-adult survival) specifying season and location would be necessary.

The limiting factors framed as goals do not need to be directly tested as formal hypotheses. The process relies on the models (above) or the wider knowledge base to identify the limiting factors and assumes that alleviating those factors will in fact address the problem.

Desired change

To link with the goal statements described above, the "desired change" category would be logically called "BDCP objectives." The level of quantification of the objectives depends on whether they will be used to develop prioritizations in the early planning phase (in which case they can be order-of-magnitude approximations) or if they are part of the finalized plan. If the latter, the objectives would need to be the so-called "SMART objectives" that are specific, measurable, achievable, relevant and time-based.

In some cases, the terminology "thresholds of change" has been used instead of "desired change," suggesting that there is a lower threshold of detectability of an effect or an upper threshold beyond which additional changes have no additional beneficial effects. These levels define an envelope of effects or change that is either detectable or relevant. We find the use of this terminology confusing and, in some instances, inaccurate. It needs to be clear whether this is something to be achieved (like a target) or exceeded (like a minimum acceptable achievement).

Conservation Measures

The conservation measures are the BDCP conservation measures or actions. They relate directly to the BDCP goal and objective statements and reduce the limiting factors within the BDCP planning area. Linking proposed conservation measures to BDCP goals and objectives will help to show gaps, such as objectives for which no appropriate measure exists.

Once the conservation measures have been described, a clear prioritization process would be useful, as not all measures will be logistically, financially, or politically feasible. Such prioritization could be based on an evaluation of cost effectiveness of measures relative to their outcomes and the linkages between implementation, analysis, and adaptive management. Negative consequences and the timing of actions (sequencing) would also need to be considered.

Outcomes

The projected outcomes currently are not framed as quantitative, testable hypotheses. It is at this level of the logic chain where such hypothesis testing should occur. Stated as such, these hypotheses would drive the analytical approaches for evaluating the hypotheses and the form and structure of monitoring (i.e., gathering the information to evaluate or test the hypotheses).

The monitoring design (or experimental design) may vary among different conservation measures or be applied in different ways to different places for the same conservation measure (i.e., a real experiment). It will be critical to determine what level of measurement, monitoring, and analysis would be considered not too little (to demonstrate an effect), nor not too much (a huge investment in limited resources), but just right (the Goldilocks approach). Costing of the analytical methods and monitoring would be a consideration in the prioritization of conservation measures mentioned above. The monitoring structure will in turn lead to the selection of appropriate metrics and consideration of such key attributes as spatial and temporal resolution, statistical power, analytical framework to employ, and best representation and visualization of results.

Analysis

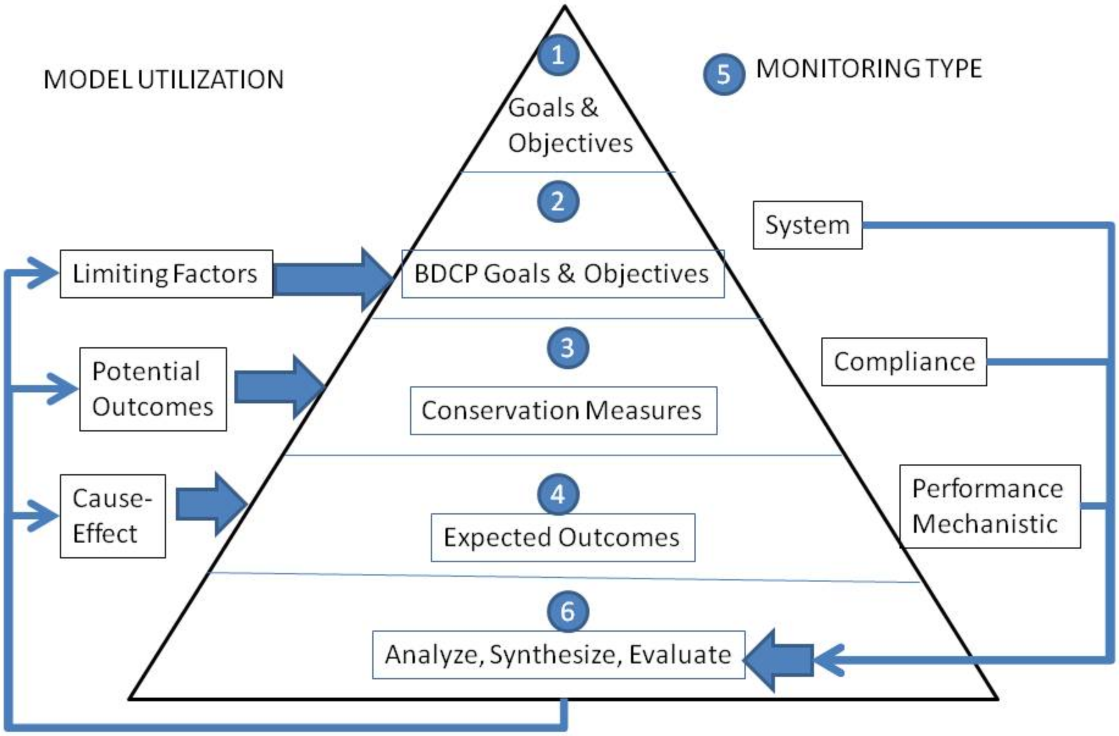
The analysis box in the Delta smelt logic chain provided would benefit from being more detailed and expanded to include the adaptive management loop. Adaptive management is not the same thing as the hypothesis testing that is included as part of the logic chain. Implementation of conservation measures leads to actual outcomes that must be monitored and analyzed. The comparison of projected outcomes (the hypotheses) with the actual outcomes is the focus of analysis. These results then feed into the adaptive management loop and back into other components of the logic chain (see next section). This is also where the system metrics may come in - how do the outcomes relate back not only to the specific objectives (e.g., food supply), but to the broader objectives (e.g., population growth, survival).

The adaptive management phase involves not only the analytical element, but the synthesis/interpretation component – what does analysis comparing projected and actual outcomes mean in terms of the objectives, identification of limiting factors, goals, or problem statement? To be effective, adaptive management needs to be part of the process, not an add-on at the end or a post-facto component once the actions have been taken. The details of adaptive management are missing from the logic chain.

There are two aspects of the hypothesis testing/analysis/interpretation components that must be distinguished: (1) the “virtual,” in which the analysis is conducted as a sophisticated conceptual or analytical modeling exercise, to explore the *anticipated* consequences of a conservation measure and the adaptive management loop; and (2) the “real,” in which the conservation measure has been implemented and we are looking at what *actually* results.

An Alternative Approach

Although there is much of value in the logic-chain approach, our evaluation and comments suggest that there is room for improvement, especially to clarify some of the logical relationships in the logic chain. We offer here an alternative approach that incorporates elements of the logic chain. The following diagram traces the main elements of this approach; the following comments are keyed to the numbered sections in the diagram.



1. At the top of triangle are the recovery/species goals and objectives. Because the BDCP needs to contribute to recovery of the covered species, there must be a clear link to the needs of those species. This is best defined by existing recovery plans for the species. If a recovery plan is not available, the responsible agencies should provide guidance on appropriate goals and objectives for the species as a whole.

2. The contribution to recovery made by BDCP is not predefined. Expert opinion and conceptual models of the species can be used to identify limiting factors/stressors for the species; BDCP should further select those limiting factors/stressors that can be addressed by the potentially regulated entities (PREs) and that occur within the planning area. From this subset of limiting factors, BDCP can then identify more specific goals and objectives that are within its scope and that are scaled by the level of effort envisioned for the Plan.

3. Conservation Measures must be identified that have the capacity to achieve the BDCP goals and objectives. Candidate measures can be screened using simple models (e.g., conceptual, statistical) to assess potential outcomes, both positive and negative. After

screening an initial list of conservation measures, some BDCP goals and objectives may appear unlikely to be addressed; additional conservation measures should then be developed and/or the BDCP goals and objectives should be revisited to ensure that their scale and scope generally match with the level of effort envisioned for the Plan.

4. Once the types and overall scale of the conservation measures have been determined, they can be further developed to the ‘project level’ and more specific expected outcomes identified. At this level of specificity, models of all types can be used to apply cause-effect relationships and find outcomes that achieve BDCP goals and objectives (and identify any potential negative outcomes). Where cause-effect relationships are weak or there is disagreement over the nature or magnitude of outcomes, testable hypotheses can be developed linking the action to the outcome and projects designed to test the hypotheses. The analytical framework for testing these hypotheses (and the necessary mechanistic monitoring) should be developed at this stage, prior to implementation of the projects.

5. Monitoring informs all of these steps. System-level monitoring informs whether goals and objectives for BDCP and the species are being achieved. Compliance monitoring ensures that measures (e.g., actual Old and Middle River (OMR) flows, elevation of grade or fill, water quality standards) are being implemented as expected. Performance monitoring is used to tell whether a conservation measure is achieving the expected outcomes, and mechanistic monitoring provides diagnostic information on why the expected outcomes are or are not being achieved. These types of monitoring are described in the Independent Advisors’ Report on Adaptive Management.

6. Once projects have been implemented and monitoring data are available, the key adaptive management step of Analyze, Synthesize and Evaluate must be conducted to: a) assess performance; b) inform adjustments to implemented projects and future actions; c) incorporate information as part of the knowledge base and; d) utilize information in models for future use in the planning process. This is the essence of adaptive management.

Linking Conservation Measures to Outcomes: Issues of Study Design, Quantification, Metrics, and Monitoring

Specific conservation measures provide the opportunity to develop clear hypotheses that predict outcomes, require rigorous quantification, and lead to well-designed studies with defined metrics and monitoring approaches. Conservation measures exert themselves at a variety of spatial scales. For example, reduction in a specific stressor might produce a response at the scale of the entire Delta while a habitat restoration project will impact a specific location. Study designs must necessarily consider the spatial component of the conservation measures and monitor appropriate response variables to the action. Study designs also must consider appropriate analytical frameworks for comparing responses to the actions. Will evaluation of the conservation measure be compared to a long-term trend, a control site, or a change in trajectory within a specific location? Scientists should be engaged to address the challenges of designing studies that effectively evaluate whether implemented conservation measures are yielding desired outcomes. This is an area where scientific expertise should be focused rather than on identifying overarching goals and objectives.

Well-designed studies linked to specific conservation measures are critical for developing the larger integrated monitoring framework. Finite resources will be available to evaluate the effectiveness of conservation measures agreed upon through BDCP. The sooner that study designs with designated metrics and monitoring locations are developed for each conservation measure to be implemented, the more readily can decisions be made on the best package of metrics to deploy, the locations for these measurements, and the analytical framework for data analyses. These decisions are integral to application of adaptive management, communication of outcomes from specific conservation measures, and informing decision-makers on management actions. These steps must be carried out within the context of the overall planning effort and not left until later.

The Role of Adaptive Management

In a system as complex as the Bay-Delta, involving multiple constituencies and numerous projects that entail huge investments, it is essential to avoid costly mistakes. The focus of the logic-chain approach on defining meaningful goals and objectives for BDCP is an important part of a successful planning process. It is also an essential element of adaptive management, which itself must be a core part of BDCP. Much has been made of adaptive management and its role in effective conservation and management. *Real* adaptive management, however, is rarely undertaken. In particular, the part of the process that involves assessment and synthesis of information gained after actions have been taken is often neglected or short-circuited, and the critical phase of linking that knowledge to decisions about whether to continue, modify, or stop actions, refine objectives, or alter monitoring efforts is usually missing. The report of Independent Science Advisors on Adaptive Management to the BDCP Steering Committee provides detailed guidance that should be incorporated into any logic-chain approach in BDCP.

Several aspects of adaptive management merit particular attention in relation to the logic-chain approach. First, adaptive management must begin with a clear definition of the problem to be addressed and the goals and objectives to be met. The hierarchical structure of logic plans helps to bring clarity to these statements of goals and objectives. Second, models can play a valuable role in adaptive management. Many of the conservation measures being proposed for the Bay-Delta are large and expensive; simulation or scenario models can be used to explore the likely outcomes of these measures before actually implementing the measures, and this information can be used in an adaptive-management framework to adjust goals, objectives, hypotheses, or measures as appropriate. Third, the adaptive-management phases of assessment, synthesis, translation, and communication must be integral parts of either model-based or actual implementations of adaptive management. Little is accomplished by producing model output or monitoring following the implementation of conservation measures if the resulting information does not make its way, in a carefully evaluated and readily comprehensible form, into the decision-making process.

Prioritization and Sequencing

The successful development of quantifiable objectives for BDCP will provide added benefits by allowing the expected outcomes of individual conservation measures to be compared to one another and used with other data to prioritize and sequence implementation. Measures with more significant outcomes and a broader range of species to benefit will be identified. Together with cost information (including the potential for negative outcomes), this information can be used by BDCP to develop a prioritized list of conservation measures, with the order of implementation being dependent upon decision criteria such as risk tolerance, availability of funds, cost relative to expected benefit, water requirements, and ease of implementation. For example, an implementation plan could sequence high-priority projects based on costs and reliability of benefits to seek to achieve early successes at minimal cost. Well-developed decision-support tools, such as ecological risk assessment or return-on-investment analysis, should be incorporated into the prioritization process.

APPENDIX 1

Specific Questions to the Panel and Panel Responses

The charge to the Review Panel included several specific questions. Here are our answers; the main body of the report describes our responses, evaluations, and suggestions in greater detail.

Purpose

- Does the framework reflect the recommendations made in February 2009 by the BDCP Independent Science Advisors' Report on Adaptive Management? *No*
- Can the framework adequately serve as a basis for refining the BDCP goals and objectives and developing an adaptive management plan? *Yes, if developed fully*
- Is the logic framework clearly defined and described? *Only partially*
- Is it internally consistent? *It is not consistent in how hypothesis testing is being employed*
- Is it clear for what purpose and how the framework might be used? *Yes, although greater clarity in linking BDCP goals and objectives to conservation measures and outcomes would be an improvement*

Approach

- Are the linkages between elements of the framework clear? *Yes*
- Is the relationship between recovery plan goals and BDCP goals and objectives clear? *No*
- What level of detail is necessary for the goals and objectives and for the framework in general? *Recovery/species goals and objectives can be stated qualitatively if sufficient detail is not available; BDCP objectives can be stated qualitatively or with order-of-magnitude approximations in the early planning stages, but with greater quantification as the plan is finalized for implementation; expected outcomes to conservation measures should be stated in sufficient quantitative detail to permit measurement, analysis, and testing of hypotheses.*
- Is the current use of conceptual models and hypotheses clear and helpful? *Only partially; currently the hypotheses are in the wrong place in the logic chain.* If not, how might this be changed or refined? *We have offered a refinement of the logic chain approach that improves clarity*
- What are the next steps regarding populating the logic chain? *General goals and objectives should be defined and populated by the appropriate regulatory agencies; it should be an immediate priority to develop clearer, more concise language and to find consensus on goals and objectives within the BDCP steering committee*
- What, if any, future role/need is there for additional scientific input? *The hypotheses linking conservation measures to projected outcomes, the design of studies to assess these linkages, and the framework for implementing adaptive management would benefit from additional scientific input*

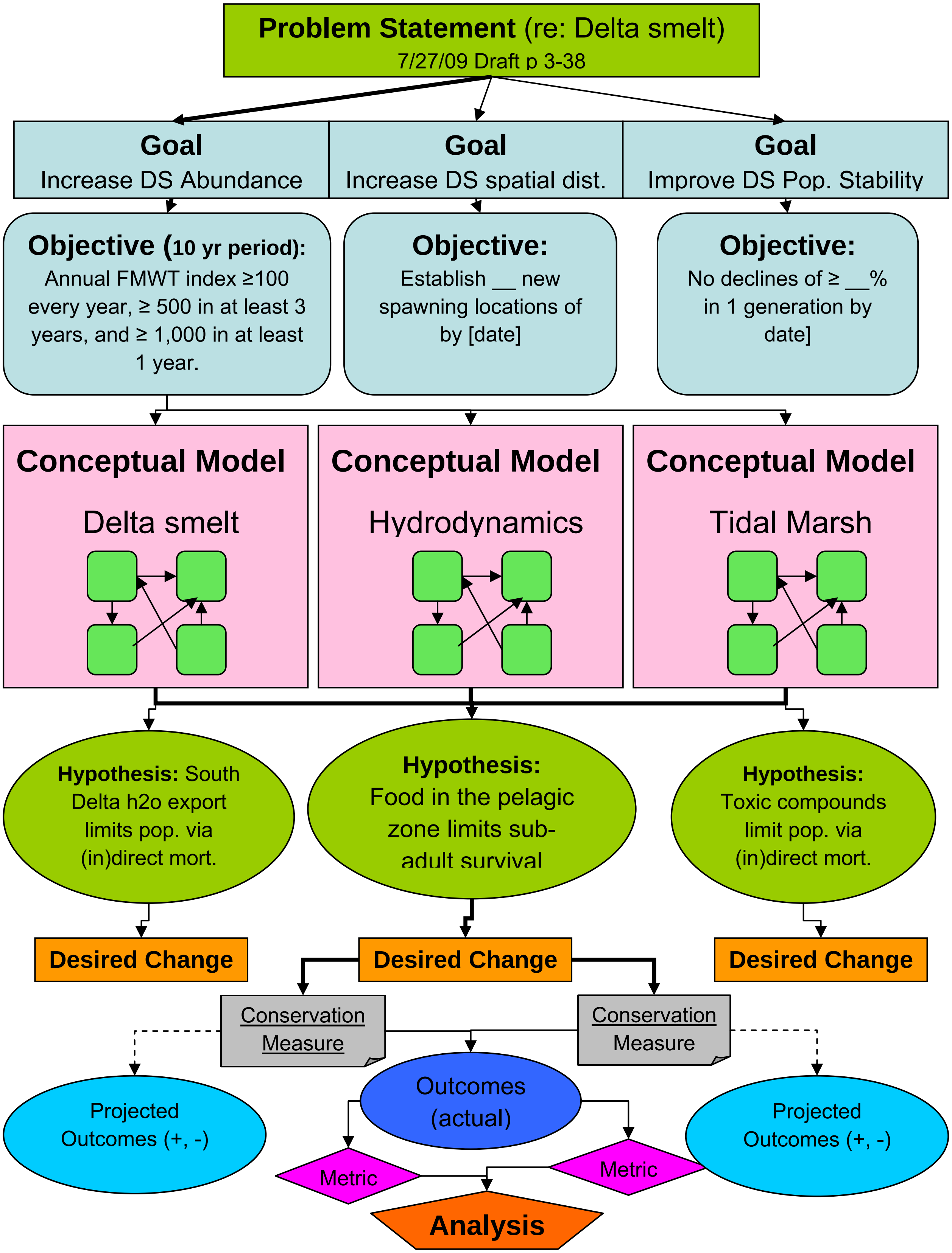
Feasibility

- Is the framework approach feasible to implement? *Yes, if done so in a focused manner*

- If not, what can be done to streamline or phase the approach? *Conduct a complete logic chain assessment for 2-3 species as proof of concept*

APPENDIX 2

The Current Version of the Logic Chain for Delta Smelt (Appendix B of the Logic Chain provided by American Rivers and The Bay Institute)


Problem Statement (re: Delta smelt)
7/27/09 Draft p 3-38
Goal
Increase DS Abundance
Goal
Increase DS spatial dist.
Goal
Improve DS Pop. Stability
Objective (10 yr period):
Annual FMWT index ≥100 every year, ≥ 500 in at least 3 years, and ≥ 1,000 in at least 1 year.
Objective:
Establish __ new spawning locations of by [date]
Objective:
No declines of ≥ __% in 1 generation by date]
Conceptual Model
Delta smelt
Conceptual Model
Hydrodynamics
Conceptual Model
Tidal Marsh
Hypothesis: South Delta h2o export limits pop. via (in)direct mort.
Hypothesis: Food in the pelagic zone limits sub-adult survival
Hypothesis: Toxic compounds limit pop. via (in)direct mort.
Desired Change
Desired Change
Desired Change
Conservation Measure
Conservation Measure
Projected Outcomes (+, -)
Outcomes (actual)
Projected Outcomes (+, -)
Metric
Metric
Analysis

Scientific Evaluation Worksheet (DRERIP Tool)

The scientific evaluation process provides a framework for evaluating and documenting the scientific basis for potential Delta restoration actions. Instructions and definitions for completing the worksheet are provided at the end of the worksheet.

Evaluation Team:

Date:

Action:

Step 1: Is the action written in such a way that it can be evaluated?

If yes, list the action, approach, and outcome below and continue.

Action:

Approach:

Outcome(s):

If no, explain why below, reject the action as written and move on to another action. Do not attempt to rewrite the action.

Problem(s) with Action as written:

Step 2: Assess Support for Action-Outcome Relationship Using Outcomes and Stressor Tables

Is the cause-effect relationship inferred in the Action supported by the Conceptual Models or Other Source Information?

If yes, document the specific model sections and/or page numbers, or other source materials that support this conclusion and continue.

Models used:

Other sources:

If no, document the rationale for the finding and stop.

Rationale:

Comments and suggestions for changing Action:

Identify data gaps and information that would be helpful in evaluating the action.

Step 3: Identify positive and negative outcome(s) for covered species

Positive Outcomes to Evaluate

Species	Outcome (i.e. effect on species)	Source (name of Conceptual Model or external reference)
	Outcome P1 (intended):	
	Outcome P2:	
	Outcome P"X":	

Negative Outcomes to Evaluate

Species	Outcome (i.e. effect on species)	Source (name of Conceptual Model or external reference)
	Outcome P1 (intended):	
	Outcome P2:	
	Outcome P"X":	

Step 4: Identify Scale of Action *(Large, Medium, Small: see instructions)*

Scale:

Rationale:

Step 5: Describe Relation to Existing Conditions

Would the action result in a change to system dynamics (either within the Delta or as inputs to the Delta) such that the current understanding of how the system works may no longer hold?

<u>If yes</u>, describe the specific boundary conditions that are expected to change and the likely extent of the change. Consider how the changes may affect the ability to evaluate the action using existing models and information.

<u>If no</u>, describe why not and continue.

Step 6: Score Magnitude, Certainty, and Worth of Potential Positive Ecological Outcome(s)

Outcome P1:

	Criteria Score[1]	**Rationale for Scoring, Document DLO paths/additional information used**
Magnitude		
Certainty		

Worth Score P1:

Outcome P2:

	Criteria Score	**Rationale for Scoring, Document DLO paths/additional information used**
Magnitude		
Certainty		

Worth Score P2:

Outcome P3:

	Criteria Score	**Rationale for Scoring, Document DLO paths/additional information used**
Magnitude		
Certainty		

Worth Score P3:

Comments and/or Assumptions used in scoring:

---

[1] See Appendix A

Step 7: Score Magnitude, Certainty and Risk of Potential <u>Negative</u> Ecological Outcome(s)

Outcome N1:

	Criteria Score	**Rationale for Scoring, Document DLO paths/additional information used**
Magnitude		
Certainty		

Risk Score N1:

Outcome N2:

	Criteria Score	**Rationale for Scoring, Document DLO paths/additional information used**
Magnitude		
Certainty		

Risk Score N2:

Outcome N3:

	Criteria Score	**Rationale for Scoring, Document DLO paths/additional information used**
Magnitude		
Certainty		

Risk Score N3:

Comments and/or assumptions used in scoring:

Step 8: Identify any Important Gaps in Information and/or Understanding

Data Needs *(indicate specific models, DLO relationships, or other information indicating the need):*

Research Needs *(describe specific research activities that could be employed to increase understanding):*

Step 9: Estimate Overall Degree of Worth and Risk

Combined Worth and Risk Scores

Outcome	Worth Scores	Risk Scores
P1		
P2		
N1		
N2		

Cumulative Score	

Provide rationale for the overall scores:

Step 10: Assess Reversibility and Opportunity for Learning

Reversibility *(yes/easy, no/hard - see instructions):*

Comments:

Opportunity for Learning *(high, low - see instructions):*

Comments *(refer to specific sources of information that support the above determination and identify high priority research questions and testable hypotheses):*

Step 11: Assign the Adaptive Management Category Using the Decision Tree

Adaptive Management Category *(full, pilot project, targeted research, discard):*

Comments:

Instructions

Step 1: **Is the action written in such a way that it can be evaluated?**

The action should be clearly written and contain basic components (action, approach, and outcome) as outlined in the Guidelines for Writing and Parsing Actions (*7/16/07*). An action can include multiple outcomes, but should list only one approach.

Step 2: **Is the cause and effect relationship between the action, approach, and outcome supported by the conceptual models, or other source material?**

Review General Outcomes table to identify conceptual models that include the general type of outcome identified in the action. Use these models and any other relevant source materials to assess if the relationship inferred by the action has been documented. If it is determined that the cause and effect relationship is not supported, document why and provide suggestions for how the actions might be re-cast to better achieve the desired outcome based on information in the conceptual models and other available scientific information. These suggestions can be used by action developers to improve the action for the next round of screening.

Step 3: **Identify positive and negative outcome(s) for covered species**

Using the standardized lists of outcomes and stressors from the Outcomes Table, identify as many positive and negative outcomes as possible (including the intended outcome). Outcomes should not be evaluated at this step, just simply listed. Outcomes not captured in models but identified based on other available information should be included, with notes describing the information used to identify the outcomes.

Identify positive and negative outcomes focusing only on covered species, but ensuring that all covered species anticipated to be affected are addressed, i.e., if the action is intended to benefit salmon, still look at effects on smelt.

Step 4: **Identify Scale of Action**

Identify the scale of the Action ‘scope’ based on the following criteria. The purpose of establishing Action scale is to assist with determining the magnitude of effect on the ecosystem. Large, medium and small should be considered relative to the Delta and the temporal dynamics of processes being manipulated.

Large:	Broad spatial extent, significant duration and/or frequency, and/or major reversal compared to existing conditions. Landscape scale.
Medium:	Moderate spatial extent, moderate duration and/or frequency, and/or moderate change compared to existing conditions. Regional scale.
Small:	Small acreage, short duration or only occasionally, and/or small change compared to existing conditions. Local scale.

Step 5: Describe Relation to Existing Conditions

Review the Boundary Conditions paper to assess whether or not the action has the potential to change system dynamics (either within the Delta or as inputs to the Delta) beyond the existing range conditions (i.e. change in inflows to the Delta, modified hydrodynamic conditions, or salinity regimes) such that the current understanding of how the system works may no longer hold? Consider how the changes may affect the ability to evaluate the action using existing models and information.

Step 6: Score Magnitude, Certainty and Worth of Potential Positive Ecological Outcome(s)

Using the conceptual models and other relevant source materials, identify and score the expected magnitude and certainty of the identified positive ecological outcomes. Record the magnitude and certainty for each positive outcome. ***Use one table per positive outcome.*** Add additional tables as needed to reflect additional outcomes.

Use the definition, criteria, and conversion tables in Appendix A to guide the scoring determination and to select an estimate of "Worth". Document how scores for magnitude and certainty were arrived at, including citation of specific model sections and page numbers, and/or additional information used in the rationale section.

Step 7: Score Magnitude, Certainty and Risk of Potential Negative Ecological Outcome(s)

Using the conceptual models and other relevant source materials identify and score the expected magnitude and certainty of each negative ecological outcome. Record the magnitude and certainty in the tables below. ***Use one table per outcome***. Add additional tables as needed to reflect additional outcomes.

Use the criteria and conversion tables in Appendix A to guide the scoring determination and to select an estimate of "Risk". Document how scores for magnitude and certainty were arrived at, including citation of specific model sections and page numbers, and/or additional information used in the rationale section.

Step 8: Identify any Important Gaps in Information and/or Understanding

Using the levels of understanding assigned to the DLO relationships used in the evaluation thus far, and/or any additional information from other sources, identify important data or research needs, that could enhance future evaluation of this or similar actions.

Step 9: Estimate Overall Degree of Worth and Risk

Enter scores for Worth and Risk from Steps 5 and 6 above into the table below and estimate the overall Worth and Risk scores for the Action as a whole. Add additional rows to the table as needed to reflect additional positive or negative outcomes.

Overall Worth score should be determined based on consideration of the cumulative positive outcomes (several medium outcomes could justify an overall score of “High” worth).

Overall Risk should be based on the highest single risk score (i.e. if any one of the outcomes has a high risk, then the overall Risk should be “high”).

Step 10: Assess Reversibility and Opportunity for Learning

Assess reversibility and opportunity to learn using the criteria below.

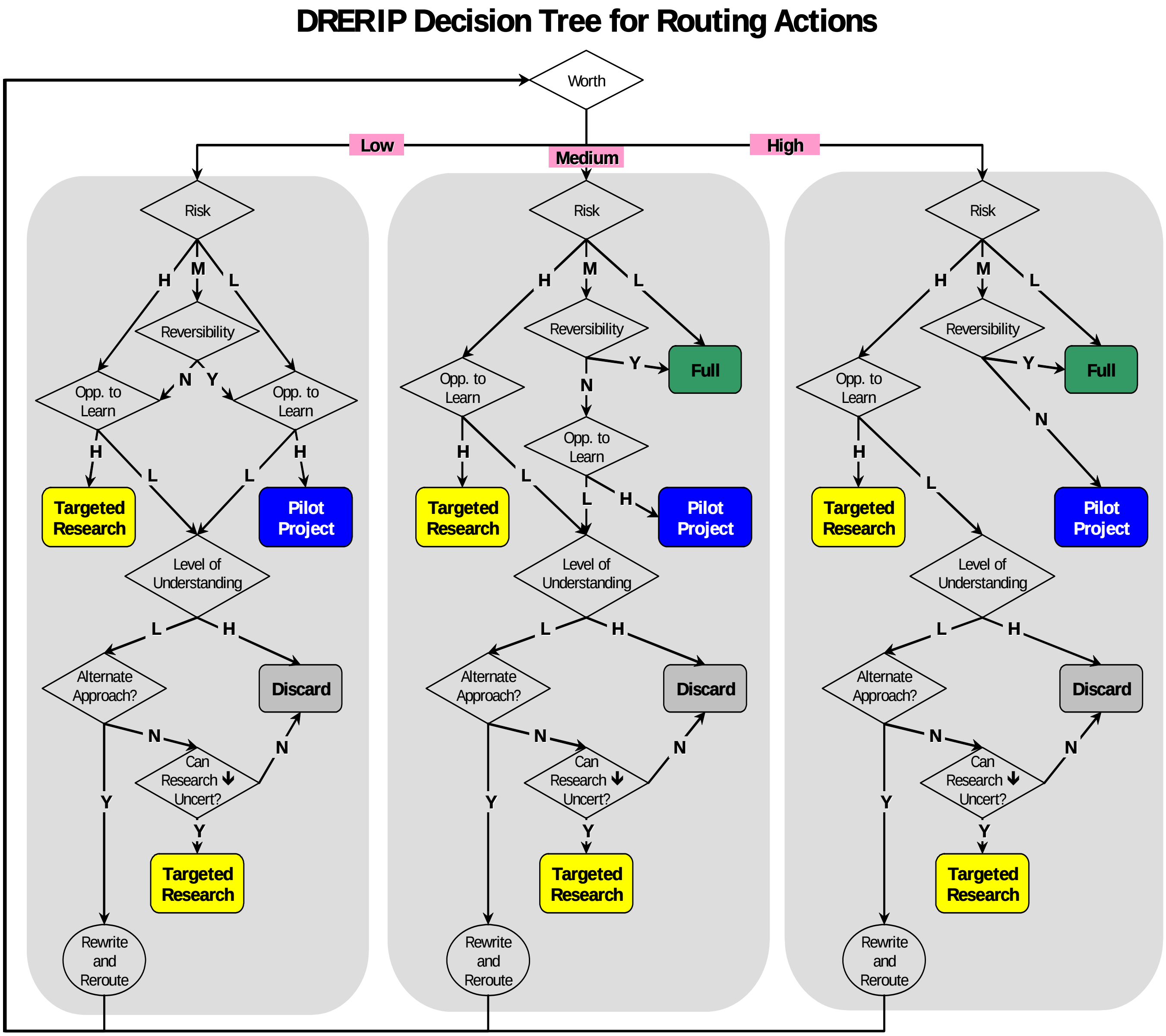
<u>Reversibility</u>

Yes/Easy	Outcome could likely be reversed as, or more quickly and cheaply than implementing the action.
No/Hard	Reversing outcomes would require more time or more money than implementing the action; outcomes may not be completely reversible.

<u>Opportunity for Learning</u>

High	Expect to advance our understanding of critical uncertainties as identified in Conceptual Models in a quantifiable manner
Low	Impractical or excessive time or resources likely required to achieve such understanding.

Step 11: Assign the Adaptive Management Category Using the Decision Tree



Appendix A:

Definitions, Criteria and Conversion Matrices

The following definitions, criteria, and conversion matrices, are provided to aid the Scientific Evaluation process. Some of the definitions pertain to terms used in the conceptual models, such as understanding and predictability. Other definitions relate directly to completion of the Scientific Evaluation worksheet.

Scientific Evaluation Terms

The terms ***scale, magnitude, and certainty*** are Scientific Evaluation terms used to characterize the cumulate "path" or "chain" found between a Restoration Action being evaluated and each Outcome being considered within Scientific Evaluation. Such a path or chain is not the same as the linkages in the conceptual models that describe the cause-effect relationships between a single driver and a single outcome (see conceptual model terms below).

The terms ***worth, risk, reversibility, and opportunity for learning*** are Scientific Evaluation terms that combine considerations of magnitude and certainty to assess the consequences of an action and recommend whether the action should be considered as targeted research, a pilot study, a full-scale implementation project, or discarded using the Scientific Evaluation decision tree.

> ***Scale*** - Scale addresses temporal and spatial considerations, quantity and/or degree of change contained within the Action.
>
> ***Magnitude –*** Magnitude assesses the size or level of the outcome, either positive or negative, as opposed to the scale of the Action. It can be assigned using consideration of population or habitat effects, and higher scores require consideration of the scale of the Action shown to result in the outcome. Magnitude scores are assigned by expert assessment, documented in the Scientific Evaluation worksheet, of the DLO pathway linking the action and the outcome, and/or any additional information available to the Scientific Evaluation team, the use of which must be documented in the Scientific Evaluation worksheet.
>
> ***Certainty*** - Certainty describes the likelihood that a given Restoration Action will achieve a certain Outcome. Certainty considers both the predictability and understanding of linkages in the DLO pathway from the action to the outcome. Generally, high importance-low predictability linkages drive the scoring; it is important to ensure that certainty is not unduly weighted by a comparatively low-importance, albeit low-predictability linkage.
>
> ***Worth*** - Combines the ***magnitude*** and ***certainty*** of positive outcomes to convey the cumulative "value" of a Restoration Action toward achieving an Outcome.

Risk - Combines the ***magnitude*** and ***certainty*** of negative outcomes to convey the cumulative "potential" for a Restoration Action to result in an adverse, or negative Outcome.

Reversibility - The ease and predictability with which the outcome(s) of a Restoration Action or a group of Restoration Actions can be undone and/or reversed. For example, if the Action changes the ecosystem structure, can the original form be re-established? Have such outcomes been un-done in the past? A change to a flow regime is relatively easy to reverse; successful introduction of a new species is relatively difficult to reverse.

Opportunity for learning - Opportunity for learning is the likelihood that a Restoration Action or a group of Restoration Actions will increase the level of understanding with regard to the species, process, condition, region or system that is in question or of concern, assuming that appropriate monitoring and evaluation is conducted.

Conceptual Model Terms

The terms ***importance, predictability, and understanding*** are used in the conceptual models to characterize individual linkages (depicted as arrows in the models) between a driver and an outcome. The terms pertain to specific processes or mechanisms within a given model (e.g. how important is the supply of organic matter to mercury methylation?). The graphical forms of the conceptual models apply line color, thickness, and style to represent these three terms.

Importance - The degree to which a linkage controls the outcome *relative to* other drivers and linkages affecting that same outcome. Models are designed to encompass all identifiable drivers, linkages and outcomes but this concept recognizes that some are more important than others in determining how the system works. If a driver is potentially more important under particular environmental conditions, the graphic should display the maximum level of importance of this driver with the narrative describing the range of spatial and temporal conditions associated with this driver.

Predictability - The degree to which the performance or the nature of the outcome can be predicted from the driver. Predictability seeks to capture the variability in the driver-outcome relationship. Predictability can encompass temporal or spatial variability in conditions of a driver (e.g., suspended sediment concentration or grain size), variability in the processes that link the driver to the outcome (e.g., sediment deposition or erosion rate as influenced by flow velocity), or our level of understanding about the cause-effect relationship (e.g., magnitude of sediment accretion inside vs. outside beds of submerged aquatic vegetation). Any of these forms of variability can lead to difficulty in predicting change in an outcome based on changes in a driver.

Understanding – A description of the known, established, and/or generally agreed upon scientific understanding of the cause-effect relationship between a single driver and a single outcome. Understanding may be limited due to lack of knowledge and information or due to disagreements in the interpretation of existing data and information; or because the basis for assessing the understanding of a linkage or outcome is based on studies done elsewhere and/or on different organisms, or conflicting results have been reported. Understanding should reflect the degree to which the model that is used to represent the system does, in fact, represent the system.

Scientific Evaluation Scoring Criteria

The following tables should be used to inform ***magnitude and certainty*** scores for Scientific Evaluation. These entail looking holistically at the cumulative value (positive or negative) of an action.

Table 1 - Criteria for Scoring Magnitude of Ecological Outcomes (positive or negative)

4 - High: expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population's natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics. Requires a large-scale Action.
3 - Medium: expected sustained minor population effect or effect on large area (regional) or multiple patches of habitat. Requires at least a medium-scale Action.
2 - Low: expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial (local) or temporal habitat effects.
1 - Minimal: Conceptual model indicates little effect.

Table 2 - Criteria for Scoring Certainty of Ecological Outcomes (positive or negative)

4 - High: Understanding is high (based on peer-reviewed studies from within system and scientific reasoning supported by most experts within system) and nature of outcome is largely unconstrained by variability (i.e., predictable) in ecosystem dynamics, other external factors, or is expected to confer benefits under conditions or times when model indicates greatest importance.
3 - Medium: Understanding is high but nature of outcome is dependent on other highly variable ecosystem processes or uncertain external factors or understanding is medium (based on peer-reviewed studies from outside the system and corroborated by non peer-reviewed studies within the system) and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
2 - Low: Understanding is medium and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors or understanding is low (based on non peer-reviewed research within system or elsewhere) and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
1 - Minimual: Understanding is lacking (scientific basis unknown or not widely accepted), or understanding is low and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors

Conversion Matrices

The following two matrices are designed to combine scores for magnitude and certainty to develop overall values for Worth and Risk.

Table 3. Conversion Matrix for Determining Worth from the Criteria Scores for Positive Outcomes.

Is It Worthwhile?

Combining Magnitude and Certainty

		Certainty			
		1	2	3	4
Magnitude	1	***Low***	***Low***	***Med***	***Med***
	2	***Low***	***Med***	***Med***	***High***
	3	***Med***	***Med***	***High***	***High***
	4	***Med***	***High***	***High***	***High***

Table 4. Conversion Matrix for Determining Risk from the Criteria Scores for Negative Outcomes.

Is It Risky?

Combining Magnitude and Certainty

		Certainty (understanding + predictability)			
		1	2	3	4
Magnitude	1	***Med***	***Med***	***Low***	***Low***
	2	***High***	***Med***	***Med***	***Low***
	3	***High***	***High***	***Med***	***Med***
	4	***High***	***High***	***High***	***Med***

Feasibility Investigation of Re-Operation of Shasta and Oroville Reservoirs in Conjunction with Sacramento Valley Groundwater Systems to Augment Water Supply and Environmental Flows in the Sacramento and Feather Rivers

Northern Sacramento Valley Conjunctive Water Management Investigation

Sponsored by
The Natural Heritage Institute
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Executive Summary

Introduction

In 2006, the Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) jointly embarked on this investigation to explore how the largest water storage reservoir in the Federal Central Valley Project (CVP), Shasta, and the only such reservoir in the State Water Project (SWP), Oroville, could be re-operated in conjunction with northern Sacramento Valley groundwater aquifers to increase water supplies for both environmental and economic uses. GCID is the Sacramento Valley's largest agricultural water supplier with annual water entitlements of 825,000 acre-feet in most years, based on pre-1914 Sacramento River and other water rights. The Natural Heritage Institute (NHI) is a non-governmental, non-profit organization that works at the global scale to preserve and restore the natural functions of river systems and the services they provide to sustain and enrich human life. The investigation was enabled by a combination of state and federal grant funding, including Proposition 50 funding administered by the Department of Water Resources (DWR) and federal funds channeled through the Bureau of Reclamation's (Reclamation) Mid-Pacific Region.

Two other agricultural water suppliers, Western Canal Water District (WCWD) and Richvale Irrigation District (RID), participated in the investigation to the extent of providing technical information and by expressing their interest and potential willingness to support a conjunctive water management project, subject to their review of the investigation's findings. Both districts have water entitlements to Feather River water supplies delivered through the SWP.

Public outreach was conducted in a variety of forums to guide the investigation and to inform interested parties regarding findings and progress. Outreach activities included seven publicly noticed meetings held in the Sacramento Valley, three executive briefings for Reclamation and DWR management staff and four workshops designed primarily to facilitate collaboration with DWR and Reclamation staff involved with operating the CVP and SWP, respectively. Additionally, the project technical team met many times with Reclamation and DWR staff to advance and coordinate the technical work.

At its inception, the investigation focused on the Sacramento Valley's deep aquifers, particularly the Lower Tuscan Formation, which underlies much of the northern portion of the Sacramento Valley. However, as the investigation progressed the study team recognized that such a narrow focus was both overly constraining on the scope of the study and somewhat misleading because it implied that any effects on the aquifer system due to additional recharge or pumping could somehow be confined to a particular portion of the groundwater system. Ultimately the project evaluated the effects of exercising both the northern Sacramento Valley's deep aquifer system, which is presently relatively undeveloped, and the shallower, regional aquifer, which is more heavily pumped for both domestic and agricultural needs.

The investigation began with the expectation that surplus water generated through the re-operation of these reservoirs could be banked in the groundwater aquifers in the Sacramento Valley, like other conjunctive use programs in the San Joaquin Valley of California, with water put into groundwater storage in wet years and extracted in dry years. However, initial assessment and site screening revealed that conditions in the Sacramento Valley are not conducive to this mode of conjunctive management, primarily because groundwater aquifers, although extensively developed and pumped in many areas, mostly for agricultural irrigation, generally recover fully during the precipitation season. What emerged was a conjunctive management approach based on reservoir re-operation backstopped by several options for reducing the draw on reservoir storage when refill is insufficient.

Core Conjunctive Management Concept

The central thesis of this investigation is that most major reservoirs that are operated today for a limited set of water supply and flood control objectives could be re-operated to achieve newly defined ecological restoration benefits while also improving water supply reliability, reducing flood risks, and buffering the effects of climate change. The objective of the project was to explore the potential to optimize operations for all of these benefits without compromising any of them.

Reservoirs that have dual water supply and flood control functions, like the CVP and SWP reservoirs, are typically operated under conservative rules designed to maximize water supply while avoiding flood risks. This results in relative high carryover storage levels but frequent “spills” of water during the refill period to create sufficient flood reservation capacity as necessary to prevent flood damage to the development that has occurred in the downstream floodplain. These spills represent the component of the runoff hydrograph that is not controlled and therefore not appropriated for beneficial use under California water law. To capture and manage this water would require creating additional storage capacity. One way to do that without enlarging the reservoir, or constructing additional ones, is to lower the water storage levels going into the refill period, thereby creating more reservoir capacity to capture high flows. Storage levels can be lowered by delivering additional water from the conservation pool to meet new water supply objectives, including enhancing flows for environmental benefits and augmenting water supplies for consumptive uses such as agriculture.

However, making additional reservoir releases before the ensuing refill period incurs a larger risk of water supply shortages in the event that the quantity of runoff during the refill season, which is always uncertain, is not sufficient to recover the reservoir storage to the level that would have occurred if the additional releases had not been made. Failure for the reservoir to refill would impinge on the reservoir’s function, manifest as water supply shortages, inadequate cold water reserves or reduced carryover storage, or some combination of these factors, unless the reservoir deficit can be made up from other sources.

Three strategies for “paying back[1]” the reservoirs in this manner were investigated:[2]

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[1] The terms reservoir “refill” and reservoir “payback” are used in this report. Reservoir refill refers to recovery of reservoir storage by either capturing surplus surface water flow or by not making reservoir releases that would otherwise need to be made. The latter means of reservoir refill (not making reservoir releases that would otherwise need to be made) is referred to as reservoir payback. Different reservoir payback strategies and mechanisms are described in the report.

[2] A fourth payback strategy that was not considered in this study would be to repay the reservoirs with water conveyed to and banked in aquifers south of the Delta in previous years. This option poses certain advantages to the Sacramento Valley by eliminating or substantially reducing the need to exercise Sacramento Valley aquifers for payback and making surplus water available when and where it has the highest economic value. While, this option is beyond the scope of this phase of investigation, these advantages suggest that it may be a particularly robust alternative that warrants investigation in a subsequent phase of analysis. Notably, this option is only viable if and when additional conveyance capacity through, around or under the Delta becomes available, as is currently being considered in the development of the Bay Delta Conservation Plan (BDCP).

1. Payback from water generated by the project in previous years and stored (or “banked”) in aquifers in the Sacramento Valley;

2. Payback from groundwater pumped by cooperating water suppliers served by the CVP or SWP to substitute for water that would otherwise have had to be delivered from the reservoirs; and,

3. Payback from reduction in water demands on the reservoirs, achieved by temporary crop idling on a voluntary, compensated basis.

Project Objectives and Principles

The basic objective of reservoir re-operation is to generate additional water supplies (or “assets”) for discretionary uses. In this case, the investigation looked at dedicating additional water supplies generated through re-operation of Shasta and Oroville to two primary in-Valley purposes:

1. **Enhancing ecosystem functions in the Sacramento and Feather Rivers.** Healthy rivers are not just environmentally valuable, they also are central to ensuring reliable, sustainable water supplies. Water supply systems that work in concert with the environment are less likely to be encumbered by court orders, water rights hearings, and other restrictions that can have drastic effects on water supplies for farming and other economic uses.

2. **Improving local water supply reliability, particularly in times of scarcity.** The investigation used historical unmet agricultural water demands to represent the need for additional water supplies in the Valley; however, the additional water supplies could be allocated to other uses and locations.

Design principles were established early on to guide development of project scenarios. The principles were derived in part from public input as well as from the sensibilities of the project sponsors and funding agencies, all aimed at identifying realistic, implementable water management improvements. The primary design principles are as follows:

1. Honor all existing CVP and SWP obligations and operational constraints: The CVP and SWP operate under a complex set of rules and conventions consistent with project water supply and flood control objectives and regulatory requirements, including temperature criteria, State Water Resources Control Board (SWRCB) Decision 1640 (D-1640), and the Central Valley Project Improvement Act (CVPIA). All of these existing objectives and constraints must be observed in any conjunctive management scenario so that water supply obligations to contractors are met to the same extent as under existing operations, and all applicable regulations are satisfied.

2. Achieve net environmental benefits, recognizing that there may be some tradeoffs among different environmental objectives and different times and locations: The Project would be operated to achieve or contribute to achieving certain environmental flow improvements in the mainstem Sacramento and Feather Rivers designed specifically to enhance ecologic functions important to the viability of protected species, particularly Chinook salmon. Three such tradeoffs are acknowledged in the Report:

    - Peak flood control releases, which may be environmentally beneficially, would be captured and released in a controlled pattern to achieve more tailored environmental and geomorphic benefits. In a sense, this is a strategy to use limited environmental water supplies in a more efficient manner.

- When groundwater pumping is needed for reservoir payback (under payback option #2, above), this could result in temporary reductions in base flows in the tributary streams that are also important to protected species.
- More aggressive exercise of the reservoirs to improve flow conditions for ecosystem enhancement may entail a greater risk of depleting cold water reserves needed for downstream temperature maintenance.

Such potential tradeoffs would be addressed through consultation with the listing agencies as part of the NEPA/CEQA compliance by project sponsors. Additional tradeoffs between restoration of more natural river flow regimes and maintenance of cold water pools for river temperature control are also possible and are discussed later in this report.

3. Hold other groundwater users harmless: The participating water districts are legal users of groundwater, and, like all other groundwater users in the basin, enjoy a correlative and co-equal right to increase their groundwater extractions for use by the overlying landowners, subject to the mutual avoidance of harm. Notwithstanding the legality of the participating districts' groundwater withdrawals, the Project would adhere to a "good neighbor" principle and design its mitigation plan to the higher standard of assuring no appreciable, unmitigated harm to existing groundwater users.

4. Generate net economic benefits so that the program can be self-financing: The project must be able to generate revenues that more than offset the expenditures associated with project implementation, including construction, operation, maintenance and any mitigation costs. In the economic analysis conducted for the study, revenues were included only for water sales; no monetary value was attached to ecosystem restoration benefits, although these benefits may be quite appreciable.

Project Site Screening and Selection

A systematic, qualitative assessment of conditions within the Sacramento Valley was conducted to identify particular areas where conjunctive operations appear promising. The team examined fall groundwater elevation maps, water supplier boundaries and distribution system coverages, and water source maps. The project and technical teams developed an initial list of project sites from a review of groundwater maps and their professional knowledge of the Sacramento Valley. Sites were named according to the overlying water districts, though potential sites did not strictly conform to water district boundaries. Information considered in this analysis included the location, water source, existing surface water contracts, current infrastructure and additional infrastructure necessary for delivery of surface water and for extraction of groundwater, operational concepts, and information on existing groundwater conditions. Table ES-1 summarizes this information considered for the nine initial sites.

Evaluation of existing groundwater conditions within the Sacramento Valley shaped the site screening and selection. In general, the evaluation revealed that while groundwater levels are drawn down during the irrigation season in many areas of the basin, levels recover during the precipitation season except during prolonged (multi-year) dry periods. Cones of depression generally do not persist over the

TABLE ES-1
Initial Project Sites and Parameters
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Location	Water Source	Site Type	Annual Surface Water Contract	Project to Integrate With	Currently Integrated?
Butte Basin	Surface	GW Pumping	~ 300 TAF/yr	SWP	Yes
Orland-Artois WD	Mixed	Both	53 TAF/yr	CVP	Yes
Rancho Capay WD	Ground	GW Banking	None	CVP	No
Corning Canal Area	Mixed	Both	33 TAF/yr	CVP	Yes
Yolo-Zamora WD	Ground	GW Banking	None	CVP	No
Glenn-Colusa ID	Surface	GW Pumping	825 TAF/yr	CVP	Yes
Stony Creek Fan area	Surface	GW Pumping	~ 100 TAF/yr	Orland	No
Colusa County WD	Mixed	Both	68 TAF/yr	CVP	Yes
Olive Percy Davis Ranch	Surface	GW Pumping	32 TAF/yr	CVP	Yes

multiple years necessary to make the dewatered aquifer space suitable for banking[3]. Any additional water recharge induces additional groundwater discharge to the streams. The conclusion from this analysis was that conjunctive operations based on a groundwater banking payback mechanism are not feasible in the Sacramento Valley at this time. Thus, further effort was concentrated on a second option for a payback mechanism: pumping groundwater in lieu of making reservoir deliveries in years when reservoir payback would be necessary.

Two sites were identified on which to conduct more refined analyses with surface and groundwater modeling tools. The GCID and Butte Basin Projects[4], supplied by the CVP and SWP, respectively, provided the potential to pump the largest quantity of groundwater compared to other sites, and are already well integrated with the surface water system. Under this option, conjunctive management operations would utilize wells within GCID and the Butte Basin as a backstop for more aggressive operation of Shasta Reservoir and Oroville Reservoir, respectively.

Ecological Flow and Agricultural Water Supply Targets for Conjunctive Operations

A major element of this investigation was the development of specific ecological flow objectives for the Sacramento and Feather Rivers to use to formulate and evaluate reservoir re-operation scenarios. The ecologic flow objectives fall into two categories, three that were designed for Chinook salmon recovery, and one that was designed for riparian habitat recovery. These may be summarized as follows:

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[3] Based on the most recent (Fall 2011) data collected by DWR, there appear to be some areas in the northern Sacramento Valley with persistent groundwater level declines, primarily in Glenn and Tehama Counties. These areas should be evaluated for potential groundwater banking operations in future work phases.

[4] The major water surface water suppliers within the Butte Basin are WCWD, RID and Biggs-West Gridley Water District (BWGWD). BWGWD declined to participate in the investigation, so development of the Butte Basin project concentrated on the other two districts. It is noted that WCWD and RID were passive project participants meaning they provided information for the investigation but did not assume a sponsorship role. Additionally, the Stony Creek Fan area and Orland Project was identified as a third potential project. However, upon further evaluation into potential groundwater pumping capacities and the ability to integrate the project with the Sacramento River system, it was determined that this project would not be investigated during this phase of the project. However, this project does deserve additional analysis in future phases of investigation.

For Chinook salmon:

- Geomorphic objectives: Sediment transport, bed mobilization and bed scour; channel migration and floodplain processes; inundation and fine sediment deposition

- Floodplain inundation objectives : inundated floodplain habitat for rearing juveniles during the later winter and early spring; maintain and recruit spawning habitat, but avoid scouring gravels while eggs or alevon are present

- Spring pulse flow objectives: Suitable flow conditions and temperatures for all life stages;

For Riparian Habitat:

- Fremont cottonwood seedbed preparation, seed germination and seedling growth; periodic large-scale disturbance of the riparian zone; riparian stand structure and diversity

In each category, the objectives are expressed as quantitative flow targets for the two rivers, respectively, defined in terms of flow magnitude, duration, frequency and seasonality, by river reach[5]. The various objectives are coupled with a dynamic decision system for prioritizing objectives from year to year.

Historical agricultural water supply shortages in the Sacramento Valley were used to represent the targets for water supply enhancements. Specifically, for the CVP/Sacramento River, unmet demands of CVP contractors within the Tehama-Colusa Canal Authority (TCCA) were used to represent additional demands. Members of the TCCA, including contractors supplied from the Corning Canal, hold agricultural service contracts for approximately 320 TAF of contract supply from the CVP, subject to shortages. Historical shortages (as simulated in CalSim II) were used to quantify unmet demands. On the Feather River system, the majority of SWP contractors have reliable water supplies with the exception of a few small contractors. There are no existing SWP contractors with large, frequently unmet agricultural demands in the Butte Basin. Therefore a more general unmet agricultural demand was defined for the Feather River based on user input and judgment.

Initial Project Scenarios

Four conjunctive operations scenarios were developed for the GCID and Butte Basin project locations for initial analysis. The scenarios are differentiated primarily by the following two parameters:

- Maximum Payback Capacity. This is the maximum volume of groundwater pumping that would occur in any year within the pumping period (see below) in GCID and the Butte Basin, respectively. This capacity essentially establishes the scale of the conjunctive operation, since the water deficit in the reservoirs cannot exceed the capacity to repay it, when that becomes necessary. Maximum capacities were based primarily on professional judgment taking into consideration historical pumping in the two areas and average pumping intensity (acre-feet per acre). The payback capacities selected for analysis were:
    - 100 TAF in GCID and 50 TAF in Butte Basin; total 150 TAF

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[5] Although developed specifically for the purpose of formulating conjunctive management strategies, the recommended objectives and flows are believed to have broader utility beyond this investigation.

  - 200 TAF in GCID and 100 TAF in Butte Basin; total 300 TAF

- Pumping Period. Pumping must occur when there is a demand for water that would otherwise be satisfied by reservoir releases. In both project areas, the dominant crop is rice, which is typically planted between mid-April and early June and harvested in September. Following harvest, most rice fields are re-flooded between September and November for rice straw decomposition and to create waterfowl habitat. Thus the water delivery season in both areas is from mid-April through November. Based on this, three pumping periods listed below were identified for analysis. Different pumping periods were evaluated primarily to reveal differences in aquifer response to differences in the timing and rate of pumping. Additionally, the pumping period affects the capital investment needed for pumping facilities.
  - “Summer” defined as May through August
  - “Fall” defined as September through November
  - “Summer and Fall” defined as May through November

The combinations of payback capacity and pumping periods selected to form scenarios are listed in Table ES-2.

TABLE ES-2
Project Scenarios Evaluated
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Scenario	GCID Annual Pumping Capacity	Butte Basin Annual Pumping Capacity	Pumping Season
1	100 TAF	50 TAF	Summer (May through August)
2	200 TAF	100 TAF	Summer (May through August)
3	100 TAF	50 TAF	Fall (September through November)
4	100 TAF	50 TAF	Summer and Fall (May through November)

TAF = thousand acre-feet

Additionally, two well field configurations were evaluated for each scenario, one corresponding to existing wells screened at depths between 100 to 500 feet and a second well field corresponding to new wells screened at depths of 900 to 1,100 feet. Thus a total of eight operational scenarios were evaluated.

Analytic Tools

Formulating and evaluating potential conjunctive management projects requires simulation of both surface water and groundwater systems. Simulating the surface water system is necessary to determine when water is available to refill reservoirs and to estimate unmet agricultural demands, environmental objectives, and flow conditions. A groundwater model is necessary to estimate the effects of additional pumping on aquifer systems, including the spatial extent and magnitude of drawdown and potential change in stream-aquifer interaction. Changes in stream-aquifer interactions may affect the surface water system, depending on stream conditions when the changes occur. For example, if additional pumping results in more stream loss to the aquifer or less aquifer contribution to stream flow during the winter season of relatively wet years when the surface water system has surplus flow, there may be little or no impact. However, if pumping reduces stream flow during months and years when the surface water system is being operated to meet specific flow or water quality requirements, any reduction in stream flow will require a corresponding increase in reservoir release to ensure the flow requirement continues to be met. This decreases the water supply benefit of conjunctive management projects.

Evaluating this aspect of conjunctive management projects required coordinated operation of surface water and groundwater models.

The main tool used to evaluate alternative conjunctive management operations strategies and test alternative environmental flow thresholds and priorities was a spreadsheet-based surface water model. The model simulates changes in operation of Lake Shasta and Lake Oroville relative to conditions depicted in a baseline CalSim II simulation of CVP and SWP operations. The CalSim II baseline provides time series of reservoir storage levels, stream flows, and water deliveries which are used by the surface water model. Conjunctive management operations are simulated and layered onto baseline operations based on user inputs, while maintaining compliance with existing CVP and SWP rules, regulation, and operations. Consistent with currently available CALSIM II runs, the surface water model operates over the 82-year period from 1922 through 2003, inclusive.

For the groundwater analysis, an existing simplified groundwater modeling tool was completely re-designed and improved, to yield a powerful analytical package now referred to as the Sacramento Valley Groundwater Model (SACFEM). SACFEM is a full water budget based transient groundwater flow model that incorporates all of the groundwater and surface water budget components on a monthly time step over the period of simulation. The model domain covers the entire Sacramento Valley floor from Redding in the north to Sacramento in the south, and includes explicit representations of all major and many minor streams. The model provides very high resolution estimates of groundwater level and streamflow effects due to conjunctive water management pumping. In contrast to the surface water model, the groundwater model operates over a 17-year period from 1987 to 2003, due to the lack of historical data needed to calibrate the model prior to 1987.

Performance of Initial Project Scenarios

The performance of the initial project scenarios was evaluated by simulating operations with the surface water model. Scenarios 1, 3 and 4 are identical from a surface water operations perspective because they have the same payback pumping capacity in GCID and in the Butte Basin, respectively. Scenario 2 is different because GCID and Butte Basin pumping capacities are higher compared to Scenarios 1, 3 and 4.

The project benefits in terms of environmental flow targets met and agricultural water supplies generated are presented in Table ES-3. In GCID, at the 100 TAF project scale (associated with Scenarios 1, 3 and 4), environmental flow releases are made in 23 years in the 82 year period of analysis, or 28 percent of the years. The average environmental release volume is 46 TAF in the years made, or 13 TAF averaged over the full 82-year period. Agricultural water supply releases were made in 24 years, or 29 percent of the years, with the average release volume being 46 TAF in the years made and 14 TAF averaged over the full 82-year period. When the GCID project scale is doubled to 200 TAF (Scenario 2), project benefits increase appreciably. Environmental flow releases are made in 40 years, or 49 percent of the time, with the average release being 96 TAF in the years of occurrence and the 82-year average being 47 TAF. Agricultural water supply releases also increase but not by as much proportionally as environmental releases. The frequency of agricultural releases stays the same (at 24 years), but the average release increases to 75 TAF in the years of occurrence and 22TAF over the 82-year period.

In Butte Basin, at the 50 TAF project scale (associated with Scenarios 1, 3 and 4), environmental flow releases are made in 28 years in the 82 year period of analysis, or 34 percent of the years. The average environmental release volume is 21 TAF in the years made, or 7 TAF averaged over the full 82-year period. Agricultural water supply releases were made in 30 years, or 37 percent of the years, with the average release volume being 27 TAF in the years made and 10 TAF averaged over the full 82-year

TABLE ES-3
Environmental and Agricultural Water Supply Benefits under Conjunctive Operations
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

			Environmental Benefits			Agricultural Benefits		
Scenario(s)	Project/System	Payback Pumping Capacity (TAF)	Number of Years	Avg in Yrs of Occurrence (TAF)	Avg Over All Yrs (TAF)	No. Yrs.	Avg in Yrs of Occurrence (TAF)	Avg Over All Yrs (TAF)
1, 3 and 4	GCID/CVP Lake Shasta-Sac R	100	23	46	13	24	46	14
1, 3 and 4	Butte Basin/SWP Lake Oroville-Feather R	50	28	21	7	30	27	10
2	GCID/CVP Lake Shasta-Sac R	200	40	96	47	24	75	22
2	Butte Basin/SWP Lake Oroville-Feather R	100	44	43	23	30	52	20

period. When the Butte Basin project scale is doubled to 100 TAF (Scenario 2), project benefits increase appreciably. Environmental flow releases are made in 44 years, or 54 percent of the time, with the average release being 43 TAF in the years of occurrence and the 82-year average being 23 TAF. Agricultural water supply releases also increase but not by as much proportionally as environmental releases. The frequency of agricultural releases stays the same (at 30 years), but the average release increases to 52 TAF in the years of occurrence and 20TAF over the 82-year period.

A fundamentally important finding is revealed through inspection of how the reservoirs are refilled following draw down to make project releases (Table ES-4). For the GCID 100 TAF project scale (Scenarios 1, 3 and 4), reservoir refill occurs in 33 years. But in 29 years the refill comes from surplus surface flows. In only 4 years is it necessary to pump from project groundwater. That is less than 5 percent of the years of operation. The average refill from surplus surface flows is 70 TAF in the years of occurrence and 24 TAF over the full period. In contrast, the refill from project groundwater pumping is also 70 TAF in the years of occurrence but just 4 TAF annually averaged over the full period. Importantly, the maximum year pumping is 98 TAF or nearly the full assumed repayment pumping capacity. At the 200 TAF project scale in GCID (Scenario 2), reservoir refill occurs in 41 years, with refill from surplus surface water occurring in 35 years and from project groundwater pumping in 6 years. The average refill from surplus surface flows is 139 TAF in the years of occurrence and 58 TAF annually over the full period.

For the Butte Basin 50 TAF project scale (Scenarios 1, 3 and 4), reservoir refill occurs in 43 years, including 37 years of refill from surplus surface flows and just 6 years from project groundwater pumping. The average refill from surplus surface flows is 32 TAF in the years of occurrence and 14 TAF over the full period. In contrast, the refill from project groundwater pumping is 44 TAF in the years of occurrence but just 3 TAF annually averaged over the full period. Importantly, the maximum year pumping is 50 TAF, the full assumed repayment pumping capacity. At the 100 TAF project scale in Butte Basin (Scenario 2), reservoir refill occurs in 51 years, with refill from surplus surface water occurring in 43 years and from project groundwater pumping in 8 years. The average refill from surplus surface flows is 72 TAF in the years of occurrence and 36 TAF annually over the full period.

TABLE ES-4
Reservoir Refill under Conjunctive Operations
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Scenario(s)	Project/System	Payback Pumping Capacity (TAF)	Surplus Surface Water			Project Groundwater Pumping			
			Number of Years	Avg in Yrs of Occurrence (TAF)	Avg Over All Yrs (TAF)	No. Yrs.	Avg in Yrs of Occurrence (TAF)	Avg Over All Yrs (TAF)	Maximum Year (TAF)
1, 3 and 4	GCID/CVP Lake Shasta-Sac R	100	29	70	24	4	70	4	98
1, 3 and 4	Butte Basin/SWP Lake Oroville-Feather R	50	37	32	14	6	44	3	50
2	GCID/CVP Lake Shasta-Sac R	200	35	139	58	6	123	9	198
2	Butte Basin/SWP Lake Oroville-Feather R	100	43	72	36	8	75	7	100

For the Butte Basin 50 TAF project scale (Scenarios 1, 3 and 4), reservoir refill occurs in 43 years, including 37 years of refill from surplus surface flows and just 6 years from project groundwater pumping. The average refill from surplus surface flows is 32 TAF in the years of occurrence and 14 TAF over the full period. In contrast, the refill from project groundwater pumping is 44 TAF in the years of occurrence but just 3 TAF annually averaged over the full period. Importantly, the maximum year pumping is 50 TAF, the full assumed repayment pumping capacity. At the 100 TAF project scale in Butte Basin (Scenario 2), reservoir refill occurs in 51 years, with refill from surplus surface water occurring in 43 years and from project groundwater pumping in 8 years. The average refill from surplus surface flows is 72 TAF in the years of occurrence and 36 TAF annually over the full period.

It is evident from this summary that there are opportunities to generate appreciable incremental benefits through conjunctive operations in terms of increased environmental flow releases and agricultural water supplies, without infringing on CVP and SWP operations. Additional results from operations simulations are described in the body of this report.

Impacts of Project Groundwater Pumping

Impacts to Existing Groundwater Pumpers

The effects of the additional project groundwater pumping for reservoir payback were evaluated using the groundwater model. This was done by imposing the payback pumping monthly time series determined by the surface water model on baseline pumping to estimate the effects on groundwater levels. The effects of changes in groundwater levels on the operability of existing wells in the project area and on pumping costs were then evaluated.

There are approximately 15,400 existing groundwater production wells in the project area, with about 9,100 of those wells (59%) being relatively shallow, domestic supply wells and about 4,500 wells (29%) being irrigation wells. The remaining wells are for unknown or other purposes (Table ES-5).

TABLE ES-5
Number of Water Supply Wells in Project Area[6]
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Use	Number of wells
Domestic	9,058
Irrigation	4,455
Unknown[7]	1,388
Other	267
Municipal	139
Stock	75
Public	52
Total	15,434

The surface model predicted the need for pumping in about 10 percent of the years in the Butte Basin and about 7 percent of the years in GCID under the 300 TAF pumping scenarios (200 TAF GCID, 100 TAF Butte Basin; see Table ES-6). In years in which pumping occurs, pumping is usually required in either GCID or in the Butte Basin, but not both. However, in exceptionally dry years, pumping would occur in both areas in the same year (see bolded years in Table ES-6).

TABLE ES-6
Occurrence of Pumping
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Maximum Pumping	Number of times pumping occurs (82 years of record)		Years in which pumping occurs		Number of times pumping occurs in GCID and/or Butte Basin
	GCID - Shasta	Butte - Oroville	GCID - Shasta	Butte - Oroville	
150 TAF (100 TAF GCID; 50 TAF Butte Basin)	4	6	1947, 1987, 1988, **1990**	1933, 1961, **1990**, 1992, 1994, 2002	9
300 TAF (200 TAF GCID;100 TAF Butte Basin)	6	8	1923, **1929**, **1947**, 1987, 1988, **1990**	**1929**, 1933, **1947**, 1961, **1990**, 1992, 1994, 2002	11

* **bolded** years indicate that pumping would have occurred in both GCID and Butte Basin under the Project.

The additional (or interference) drawdown in the shallow aquifer caused by project pumping is shown in Table ES-7, indicating that the maximum additional drawdown is generally less than 10 feet and the average is generally less than one foot. Maximum drawdown occurs near project pumping wells but dissipates rapidly moving away from wells.

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[6] Data provided by California Department of Water Resources Northern District Office. 2009.

[7] May include monitoring wells, vapor recovery wells, or other wells not constructed for water supply purposes.

TABLE ES-7
Summary Statistics of Monthly Average Interference Drawdown in the Shallow Aquifer by Pumping Scenario, 1987 – 2003
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Interference Drawdown (ft)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	0.0	13.6	0.5	0.3	0.7
300 TAF Summer Pumping, Existing Well Field	0.0	8.3	0.4	0.2	0.6
150 TAF Summer Pumping, New Well Field	0.0	6.2	0.3	0.2	0.4
150 TAF Summer Pumping, Existing Well Field	0.0	5.4	0.3	0.2	0.4
150 TAF Fall Pumping, New Well Field	0.0	7.0	0.4	0.2	0.4
150 TAF Fall Pumping, Existing Well Field	0.0	6.1	0.4	0.2	0.5
150 TAF Summer & Fall Pumping, New Well Field	0.0	5.9	0.4	0.2	0.4
150 TAF Summer & Fall Pumping, Existing Well Field	0.0	5.0	0.4	0.2	0.5

Based in the interference drawdown simulated by the groundwater model, the results of the analysis of impacts to existing groundwater users are summarized as follows:

- The operability of some domestic wells is likely to be affected because these wells tend to be shallow and the magnitude of interference drawdown caused by project pumping is significant relative to the screened intervals of these wells. The maximum number of domestic wells impacted is estimated to be between 153 and 284, which is a relatively small percentage (about 3%) of the total number of domestic wells. This impact occurs in 1990 when pumping occurs in both GCID and the Butte Basin and may be overstated to the extent that some of the impacted wells are no longer in operation. It is noted that goal in project implementation would be to minimize or avoid impacts to domestic wells, if possible.

- Impacts to the operability and yields of existing irrigation wells are negligible because the magnitude of interference drawdown from project pumping is small relative to the screened intervals of these wells.

- Energy requirements and costs will be increased for both domestic and irrigation pumping due to increased pumping lifts. On an annualized basis, the increased energy cost for irrigation pumping is estimated to range between $123,000 and $228,000, and for domestic pumping is estimated to range between $3,000 and $5,000.

Impacts on Streamflow

The modeled project pumping scenarios result in some streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams (Table ES-8). To compensate for these losses, the modeling incorporated releases from Shasta and Oroville when the system is “in balance.” Although these releases help maintain streamflow in the Sacramento and Feather Rivers, while insuring the system as whole doesn’t experience significant losses, the releases do not directly mitigate the impact of *tributary* streamflow losses to ecosystems and species. As a starting point for the assessing impact to tributary streams, the project analyzed Butte Creek due to its high ecosystem value combined with some of the largest discharge losses due to pumping. An additional consideration is that historical streamflow records are available for Butte Creek but generally not for other smaller streams.

TABLE ES-8
Peak Effects on Streamflow from Conjunctive Management Operations
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Stream	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**
All Streams[a]	54	53	111	105	80	90	64	65
Butte Creek	13	12	72	69	50	48	39	33
Sacramento River – GCID to Wilkins Slough	42	37	32	28	16	18	16	15
Feather River	3	3	6	6	4	4	4	4
Little Chico Creek	3	3	6	5	4	3	4	3
Salt River	1	5	5	8	2	5	2	5
Stone Coral Creek	6	9	11	15	7	10	6	9
Stony Creek	4	5	7	7	4	6	4	4

[a] Includes the 7 streams listed below.

The Butte Creek analysis yielded the following key results:

- Project pumping will not impact the uppermost reach in the project areas, the primary spawning area for Spring-run Chinook and Central Valley steelhead

- Pumping will have a greater impact on the lower reaches of Butte Creek, than the upper
  - In addition to cumulative effects, the *rate* of leakage is higher in downstream reaches

- The largest absolute losses in streamflow occur when discharge is also highest (Jan.-Mar)
  - The magnitude of impacts in relation to the baseflow at this time is not substantial (maximum of 1-3% loss in streamflow)

- The largest percentage loss in stream flow occurs in the lowest reach during summer/ early fall when Spring-run have already migrated upstream and steelhead are only beginning to enter the streams

- Project pumping never causes average monthly discharge to fall below the instream flow standards in the four upstream reaches

- June average monthly discharge in the lowermost reach, falls below the 40 cfs instream standard twice in the 17 year record due to pumping of up to 150K, and four times under pumping of up to 300K
  - Most Spring-run migration has already occurred by June, but some late Spring-run migrants, may experience minimal impacts
  - These impacts occur during the drought years of 1990, 1991, 1992, 1994, when Butte County irrigators participated in the drought water bank

The results of the analysis do not reveal any significant negative impact to Spring-run Chinook or Central Valley Steelhead in Butte Creek due to project pumping. Furthermore, this analysis focused only on those years with stream impacts (water years 1987 - 2003), during which time groundwater would have been pumped more frequently than over the entire period assessed by the surface water model (1922-2003). As such, on average impacts would likely be less significant and rarer than those projected in this analysis.

Economic Analysis

The economic analysis did not assign a monetary value to the environmental benefits that would accrue. This was not because these would be negligible. In fact, the potential increase in salmon productivity could be quite substantial. Rather, the economic analysis was conducted in part to determine whether the revenue from the project's potential water sales alone would be large enough to pay for the capital and operational costs. In sum, the question was not whether the project would be worthwhile, but whether it could pay for itself.

The net benefit of the project considering the associated costs and expected benefits varies depending primarily on where the water generated by the project can be sold and, to some extent, on whether new wells are constructed or the project is operated using primarily existing wells. As summarized in Table ES-9, if the water generated through conjunctive operations is sold in the Sacramento Valley, only one of the scenarios has a positive net benefit, with the others having modest to strong negative net benefits. In contrast, if the water were valued at rates paid in ag sectors outside the Sacramento Valley or by urban customers, only one of the scenarios has a negative net benefit with the others being positive. Interestingly, even though the 150 TAF summer and fall pumping using the existing wells was the least-cost scenario, the analysis demonstrates that the largest net benefit is associated with the 300 TAF summer pumping scenario using the existing wells (if the water could be exported south of the Delta).

It can be seen from Table ES-9 that the existing well scenarios dominate the new well scenarios in terms of net benefits. The high capital costs associated with constructing new wells make this option less economically viable.

TABLE ES-9
Net Benefit under Various Pumping Scenarios
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Scenario	**Annual benefits, local use ($M)**	**Annual benefits, exports ($M)**	**Total Cost (PV, $M)**	**Net benefits, local use ($M)**	**Net benefits, export ($M)**
1 300 TAF Summer New Wells	183	365	290	-107	76
2 300 TAF Summer Existing Wells	183	365	212	-30	153
3 150 TAF Summer New Wells	73	145	135	-62	11
4 150 TAF Summer Existing Wells	73	145	94	-21	52
5 150 TAF Fall New Wells	74	148	210	-136	-62
6 150 TAF Fall Existing Wells	74	148	144	-70	4
7 150 TAF Summer & Fall New Wells	73	147	88	-14	59
8 150 TAF Summer & Fall Existing Wells	73	147	65	8	81

Operational and Analytic Refinements Recommended by Project Operators

Beginning in April 2010, a series of three ½-day workshops were held with a select group of CVP and SWP operators for the purpose of refining project scenarios. The main purposes were: (1) to identify additional project purposes and benefits that could potentially be realized through conjunctive operations as a means of enhancing project economic performance and (2) to ensure that the simulations were as realistic as possible. The workshops were complemented with one-on-one consultations between operators and project team members as needed to clarify comments and develop specific recommendations for incorporation into scenario development and the supporting modeling methodology.

Specific refinements identified through collaboration with the project operators included the following:

- Updated CALSIM II Baseline. The CALSIM II baseline used for the initial modeling pre-dated the 2008 Biological Opinion on delta smelt (smelt BO) and the 2009 Biological Opinion on Chinook salmon (salmon BO). The baseline was updated with a CALSIM II model run with the smelt BO and salmon BO included. This baseline was used for further development and evaluation of project scenarios.

- Shasta and Oroville Reservoir Minimum Release Constraints. CVP operators expressed concerns about the ability to reduce Shasta releases under conditions when releases are driven by temperature compliance in the Sacramento River below the reservoir rather than water supply demands further downstream. Constraints on the ability to reduce Shasta releases were specified in the form of monthly minimum Keswick releases for temperature compliance. Constraints on the ability to reduce Oroville releases for temperature compliance were specified by SWP operators as a function of Oroville releases and time of year. Potential reductions ranged from zero to 1,000 cfs.

- Forecast-Based Operations. The initial surface water model made project asset decisions (volume of additional reservoir release) based on a perfect forecast of September reservoir storage. The implication of this assumption was to minimize the risk of achieving targeted levels of carryover storage due to conjunctive operations. The surface water model was refined to include a forecast of fall storage conditions based on current reservoir storage, runoff forecasts, and an estimate of reservoir releases from the current month through September. This change made the simulations more like actual project operations.

- Oroville Reservoir Carryover Storage Targets. SWP operators specified Oroville storage targets for the purpose of increasing carryover storage when at or below 1.5 million acre-feet (MAF) under base conditions by up to a maximum of 200 thousand acre-feet (TAF). These targets were developed to assist in mitigating effects of damage to the low-elevation outlet that occurred during gate testing several years ago. Damage to the low-elevation outlet has effectively increased dead storage in Lake Oroville leading to a desire to increase carryover storage.

- Crop Idling for Reservoir Payback. The surface water model was modified to simulate crop idling as a payback mechanism to recover reservoir storage. This was done to reduce or avoid the need for project pumping, thereby reducing project costs and enhancing overall project cost-effectiveness. A number of assumptions and constraints were placed on crop idling operations, the main assumptions being that crop idling would be voluntary and incentive-driven and would be limited in extent to no more than 20% of the irrigated area in GCID and the Butte Basin (WCWD and RID).

With these refinements made to the surface water model and project operating objectives and constraints, the project scenarios were reassessed, leading to the following observations:

- Updating the CALSIM II baseline to include the smelt and salmon BOs had negligible effect on project performance.
- The addition of forecast-based operations together with minimum reservoir releases for water temperature compliance dramatically reduced project performance with respect to generating environmental flow releases and agricultural water supplies. Relative to initial conditions, benefits were reduced by one-half to two-thirds. The procedures developed for forecasting end-of-year reservoir storage were deliberately conservative to limit risks to carryover storage; however, the effect of the forecasts was to substantially reduce the estimated project water assets, which severely reduced both environmental flow releases and agricultural water supplies. The effect of minimum reservoir releases was to reduce the times when payback pumping can effectively recover reservoir levels, also diminishing project performance.
- Employing project pumping to assist in meeting Oroville Reservoir carryover targets is not effective because project pumping is called on frequently, to the extent that groundwater impacts could become problematic. Additionally, much of the water held in reservoir storage subsequently spills due to displacement with by surplus surface flows.
- Temporary crop idling is not an effective means of reservoir payback, primarily because crop idling decisions need to be made early in the season and involve making an irreversible commitment to participating growers for purchasing the water generated through crop idling regardless of whether the water can be held in upstream storage or put to beneficial use downstream. Modeling shows that too frequently temperature releases govern reservoir operations and the water generated by crop idling cannot be held in storage.

Fundamental Conclusions

The seminal conclusion of this investigation is that re-operating Shasta and Oroville Reservoirs in conjunction with operation of Sacramento Valley groundwater aquifers could produce appreciable additional water supplies for discretionary allocation to environmental enhancement flows in the Sacramento and Feather Rivers, for increased local and regional water supply reliability and potentially for meeting water demands outside the Sacramento Valley. This can be done with low risk to CVP and SWP reservoir storage levels and water deliveries under most conditions because additional releases made for these purposes are replaced with reservoir refill from surplus surface flows most of the time, with groundwater pumping for reservoir “payback” required relatively infrequently. In the years needed, groundwater pumping would be appreciable but potential impacts to existing Sacramento Valley groundwater conditions in the areas of pumping appear be manageable and could be mitigated. Overall, the project would result in a net gain of groundwater storage in the Sacramento Valley if, as assumed, additional water supplies generated by re-operation are used to meet demands that would otherwise be met by pumping groundwater.

Modeling of conjunctive operations reveals that the ability to recover reservoirs by pumping groundwater when they fail to recover sufficiently from surplus surface flows is constrained at times by the need to sustain reservoir releases for temperature control, in order to provide desirable conditions for salmonids. In effect, the scale of conjunctive operations and the ability to generate one kind of environmental benefits (ecologic flows) is constrained by existing operational requirements for another kind of environmental benefits (temperature control). This tradeoff between different environmental water uses points to the need for comprehensive, holistic approaches to environmental water management. The analytical tools developed for this project are sufficient to support development of such approaches.

While an economically feasible in-Valley operation scenario was not identified by the investigation, prospects of a viable formulation appear promising and further development and integration of the core concept is warranted, particularly if greater revenues can be derived by selling water at higher prices, or there was a willingness to pay for the environmental benefits provided. It is noted that the ecologic benefits that could be achieved by improving flow regimes in the Feather and Sacramento Rivers through conjunctive operations were not included in the assessment of the project's economic feasibility. This is because methodologies for valuing those benefits are somewhat speculative. Additionally, the benefits that would result from improved groundwater conditions within the Sacramento Valley due to the delivery of additional surface water supplies and consequent relaxation of groundwater pumping were not factored into the economic analysis. Valuation and inclusion of these benefits in any future phases of investigation would enhance the economic feasibility of conjunctive operations.

Recommended Further Investigation

A number of specific recommendations for further development and refinement of Sacramento Valley conjunctive water management are provided in the body of this final report. These are primarily technical in nature, involving reconciling tradeoffs among different types of environmental water uses, more detailed water temperature modeling, refined reservoir payback operations, integration with south of Delta groundwater banking and refinement of analytic tools.

Beyond the technical factors lie significant institutional and social challenges that would need to be addressed if there is sufficient interest in advancing the project toward implementation. These include developing protocols and procedures for real-time operations decisionmaking, integrating conjunctive operations into the Coordinated Operations Agreement, developing project governance structures among local political jurisdictions, and developing formulae for allocating project benefits and costs.

However daunting these challenges may appear, the potential benefits relative to risks revealed through this investigation suggest that further efforts to develop and implement conjunctive water management in the Sacramento Valley are warranted.

1. Principal Findings and Conclusions

The main findings and conclusions reached through this investigation are summarized below:

1. The core concept of augmenting yield from Lake Shasta and Lake Oroville by increasing releases before the refill season, and thereby reducing carry-over storage levels to allow subsequent capture of a larger fraction of flood flows, is hydrologically feasible. In most years, the additional reservoir space evacuated is refilled by surplus surface flows that otherwise would have been lost as flood control releases. However, in some years, reservoir storage does not recover to levels that would have occurred without the additional releases, resulting in a reservoir storage deficit compared to baseline conditions.

2. To satisfy CVP and SWP supply obligations at current levels and to comply with current environmental regulations, especially those pertaining to water temperature, it is necessary to have a method for "paying back" any reservoir deficits resulting from the additional releases. The scale of the re-operation that is feasible without risk to water supply and project operations is limited by the capacity to pay back the reservoir because the maximum reservoir deficit cannot be larger than the ability to pay it back in a single year, when necessary.

3. At the two payback scales investigated (see Section 5), simulations indicate that between 27 thousand acre-feet (TAF) and 69 TAF of additional water supplies could be generated on an average annual basis from Shasta re-operation, while Oroville re-operation could yield between 17 TAF to 43 TAF on an average annual basis. However, these estimates do not take into account the minimum mandatory reservoir releases for temperature control or forecast-based reservoir operations as described below.)

4. Four strategies for reservoir payback have been identified as warranting consideration, three of which were analyzed in this phase of the project. The three payback mechanisms analyzed in this phase are:
    a. Drawing on project surplus water that would be banked through intentional recharge of groundwater at sites within the Sacramento Valley;
    b. Pumping groundwater within Glenn Colusa Irrigation District (GCID), a CVP settlement contractor, to pay back Shasta Reservoir and within Western Canal Water District (WCWD) and Richvale Irrigation District (RID), both served through the SWP collectively referred to as the "Butte Basin", to pay back Oroville Reservoir; and
    c. Reducing surface water demands through voluntary, temporary, and compensated idling of crop lands by willing growers in these participating districts[8].

5. Payback through groundwater banking in the Sacramento Valley proved to be infeasible because, under existing levels of groundwater use, the seasonally dewatered aquifer space tends to recharge annually during the following precipitation season. Cones of depression from groundwater pumping typically do not persist over the multiple years necessary for an efficient, actively recharged, banking operation. Therefore, additional recharge for water banking tends to

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[8] Another strategy for demand reduction is foregoing flooding rice lands at the end of the growing season for rice straw decomposition. The potential to substitute other means of disposing of the straw, such as removal to delta islands to rebuild their elevation, has not been analyzed because this option has the disadvantage of eliminating valuable waterfowl refugia during the late fall and winter seasons.

cause rejection of recharge from other sources or increased aquifer discharge, with little net gain in groundwater storage. Consequently, this payback option was not further pursued.

6. Payback through groundwater pumping within the participating water districts was found to be technically feasible with impacts on other existing groundwater users small enough to be mitigated and compensated. Impacts to the yields and operability of agricultural wells would be negligible, while up to approximately 3 percent of the large number (more than 9,000) of existing domestic wells would become inoperable and would therefore needed to be deepened or replaced. The pumping lift for all wells would increase resulting in increased pumping costs.

7. The investigation also addressed the feasibility of repaying the reservoirs through reducing water demands in the participating districts instead of pumping groundwater. This would have the advantage of avoiding entirely impacts on other groundwater users. This could be accomplished through a program of voluntary crop idling by growers in these districts pursuant to a water buy-back arrangement. This payback strategy proved to be inefficient because the decision to call on crop idling for payback must be made before the planting season begins, when the extent of reservoir refill is still highly uncertain. Particularly because end-of-season reservoir storage forecasts are made conservatively, there is a significant probability that the water made available through crop idling is either not needed or is spilled from the reservoir. Consequently this payback option does not perform as well as groundwater pumping from a cost-effectiveness perspective.[9]

8. The fourth payback mechanism, identified but not evaluated in this phase, involves drawing on project water banked in dewatered aquifers south of the delta. This option becomes much more viable if existing pumping constraints at the Banks and Jones plants in the south delta are alleviated by an isolated diversion and conveyance facility around or under the delta to the state and federal canals, such as is being considered in the Bay Delta Conservation Plan (BDCP). This option will be evaluated in the next phase by which time BDCP options presumably will have been clarified. It is notable that this option would allow the surplus water to be stored and used at times and places of greatest economic value, compared to the other strategies that were evaluated. It is also notable that this option would not entail increasing the volume of water that is exported from the Sacramento Valley currently, but would convert some portion of delta outflow during the flood season to water supply south of the delta.

9. All of the payback mechanisms investigated would be constrained during periods when reservoir releases governed by water quality objectives (mainly temperature) exceed the releases needed to serve downstream demands. Under these conditions, regardless of how it is generated, payback water cannot be held in upstream storage because reservoir releases cannot be reduced and still meet water quality objectives. Minimum releases at Keswick (on the Sacramento River) are prescribed by current water quality regulations imposed by the biological opinions of the National Marine Fisheries Service at the federal level and by the State Water Resources Control Board at the state level to prevent lethal temperature occurrence in the

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[9] Another strategy for implementing temporary crop idling was identified but not evaluated as part of the investigation. Rather than invoke crop idling prior to planting, the idea would be to trigger idling during the crop season when the determination of the need for and effectiveness of payback could be forecast with much greater reliability. Certain crops, such as alfalfa, are adapted to intermittent irrigation, although production losses more or less proportional to water shortages are expected.

Sacramento River for spring and winter run salmon. Operational protocols to maintain viable temperatures for the Feather River below the Thermalito re-regulation dam are also prescribed in the proposed settlement agreement for the Oroville relicensing by the Federal Energy Regulatory Commission (FERC). The extent to which these may also constrain the payback potential for Oroville should be analyzed further.. Like the other payback options, the extent to which the reservoir carryover storage can be reduced through additional releases for the project purposes (environmental flows and water supply) is limited by the ability to make up any storage deficits that result from insufficient reservoir inflow in subsequent precipitation seasons. Substituting groundwater pumping for surface water deliveries is a means to do that. But in the case of Shasta reservoir (and probably also Oroville reservoir under the FERC relicensing agreement), such substitution will only work to the extent that a commensurate amount of water can be retained in the reservoir. The requirement to release prescribed amounts of water at Keswick dam for temperature control means that in many years, groundwater pumping cannot completely replace reservoir water.

10. Shasta and Oroville Reservoirs are operated at present in a conservative manner that minimizes the risks of temperature stresses for salmonids in the downstream rivers. These conservative operations dramatically reduce potential improvements in environmental flows made possible by project conjunctive operations. Three of the project’s four environmental flow improvements are designed to benefit salmon through increased spring pulses for out-migration, floodplain inundation for rearing and food, and geomorphic flows to improve spawning conditions. Yet the more aggressive reservoir operations to generate these environmental flows unavoidably increase the risks to the cold water pool to some extent. It is apparent that there is a tradeoff between temperature risk reduction and environmental flow benefits. Whether the loss of suitable habitat in some reaches of the rivers due to adverse temperatures, if any, is more than offset by the improvements in habitat for salmon resulting from meeting the other environmental flow improvements more frequently will also be investigated in the next phase of this project. It is also possible that fish passage to access the cold water resources above the dams, such has been recommended by NMFS as a salmon recovery measure, would also alleviate the volume and timing of cold water releases needed for temperature control below the dams. This will also be investigated in the next phase. These subsequent investigations will illuminate whether the optimal strategy can result in less constraining minimum releases at Keswick and larger and more frequent yields of water for environmental flows and water supply.

11. Simulations of conjunctive operations with the effects of minimum reservoir releases for temperature control (in combination with forecast-based simulation techniques) revealed that project benefits are dramatically reduced, by approximately one-half to two-thirds of the levels discussed above in #3. At this scale, the economic benefits are also small in light of the costs of the projects, including primarily the energy cost for pumping payback groundwater and the costs of mitigating the effects of this pumping on other groundwater users.

12. The economic benefits of the project in the near term with this (groundwater pumping) payback mechanism include the market value of the additional water within the Sacramento Valley, estimated to be $50 per AF.

2. Introduction

2.1.Purpose

In 2006, the Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) jointly embarked on this investigation to explore how the largest water storage reservoir in the Federal Central Valley Project (CVP), Shasta, and the only such reservoir in the State Water Project (SWP), Oroville, could be re-operated in conjunction with northern Sacramento Valley groundwater aquifers to increase water supplies for both environmental and economic uses. The investigation was enabled by a combination of state and federal grant funding, including Proposition 50 funding administered by the Department of Water Resources (DWR) and federal funds administered by the Bureau of Reclamation’s (Reclamation) Mid-Pacific Region.

The potential of conjunctive water management in the Sacramento Valley has long been perceived as offering significant potential to produce additional water supplies due to the presence of large surface reservoirs and extensive, although not well understood, groundwater aquifers. Conceptual level investigations, including one completed by NHI in 1999, have generally confirmed this potential but have not fully taken into account the myriad factors governing reservoir operations, including the existing water supply obligations of the reservoirs, flood control functions and environmental regulations. The purpose of this investigation was to further investigate Sacramento Valley conjunctive management opportunities taking into consideration these constraints. Additionally, there has been little definitive investigation of the effects that aquifer recharge and additional pumping implicit to conjunctive management might have on groundwater conditions in the Sacramento Valley. This was also an objective of this investigation.

2.2.Evolution of Project Perspective and Scope

At its inception, the investigation focused on the Sacramento Valley’s deep aquifers, particularly the Lower Tuscan Formation, which underlies much of the northern portion of the Sacramento Valley. However, as the investigation progressed the study team recognized that such a narrow focus was both overly constraining on the scope of the study and somewhat misleading because it implied that any effects on the aquifer system due to additional recharge or pumping could somehow be confined to a particular portion of the groundwater system. Ultimately the project evaluated the effects of exercising both the northern Sacramento Valley’s deep aquifer system, which is presently relatively undeveloped, and the shallower, regional aquifer, which is more heavily pumped for both domestic and agricultural needs.

The investigation began with the expectation that surplus water generated through the re-operation of these reservoirs could be banked in the groundwater aquifers in the Sacramento Valley, like other conjunctive use programs in the San Joaquin Valley of California, with water put into groundwater storage in wet years and extracted in dry years. However, initial assessment and site screening revealed that conditions in the Sacramento Valley are not conducive to this mode of conjunctive management, primarily because groundwater aquifers, although extensively developed and pumped in many areas, mostly for agricultural irrigation, generally recover fully during the precipitation season. What emerged was a conjunctive management approach based on reservoir re-operation backstopped by several options for reducing the draw on reservoir storage when refill is insufficient.

The scope of the investigation included technical, economic, institutional and outreach components. Technical work concentrated on developing coordinated groundwater and surface water models for formulating and evaluating alternative conjunctive management strategies and project configurations. Model development consumed more time and a larger percentage of the project's resources than initially intended, which required reallocation of resources from the economic and institutional analyses. Robust outreach was conducted throughout the course of the effort at many different levels and in different forms.

The investigation was originally scoped to evaluate conjunctive water management opportunities within the Sacramento Valley. However, as the investigation proceeded, it became clear that there may be opportunities to enhance the cost-effectiveness of conjunctive operations through integration with Bay-Delta (Delta) export operations, depending to some degree on the outcomes of current efforts to address Delta issues and governance. Inasmuch as these outcomes are still highly uncertain, and to maintain consistency with the project's original scope, Delta export operations were not investigated but are discussed in the context of possible further investigation. It should be noted that, at a conceptual level, it appears that integration of Sacramento Valley conjunctive management with Delta export operations could provide in-Valley benefits with lower risk compared to the in-Valley configurations evaluated.

The other significant changes that occurred while the investigation was underway were the issuance of the 2008 Biological Opinion on delta smelt (smelt BO) and the 2009 Biological Opinion on Chinook salmon (salmon BO). The project baseline was adjusted during the course of investigation in response to requirements stemming from these changes.

2.3.Report Contents

Following this Introduction, the agencies that sponsored, participated in and funded the investigation are described and the public outreach process is summarized (Section 3). The analytic approach to the investigation is presented in Section 4. The discussion focuses on the core conjunctive operations concept of reservoir re-operation backed by groundwater pumping for reservoir "payback". Additionally, specific reservoir payback mechanisms are described and the objectives, principles and constraints that formed the analytical framework are presented.

The initial project scenarios are presented in Section 5, including descriptions of the scenarios, development of the analytic tools (models) used to formulate and evaluate potential project operations and summaries of how the scenarios performed in physical and economic terms. Section 5 concludes with a discussion of interim findings that shaped further analysis and refinement of project scenarios.

Section 6 describes the phase of the project involving collaboration with the operators of the Central Valley Project (CVP) and State Water Project (SWP). During this phase, in response to operators' suggestions, certain modifications were made to the analytic tools to incorporate constraints that presently govern CVP and SWP operations, particularly reservoir operations for cold water management and additional project objectives were assessed. These factors are described along with the conclusions drawn from the refined and extended analysis.

Finally, in Section 7, ideas and suggestions to guide further investigation of Sacramento Valley conjunctive water management are offered. Among the recommendations are suggestions to investigate integration with Delta export operations.

2.4.Acknowledgements

NHI and GCID are grateful for the opportunity to sponsor this investigation and wish to acknowledge DWR and Reclamation for awarding the enabling grant funds. Additionally, DWR provided groundwater well information and other data without which development of analytic tools and evaluation of impacts of additional groundwater pumping would not have been possible.

In particular, the sponsors wish to thank the individual DWR and Reclamation staff members who operate the CVP and SWP and gave freely of their time during the collaborative phase to enhance the pertinence of the investigation.

Finally, the sponsors are grateful to the many members of the public and representatives of public interest groups who participated in the project’s public meetings. The comments received during these meetings were heard and carefully considered.

3. Project Sponsors, Participants and Donors

3.1. Sponsors

3.1.1. Glenn Colusa Irrigation District

The Glenn-Colusa Irrigation District (GCID) appropriative water rights begin on the Sacramento River with an 1883 filing posted on a tree by Will S. Green, surveyor, newspaperman, public official, and pioneer irrigator. His first claim was for 500,000 miner's inches under 4 inches of pressure and was one of the earliest and largest water rights on the Sacramento River.

GCID was organized in 1920, after several private companies failed financially, and a group of landowners reorganized and refinanced the irrigation district, retaining claim to Green's historic water right. The disastrous rice crop failure of 1920–21 nearly destroyed the district at its inception, and the "great depression" took a further toll, making it necessary for the district to refinance in the 1930s. Additionally, the United States purchased lands within GCID during this period which would later become three federal refuges totaling approximately 20,000 acres.

Today, after surviving many challenges, GCID is the largest district in the Sacramento Valley. Located approximately eighty miles north of Sacramento, California, the district boundaries cover approximately 175,000 acres; of which 153,000 acres are deeded property and 138,800 are irrigable. There are 1,076 landowners in the District and an additional 300 tenant water users. There are an additional 5,000 acres of private habitat land, and winter water supplied by GCID to thousands of acres of rice land provides valuable habitat for migrating waterfowl during the winter months.

GCID's main pump station, its only diversion from the Sacramento River, is located near Hamilton City. The District's 65-mile long Main Canal conveys water into a complex system of nearly 1,000 miles of canals, laterals and drains, much of it constructed in the early 1900s. The District headquarters are located in Willows, the county seat of Glenn County, approximately 90 miles north of Sacramento on Interstate 5.

A five-member board of directors, who represent five subdivisions within the District, governs the District. The annual budget is $15 million. GCID's mission is to provide reliable, affordable water supplies to its landowners and water users, while ensuring the environmental and economic viability of the region.

From its first diversions until 1964, GCID relied upon its historic water rights and adequate water supply from the Sacramento River hydrologic system which receives rainfall and snowmelt from a 27,246 square mile watershed with average runoff of 22,389,000 acre-feet, providing nearly one-third of the state's total natural runoff. In 1964, after nearly two decades of negotiations with the United States, GCID along with other Sacramento River water rights diverters entered into "Settlement Water Contracts" with the Bureau of Reclamation (Bureau). These Settlement Contracts were necessary at that time to allow the Bureau to construct, operate, and divert water for the newly constructed Central Valley Project. The contract provided GCID with water supply for the months of April through October for 720,000 acre-feet of base supply, and 105,000 acre-feet of Central Valley Project water that is purchased during the months of July and August. During a designated critical year when natural inflow to Shasta Reservoir is less than 3.2 million acre-feet, GCID's total supply is reduced by 25 percent, to a total of 618,000 acre-feet.

Additionally, the District has rights under a State Water Resources Control Board (SWRCB) permit to "winter water" from November 1 through March 31 at a 1,200 cubic feet per second (cfs) diversion rate. This water supply is used for rice straw decomposition and waterfowl habitat. The permit provides 150,000 acre-feet for rice straw decomposition and 32,900 acre-feet for crop consumption. Groundwater can be used to supplement GCID's supplies, with 5,000 acre-feet available from District wells, and approximately 45,000 acre-feet from privately owned landowner wells.

3.1.2. Natural Heritage Institute

Natural Heritage Institute (NHI) is a non-governmental, non-profit organization founded in 1989 to restore and protect the natural functions that support water-dependent ecosystems and the services they provide to sustain and enrich human life. Its founders foresaw the need for a toolkit for the next era of environmental problem-solving: where the technical challenges are more complex, the solutions more elusive, the economics more central, the ramifications more global, and the conventional pathways less efficacious. NHI is motivated by the realization that, when the earth's limited stock of natural resources is squandered, the legacy bequeathed to future generations is impoverished, sometimes for all time. The only hope for this beleaguered planet is to do more with less and to restore the damage of the past. Increasingly, the environmental challenge is to move from strategies that freeze the status quo to those that ensure that the economic use of natural resources also yields net environmental gains.

Previous work by NHI has shown that re-operating existing Central Valley reservoirs in conjunction with groundwater banks could generate surplus water to restore more natural flow patterns in the eleven regulated tributaries of the Central Valley – comprising by far the largest ecosystem restoration program ever undertaken in this geography – while also satisfying growing demand from agricultural and urban users. Because it utilizes existing infrastructure, conjunctive management is faster and less costly to implement than other water supply augmentation strategies. Indeed, it could generate more new water supply than any other current alternative, and, uniquely, do so without any governmental subsidies.

The system-wide analysis has now progressed through the "proof of concept" stage, and NHI is applying the results in regional demonstration projects. The first regional component is being pursued in the Sacramento Valley through this investigation in collaboration with the Glenn Colusa Irrigation District. This work in the Central Valley of California serves as a model for conjunctive water management in watersheds worldwide through NHI's Global Dam Re-optimization Initiative, which is funded by major foundation, national governments and intergovernmental organizations.

3.2. Participating Water Suppliers

Western Canal Water District (WCWD) and neighboring Richvale Water District (RID) elected to participate in this study in a passive manner by expressing their interest in potential willingness to support a conjunctive management project, subject to the findings of the investigation. WCWD and RID are two of four districts collectively referred to as the Joint Water Districts, the others being Biggs West Gridley Water District (BWGWD) and Butte Water District (BWD). Each year, on average, the Joint Water Districts import about 610 TAF of Feather River water into Butte Basin for irrigation purposes. The unconsumed portion of the imported flows serve in part to recharge underlying aquifers and to sustain flows that serve as supply sources for downstream water users.

3.2.1. Western Canal Water District

Western Canal Water District was formed by an election of District landowners on December 18, 1984, which elected five Directors and authorized the purchase of the District from Pacific Gas and Electric Company. PG&E had obtained the District from their predecessor, The Great Western Power Company, who had developed the hydroelectric power facilities on the Feather River early in the 1900s. The acquisition included pre-1914 water rights on the Feather River for use by the District. These consist of 150,000 acre feet of natural flow of the river and 145,000 acre feet of water stored in the North Fork Feather River Project. The District also has adjudicated rights to a small amount of Butte Creek water.

WCWD is comprised of a gross area of 65,000 acres with irrigable acreage of about 58,500 acres. The primary crop is rice with a small amount of pasture and orchard crops. The District has ten employees and an operations budget of about $1.3M. Two-thirds of the District lies in Butte County, and the rest in Glenn County.

In 1998, the District completed the WCWD Fish Passage Improvement Project, which allowed for removal of four dams on Butte Creek. Butte Creek is one of three remaining tributaries to the Sacramento River that sustain a Spring-Run Chinook salmon population. This award winning project was funded by WCWD, the Department of Interior, and CALFED at a cost of $9.1M.

WCWD supports conjunctive use of groundwater and surface water in order to most efficiently and effectively use the resource for maximum benefit to the local area as well as the entire state, and has participated in several drought years to assist the State Water Bank by facilitating groundwater substitution exchanges. WCWD has developed a Groundwater Management Plan with Rules and Regulations, which provide for conjunctive use in a responsible and safe manner. The District strives to protect their water rights while working in a in a cooperative manner with all users of the water resources, locally and on a statewide basis.

3.2.2. Richvale Irrigation District

Richvale Irrigation District (RID) was formed on July 7, 1930 by purchasing a portion of the Sutter Butte Canal Company. Governance is provided by a three member Board of Directors that appoints a treasurer and employs a District Secretary/General Manager. The director terms are four years and rotate on odd years.

RID holds pre-1914 water rights to the Feather River in conjunction with three other districts (Western Canal Water District, Biggs West Gridley and Butte Water District) that make up the Joint Water Districts. RID consists of approximately 34,000 irrigable acres with rice being the primary crop. RID’s service area includes the Upper Butte Basin Wildlife Area.

RID has a water service contract with DWR for an annual allocation of 149,850 acre feet. All of the district deliveries are made through intake structures utilizing a screw gate or flashboard weir type structures. All water is distributed through earthen canals by gravity flow.

3.3.Funding Agencies

3.3.1. Department of Water Resources

The mission of the California Department of Water Resources (DWR) is to manage the water resources of California in cooperation with other agencies, to benefit the State’s people, and to protect, restore, and enhance the natural and human environments. To this end and in support of the legislative objectives of DWR, development of a System Re-operation Program (SRP) that will identify viable re-operation strategies of California's statewide water system, has been an ongoing process comprised of a diverse set of local, state, and federal agencies. The Glenn Colusa Irrigation District (GCID) is one such local agency that has teamed with DWR to explore the feasibility of an Integrated Regional Water Management Program (IRWMP) in the Northern Sacramento Valley region as a potential integral part of the SRP. Funding for the GCID IRWMP is made possible through DWR's Water Supply Reliability Program (a portion of the voter-approved Proposition 50 water bond measure) and primarily works toward achieving three of DWR eight Strategic Planning Goals as follows:

Goal 2	Plan, design, construct, operate, and maintain the State Water Project to achieve maximum flexibility, safety, and reliability.
Goal 3	Protect and improve the water resources and dependent ecosystems of statewide significance, including the Sacramento-San Joaquin Bay-Delta Estuary.
Goal 6	Support local planning and integrated regional water management through technical and financial assistance.

While a Coordinated Operating Agreement that was initiated in the 1970's and finalized in 1986 has instilled a significant degree of integration between operation of the State's two largest water management systems, the State Water Project (SWP) and the federal government's Central Valley Project (CVP) that were otherwise designed as standalone systems, the GCID IRWMP seeks to further explore opportunities to re-operate portions of California's statewide water system to yield increased water resources related benefits. In addition, recent action by the State Legislature in Senate Bill X2 1 (SB X2 1) (Perata, 2008 – Water Code Section 83002.5), mandates and allocates resources for "planning and feasibility studies to identify potential options for the re-operation of the state's flood protection and water supply systems that optimize the use of existing facilities and groundwater storage capacity. Specifically, SB X2 1 stipulated that the studies shall incorporate appropriate climate change strategies and be designed to determine the potential to achieve, among other things, the following objectives:

- Integration of flood protection and water supply systems to increase water supply reliability and flood protection, improve water quality, and provide for ecosystem protection and restoration.

- Re-operation of existing reservoirs, flood facilities, and other water facilities in conjunction with groundwater storage to improve water supply reliability, flood hazard reduction, and ecosystem protection and to reduce groundwater overdraft.

- Promotion of more effective groundwater management and protection and greater integration of groundwater and surface water resource uses.

- Improvement of existing water conveyance systems to increase water supply reliability, improve water quality, expand flood protection, and protect and restore ecosystems.

3.3.2. Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Through leadership, use of technical expertise, efficient operations, responsive customer service and the creativity of people, Reclamation seeks to protect local economies and preserve natural resources and ecosystems through the effective use of water.

The Mid-Pacific Region (MP Region) of the Bureau of Reclamation was created by the Secretary of the Interior in 1942. MP Region comprises numerous dams, reservoirs and conveyances that provide water for urban, industrial, agricultural, and fish and wildlife/environmental uses; generate hydro-electric power; and provide for flood protection, river navigation, and recreation. The Region includes lands from Klamath Falls, Oregon, south to Bakersfield, California, and most of northwestern Nevada. The MP Region is one of five Regions that carry on day-to-day planning, management, and operational activities for the Bureau of Reclamation.

Created by the Secretary of the Interior in 1942, the MP Region is headquartered in Sacramento, California and has Area Offices located at Shasta Lake, Folsom, and Fresno, California; Carson City, Nevada; and Klamath Falls, Oregon. Supporting offices include the Central Valley Operations Office in Sacramento and the Mid-Pacific Construction Office in Willows, CA.

The Mid-Pacific Region is best known for the massive Central Valley Project (CVP) built to tame the flood waters and irrigate the semi-arid acreage of California's vast Central Valley, the CVP grew over the last 50 years to become one of the largest water storage and transport systems in the world. The CVP is a system of 20 reservoirs and more than 500 miles of major canals and aqueducts that encompasses 35 counties. The CVP has a combined storage capacity of more than 11 million acre-feet of water, manages approximately 9 million acre-feet of water, and delivers more than 7 million acre-feet in a year, more than any other single California agency in a normal year. There are 11 hydroelectric power plants providing an average of 5.5 billion kilowatt hours of electricity to supply around 1.5 million people with power throughout the Mid-Pacific Region.

3.4.Public Outreach

Public outreach was conducted in a variety of forms to guide development of the project and to inform interested parties. The various meetings held to effect outreach, as well as achieve technical coordination among the project team, are listed in Table 3-1 and discussed in the following subsections.

3.4.1. Public Outreach

A total of seven public outreach meetings were conducted during the course of the project to both inform the public and to solicit feedback to guide the project’s direction. Initial public outreach concentrated on Sacramento Valley counties and consisted of two formal meetings complemented by informal one-on-one discussions with key county staff and elected officials. These meetings were very useful in framing local and regional sensitivities, and provided good background for scoping and directing the project.

Later, the team engaged the public through publicly noticed meetings, which generally drew sizeable, interested crowds and generated useful dialogue and feedback. Three public meetings were held in the latter half of 2008 and two more in late 2010 for this purpose. All meetings were held in the Chico vicinity. Materials for the two 2010 meetings (October 21 and December 8) are included in Appendix A.

3.4.2. Executive Briefings

Three executive briefings were provided by the team, two with DWR management and staff and one with Reclamation management and staff. These briefings generally consisted of high-level overviews of project status, with emphasis on linkage and coordination with related agency initiatives.

TABLE 3-1
Chronological List of Outreach and Technical Team Meetings
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Event #	Date	Location	Meeting Type	Participants	Purpose/Notes
1	11/16/2006	GCID	Public Oureach	GCID, NHI, Sac Valley county staff	General information; gauge interest; gather feedback
2	12/19/2006	GCID	Public Oureach	GCID, NHI, Sac Valley county staff	General information; gauge interest; gather feedback
3	6/19/2007	MBK Engineers/Sacramento	Technical	GCID, NHI, technical team members	Project site selection, model development, environmental flows
4	7/30/2007	MBK Engineers/Sacramento	Technical	GCID, NHI, technical team members	Project site selection, model development, environmental flows
5	9/21/2007	MBK Engineers/Sacramento	Project Coordination	GCID-NHI	Comprehensive review of technical work; strategic issues
6	9/21/2007	MBK Engineers/Sacramento	Technical	GCID, NHI, technical team members, DWR staff	Project site selection, model development, environmental flows; Delta issues
7	10/23/2007	MBK Engineers/Sacramento	Technical	GCID, NHI, technical team members, DWR staff	Model develop and interaction; environmental flows
8	2/25/2008	MBK Engineers/Sacramento	Technical	GCID, NHI, technical team members, DWR staff	Model develop and interaction; environmental flows
9	5/23/2008	MBK Engineers/Sacramento	Technical	GCID, NHI, technical team members, DWR staff	Model develop and interaction
10	5/29/2008	MBK Engineers/Sacramento	Technical	Modeling subteam (selected technical team members)	Model development and calibration
11	6/18/2008	MBK Engineers/Sacramento	Technical	Modeling subteam (selected technical team members)	Model update and demonstration
12	7/8/2008	MBK Engineers/Sacramento	Technical	Modeling subteam (selected technical team members)	Model update and demonstration
13	8/4/2008	Chico City Hall	Public Oureach	GCID, NHI, Chico area interested/concerned parties	Respond to particular concerns and quesitons raised by participants
14	9/5/2008	DWR/Sacramento	Executive Briefing	NHI, Tracie Billington/DWR	General information/update
15	9/16/2008	GCID Pump Station/Hamilton City	Public Oureach	GCID, NHI, Sacramento Valley public	Update public and receive comment on recent project activities
16	12/8/2008	Durham	Public Oureach	GCID, NHI, Sacramento Valley public	Update public and receive comment on recent project activities
17	1/6/2009	CirclePoint/Sacramento	Planning Meeting	GCID, NHI, program manager	Comprehensive review of technical work and public outreach
18	5/1/2009	MBK Engineers	Technical	Tech Team	Develop methodology for assessing groundwater impacts
19	8/11/2009	USBR/Sacramento	Executive Briefing	NHI, GCID, Don Glaser/USBR, USBR staff	General information/update
20	1/6/2010	Davids Engineering/Davis	Technical	GCID, NHI, technical team members	Project economics
21	4/8/2010	CVO/Sacramento	Workshop	CVP and SWP operators	Collaborative Workshop #1
22	6/11/2010	San Francisco	Executive Briefing	NHI Annual Board Meeting	General information
23	7/9/2010	CVO/Sacramento	Workshop	CVP and SWP operators	Collaborative Workshop #2
24	9/8/2010	MBK Engineers/Sacramento	Workshop	CVP and SWP operators	Collaborative Workshop #3
25	10/21/2010	Chico	Public Oureach	GCID, NHI, Sacramento Valley public	Update public and receive comment on recent project activities
26	12/8/2010	Masonic Lodge/Chico	Public Workshop/Oureach	GCID, NHI, Sacramento Valley public	Update public and receive comment on recent project activities
27	3/17/2011	DWR/Sacramento	Executive Briefing	Ajay, Goyal and DWR	Coordination with other DWR initiatives

3.4.3. Workshops

Three of the four workshops conducted for the project were held specifically to engage the CVP and SWP operators. These workshops were used to present the results of technical analyses and to frame and discuss the various assumptions being made by the team regarding existing operation of the CVP and SWP and implications and opportunities associated with conjunctive operations. These workshops were invaluable in refining the project's analytic tools and operations simulations. (Also see section 6.)

The fourth project workshop was designed to engage the Chico area public specifically to walk through the unique conjunctive operation strategy identified for the project (which emphasizes reservoir re-operation backed by limited groundwater pumping).

3.4.4. Technical and Other Team Meetings

During the initial technical formulation of the project from roughly mid-2007 through mid-2008, a series of rigorous meetings were held among the technical team, but also including agency staff. It was during these meetings that the core conjunctive operations concept was developed, project areas screened and models developed and tested. In some cases, adjunct meetings of the project sponsors were conducted before or after the technical team sessions to discuss project strategic issues.

Other project coordination and planning meetings were held occasionally, as needed, to ensure adequate coordination among team members and with the funding agencies.

4. Analytic Approach

4.1.Overview

Development of project scenarios evolved over the period from 2007 to 2011 including efforts to develop appropriate analytic tools (or models) and to evaluate model outputs and project performance (Figure 4-1). Scenario development began by framing projects objectives and principles consistent with the original project proposals but also reflecting input received through initial public outreach. Once these guiding materials were developed, efforts branched onto two parallel, coordinated tracks, one to develop specific environmental flow targets for the Sacramento and Feather Rivers, and another to identify areas within the Sacramento Valley for more detailed investigation. Information compiled for project site screening also provided a basis for assessing different conjunctive operations modes at a conceptual level, leading to identification of the most promising conjunctive management approaches.

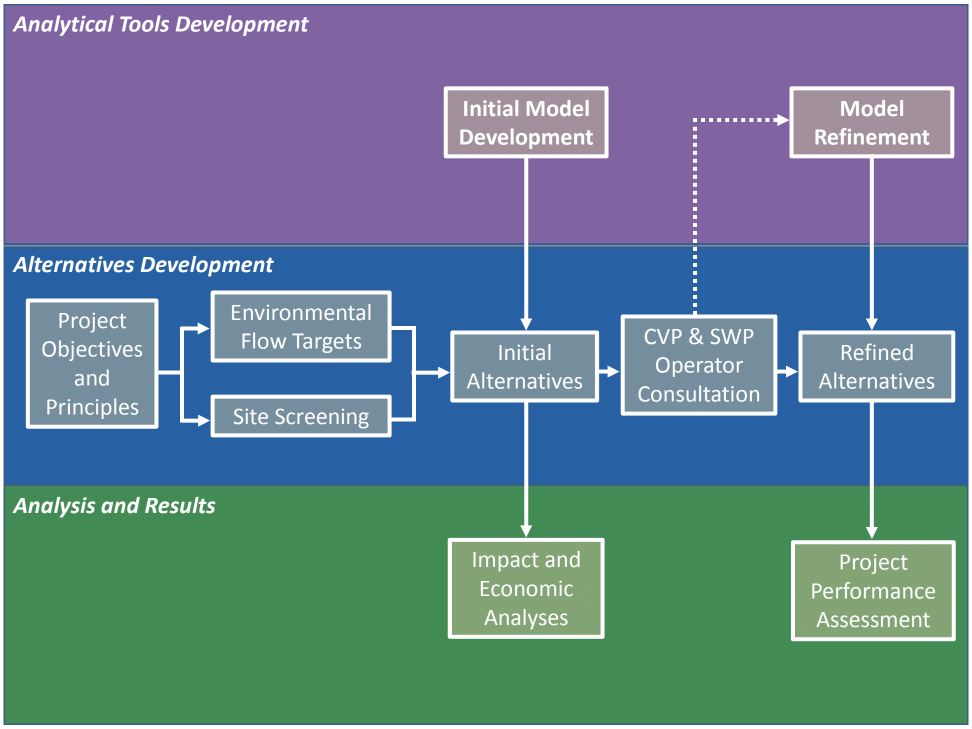

FIGURE 4-1
Project Analytical Components
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

With environmental flow targets established and a clear vision of the conjunctive operations strategy, work began on development of the scenarios themselves and supporting analytical tools. The initial project scenarios that resulted were analyzed in detail, providing a basis for additional public outreach and focused consultations with the operators of the Central Valley Project and State Water Project. The consultation with project operators was particularly instructive, leading to important refinement of the project scenarios and identification of additional project objectives to be tested, along with some as refinement of the models themselves.

The project's core conjunctive operations concept, site screening process and develop of environmental flow targets are discussed in detail in this section (Section 4). Initial model development and scenario development and evaluation are discussed in Section 5, with Section 6 covering model and scenarios refinement and assessment of project performance. The relationship between the analytic components and report structure are presented below in Figure 4-2.

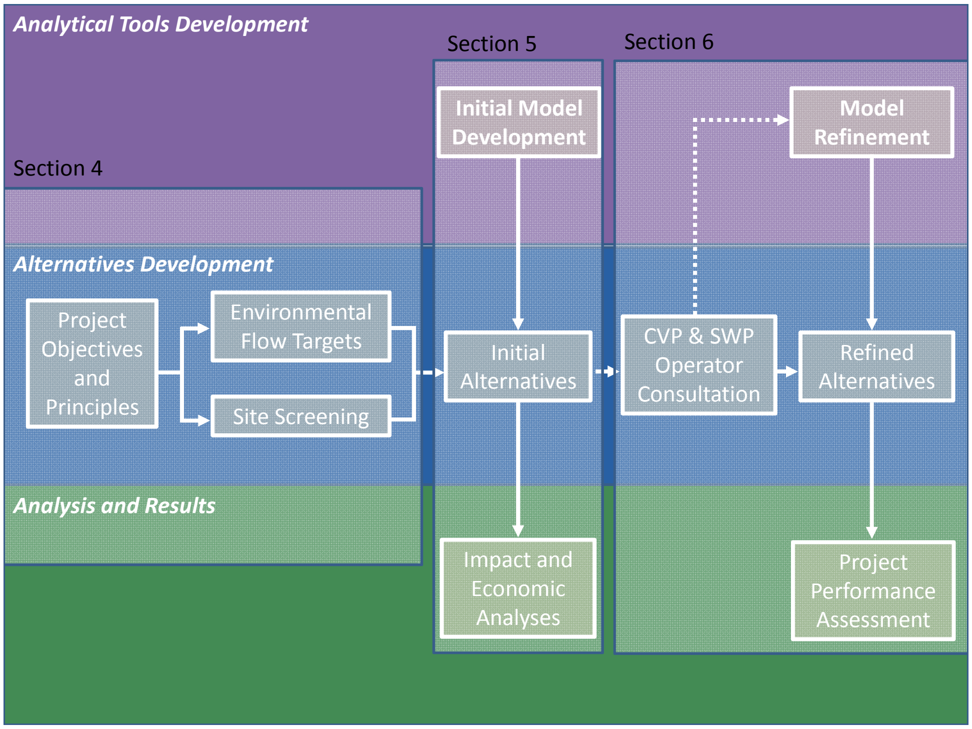

FIGURE 4-2
Relationship between Analytical and Report Organization
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

4.2. The Core Reservoir Re-operation and Payback Concept

The central thesis of this investigation is that most major reservoirs that are operated today for a limited set of water supply and flood control objectives could be re-operated to achieve newly defined ecological restoration benefits while also improving water supply reliability, reducing flood risks, and buffering the effects of climate change. The objective of the project was to explore the potential to optimize operations for all of these benefits without compromising any of them. This opportunity was recognized by the authors of CALFED's Strategic Plan for Ecosystem Restoration:

> "There is underutilized potential to modify reservoir operations rules to create more dynamic, natural high-flow regimes in regulated rivers without seriously impinging the water storage purposes for which the reservoir was constructed. Water release operating rules could be changed to ensure greater variability of flow, provide adequate spring flows for riparian vegetation establishment, simulate effects of natural floods in scouring riverbeds and creating point bars, and increase the frequency and duration of overflow onto adjacent floodplains[10]."

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[10] CALFED Bay-Delta Program, Ecosystem Restoration Program Plan, Strategic Plan for Ecosystem Restoration, Final programmatic EIS/EIR technical Appendix, July 2000.

Reservoirs that have dual water supply and flood control functions, like the CVP and SWP reservoirs, are typically operated under conservative rules designed to maximize water supply while avoiding flood risks. This results in relative high carryover storage levels but frequent “spills” of water during the refill period to create sufficient flood reservation capacity as necessary to prevent flood damage to the development that has occurred in the downstream floodplain. These spills represent the component of the runoff hydrograph that is not controlled and therefore not appropriated for beneficial use under California water law. To capture and manage this water would require creating additional storage capacity. One way to do that without enlarging the reservoir, or constructing additional ones, is to lower the water storage levels going into the refill period, thereby creating more reservoir capacity to capture high flows. Storage levels can be lowered by delivering additional water from the conservation pool to meet new water supply objectives, including enhancing flows for environmental benefits and augmenting water supplies for consumptive uses such as agriculture.

However, making additional reservoir releases before the ensuing refill period incurs a larger risk of water supply shortages in the event that the quantity of runoff during the refill season, which is always uncertain, is not sufficient to recover the reservoir storage to the level that would have occurred if the additional releases had not been made. Failure for the reservoir to refill would impinge on the reservoir’s function, manifest as water supply shortages, inadequate cold water reserves or reduced carryover storage, or some combination of these factors, unless the reservoir deficit can be made up from other sources.

The concept of re-operation described above was investigated in relation to Sacramento Valley reservoirs, including three options for filling any reservoir storage deficits caused by re-operation. The three options, referred to as reservoir “payback”, are listed below. It should be noted that payback does not involve sending water to the reservoir from other sources. Rather, the reservoir is “paid back” by not releasing water from it that otherwise could be called on, and meeting the water demands that would have been met with reservoir releases with other supplies, or by reducing water demands. The three payback options considered in this study are:

1. Payback from water generated by the project in previous years and stored (or “banked”) in aquifers in the Sacramento Valley;

2. Payback from groundwater pumped by cooperating water suppliers served by the CVP or SWP to substitute for water that would otherwise have had to be delivered from the reservoirs; and,

3. Payback from reduction in water demands on the reservoirs, achieved by temporary crop idling on a voluntary, compensated basis.

Each of these payback options is discussed in greater detail later in this section.

A fourth option that was not considered in this study is to repay reservoirs with water conveyed to and banked in aquifers south of the Delta in previous years. This option poses certain advantages to the Sacramento Valley by eliminating or substantially reducing the need to exercise Sacramento Valley aquifers for payback. However, this option is beyond the scope of this phase of investigation and would be overly speculative at this time given the uncertainty in the status and configuration of Delta conveyance and export options presently being evaluated under the Bay Delta Conservation Plan (BDCP).

4.3. Project Objectives, Design Principles and Constraints

The basic objective of reservoir re-operation is to generate additional water supplies (or “assets”) for discretionary uses. In this case, the investigation looked at dedicating additional water supplies generated through re-operation of Sacramento Valley reservoirs to two primary in-Valley purposes:

1. **Enhancing ecosystem functions in the Sacramento and Feather Rivers.** Healthy rivers are not just environmentally attractive, they also are central to ensuring reliable, sustainable water supplies. Water supply systems that work in concert with the environment are less likely to be encumbered by court orders, water rights hearings, and other restrictions that can have drastic effects on water supplies for farming and other economic uses.

2. **Improving local water supply reliability, particularly in times of scarcity**, to help fill water supply shortages that occur occasionally during hydrologically dry periods. The investigation used historical unmet agricultural water demands to represent the need for additional water supplies in the Valley; however, the additional water supplies could be allocated to other uses and locations.

While not an explicit component of the investigation, it should be noted that the additional water released for ecosystem enhancement becomes additional Delta inflow, which could be used for meeting Delta water quality objectives, for export from the Delta to meet water demands elsewhere in the state or some combination of the two. As discussed later in this report, to the extent that additional Delta exports could be generated while Sacramento Valley water supply reliability is increased and Delta water quality requirements are satisfied, the economic viability of reservoir re-operation and payback would be dramatically improved. Further investigation is needed to examine how these benefits could be optimized.

Design principles were established early on to guide development of project scenarios. The principles were derived in part from public input as well as from the sensibilities of the project sponsors and funding agencies, all aimed at identifying realistic, implementable water management improvements. The primary design principles are as follows:

1. <u>Honor all existing CVP and SWP obligations and operational constraints:</u> The CVP and SWP operate under a complex set of rules and conventions consistent with project water supply and flood control objectives and regulatory requirements, including temperature criteria, State Water Resources Control Board (SWRCB) Decision 1640 (D-1640), and the Central Valley Project Improvement Act (CVPIA). All of these existing objectives and constraints must be observed in any conjunctive management scenario so that water supply obligations to contractors are met to the same extent as under existing operations, and all applicable regulations are satisfied.

2. <u>Achieve net environmental benefits, recognizing that there may be some tradeoffs among different environmental objectives and different times and locations:</u> The Project would be operated to achieve or contribute to achieving certain environmental flow improvements in the mainstem Sacramento and Feather Rivers designed specifically to enhance ecologic functions important to the viability of protected species, particularly Chinook salmon. When groundwater pumping is needed for reservoir payback (under payback option #2, above), this could result in temporary reductions in base flows in the tributary streams that are also important to protected species. Such potential tradeoffs would be addressed through consultation with the listing

agencies as part of the NEPA/CEQA compliance by project sponsors. Additional tradeoffs between restoration of more natural river flow regimes and maintenance of cold water pools for river temperature control are also possible and are discussed later in this report.

3. Hold other groundwater users harmless: The participating water districts are legal users of groundwater, and, like all other groundwater users in the basin, enjoy a correlative and co-equal right to increase their groundwater extractions for use by the overlying landowners, subject to the mutual avoidance of harm. Notwithstanding the legality of the participating districts' groundwater withdrawals, the Project would adhere to a "good neighbor" principle and design its mitigation plan to the higher standard of assuring no appreciable, unmitigated harm to existing groundwater users.

4. Generate net economic benefits so that the program can be self-financing: The project must be able to generate revenues that more than offset the expenditures associated with project implementation, including construction, operation, maintenance and any mitigation costs. In the economic analysis conducted for the study, revenues were included only for water sales; no monetary value was attached to ecosystem restoration benefits, although these benefits may be quite appreciable.

Given the project objectives and design principles set forth above, certain constraints emerged during formulation and evaluation of project scenarios that limit the feasible scale of reservoir re-operation. These are listed below and are described at length later in this report.

- Capacity to produce water for reservoir payback. The capacity to produce water for reservoir payback governs the scale of reservoir re-operation, considering that the water debt owed to any reservoir cannot exceed the capacity to repay the reservoir payback in a single year, if necessary. However, particularly for reservoir payback based on additional groundwater pumping (option #2 above), the greater the payback capacity the greater the risk of impacting existing groundwater pumpers and critical streams.

- Minimum reservoir releases governed by temperature control criteria. There are conditions under which Lake Shasta reservoir releases are governed by temperature management in the Sacramento River between Keswick and Red Bluff, upstream of the locations were payback water would be generated. Under these conditions, the payback mechanism is rendered ineffective because reservoir releases cannot be reduced commensurate with the production of payback water. (The prospective temperature standards for the Feather River under the relicensing settlement for Oroville may also pose a constraint on re-operation of Lake Oroville for project purposes, but this has not yet been evaluated).

Within these limits, the investigation considered whether it is feasible through reservoir re-operation to increase the benefits that can be derived from a fixed hydrology and surface storage infrastructure.

4.4.Reservoir Payback Mechanisms

4.4.1. Groundwater Banking

Groundwater banking for reservoir payback involves making additional reservoir releases at certain times and storing the water in aquifers for recovery months or years later. Releases generally are made in above normal or wetter years with recovery occurring in relatively dry years. Surface water can be placed in storage by artificial recharge (surface spreading or injection wells) or by supplying it to water users who would otherwise pump groundwater (in-lieu recharge). Conditions required for groundwater banking include available storage space in an aquifer where water can be retained over periods of several years and a feasible means of recharge. Typically, in-lieu recharge is more cost-effective than artificial recharge; however, in-lieu recharge requires that there is baseline groundwater pumping that can be suspended at times when additional reservoir releases are being made. Thus, in areas where groundwater pumping is negligible or would not occur when reservoir releases would be made, in-lieu recharge is not feasible.

4.4.2. Groundwater Pumping

Groundwater pumping for reservoir payback without having first banked the water underground implies depleting groundwater storage. In order to be sustainable, groundwater storage depletion must be temporary with depletions eventually offset by additional recharge induced by the pumping. Additionally, practical restrictions need to be placed on the location, frequency, magnitude and duration of pumping to avoid or minimize any impacts to streams and existing groundwater users.

4.4.3. Temporary Crop Idling

Temporary crop idling involves not planting crops that would otherwise be grown and irrigated. Suspension of irrigation in this manner reduces demands on the reservoir being re-operated, allowing water to be held in storage that would otherwise be released. In order to attract farmers into voluntary participation in temporary crop idling programs, they must be compensated at a level that, at a minimum, provides a net benefit equivalent to production of the crop not planted. One of the main challenges to effective crop idling is the timing of decisionmaking by participating farmers relative to decisions that need to be made for project operations. Farmers typically are making crop decisions and purchasing production inputs in late winter into early spring meaning that offers to participate in crop idling must be presented in the same timeframe. However, at that time, the need for refill water cannot be forecast accurately while the commitments to idling and the associated payments are irrevocable. Thus, with crop idling, there is the possibility that actual reservoir inflow turns out to be greater than forecast, potentially rendering the water produced by crop idling unusable.

4.5. Project Site Screening

A systematic, qualitative assessment of conditions within the Sacramento Valley was conducted to identify particular areas where conjunctive operations appear promising. This process did not conclusively identify the very best or most feasible sites within the Valley, but did identify relatively attractive sites for conjunctive operations based on a comparative assessment using certain criteria.

The team examined fall groundwater elevation maps, water supplier boundaries and distribution system coverages, and water source maps. Initially it was assumed that conjunctive management operations would follow groundwater banking type operations wherein water is stored in aquifers during years of above normal water supply and extracted during years of below normal supply. These operations are typical in the San Joaquin Valley and other areas in which aquifers have been depleted and appreciable storage space exists. Following this initial assumption, the following two types of sites were identified:

- Areas in which existing groundwater levels may be lower than surrounding areas and overlying lands are supplied almost exclusively from groundwater. This type of site may provide the potential for groundwater banking in underlying aquifers.

- Areas in which minimal groundwater pumping exists because overlying areas are supplied almost exclusively from surface water. This type of site may provide a potential area for groundwater pumping.

The project and technical teams developed and initial list of project sites from a review of groundwater maps and their professional knowledge of the Sacramento Valley. Sites were named according to the overlying water district, though potential sites did not strictly conform to water district boundaries. Information considered in this analysis included the location, water source, existing surface water contracts, current infrastructure and additional infrastructure necessary for delivery of surface water and for extraction of groundwater, operational concepts, and information on existing groundwater conditions. Table 4-1 summarizes this information considered for the nine initial sites.

TABLE 4-1
Initial Project Sites and Parameters
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Location	Water Source	Site Type	Annual Surface Water Contract	Project to Integrate With	Currently Integrated?
Butte Basin	Surface	GW Pumping	~ 300 TAF/yr	SWP	Yes
Orland-Artois WD	Mixed	Both	53 TAF/yr	CVP	Yes
Rancho Capay WD	Ground	GW Banking	None	CVP	No
Corning Canal Area	Mixed	Both	33 TAF/yr	CVP	Yes
Yolo-Zamora WD	Ground	GW Banking	None	CVP	No
Glenn-Colusa ID	Surface	GW Pumping	825 TAF/yr	CVP	Yes
Stony Creek Fan area	Surface	GW Pumping	~ 100 TAF/yr	Orland	No
Colusa County WD	Mixed	Both	68 TAF/yr	CVP	Yes
Olive Percy Davis Ranch	Surface	GW Pumping	32 TAF/yr	CVP	Yes

The goal was to identify at least one site that is served by the CVP (Shasta), one by the SWP (Oroville), and one by the Orland Project. The CVP and SWP are the principal surface water systems in the Sacramento River basin and their operations are linked to the Sacramento and Feather Rivers, respectively, both of which are targeted for environmental restoration. The Orland Project, although not among the largest surface water systems in the Valley, is an area where conjunctive operations have been viewed as a possibility for many years.

The nine sites were evaluated qualitatively based on their potential to generate reservoir payback water, an estimate of the volume of water that may be developed, and relative (compared to the other sites) ease and cost of integrating the project with existing surface water systems.

The following additional criteria were used to identify prospective sites:

- Availability of reliable surface water supplies that could be substituted with groundwater to enable conjunctive operations

- The presence of highly productive, underlying groundwater aquifers that could be economically developed (or were already developed to some extent)

- The ability to locate and design production wells in a manner that would minimize effects on existing groundwater users and surface streams

Evaluation of existing groundwater conditions within the Sacramento Valley shaped the site screening and selection. In general, the evaluation revealed that while groundwater levels are drawn down during the irrigation season in many areas of the basin, levels recover during the precipitation season except during prolonged (multi-year) dry periods. Figures 4-1 through 4-15 of the Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report in Appendix B, which depict historic groundwater fluctuations in wells distributed throughout the valley, illustrate this point. Cones of depression generally do not persist over the multiple years necessary to make the dewatered aquifer space suitable for banking[11]. Any additional water recharge induces additional groundwater discharge to the streams. The conclusion from this analysis was that conjunctive operations based on a groundwater banking payback mechanism are not feasible in the Sacramento Valley at this time. Thus, further effort was concentrated on a second option for a payback mechanism: pumping groundwater in lieu of making reservoir deliveries in years when reservoir payback would be necessary.

Two sites were identified on which to conduct more refined analyses with surface and groundwater modeling tools. The GCID and Butte Basin Projects, supplied by the CVP and SWP, respectively, provided the potential to pump the largest quantity of groundwater compared to other sites, and are already well integrated with the surface water system. Under this option, conjunctive management operations would utilize wells within GCID and the Butte Basin as a backstop for more aggressive operation of Shasta Reservoir and Oroville Reservoir, respectively.

The major water surface water suppliers within the Butte Basin are WCWD, RID and Biggs-West Gridley Water District (BWGWD). BWGWD declined to participate in the investigation, so development of the Butte Basin project concentrated on the other two districts. It is noted that WCWD and RID were passive project participants meaning they provided information for the investigation but did not assume a sponsorship role.

Additionally, the Stony Creek Fan area and Orland Project was identified as a third potential project. However, upon further evaluation into potential groundwater pumping capacities and the ability to integrate the project with the Sacramento River system, it was determined that this project would not be investigated as part of this investigation. However, this project should be considered for further analysis in any future investigations.

Project site screening is discussed in additional detail in Appendix C.

4.6. Environmental Flow Objectives

A major element of this investigation was the development of specific ecological flow objectives for the Sacramento and Feather Rivers to use to formulate and evaluate reservoir re-operation scenarios. The objectives are expressed as quantitative flow targets for the two rivers, respectively, and are coupled with a dynamic decision system for prioritizing objectives from year to year. The target flows are defined in terms of magnitude, duration, frequency and seasonality, by river reach. Although developed specifically for the purpose of formulating conjunctive management strategies, the recommended objectives and flows are believed to have broader utility beyond this investigation.

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[11] Based on the most recent (Fall 2011) data collected by DWR, there appear to be some areas in the northern Sacramento Valley with persistent groundwater level declines, primarily in Glenn and Tehama Counties. These areas should be evaluated for potential groundwater banking operations in future work phases.

The general approach and rationale are briefly summarized in the following section, followed by a discussion of how the quantitative flow objectives and dynamic prioritization process are represented in the surface water model (described in Section 5). The process for developing recommended environmental flow objectives is described in detail in Appendix D.

4.6.1. General Approach and Rationale

It should be noted that the development of environmental flow regimes is as much an art as a science. However, the team attempted, to the extent possible, to use established methods to develop a transparent and replicable approach for identifying an environmental flow regime. The team conducted a detailed literature review of various methods and approaches previously utilized to develop environmental flow recommendations, and to employ a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento and Feather Rivers. This approach relies heavily on hydrological evaluations, previous studies and modeling analysis of historical hydrology, and expert opinion to estimate environmental flow requirements.

The approach consists of five basic steps:

1. Identify specific environmental objectives (i.e. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).

2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to achieve identified environmental objectives.

3. Compare and analyze existing and historical hydrology to understand natural hydrologic patterns and how they have been altered.

4. Identify obvious gaps between flows necessary to achieve objectives and existing flows.

5. Modify the existing hydrograph into an environmental flow hydrograph based on an understanding of natural hydrology and the flows necessary to achieve key objectives.

Employing this approach, the team designed the environmental hydrograph to achieve the following three types of objectives.

- Geomorphic Functionality: Bed mobility, channel migration, and floodplain inundation

- Riparian Habitat Sustainability: Recruitment and maintenance of Fremont Cottonwood

- Chinook Salmon: Improved habitat, particularly rearing habitat, for all runs

The team relied on field data, modeling results, and studies, particularly the recent Nature Conservancy Study of the Sacramento River[12], to identify the minimum flows and critical thresholds to achieve each of the three types of objectives. Then historical and existing hydrology were analyzed to understand how the objectives may have been achieved under pre-dam conditions and to evaluate how existing

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[12] Sacramento River Ecological Flows Study Final Report, CALFED Ecosystem Restoration Program, The Nature Conservancy, et al, March 2008.

hydrology may fall short of meeting those objectives. The gaps identified in this manner are the basis for identifying flow objectives.

Analyses of the hydrology on both rivers reveals that the most obvious and significant change between pre-dam and post-dam eras is a sharp reduction in the magnitude and duration of the late winter and early spring hydrograph and a corresponding reduction of inundated floodplain habitat. The reduction in late winter and spring flows reduces the frequency of geomorphic and riparian flows and substantially reduces the extent and frequency of occurrence of inundated floodplain rearing habitat for salmonids. Thus, for both the Sacramento and Feather Rivers, an increase in late winter and early spring flow is the primary component of the recommended environmental flow regime, but a corresponding reduction in summer base flows is also recommended. Reduced summer flows are primarily needed to free-up water needed to restore the spring hydrograph but may also provide ecological benefits by better approximating the natural hydrograph. Reducing summer base flows could, however, increase summer temperatures and harm salmonids including the endangered winter-run Chinook salmon. On the other hand, cool water temperatures in the upper Sacramento River are largely controlled by the volume of cold water storage behind Shasta Dam and the environmental flow regime identified here does not involve modifying coldwater pool management.

The summer temperature issue is one of several key uncertainties that are inherent in establishing environmental flow targets and must be addressed before any significant modifications to the flow regime can be refined and implemented for environmental purposes. However, articulating a hypothetical environmental flow regime is the first step in identifying and addressing constraints and uncertainties associated with improving environmental flow regimes on regulated rivers. To that end, the team welcomes constructive comments and criticisms that can be used to improve upon the recommendations presented here as we learn more about the rivers and the people who depend upon them for their livelihood.

This study focuses on the magnitude and timing of flows necessary to replicate key ecological and geomorphic processes, and considers the flows necessary to provide suitable conditions for various life stages of Chinook salmon and steelhead. This study does not identify specific population targets for salmonid restoration, nor does it address important non-flow objectives such as habitat area required for restoration of target species or augmentation of coarse sediment supplies necessary to restore full geomorphic structure and function. Rather this study focuses on magnitude, pattern, and quantity of water necessary to restore ecological functions assuming that adequate physical habitat exists or will be created to complement a suitable environmental flow regime. The rationale of this focus is to identify a hypothetical environmental flow regime for the purpose of evaluating whether it is possible to reestablish ecological and geomorphic flows on the rivers of the Sacramento Basin without reducing water supply deliveries to existing water users.

Analysis of historical (pre-dam) hydrology and the habitat it created were analyzed to provide a reference point for identifying ecosystem restoration goals, recognizing that it is not possible to restore historic conditions in highly altered systems such as the Sacramento River. Historical hydrologic analysis is useful for identifying patterns in the timing, magnitude, duration, and frequency of flows that may be important for maintaining native species, but it is less useful in developing specific flow prescriptions, because physical habitat has been so profoundly changed by dams and levees and there are now competing demands for the water. We recognize that it is not possible to fully restore historical hydrology or habitat conditions in the Sacramento Valley, but ecosystem restoration will require reestablishment of a minimum threshold of both hydrologic and physical habitat conditions.

Although this study identifies hypothetical restoration flow regimes for the Sacramento and Feather Rivers, we recognize that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The hypothetical flow regime serves as a reasonable starting point for evaluating the economic feasibility of re-operating reservoirs and a long-term adaptive management program. The assumptions and uncertainties associated with the hypothetical flow regime are important to acknowledge and understand. To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of modeling, pilot flow studies, model calibration, and long-term implementation.

The ecologic flow objectives fall into two categories, three that were designed for Chinook salmon recovery, and one that was designed for riparian habitat recovery. These may be summarized as follows:

For Chinook salmon:

- Geomorphic objectives: Sediment transport, bed mobilization and bed scour; channel migration and floodplain processes; inundation and fine sediment deposition
- Floodplain inundation objectives : inundated floodplain habitat for rearing juveniles during the later winter and early spring; maintain and recruit spawning habitat, but avoid scouring gravels while eggs or alevon are present
- Spring pulse flow objectives: Suitable flow conditions and temperatures for all life stages;

For Riparian Habitat:

- Fremont cottonwood seedbed preparation, seed germination and seedling growth; periodic large-scale disturbance of the riparian zone; riparian stand structure and diversity

4.6.2. Representing Environmental Flow Objectives in the Surface Water Model

The different flow objectives developed for the Sacramento and Feather Rivers are simulated as all-or-nothing thresholds, meaning that a decision to satisfy an objective is made only if the full target flow can be sustained for the specified duration. As discussed in Appendix D, environmental objectives are based on the magnitude and duration of flows required to replicate certain ecological and geomorphic processes. Environmental objectives are specified and prioritized by water year type. The Sacramento River Water Year Type Index (Sacramento River Index), sometime referred to as the 40-30-30 Index, is used to classify each year as either wet, above normal, below normal, dry, or critical.

Each of the environmental flow objectives is described quantitatively below.

4.6.2.1. Geomorphic Flow Objectives

Geomorphic releases are short-duration, high-flow events for the purpose of sediment transport, channel migration, and flood plain processes, such as inundation and fine sediment transport. Geomorphic releases are targeted from March through April and are only required to last several hours. The surface water model simulates geomorphic events lasting one day due to the ramping requirements when making these large releases from reservoirs. Table 4-2 presents geomorphic flow objectives for Sacramento and Feather Rivers.

TABLE 4-2
Geomorphic Flow Objectives for Sacramento and Feather Rivers
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Sacramento River Index	Sacramento River (cfs)	Feather River (cfs)
Wet	105,000	50,000
Above Normal	85,000	35,000
Below Normal	65,000	20,000
Dry	35,000	10,000

No objective specified in critical year types.

4.6.2.1. Riparian Establishment

The purpose of riparian establishment flows is to recruit and grow cottonwoods in the riparian areas along the rivers. Riparian establishment flows are designed to assist in several phases of early cottonwood growth including seedbed preparation, seed germination, and seedling growth. These flows also create periodic large-scale disturbances of the riparian zone. Riparian establishment objectives (see Figure 4-3) are specified for the period of mid-April through mid-June to coincide with the cottonwood reproductive cycle. Riparian recruitment flows are large-magnitude flows for extended periods of time and are typically only possible during years of above average runoff. Therefore these objectives are only specified in years classified as wet or above normal by the Sacramento River Index.

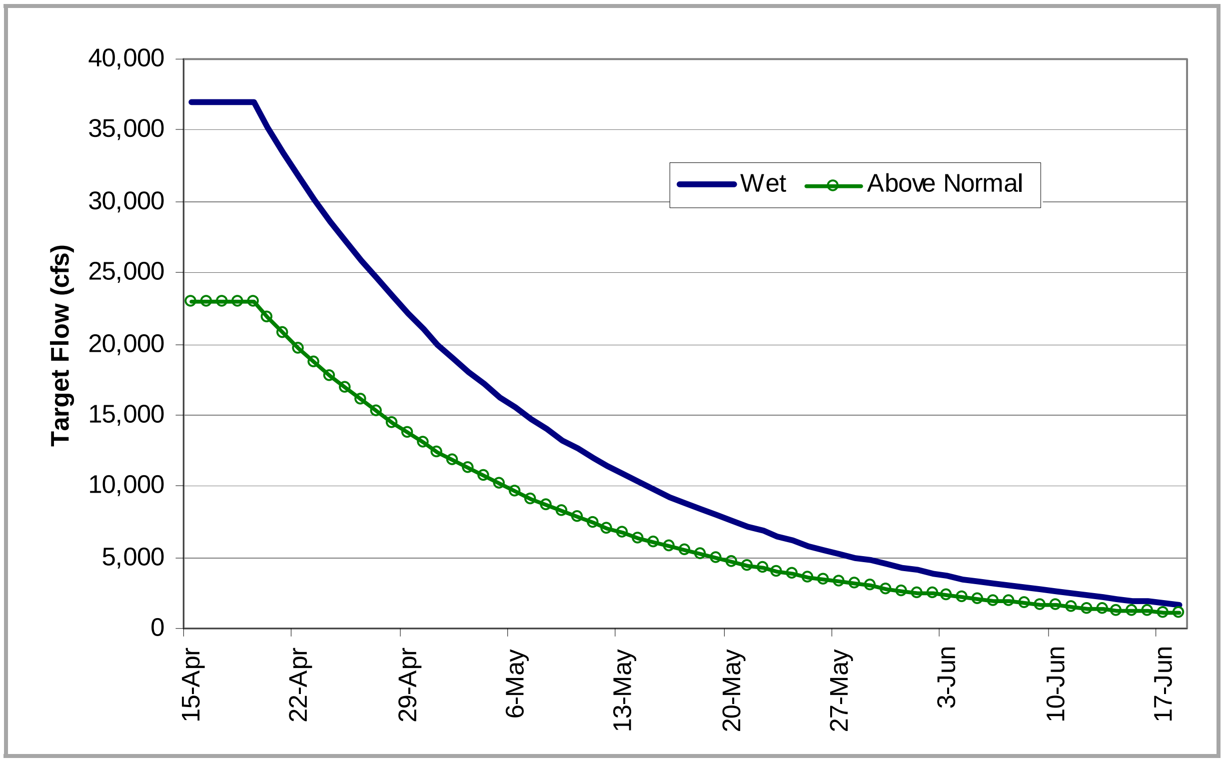

FIGURE 4-3
Sacramento River Riparian Establishment Objective
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Figure 4-3 illustrates the shape of the of riparian establishment objectives. The objective begins with a high-flow event held for a period of 5 days followed by a 60-day recession limb when the target each day is 5 percent less than the previous day's target. Table 4-3 summarizes the objectives for both the Sacramento and Feather Rivers.

4.6.2.2. Spring Pulse Flows

Spring pulse flows are designed to simulate a portion of the historic unimpaired runoff of the river to help create suitable flow conditions and temperatures for Chinook salmon migration. These flows also are designed to help maintain and recruit spawning habitat and avoid scour when eggs are in redds. Spring pulse flow targets are specified in all but critical year types, though the magnitude and duration of the target is reduced in years with less runoff. Tables 4-4 and 4-5 summarize the spring pulse objectives.

4.6.2.3. Flood Plain Inundation

Inundation of the Sutter and Yolo Flood Bypass channels is another environmental objective. It is assumed for this study that the weirs that currently block flow into the bypasses below certain river stages can be modified to allow inundation at lower river stages and flows. Inundation of the flood bypasses provides rearing habitat for juvenile salmonids. These inundation flows are targeted to correspond with outmigration of salmonids in the spring months and designed to last for 45 days. Flood plain inundation flows can be set for one of three different time-periods in the surface water model: February 15 to March 30, March 1 to April 15, or March 15 to April 30. Table 4-6 presents flood inundation objectives for Sacramento and Feather Rivers.

TABLE 4-3
Riparian Establishment Objectives
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Sacramento River Index	**Sacramento River**		**Feather River**	
	5-day Flow (cfs)	**Recession Rate**	**5-day Flow (cfs)**	**Recession Rate**
Wet	37,000	5%	12,000	5%
Above Normal	23,000	5%	10,000	5%

Note: No objective specified in below normal, dry, or critical year types

TABLE 4-4
Sacramento River Spring Pulse Objective
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Sacramento River Index	**Flows (cfs) by Date**					
	3/15-3/31	**4/1-4/14**	**4/15-4/30**	**5/1-5/14**	**5/15-5/31**	**6/1-6/14**
Wet	14,000	14,000	14,000	14,000	14,000	8,500
Above Norm	12,500	14,000	14,000	14,000	8,500	
Below Norm	12,500	12,500	12,500	8,500		
Dry	10,000	12,000	12,000	8,500		

Note: No objective specified in critical year types

TABLE 4-5
Feather River Spring Pulse Objective
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Sacramento River Index	Flows (cfs) by Date					
	3/1-3/14	3/15-3/31	4/1-4/14	4/15-4/30	5/1-5/14	5/15-5/31
Wet	8,000	12,500	12,500	11,000	6,000	4,000
Above Norm	6,500	6,500	10,000	10,000	5,000	3,000
Below Norm	3,200	3,200	8,000	8,000	3,200	
Dry	2,700	2,700	5,500	5,500	2,700	

Note: No objective specified in critical year types

TABLE 4-6
Flood Plain Inundation Objective for Sacramento and Feather Rivers
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Sacramento River Index	Sacramento River at Fremont Weir (cfs)
Wet	45,000
Above Normal	35,000
Below Normal	35,000
Dry	35,000

Note: No objective specified in critical year types

4.6.2.4. Prioritization of Environmental Flow Objectives and Decision Month

Environmental objectives are prioritized based primarily on hydrologic year type and the frequency with which the various objectives are satisfied. Considering the frequency of when objectives have been satisfied places higher priority on objectives that have not been met in recent years relative to those that have. For example, if the spring pulse objective is typically the highest priority in an above normal year but was met in the previous year (either in the base condition or with a project release) it may be desirable to shift the highest priority to the flood plain inundation objective instead.

To implement this dynamic prioritization scheme that shifts the priority from one year to the next depending on year type and occurrence interval a user-specified relative priority value is combined with the number of years since an objective was last satisfied to determine the final priority of objectives each year.

Table 4-7 contains the relative priority matrix developed by the project team for use in the surface water model. Lower numbers denote higher priorities.

Final priority is determined by subtracting the relative priority from the number of years since the objective was met and comparing the results for all objectives.

Table 4-8 provides an example prioritization calculation for a hypothetical wet year on the Feather River system.

TABLE 4-7
Relative Priority Matrix for Environmental Objectives
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Sacramento River			Both Rivers	Feather River		
Sacramento River Index	**Geomorphic**	**Riparian Recruitment**	**Spring Pulse**	**Flood Plain Inundation**	**Geomorphic**	**Riparian Recruitment**	**Spring Pulse**
Wet	10	2	10	10	10	2	10
Above Normal	15	6	2	4	15	5	2
Below Normal	2	99	1	3	2	99	1
Dry	5	99	2	90	5	99	2
Critical	80	99	1	90	80	99	1

TABLE 4-8
Example Prioritization of Environmental Objectives, Feather River, Wet Year
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Flood	**Geo**	**Rip.**	**Spring**
Years Since Met	6	1	4	25
Relative Priority	10	10	2	10
Final Priority	-4	-9	2	15

The objectives are prioritized by descending final priority scores, as follows: Spring Pulse, Riparian Recruitment, Flood Plain Inundation, and Geomorphic. In this example, because it had been 25 years since the spring objective had been met, Spring Pulse became the first priority objective, though its relative priority was lower than the Riparian Objective.

A decision must be made each spring to determine which objectives the model will attempt to meet that year. Several of the environmental objectives have variable start times and durations. To avoid always meeting the objective that starts earliest in the year or miss meeting an objective in hopes of satisfying a future objective, a user-specified decision month is used in the model. Project assets, water costs, and prioritization of environmental objectives are all determined during the decision month and results are used for operations that year. The decision month is used to determine what objectives the model will attempt to meet each year.

4.7. Agricultural Water Supply Objectives

As previously mentioned, historical agricultural water supply shortages in the Sacramento Valley were used to represent the targets for water supply enhancements. Specifically, for the CVP/Sacramento River, unmet demands of CVP contractors within the Tehama-Colusa Canal Authority (TCCA) were used to represent additional demands. Members of the TCCA, including contractors supplied from the Corning Canal, hold agricultural service contracts for approximately 320 TAF of contract supply from the CVP. Annual allocations to CVP contractors are simulated in CalSim II based on forecasted reservoir inflows, reservoir storage conditions, and the ability to deliver water. Simulated allocations range from 0 to 100 percent of full contract supply. When simulated allocations are less than 100 percent, it is assumed that the difference between simulated allocations and full contract supply is an unmet agricultural demand within the TCCA.

Figure 4-4 illustrates the annual unmet agricultural demand as a function of simulated allocations to the TCCA for each year of the study. The annual unmet demand illustrated in Figure 4-4 was assumed to occur on a typical agricultural demand pattern during the irrigation season.

On the Feather River system, the majority of SWP contractors have reliable water supplies with the exception of a few small contractors. There are no existing SWP contractors with large, frequently unmet agricultural demands in the Butte Basin. Therefore a more general unmet agricultural demand was defined for the Feather River based on user input and judgment. Table 4-9 summarizes the assumed unmet agricultural demand that could be met from Feather River supplies for purposes of modeling.

Figure 4-5 illustrates the annual volume of demand based on the assumptions in Table 4-9.

It should be noted again that the estimates of unmet agricultural demands described above are regarded as surrogates for any type of water supply need that might be identified for the Sacramento and Feather River systems.

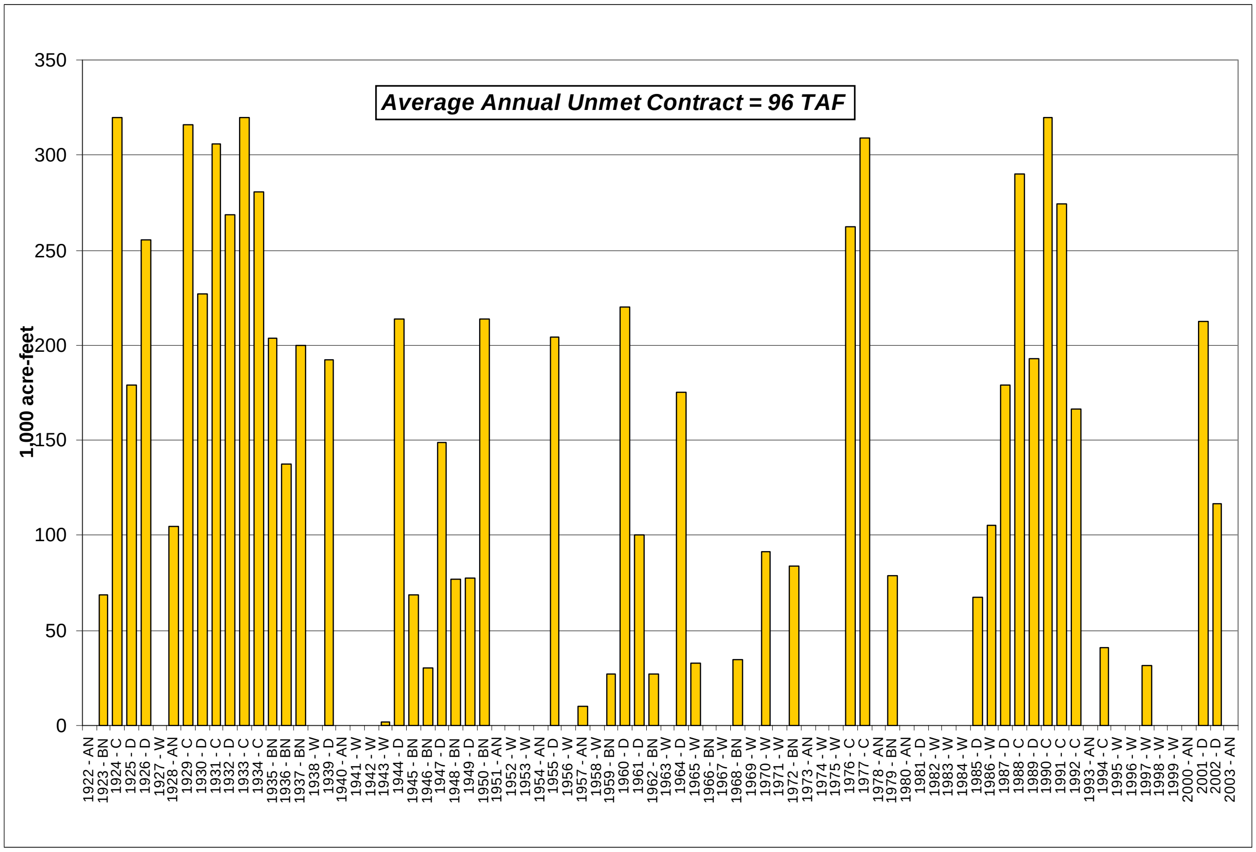

FIGURE 4-4
Unmet Agricultural Demand within TCCA Service Area
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

TABLE 4-9
Assumed Unmet Agricultural Demand within the Feather River System
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Sacramento Valley Index	Unmet Agricultural Demand (TAF)
Wet	0
Above Normal	40
Below Normal	75
Dry	90
Critical	100

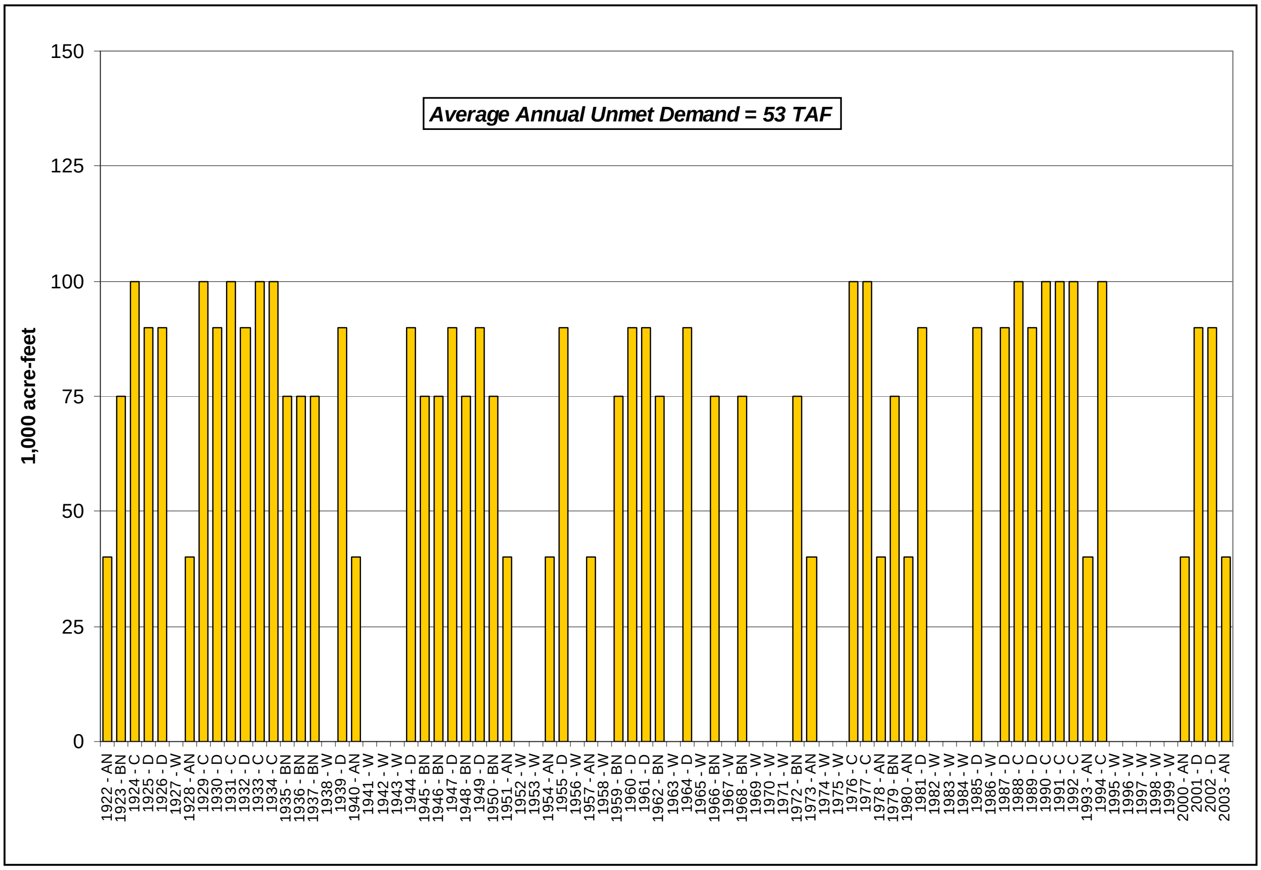

FIGURE 4-5
Assumed Unmet Agricultural Demand within Feather River System
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

5. Development and Assessment of Initial Project Scenarios

5.1.Initial Project Scenarios

Four conjunctive operations scenarios were developed for the GCID and Butte Basin project locations for initial analysis. The scenarios are differentiated primarily by the following two parameters:

- Maximum Payback Capacity. This is the maximum volume of groundwater pumping that would occur in any year within the pumping period (see below) in GCID and the Butte Basin, respectively. This capacity essentially establishes the scale of the conjunctive operation, since the water deficit in the reservoirs cannot exceed the capacity to repay it, when it becomes necessary. Maximum capacities were based primarily on professional judgment taking into consideration historical pumping in the two areas and average pumping intensity (acre-feet per acre). The payback capacities selected for analysis were:
    - 100 TAF in GCID and 50 TAF in Butte Basin; total 150 TAF
    - 200 TAF in GCID and 100 TAF in Butte Basin; total 300 TAF

- Pumping Period. Pumping must occur when there is a demand for water that would otherwise be satisfied by reservoir releases. In both project areas, the dominant crop is rice, which is typically planted between mid-April and early June and harvested in September. Following harvest, most rice fields are re-flooded between September and November for rice straw decomposition and to create waterfowl habitat. Thus the water delivery season in both areas is from mid-April through November. Based on this, three pumping periods listed below were identified for analysis. Different pumping periods were evaluated primarily to reveal differences in aquifer response to differences in the timing and rate of pumping. Additionally, the pumping period affects the capital investment needed for pumping facilities.
    - “Summer” defined as May through August
    - “Fall” defined as September through November
    - “Summer and Fall” defined as May through November

The combinations of payback capacity and pumping periods selected to form scenarios are listed in Table 5-1.

TABLE 5-1
Project Scenarios Evaluated
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Scenario	GCID Annual Pumping Capacity	Butte Basin Annual Pumping Capacity	Pumping Season
1	100 TAF	50 TAF	Summer (May through August)
2	200 TAF	100 TAF	Summer (May through August)
3	100 TAF	50 TAF	Fall (September through November)
4	100 TAF	50 TAF	Summer and Fall (May through November)

TAF = thousand acre-feet

Additionally, two well field configurations were evaluated for each scenario, one corresponding to existing wells screened at depths between 100 to 500 feet and a second well field corresponding to new wells screened at depths of 900 to 1,100 feet. Thus a total of eight operational scenarios were evaluated.

The well field configurations corresponding to the different payback capacities and pumping depths are illustrated in Figures 5-1 through 5-4.

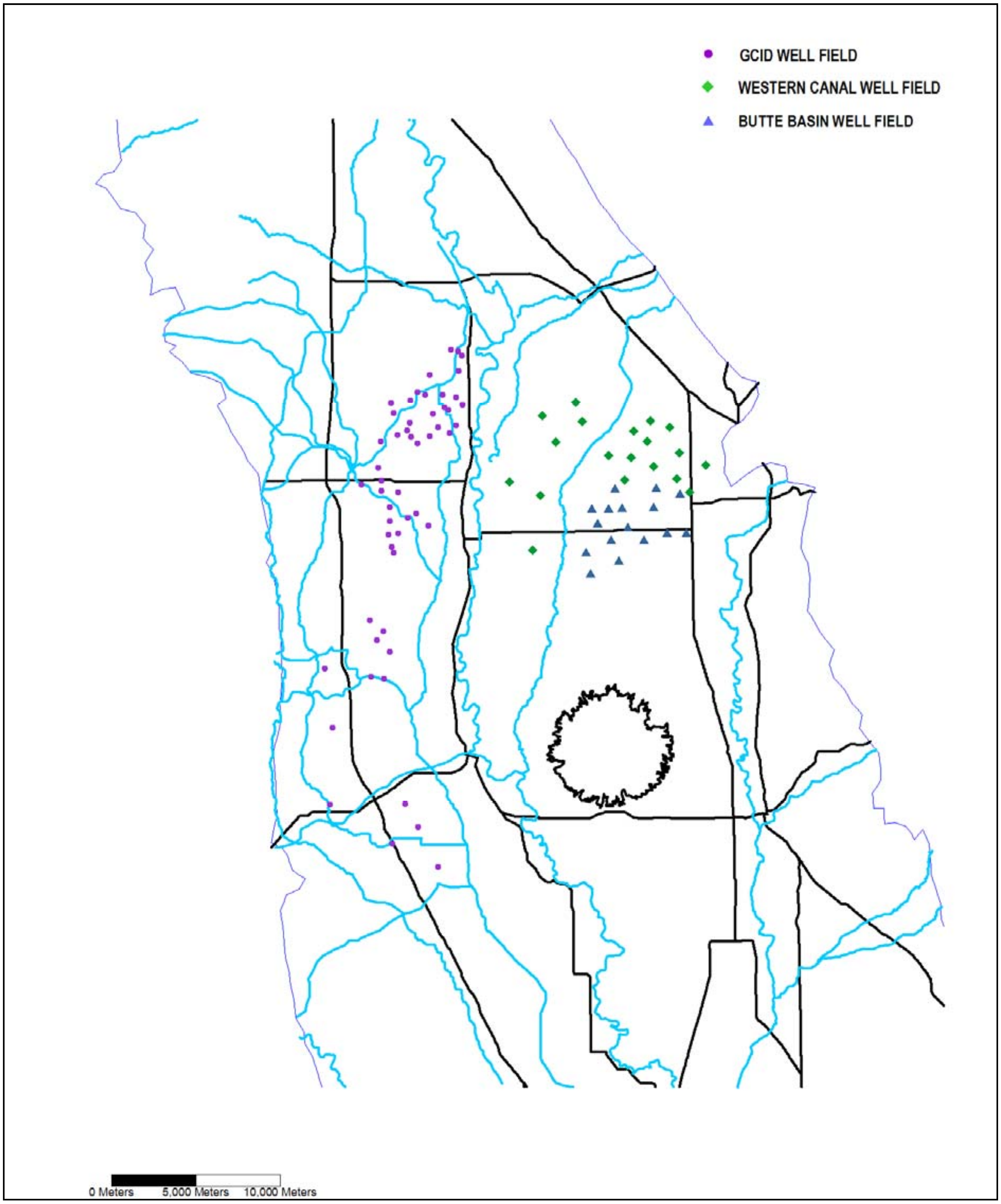

FIGURE 5-1
Existing Well Locations, 100 TAF GCID And 50 TAF RID and WCWD Well Field
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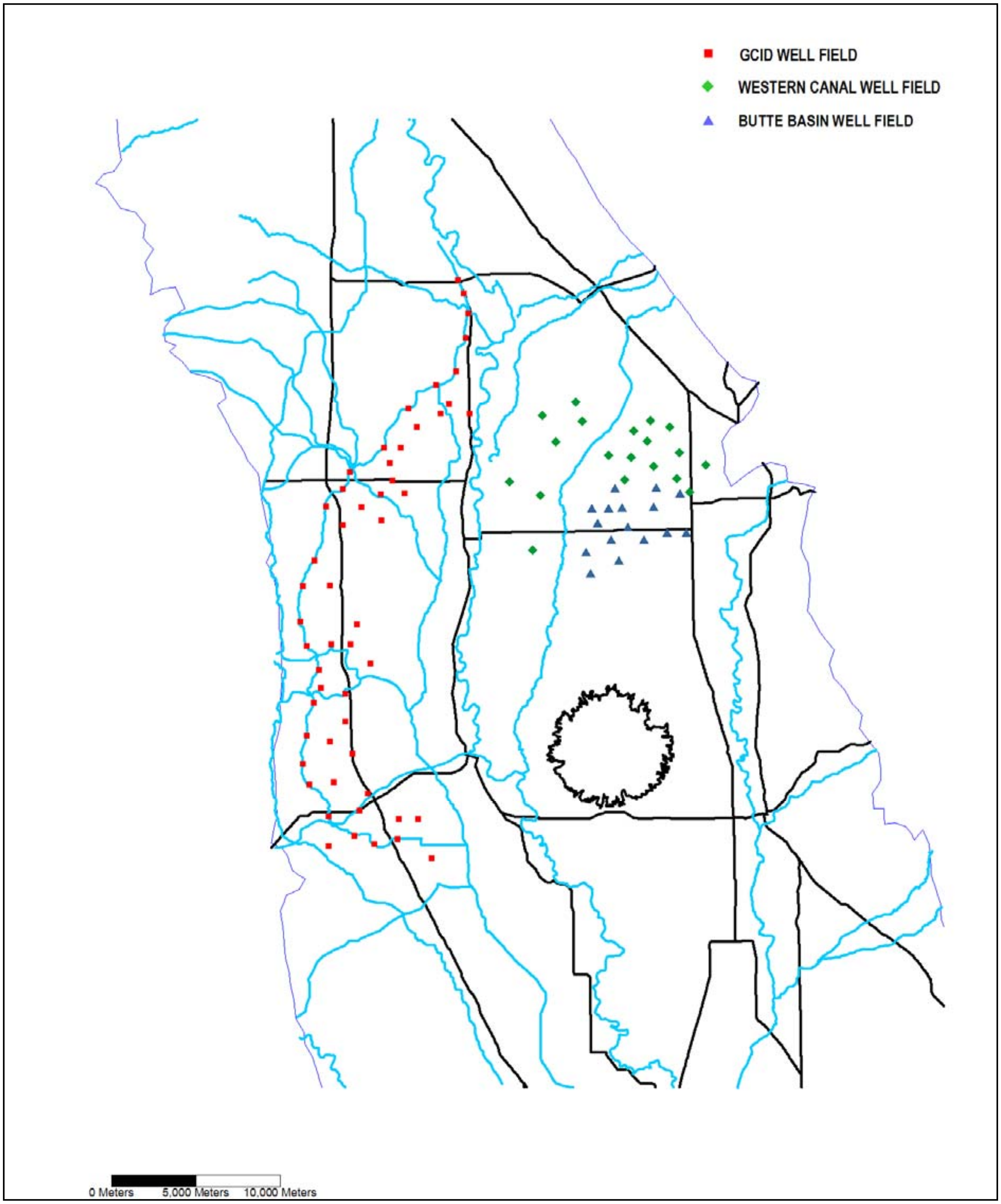

FIGURE 5-2
New Well Locations, 100 TAF GCID and 50 TAF Butte Basin Well Fields
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

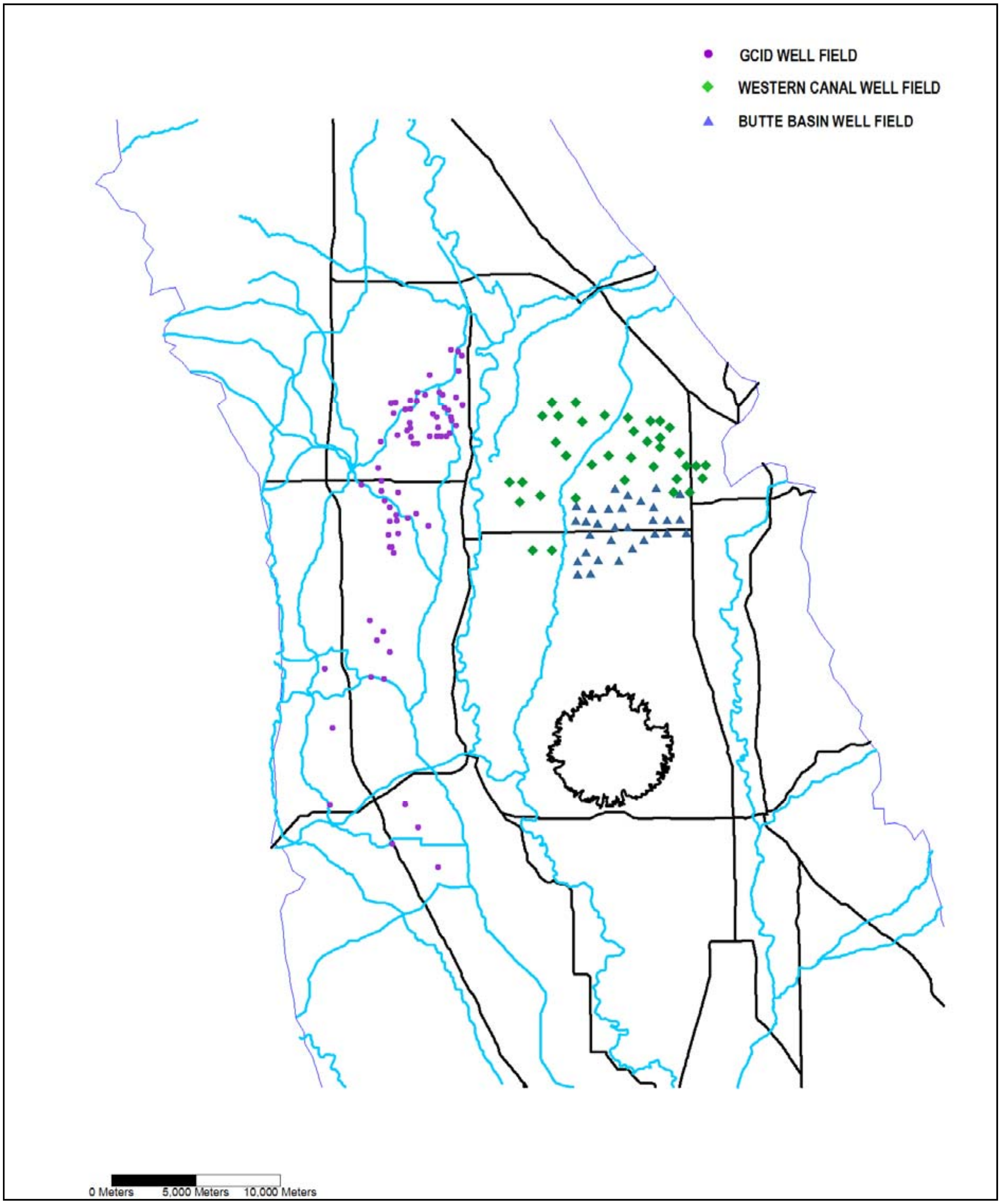

FIGURE 5-3
Existing Well Locations, 200 TAF GCID and 100 TAF Butte Basin Well Fields
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

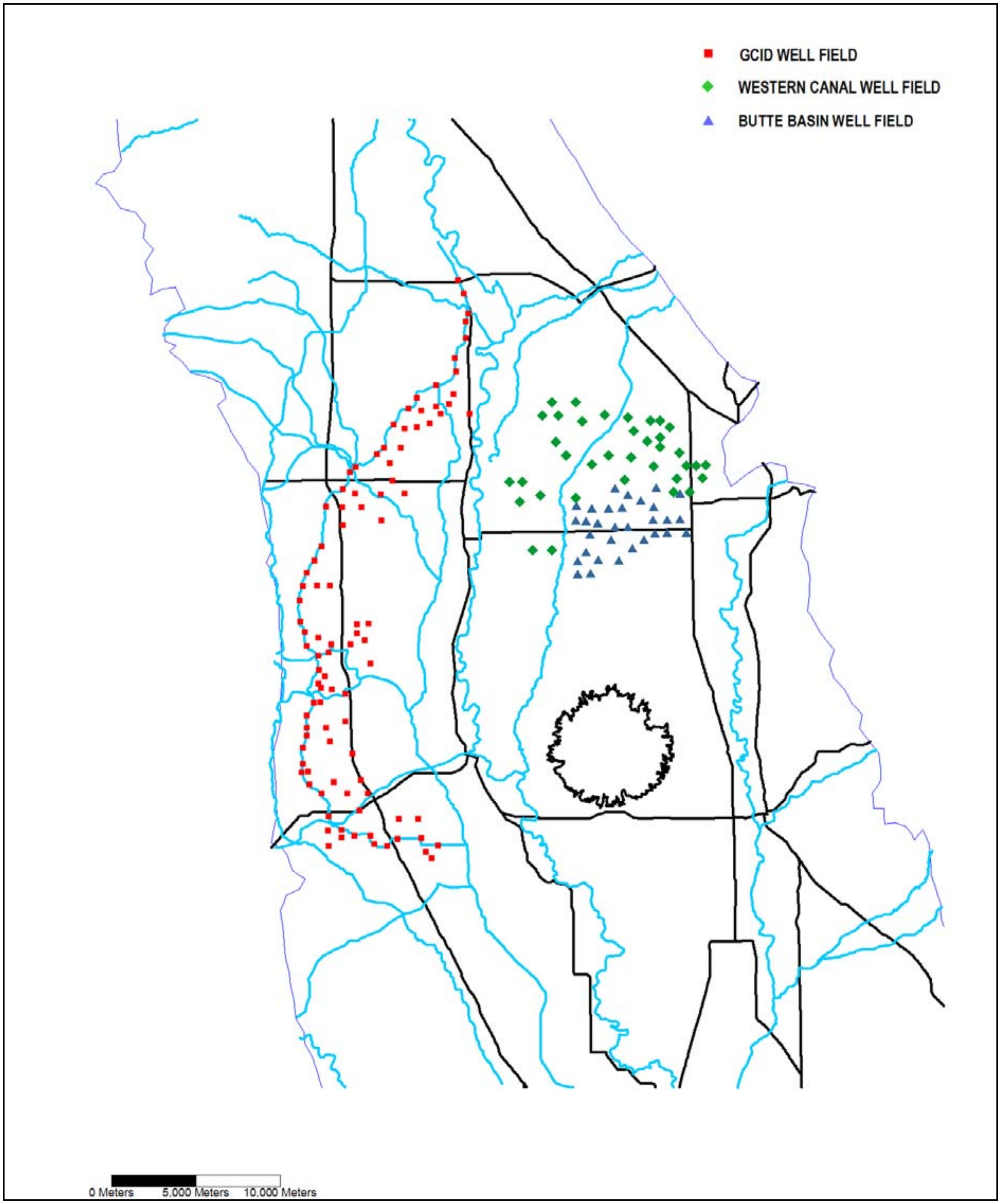

FIGURE 5-4
New Well Locations, 200 TAF GCID and 100 TAF Butte Basin Well Fields
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5.2.Initial Model Approach and Development

5.2.1. Overview

Formulating and evaluating potential conjunctive management projects requires simulation of both surface water and groundwater systems. Simulating the surface water system is necessary to determine when water is available to refill reservoirs and estimate unmet agricultural demands, environmental objectives, and flow conditions. A groundwater model is necessary to estimate the effects of additional pumping on aquifer systems, including the spatial extent and magnitude of drawdown and potential change in stream-aquifer interaction. Changes in stream-aquifer interactions may affect the surface water system, depending on stream conditions when the changes occur. For example, if additional pumping results in more stream loss to the aquifer or less aquifer contribution to stream flow during the winter season of relatively wet years when the surface water system has surplus flow, there may be little or no impact. However, if pumping reduces stream flow during months and years when the surface water system is being operated to meet specific flow or water quality requirements, any reduction in stream flow will require a corresponding increase in reservoir release to ensure the flow requirement continues to be met. This decreases the water supply benefit of conjunctive management projects. Evaluating this aspect of conjunctive management projects requires interaction between surface water and groundwater models.

The main tool used to evaluate alternative conjunctive management operations strategies and test alternative environmental flow thresholds and priorities is a spreadsheet-based surface water model (Figure 5-5). It is set up to simulate changes in operation of Lake Shasta and Lake Oroville relative to conditions depicted in a baseline CalSim II simulation of CVP and SWP operations. The CalSim II baseline provides time series of reservoir storage levels, stream flows, and water deliveries which are used by the surface water model. Conjunctive management operations are simulated and layered onto baseline operations based on user inputs, while maintaining compliance with existing CVP and SWP rules, regulation, and operations.

The surface water model is configured by defining target river flows through specification of environmental objectives and inputting other user-defined parameters, including groundwater (payback) pumping capacity, reservoir operations objectives and constraints and other factors. The groundwater model is not operated for each surface water model run because it is much more computationally intensive and takes much longer to run. Instead, the groundwater model was used to develop functions that describe general surface water-groundwater interactions. These functions reside in the surface water model and are used to account for increases in stream leakage caused by project pumping that must be offset by additional project releases under certain conditions. This approach allows quick testing and evaluation of alternative conjunctive operations scenarios without having to make matching groundwater model runs.

The groundwater model was used to evaluate the particular scenarios previously described with respect to changes in groundwater levels and stream leakages caused by additional groundwater pumping. This was done by simulating the time series of project pumping determined through the surface operations simulations in the groundwater model.

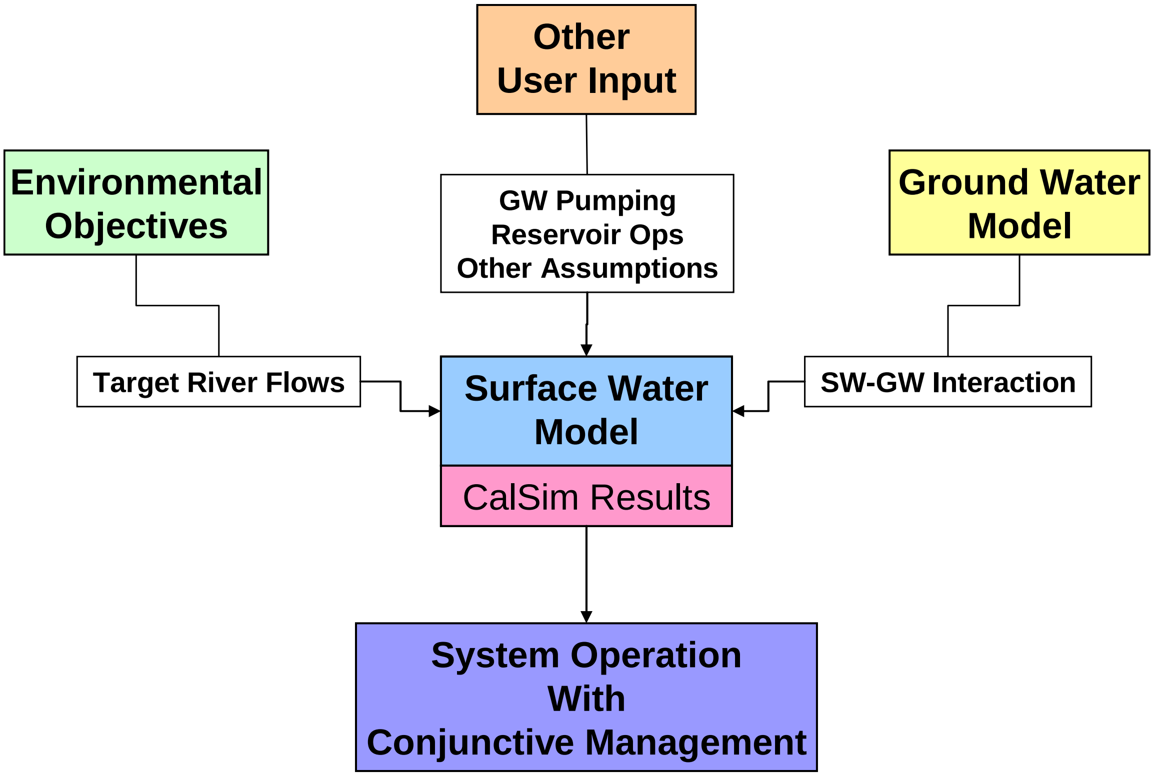

FIGURE 5-5
Surface Water Model Inputs and Operations
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5.2.2. Surface Water Model

The surface water model includes a forecast of fall storage conditions based on current reservoir storage, runoff forecasts, and an estimate of reservoir releases from the current month through September[13]. The model simulates risk associated with making decisions based on imperfect information. Runoff forecasts at different exceedance levels are used during the spring with more conservative forecasts, 99 or 90 percent exceedance, used in February and March, respectively. A method to estimate reservoir release volumes was developed for Shasta and Oroville by correlating simulated CalSim II releases with a system-wide CVP water supply index and SWP allocations, respectively. The CVP water supply index is the sum of current storage in Trinity, Shasta, Folsom, and CVP San Luis plus runoff forecasts on the Sacramento and American Rivers, plus Kings River flow to Mendota Pool. The CVP water supply index and runoff forecasts for the Sacramento, Feather, and American Rivers are the same as used in CalSim II for simulation of CVP/SWP operations. Initial correlations were developed and adjusted to balance how forecasted storage compared with CalSim II simulated storage across various year types.

The surface water model treats the groundwater system as a source of water and does not simulate groundwater flows or conditions. It does, however, include features to account for estimated effects of groundwater pumping on stream flow accretion and depletion through use of functions derived from

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[13] This methodology for forecasting fall reservoir storage was added as part of model refinements made in response to suggestions provided by CVP and SWP operators (see Section 6). For the initial analysis, the model used future (September) reservoir storage levels to make project operation decisions.

complementary simulations of pumping in the groundwater model. These functions provided a coarse but adequate representation of stream-aquifer interaction so that the surface water model could be used for gaming sessions without having to operate the groundwater model. Final scenarios were evaluated using actual changes in stream-aquifer interaction based on complimentary groundwater model simulations.

5.2.3. Groundwater Model

Numerous improvements were made to previously existing modeling tools, and new tools were developed for this analysis of conjunctive management projects. For the groundwater analysis, an existing simplified groundwater modeling tool was completely re-designed and improved, to yield a powerful analytical package now referred to as the Sacramento Valley Groundwater Model (SACFEM). The basis for the SACFEM model was a simplified superposition-based groundwater model previously developed to support the Sacramento Valley Water Management Program. That model represented a very simplified depiction of the Sacramento Valley aquifer system as no recharge components to the aquifer system (deep percolation of precipitation and applied water) or discharge components (regional agricultural pumping) were included, and therefore the model could only compute the incremental change in groundwater levels and streams flows during the irrigation season. It was assumed that the aquifer system fully re-filled every winter, and each year of pumping was independent of previous aquifer stresses.

The SACFEM model is a full water budget based transient groundwater flow model that incorporates all of the groundwater and surface water budget components on a monthly time step over the period of simulation. This model provides very high resolution estimates of groundwater level and streamflow effects due to conjunctive water management pumping across the valley.

The surface water model is a new tool designed specifically to analyze conjunctive management projects for agricultural and environmental benefits. Its flexibility for use in gaming sessions and for sensitivity and tradeoff analysis helped provide understanding of conjunctive management concepts, operations, and limitations.

The integration of surface water and groundwater modeling tools and the simulation of effects of additional groundwater pumping on the surface water system is a significant advancement over previous modeling tools. Simulation of changes in stream-aquifer interaction, the spatial and temporal variations in those changes, and conditions in the surface water system when changes occur are key components for evaluating conjunctive management projects and understanding their benefits and risks.

Development and calibration of the surface water and groundwater models used to develop and analyze the project scenarios is documented in detail in Appendix B.

5.2.4. Surface and Groundwater Model Interaction

As previously mentioned, evaluation of conjunctive management projects requires simulation of both surface water and aquifer systems. However, regional groundwater models with the needed level of refinement to adequately simulate pumping projects require run times that prohibit their use in gaming situations and for quickly evaluating multiple scenarios. Therefore, the surface water and groundwater model were used in an iterative fashion to simulate conjunctive management operations in both systems (see Figure 5-6).

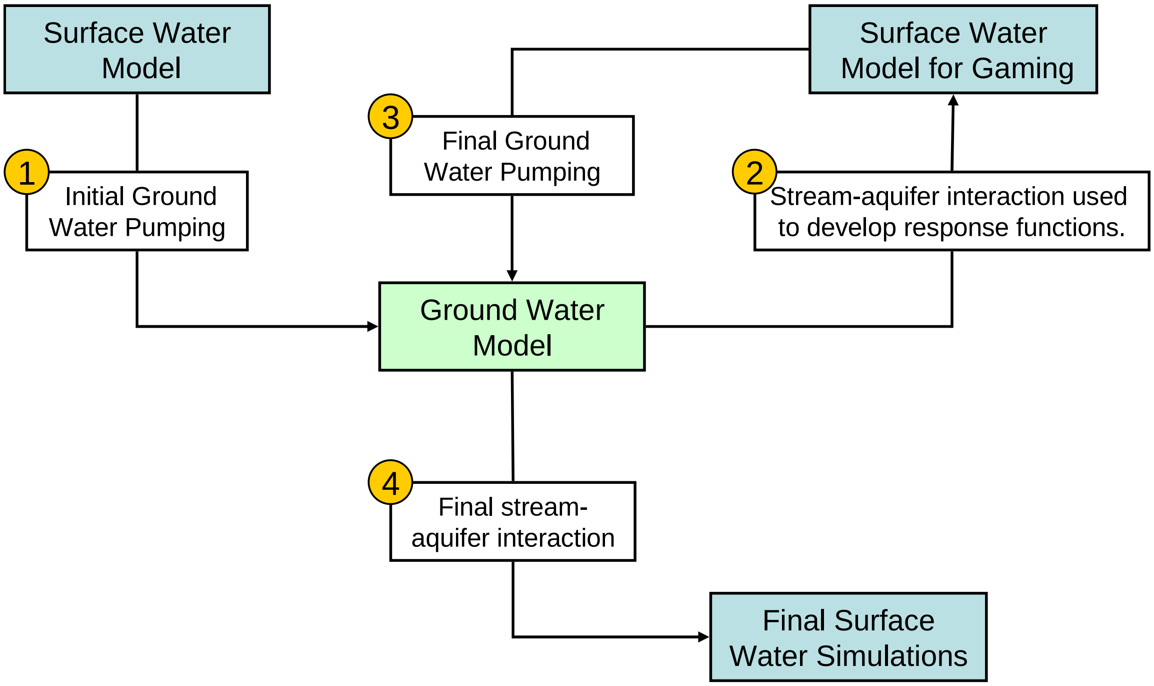

FIGURE 5-6
Surface Water and Groundwater Model Interaction
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

An initial surface water model was developed to simulate project operations and develop the time series of groundwater pumping at each project site. Pumping time series were simulated in the groundwater model and results were reviewed, including changes in stream-aquifer interactions. These initial changes were used to develop response functions for use in the gaming model to quickly approximate changes in stream-aquifer interaction when simulating various conjunctive management operations.

Response functions were used during the gaming sessions and when conducting tradeoff analyses to determine the final project scenarios. Pumping time series from the final project scenarios were then provided to the groundwater model for final simulation and resulting changes in stream-aquifer interactions associated with the pumping schedules were input back into the final surface water simulations.

5.2.5. Qualifications

Modeling analyses were performed at a planning level to help prove concepts and define conjunctive management projects and operations. Analyses were conducted for general projects, locations, and operations. More specific and refined analyses will be required as specific projects are defined. Most analysis was conducted in a comparative, rather than absolute, manner and results must be interpreted as such.

Additionally, mathematical modeling tools typically report results at a level of precision that exceeds their level of accuracy. For example, planning-level surface water models may provide estimates of water supply accurate to within a range of several thousand acre-feet, but results with a precision down to an acre-foot. Model results presented in subsequent sections are rounded to levels of precision appropriate for comparison with results from other scenarios. Planning-level modeling tools used in this analysis are not necessarily accurate to this level.

5.3. Performance of Initial Scenarios

The performance of each of the initial scenarios is summarized in this section in terms of the effects of project operations on the surface water system including reservoir storage, the frequency and magnitude of environmental flow and water supply releases and reservoir refill. Scenarios 1, 3 and 4 all have the same effects on the surface water system because they have the same payback pumping capacity. (Scenarios 1, 3 and 4 are differentiated by pumping season, not by pumping volume; therefore, each scenario has its unique effects on groundwater conditions.) Scenario 2 has different effects because it has a different payback capacity. The material presented here is also presented and discussed in greater detail in Appendix B.

5.3.1. Scenarios 1, 3 and 4 – Shasta Reservoir and Sacramento River

Scenarios 1, 3 and 4 are defined by maximum seasonal groundwater pumping capacities of 100 TAF in GCID and 50 TAF in the Butte Basin. Environmental objectives and unmet agricultural demands are as presented in preceding sections. The model first determines ability to meet environmental objectives and then uses remaining project assets to meet agricultural demands. Sensitivity to prioritization of environmental objectives and agricultural demands was evaluated and is explained in subsequent sections of this report.

The following series of plots summarize the annual operations with conjunctive management. The first series of plots summarize Sacramento River and Shasta Reservoir operations and the second series summarize Feather River and Oroville Reservoir operations. Plots are arranged in order of how operations occur each year. In winter and spring months, additional water is released from reservoirs to satisfy environmental objectives. During summer months additional water is released to meet agricultural demands. The result is that fall reservoir storage levels are lower than they would be under operations without conjunctive management projects, as shown on Figure 5-7. Reservoir storage space is typically refilled with surplus surface water during subsequent winter and spring periods. If reservoirs do not refill with surplus surface water and fall reservoir storage levels are forecasted to be low, reservoirs are refilled by pumping groundwater in conjunctive management projects and holding a similar volume of surface water in the reservoir.

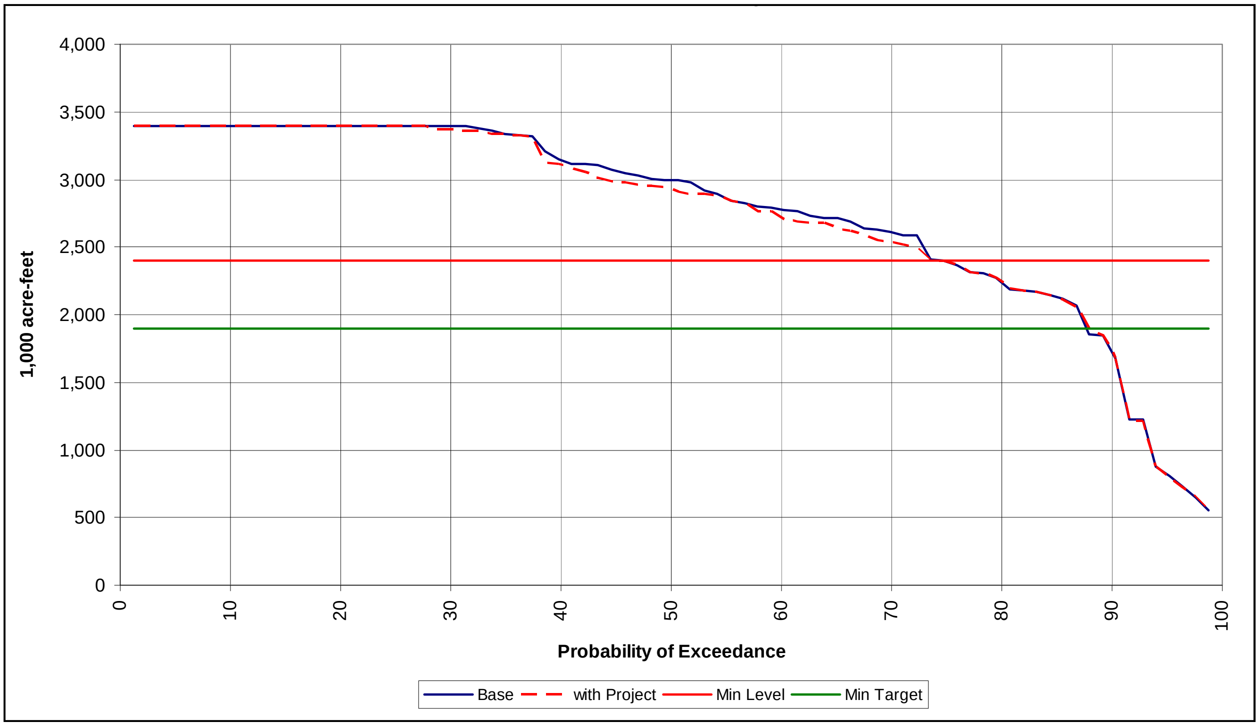

FIGURE 5-7
Shasta Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenarios 1, 3 and 4
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Figure 5-8 illustrates annual volumes of water released to satisfy various environmental objectives on the Sacramento River. Color-coded bars and the legend refer to relative priority of objectives in each year. For example, in 1928 the red bar indicates that water was released to meet objective 4, the lowest priority objective. The type of objective, either geomorphic (Geo), riparian recruitment (Rip), spring pulse (Spring), or flood plain inundation (Flood) is labeled above the corresponding bar. Geomorphic objectives are met most frequently due to lower water costs associated with the short duration objective. Average annual release for environmental objectives is 13 TAF.

Figure 5-8 shows only years when environmental objectives are met through project release. Environmental objectives are also met at times under existing (baseline) system operation. This information is summarized in Table 5-2. For the flood plain inundation objective, the project includes modifications to the Freemont Weir to allow inundation with less Sacramento River flow than is required under existing conditions. The existing Fremont Weir crest limits inundation of the Yolo Bypass for flows less than approximately 62,000 cfs. The project assumes it is possible to modify the weir to allow inundation with flows of approximately 35,000 cfs. Therefore this objective can be met by the project, either under base condition flows between 35,000 and 62,000 cfs (flows in excess of 62,000 cfs meet the objective in the base condition) or through additional reservoir release to create flows of approximately 35,000 cfs.

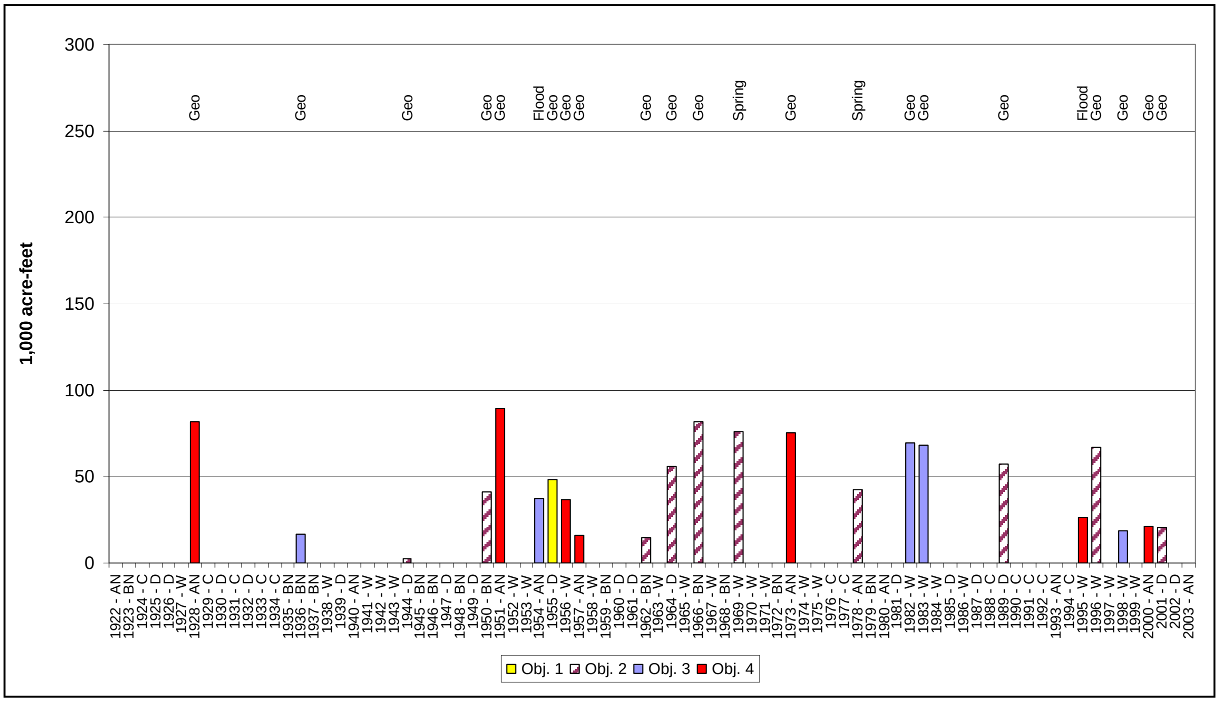

FIGURE 5-8
Sacramento River Environmental Objectives Met with Conjunctive Management, Scenarios 1, 3 And 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

TABLE 5-2
Number of Years Sacramento River Environmental Objectives are Met, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Objective	**Met with Base Conditions Flows**	**Met with Project Flows**	**Total**
Spring Pulse	5	2	7
Riparian Recruitment	0	0	0
Geomorphic	25	18	43
Flood Plain Inundation	21	20	41

Table 5-2 show the flood plain objective is met in 20 years with the project, though there are only 2 years with releases for this objective illustrated on Figure 5-8. This indicates that the objective was met with base condition flows between 35,000 and 62,000 cfs (without additional reservoir release) in 18 years.

In some years, an objective may be met with base condition flows either before or after it is met with project releases during that same year. Results presented in Table 5-2 account for these occurrences and assume the objective is met in the base condition to prevent double counting in any year. For example, Figure 5-8 shows that releases were sufficient to meet the geomorphic objective in 19 of the 82 years analyzed. However, in one year (1956) the objective was met both under base conditions and then simulated to be met through project release. Results presented in Table 5-2 only show this objective being met during base condition flows to prevent potential double counting.

Figure 5-9 illustrates annual releases from Shasta Reservoir to meet additional agricultural demand in the TCCA service area. Dashed lines show annual unmet contract supply from CalSim II results and green bars illustrate the portion of unmet contract supply satisfied with conjunctive management operations.

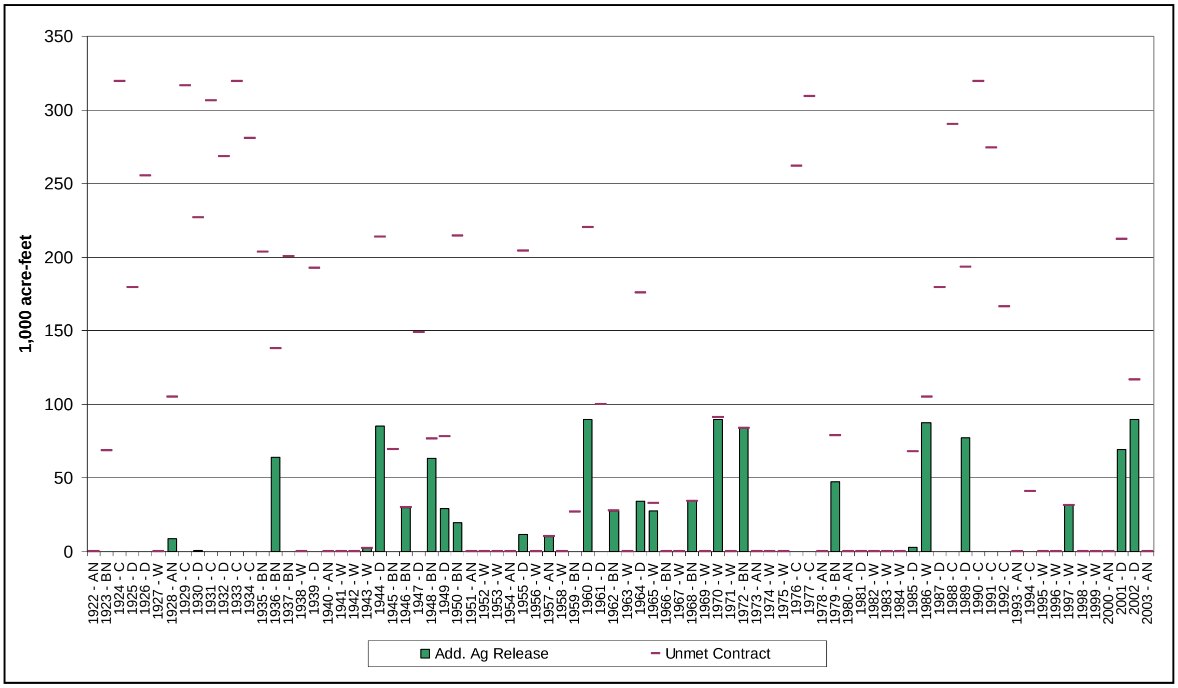

FIGURE 5-9
Sacramento River Additional Agricultural Demand Met with Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Additional agricultural releases are made in 24 of the 82 years simulated, or approximately 29 percent of the years. The average release in those years is 46 TAF, while the average annual agricultural delivery over the 82-year simulation period is 14 TAF.

Figure 5-9 illustrates that in many years when unmet contract supply for the TCCA is highest, there are no deliveries with conjunctive use. This is because in these years, project assets are typically low, either because fall reservoir storage is forecast to be low and no additional releases would be made or it is a Shasta Critical year and additional groundwater pumping for conjunctive management is assumed to be zero[14].

Additional reservoir releases for either environmental objectives or for additional agricultural delivery result in lower fall carryover storage in Lake Shasta. Figure 5-7 illustrates this with a probability of exceedance plot for end of September storage conditions. The solid blue line indicates fall storage conditions under base (without project) conditions. The red dashed line indicates conditions with conjunctive management. A solid red line at 2,400 TAF indicates the level when conjunctive management operations would not occur to limit the risk to cold water pool management in future years. Storage conditions below the solid green line at 1,900 TAF are when conjunctive management operations attempt to increase storage by pumping groundwater and holding water in Shasta above base levels[15].

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[14] Curtailment of project pumping in Shasta Critical years was imposed to avoid potential conflicts with the incremental groundwater pumping that typically occurs in those years as Sacramento River settlement contractors attempt to make up for water supply shortages.

[15] The Shasta Reservoir storage levels at which project pumping would be suspended for project purposes or would be invoked for purposes of sustaining Shasta storage are user defined values. Values of 2,400 TAF and 1,900 TAF for these parameters were established through parametric analyses and discussion with CVP operators.

Figure 5-7 illustrates that fall storage levels are lower in approximately 45 percent of the years and only when end of September storage is above 2,400 TAF. In wet years, when fall storage is at the flood control level of 3,400 TAF, releases in spring may refill in later months within the same year resulting in no change in fall storage conditions.

Figure 5-10 illustrates how storage deficits presented on Figure 5-7 are frequently refilled by the capture of surplus surface water. Surplus is water that would otherwise be released from the reservoir to maintain flood control storage and is not diverted downstream. This water is now stored in reservoir space created by making additional releases to meet agricultural and environmental objectives. Refill from surplus surface water occurs in 29 years with an average annual refill of 70 TAF in those years. Average annual refill with surplus surface water for the 82-year simulation is approximately 24 TAF.

In some years, following additional reservoir releases for agricultural and environmental objectives, there is no surplus surface water, and reservoir storage levels continue to decline putting future water supplies and cold water pool management at risk. In these years groundwater pumping in the conjunctive management projects is used to recover reservoir storage levels. Figure 5-11 illustrates this annual pumping. Conjunctive management pumping occurs in 4 of the 82 years simulated, or 5 percent of years. The average annual pumping in those years is 70 TAF. The average annual pumping for the entire 82-year simulation is approximately 3 TAF with a maximum annual pumping of nearly the full 100 TAF of payback capacity. Pumping typically occurs in drier year types when reservoirs do not refill with surplus surface water.

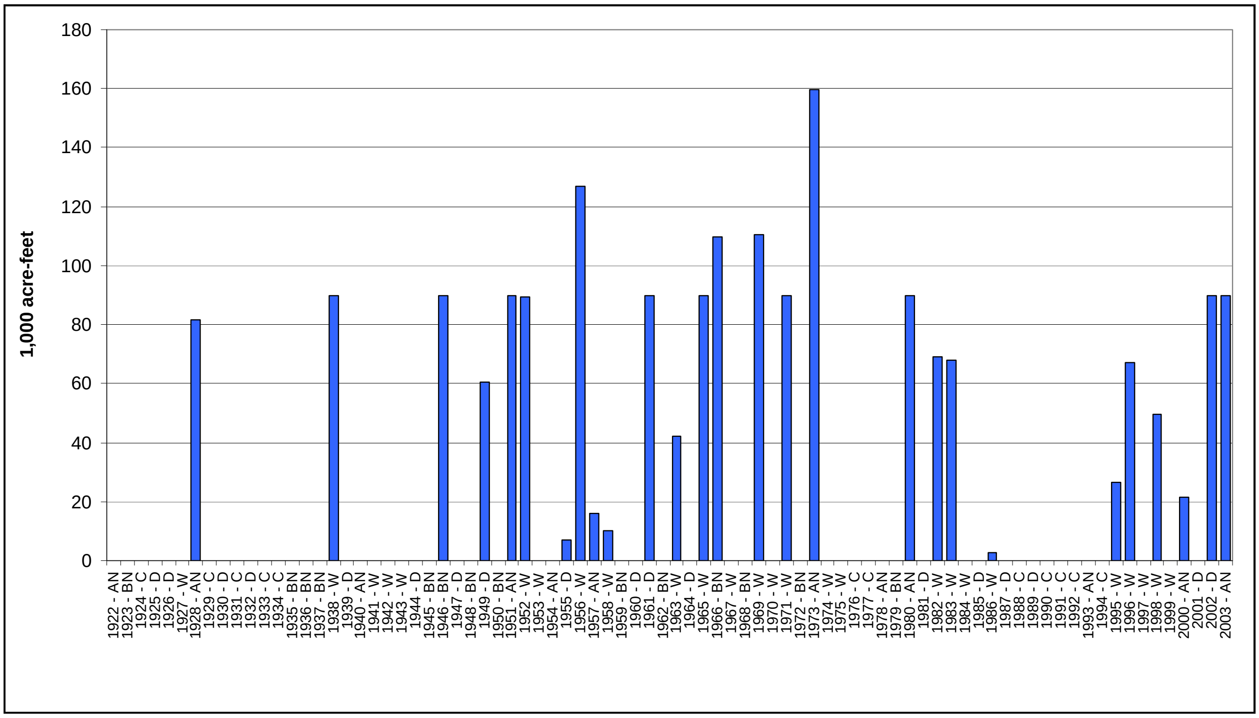

FIGURE 5-10
Refill of Shasta Reservoir from Surplus Surface Water, Scenarios 1, 3 And 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

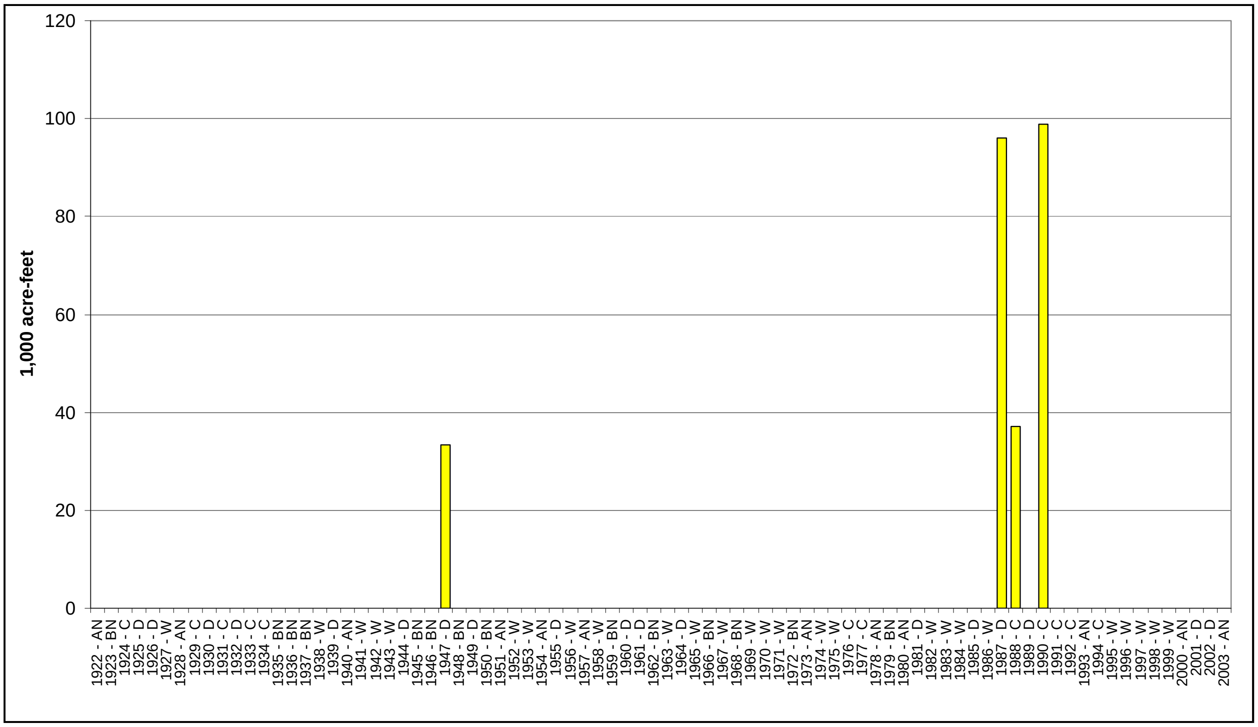

FIGURE 5-11
Refill of Shasta Reservoir from Conjunctive Management Pumping, Scenarios 1, 3 And 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Over the 82-year simulation period, additional reservoir releases are made in 37 years, or 45 percent of the years. Reservoir refill is accomplished with surplus surface flows in 29 years and with project pumping in 4 years. The number of years with additional releases exceeds the number of years with refill because reservoir storage deficits do not have to be completely refilled before making additional releases, as long as the total reservoir storage deficit does not exceed the capacity of the project to refill the reservoir in a single year. Of the total average annual additional releases of 27 TAF (14 TAF for agriculture and 13 TAF for environmental objectives), 24 TAF is refilled from surplus surface water and 3 TAF from conjunctive management pumping. Over the 82-year period of analysis, a total of 1,148 TAF would be delivered to satisfy agricultural demands that would otherwise be met from groundwater pumping. Over the same period, the total volume of project pumping required for reservoir payback would be just 246 TAF. Thus, conjunctive operations would result in a net gain to the groundwater system of more than 900 TAF over the analysis period.

5.3.2. Scenarios 1, 3 and 4 – Oroville Reservoir and Feather River

Figure 5-12 illustrates annual volumes of water released to meet environmental objectives on the Feather River. Hydrology and operations on the Feather River result in meeting different objectives in different years compared to the Sacramento River. Similar to the Sacramento River operations, the geomorphic objective is satisfied most frequently due to lower water cost associated with meeting the shorter duration objective. Average annual release for environmental objectives on the Feather River is 7 TAF.

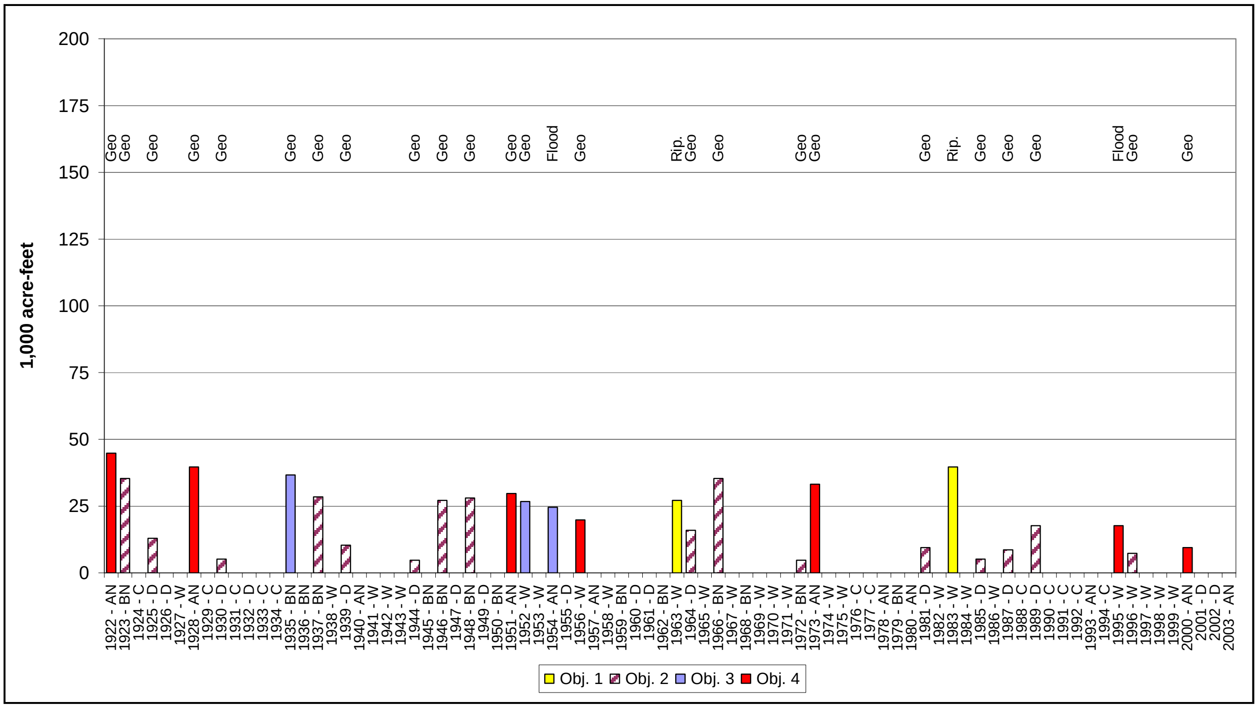

FIGURE 5-12
Feather River Environmental Objectives Met With Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Table 5-3 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on 5-12. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

Table 5-3
Number of Years Feather River Environmental Objectives are Met, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Objective	Met in Base	Met with Project	Total
Spring Pulse	3	0	3
Riparian Recruitment	1	2	3
Geomorphic	31	17	48
Flood Plain Inundation	21	20	41

Figure 5-13 illustrates additional agricultural deliveries possible with conjunctive management on the Feather River. Dashed lines relate to assumed unmet demands within the Feather River basin and correspond to the Sacramento Valley Index. Similar to operations on the Sacramento River, project assets do not allow additional releases for either environmental or agricultural objectives during drier year types when agricultural demands are higher. Additional agricultural releases are made in 30 of the 82 years simulated, or approximately 37 percent of the years. The average release in those years is 27 TAF, while the average annual agricultural delivery over the 82-year simulation period is 10 TAF.

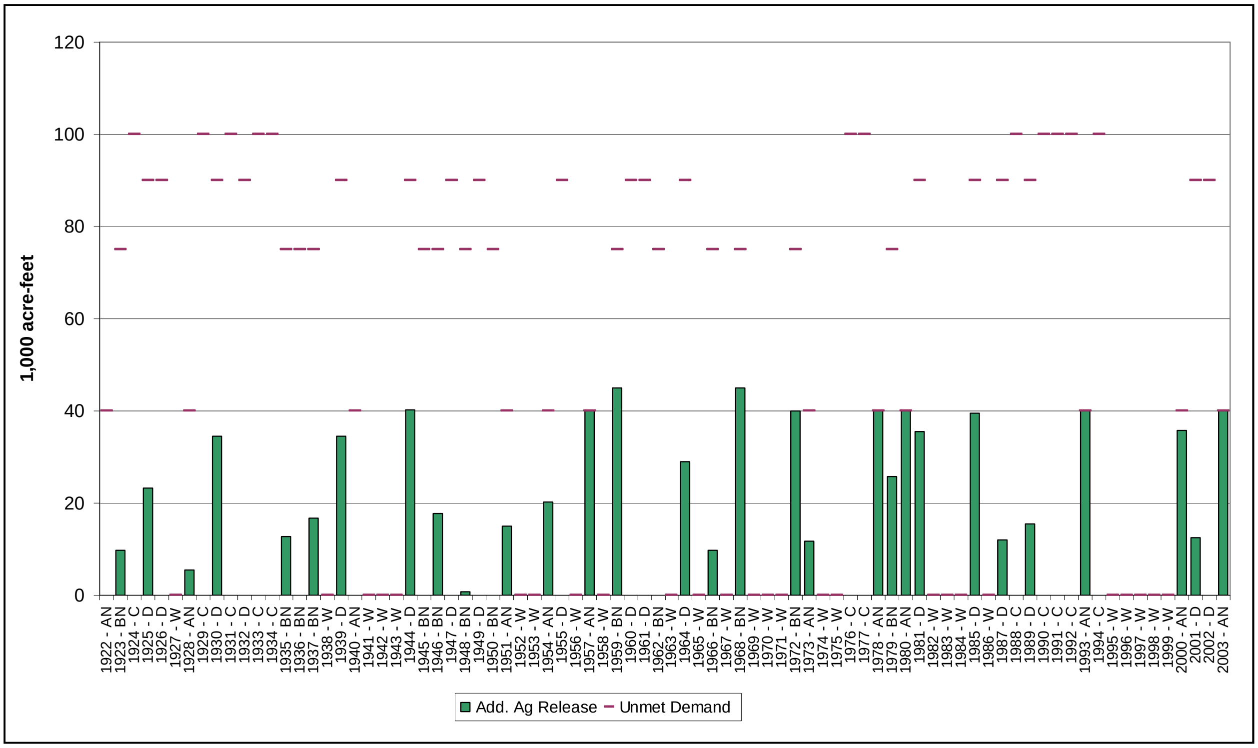

FIGURE 5-13
Feather River Additional Agricultural Demand Met with Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Figure 5-14 illustrates how conjunctive management operations result in slightly lower Oroville Reservoir fall storage conditions in approximately 60 percent of the years. Fall storage is not affected below the minimum level of 1,500 TAF. The solid green line at 1,200 TAF denotes target storage for cold water pool management when conjunctive management may be used to increase storage.

Figure 5-15 shows how storage space created in Oroville Reservoir through additional releases for agricultural and environmental objectives is frequently refilled with surplus surface water. Refill from surplus surface water occurs in 37 years with an average annual refill of 32 TAF in those years. The average annual refill with surplus for the 82-year simulation period is 14 TAF.

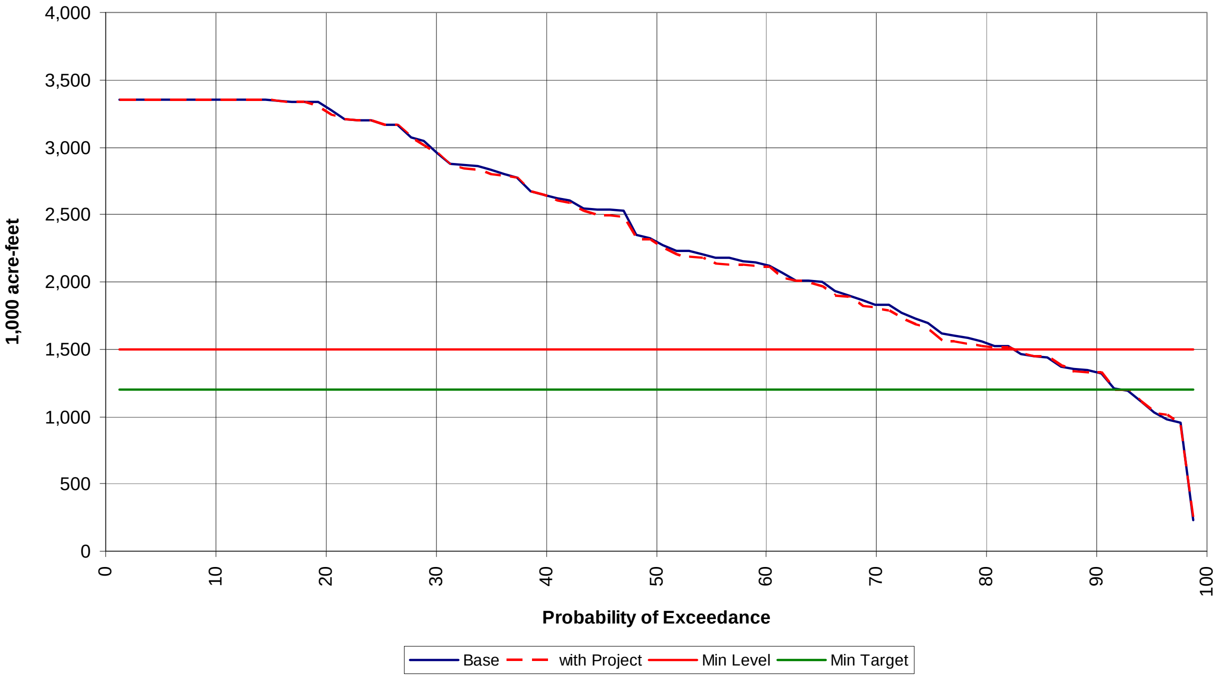

FIGURE 5-14

Oroville Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenarios 1, 3 and 4

Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

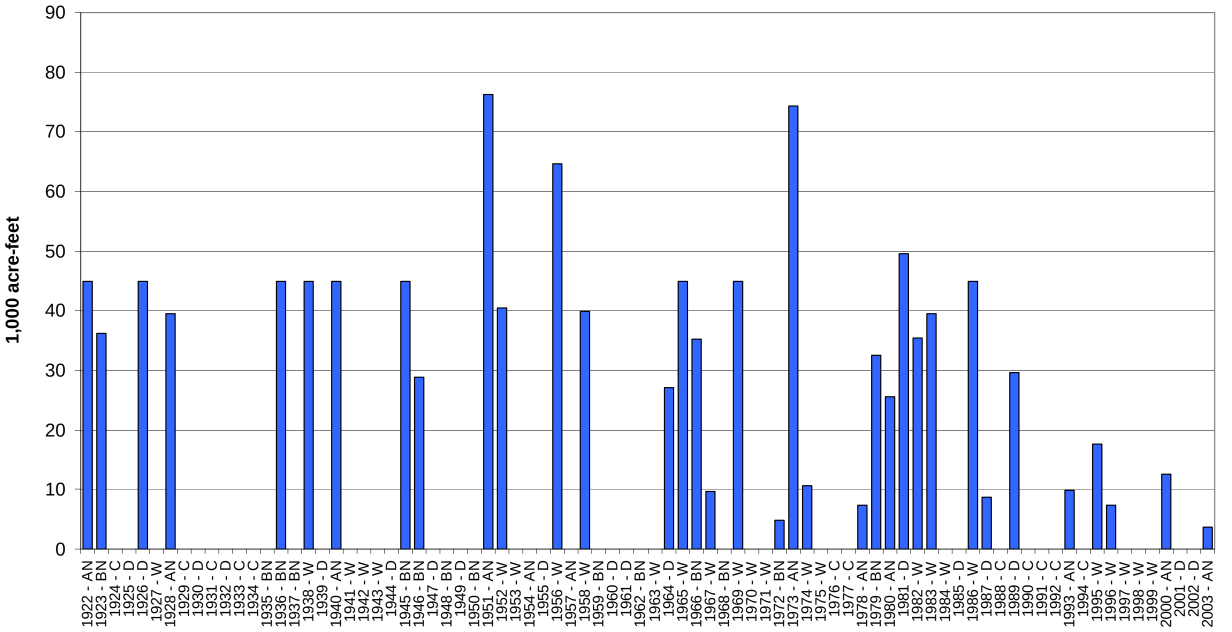

FIGURE 5-15

Refill of Oroville Reservoir from Surplus Surface Water, Scenarios 1, 3 and 4

Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Figure 5-16 presents annual conjunctive management pumping in the Butte Basin project. Conjunctive management pumping occurs in 6 of the 82 years simulated or 7 percent of the years. The average annual pumping in those years is 44 TAF. The average annual pumping for the entire 82-year simulation is approximately 3 TAF with a maximum annual pumping of the full 50 TAF of pumping capacity.

Over the 82-year simulation period, additional reservoir releases are made in 37 years, or 45 percent of the years. Reservoir refill is accomplished with surplus surface flows in 37 years and with project pumping in 6 years. The number of years with refill exceeds the number of years with additional release because reservoir storage deficits may not completely refill in a single year, but instead refill over the course of several years. In summary, of total average annual additional releases of 17 TAF (10 TAF for agriculture and 7 TAF for environmental objectives), 14 TAF is refilled from surplus surface water and 3 TAF from conjunctive management pumping. Over the 82-year period of analysis, a total of 820 TAF would be delivered to satisfy agricultural demands that would otherwise be met from groundwater pumping. Over the same period, the total volume of project pumping required for reservoir payback would be just 246 TAF. Thus, conjunctive operations would result in a net gain to the groundwater system of 574 TAF over the analysis period.

5.3.3. Scenario2 – Shasta Reservoir and Sacramento River

Scenario 2 is defined by maximum seasonal pumping capacities of 200 TAF in GCID and 100 TAF in the Butte Basin. This scenario is the same as Scenarios 1, 3 and 4 with respect to environmental and water supply objectives and operating constraints, but with twice the pumping capacity.

Figure 5-17 illustrates annual volumes of water released to satisfy various environmental objectives on the Sacramento River. The geomorphic objective is met most frequently due to lower water cost associated with the short duration, but the larger pumping capacity increases project assets and allows other objectives to be met more frequently than in Scenario 1. Additionally, in some years more than one objective may be met as indicated by stacked bars. Average annual release for environmental objectives under Scenario 2 is 45 TAF.

Figure 5-17 shows only years when environmental objectives are met through project release. Environmental objectives may also be met under the base operations of the system.

Table 5-4 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Sacramento River. Values reported in the table for the geomorphic objective only include those years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 5-17. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

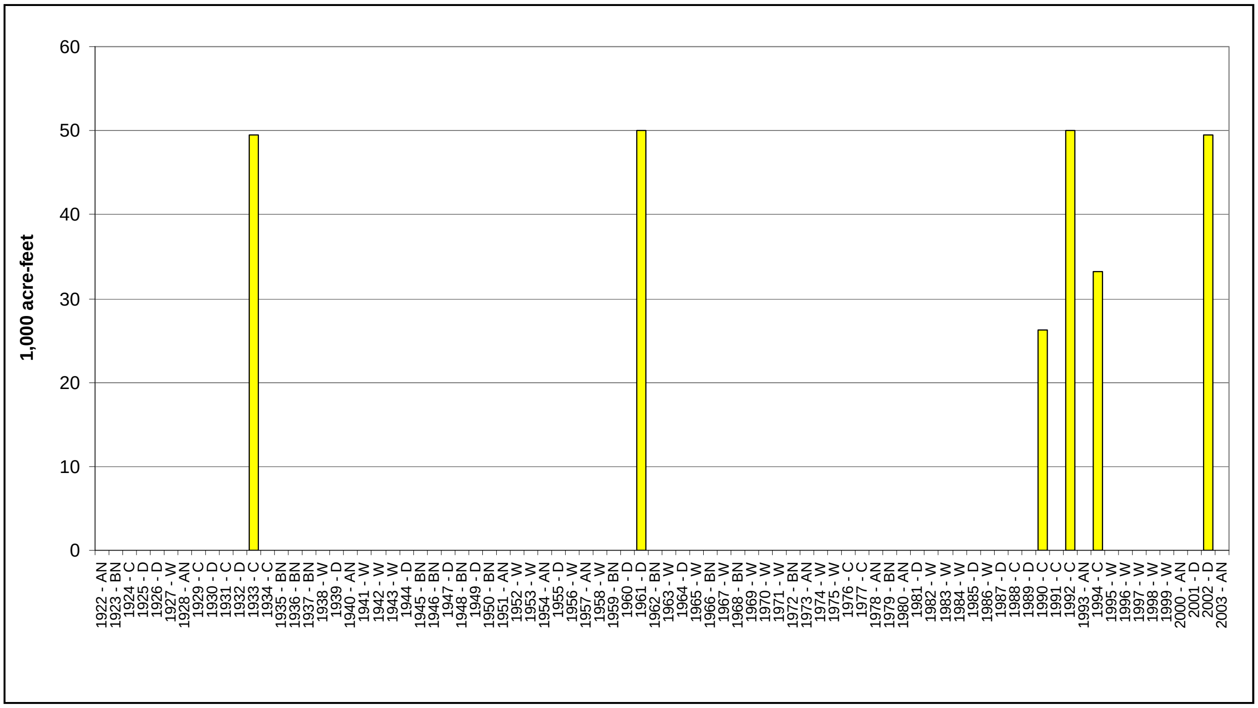

FIGURE 5-16
Refill of Oroville Reservoir from Conjunctive Management Pumping, Scenario 1
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

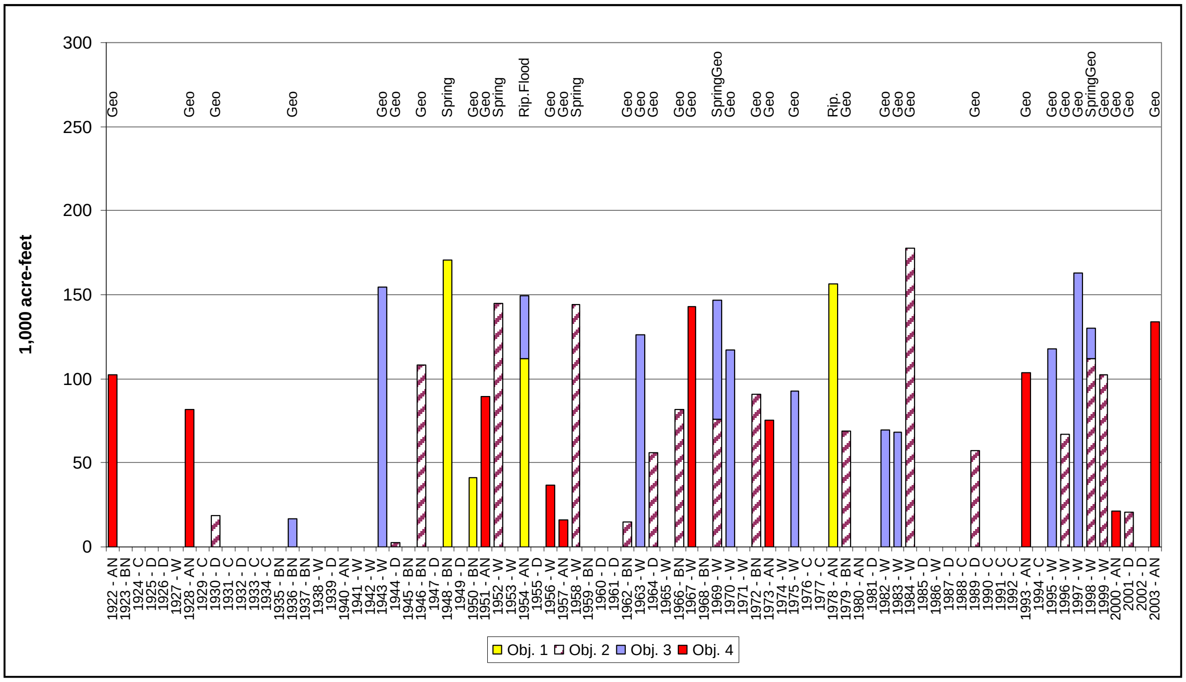

FIGURE 5-17
Sacramento River Environmental Objectives Met With Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

TABLE 5-4
Number of Years Sacramento River Environmental Objectives Are Met, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Objective	Met in Base	Met with Project	Total
Spring Pulse	5	5	10
Riparian Recruitment	0	2	2
Geomorphic	25	30	55
Flood Plain Inundation	21	20	41

Figure 5-18 illustrates annual release from Shasta to meet additional agricultural demand in the TCCA service area. Additional agricultural releases are made in 24 of the 82 years simulated, or approximately 29 percent of the years. The average release in those years is 75 TAF, while the average annual agricultural delivery over the 82-year simulation period is 22 TAF. Additional agricultural deliveries are made in many of the same years as in Scenario 1, but at higher volumes.

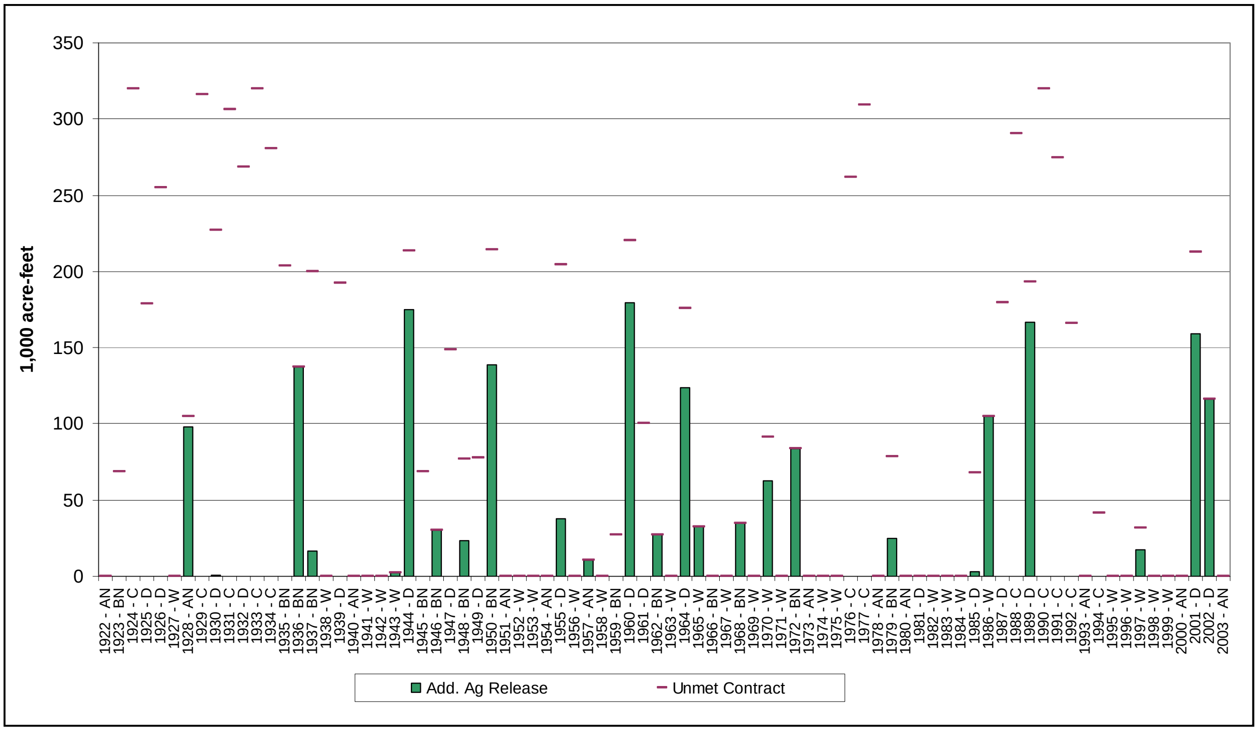

FIGURE 5-18
Sacramento River Additional Agricultural Demand Met With Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Additional reservoir releases for either environmental objectives or for additional agricultural delivery result in lower fall carryover storage in Lake Shasta. Figure 5-19 illustrates that fall storage levels are lower in approximately 45 percent of the years and only when end of September storage is more than 2,400 TAF. During these years fall storages are lower compared to Scenario 1 because larger pumping capacity allows for more aggressive operation of the reservoir. Additionally, a small increase in fall storage below the 1,900 TAF target may also be possible.

Figure 5-20 illustrates how storage deficits presented on Figure 5-19 are frequently refilled by capture of surplus surface water. Refill with surplus surface water occurs in 35 years with an average annual refill of 139 TAF in those years. Average annual refill with surplus surface water for the 82-year simulation is approximately 58 TAF.

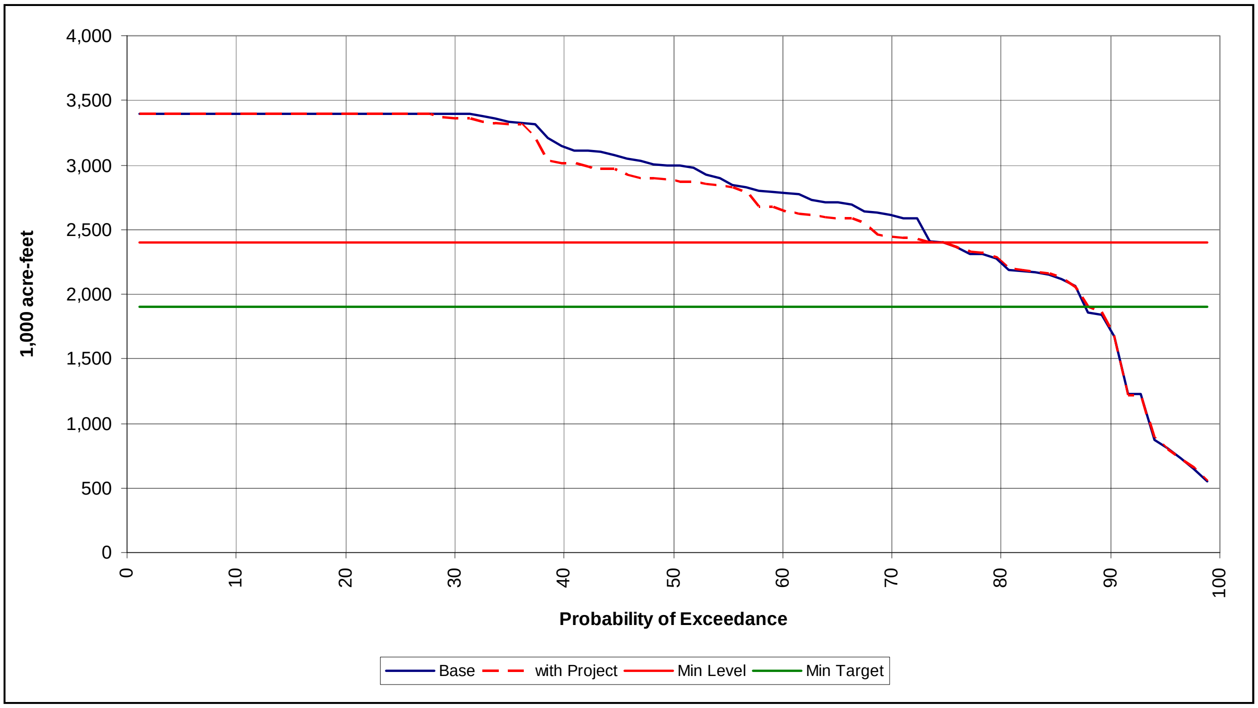

FIGURE 5-19
Shasta Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

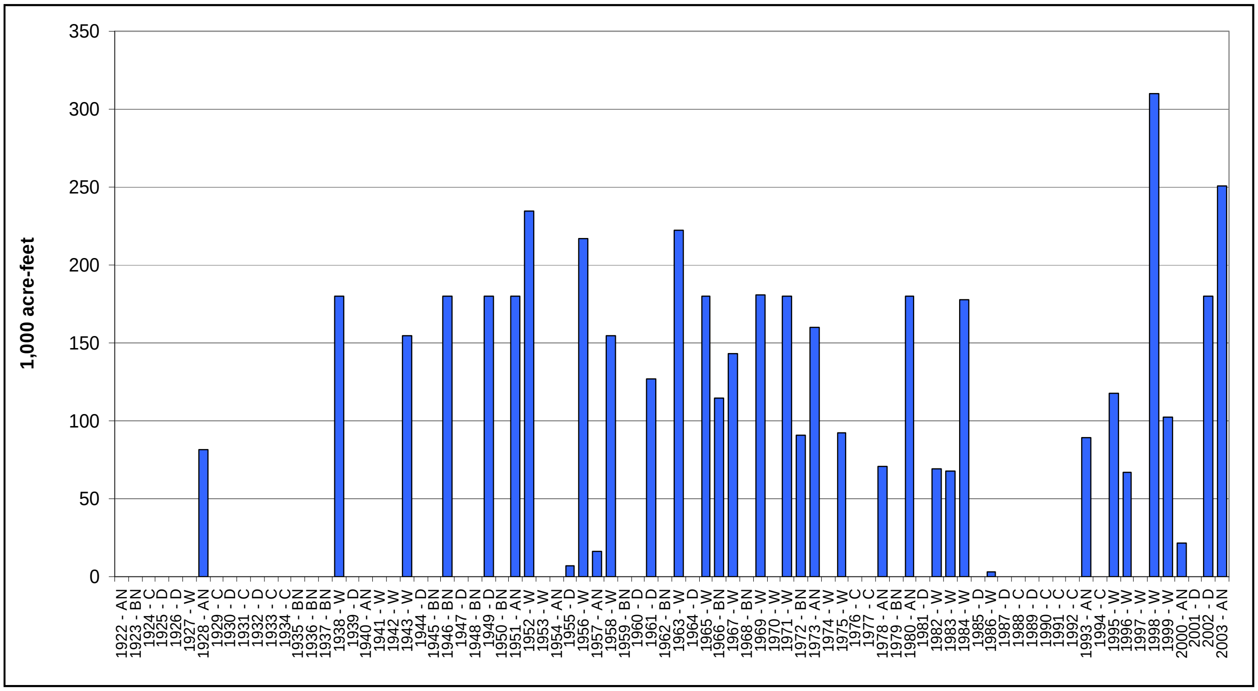

FIGURE 5-20
Refill of Shasta Reservoir from Surplus Surface Water, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Figure 5-21 illustrates annual conjunctive management groundwater pumping for Scenario 2. Conjunctive management pumping occurs in 6 of the 82 years simulated, or 7 percent of years. The average annual pumping in those years is 123 TAF. The average annual pumping for the entire 82-year simulation is approximately 9 TAF with a maximum annual pumping of nearly the full 200 TAF of capacity. Pumping typically occurs in drier year types when reservoirs do not refill with surplus surface water.

Over the 82-year simulation period, additional reservoir releases are made in 48 years, or 59 percent of the years. Reservoir refill is accomplished with surplus surface flows in 35 years and with project pumping in 6 years. The number of years with releases exceeds the number of years with refill because reservoir storage deficits do not have to be completely refilled before making additional releases, as long as the total reservoir storage deficit does not exceed the capacity of the project to refill the reservoir in a single year. In summary, of total average annual additional releases of 67 TAF (22 TAF for agriculture and 45 TAF for environmental objectives), 58 TAF is refilled from surplus surface water and 9 TAF from conjunctive management pumping. Over the 82-year period of analysis, a total of 1,804 TAF would be delivered to satisfy agricultural demands that would otherwise be met from groundwater pumping. Over the same period, the total volume of project pumping required for reservoir payback would be just 738 TAF. Thus, conjunctive operations would result in a net gain to the groundwater system of 1,066 TAF over the analysis period.

5.3.4. Scenario 2 – Oroville Reservoir and Feather River

Figure 5-22 illustrates annual volumes of water released to meet environmental objectives on the Feather River. Similar to the Sacramento River operations, the geomorphic objective is satisfied most frequently, but increased groundwater pumping capacity allows for more aggressive reservoir operations allowing other objectives to also be satisfied. Average annual release for environmental objectives on the Feather River is 23 TAF.

Table 5-5 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include those years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 5-22. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

Figure 5-23 illustrates additional agricultural deliveries under Scenario 2. Additional agricultural releases are made in 30 of the 82 years simulated, or approximately 37 percent of the years. The average annual release in those years is 52 TAF, while the average annual agricultural delivery over the 82-year simulation period is 20 TAF.

Figure 5-24 illustrates how conjunctive management operations result in lower Oroville fall storage conditions in approximately 60 percent of the years. Fall storage may be increased in a few years when it is below the minimum target level of 1,200 TAF.

Figure 5-25 shows how storage space created in Oroville Reservoir through additional releases for agricultural and environmental objectives is frequently refilled with surplus surface water. This occurs in 43 years with an average annual refill of 72 TAF in those years. Average annual refill with surplus for the 82-year simulation period is approximately 36 TAF.

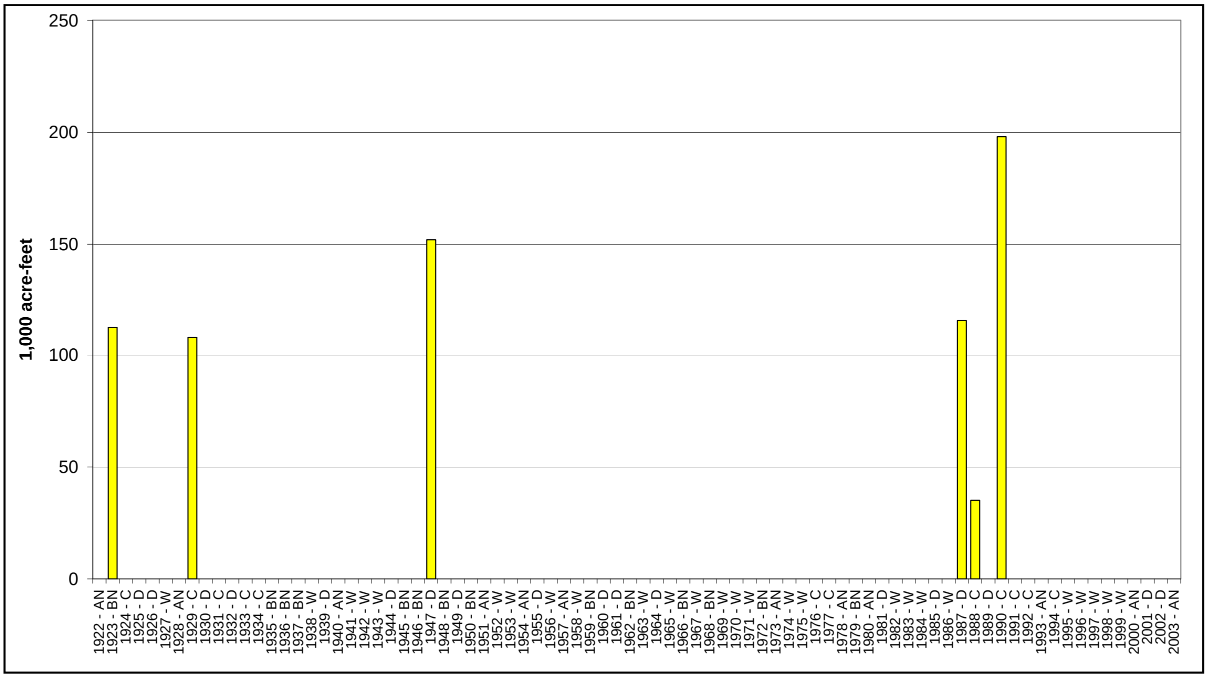

FIGURE 5-21
Refill of Shasta Reservoir from Conjunctive Management Pumping, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

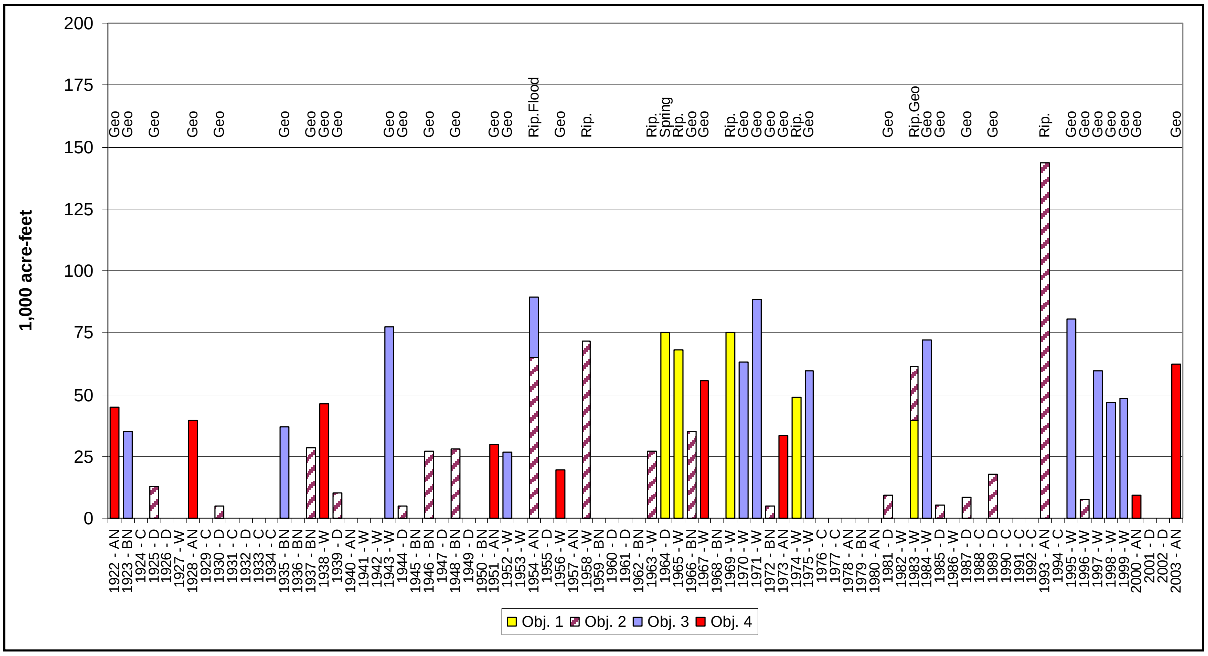

FIGURE 5-22
Feather River Environmental Objectives Met With Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

TABLE 5-5
Number of Years Feather River Environmental Objectives are Met, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Objective	**Met in Base**	**Met with Project**	**Total**
Spring Pulse	3	1	4
Riparian Recruitment	1	8	9
Geomorphic	31	25	56
Flood Plain Inundation	21	20	41

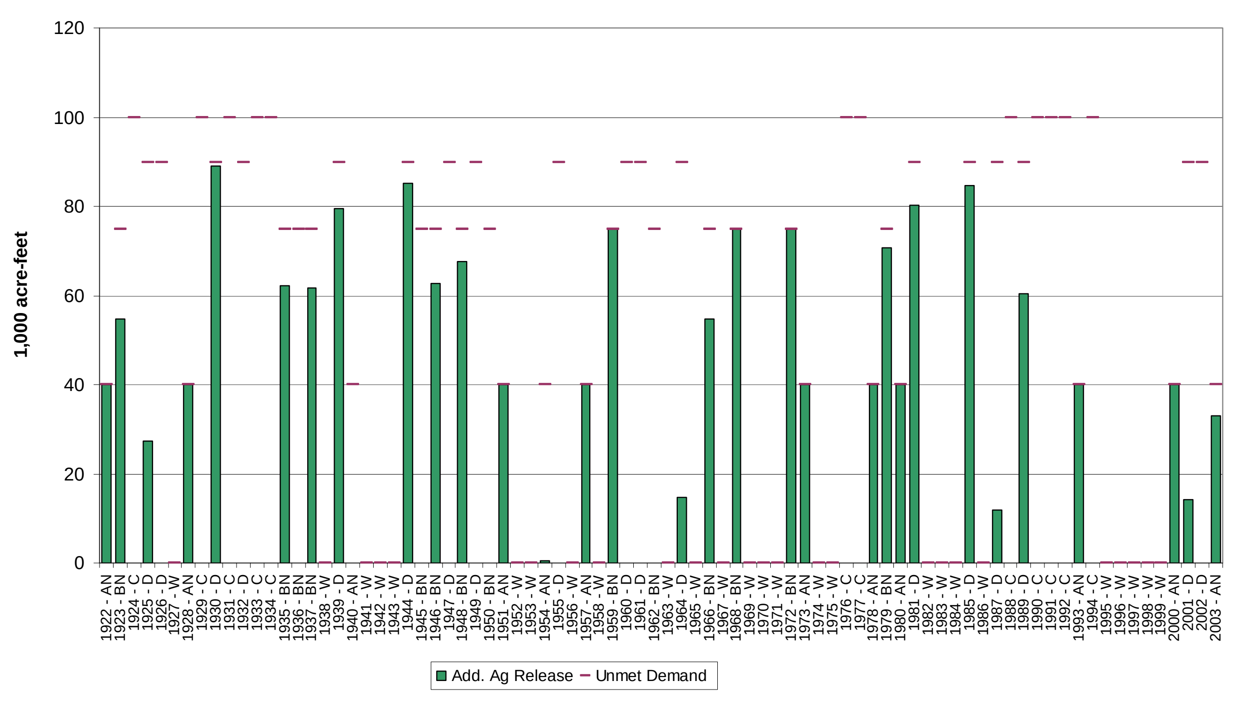

FIGURE 5-23
Feather River Additional Agricultural Demand Met with Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

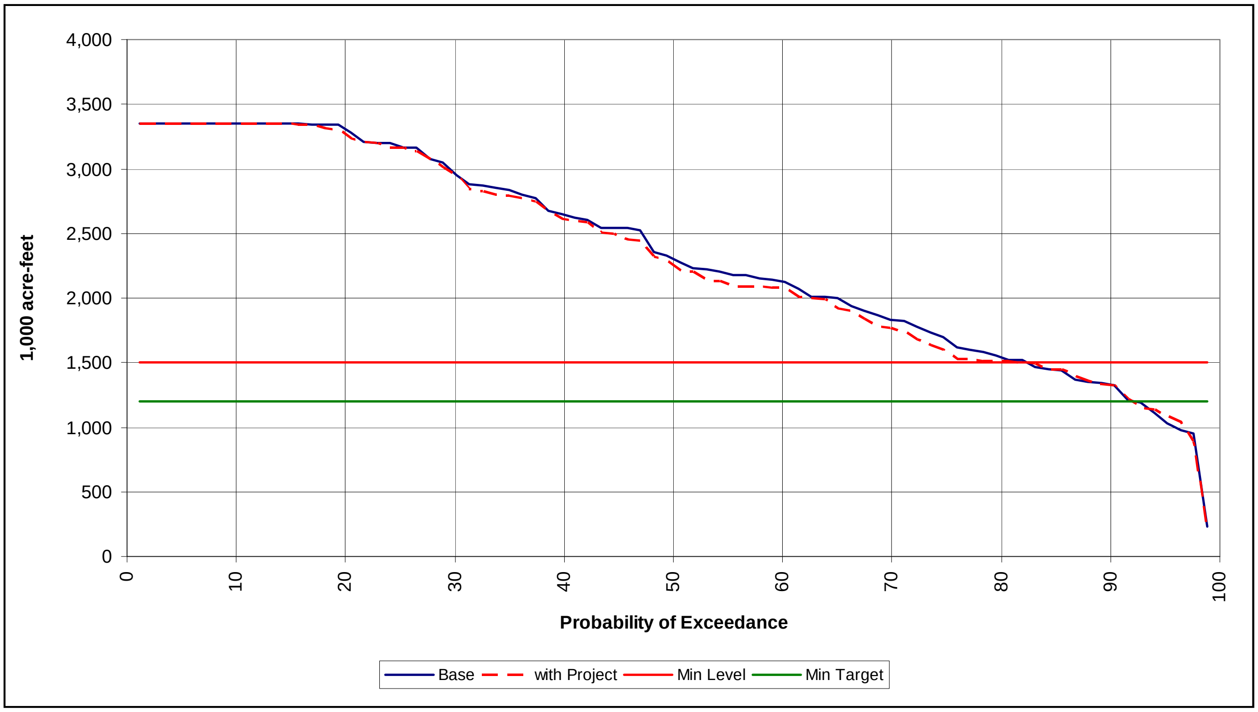

FIGURE 5-24
Oroville Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

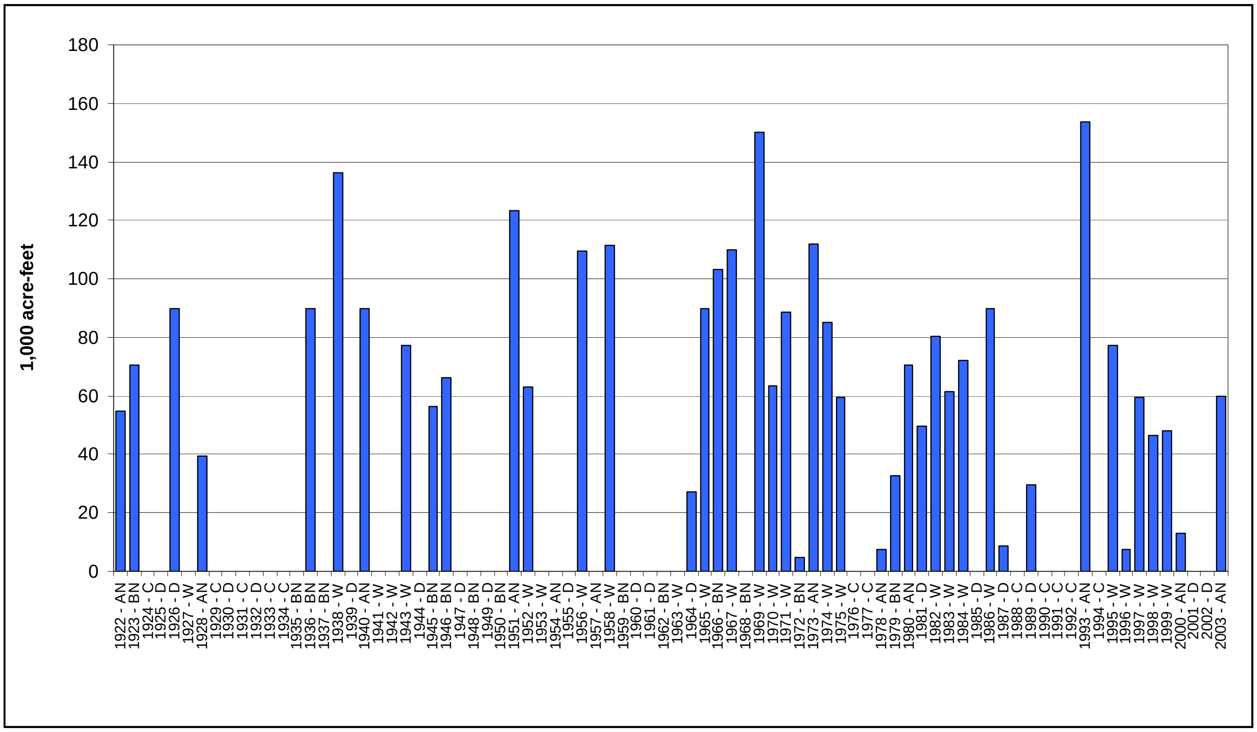

FIGURE 5-25
Refill of Oroville Reservoir from Surplus Surface Water, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Figure 5.26 presents the annual conjunctive management pumping in the Butte Basin project for Scenario 2. Conjunctive management pumping occurs in 8 of the 82 years simulated or 10 percent of the years. The average annual pumping in those years is 75 TAF. The average annual pumping for the entire 82-year simulation is approximately 7 TAF with a maximum annual pumping of the full 100 TAF of pumping capacity.

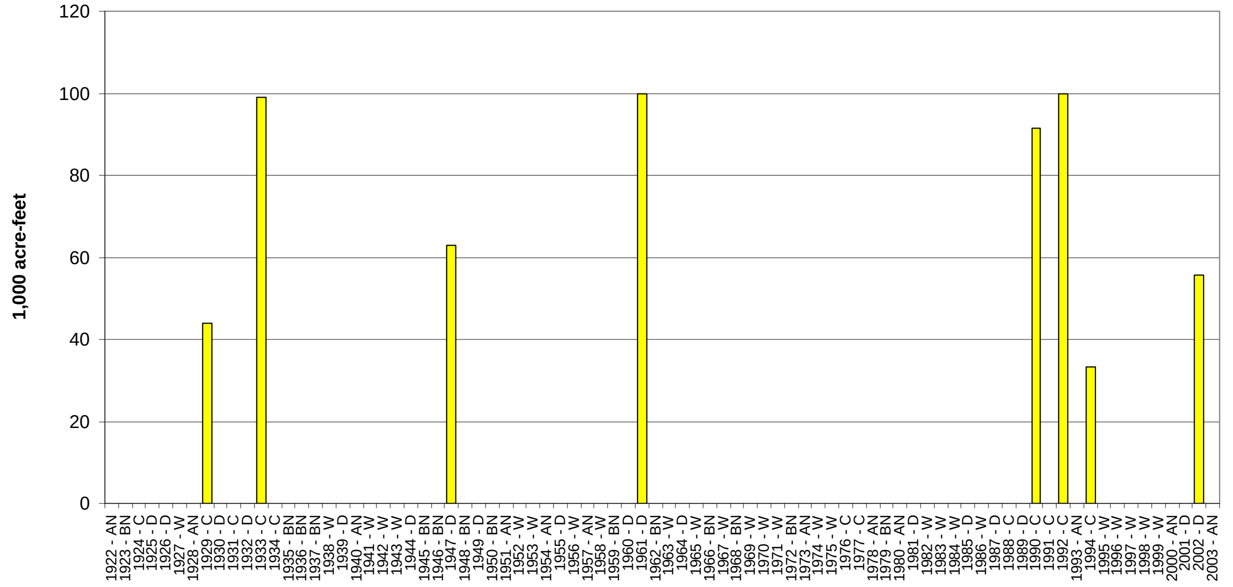

FIGURE 5-26
Refill of Oroville Reservoir from Conjunctive Management Pumping, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Over the 82-year simulation period, additional reservoir releases are made in 51 years, or 62 percent of the years. Reservoir refill is accomplished with surplus surface flows in 43 years and with project pumping in 8 years. For Scenario 2 on the Feather River system, out of total additional releases of 43 TAF (23 TAF for agriculture and 20 TAF for environmental objectives), 36 TAF is refilled from surplus surface water and 7 TAF from conjunctive management pumping. Over the 82-year period of analysis, a total of 1,886 TAF would be delivered to satisfy agricultural demands that would otherwise be met from groundwater pumping. Over the same period, the total volume of project pumping required for reservoir payback would be just 574 TAF. Thus, conjunctive operations would result in a net gain to the groundwater system of 1,312 TAF over the analysis period.

5.4.Impacts and Evaluation of Initial Scenarios

In the preceding section the initial project scenarios are described with respect to their performance; that is, the ability to achieve targeted project objectives (environmental flows and agricultural water supplies) subject to identified constraints. In this section, the scenarios are described in terms of how project pumping would affect groundwater conditions with particular emphasis on impacts to existing groundwater users, groundwater pumping costs and streamflows.

5.4.1. Impacts on Groundwater Users

During average rainfall years, groundwater supplies 18 percent of the total demand for the Sacramento River Basin, and during drought years groundwater supplies 25 percent of total demand.[16] Wells in the Project area primarily provide groundwater directly to homes and farms. A few municipal water supply agencies also utilize groundwater on the fringes of the Project area, including Chico and Durham.

The great majority of wells in the area are associated with domestic use, with groundwater supplying water to essentially all households. Conversely, surface water is the primary source of irrigation supply for the majority of the farmers. Most of these are incorporated into water or irrigation districts, the largest of which are the partners in this Project, Glenn-Colusa Irrigation District, Western Canal Water District, and Richvale Irrigation District, and various smaller reclamation and irrigation districts and water user associations. However, for those agricultural users outside these districts, many of which are orchardists, groundwater is the main source of supply. It is the domestic well users and farmers growing permanent crops that are most vulnerable to increases in groundwater extractions.

Based on well log data maintained by the Department of Water Resources, there are approximately 15,000 water supply wells (in contrast to monitoring wells) within the Project area, of which approximately two thirds are domestic wells and one third are irrigation wells (Table 5-6). Municipal and irrigation wells are typically screened at lower levels than domestic wells, yet there is a wide range of depths for all types of wells. Approximately 335 wells in the Sacramento Valley extract water from the Lower Tuscan Formation, and these tend to be larger irrigation or public water supply wells. Most of these are located on the east side of the Valley in Butte County, while several agricultural wells on west side of the Valley in GCID and other districts also tap into the Lower Tuscan aquifer.[17]

TABLE 5-6
Number of Water Supply Wells in Project Area[18]
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Use	**Number of wells**
Domestic	9,058
Irrigation	4,455
Unknown[19]	1,388
Other[4]	267
Municipal	139
Stock	75
Public	52
Total	15,434

Agriculture is the major industry throughout the Project area. Primary crops consist of rice and orchards (almonds, grapes, walnuts). The proportion of agricultural land planted as orchards is increasing as the

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[16] Domagalski, J.L., Knifong, D.L., Dileanis, P.D., Brown, L.R., May, J.T., Connor, Valerie, and Alpers, C.N. 2000. Water Quality in the Sacramento River Basin, California, 1994–98: U.S. Geological Survey Circular 1215. Available on-line at http://pubs.water.usgs.gov/circ1215/.

[17] Northern California Water Users Association. 2005. Sacramento Valley Groundwater: An approach to better understand and manage the Lower Tuscan groundwater resources for northern California. Available at: http://www.norcalwater.org/pdf/sacramento_valley_groundwater_0919.pdf.

[18] Data provided by California Department of Water Resources Northern District Office. 2009.

[19] May include monitoring wells, vapor recovery wells, or other wells not constructed for water supply purposes.

area transitions from row crops to perennial crops and from low-value agronomic crops to higher value vegetable or other row crops. Many individual growers' livelihoods are dependent on having an adequate and affordable supply of groundwater to meet crop water requirements at all times. Of these users, growers of perennial crops and particularly orchardists are often solely dependent on groundwater and are especially vulnerable to even temporary decreases in supply.

5.4.1.1. *Occurrence of Project Pumping and Potential Impacts*

The Project pumping scenarios designate an annual maximum volume of water that can be released from existing reservoirs to meet local irrigation demands and environmental flow targets. As noted above, in most years, the reservoir space created by additional Project releases is naturally refilled with surplus surface water, which dam operators would otherwise release for flood control. However, in years when refill is less than would have otherwise occurred, pumping of groundwater in lieu of diverting surface water is implemented to make up the difference. This allows a volume of water equivalent to the foregone diversions to remain in reservoir storage.

The surface model predicted the need for pumping in about 10 percent of the years in the Butte Basin and about 7 percent of the years in GCID under the 300 TAF pumping scenarios (see Table 5-7). In years in which pumping occurs, pumping is usually required in either GCID or in the Butte Basin, but not both. However, in exceptionally dry years, pumping would occur in both areas in the same year.

TABLE 5-7
Occurrence of Pumping
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Maximum Pumping	Number of times pumping occurs (82 years of record)		Years in which pumping occurs		Number of times pumping occurs in GCID and/or Butte Basin
	GCID - Shasta	Butte - Oroville	GCID - Shasta	Butte - Oroville	
150 TAF (100 TAF GCID; 50 TAF Butte Basin)	4	6	1947, 1987, 1988, **1990**	1933, 1961, **1990**, 1992, 1994, 2002	9
300 TAF (200 TAF GCID;100 TAF Butte Basin)	6	8	1923, **1929**, **1947**, 1987, 1988, **1990**	**1929**, 1933, **1947**, 1961, **1990**, 1992, 1994, 2002	11

* **bolded** years indicate that pumping would have occurred in both GCID and Butte Basin under the Project.

The groundwater model results reveal that the project pumping scenarios will result in increased energy requirements and associated costs to maintain existing pumping volumes.[20] However, at the scale of feasible operations under the Keswick minimum release constraint, the additional drawdown is not expected to reduce the yield of either agricultural or domestic wells. This is particularly clear for the irrigation wells because the screened interval (which provides a bases for estimating minimum saturated thickness under pumping conditions) and well depth tend to be much greater than peak interference drawdown associated with the payback pumping.

The numbers of wells experiencing reduced yield due to interference drawdown were estimated for individual domestic wells within the Project area based on comparison of the length of the screened

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[20] Well yield impacts and increases in energy costs associated with increased lift were assessed using a combination of data provided by DWR describing screened interval lengths within the Project area in conjunction with interference drawdown estimated using the groundwater model.

interval to peak interference drawdown. Because screened interval length data were not available for all wells, results for wells with available data were scaled upwards to provide estimates of the total probable range of wells impacted.

Individual domestic wells were considered to be adversely impacted under the following conditions:

1. When the amount of peak interference drawdown from project pumping results in less than 25 percent of the total screened interval remains saturated, assuming that 50 percent of the screened interval would remain saturated under baseline pumping drawdown,. This criterion was established to provide an estimate of the maximum probable number of wells impacted.

2. When the amount of peak interference drawdown from project pumping results in less than 33 percent of the remaining screened interval (17% of the total) remaining saturated, assuming that 50 percent of the screened interval remains saturated under baseline pumping drawdown. This criterion was established to provide an estimate of the minimum probable number of wells impacted.

A summary of the estimated probable range of wells impacted within potential impact zones, delineated as areas experiencing peak interference drawdown greater than or equal to 2 feet, is provided in Table 5-8. A summary of average monthly interference drawdown within the Project area calculated at the section scale over the 17 year analysis period for each scenario is provided in Table 5-9. In general, the pumping of new wells, screened at 900 to 1100 feet below ground surface (ft-bgs), results in less yield impacts than the equivalent volume of water pumped on the same schedule from existing domestic wells screened at 0 to 300 ft-bgs. This is the case notwithstanding that production from new wells results in greater drawdown in the shallow aquifer, on average, than pumping the same quantities at the same rates from existing wells. This is explained by the hypothesis that greater yield impacts occur with less interference drawdown for the pumping scenarios relying on existing wells because existing production wells are closer to existing domestic wells than the new well field. Also, for a given project production capacity and well field, the greatest peak drawdown is observed in fall pumping simulations because pumping is concentrated within three months as compared to four months for the summer pumping scenarios and seven months for the summer and fall pumping scenarios. As expected, an intermediate magnitude of drawdown is observed for pumping over the four month summer period, and the least drawdown is predicted for the seven month summer and fall pumping period.

5.4.1.2. Timing of Peak Interference Drawdown and Associated Impacts

Under each of the pumping scenarios, peak interference drawdown occurs for most domestic wells in 1990, when Project pumping occurred in both GCID and the Butte Basin. Additionally, in the simulations, the largest volume of water was pumped out of GCID in 1990, and the largest total volume of water was pumped for the Project as a whole in that year (Table 5-10). Thus, 1990 represents a “worst-case scenario” for the period of record.

Within the potential impact area for yield impacts (interference drawdown of 2 feet or more) for each pumping scenario, the maximum number of domestic wells experiencing peak drawdown occurs in 1990. Peak drawdown at a well lags project pumping by a few months due to the time required for pumping in the lower aquifer to result in drawdown in the shallow aquifer. The time series of project pumping and domestic wells experiencing peak drawdown is shown for the 300 TAF summer pumping scenarios in Figure 5-27.

TABLE 5-8
Estimated Probable Range of Domestic Well Yield Impacts
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Pumping Scenario	Total Wells[1]	Minimum Probable Impacts[2] Percent Impacted[4]	Minimum Probable Impacts[2] Total Impacted[5]	Maximum Probable Impacts[3] Percent Impacted[4]	Maximum Probable Impacts[3] Total Impacted[5]
300 TAF, Summer Pumping, New Well Field	756	8%	58	21%	158
300 TAF, Summer Pumping, Existing Well Field	696	22%	153	41%	284
150 TAF, Summer Pumping, New Well Field	120	5%	6	23%	27
150 TAF, Summer Pumping, Existing Well Field	346	26%	91	50%	173
150 TAF, Fall Pumping, New Well Field	182	3%	6	16%	29
150 TAF, Fall Pumping, Existing Well Field	405	21%	84	44%	180
150 TAF, Summer and Fall Pumping, New Well Field	156	5%	8	16%	25
150 TAF, Summer and Fall Pumping, Existing Well Field	373	17%	63	35%	130

1. Total domestic wells within potential impact zones (maximum interference drawdown greater than or equal to 2 feet).
2. Estimated impacts based on peak interference drawdown greater than 67% of estimated saturated screened interval.
3. Estimated impacts based on peak interference drawdown greater than 50% of estimated saturated screened interval.
4. Percent of wells within potential impact zones with yield impacts.
5. Estimated total number of wells within potential impact zones with yield impacts.

TABLE 5-9
Summary Statistics of Monthly Average Interference Drawdown in the Shallow Aquifer by Pumping Scenario, 1987 – 2003
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Pumping Scenario	Interference Drawdown (ft) Min	Interference Drawdown (ft) Max	Interference Drawdown (ft) Mean	Interference Drawdown (ft) Median	Interference Drawdown (ft) Std. Dev.
300 TAF Summer Pumping, New Well Field	0.0	13.6	0.5	0.3	0.7
300 TAF Summer Pumping, Existing Well Field	0.0	8.3	0.4	0.2	0.6
150 TAF Summer Pumping, New Well Field	0.0	6.2	0.3	0.2	0.4
150 TAF Summer Pumping, Existing Well Field	0.0	5.4	0.3	0.2	0.4
150 TAF Fall Pumping, New Well Field	0.0	7.0	0.4	0.2	0.4
150 TAF Fall Pumping, Existing Well Field	0.0	6.1	0.4	0.2	0.5
150 TAF Summer & Fall Pumping, New Well Field	0.0	5.9	0.4	0.2	0.4
150 TAF Summer & Fall Pumping, Existing Well Field	0.0	5.0	0.4	0.2	0.5

TABLE 5-10
Volume of Water Pumped by Year, Scenario, and Area
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Calendar Year	Pumping Scenario											
	300 TAF Summer			150 TAF Summer			150 TAF Fall			150 TAF Summer and Fall		
	GCID	Butte	TOTAL	GCID	Butte	TOTAL	GCID	Butte	TOTAL	GCID	Butte	TOTAL
1987	116	0	116	96	0	96	96	0	96	95	0	95
1988	35	0	35	37	0	37	60	0	60	53	0	53
1990	198	92	289	99	26	125	99	50	149	97	41	138
1992	0	100	100	0	50	50	0	50	50	0	50	50
1994	0	33	33	0	33	33	0	50	50	0	48	48
2002	0	56	56	0	49	49	0	49	49	0	48	48
TOTAL	349	280	629	232	159	391	255	199	454	245	188	432

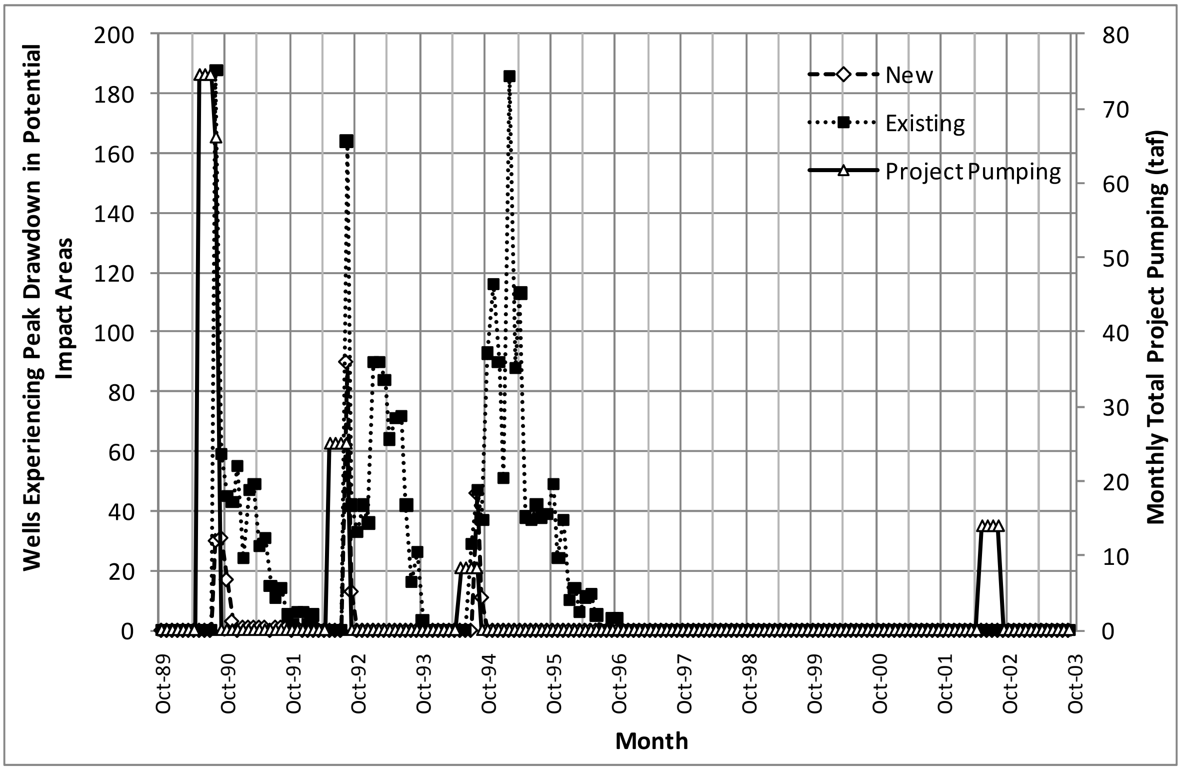

FIGURE 5-27
Project Pumping for 300 TAF Summer Pumping Scenarios and Number of Domestic Wells Experiencing Peak Interference Drawdown
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

5.4.1.3. Increase in Pumping Energy Costs

Project pumping will result in amounts of drawdown that will not be great enough to adversely impact yield in nearby wells in most cases; however, the drawdown will require all groundwater users (agricultural and domestic) to lift water from slightly greater depths, resulting in additional pumping costs. Additional pumping costs associated with increased lift were estimated for irrigation wells based on baseline groundwater pumping from the surface water model, interference drawdown from the groundwater model, estimated mean overall pumping plant efficiency for irrigation wells, and the estimated agricultural energy cost per kilowatt-hour. For domestic wells, additional pumping costs were estimated based on baseline pumping estimated from the combination of spatially distributed U.S. Census data for 2000 and per-capita non-irrigation groundwater pumping for 2005 from USGS, interference drawdown from the groundwater model, estimated mean overall pumping plant efficiency for domestic wells, and the estimated residential energy cost per kilowatt-hour. Increased energy requirements and associated costs were estimated for individual sections within the Project area on a monthly time step for water years 1987 to 2003.

Baseline pumping and interference drawdown vary with time and location within the project area. As a result, associated increases in pumping costs vary. Summary statistics of increased annual energy requirements per acre to maintain existing levels of groundwater pumping for irrigation are provided for each pumping scenario in Table 5-11. Summary statistics of increased annual energy requirements per acre to maintain existing irrigation pumping are provided in Table 5-12. The summary statistics describe the increased energy requirements for 1589 of 1786 sections within the Project area that pump groundwater for irrigation based on the results of the surface water model. Summary statistics of total annual increases to energy costs within the Project area for the 17 years of analysis are provided in Table 5-13.

Increases in energy requirements and associated costs are greatest for the 300,000 ac-ft pumping scenarios due to greater interference drawdown resulting from greater Project pumping volumes.

TABLE 5-11
Summary Statistics of Increased Annual Energy Requirements Per Acre to Maintain Existing Groundwater Pumping for Irrigation
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Increased Annual Energy Requirement (kwh/ac)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	0.00	55.6	1.60	0.63	2.80
300 TAF Summer Pumping, Existing Well Field	0.00	46.9	1.36	0.48	2.61
150 TAF Summer Pumping, New Well Field	0.00	27.8	0.97	0.41	1.63
150 TAF Summer Pumping, Existing Well Field	0.00	42.5	1.03	0.39	1.85
150 TAF Fall Pumping, New Well Field	0.00	21.0	0.86	0.38	1.39
150 TAF Fall Pumping, Existing Well Field	0.00	28.0	0.97	0.38	1.65
150 TAF Summer & Fall Pumping, New Well Field	0.00	19.4	0.98	0.44	1.53
150 TAF Summer & Fall Pumping, Existing Well Field	0.00	30.2	1.06	0.42	1.76

TABLE 5-12
Summary Statistics of Increased Annual Energy Costs Per Acre to Maintain Existing Groundwater Pumping for Irrigation
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Increased Annual Energy Cost ($/ac)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	$ -	$ 12.23	$ 0.35	$ 0.14	$ 0.62
300 TAF Summer Pumping, Existing Well Field	$ -	$ 10.31	$ 0.30	$ 0.11	$ 0.58
150 TAF Summer Pumping, New Well Field	$ -	$ 6.11	$ 0.21	$ 0.09	$ 0.36
150 TAF Summer Pumping, Existing Well Field	$ -	$ 9.35	$ 0.23	$ 0.09	$ 0.41
150 TAF Fall Pumping, New Well Field	$ -	$ 4.62	$ 0.19	$ 0.08	$ 0.30
150 TAF Fall Pumping, Existing Well Field	$ -	$ 6.16	$ 0.21	$ 0.08	$ 0.36
150 TAF Summer & Fall Pumping, New Well Field	$ -	$ 4.28	$ 0.22	$ 0.10	$ 0.34
150 TAF Summer & Fall Pumping, Existing Well Field	$ -	$ 6.63	$ 0.23	$ 0.09	$ 0.39

TABLE 5-13
Summary Statistics of Total Increased Annual Energy Costs to Maintain Existing Groundwater Pumping for Irrigation
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Increased Annual Energy Cost (Total $)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	$65,770	$705,326	$228,397	$168,480	$177,411
300 TAF Summer Pumping, Existing Well Field	$60,110	$497,233	$194,859	$154,452	$140,481
150 TAF Summer Pumping, New Well Field	$37,538	$377,222	$139,402	$104,710	$ 94,209
150 TAF Summer Pumping, Existing Well Field	$39,866	$367,467	$148,075	$126,209	$ 97,078
150 TAF Fall Pumping, New Well Field	$10,993	$344,156	$122,601	$124,133	$ 80,913
150 TAF Fall Pumping, Existing Well Field	$10,292	$401,570	$138,222	$134,018	$ 95,827
150 TAF Summer & Fall Pumping, New Well Field	$44,736	$294,296	$140,169	$120,727	$ 81,830
150 TAF Summer & Fall Pumping, Existing Well Field	$47,471	$345,330	$151,533	$132,451	$ 91,202

Increases in energy requirements are least for the fall pumping scenarios due to the lesser volume of Project pumping (as compared to the 300 TAF summer pumping scenarios) and due to Project pumping occurring after the peak irrigation season, when baseline irrigation pumping is less. Costs tend to be similar whether Project pumping relies on a new or existing well field.

Annual baseline irrigation pumping, Project pumping, and increased energy costs by water year are shown for the 300 TAF summer pumping scenario with a new well field in Figure 5-28. Annual baseline irrigation pumping, Project pumping, and increased energy costs by water year are shown for the 300 TAF summer pumping scenario with an existing well field in Figure 5-29.

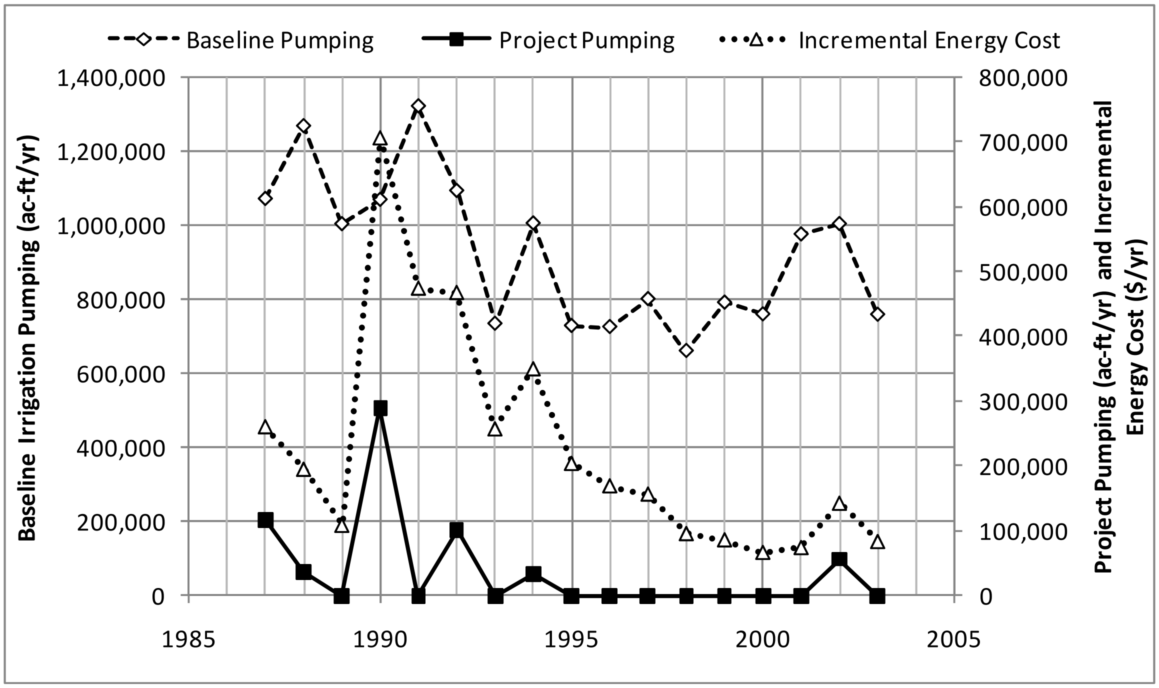

FIGURE 5-28
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, New Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

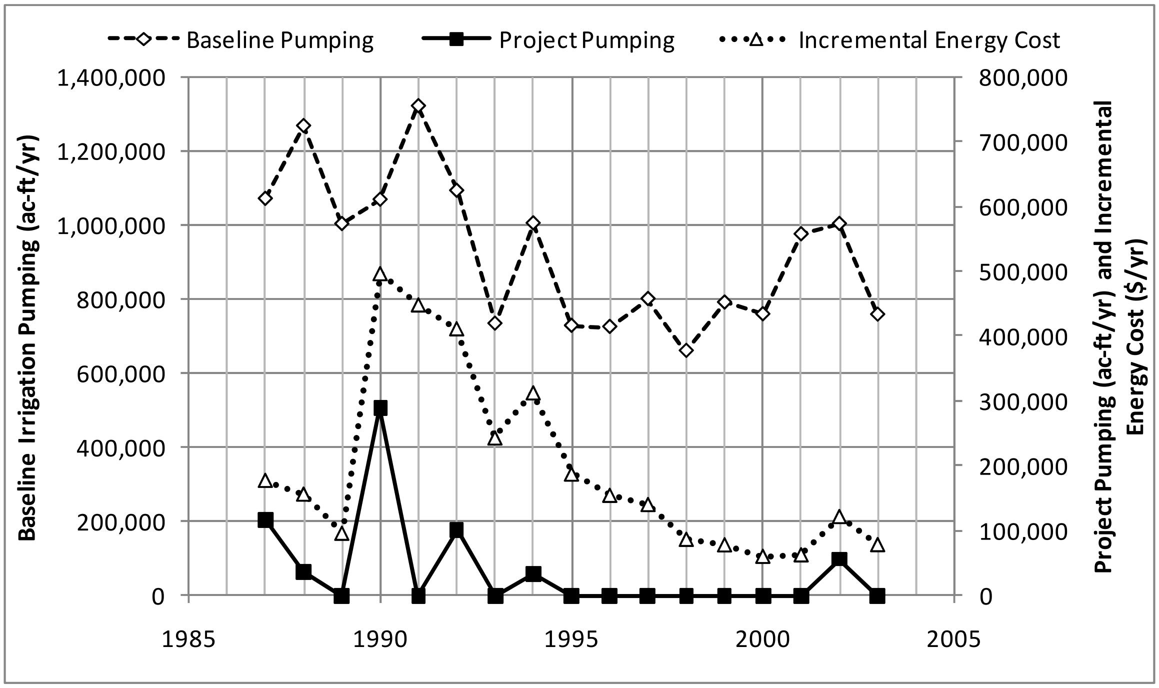

FIGURE 5-29
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, Existing Well Field
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Incremental energy costs are greatest in years when project pumping is greatest but are also directly proportional to the amount of baseline irrigation pumping, all else equal. Project pumping in 1990 results in interference drawdown that causes increased lift and associated increased energy costs for the years to follow. The incremental energy costs resulting from Project pumping with the new well field are substantially greater than the incremental energy costs for the existing well field in 1990, the year of maximum pumping in GCID and maximum total project pumping.

Summary statistics of increased annual energy requirements per acre to maintain existing levels of groundwater pumping for non-irrigation (primarily domestic) use are provided for each pumping scenario in Table 5-14. Summary statistics of increased annual energy requirements per acre to maintain existing non-irrigation pumping are provided in Table 5-15. The summary statistics describe the increased energy requirements for 1329 of 1786 sections within the Project area that pump groundwater for non-irrigation uses based on the analysis of year 2000 Census data. Summary statistics of total annual increases to energy costs within the Project area for the 17 years of analysis are provided in Table 5-16.

Similar to the results for irrigation pumping, increases in energy requirements and associated costs are greatest for the 300,000 ac-ft pumping scenarios due to greater interference drawdown resulting from greater Project pumping volumes. Increases in energy requirements are least for the fall pumping scenarios due to the lesser volume of Project pumping (as compared to the 300 TAF summer pumping scenarios) and due to Project pumping occurring after the peak irrigation season, when baseline irrigation pumping is less (non-irrigation pumping, which includes landscape watering for purposes of this analysis, tends to follow a similar distribution as irrigation pumping, with the greatest use during peak demand periods). Costs are similar whether Project pumping relies on a new or existing well field.

TABLE 5-14
Summary Statistics of Increased Annual Energy Requirements Per Acre to Maintain Existing Groundwater Pumping for Non-Irrigation Uses
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Increased Annual Energy Requirement (kwh/section)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	0.00	2,313.0	15.60	1.05	80.86
300 TAF Summer Pumping, Existing Well Field	0.00	1,951.9	13.38	0.72	71.73
150 TAF Summer Pumping, New Well Field	0.00	1,571.6	9.26	0.65	48.63
150 TAF Summer Pumping, Existing Well Field	0.00	1,864.0	9.18	0.60	50.43
150 TAF Fall Pumping, New Well Field	0.00	1,761.8	10.58	0.69	56.02
150 TAF Fall Pumping, Existing Well Field	0.00	2,038.2	10.62	0.64	58.38
150 TAF Summer & Fall Pumping, New Well Field	0.00	1,675.6	10.32	0.70	53.93
150 TAF Summer & Fall Pumping, Existing Well Field	0.00	1,951.9	10.27	0.65	55.91

TABLE 5-15
Summary Statistics of Increased Annual Energy Costs Per Acre to Maintain Existing Groundwater Pumping for Non-Irrigation Uses
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Increased Annual Energy Cost ($/section)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	$ -	$ 555.11	$ 3.74	$ 0.25	$ 19.41
300 TAF Summer Pumping, Existing Well Field	$ -	$ 468.47	$ 3.21	$ 0.17	$ 17.21
150 TAF Summer Pumping, New Well Field	$ -	$ 377.18	$ 2.22	$ 0.16	$ 11.67
150 TAF Summer Pumping, Existing Well Field	$ -	$ 447.36	$ 2.20	$ 0.14	$ 12.10
150 TAF Fall Pumping, New Well Field	$ -	$ 422.84	$ 2.54	$ 0.17	$ 13.44
150 TAF Fall Pumping, Existing Well Field	$ -	$ 489.16	$ 2.55	$ 0.15	$ 14.01
150 TAF Summer & Fall Pumping, New Well Field	$ -	$ 402.15	$ 2.48	$ 0.17	$ 12.94
150 TAF Summer & Fall Pumping, Existing Well Field	$ -	$ 468.47	$ 2.46	$ 0.16	$ 13.42

TABLE 5-16
Summary Statistics of Total Increased Annual Energy Costs to Maintain Existing Groundwater Pumping for Non-Irrigation Uses
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Increased Annual Energy Cost (Total $)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	$ 927	$ 7,823	$ 4,976	$ 4,787	$ 2,218
300 TAF Summer Pumping, Existing Well Field	$ 485	$ 6,962	$ 4,267	$ 4,511	$ 2,058
150 TAF Summer Pumping, New Well Field	$ 839	$ 4,263	$ 2,883	$ 2,680	$ 1,022
150 TAF Summer Pumping, Existing Well Field	$ 613	$ 4,278	$ 2,856	$ 2,757	$ 1,084
150 TAF Fall Pumping, New Well Field	$ 88	$ 5,241	$ 3,374	$ 3,351	$ 1,441
150 TAF Fall Pumping, Existing Well Field	$ 74	$ 5,168	$ 3,315	$ 3,333	$ 1,458
150 TAF Summer & Fall Pumping, New Well Field	$ 512	$ 5,014	$ 3,292	$ 3,155	$ 1,260
150 TAF Summer & Fall Pumping, Existing Well Field	$ 396	$ 4,867	$ 3,207	$ 3,123	$ 1,290

Annual baseline non-irrigation pumping, Project pumping, and increased energy costs by water year are shown for the 300 TAF summer pumping scenario with a new well field in Figure 5-30. Annual baseline irrigation pumping, Project pumping, and increased energy costs by water year are shown for the 300 TAF summer pumping scenario with an existing well field in Figure 5-31. As indicated in the figures, non-irrigation pumping has been assumed to remain constant from year to year for purposes of this analysis.

Incremental energy costs are greatest in years following substantial project pumping. The lag between peak project pumping and peak incremental costs results from gradual reductions in water levels in the shallow aquifer as the regional aquifer and/or lower aquifer is refilled. Interference drawdown in the shallow aquifer in some areas of the Valley may occur more quickly following peak project pumping, but the incremental energy costs may be low if little or no non-irrigation pumping occurs in these areas. The incremental energy costs resulting from project pumping with the new well field are somewhat less than the incremental energy costs for the existing well field but follow a similar trend over time.

In summary, the greatest costs associated with increased lift resulting from interference drawdown will be incurred by agricultural groundwater users due primarily to the greater volume of water pumped. Additionally, project pumping and associated interference drawdown tends to be greatest in agricultural areas away from population centers. Costs are highly variable from location to location and over time but, in aggregate, are similar among pumping scenarios of the same volume (e.g., 300 TAF or 150 TAF). Peak incremental energy costs may occur multiple years after project pumping, particularly for non-irrigation pumping from the shallow aquifer.

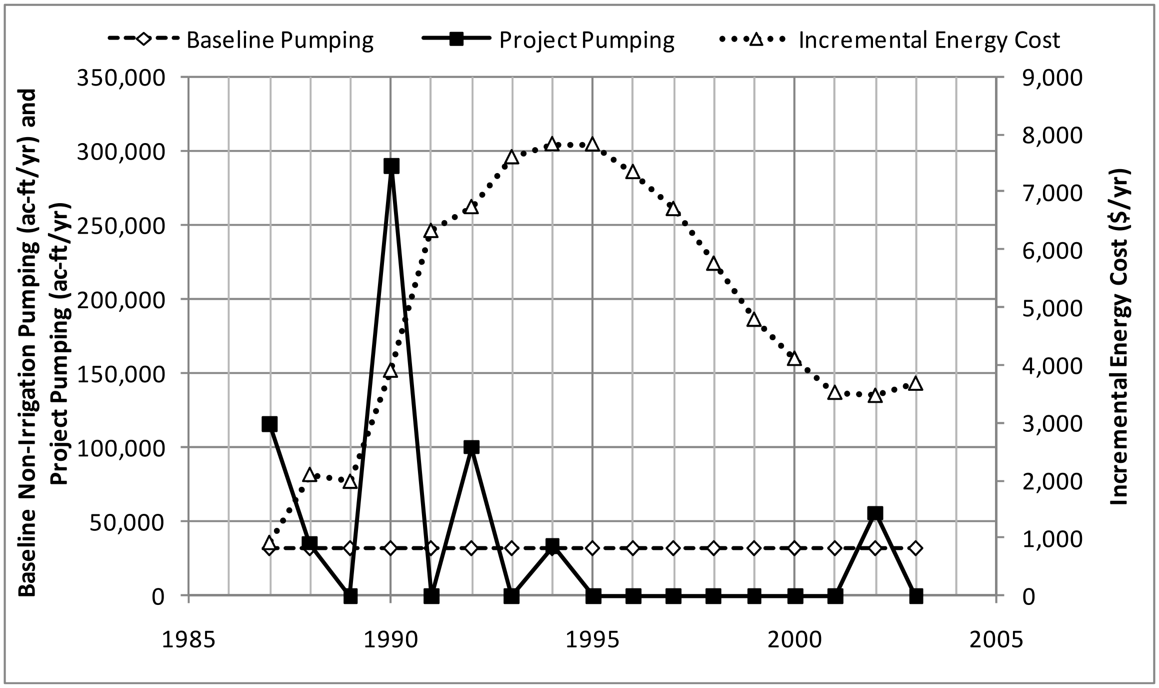

FIGURE 5-30
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, New Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

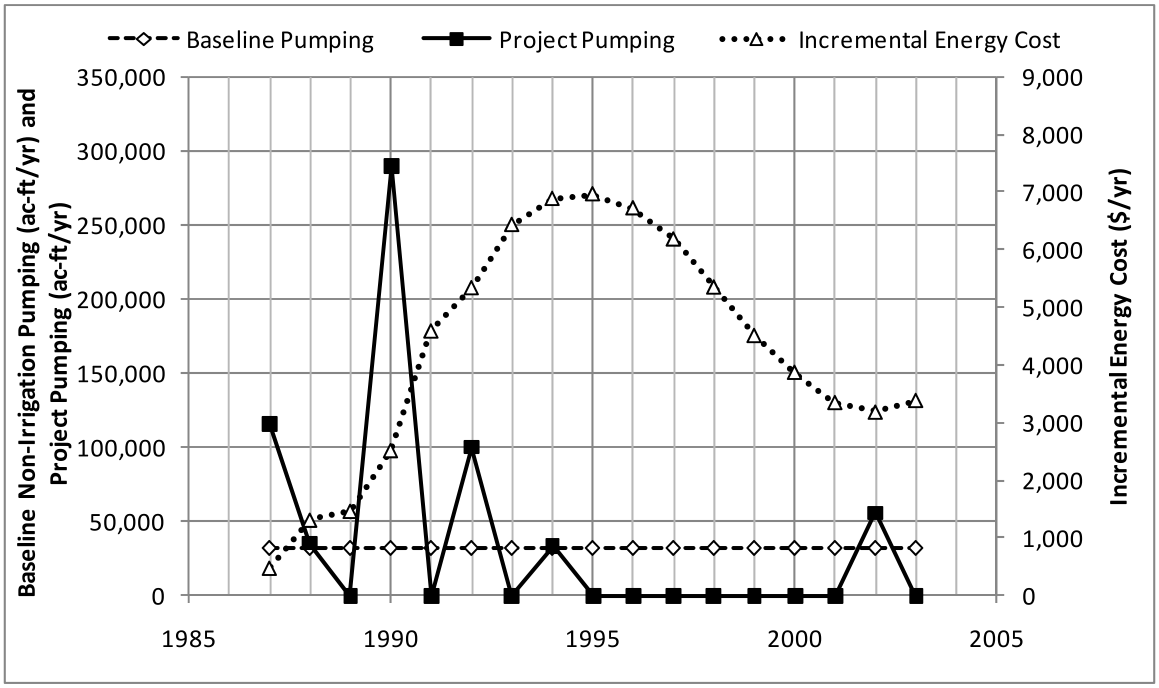

Figure 5-31
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, Existing Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Spreading the payback pumping over two seasons (summer and fall) will moderate the impact. The volume and timing of the pumping will also be efficiently managed by assessing the condition of the groundwater basin in the spring while evaluating its capacity for pumping that year.

If some form or degree of the groundwater pumping payback method is eventually adopted, a mitigation program will be instituted to compensate the owners of the impacted domestic or municipal wells for the expected increase in their pumping cost due to the increased lift.

As yield impacts are not expected at the permissible level and scheduling of the pumping, it should not be necessary to improve their wells or build new and more efficient ones in order to deal with yield impacts.

5.4.1.4. Groundwater Levels

Production of 150 TAF of groundwater from existing wells over the summer/fall period (May through November) results in a maximum of about 30 feet of drawdown in the pumped aquifer compared to a maximum of approximately 40 feet of drawdown if the same production occurs in the summer only.

Simulated drawdown in the vicinity of the eastern well fields in the Butte Basin Project are significantly lower than those observed on the west. This is due to a combination of lower overall production rates from the east and a greater production well spacing.

5.4.2. Impacts on Streamflow

Peak effects on streamflow due to groundwater production in the Sacramento Valley are summarized in Table 5-17.

TABLE 5-17
Peak Effects on Streamflow from Conjunctive Management Operations
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Stream	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**
All Streams	54	53	111	105	80	90	64	65
Butte Creek	13	12	72	69	50	48	39	33
Sacramento River – GCID to Wilkins Slough	42	37	32	28	16	18	16	15
Feather River	3	3	6	6	4	4	4	4
Little Chico Creek	3	3	6	5	4	3	4	3
Salt River	1	5	5	8	2	5	2	5
Stone Coral Creek	6	9	11	15	7	10	6	9
Stony Creek	4	5	7	7	4	6	4	4

Specific conclusions regarding surface water effects are as follows:

The modeled project pumping scenarios result in some streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams. To compensate for these losses, the modeling incorporated releases from Shasta and Oroville when the system is "in balance." Although these releases help maintain streamflow in the Sacramento and Feather Rivers, while insuring the system as whole doesn't experience significant losses, the release do not directly mitigate the impact of *tributary* streamflow losses to ecosystems and species. As a starting point for the assessing impact to tributary streams, the project analyzed Butte Creek due to its high ecosystem value combined with some of the largest discharge losses due to pumping. An additional consideration is that historical streamflow records are available for Butte Creek but generally not for other, smaller tributary streams. The analysis yielded the following key results:

- Project pumping will not impact the uppermost reach in the project areas, the primary spawning area for Spring-run Chinook and Central Valley steelhead
- Pumping will have a greater impact on the lower reaches of Butte Creek, than the upper
    - In addition to cumulative effects, the *rate* of leakage is higher in downstream reaches
- The largest absolute losses in streamflow occur when discharge is also highest (Jan.-Mar)
    - The magnitude of impacts in relation to the baseflow at this time is not substantial (maximum of 1-3% loss in streamflow)
- The largest percentage loss in stream flow occurs in the lowest reach during summer/ early fall when Spring-run have already migrated upstream and steelhead are only beginning to enter the streams
- Project pumping never causes average monthly discharge to fall below the instream flow standards in the four upstream reaches

- June average monthly discharge in the lowermost reach, falls below the 40 cfs instream standard twice in the 17 year record due to pumping of up to 150K, and four times under pumping of up to 300K
    - Most Spring-run migration has already occurred by June, but some late Spring-run migrants, may experience minimal impacts
    - These impacts occur during the drought years of 1990, 1991, 1992, 1994, when Butte County irrigators participated in the drought water bank

The results of the analysis do not reveal any significant negative impact to Spring-run Chinook or Central Valley Steelhead in Butte Creek due to project pumping. Furthermore, this analysis focused only on those years with stream impacts (water years 1987 - 2003), during which time groundwater would have been pumped more frequently than over the entire period assessed by the surface water model (1922-2003). As such, on average impacts would likely be less significant and rarer than those projected in this analysis.

5.4.3. Stream Impact Analysis

The modeled project pumping results in some streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams. The greatest impact to surface streams occurs to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Project modeling and operations account for the effects of stream leakage when the system is “in balance”, the condition when there is no excess flow in the system and the reservoirs are releasing to satisfy critical conditions. Depending on location and timing of stream leakage, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. However, if leakage occurs at times when the system is "in surplus", additional reservoir releases may not be necessary. Although this helps maintain flow conditions on the Feather and Sacramento Rivers, as well as minimizing losses to the system as a whole, it does not account for potential stream leakage impacts on fisheries in tributaries, which were examined.

The Sacramento River and several of its tributaries are designated as critical habitat for Spring-run Chinook salmon (SRCS) and Central Valley steelhead, both listed as "threatened" species, as well as the fall and late-fall run Chinook, which are listed as a “species of concern”. The stream analysis in this report focuses on the National Marine and Fisheries Service (NMFS) designated critical habitat within the project area. At this time, the assessment is primarily limited to impact to stream discharge, although other factors, such as water quality parameters, may need to be further assessed if the project proceeds.

The first time pumping occurs within the 17-year groundwater model simulation period (1987 to 2003) is in 1987 to refill Shasta and in 1990 to refill Oroville. Impacts from the initial pumping, as well as additional groundwater pumping in 1988 and 1990 to refill Shasta and in 1992, 1994, and 2002 to refill Oroville, produce stream impacts through 2003. This stream impact analysis focuses only on those years with stream impacts, water years 1987 - 2003. It should be noted that pumping occurred more frequently during this span of the groundwater model than during the longer period assessed by the surface water model (1922-2003). The surface model predicted the need for pumping at most once every seven years, yet pumping occurred six times in the 17-year time span of this analysis.

An initial and conservative assessment of potential pumping impacts to the critical habitat streams in the project area demonstrated that the maximum impact (under up to 300K pumping of existing wells) would yield a less than one cubic foot per second decrease in average monthly streamflow in the majority of critical streams. Table 5-18 lists the streams located in the project area, which are designated as critical habitat for Spring-run Chinook salmon and steelhead, along with the potential impact to streamflow due to pumping.[21] As mentioned above, additional releases from Shasta and Oroville mitigate any negative impact on streamflow in the Sacramento or Feather. The rarity in occurrence of the maximum decrease in discharge, noted in the following table, further nullifies most concerns about any negative impact to fisheries.

The impact to the three highlighted streams (Butte Creek, Little Chico Creek, and Stony Creek) in relation to their actual streamflow did warrant further investigation. The noted ecosystem value of Butte Creek, in conjunction with non-trivial projected project impacts, justified a more in-depth analysis, which is subsequently described. Based on the analysis of Butte Creek, the impact of pumping on Little Chico and Stony Creek, which experience a much less significant loss in stream flow, is determined to also be minimal at this time. If the Project does proceed, more detailed analysis of the impact to Little Chico and Stony Creek may be warranted. With respect to the streamflow impacts, the Project would be operated to assure a net improvement in streamflow parameters important to the viability of protected species, specifically Chinook salmon. Reductions in base flows that may occur in the tributary streams due to additional pumping of groundwater would be more than offset by improvements to environmental flow parameters in the mainstem Sacramento and Feather Rivers and in the resulting inflows to the Delta. Indeed, this Project is designed to contribute substantially to the recovery of these species. That result will be demonstrated to the listing agencies in the consultation process that the CVP, SWP and participating districts will engage in as part of their NEPA/CEQA compliance.

5.5.Economic Analysis

The team compared the costs and benefits of the eight different initial scenarios as a means of evaluating the economic feasibility of the project. This analysis is summarized below.

The economic analysis did not assign a monetary value to the environmental benefits that would be achieved by project ecologic flows releases. This was not because these benefits would be negligible. In fact, the potential increase in salmon productivity could be quite substantial. Rather, methods for valuing environmental benefits are somewhat speculative so, to avoid basing economic feasibility on uncertain benefits, the economic analysis was conducted in part to determine whether the revenue from the project’s potential water sales alone would be large enough to pay for the capital and operational costs. Additionally, the benefits that would result from improved groundwater conditions within the Sacramento Valley due to the delivery of additional surface water supplies and consequent relaxation of groundwater pumping were not factored into the economic analysis. In sum, the question was not whether the project would be economically justified, but whether it could pay for itself.

5.5.1. Cost Assessment

The costs of the different scenarios are presented in Table 5-19, including costs capital outlays for project facilities (primarily existing production well rehabilitation or new well construction), project operation and maintenance, compensation for increased pumping costs (ag and domestic), replacement of a certain number of domestic wells and project legal and administrative charges. These costs are described in detail in Appendix E. The present value of these costs based on a real discount

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[21] NOAA. National Marine Fisheries Service - Southwest office. GIS Data. Accessed at: http://swr.nmfs.noaa.gov/salmon/layers/finalgis.htm.

TABLE 5-18
Critical Fish Habitat Areas Assessed in Stream Impact Study
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Critical Habitat		**Maximum Decrease in Mean Monthly Discharge***	
Stream	**Spring-run Chinook**	**Steelhead**	**cfs**	**Comments**
American River	yes	yes	0	No impact
Antelope Creek	yes	yes	0.006	Minimal impact
Bear River	yes	yes	0.008	Minimal impact
Big Chico Creek	yes	yes	0.791	Minimal impact
Butte Creek	yes	yes	26.729	Further study conducted
Butte Creek, Sutter Bypass	yes	yes	Not assessed	Further study conducted
Colusa Bypass	yes	yes	0.962	Minimal impact
Cosumnes River	no	yes	$<10^{-3}$	Minimal impact
Deer Creek	yes	yes	0.056	Minimal impact
Elder Creek	yes	yes	0.049	Minimal impact
Feather River	yes	yes	6.142	Oroville releases to compensate
Little Butte Creek	no	yes	Not assessed	Minimal impact based on Butte Cr. analysis
Little Chico Creek	no	yes	4.875	Minimal impact, but further study may be warranted if the Project proceeds

TABLE 5-18
Critical Fish Habitat Areas Assessed in Stream Impact Study (con't.)
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Stream	**Critical Habitat**		**Maximum Decrease in Mean Monthly Discharge***	
	Spring-run Chinook	**Steelhead**	**cfs**	**Comments**
Little Dry Creek	no	yes	Not assessed	Minimal impact based on Butte Cr. analysis, but further study may be warranted
Mill Creek	yes	yes	0.006	Minimal impact
Mokelumne River	no	yes	$<10^{-4}$	Minimal impact
Paynes Creek	no	yes	$<10^{-4}$	Minimal impact
Putah Creek	no	yes	0.002	Minimal impact
Sacramento Bypass	yes	yes	Not assessed	Shasta releases to compensate
Sac. Deep Water Channel	no	yes	Not assessed	Shasta releases to compensate
Sacramento River	yes	yes	67.795	Shasta releases to compensate
Stony Creek	yes	yes	7.183	Minimal impact, but further study may be warranted if the Project proceeds
Thomes Creek	yes	yes	0.173	Minimal impact
Yuba River	yes	yes	0.044	Minimal impact

TABLE 5-19
Total Cost Associated with the Project for Each Pumping Scenario
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Scenario	Capital	O&M	Dom. & Ag. Energy Compensation	Domestic Well Replacement	Admin & Legal	Total Cost (PV)
1 300 TAF Summer New Wells	$220,604,741	$61,940,720	$3,287,267	$1,776,873	$1,919,003	$289,528,604
2 300 TAF Summer Existing Wells	$140,118,788	$63,962,075	$2,804,880	$3,594,878	$1,919,003	$212,399,624
3 150 TAF Summer New Wells	$108,940,613	$23,368,466	$733,017	$99,285	$1,704,928	$134,846,308
4 150 TAF Summer Existing Wells	$67,481,217	$22,826,909	$777,553	$794,280	$1,704,928	$93,584,886
5 150 TAF Fall New Wells	$176,120,657	$31,067,457	$647,334	$105,034	$1,704,928	$209,645,410
6 150 TAF Fall Existing Wells	$110,980,583	$29,442,275	$727,303	$792,257	$1,704,928	$143,647,345
7 150 TAF Summer & Fall New Wells	$65,364,368	$19,670,551	$721,787	$96,963	$1,704,928	$87,558,597
8 150 TAF Summer & Fall Existing Wells	$42,168,421	$20,133,635	$778,535	$567,088	$1,704,928	$65,352,605

rate of 3 percent ranges from $65M to $298M, with the lower cost scenarios being those relying on existing wells or having longer repayment pumping period and the higher costs scenarios being those relying on new wells and having shorter pumping periods. The scenarios that involve development of new wells are more expensive compared to their sister scenario using existing wells primarily because of the higher capital investment required to build the new wells. The capital cost is almost 60 percent higher to develop new wells than use existing wells.

The results show that the 150 TAF summer and fall pumping scenario using the existing wells is the least expensive scenario. Under the 150 TAF summer and fall pumping scenarios (scenarios 7 and 8) the number of wells required to accommodate project pumping is relatively low because users can withdraw water during a longer period (almost 7 months), which results in a need for fewer wells and the least amount of groundwater level drawdown.

The analysis reveals that the costliest scenarios (in terms of average cost per AF of pumping) are the 150 TAF summer and 150 TAF fall pumping scenarios using new wells (Scenarios 3 and 5) which result in the highest drawdown (Table 5-20). This is due to the shorter pumping period (three or four months) compared to the summer and fall pumping scenarios (seven months). Our analysis shows that the optimal scenario, considering only costs, is the 150 TAF summer and fall pumping scenario using existing wells.

5.5.2. Valuing Benefits

To value the benefits of the additional water supply, potential market value of various time series of additional reservoir releases were considered. The releases will become supplemental streamflow and may be left in the Feather and Sacramento rivers to augment flow, or possibly exported. Benefits are directly linked to the timing of the releases and how far in advance the buyers can be informed about the quantity of these surplus releases. Additional water supplies could be delivered in the Sacramento Valley, or could be left instream to become Delta inflow.

The value of additional water supplies generated through conjunctive operations was estimated in two ways to bracket the economic analysis. Consistent with the in-Valley focus of the investigation one valuation was based on the water being integrated into CVP and SWP project deliveries according to existing water service contracts in the Sacramento Valley. The second valuation, intended to serve as an upper bound, was based on an assumption that the additional supplies could be exported south of the Delta and made available to urban users as a dry year supply[22].

Under the assumption that the water is used within the Sacramento Valley when it is made available, the main feasible uses are groundwater recharge and environmental flows. An examination of water market data reveals that over the past decade, water sold on the Sacramento Valley market for these purposes averaged around $50/AF.[23]

If it were feasible to export the additional water supplies south of the Delta, the additional yield of the project would be worth more. To approximate the value of exportable supplies, the net willingness

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[22] Consistent with the in-Valley scope of the investigation, no analysis was conducted concerning the feasibility of exporting project water supplies. Additional analyses would be needed to determine the frequency with which project releases might be exported and the economic analysis revised accordingly.

[23] Stratecon Inc., "Water Strategist: Analysis of Water Marketing, Finance, Legislation and Litigation," Monthly publications January 2000 – December 2009. The actual average was $57/AF in average to wet hydrologic years.

TABLE 5-20

Average Cost of Pumping and Releases for Each Pumping Scenario

Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Scenario	Total Cost (PV)	Pumping Volume (AF)	Avg Cost of Pumping ($/AF)	Avg Annual Releases (AF)	Avg Cost of Annual Releases ($/AF)
1 300 TAF Summer New Wells	$289,528,604	1,307,759	$221	109,596	$79
2 300 TAF Summer Existing Wells	$212,399,624	1,307,759	$162	109,596	$58
3 150 TAF Summer New Wells	$134,846,308	523,547	$258	43,609	$93
4 150 TAF Summer Existing Wells	$93,584,886	523,547	$179	43,609	$64
5 150 TAF Fall New Wells	$209,645,410	608,963	$344	44,298	$142
6 150 TAF Fall Existing Wells	$143,647,345	608,963	$236	44,298	$97
7 150 TAF Summer & Fall New Wells	$87,558,597	574,129	$153	43,955	$60
8 150 TAF Summer & Fall Existing	$65,352,605	574,129	$114	43,955	$45

of urban agencies in the South Coast to pay for dry year water was calculated, and then expenses for conveyance and storage were subtracted, while accounting for carriage and storage losses. Currently, the WD Tier 2 rate for untreated, delivered water is $594/AF.[24] The cost of conveyance to transport the water from Shasta and Oroville to the South Coast is around $220/AF.[25] We used information from Semitropic-Rosamond Water Bank Authority (SRWBA) to approximate the cost of groundwater storage necessary to convert wet year water to dry year water. The volumetric cost of using SRWBA facilities is approximately $230/AF.[26] Water sold south of the Delta will incur storage and carriage losses, which are set at 30 percent based on SRWBA contract terms and pre-Wanger conveyance losses. Taking these numbers together, it follows that the value of additional supply under the assumption that it could be exported through the Delta under pre-Wanger conditions is approximately $100/AF.

It is noted here that under current Delta restrictions, it would not be possible to export additional supplies south of the Delta. To the extent that this option turns out to be economically beneficial, it is another demonstration of the economic cost of current Delta pumping restrictions and the type of benefit that would result from construction of some type of through-or around-Delta conveyance facility.

5.5.3. Results of Economic Analysis

The net benefit of the project considering the associated costs and expected benefits varies depending primarily on where the water can be sold and, to some extent, on whether new wells are constructed or the project is operated using primarily existing wells. As summarized in Table 5-21, if the water generated through conjunctive operations is sold in the Sacramento Valley, only one of the scenarios has a positive net benefit, with the others having modest to strong negative net benefits. In contrast, if the water is valued at export rates, only one of the scenarios has a negative net benefit with the others being positive. Interestingly, even though the 150 TAF summer and fall pumping using the existing wells was the least-cost scenario, the analysis demonstrates that the largest net benefit is associated with the 300 TAF summer pumping scenario using the existing wells (if the water could be exported south of the Delta).

It can be seen from Table 5-21 below that the existing well scenarios dominate the new well scenarios in terms of net benefits. The high capital costs associated with constructing new wells make this option less economically viable.

Overall, Sacramento Valley conjunctive operations appear to be more attractive in the event the additional supplies could be exported south of the Delta.

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[24] MWD rates came from MWD's website: http://www.mwdh2o.com/mwdh2o/pages/finance/ finance_03.html, accessed March 22, 2010

[25] The total conveyance cost is comprised of $1 97/AF for use of the SWP aqueduct and $23 for distribution. Division of Planning and Local Assistance, California Department of Water Resources, "Least Cost Planning and Simulation Model User Manual," 2009.

[26] This storage cost assumes 100,000 shares are purchased in the Antelope Valley Water Bank. The capital payments are $1,662 per share which amortized by multiplying by a 3 percent real interest rate. The annual payments are $12.80 per share for the management fee and $11.70 per share for the maintenance fee. The usage fee is $77.68 per AF for recharge and $77.68 per AF for recovery. In the Antelope Valley Water Bank, one share is equivalent to one acre-foot of water. Semitropic-Rosamond Water Bank Authority, "Rate Structure for Customers," January 20, 2010, accessed at: http://www.semitropic.com/pdfs/SRWBA-Rate%20Structure_Bd%20Adopted1_20_2010.pdf, March 22, 2010

TABLE 5-21
Net Benefit under Various Pumping Scenarios
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Scenario	Annual benefits, local use ($M)	Annual benefits, exports ($M)	Total Cost (PV, $M)	Net benefits, local use ($M)	Net benefits, export ($M)
1 300 TAF Summer New Wells	183	365	290	-107	76
2 300 TAF Summer Existing Wells	183	365	212	-30	153
3 150 TAF Summer New Wells	73	145	135	-62	11
4 150 TAF Summer Existing Wells	73	145	94	-21	52
5 150 TAF Fall New Wells	74	148	210	-136	-62
6 150 TAF Fall Existing Wells	74	148	144	-70	4
7 150 TAF Summer & Fall New Wells	73	147	88	-14	59
8 150 TAF Summer & Fall Existing Wells	73	147	65	8	81

5.6. Provisional Conclusions Guiding Refinement of Scenarios

The main conclusion derived from the formulation and evaluation of preliminary project scenarios is that conjunctive management based on re-operating reservoirs to release additional water supplies for environmental flow enhancements or water supply, backstopped by groundwater pumping when necessary, is hydrologically feasible. Modeling indicates that reservoir re-operation can produce appreciable additional water supplies while meeting all existing CVP and SWP obligations and regulatory requirements governing project operations, provided that groundwater pumping can be exercised when needed. The additional storage space evacuated by making additional reservoir releases is refilled primarily by retaining in storage high flows that otherwise would be released for flood control purposes. Groundwater pumping is called on in only about 1 year in 10, on average, and contributes roughly 10 percent to 20 percent of the reservoir payback with 80 percent to 90 percent of refill coming from surplus surface water that would otherwise have been lost.

Because groundwater is called on infrequently for reservoir payback, impacts to existing groundwater users and to flows in surface streams are modest. Effects on the operability and productivity of existing agricultural wells of additional groundwater pumping to backstop reservoir re-operation are negligible because the estimated changes in groundwater levels are small relative to the screened intervals of agricultural wells. Agricultural pumpers will incur some additional cost for pumping due to the moderately higher lifts caused by drawdown; however, these costs are very small relative to baseline pumping costs and could be mitigated. Because they are much shallower and have shorter screened intervals compared to agricultural wells, it is likely that some existing domestic wells would need to be deepened or replaced. It was estimated that between 6 and 284 domestic wells would need to be replaced depending on assumptions and the scenario considered. This is between 3 and 41 percent of the estimated number of wells in the estimated impact areas (areas with incremental drawdown greater than 2 feet), and between just 0.1 percent and 3 percent of the 9,000+ domestic wells in the region.

The most significant conclusion is that the net benefits of Sacramento Valley conjunctive operations are strongly dependent on where the water could be marketed and the price received. If the water is sold in the Sacramento Valley at current market rates, the project appears not to be economically justified. On the other hand, if the water could be conveyed south of the Delta for storage in a groundwater bank and sold at dry year market rates, the project appears to be economically viable. Of course, such an export operation would require resolution of current Delta conveyance and export constraints and further analysis beyond that performed in this phase of investigation.

Alternatively, if an in-Valley scenario is desired, there is a need to reduce project costs or increase benefits or some combination of the two. One means of reducing costs would be to avoid the large, infrequently utilized capital investments in groundwater production wells by relying to the maximum practical extent on existing groundwater wells. It should be noted, however, that using existing wells rather than constructing new ones does not completely eliminate capital investment because growers would need to be compensated for their sunk costs at a level that would attract them to willingly sell their wells or enter into use agreements. Additionally, some wells would need to be rehabilitated or re-equipped with electrical motors to avoid air emission regulations.

Another potential means of reducing costs would be to employ temporary crop idling as a payback mechanism because crop idling payments would be required only in the years when reservoir payback is triggered.

For purposes of expanding or enhancing project benefits, the decision was made to engage the CVP and SWP operators to see whether they could assist the project team in identifying additional objectives that might achieved through conjunctive operations. Consultation with the CVP and SWP operators is discussed in the next section along with the various refinements made to the surface water model to simulate project operations more realistically and to achieve additional project benefits.

6. Collaboration with CVP and SWP Operators for Refinement of Project Scenarios

6.1.Collaborative Workshops with CVP and SWP Operators

Beginning in April 2010, a series of three ½-day workshops were held with a select group of CVP and SWP operators for the purpose of refining project scenarios. The main purposes were: (1) to identify additional project purposes and benefits that could potentially be realized through conjunctive operations as a means of enhancing project economic performance and (2) to ensure that the simulations were as realistic as possible. The workshops were complemented with one-on-one consultations between operators and project team members as needed to clarify comments and develop specific recommendations for incorporation into scenario development and the supporting modeling methodology. The dates, purposes and outcomes of the workshops are summarized below. Outcomes are discussed in additional detail in the following sections.

- Workshop #1: April 8, 2010. The project team presented the particular conjunctive operations concept being develop (reservoir re-operation with groundwater pumping payback) and an overview of development and performance of the initial project scenarios with particular focus on the surface water model. The main outcomes of the workshop were the following operator recommendations:
    - Update the surface water model to operate from a baseline condition (represented in CALSIM II model outputs) that includes current environmental objectives and constraints (primarily the smelt and salmon BOs)
    - Modify the model to include a forecast-based method for estimating end of year (September) Shasta and Oroville reservoir storage levels (which are used quantifying project assets and project reservoir releases) rather than the method used for initial scenario analysis based on perfect foresight

- Workshop #2: July 9, 2010. The project team presented the refined surface model reflecting the updated CALSIM II baseline with smelt BO and salmon BO operating requirements, and a forecast-based reservoir storage estimating routine. The effects of these changes on project performance were presented and discussed. Further dialogue focused on project operation for additional benefits, including the ability to generate additional environmental flows, support in complying with smelt BO and salmon BO operational requirements, water supply reliability, operational flexibility and cold water pool management in Shasta and Oroville. The main outcome from the meeting was a decision that the project team would work with the CVP and SWP operators to explore two primary interests:
    - Project operations for the purpose of holding water in storage to recover reservoir storage levels
    - Balancing reservoir releases with risk to reservoir carryover storage and related cold water pool management

- Workshop #3: September 9, 2010. A meeting/gaming session was held with operators and the project team at which the surface water model was used to demonstrate effects of additional constraints suggested by the operators in Workshop #2. Generally these constraints reduced project benefits relative to the initial project scenarios and identified areas of risk due to project operations, particularly cold water pool management. Several options for additional analysis were discussed at this meeting, including: revising operator constraints to be less conservative, temperature modeling to refine operating rules, and further modeling to identify system-wide effects.

6.2.Surface Water Model Refinements

The collaborative engagement with CVP and SWP operators resulted in a number of suggestions for refinement to the initial surface water model. Each of these is described below.

6.2.1. Updated CALSIM II Baseline Conditions

As previously explained, the surface water model simulates conjunctive operations by tracking incremental changes from a baseline condition of flows and reservoir storage levels generated by a CALSIM II model run. The CALSIM II baseline used for the initial modeling pre-dated the 2008 Biological Opinion on delta smelt (smelt BO) and the 2009 Biological Opinion on Chinook salmon (salmon BO). The baseline was updated with a CALSIM II model run with the smelt BO and salmon BO included. This baseline was used for further development and evaluation of project scenarios.

6.2.2. Ability to Reduce Shasta Reservoir Releases to Recover Storage

CVP operators expressed concerns about the ability to reduce Shasta releases under conditions when releases are driven by temperature compliance in the Sacramento River below the reservoir rather than water supply demands further downstream. Constraints on the ability to reduce Shasta releases were specified in the form of monthly minimum Keswick releases for temperature compliance, presented below in TABLE 6-1.

TABLE 6-1
Minimum Keswick Release for Temperature Compliance (cfs)
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Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
6,000	5,000	4,000	4,000	4,000	6,000	7,000	9,000	11,000	13,000	12,000	11,000

The values presented in Table 6-1 are the minimum flows that operators thought were possible while achieving Sacramento River temperature compliance. The significance of these minimum flows is that only the portion of baseline Keswick releases in excess of the minimum flows in TABLE 6- can be held in storage and offset by a similar quantity of groundwater pumping or water made available through crop idling. These minimum Keswick release constraints significantly reduced the ability of the project to recover reservoir storage through reservoir payback mechanisms.

Constraints on the ability to reduce Oroville releases for temperature compliance were specified by SWP operators in a different manner, expressed as a function of Oroville release according to the following Table 6-2.

This constraint allows project operations to recover reservoir storage lowered due to project releases, or to increase carryover storage levels above those in the baseline simulation.

TABLE 6-2
Ability to Reduce Oroville Release (cfs)
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Oroville Release (cfs)	Oct	Nov	Dec-Jun	Jul	Aug	Sep
< 3,000	0	0	0	0	0	0
3,000 – 6,000	500	500	0	500	500	500
> 6,000	1,000	1,000	0	1,000	1,000	1,000

6.2.3. Forecast-Based Operations

The initial surface water model made project asset decisions (volume of additional reservoir release) based on a perfect forecast of September reservoir storage. The implication of this assumption was to minimize the risk of achieving targeted levels of carryover storage due to conjunctive operations. In actual operation, decisions would have to be made based on assumed reservoir inflows and releases to forecast fall reservoir storage. To the extent that actual conditions differ from those assumed for the forecast, actual fall reservoir storage could fall short of certain targets or could impact temperature compliance operations, in some years. The initial model did not simulate these risks.

The surface water model was refined to include a forecast of fall storage conditions based on current reservoir storage, runoff forecasts, and an estimate of reservoir releases from the current month through September. Runoff forecasts at different exceedance levels are used during the spring with more conservative forecasts (user-defined 90 or 99 percent exceedance) used in February and March, respectively. A method to estimate reservoir release volumes was developed for Shasta and Oroville by correlating simulated CalSim II releases with a system-wide CVP water supply index and SWP allocations, respectively. The CVP water supply index is the sum of current storage in Trinity, Shasta, Folsom, and CVP San Luis plus runoff forecasts on the Sacramento and American Rivers, plus Kings River flow to Mendota Pool. The CVP water supply index and runoff forecasts for the Sacramento, Feather, and American Rivers are the same as used in CalSim II for simulation of CVP/SWP operations. Initial correlations were developed and adjusted to balance how forecasted storage compared with CalSim II simulated storage across various year types.

6.2.4. Oroville Carryover Targets

SWP operators expanded a previous project objective related to carryover storage in Lake Oroville. Oroville storage targets were defined to increase carryover storage when at or below 1.5 million acre-feet (MAF) under base conditions by up to a maximum of 200 thousand acre-feet (TAF). These targets were developed to assist in mitigating effects of damage to the low-elevation outlet that occurred during gate testing several years ago. Damage to the low-elevation outlet has effectively increased dead storage in Lake Oroville leading to a desire to increase carryover storage.

6.2.5. Crop Idling for Reservoir Payback

The surface water model was modified to simulate crop idling as a payback mechanism to recover reservoir storage. Assumptions used in the model to simulate crop idling include annual evapotranspiration of applied water (ETAW) for rice (the dominant crop in both project areas), the monthly pattern of ETAW, total number of acres available for crop idling within the project areas, and the decision month for implementing crop idling. An estimate of the maximum total number of acres available for crop idling within each project area was made based on requirements for crop idling contained in an April 2009 Memorandum from the United States Fish and Wildlife Service (USFWS) on

Endangered Species Consultation on the Proposed 2009 Drought Water Bank (2009 USFWS Memo) and the February 2010 Final Environmental Assessment for the 2010-2011 Water Transfer Program (2010 EA) by the United States Bureau of Reclamation (Reclamation). Limitations on acres available for crop idling are established to protect endangered species habitat for the Giant Garter Snake. An additional assumption that no more than 20 percent of the total rice acreage with the project area would be idled in any year was made based maximum potential participation by growers and local acceptability.

Total rice acreage, maximum acres available for crop idling, and maximum annual quantities of surface water made available by crop idling are summarized in TABLE 6-3. Rice ETAW was assumed to be 3.3 acre-feet per acre for the may through September period, distributed monthly as follows: May, 15 percent; June, 22 percent; July and August, 24 percent each; and September, 15 percent.

TABLE 6-3
Summary of Rice Acreage and Maximum Acres for Crop Idling with each Project Area
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Project Area	Total Rice Acreage (acres)	Max. Percent of Acres Idled in Any Year	Max. Acres Idled (acres)	Max. Annual Quantity of Surface Water Made Available by Crop Idling (acre-feet)
GCID	105,000	20%	21,000	69,300
Butte Basin	78,000	20%	15,600	51,480

It was assumed that decisions on acres idled would be made in March, the same decision month for project assets and releases. Compared to decisions involving groundwater pumping for reservoir payback, crop idling decisions must be made earlier in the year, prior to planting before growers make financial outlays for rice production (field preparation, seed, fertilizer, pesticides, and other costs). The earlier decisions necessary for implementing crop idling can result in more frequent crop idling compared to groundwater pumping. Additionally, the fixed pattern of when water is made available with crop idling can result in water made available when it is impossible for it to be held in upstream reservoirs or put to beneficial use downstream. For example, 37 percent of water made available from crop idling occurs in May and June, but it is not possible to reduce Oroville releases in these months (see TABLE 6-2).

6.3.Refined Model Simulation Results

The surface water model was refined to include the first three operator recommendations discussed above; namely, to use an updated CALSIM II baseline; to include restrictions on the extent to which reservoir releases could be reduced due to temperature considerations; and to include a forecast-based estimate of September reservoir levels to use as a basis for calculating project assets and determining additional environmental releases and agricultural deliveries. All of these features make the project simulations more realistic. Once the model was refined, it was used to reevaluate the initial project scenarios and to evaluate the feasibility of operating the project to sustain Oroville carryover storage and using temporary crop idling as a reservoir payback mechanism.

The refined model resulted in differences between how the project operates with the CVP/Shasta Reservoir versus the SWP/ Oroville Reservoir. Therefore results and conclusions are presented below for the CVP and SWP, respectively.

6.3.1. CVP and Shasta Reservoir Results

6.3.1.1. Operations for Core Project Purposes

A comparison of initial and refined simulation results are presented in Table 6-4 for the 100 TAF and 200 TAF GCID project scales (pumping capacity). For the 100 TAF scale, project benefits are reduced by more than 50 percent, from 27 TAF to 12 TAF, with environmental releases reduced by almost two-thirds and agricultural deliveries reduced by half. Corresponding to the reduction in project benefits, reservoir payback is accomplished almost entirely by refill with surplus surface water. Project pumping is reduced from 4 years over the 82-year simulation to just 1 year and the maximum year pumping is reduced from 98 TAF to just 6 TAF. Average annual project pumping was 3 TAF.

TABLE 6-4
Comparison of Initial to Refined Simulation or Project Scenarios (Shasta/CVP)
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			Project Benefits (TAF)			**Reservoir Payback (TAF)**			**Project Pumping**		
Scenario #	**Project Scale (Pumping Capacity)**	**Model**	**Enviro. Release**	**Ag. Deliveries**	**Total Project Benefit**	**Surplus Surface Water**	**Project Groundwater Pumping**	**Total**	**Number of Years**	**Peak Year Pumping (TAF)**	**Peak Pumping Year**
1, 3 and 4	100 TAF	Initial	13	14	27	24	3	27	4	98	1990
		Revised	5	7	12	12	0	12	1	6	1976
		Difference	-8	-7	-15	-12	-3	-15	-3	-92	N/A
2	200 TAF	Initial	45	22	67	58	9	67	6	195	1990
		Revised	15	8	23	23	0	23	1	6	1976
		Difference	-30	-14	-44	-35	-9	-44	-5	-189	N/A

Results for the 200 TAF project scale are even more dramatic, with project benefits reduced by roughly two-thirds for both environmental releases and agricultural deliveries. Even at this scale, reservoir refill is accomplished almost entirely with surplus surface water and negligible groundwater pumping.

The dramatically reduced benefits under the refined operations are due primarily to the effects of forecast-based operations added to the model. The forecast of September storage is deliberately conservative to avoid excess risk to reservoir storage; it is based on a 90 percent exceedance forecast for March runoff and 50 percent exceedance in later months. This frequently results in an under estimation of available project assets and therefore much smaller reservoir releases for environmental flows and agricultural water supplies compared to the initial modeling based on perfect storage forecasts.

The minimum Shasta (Keswick) release constraints prescribed by the operators, together with the forecast-based simulation, also resulted in some additional risk to reservoir carryover storage relative to baseline conditions. The risk was greatest when Shasta storage is below 2.0 MAF when project releases in one year are not refilled from surplus surface water in subsequent years and the project is not able to recover the storage deficit due to an inability to reduce reservoir releases and retain payback water into Shasta. The project is not able to recover the storage deficit due to the minimum Keswick release requirement prescribed by operators for purposes of complying with Sacramento River temperature requirements for protection of endangered species. Simulated project operations resulted in slightly diminished ability to meet Shasta carryover targets specified in the salmon BO relative to the CALSIM II baseline.

Because the minimum Keswick releases had such a strong effect on project performance, the model was used to test the sensitivity of Shasta carryover storage to relaxed minimum release targets relative to those specified by the operators. Relaxing the minimum releases by 2,000 cfs in all months (relative to those listed in Table 6-1) revealed only limited potential to improve carryover storage conditions when below approximately 2.0 MAF. Because of the significant constraints posed to project operation by the Keswick releases, it was concluded that temperature modeling should be performed to better evaluate relaxed minimum reservoir releases and the resulting implications to temperature compliance operations.

6.3.1.2. Effectiveness of Temporary Crop Idling as a Payback Mechanism

The operator-prescribed constraints on the ability to retain payback water in Lake Shasta discussed above also apply to crop idling. However, there are additional factors associated with crop idling related to the timing of decision making and the inflexibility in when the water is produced that affect its performance as a payback mechanism.

As previously explained, crop idling decisions need to be made earlier in the season and involve making an irreversible commitment to participating growers for purchasing the water generated through crop idling regardless of whether or not the water can be held in upstream storage or put to beneficial use downstream.

A scenario was evaluated where idling provided 70 TAF of payback capacity (requiring idling of 21,000 acres of rice land) and groundwater pumping 130 TAF to achieve a total of 200 TAF of payback in GCID (corresponding to Scenario 2). Payback priority was placed on crop idling in order to minimize groundwater pumping. Under these assumed conditions, crop idling was called on about 1/3 of the time during the 82-year simulation, in most cases utilizing the maximum 70 TAF of payback capacity and associated land idling (21,000 acres). It was found that only 17 percent of the water generated by idling was actually retained in Shasta to recover reservoir storage due to much of the water being produced when minimum Shasta releases for temperature control were controlling. It was shown that the effectiveness of crop idling is sensitive to the magnitude of the specified minimum releases. When releases were relaxed by 2,000 cfs in all months as described above, the portion of idling payback water retained in storage increased to 58 percent and the frequency with which idling was called on was reduced.

As expected, placing priority on idling for reservoir payback was found to appreciably reduce the magnitude of groundwater pumping needed for Shasta payback.

While the effectiveness of crop idling probably could be improved through refinement in when and how it is called on, and despite the fact that it can be used to offset groundwater pumping for payback, it is doubtful that crop idling offers a cost-effective means of reservoir payback due to the risks associated with the early timing of the decision, the irreversible commitment to follow through once a decision has been made, and the inflexible pattern on which water is made available.

6.3.1.3. Operation for Cold Water Pool Management

During collaborative discussions with operators, interest was expressed in evaluating how project operations could be used to improve carryover storage and management of cold water resources in Lake Shasta. An additional analysis was conducted with the refined surface water model to estimate the upper limit of potential project contributions to carryover storage (based on 200 TAF of pumping capacity in GCID). The minimum Keswick release constraints discussed above were maintained for this analysis; however, it was assumed that project pumping capacity would be used whenever it was possible to back water into storage, regardless of storage conditions.

This analysis revealed that project pumping frequency and magnitude were significantly increased relative to the levels observed for operations for generating additional reservoir releases, probably to levels that would be problematic from the standpoint of groundwater impacts. Additionally, the analysis showed that most of the water placed in storage was subsequently lost as reservoir spillage due to the high probability of reservoir refill from runoff. This scenario was simulated with only groundwater pumping as a payback mechanism to simplify the analysis. Although crop idling is not precluded as a payback mechanism and could be explored, it is likely that it would perform even less efficiently due to the issues discussed above.

Operating the project in this manner to maintain Shasta storage is fundamentally in conflict with operations for increasing reservoir releases to generate project benefits; nevertheless, project reservoir releases were included in the simulation because they are fundamental to the project goals. As expected, benefits increase slightly due to project water stored in Shasta in previous years being available in subsequent years for release.

This scenario could be refined to limit pumping based on Shasta storage, thereby reducing both pumping and project spills and creating a more efficient operation; however, the high probability of reservoir refill from runoff puts project generated storage at high risk of spilling. Additionally, the relatively high frequency and large magnitudes of pumping involved would likely create unacceptable impacts. The scenario was useful for understanding the upper limit of conjunctive operations to increase carryover storage but it does not appear to be a feasible mode of project operation.

6.3.1.4. Yolo Bypass Inundation

The CVP and SWP operators also expressed interest in evaluating methods to increase the frequency, duration, and magnitude of flooding in the Yolo Bypass. Results from the initial analyses indicated the Yolo Bypass could be inundated more frequently if it was possible to notch the Fremont Weir, which currently blocks flow into the bypass below certain river stages, to allow inundation at lower river stages and flows. Weir modifications were the cause of increased Yolo Bypass inundation in 19 out of 20 years when the project (as opposed to base operations) inundated the bypass in the phase 1 analysis. Increased project releases inundated the bypass in the other year.

An additional analysis was conducted with the refined surface water model to estimate the upper limit of the ability of the project to increase inundation in the Yolo Bypass. This analysis included turning off all other environmental objectives to ensure inundation was the first priority objective every year and would not be affected by releases for lower priority objectives in previous years. It was revealed that the project would enable Yolo Bypass inundation in an additional 20 years relative to baseline operations; however, as with the initial analysis, all 20 years were due to weir modification, not additional project release. Therefore, in all years the water cost associated with inundating the Yolo Bypass exceeded project assets. This is not an unexpected result given the significant reduction in project assets caused by the addition of forecast-based operations as recommended by the project operators.

6.3.2. SWP and Oroville Reservoir Results

The results discussed below are for simulations made with the addition of forecast-based operations, restrictions on ability to reduce Oroville releases, and addition of carryover storage targets as described above. Additionally, it should be noted that updating the base conditions to include the smelt and salmon BOs had a more significant effect on Oroville operation than on Shasta operations. Operations under the smelt BO and salmon BO result in lower storage in Oroville. This occurs because winter and spring Delta export restrictions reduce the SWP's ability to capture Delta surplus in those months, which results in increased reliance on Oroville storage releases into the Delta in the summer and early fall.

6.3.2.1. *Operations for Core Project Purposes*

A comparison of initial and refined simulation results are presented in Table 6-5 for the 50 TAF and 100 TAF Butte Basin project scales (pumping capacity). For the 50 TAF scale, project benefits are reduced by about 40 percent, from 17 TAF to 10 TAF, with agricultural deliveries being reduced by 50 percent and environmental releases by 30 percent. For both the initial and refined simulation about 80 percent of reservoir refill is accomplished by surplus surface water and 20 percent by project pumping, although the total refill is reduced in the refined simulation corresponding to the reduction in project benefits. Average annual project pumping is reduced from 3 TAF to 2 TAF, but the number of years of pumping and peak annual pumping are not appreciably reduced.

The disproportionate reduction of agricultural benefits noted above is due to the combination of lower base storage conditions, higher carryover storage targets, and assumptions on additional agricultural demands that are based on water year types. Lower base storages combined with higher carryover storage targets reduce the frequency and volume of project assets and typically result in assets being available in only wetter year types (when agricultural shortages tend not to occur). Additional agricultural demands are assumed to be higher in drier year types, when project assets are less, thereby reducing average annual project agricultural deliveries and shifting more of the deliveries into wetter year types. Overall, project benefits are reduced by 30 percent relative to the initial 100 TAF Butte Basin scenario.

TABLE 6-5
Comparison of Initial to Refined Simulation of Project Scenarios (Oroville/SWP)
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			Project Benefits (TAF)			Reservoir Payback (TAF)			Project Pumping		
Scenario #	Project Scale (Pumping Capacity)	Model	Enviro. Release	Ag. Deliveries	Total Project Benefit	Surplus Surface Water	Project Groundwater Pumping	Total	Number of Years	Peak Year Pumping (TAF)	Peak Pumping Year
1, 3 and 4	50 TAF	Initial	7	10	17	14	3	17	6	50	1961, 1992
		Revised	5	5	10	8	2	10	5	49	1925
		Difference	-2	-5	-7	-6	-1	-7	-1	-1	N/A
2	100 TAF	Initial	23	20	43	36	7	43	8	100	1961, 1992
		Revised	18	9	27	24	3	27	6	99	1925
		Difference	-5	-11	-16	-12	-4	-16	-2	-1	N/A

Modification of carryover storage targets results in more frequent project pumping (or crop idling) and spill of project water stored in Oroville. Average annual pumping increases from

Additional pumping and storage also provides a slight increase in project agricultural and environmental benefits because water stored in Oroville is a project asset and available for meeting project objectives in future years. This results in a less efficient operation (with efficiency defined as refill of project releases for agricultural and environmental purposes from capture of surplus surface water as opposed to groundwater pumping), but a similar level of benefits.

6.3.2.2. *Effectiveness of Temporary Crop Idling as a Payback Mechanism*

As noted above (see Table 6-4), crop idling in the Butte Basin has the potential to provide approximately 50 TAF of water in a year by idling approximately 15,600 acres, or 20 percent of the rice acreage in Western Canal Water District and Richvale Irrigation District. A scenario was evaluated where idling provided the 50 TAF of payback capacity noted above and groundwater pumping 50 TAF to achieve a total of 100 TAF of payback in GCID (corresponding to Scenario 2). Payback priority was placed on crop idling in order to minimize groundwater pumping.

Under these assumed conditions, crop idling was called on about 40 percent of the time during the 82-year simulation, in most cases utilizing the maximum 50 TAF of payback capacity and associated land idling (15,600 acres). It was found that about 50 percent of the 23 TAF of water generated by crop idling was retained in Oroville to recover reservoir storage with the remainder spilled.

As expected, placing priority on idling for reservoir payback was found to appreciably reduce the magnitude of groundwater pumping needed for Oroville payback. Average annual payback pumping was reduced from 20 TAF to 10 TAF.

6.4.Conclusions Drawn from Refined Model and Scenario Analyses

Several conclusions were drawn from the refined modeling and scenario analyses to guide development of project scenarios that are most likely to provide cost-effective opportunities for achieving the environmental and water supply benefits possible through conjunctive operation Sacramento Valley surface water and groundwater reservoirs. These conclusions are discussed below:

1. The input and recommendations provided by CVP and SWP operators for refining project scenarios reflect the challenges and risks that they routinely face in balancing project operations for water supply and complying with environmental regulations governing project operations. In particular, as described above, project operators were primarily interested in conjunctive operations for the purpose of maintaining reservoir levels when reservoir storage dropped below certain thresholds as a means of observing carryover storage and increasing the probability of complying with temperature standards. While logical from a risk management perspective, operating conjunctively for this purpose cuts deeply into the ability to generate additional water supplies for environmental releases and water supply. Additionally, the efficiency of reservoir payback operations is reduced appreciably because much of the project water placed in storage eventually spills due to subsequent reservoir refill from surplus flows.

   These findings reveal important and complex tradeoffs among environmental objectives that are embedded in project operations. By definition, producing additional water supplies to dedicate to environmental flows without infringing on base supplies to CVP and SWP contractors involves making additional reservoir releases. However, increasing reservoir releases reduces reservoir storage and unavoidably introduces some additional risk to coldwater pool management.

2. The minimum Keswick releases specified by the CVP operators as surrogates for temperature targets in the Sacramento River dramatically reduce the effectiveness of reservoir payback operations because payback is possible only when reservoir releases exceed the minimum specified values. This reduces the time during which water generated by payback operations can actually be used to offset reservoir releases. This is another manifestation of the tradeoffs among environmental objectives, with the objective of maintaining river temperature constraining the ability to operate conjunctively for other environmental benefits.

3. The general conclusion to be drawn from 1) and 2) above is that the tradeoffs among environmental objectives call for further investigation and development of operating strategies and criteria that best balance competing objectives for maximum net environmental benefit.

Addressing this need is foundational to moving ahead with development of conjunctive management strategies for the Sacramento Valley. However, until tradeoffs among environmental objectives are reconciled, planning must account for the operational constraints as they are currently defined.

4. Crop idling is an inefficient payback mechanism in comparison to groundwater pumping. The main reasons are that crop idling must be triggered early in the year before farmers commit to planting crops, which introduces additional risk in forecasting the need for the payback water, and that once the commitment is made, it cannot be undone. These factors result in frequent, unnecessary crop idling with associated lost production, with much of the water made available being lost as reservoir spillage or surplus Delta outflow. The original attraction to temporary crop idling was that it does not require up front capital investment and can be exercised as needed on a year to year basis. However, the inefficiencies revealed through the simulations suggest that crop idling is likely to be a less viable, and undoubtedly less acceptable, payback mechanism as compared to groundwater pumping, especially if pumping can be achieved with existing groundwater production wells to minimize required capital inputs.

5. All of the various suggestions for refinement of the project scenarios and model have the effect of either reducing project benefits (relative to the initial analysis) or reducing the efficiency of payback operations, thereby detracting from project cost-effectiveness.

Based on these conclusions, further planning and modeling proceeded within a framework defined by the following parameters:

1. The project baseline will be represented by a CALSIM II run that includes the effects of the smelt and salmon BO’s.

2. Forecast based operations will be used because they are more realistic.

3. Restrictions on reservoir releases as specified by CVP and SWP operators will be observed because they are the best available representation of temperature compliance conditions.

4. The objective will be to generate benefits through additional environmental releases and water supplies, not through operations to sustain reservoir levels.

5. Payback operations will be based on groundwater pumping, not temporary crop idling.

6.5. Analysis of Project Scale

Within the planning and modeling framework defined above, a set of model runs was made for the two project areas to examine the relationship between project payback capacity, simulated project pumping and project benefits. In addition to the parameters specified above, a decision was made to use a summer and fall payback pumping period, rather than summer only, to maximize the opportunity for payback operations, thereby minimizing the constraint posed by minimum reservoir releases. The results are presented and discussed separately for the two project areas.

6.5.1. GCID/CVP-Shasta

A set of 11 model runs were made with specified payback pumping ranging from 20 TAF to 300 TAF and all other model parameters held constant. This wide range was selected to better understand project performance from the surface water perspective and does not reflect an assumption or an assertion that annual pumping volumes of up to 300 TAF would be feasible in GCID. Results are summarized Table 6-6.

TABLE 6-6
GCID/CVP-Shasta Average Annual Project Benefits, Reservoir Payback and Project Pumping in Relation to Project Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Avg. Annual Project Benefits (TAF)			Average Annual Reservoir Payback (TAF)			Project Pumping		
Payback Pumping Capacity	Enviro. Release	Ag. Deliveries	Total	Surplus Surface Water	Groundwater Pumping	Total	Peak Annual Pumping	Percentage of Payback Capacity Used	Peak Pumping Year
20	0	3	3	3	0	3	3	15%	1930
40	1	4	5	5	0	5	6	15%	1930
60	3	4	7	7	0	7	9	15%	1930
80	4	5	9	9	0	9	11	14%	1930
100	5	7	12	12	0	12	11	11%	1930
120	7	8	15	15	0	15	11	9%	1930
150	11	8	19	19	0	19	11	7%	1930
200	15	8	23	23	0	23	11	6%	1930
240	20	9	29	28	1	29	96	40%	1939
270	24	7	31	30	1	31	98	36%	1939
300	25	7	32	30	2	32	98	33%	1939

It can be seen that, as pumping capacity increases, average annual project benefits are initially weighted in favor of agricultural deliveries but then switch in favor of environmental releases when capacity exceeds about 120 TAF. This is due primarily to environmental release targets being large and being made only when they can be completely satisfied. Smaller pumping capacities and associated project assets reduce the likelihood of being able to make these large releases. In contrast, agricultural deliveries are typically smaller than environmental releases and do not need to be fully satisfied; thus, some agricultural releases are possible even with very small project pumping capacities. Project benefits in relation to project pumping capacity are plotted in Figure 6-1.

It is important to note that the average annual total project benefit (sum of environmental releases and agricultural deliveries) is much smaller than the specified pumping capacity over the full capacity range evaluated. As previously discussed, this stems primarily from the nature of forecast-based operations and the associated conservative estimates of project assets used to avoid excessive risk to reservoir storage.

As expected, average annual reservoir payback is weighted strongly in favor of surplus surface water over the full range of pumping capacity, due to priority being placed on refill from surplus surface flows and pumping being called on only when needed. Simulated average annual project pumping is negligible until the specified pumping capacity exceeds 200 TAF, and then is modest on an average annual basis.

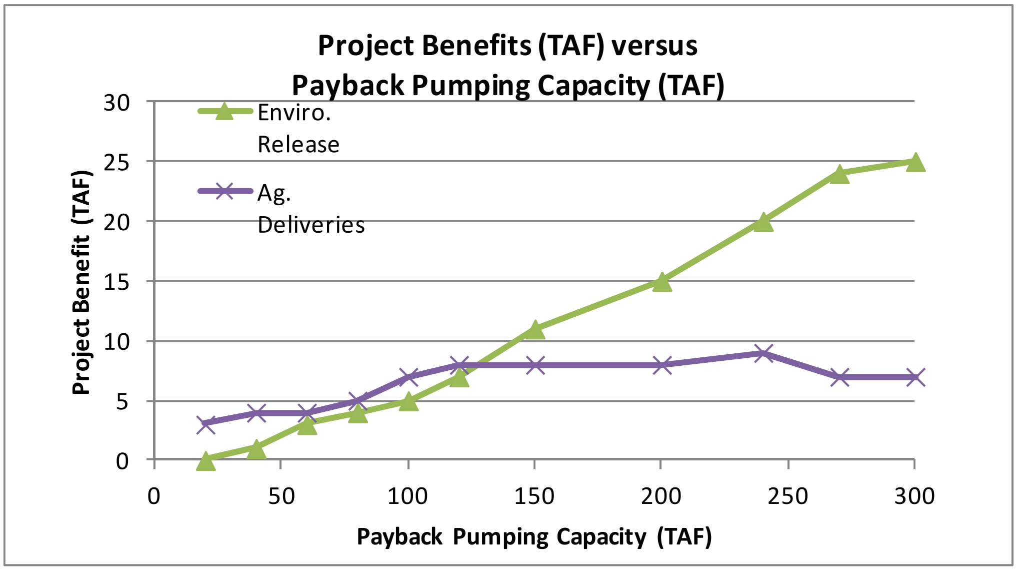

FIGURE 6-1
GCID/CVP-Shasta Average Annual Project Benefits in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Peak year pumping is negligible below a pumping capacity of 200 TAF, ranging between 3 TAF and 11 TAF (Table 6-6, Figure 6-2). Above pumping capacity 200 TAF, when larger project assets are available and large environmental releases become possible, peak year pumping increases appreciably, utilizing more of the available pumping capacity. However, even at these levels, simulated peak year pumping is less than half of the pumping capacity. This is explained by the same factors discussed above in relation project benefits being small in relation to pumping capacity. Additionally, simulated pumping is constrained when minimum Keswick releases govern and it is not possible to hold payback water in storage.

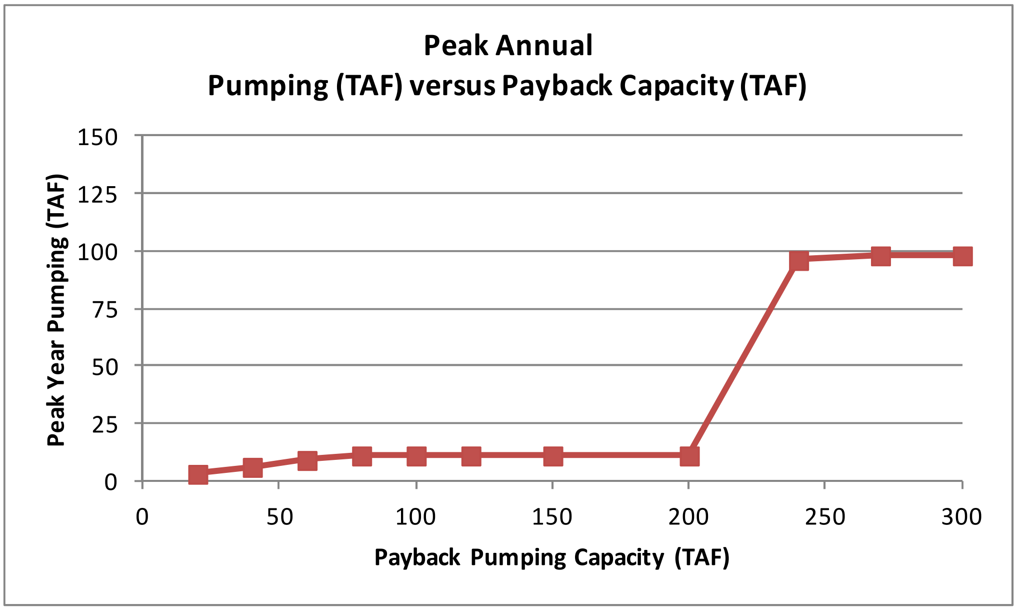

FIGURE 6-2
GCID/CVP-Shasta Peak Annual Project Pumping in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

6.5.2. Butte Basin/SWP-Oroville

A set of model runs analogous to those made for GCID were also made for the Butte Basin, with specified payback pumping ranging from 20 TAF to 300 TAF and all other model parameters held constant. As noted above, this wide range was selected to better understand project performance from the surface water perspective and does not reflect an assumption or an assertion that annual pumping volumes of up to 300 TAF would be feasible in Butte Basin. Results, summarized in Table 6-7, are similar to those for GCID, with certain exceptions.

TABLE 6-7
Butte Basin/SWP-Oroville Average Annual Project Benefits, Reservoir Payback and Project Pumping in Relation to Project Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Avg. Annual Project Benefits (TAF)			Average Annual Reservoir Payback (TAF)			Project Pumping		
Payback Pumping Capacity	Enviro. Release	Ag. Deliveries	Total	Surplus Surface Water	Groundwater Pumping	Total	Peak Annual Pumping	Percentage of Payback Capacity Used	Peak Pumping Year
20	0	3	3	2	1	3	12	60%	1925
40	3	4	7	6	1	7	24	60%	1925
60	8	5	13	11	1	12	36	60%	1925
80	13	7	20	17	2	19	48	60%	1925
100	18	9	27	24	3	27	59	59%	1925
120	19	10	29	26	3	29	71	59%	1925
150	19	11	30	26	4	30	89	59%	1925
200	23	9	32	29	4	33	91	46%	1925
240	36	10	46	41	4	45	125	52%	1955
270	42	11	53	47	5	52	130	48%	1955
300	51	10	61	55	5	60	130	43%	1955

Similar to GCID, as pumping capacity increases, average annual project benefits are initially weighted in favor of agricultural deliveries but switch more quickly in favor of environmental releases. Above about 40 TAF of pumping capacity, environmental benefits gradually increase while agricultural deliveries plateau at about 10 TAF above 100 TAF of capacity. The factors explaining this are generally the same as for GCID. Project benefits in relation to project pumping capacity are plotted in Figure 6-3.

As in GCID, the average annual total project benefit (sum of environmental releases and agricultural deliveries) is small relative to the specified pumping capacity over the full capacity range evaluated.

As expected, average annual reservoir payback is weighted strongly in favor of surplus surface water over the full range of pumping capacity, due to priority being placed on refill from surplus surface flows and pumping being called on only when needed. However, in contrast to GCID, both refill from surplus surface water and from project pumping increase gradually over the full range of project pumping.

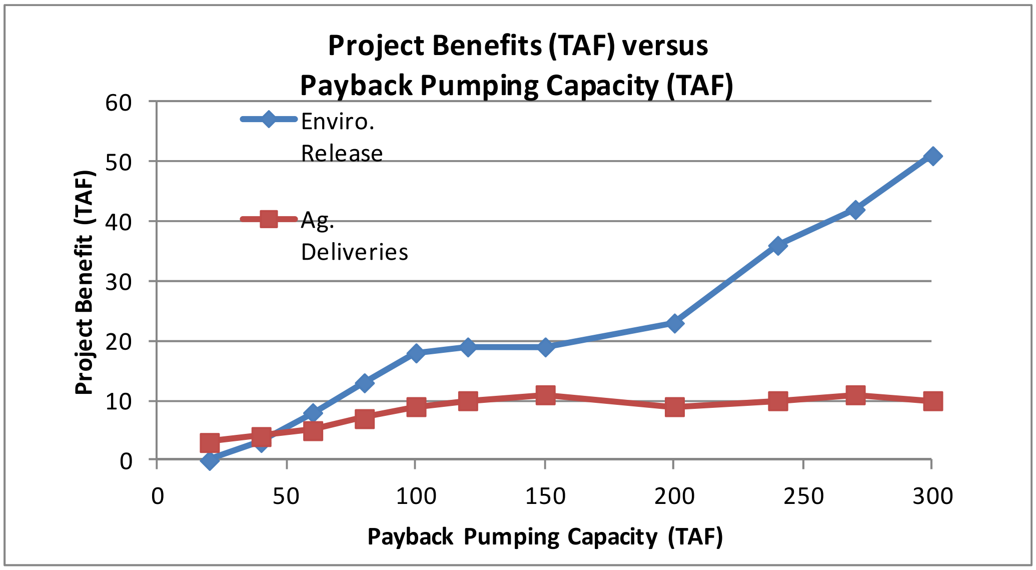

FIGURE 6-3
Butte Basin/SWP-Oroville Average Annual Project Benefits in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Somewhat different than in GCID, peak year pumping increases more or less in proportion and is larger relative to project pumping capacity (Table 6-7, Figure 6-4). Peak year pumping ranges from 12 TAF to 130 TAF, representing between 43 percent and 60 percent of specified pumping capacity.

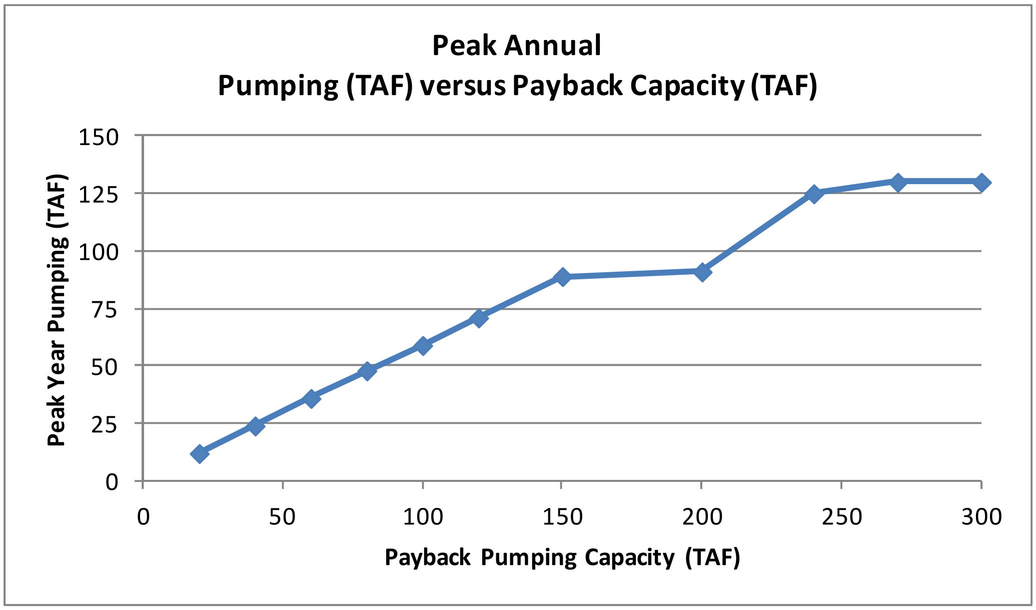

FIGURE 6-4
Butte Basin/SWP-Oroville Peak Annual Project Pumping in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

6.5.3. Discussion

The most important revelation from the foregoing analysis of project scale is the significant underutilization of payback pumping capacity in both project locations. Over the 82-year period of analysis and the range of payback capacities evaluated (20 TAF to 300 TAF), the maximum annual payback pumping in GCID was just 40 percent (at 240 TAF capacity; see Table 6-7) and was just 60 percent of capacity in Butte Basin (between capacity 20 and 80 cfs; see Table 6-7). Average annual pumping is even more extreme in both locations, with less than 1 percent of capacity used on average in GCID and less than 2 percent used on average in Butte Basin.

The low utilization of project pumping capacity stems in part from the conservative nature of the forecast September reservoir storage, which tends to underestimate project assets, and in part from constraints on payback pumping posed by minimum reservoir releases made for temperature control purposes. However, regardless of its cause, the low utilization of project pumping capacity combined with its high capital cost is economically infeasible and indicates that other approaches should be pursued to enhance project economics. One alternative would be to not attempt to recover reservoir levels reduced by project operations and instead incur some level of increased risk that CVP and SWP water deliveries would be reduced. This approach violates one of the original project principles, but may be a reasonable solution all factors considered. This idea is explored further as a recommendation for further investigation (see Section 7).

7. Recommendations for Further Investigation

The seminal conclusion of this investigation is that re-operating Shasta and Oroville Reservoirs in conjunction with operation of Sacramento Valley groundwater aquifers could produce appreciable additional water supplies with low risk to CVP and SWP reservoir storage levels and water deliveries, including requirements to maintain environmentally mandated water temperatures under most conditions. While an economically feasible in-Valley operation scenario was not identified by the investigation, prospects of a viable formulation appear promising and further development and integration of the core concept appears warranted.

The particular topics described in the following sections are in the opinion of the project team the highest priority issues to be addressed moving ahead. These are primarily technical in nature, involving reconciling tradeoffs among different types of environmental water uses, more detailed water temperature modeling, refined reservoir payback operations, integration with south of Delta groundwater banking and refinement of analytic tools.

Beyond the technical factors lie significant institutional and social challenges that would need to be addressed if there is sufficient interest in advancing the project toward implementation. These include the following:

- Developing protocols and procedures for real-time operations decisionmaking that are more nuanced and realistic than the procedures and criteria that have been used to simulate conjunctive operations for planning purposes. Ultimately, these procedures would need to be integrated into the Coordinated Operations Agreement, which governs the combined operation of the CVP and SWP.

- Developing project governance structures among local political jurisdictions. This phase of project planning was conducted without regard to ultimate project sponsorship. The presumption, however, is that a Sacramento Valley conjunctive water management project like that described in this document would most logically be sponsored and operated by a coalition of local political jurisdictions, potentially including counties and existing water suppliers (local districts).

- Developing formulae for allocating project benefits and costs, which would be needed to develop plan for financing project implementation, if the project moves ahead.

7.1. Reconcile Tradeoffs among Environmental Project Functions

A major revelation of this investigation is that opportunities for enhancement of Sacramento and Feather River ecologic functions (as well as opportunities to produce additional water supplies for in-Valley uses) are dramatically constrained by existing environmental requirements placed on CVP and SWP operations. In particular, the study revealed that CVP operations are frequently governed by releases for temperature compliance in the Sacramento River below Shasta, which has the effect of reducing the ability to recover Shasta by project pumping because pumped water cannot be retained in storage. In effect, the magnitude of the water asset that could be developed through conjunctive operations is diminished, which reduces the ability to fulfill the geomorphic, flood plain inundation and spring pulse flow objectives identified by the study.

Efforts are urgently needed to establish the relative benefits of alternative, competing environmental water uses so that ecosystem functions can be restored and species can be recovered while overall water use efficiency is enhanced. This calls for cooperation and compromise among the various fish and wildlife management agencies as well as ongoing research and adaptive management.

7.2.Refine Reservoir Operation Rules Based on Temperature Modeling

In the simulations conducted for this investigation, water temperature objectives were represented indirectly by minimum reservoir releases provided by project operators. These flows are based on operator judgment and provided useful guidance for investigation thus far. However, because the minimum flows were found to dramatically reduce the efficiency of payback operations, as noted above, it is recommended that more sensitive operating rules be developed through application of temperature models.

The recommended approach is to conduct a series of parametric CALSIM II model runs where operating objectives and constraints are held constant while minimum reservoir releases are varied over a range between the relatively conservative flows that were used in this investigation down to flows that would likely be inadequate to achieve temperature targets. Then one (or possibly more) of the existing temperature models would operate on the CALSIM II outputs to estimate the water temperatures that would occur under each flow regime. This would presumably provide insights into the nature of water temperature fluctuations as they relate to flows, time of year and other factors, and provide a basis for developing more sensitive operating rules. The refined rules would then be incorporated into the surface water model for use in formulating, comparing and evaluating project scenarios.

7.3.Refine Reservoir Payback Pumping Strategies and Costs

The investigation revealed that developing new groundwater production wells for payback pumping is not cost-effective because the wells are expensive, they are called on only infrequently and their operation for recovering reservoirs is limited by other operation requirements, particularly, by reservoir releases made to comply with temperature requirements. Large investment in capital works that are rarely used simply does not make good economic sense. This is why temporary crop idling was investigated as an alternative payback mechanism, because costs are incurred only when idling is called on. Unfortunately, however, crop idling is not compatible with the project’s operational requirements and would be triggered in many cases when it is not ultimately needed or the water generated cannot be held in storage.

In the next phase of work, three alternative payback strategies should be explored. Each of these is described below; however, it should be kept in mind that the strategies could be combined for optimal project performance.

7.3.1. Revised Temporary Crop Idling

The investigation revealed that temporary crop idling is not an efficient form of reservoir payback, mainly because much of the water generated by crop idling is either later found to not be needed or is stored in project reservoirs and subsequently spills. These outcomes result from the decision to exercise crop idling being made in February when forecasts of September reservoir storage are relatively uncertain. Once made the commitment to idle land (by paying voluntarily enrolled growers) is irreversible and the water generated is frequently not used.

Rather than make the decision to idle land in February, the possibly of making the decision later, when better forecasts of reservoir storage can be made, should be explored. Under this arrangement, growers would commit to growing their crops but they would enter voluntarily into agreements that would allow the project to interrupt water supplies at any time. For example, a grower might commit to growing a corn crop on the usual schedule with a certain probability that he would be asked to suspend irrigation with surface sometime during the crop season. He would be required to suspend irrigation in exchange for payments designed to compensate for lost production. (Alternatively, the grower could access a groundwater source and continuing irrigation. The farther into the season the idling call was made, the more incentive the grower would have to find an alternative water supply to finish the crop.) A crop that is particularly well suited to mid-season irrigation interruption is alfalfa because, when water is withheld, the crop goes dormant as soil moisture is depleted and resumes growth when irrigation is resumed.

Analysis would focus on the cost and efficiency of generating payback water in this manner.

7.3.2. Incurring Managed Increased Risk to Reservoir Carryover Storage

The objective of paying reservoirs back is to avoid impacts to water supply due to project operations. Analyses to date reveal that re-operated reservoirs frequently recover from surplus surface flows and need to be paid back only infrequently. Given infrequent need for and high cost of reservoir payback, one alternative is simply to deal with the occasional shortages caused by project operations when they occur. Essentially this means passing water supply shortages on to existing CVP and SWP water users. The first step in exploring this option would be to characterize the frequency and magnitude of water supply shortages and then develop strategies for compensating water users accordingly. For example, some users might alternative supplies that could be called on or conservation measures that could be invoked to deal with temporary shortages.

7.3.3. Sharing Private Groundwater Wells

Two options for establishing project groundwater pumping capacity have been explored thus far, including constructing new groundwater production wells and purchasing existing groundwater wells from willing sellers. Both of these are expensive options. The objective of further investigation would be to explore ways to access existing private wells in a manner that avoids the full capital outlay associated with new well construction (or existing well purchase) yet offers reasonably reliable access to payback capacity for project operations, when needed. This would be approached through interviews with landowners to test their willingness and the terms under which they would share production well costs and groundwater supplies with the project.

7.4.South of Delta Groundwater Banking

As previously noted, this investigation was conducted consistent with its original Sacramento Valley focus. Accordingly, reservoir releases made for project environmental purposes were tracked into the Delta but no analyses were performed to estimate whether or to what extent those inflows might be exported from the Delta. The economic analysis did reveal that project economics are dramatically improved if project water supplies could be sold at the higher rates associated with south of Delta water markets compared to Sacramento Valley rates. Beyond higher water sales revenues, banking project water in south of Delta groundwater banks might reduce reliance on Sacramento Valley reservoir payback operations. For example, there may be times when CVP and SWP reservoir releases can be reduced in exchange for water withdrawn from south of Delta groundwater banks. However, this is unlikely to be the case in very dry conditions when reservoir releases are being made exclusively for temperature control and not for export. Operations analyses are needed to reveal whether such opportunities exist.

A major challenge to the analysis will be the current uncertainty in Delta conveyance capacity and operating conventions, presently under consideration in development of the Bay-Delta Conservation Plan.

7.5. Develop System-wide Project Accounting Conventions

The central tenant of the conjunctive operations strategy developed through this project is that existing project beneficiaries can be kept whole while additional environmental flow and water supply benefits are generated. Keeping existing beneficiaries whole requires that an accounting be maintained of project assets, debts and repayment. In the simulations conducted for the project, operational changes (incremental project releases and refill) were isolated in either Shasta or Oroville and therefore easily accounted for. In actual operations, such an explicit accounting would not be practical considering that operations are highly interconnected and effects would likely be distributed among CVP and SWP reservoirs. This point was emphasized by the CVP and SWP project operators.

The purpose of this task would be to identify and evaluate alternative approaches to accounting for the effects of conjunctive operations on reservoir operations throughout the CVP and SWP systems. One approach would be to keep two sets of records, once for actual operations and another set for hypothetical operations as if the project was not operating. This is not considered to be practical or advisable due to the uncertain and, at times, arbitrary nature of maintaining the shadow records. Instead, a more practical approach would be to develop simplified accounting conventions based on simulated project operations.

7.6. Update and Refine Surface Water and Groundwater Models

The surface water and groundwater models developed for this investigation were adequate for planning level analyses but should be refined if further investigations are conducted. The main opportunities for improvements are as follows:

- A preliminary assessment of the accuracy of SACFEM at matching a limited number of historic hydrographs was performed, and the model appears to generally replicate historically observed water levels quite well over the 22-year period of simulation (1982 through 2003). It is recommended that a rigorous transient calibration be conducted of the SACFEM groundwater model to observed historic water level hydrographs across the valley. This effort would help improve the level of confidence that the model is accurately simulating transient patterns in groundwater levels seen historically.

- Another area of potential SACFEM refinement is to further evaluate hydrology of smaller unregulated tributaries across the valley, specifically to better understand timing and magnitude of groundwater recharge that occurs from these surface water features. In the current analysis, it was assumed that unregulated streams were dry from June through October. While this assumption is reasonable, it is likely that behavior of these streams is more complex. Further, some of these tributary streams are used as conveyance facilities to deliver water within various water districts. This would result in streams being active over summer months, and potential sources of recharge to the groundwater system. An analysis of these stream characteristics could improve the accuracy of the simulation of recharge sources to the groundwater system, especially over the summer months.

- Conjunctive management operations as simulated for this investigation may have impacts on the generation and use of CVP and SWP hydropower. For example, in some years, making large reservoir releases for certain environmental objectives may be constrained by power plant capacities and may occur at times when power is less valuable. A better understanding of these constraints and simulation of resulting effects is necessary if further investigation is undertaken.

- Analysis presented in this report focused on operation of only part of the CVP/SWP system. Shasta and Oroville Reservoirs and the Sacramento and Feather Rivers are part of a larger system that is operated in a coordinated manner. Simulation of only part of the system may underestimate benefits or impacts to other areas of the system. Preliminary analysis of systemwide effects based on how conjunctive management operations change, Delta inflows need to be refined and expanded to other areas of the system

Appendices

Appendix A
Materials from October 21, 2010 and
December 8, 2010 Public Meetings

October 21, 2010
Public Meeting Materials

Northern Sacramento Valley
Conjunctive Water Management Investigation

Public Workshop

Glenn-Colusa Irrigation District Main Pump Station
7854 County Road 203
Hamilton City, California

October 21, 2010

3:00 to 5:00 PM

Workshop Objectives

- Provide a status report on the investigation progress
- Listen/Respond to stakeholder questions
- Describe next steps to investigation, public meetings, and final report

Agenda

1. Welcome, Introductions, Workshop Process
2. Workshop Objectives
3. Recent Regulatory and Legislative Changes and Impacts
4. Investigation Review and Update – Presentation
5. Q&A
6. Regional Water Issues
7. Next Steps
8. Closing

Northern Sacramento Valley Conjunctive Water Management Investigation
Public Meeting
October 21, 2010
GCID Pump Station
Hamilton City, California
Sign in Sheet

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Northern Sacramento Valley Conjunctive Water Management Investigation

The Glenn-Colusa Irrigation District and
The Natural Heritage Institute

October 21, 2010

Today's Workshop Objectives

- Provide a status report on the investigation progress
- Listen/Respond to stakeholder questions
- Describe next steps to investigation, public meetings, and final report

Motivating Factors - Regulatory and Legislative Changes

- Significant Values are at Risk: Regional Sustainability
  - Environmental
  - Water supply
  - Economy
- New Challenges
  - SWRCB Flow Report: 75% unimpaired flow to the Delta November-June
  - DFG Report confirms similar flow needs
  - Delta species (smelt) dominate, salmon at risk
  - Delta Stewardship Council: All Delta all the time
  - Scott Valley/Siskiyou County Groundwater Pumping Lawsuit
- The Past is the past, How do we control our destiny?
- Historical operations and uses are constantly changing
- Local needs and flexibility are now challenged in the Delta context
- Increasing costs and fees
- Long term stability and reliability?

Emerging Values

- What does the region want, what values should be protected?
  - Water supply reliability (surface/groundwater)?
  - Environmental protection/enhancement, both instream and terrestrial?
  - System sustainability, what is it?
  - Others…?
- What strategies should be pursued to achieve regional goals?
  - Status quo?
  - Regional water investigations and planning?
  - Others…?
- Just say no…will that do?

Overview of Investigation to Date

Program Objective

- Examine whether and how operation of groundwater aquifers in the Sacramento Valley could be integrated with operation of existing surface water reservoirs to produce additional firm water supplies
- Potential benefits:
  - Improved water supply reliability (local, regional, State)
  - Ecosystem restoration (Sacramento and Feather Rivers)
  - Improved Delta inflow per BDCP
  - Increased operational flexibility (CVP, SWP, local)
  - Buffer effects of climate change

Program Requirements

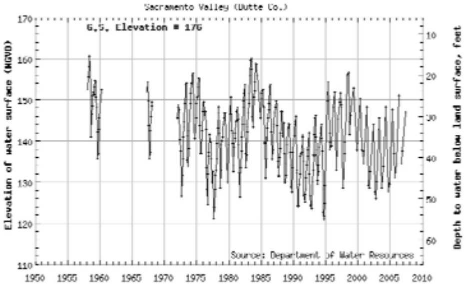
- New net benefits for Sacramento Valley environment and water users
- CVP and SWP commitments honored (to the extent they presently are)
- No unmitigated impacts to existing groundwater users
- Economic feasibility

Initial Site Screening

What Makes for an Attractive <u>Water Banking</u> Site?

- Groundwater conditions
  - Available aquifer storage space
  - Viable recharge mechanism
  - Productive groundwater wells
  - Suitable GW quality
- Surface water conditions
  - Surplus flows at times
  - Connection to CVP, SWP or other surface water reservoirs
  - Dual SW and GW use option
- Impacts/mitigation
  - Isolation from important surface streams
  - Isolation from existing groundwater production wells
  - Ability to mitigate or compensate impacts that cannot be avoided

Typical Sacramento Valley GW Hydrograph (Butte Co.)



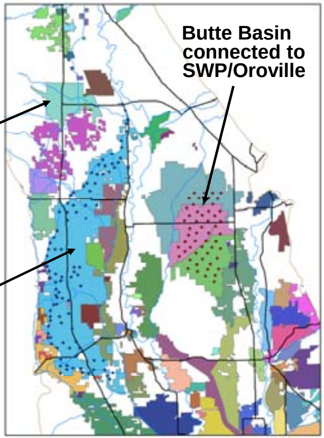
Source: Department of Water Resources

Early Finding: Traditional water banking generally not viable in the Sacramento Valley due to lack of aquifer storage space.

Re-operate Surface Reservoirs with Groundwater "Backstop"

- Reservoir re-operation
  - Additional releases to meet program objectives
  - Hope for reservoir refill from surplus surface flows
  - Honor existing CVP and SWP delivery obligations and operations constraints
- Groundwater operation
  - Pump groundwater to "repay" reservoirs if storage conditions put contract deliveries or temperature control at risk
  - Groundwater used in lieu of surface entitlements that then remain in storage

Three Sites Identified

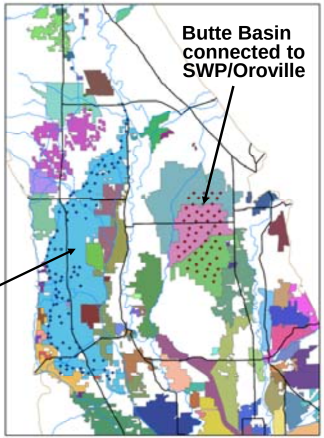


Butte Basin connected to SWP/Oroville

Orland Unit connected to Stony Creek Reservoirs

Glenn-Colusa ID connected to CVP/Shasta

Two Sites Selected for Modeling



Butte Basin connected to SWP/Oroville

Glenn-Colusa ID connected to CVP/Shasta

Re-operation Conceptual Example

- Release water from CVP and/or SWP reservoirs to meet project objectives:
  - Unmet local ag demands
  - Regional environmental flow targets
- If reservoirs refill, no subsequent GW pumping is needed
- If reservoirs do not refill, pump GW and forego use of surface water in following year as needed for reservoir "payback"
- New SW supplies can be generated with infrequent additional GW pumping, because reservoirs refill most years

Project Scenarios Defined by Groundwater Pumping Capacity and Season

Scenario	Groundwater Pumping Capacity (thousand acre-feet)			Pumping Season
	GCID (CVP)	Butte Basin (SWP)	Total	
1	100	50	150	summer
2	200	100	300	summer
3	100	50	150	fall
4	100	50	150	summer & fall

All scenarios modeled with an existing (shallow) and new (deep) well field to reveal range of potential impacts to streams and existing pumpers.

Surface Water Model Results

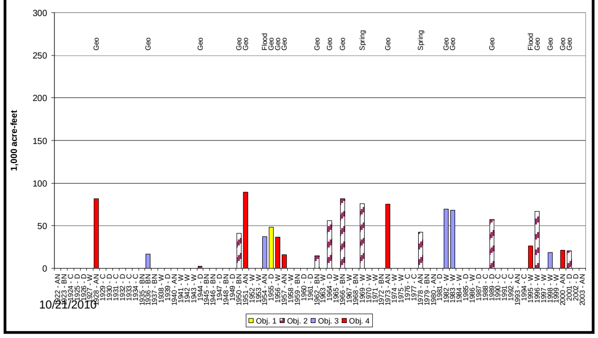
(Example for Scenario 1, Shasta/CVP, 100 TAF Pumping Capacity in GCID)

- Environmental flow releases
- Agricultural deliveries
- Refill from surplus surface water
- Refill from groundwater pumping

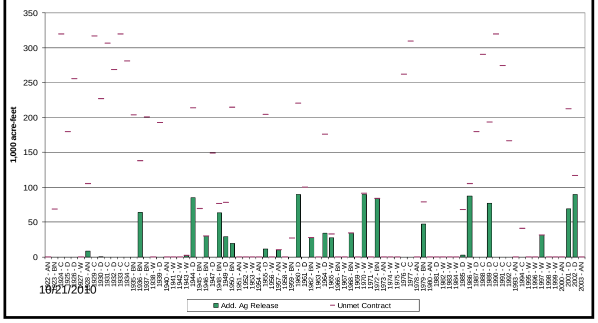
Environmental Flow Objectives

- Geomorphic
  - Single day large event
  - February or March
- Riparian establishment
  - Five day large flow with 60 day recession
  - April start
- Flood plain inundation
  - Single day large event with 45 day recession
  - Between February and April
- Spring pulse flow
  - Simulate more natural spring runoff period

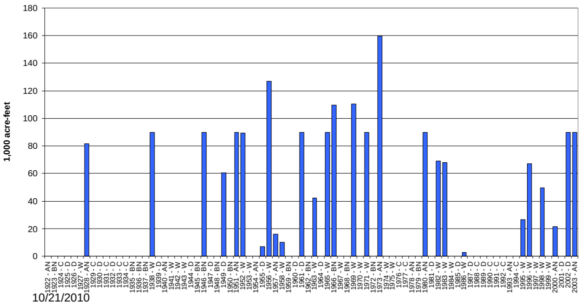
Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Environmental Flow Releases



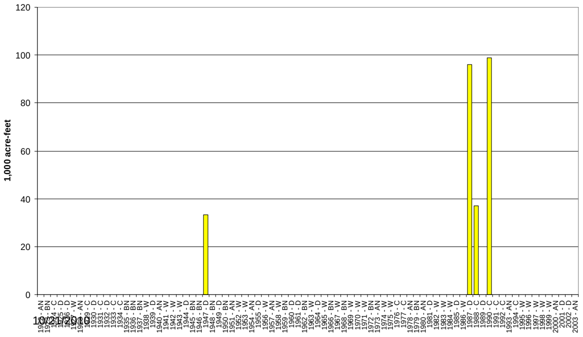
Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Sac River Agricultural Deliveries



Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Refill from Surplus Surface Water



Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Refill from Groundwater Pumping



SW Modeling Summary
(Annual averages 1922-2003, taf)

Scenario	CVP/Sacramento River				SWP/Feather River			
	Env. Rel.	Ag. Del.	Refill from SW	GW Pump	Env. Rel.	Ag. Del.	Refill from SW	GW Pump
1,3 and 4	13	14	24	3	7	10	14	3
2	45	22	58	9	23	20	36	7

SW Modeling Summary
(Average in years of occurrence 1922-2003, taf)

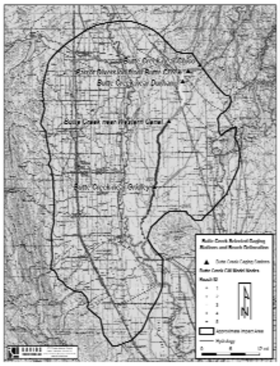
Scenario	CVP/Sacramento River				SWP/Feather River			
	Env. Rel.	Ag. Del.	Refill from SW	GW Pump	Env. Rel.	Ag. Del.	Refill from SW	GW Pump
1,3 and 4	94	46	70	70	49	27	32	44
2	187	75	139	123	95	52	72	75

Project Impacts Due to Additional Groundwater Pumping

- Streamflow
  - Butte Creek in affected area
  - Other critical streams not in affected areas
  - Ephemeral streams not analyzed
- Groundwater levels and existing wells
  - Well yield impacts
  - Incremental pumping costs (due to additional lift)

Butte Creek Impacts

- Develop baseline flow from available gauging stations
- Synthesize "with-project" flows based on cumulative reductions in streamflow from changes in stream leakance from GW model



Butte Creek Impacts

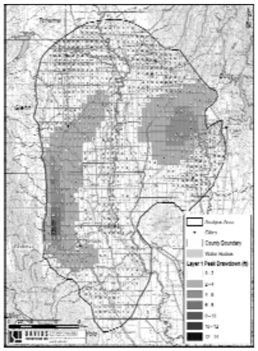
- No impact in upper reaches (primary spawning and holding areas)
- Greatest flow reduction in Jan. – Mar.
  - During times of highest discharge
- Greatest % reduction in summer/early fall
  - Spring-run have already migrated
  - Steelhead just beginning to enter stream
- Rarely drops below in-stream standards
  - June during early '90s drought
- Tradeoffs between Butte Creek impacts and main stem benefits

Impacts to Existing Wells

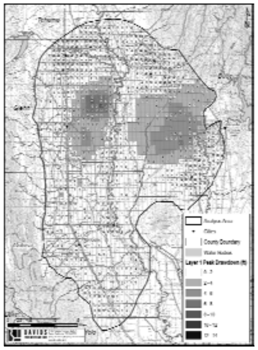
- Used DWR well inventory data
- No appreciable impact on irrigation well performance
  - Increased pumping costs accounted for
- Some impact on non-irrigation wells
  - 9,000 non-irrigation wells in analysis area
  - Up to ~800 non-irrigation wells in impact zones
  - Maximum of 25 (0.2%) to 284 (3%) of wells needing deepening or replacement

Groundwater Levels and Impacts to Wells

Potential Impact Zones:
Worst Case, New Wells



Potential Impact Zones:
Worst Case, Existing Wells



Incremental Pumping Costs

Summary Statistics of Interference Drawdown by Pumping Scenario

	Interference Drawdown (ft)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 kaf Summer Pumping, New Well Field	0.0	13.6	0.5	0.3	0.7
300 kaf Summer Pumping, Existing Well Field	0.0	8.3	0.4	0.2	0.6
150 kaf Summer Pumping, New Well Field	0.0	6.2	0.3	0.2	0.4
150 kaf Summer Pumping, Existing Well Field	0.0	5.4	0.3	0.2	0.4
150 kaf Fall Pumping, New Well Field	0.0	7.0	0.4	0.2	0.4
150 kaf Fall Pumping, New Well Field	0.0	6.1	0.4	0.2	0.5
150 kaf Summer & Fall Pumping, New Well Field	0.0	5.9	0.4	0.2	0.4
150 kaf Summer & Fall Pumping, New Well Field	0.0	5.0	0.4	0.2	0.5

Incremental Pumping Costs

Summary Statistics of Total Increased Annual Energy Costs to Maintain Existing Groundwater Pumping for Irrigation.

	Increased Annual Energy Cost (Total $)				
Pumping Scenario	Min	Max	Mean	Median	Std. Dev.
300 TAF Summer Pumping, New Well Field	$65,770	$705,326	$228,397	$168,480	$177,411
300 TAF Summer Pumping, Existing Well Field	$60,110	$497,233	$194,859	$154,452	$140,481
150 TAF Summer Pumping, New Well Field	$37,538	$377,222	$139,402	$104,710	$ 94,209
150 TAF Summer Pumping, Existing Well Field	$39,866	$367,467	$148,075	$126,209	$ 97,078
150 TAF Fall Pumping, New Well Field	$10,993	$344,156	$122,601	$124,133	$ 80,913
150 TAF Fall Pumping, Existing Well Field	$10,292	$401,570	$138,222	$134,018	$ 95,827
150 TAF Summer & Fall Pumping, New Well Field	$44,736	$294,296	$140,169	$120,727	$ 81,830
150 TAF Summer & Fall Pumping, Existing Well Field	$47,471	$345,330	$151,533	$132,451	$ 91,202

(Incremental costs for non-irrigation pumping on the order of $3000 - $5000 per year depending on pumping scenario)

Benefit-Cost Summary

All present values in million dollars [2009]

Scenario				
No.	**Description**	**Benefits**	**Costs**	**Benefit – Cost**
1	150 TAF Summer, New Wells	73	135	-62
1	150 TAF Summer, Existing Wells	73	94	-21
2	300TAF Summer, New Wells	183	290	-107
2	300 TAF Summer, Existing Wells	183	212	-29
3	150 TAF Fall, New Wells	74	210	-136
3	150 TAF Fall, Existing Wells	74	144	-70
4	150 TAF Summer & Fall, New Wells	73	88	-15
4	150 TAF Summer & Fall, Existing Wells	73	65	8

Latest Activities and Findings

Exploring Operations for Additional Environmental Benefits

- Consultation with CVP and SWP operators
- Complying with temperature requirements of greatest concern
  - Operators provided "unofficial" operations criteria for modeling
- Operating for temperature benefit involves tradeoffs with project environmental flow objectives

Temporary Crop Idling to Reduce Payback Cost

- Investigated crop idling as an alternative to GW pumping for reservoir payback
  - Voluntary, incentive driven
- Less cost-effective than pumping due to:
  - High cost: crop idling decisions have to be made early before hydrologic conditions are known
  - Marginal effectiveness: not all of the avoided water use results in reservoir payback

Principal Findings to Date

- SWP and CVP operational requirements are complex and constraining
  - Must honor all Project commitments and operations rules
  - Cold water pool management has dominant effect
- Cost of payback water is appreciable
  - Groundwater pumping
  - Temporary crop idling
- Project cost-effectiveness is marginal
  - Use of Sac groundwater to "backstop" entails mitigation costs
  - Project water produced in wetter years because it cannot be banked
  - Modest value of water in Sac Valley

Concluding Phase 1

Final Phase 1 Steps

- Technical
  - Frame existing operational constraints and tradeoffs
  - Formulate and model best performing scenario under existing conditions
  - Analyze impacts and economics
- Final Report: draft, final
- Public meetings (between draft and final)
- Scope Phase 2 of Investigation
- Continue regional dialogue

Question & Answer

Discussion

Northern Sacramento Valley Conjunctive Water Management Investigation
Conjunctive Water Management Investigation
Public Workshop
Meeting Notes
October 21, 2010

Present:	Thad Bettner, General Manager, GCID Grant Davids, Davids Engineering John Clerici, Outreach Communications Specialist Gregory Thomas, President, Natural Heritage Institute Walter Bourez, MBK Engineers Lee Bergfield, MBK Engineers Cynthia F. Davis, Director of Communications, GCID Laurie Merrill Murray, Executive Assistant, GCID

Thad Bettner, General Manager, Glenn-Colusa Irrigation District, welcomed the attendee's and introduced consultant John Clerici, outreach communications specialist, Grant Davids of Davids Engineering, Gregory Thomas, President of Natural Heritage Institute, Walter Bourez, MBK Engineers, and Lee Bergfield, MBK Engineers.

Mr. John Clerici called the public meeting to order at 3 p.m. and explained ground rules for participation during the meeting. Approximately 50 members of the public attended (see sign-in sheet).

Mr. Bettner reported that there is currently a significant risk for water in the north state. The State Water Resources Control Board released a flow report that calls for the current state of the Delta. The report recommends that 75% of all runoff goes to the Delta, and farmers in the Sacramento Valley cannot rely on a 25% supply. The Delta Stewardship Council – all the Delta – all the time. The Council is looking upstream for fixes to the Delta. Scott Valley – Siskiyou County groundwater historical operations are changing. New rules will be set up to serve the Delta. Water supply reliability. Change is upon us, outside factors are upon us.

Grant Davids presented a PowerPoint presentation, and provided information on the investigation covering the last four years. Examined how operation of aquifers in the Sacramento Valley environmental and water users. CVP and SWP have commitments to honor.

The following are general categories (in bold) of interest with some specific comments/questions as examples.

Voracity and specificity with the technical tools used to perform the evaluation.

Some commenters asserted that more detail was required in the areas of the economic analysis such as the value assigned to the groundwater, impacts to specific segments of the agricultural community, etc.

One person asked if the time-step used to develop the groundwater model (monthly) didn’t miss some spatial or temporal peculiarities associated with a specific location.

Would like to see more sophistication in terms of groundwater, particularly as it relates to permanent crops/orchards.

Why no critical dry years used in the analysis?

One lady questioned the impacts of groundwater pumping in the valley and its impacts on foothill aquifers. I assume she is confusing the Tuscan Formation and the Lower Tuscan aquifer.

Impacts as described in the investigation.

One foot impact to Big Chico Creek is a big deal in the summer.

What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

What are the critical recharge months in the upper reaches? In the area in general?

How the project works.

Frequency and severity of payback vs the benefits.

What are the benefits? This was a particular challenge for the Feather River folks. Some examples might help.

How will the reservoir releases be measured? When will we know that water needs to be repaid (what triggers payback)? How does the payback water get used?

Which aquifer are we talking about (deep or surface)? Does this study (can this study) be expanded to show the total groundwater picture?

Where does the water for environmental enhancements come from?

Do commitments still exist if Delta mandates are imposed?

Real project drivers.

Why are we here? There were water rights hearings before (she mentioned NHI but I did not get it all). The elephant in the room is junior water rights holders south of the Delta that are trying to get at our water. We need to save this area?

Land use and cropping decisions in the San Joaquin Valley were also sighted, as well as local growth concerns.

Water transfers and GCID’s role in them. How do they benefit the region?

Desire to be part of the discussion.

More meetings to work out the information with the public. Time of day and location, and more focused in terms of subject matter.

There are a lot of resources available from the local groups and individuals. We can help but you need to talk to us more proactively.

Many of these questions do not have clear answers, or are not answerable within the context of the investigation. Some of them like wanting more specific economic analysis or reducing the time-step on the model may either be impractical, or are better left to the more extensive environmental analysis required a the project level.
However providing concrete answers when they are available, as well as providing more detail around how an example project might function, its benefits and impacts, can only help to improve stakeholder understanding of what we have in mind.

I have some thoughts about how we can structure our response but would like to hear what the team has to say before discussing them further.

These are the questions and comments from the 10-21 workshop as I wrote them down. Some appear in the text above as well.

How does this relate to the planning process (city and county general plans)?

Why no critical dry years used in analysis? Doesn’t make sense.

The information is going to be used and not used appropriately. There seems to be a lot of pumping.

Confused about the water storage issue. Growth and demand is south of delta which is where he water would seem to go. There is a great deal of risk and uncertainty with what you are doing.

Where does the water for environmental enhancements come from (surface or groundwater)?

Which aquifer are we talking about (deep or surface)? Does this study (can this study) be expanded to show the total groundwater picture?

What’s the local/regional share of the 2.5 million af groundwater pumping figure? Need to be more specific.

What is the time step on the groundwater model? We notice changes weekly and even daily based on pumping. May not be reflected in the model.

Explain how there can be no impact in upper reaches of creeks? Does valley pumping impact aquifers in foothills (they think so)? Does the Tuscan aquifer extend into the foothills (Tuscan Formation vs Tuscan Aquifer?)

What are the critical recharge months in the upper reaches? In the area in general?

Seems like more detailed investigation needed to determine impacts of valley pumping on upper reaches.

What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

Payback issue needs to be explained. How does it work? Accounting?

1 foot of drop in local streams (Big Chico) are significant. Team needs perspective on this.

There are a lot of resources available from the local groups and individuals. We can help but you need to talk to us more proactively.

What is meant by “marginal impacts” at Butte Creek?

What if you end up pumping more than you expect (as a response to prolonged drought)?

Why are we here? There were water rights hearings before (she mentioned NHI but I did not get it all). The elephant in the room is Junior water rights holders south of the Delta that are trying to get at our water. We need to save this area?

Needs more community meetings, but thinks this effort might harm the area. Mentioned drought water bank.

Did you assign any value to the water in the aquifer?

Impacts of local land use decisions need to be taken in account? Have they been?

Explain the externalities in the economic impacts evaluation.

Public wants assurance that there is adequate thought going into monitoring and mitigation.

Can you do just reservoir re-operation without doing the pumping for repayment?

Do commitments still exist if Delta mandates are imposed?

What are the existing contractual obligations?

Would like to see more sophistication in terms of groundwater, particularly as it relates to permanent crops/orchards.

Clarification requested on groundwater and surface water.

Models are tools – assign value to aquifer. Add to next agenda.

December 8, 2010
Public Meeting Materials

Northern Sacramento Valley
Conjunctive Water Management Investigation

Public Workshop

Masonic Lodge
1110 W. East Avenue
Chico, CA 95926

December 8, 2010

6:00 to 8:00 PM

Workshop Objectives

- Respond to questions from October 21, 2010 workshop

Agenda

1. Welcome, Introductions, Workshop Process
2. Discuss questions from 10-21 Workshop
    a. How does the proposed project work?
    b. Investigation Tools and Data
    c. Project Benefits
    d. Project Impacts
3. Next Steps/Closing

Public Workshop

Northern Sacramento Valley Conjunctive Water Management Investigation

December 8, 2010

6:00 p.m. – 8:00 p.m.

Masonic Lodge
1110 W. East Avenue
Chico, CA 95926

The Glenn-Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) are in the process of evaluating water management opportunities in the northern Sacramento Valley. This effort, the Northern Sacramento Valley Conjunctive Water Management Investigation (Investigation), is nearing completion of several years of work with a draft final report currently under preparation.

This workshop is being sponsored specifically to provide responses to the questions and comments received at the Investigation workshop held on October 21, 2010. Topics to be addressed include potential project benefits and impacts, conjunctive operations concepts, project economics, and other issues brought up at the previous session. Time will be allowed for the public to engage in a discussion of the questions and answers and relevant issues related to the Investigation.

Northern Sacramento Valley
Conjunctive Water Management Investigation

Public Workshop

December 8, 2010

Background
On October 21, 2010, the Glenn-Colusa Irrigation District (GCID) and Natural Heritage Institute (NHI) held a public workshop to provide a status report on their Northern Sacramento Valley Conjunctive Water Management Investigation. Meeting participants were also provided an opportunity to ask questions of the investigation team.

As a result of the significant number of questions and comments provided by attendees, GCID and NHI agreed to hold a follow-up workshop. The purpose of the workshop is two-fold: to either respond to questions that could not be addressed at the last meeting, or provide clarification to questions that were answered but warranted additional follow-up; and, to allow for more substantive dialogue between the investigation team and stakeholders on these issues.

Organizing Questions
Questions and comments from the October workshop varied widely but seemed to be focused in four critical areas:

1. Project Operations (How does the proposed project work?)
2. Investigation Tools and Data
3. Project Benefits
4. Project Impacts

These four categories were used to develop the format for today's workshop. For discussion purposes, and to facilitate providing responses, comments were put into the form of a question, and multiple questions of similar nature were consolidated into a single question. Additionally, the technical team assessed which questions could be answered within the context of the current investigation, and which questions either cannot be resolved by this phase of the investigation, or required a venue more suited to a longer-term regional dialogue. The majority of questions fell into the first group and will be responded to in this workshop.

Questions by Category

Project Operations (How does the proposed project work?)

- Can you do just reservoir re-operation without doing the pumping for repayment?
- Where does the water for environmental enhancements and other project benefits come from?
- How does the payback water get used?
- How do the project benefits compare to the frequency and magnitude of payback?
- How would the reservoir releases be measured?
- How would it be determined that water needs to be repaid…what triggers reservoir payback?
- Which aquifer are we talking about, the deep or shallow?
- Does the study address the total groundwater picture?
- What are the existing contractual obligations?
- Public wants assurance that there is adequate thought going into monitoring and mitigation.

Investigation Tools

- Why are critical dry years not used in the analysis?
- What is the time-step used to develop the groundwater model? Is the time-step appropriate for capturing localized effects of day to day well operation and aquifer response?
- Were economic impacts beyond just project costs and benefits considered, such as impacts to specific segments of the agricultural community?

Project Benefits

- What are the project benefits?
- Are there benefits to the groundwater systems and were they considered in the economic analysis?

Project Impacts

- What are the impacts of groundwater pumping in the valley on foothill aquifers?
- What are the critical recharge months in the upper reaches? In the area in general?
- Project pumping may be a small share of Valley wide pumping but what proportion is it of pumping within the project area?
- Is the interconnection between streams and underlying aquifers sufficiently defined to predict the effects of even modest changes in groundwater levels (e.g., Butte and Big Chico Creeks)?
- What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

Northern Sacramento Valley Conjunctive Water Management Investigation

Public Meeting

December 8, 2010
Masonic Lodge
Chico, California
Sign in Sheet

PLEASE PRINT

	Name	Address	City, State & Zip	Telephone #	e-mail
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Northern Sacramento Valley Conjunctive Water Management Investigation
Public Meeting

December 8, 2010
Masonic Lodge
Chico, California
Sign in Sheet

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Northern Sacramento Valley Conjunctive Water Management Investigation
Public Meeting
December 8, 2010
Masonic Lodge
Chico, California
Sign in Sheet

PLEASE PRINT

Name	Address	City, State & Zip	Telephone #	e-mail
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GRACE MARVIN	162 N. Cherry St.	Chico 95926	893-7994	G-MARVIN@ COMCAST.net

Northern Sacramento Valley Conjunctive Water Management Investigation

Public Workshop

December 8, 2010

The Glenn-Colusa Irrigation District and
The Natural Heritage Institute

Workshop Objective & Process

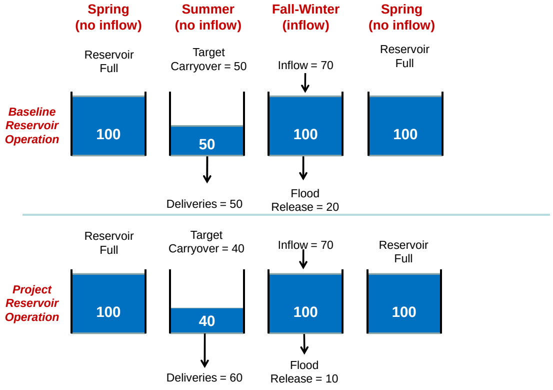
- Objective
  - – Respond to questions from October 21, 2010 workshop 1
- Process
  - – Organized questions into topics
  - – Describe each topic
  - – Provide response
  - – Engage in discussion

How Does The Proposed Project Work?

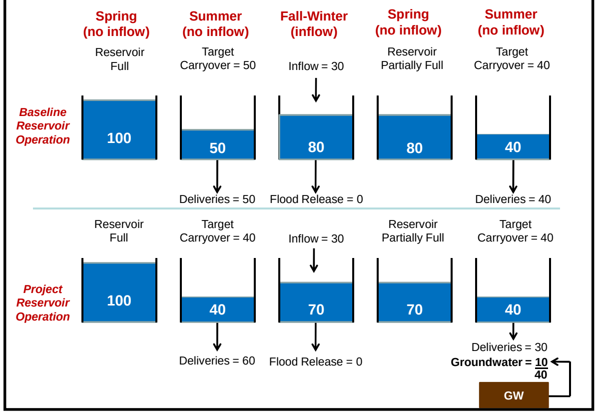
Re-operate Surface Reservoirs with Groundwater "Backstop"

- Reservoir re-operation
  - – Additional releases to meet program objectives
    (North of Delta water supply and environmental enhancement)
  - – Expect reservoir refill from surplus surface flows
  - – Honor existing CVP and SWP delivery obligations and operations constraints
- Groundwater operation
  - – Pump groundwater to "repay" reservoirs if storage conditions put contract deliveries or temperature control at risk
  - – Groundwater used in lieu of surface entitlements that then remain in storage
  - – Minimize or avoid GW impacts

Re-Operation Case 1- Reservoir Refills



Re-operation Case 2- Reservoir <u>Does Not</u> Refill



Project Performance Summary

Project Scenario 2 Evaluated with Revised Model Including Biological Opinions, Forecast-based Operation and Minimum Reservoir Release Criteria

Performance Metric	Sac R (Shasta)	Feather R (Oroville)
Total number of years in simulation (1922-2003)	82	82
Number of years no project releases made	62	45
Number of years project releases made	20	37
Average annual (82 years) project release, (TAF) (Roughly 2/3 environmental and 1/3 ag benefits) **Cumulative benefit over 82 years (TAF) =**	25 **2,050**	30 **2,460**
Maximum year project release (TAF) (Includes environmental and ag)	180	102
Number of years "payback" pumping is needed	4	11
Average annual (82 years) project pumping (TAF) **Cumulative pumping over 82 years (TAF) =**	2 **164**	9 **738**
Maximum year project pumping (TAF) (Maximums do not occur in same year)	100	100
Average annual (82 years) reservoir refill from surplus flows (TAF)	23	23
Spillage of payback water	0	-2

Questions

How Does The Proposed Project Work?

- Can you do just reservoir re-operation without doing the pumping for repayment?
- Where does the water for environmental enhancements and other project benefits come from?
- How does the payback water get used?
- How do the project benefits compare to the frequency and magnitude of payback?

Questions, continued

How Does The Proposed Project Work?

- How would the reservoir releases be measured?
- How would it be determined that water needs to be repaid…what triggers reservoir payback?
- Which aquifer are we talking about, the deep or shallow?
- Does the study address the total groundwater picture?

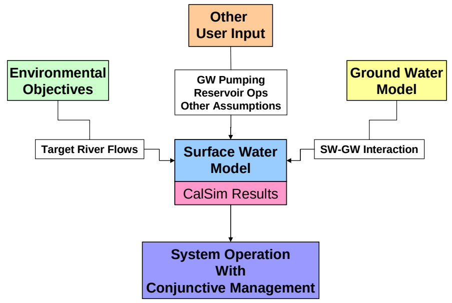
Questions, continued

How Does The Proposed Project Work?

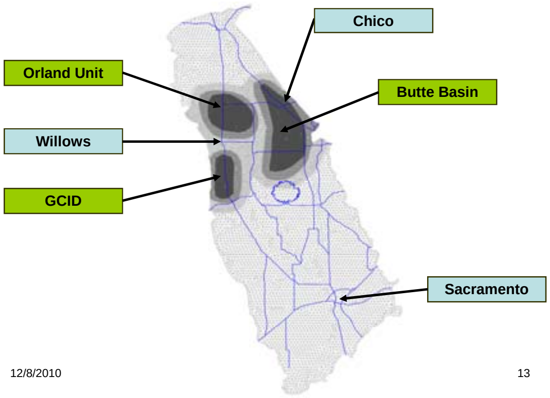
- What are the existing contractual obligations?
- Public wants assurance that there is adequate thought going into monitoring and mitigation.

Investigation Tools and Data

Overview of Analysis Tools



Groundwater Model Area and Grid Density



Groundwater Flow Model

- Regional scale with high spatial detail
  - – 5,950 square miles (3.8 million acres)
  - – 88,922 surface nodes
  - – 7 vertical layers
- Aquifer properties based on analysis of more than 1,000 production wells
- Calibration
  - – Static calibration for year 2000
  - – Water levels from 257 monitoring wells
- Monthly time step, 1982 through 2003

Surface Water Operations Model

- Spreadsheet-based for ease and speed of operation
- Re-operates Shasta and Oroville Reservoirs relative to a baseline condition depicted by CalSim II outputs (1922 through 2003)
- Driven by additional target deliveries for:
  - – Environmental restoration in Sac and Feather Rivers
  - – Unmet Sac Valley agricultural demands
- Various operational constraints
- Uses generalized SW-GW interaction functions derived from GW model

Questions

Investigation Tools and Data

- Why are critical dry years not used in the analysis?
- What is the time-step used to develop the groundwater model? Is the time-step appropriate for capturing localized effects of day to day well operation and aquifer response?
- Were economic impacts beyond just project costs and benefits considered, such as impacts to specific segments of the agricultural community?

Project Benefits

Questions

Project Benefits

- What are the project benefits?
- Are there benefits to the groundwater systems and were they considered in the economic analysis?

Project Benefits

- Increased Sac Valley surface water supply
  - – More local benefit (water supply) from CVP and SWP
  - – Reduced overall reliance on Sac Valley groundwater, though increased local pumping in certain years
- Improved habitat in Sac and Feather Rivers through
  - – Recovery of salmon populations
  - – Ecosystem sustainability

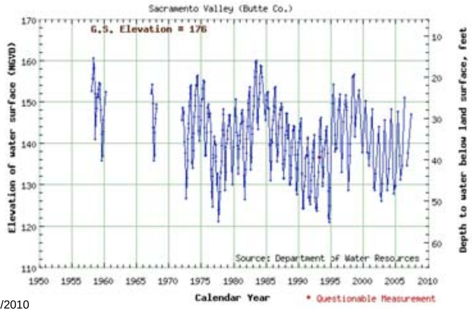
Project Impacts

Questions

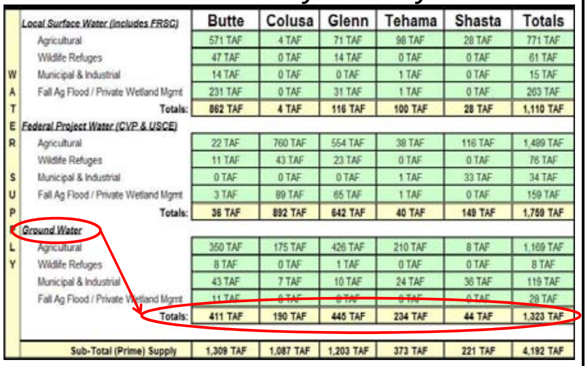
Project Impacts

- What are the impacts of groundwater pumping in the valley on foothill aquifers?
- What are the critical recharge months in the upper reaches? In the area in general?
- Project pumping may be a small share of Valley wide pumping but what proportion is it of pumping within the project area?

Typical Sacramento Valley GW Hydrograph (Butte Co.)



Sacramento Valley Water Uses and Sources by County



WATER SUPPLY

	Butte	Colusa	Glenn	Tehama	Shasta	Totals
Local Surface Water (includes FRSC)						
Agricultural	571 TAF	4 TAF	71 TAF	98 TAF	28 TAF	771 TAF
Wildlife Refuges	47 TAF	0 TAF	14 TAF	0 TAF	0 TAF	61 TAF
Municipal & Industrial	14 TAF	0 TAF	0 TAF	1 TAF	0 TAF	15 TAF
Fall Ag Flood / Private Wetland Mgmt	231 TAF	0 TAF	31 TAF	1 TAF	0 TAF	263 TAF
Totals:	**862 TAF**	**4 TAF**	**116 TAF**	**100 TAF**	**28 TAF**	**1,110 TAF**
Federal Project Water (CVP & USCE)						
Agricultural	22 TAF	760 TAF	554 TAF	38 TAF	116 TAF	1,489 TAF
Wildlife Refuges	11 TAF	43 TAF	23 TAF	0 TAF	0 TAF	76 TAF
Municipal & Industrial	0 TAF	0 TAF	0 TAF	1 TAF	33 TAF	34 TAF
Fall Ag Flood / Private Wetland Mgmt	3 TAF	89 TAF	65 TAF	1 TAF	0 TAF	159 TAF
Totals:	**36 TAF**	**892 TAF**	**642 TAF**	**40 TAF**	**149 TAF**	**1,759 TAF**
Ground Water						
Agricultural	350 TAF	175 TAF	426 TAF	210 TAF	8 TAF	1,169 TAF
Wildlife Refuges	8 TAF	0 TAF	1 TAF	0 TAF	0 TAF	8 TAF
Municipal & Industrial	43 TAF	7 TAF	10 TAF	24 TAF	36 TAF	119 TAF
Fall Ag Flood / Private Wetland Mgmt	11 TAF	8 TAF	8 TAF	0 TAF	0 TAF	28 TAF
Totals:	**411 TAF**	**190 TAF**	**445 TAF**	**234 TAF**	**44 TAF**	**1,323 TAF**
Sub-Total (Prime) Supply	**1,309 TAF**	**1,087 TAF**	**1,203 TAF**	**373 TAF**	**221 TAF**	**4,192 TAF**

Peak Year Project Pumping (100 TAF[1]) in Relation to Estimated Annual Baseline Pumping

Area	Estimated Baseline Pumping (TAF)	Project Pumping as % of Area Baseline
Butte County	411	24%
Glenn and Colusa Counties	635	16%
Butte, Glenn and Colusa Counties	1,046	10%
Northern Sacramento Valley (Butte, Glenn, Colusa, Tehama and Shasta Counties)	1,323	8%
Entire Sacramento Valley (Source: GW model water budgets)	2,500 +/-	4%

[1] Peak year project pumping is 100 TAF in the Butte Basin and in GCID but the two not occur in the same year based on the 1922 through 2003 modeling

Questions

Project Impacts

- Is the interconnection between streams and underlying aquifers sufficiently defined to predict the effects of even modest changes in groundwater levels (e.g., Butte and Big Chico Creeks)?

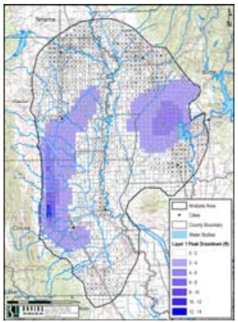
Questions, continued

Project Impacts

- What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

Comparison of Drawdown from Modeling and Averaged for Impact Analysis

Potential Impact Zones: Worst Case, New Wells



Regional Aquifer Drawdown in Aug 1990 , Scenario 1, New Well Field

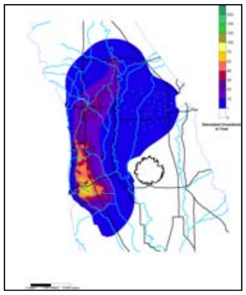


Figure 11-15, p.11-16 from Modeling Report, Feb 2010

Next Steps

- Draft and Final Investigation Report
- Additional public meetings
- Phase 2

Appendix B
Sacramento Valley Conjunctive Water Management
Technical Investigation Modeling Report
MBK/CH2M HILL

Report

Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Prepared for

Glenn Colusa Irrigation District
and the Natural Heritage Institute

February 2010

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Preface

This report was prepared by CH2M HILL and MBK Engineers for Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI).The report documents technical analyses conducted to examine potential future coordinated operation of Sacramento Valley groundwater aquifers with California's State Water Project and the federal Central Valley Project. The work was enabled by state and federal grant funds.

Principal investigators were Peter Lawson of CH2M HILL and Walter Bourez and Lee Bergfeld of MBK Engineers. Program management and technical oversight were provided by Grant Davids of Davids Engineering on behalf of GCID and NHI.

Any questions regarding the information presented in this report should be addressed to GCID, NHI, or Davids Engineering.

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Acronyms and Abbreviations

ac-ft	acre-feet
bgs	below ground surface
cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento-San Joaquin River Delta
DEM	Digital Elevation Model
DWR	California Department of Water Resources
GCID	Glenn Colusa Irrigation District
GIS	geographic information system
gpd	gallon per day
gpm	gallon per minute
NHI	Natural Heritage Institute
OCAP	Operations Criteria and Plan
Reclamation	Bureau of Reclamation
RMS	root mean square error
SACFEM	Sacramento Valley Groundwater Model
Sacramento River Index	Sacramento River Water Year Type Index
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TCCA	Tehama-Colusa Canal Authority

Executive Summary

Project Description

Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) are conducting an analysis of conjunctive management opportunities in the Sacramento Valley (Project). The purpose is to examine whether and how groundwater production from the Lower Tuscan Aquifer and related deep aquifers in the Sacramento Valley can be integrated with the operations of existing surface water reservoirs to produce additional water to satisfy unmet agricultural demands in the Valley (preferentially), or south of the Sacramento-San Joaquin River Delta (Delta). A secondary objective is to evaluate the potential to increase the operational flexibility of these reservoirs so that they can contribute to meeting environmental flow targets in the Sacramento and Feather Rivers.

Technical Analysis

The Project includes conducting planning-level technical analyses and modeling of the following:

- How conjunctive management projects may operate
- How additional water supplies may be developed
- How reservoirs can be reoperated to generate environmentally beneficial flow patterns
- What effects the Project could have on both the surface and groundwater systems in the Sacramento Valley.

This report documents the development of the surface water and groundwater modeling tools used in the analysis, the assumptions made during the development process, and presents results of the modeling analyses.

Technical analysis was performed using two models: one for the surface water system and one for the groundwater system. The surface water model was developed to analyze operations of conjunctive management projects, reservoir operations, environmental objectives, and agricultural water demands quickly for a variety of different project, operations, and objectives. The surface water model was used in gaming sessions and by members of the project team to understand benefits, risks, and limitations of various conjunctive management configurations.

A regional groundwater model was also developed to simulate the effects of conjunctive management operations on the aquifer system with a spatial resolution at project sites capable of evaluating effects on a well field scale. The groundwater model was used to investigate differences in aquifer drawdown and changes in stream-aquifer interaction for different pumping capacities, seasons, and well field configurations.

The two models were used in an interactive fashion to simulate project operations and better understand the interactions between the surface water and groundwater systems. The surface water model was used to determine timing and quantity of conjunctive management pumping. Pumping time series were then simulated in the groundwater model and changes in stream-aquifer interactions were input back into the surface water model to understand how those changes might affect system operations.

Technical analyses were performed at a planning level to help prove concepts and define potential conjunctive management configurations and operations. Analyses were conducted for general projects, locations, and operations. More specific and refined analysis will be required as specific projects are defined. Most of the analyses contained herein were conducted in a comparative (rather than absolute) manner, and results must be interpreted with this in mind. Comparisons of benefits and impacts between different scenarios or well fields help inform decisions on what projects work better than others.

Projects, Operations, and Scenarios

The project team developed an initial list of nine prospective project sites and screened these down to two project sites for more in-depth analysis and modeling. One project site is located within GCID and is integrated with the Central Valley Project's (CVP) operation of Shasta Reservoir. The second project site is located in Western Canal Water District and Richvale Irrigation District (Butte Basin) and integrated with the State Water Project's (SWP) operation of Oroville Reservoir.

The team used its understanding of annual aquifer drawdown and recovery to develop a conjunctive operation configuration that relies primarily on re-operation of existing reservoirs to achieve the project objectives, drawing on groundwater as a backstop. The term "backstop" refers to the potential to use groundwater supplies on a temporary basis to make up for shortfalls in surface water supplies due to modified operations. Groundwater provides an additional source of water to protect surface water reservoirs from being excessively depleted. This type of operation offers different opportunities and challenges than conventional groundwater banking. Surface water is not banked in the aquifer in wet years and recovered during dry years. Instead, additional water is released from surface reservoirs for delivery to meet Project objectives (unmet local irrigation demands and environmental flow targets). These releases result in lower end-of-year reservoir storage levels and more reservoir space available to capture winter runoff.

The goal of this operation is to develop additional water supply by refilling reservoir space vacated by additional Project releases with captured surplus surface water that otherwise would be released for flood control. In years when refill is not complete, Project pumping produces groundwater for use in Project areas in lieu of surface water deliveries that would otherwise be made from reservoirs. This allows an equivalent volume of water to remain in reservoir storage to recover from prior year project releases.

This mode of conjunctive operation, in which reservoir operation is used as the primary means to develop new water supply and groundwater is used infrequently as a backstop, is highly efficient because it reduces the frequency and volume of groundwater pumping in comparison to conventional groundwater banking operations. Groundwater pumping is relied upon only as needed to maintain reservoir storage when refill from surplus winter flows is insufficient.

In some years, conditions in the Sacramento Valley may be so critically dry that Project pumping would be suspended altogether. For instance, if groundwater levels were already at levels of concern (according to county Basin Management Objectives or other standards), Project wells would be turned off and the Project would generate no new supplies under these conditions.

Project operations were simulated for the four different conjunctive management scenarios summarized in Table ES-1.

TABLE ES-1
Summary of Project Scenarios Evaluated
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Scenario	GCID Annual Pumping Capacity	Butte Basin Annual Pumping Capacity	Pumping Season
1	100 TAF	50 TAF	Summer (May through August)
2	200 TAF	100 TAF	Summer (May through August)
3	100 TAF	50 TAF	Fall (September through November)
4	100 TAF	50 TAF	Summer and Fall (May through November)

TAF = thousand acre-feet

Additionally, pumping for each scenario was evaluated for two different well fields. The first well field simulated pumping from existing wells screened in the current aquifer production zones at depths between 100 and 500 feet. The second well field simulated pumping from new wells screened in the deep aquifers at depths between 900 and 1,100 feet.

Results and Conclusions

Table ES-2 presents a summary of results for each scenario and well field configuration. Water supply results are average annual new water supplies developed to meet project objectives. Groundwater results show only the peak impacts to groundwater levels and streams.

Table ES-2 shows that for the two pumping capacities evaluated, the average annual additional water supply is approximately one third of pumping capacity. Additionally, approximately 85 percent of the new water supply developed comes from capture of surplus surface water with the remaining 15 percent from additional groundwater pumping. Average annual groundwater pumping volumes are the result of infrequent but large pumping quantities up to the total project capacity in a given year.

Surface water operations and the resulting groundwater pumping are primarily driven by reservoir storage levels. Therefore, differences in the season of conjunctive management pumping evaluated with Scenarios 3 and 4 have little effect on water supply. However, the duration of the pumping season has a more significant effect on the magnitude of drawdown produced in the aquifer system, and results in differences in projected stream impacts.

TABLE ES-2

Summary of Results for Each Project Scenario and Well Field Configuration

Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Pumping Capacity (TAF)				Source of New Water Supply			Max Local Drawdown[a] (feet)		
Scenario	**GCID**	**Butte Basin**	**Pumping Season**	**New Water Supply[b] (TAF)**	**Surplus Surface Water[b] (TAF)**	**GW Pumping[b] (TAF)**	**Well Field**	**GCID**	**Butte Basin**	**Peak Streamflow Impact[c] (cfs)**
1	100	50	Summer	44	38	6	Existing	30-40	<10	54
							New	~100	10-20	53
2	200	100	Summer	110	94	16	Existing	~100	20-30	111
							New	~200	20-30	105
3	100	50	Fall	44	38	6	Existing	40-50	10-20	80
							New	~125	30-40	90
4	100	50	Summer and Fall	44	38	6	Existing	20-30	<10	64
							New	40-50	10-20	65

[a] Maximum local drawdown is the maximum monthly simulated drawdown within the pumped aquifer for that particular conjunctive management project during the period of simulation

[b] Annual Average

[c] Peak stream impact is the maximum monthly aggregated reduction in stream flow for all streams explicitly simulated in the groundwater model during the period of simulation

Note:

cfs = cubic feet per second

Table ES-2 shows that for a given project production capacity, the greatest drawdown occurs during fall pumping simulations because pumping occurs over 3 months, resulting in higher instantaneous rates. An intermediate magnitude of drawdown is observed for pumping over a 4-month summer period, and the least drawdown is predicted for the 7-month summer/fall pumping period.

Production of groundwater from new wells screened in the deeper aquifer results in greater drawdown than pumping the same quantities at the same rates from existing wells. This is because the pumping from new wells is assumed to occur from the 200-foot thickness that comprises model layer 6 (approximately 900 to 1,100 feet below ground surface ([bgs]), whereas the pumping from existing wells occurs from the approximate 400-foot thickness of the regional aquifer (200 to 600 feet bgs). This greater aquifer thickness provides a significantly greater aquifer transmissivity to provide water to the pumping wells, and therefore less drawdown is simulated for a given pumping rate. Additionally, the new well field for the GCID Project is assumed to be located closer to the low permeability bedrock that borders the western edge of the alluvial aquifer; therefore, less water is available to satisfy pumping demands. These assumptions, combined with the larger pumping volumes, help explain why the differences in drawdown between a new and existing well field are larger in the GCID Project than the Butte Basin Project.

Simulated drawdown near the Butte Basin Project is lower than simulated drawdown near the GCID Project. This is due to a combination of lower overall production rates and a greater production well spacing.

Comparisons of peak streamflow impacts between scenarios show that higher production rates generally result in greater peak impacts with the exception of a comparison between Scenario 1 and 4. Differences in peak stream impacts between Scenarios 1 and 4 can be explained by the timing of when ephemeral streams are simulated to flow in the model. The peak drawdown effects for Scenario 4 were evaluated in November (the end of the production season), when west side ephemeral streams are assumed to be active. These streams provide an additional source of recharge to the aquifer system, resulting in a lesser magnitude of predicted drawdown. This can also be seen in the cumulative peak stream impact, which is greater for Scenario 4 than for Scenario 1.

Lower project pumping rates of Scenarios 1 and 4 predict similar peak stream impacts for new and existing well fields. Moderate production rates in Scenario 3 show greater peak impacts of new wells than those produced by existing wells. At the highest production capacity in Scenario 2 the existing well field produces greater peak impacts to streams than the new well field.

SECTION 1

Introduction and Background

Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) are conducting an analysis of conjunctive management opportunities in the Sacramento Valley (Project). The purpose is to examine whether and how groundwater production from the Lower Tuscan Aquifer and related deep aquifers in the Sacramento Valley can be integrated with the operations of existing surface water reservoirs to produce additional water to satisfy unmet agricultural demands in the Valley (preferentially), or south of the Delta. A secondary objective is to evaluate potential to increase the operational flexibility of these reservoirs so that they can contribute to meeting environmental flow targets in the Sacramento and Feather Rivers.

The Project planning area encompasses the entire Sacramento River basin, although primary attention focuses on areas of the northern Sacramento Valley. This includes portions of Butte, Colusa, Glenn, and Tehama counties. Operational strategies developed do not necessarily depend on the Lower Tuscan and related deep aquifers, or any particular portion of the groundwater system for that matter. The strategies are generally applicable wherever productive aquifers exist regardless of their depth or extent.

The scope of the planning effort includes technical analyses with emphasis on surface water and groundwater modeling to define conjunctive management operations and their benefits and impacts. This report provides specific documentation on modeling tools developed for this analysis, projects and scenarios simulated, and model results. Additionally, the report supports preliminary engineering analyses and development of project cost and benefit estimates to allow for economic evaluation of prospective projects.

Any new groundwater pumping in the Sacramento Valley would have at least temporary effects on groundwater conditions and could affect existing groundwater users and flow in rivers and streams. Therefore a major component of the Project is to address risks to existing water users and streams. Risk management strategies that will be investigated include risk avoidance and minimization, such as locating and designing production wells in ways to isolate impacts, and risk mitigation to compensate for effects that cannot be avoided. An overarching principle of the Project is that existing water users, at a minimum, would not be adversely impacted and preferably will benefit from conjunctive operations.

SECTION 2

Conclusions

2.1 Surface Water System

Conjunctive management in which groundwater pumping capacity is used as a backstop to allow more aggressive operation of surface water reservoirs in the Sacramento Valley may be an efficient method to increase water supply. More aggressive operation of reservoirs produces additional water supply primarily through capture of surplus surface water and to a lesser extent through additional groundwater pumping. Table 2-1 summarizes average annual water supply developed for agricultural and environmental objectives and the source of additional supply, either surplus surface water or groundwater, for the two different project capacities evaluated.

TABLE 2-1
Summary of Average Annual Water Supply Benefits and Source of Additional Supply
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Additional Water Supply (TAF)			**Capture of Surplus Surface Water**	**Additional Groundwater Pumping**
Project Capacity	**Agricultural**	**Environmental**	**Total**		
150 TAF	24	20	44	38	6
300 TAF	42	68	110	94	16

Table 2-1 shows that for the two capacities evaluated, additional water supply is approximately one-third of project groundwater pumping capacity. Additionally, approximately 85 percent of the water supply developed comes from capture of additional surface water with the remaining 15 percent from additional groundwater pumping. Average annual groundwater pumping volumes are the result of infrequent but large pumping quantities up to the total project capacity in a year.

Surface water operations and the resulting groundwater pumping are primarily driven by reservoir storage levels. Therefore the season of conjunctive management pumping whether summer, fall, or summer and fall has only minor operational affects. However, pumping season may have more significant effects on aquifers and current groundwater users.

Additional important conclusions can be drawn from the sensitivity/tradeoff analysis. Projects with larger pumping capacities tend to contribute more toward meeting environmental objectives, while smaller capacity projects contribute more to agricultural objectives for the following two reasons:

- Water costs associated with meeting environmental objectives are typically high and require larger project capacities to meet.
- Environmental objectives were assumed to be all-or-nothing thresholds while any additional water supply could be used to meet agricultural objectives.

These two factors also result in the two objectives being less competitive for additional water supply than may be expected. A different prioritization between the two objectives did not result in a one-for-one tradeoff of benefits.

Tradeoff analysis also provided insight into risks associated with more and less aggressive conjunctive management operations. For the surface water system, these risks are focused on reservoir storage levels and ability to meet contract requirements and temperature control criteria in future years if reservoirs are drawn down too far.

Sensitivity analysis conducted when environmental flow targets were varied demonstrated that for most objectives changes of 10 percent did not erase, or greatly increase, project benefits. Therefore, conjunctive management projects, as defined in this study, could likely be used to meet environmental objectives, even with the uncertainty inherent in flow targets and real-time operations.

Conjunctive management operations within the Sacramento Valley may make additional water supply available south of Delta if reservoir releases to meet environmental objectives can be exported. There exists some ability to export these releases when not considering export restrictions for the protection of Delta smelt. However, export restrictions as proposed in the recently release Operations Criteria and Plan (OCAP) Biological Opinion likely reduce or eliminate this potential benefit.

2.2 Groundwater System

The eight simulations described in this study were designed to test four different project scenarios while holding remaining variables constant. Parameters evaluated in the four scenarios included quantity of groundwater pumped, duration of production (which influences production rate), seasonality of production, and spacing and location of production well fields, including proximity to surface streams. Conclusions are divided into those regarding groundwater level effects followed by those regarding effects on surface water flows. Drawdown estimates provided are regional drawdown estimates. The magnitude of local drawdown adjacent to individual production wells will be significantly greater.

2.2.1 Groundwater Levels

Production of 150 TAF of groundwater from existing wells over the summer (May through August) results in a maximum drawdown of approximately 40 feet in the pumped aquifer, whereas production of 300 TAF of groundwater results in a maximum of approximately 75 feet of drawdown.

Production of 150 TAF of groundwater from new deeper wells over the same months results in a maximum of approximately 75 feet of drawdown in the pumped aquifer, whereas the production of 300 TAF of groundwater results in approximately 150 feet of drawdown.

Production of 150 TAF of groundwater from existing wells over the fall period (September through November) results in a maximum drawdown of about 50 feet in the pumped aquifer compared to a maximum of approximately 40 feet of drawdown if the same production occurs in the summer.

Production of 150 TAF of groundwater from new deeper wells over the fall period results in a maximum of approximately 125 feet of drawdown in the pumped aquifer compared to a maximum of approximately 75 feet of drawdown if the same production occurs in the summer.

Production of 150 TAF of groundwater from existing wells over the summer/fall period (May through November) results in a maximum of about 30 feet of drawdown in the pumped aquifer compared to a maximum of approximately 40 feet of drawdown if the same production occurs in the summer only.

Production of 150 TAF of groundwater from new deeper wells over the summer/fall period results in a maximum of approximately 50 feet of drawdown in the pumped aquifer compared to a maximum of approximately 75 feet of drawdown if the same production occurs in the summer only.

For a given project production capacity, the greatest drawdown is observed in fall pumping simulations because the pumping occurs over 3 months, resulting in the highest instantaneous rate. An intermediate magnitude of drawdown is observed for the 4-month summer period, and the least drawdown is predicted for the 7-month summer/fall pumping cycle.

The production of groundwater from the deeper aquifer from new production wells results in the greatest predicted magnitude of drawdown. This is because the pumping is simulated to occur in a 200-foot thickness of model Layer 6 (approximately 900 to 1,100 feet bgs) whereas the pumping from existing wells is assumed to occur from wells screened throughout the approximately 400-foot thickness of the regional aquifer (200 to 600 feet bgs). Further, the new well field identified on the western side of the valley is located further west, relative to the location of the existing wells, transferring the groundwater pumping stresses closer to the low permeability bedrock which borders the western edge of the alluvial aquifer.

Simulated drawdown in the vicinity of the eastern well fields in the Butte Basin Project are significantly lower than those observed on the west. This is due to a combination of lower overall production rates from the east and a greater production well spacing.

2.2.2 Effects on Surface Water Flows

Peak effects on stream flow due to groundwater production in the Sacramento Valley are summarized in Table 2-2.

TABLE 2-2
Peak Effects on Streamflow from Conjunctive Management Operations
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
Stream	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**
All Streams	54	53	111	105	80	90	64	65
Butte Creek	13	12	72	69	50	48	39	33

TABLE 2-2
Peak Effects on Streamflow from Conjunctive Management Operations
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Stream	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**
Sacramento River – GCID to Wilkins Slough	42	37	32	28	16	18	16	15
Feather River	3	3	6	6	4	4	4	4
Little Chico Creek	3	3	6	5	4	3	4	3
Salt River	1	5	5	8	2	5	2	5
Stone Coral Creek	6	9	11	15	7	10	6	9
Stony Creek	4	5	7	7	4	6	4	4

Specific conclusions regarding surface water effects are as follows:

- The higher pumping rates associated with the 300-TAF projects clearly result in significantly larger peak stream impacts.
- For a conjunctive management project of a given size, new well fields pumping from deeper aquifers tend to produce greater peak stream impacts on western streams than pumping from existing wells tapping the regional aquifer. This is likely due to the greater magnitude of drawdown predicted on the western side of the valley from new wells as discussed above. Effects on eastern and central streams (Sacramento River) are similar.
- When looking at the cumulative peak impacts to all streams, the lower project pumping rates (150 TAF over 4 or 7 months) predict similar peak impacts for both new and existing well fields. At moderate production rates (150 TAF over 3 months), peak impacts of new wells is greater than those produced by existing wells. At the highest production capacity (300 TAF over 4 months), the existing well field produces greater peak impact to streams than the new well field.
- For all projects evaluated, peak stream impacts occur in 1990, as do peak impacts on the Sacramento River. This is also generally true of the west side streams of Stone Corral and Stony Creek.
- For all projects evaluated, peak stream impacts on the east side streams (Little Chico Creek and Butte Creek) occur in early 1995. One exception is that for the 300 TAF projects, peak impact on Butte Creek occurs in early 1993.
- Peak impacts on the Feather River occur in late 1994 or early 1995.

SECTION 3

Technical Analysis and Modeling

Technical analysis and modeling of conjunctive management operations require consideration of both surface water and groundwater systems and their interaction. This project developed and used models that simulate each system using similar water demands and system operations. Information is passed between the models to depict conjunctive management operations and effects between the surface and groundwater systems. These tools were developed to simulate and compare a baseline condition and a project condition to determine benefits and effects of conjunctive management.

Technical analyses were performed at a planning level to help prove concepts and define potential conjunctive management configurations and operations. Analyses were conducted for general projects, locations, and operations. More specific and refined analysis will be required as specific projects are defined. Most of the analyses contained herein were conducted in a comparative, rather than absolute, manner, and results must be interpreted as such. Comparisons of benefits and impacts between different scenarios or well fields help inform decisions on what projects work better than others. Interpretation of the results should not be interpreted in a highly predictive manner, such as pumping “X” amount of groundwater results in a deficit of “Y” stream flow, or release of “A” volume of water from a reservoir accomplishes “B” amount of environmental restoration.

3.1 Objectives of Groundwater Analysis

Conjunctive water management, or groundwater substitution projects, can result in depressing local groundwater levels, which could affect yields and performance of nearby water supply wells and cause a reduction of groundwater discharge to surface streams or direct leakage from streams to underlying aquifers. Timing these impacts is critical, especially for surface water. Acceptable impacts to surface water flows during certain times of year might be unacceptable during other parts of the year. As part of the technical analysis, a numerical groundwater modeling tool was developed to evaluate impacts of proposed conjunctive water management projects on groundwater levels and streamflows near proposed project sites. The groundwater model is regional in scale, covering the Sacramento Valley Groundwater Basin. This model uses transient surface water budgets developed from spatially referenced land use data, water district operations, surface water availability, and required supplementary groundwater pumping to meet agricultural demands. Specific objectives of the groundwater modeling effort included the following:

- Calculating transient valley-wide and project-specific drawdown in groundwater levels resulting from implementing conjunctive management projects at two general locations with the northern Sacramento Valley.
- Quantifying transient impacts to streams resulting from implementing conjunctive management projects.

- Considering the effects of operating conjunctive water management projects in both wet and dry hydrologic periods and operating projects only in certain selected years within a longer hydrologic period.

3.2 Objectives of Surface Water Analysis

A surface water model was developed to simulate coordinated operation of select Central Valley Project (CVP) and State Water Project (SWP) reservoirs with conjunctive management projects. The surface water model was designed for use in gaming sessions and to help improve understanding of tradeoffs associated with different project objectives and operations. Specific objectives of the surface water modeling included the following:

1. Quantifying additional water supply that might be developed with conjunctive management projects and how that water supply can be used to meet agricultural and environmental objectives.
2. Understanding how conjunctive management projects might change the operation of CVP and SWP reservoirs, including effects on storage, spills, and risks to existing contracts and cold water pool management.
3. Understanding tradeoffs and risks associated with different conjunctive management operations, project sizes, and project objectives.
4. Improving understanding of how changes in stream-aquifer interactions might result in changes to the surface water system.
5. Understanding the effects on other parts of the system, including other reservoirs, hydropower operations, the Sacramento-San Joaquin River Delta (Delta), and south-of-Delta water supplies.

SECTION 4

Current Basin Groundwater Conditions

The initial intent of the Project was to identify areas within the Sacramento Valley groundwater basin in which groundwater levels were significantly lowered due to agricultural pumping for extended periods of time and persisted through the winter recharge period. Conditions of this type would indicate the presence of a large unsaturated aquifer volume that could be used to implement a put-then-take groundwater banking program. Under a program of this type, surface water is delivered to existing groundwater users in the target area during years of above average precipitation, resulting in a replenishing aquifer storage characterized by increased groundwater levels. When dry conditions return to the area, groundwater held in storage within the aquifer is pumped to yield additional supply to meet project objectives.

The first step in the evaluation process was to identify areas within the Sacramento Valley groundwater basin that would be suitable for a put-then-take type conjunctive management project. This was done by collecting and evaluating numerous historical groundwater level hydrographs from wells throughout the basin. Results of this analysis indicated that while numerous areas within the basin show drawdown during the irrigation season, groundwater levels in most areas essentially recover during subsequent winter months, with the exception of the occurrence of multiple years of critically dry conditions. Figures 4-1 through 4-15, which depict historic groundwater fluctuations in wells distributed throughout the valley. The conclusion from this analysis was that a put-then-take water bank was not feasible in the Sacramento Valley north of the American River Basin. Providing surface water for irrigation demands in lieu of groundwater does not result in increased groundwater in storage because groundwater levels recover due to natural recharge over the winter months.

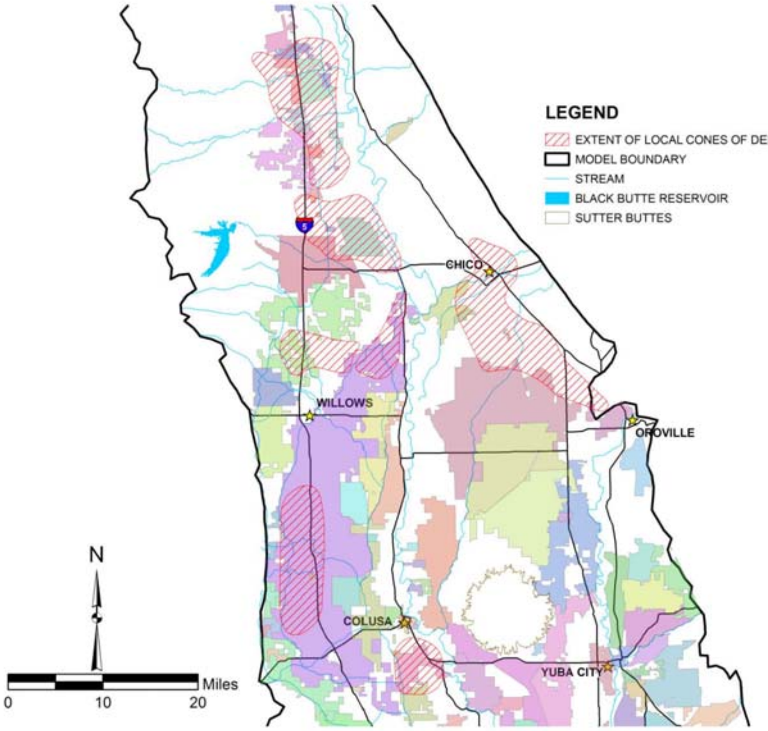


FIGURE 4-1
GROUNDWATER CONDITION STUDY AREAS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

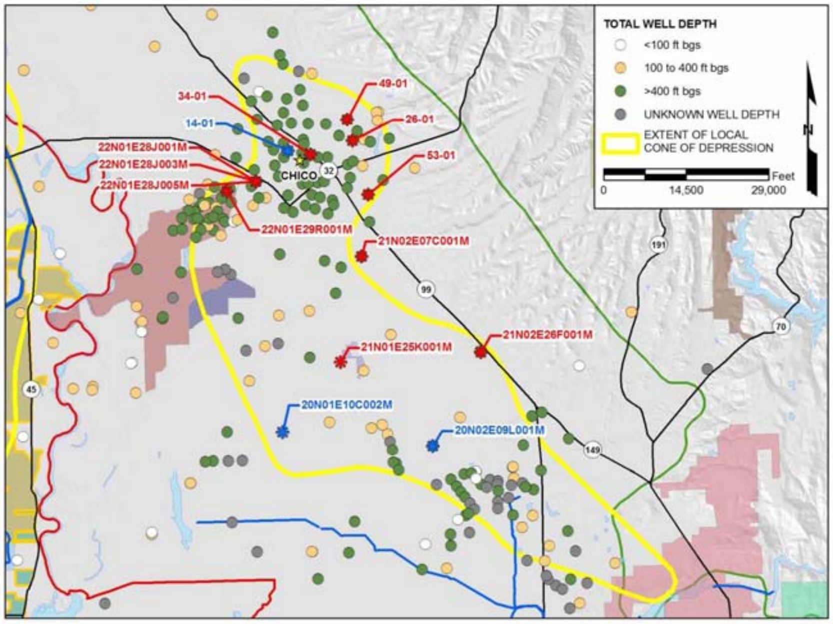


FIGURE 4-2
WELLS EVALUATED IN THE CHICO-DURHAM AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

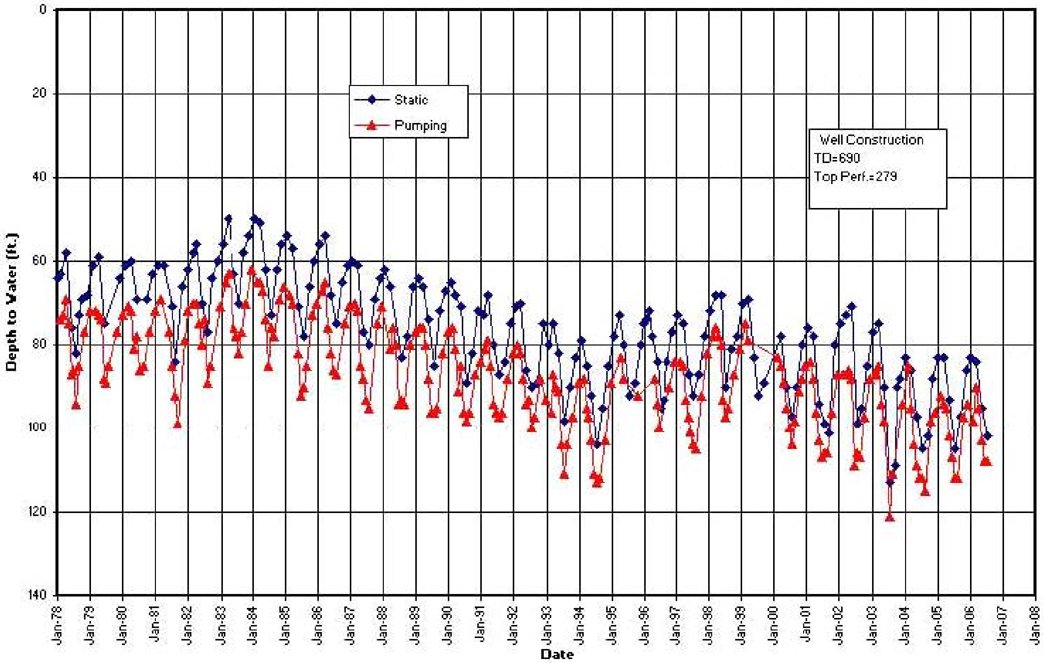


FIGURE 4-3
HYDROGRAPH OF CAL WATER WELL 34-01
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

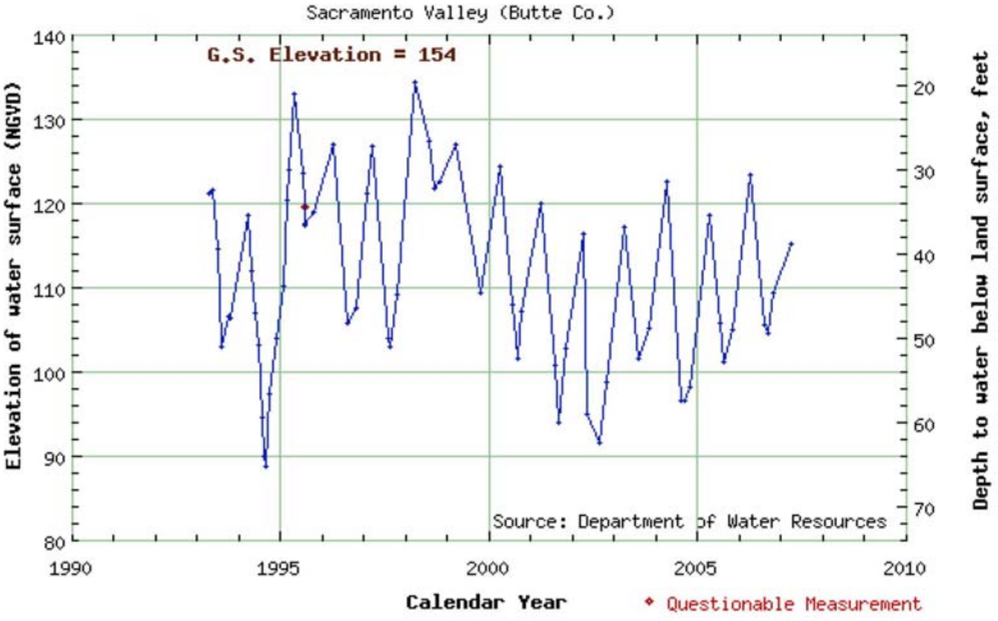
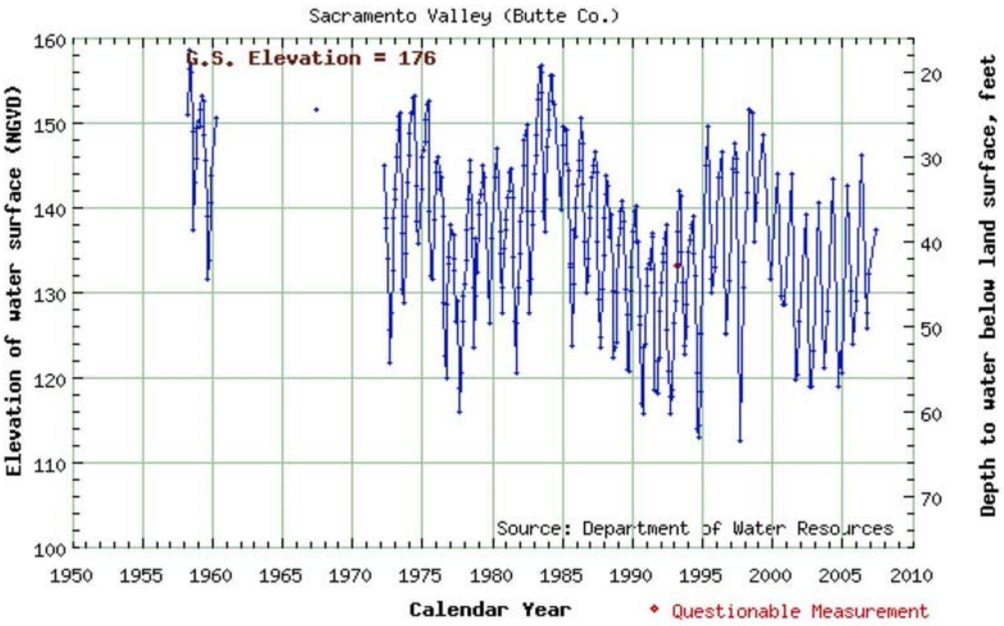
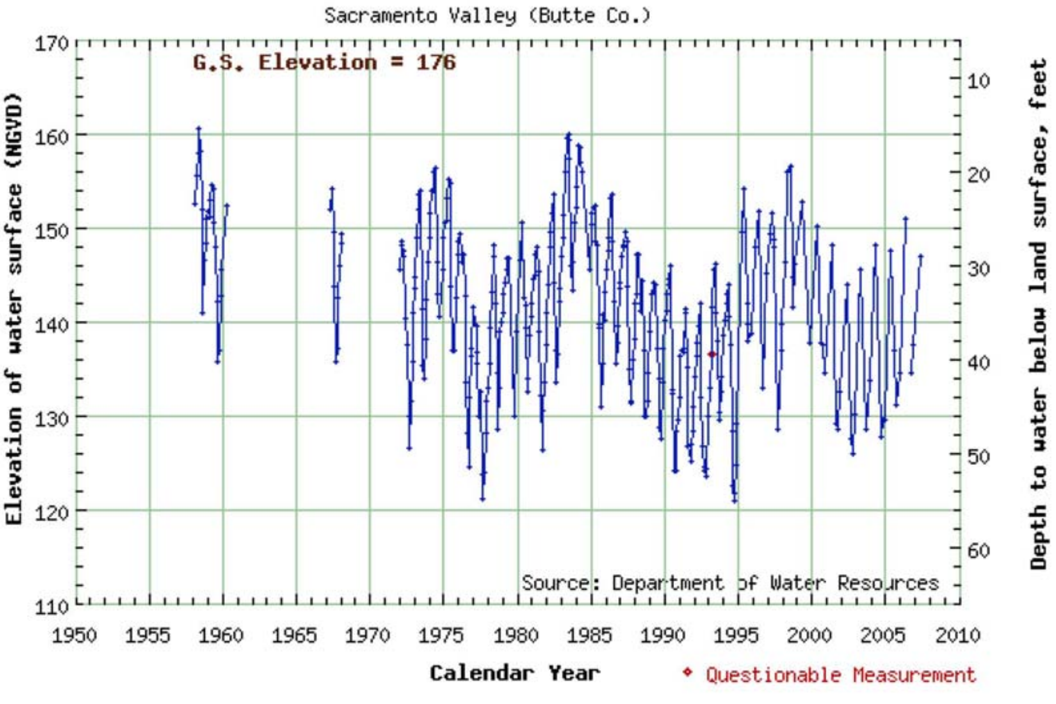


FIGURE 4-4
HYDROGRAPH OF WELL 21N01E25001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT



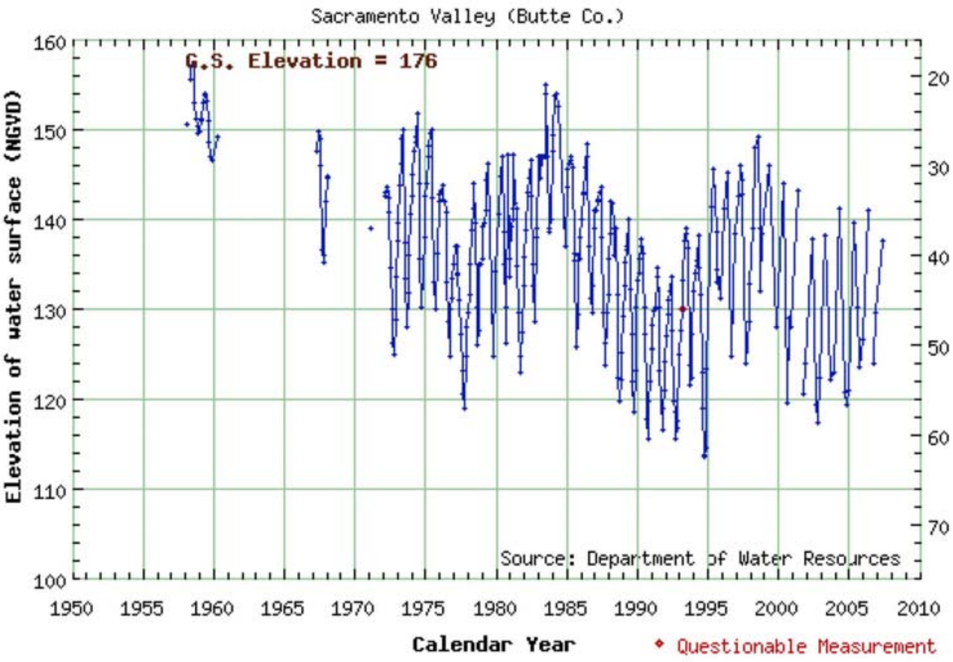
Source: Department of Water Resources

FIGURE 4-5
HYDROGRAPH OF WELL 22N01E28J001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT



Source: Department of Water Resources

FIGURE 4-6
HYDROGRAPH OF WELL 22N01E28J003M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT



Source: Department of Water Resources

FIGURE 4-7
HYDROGRAPH OF WELL 22N01E28J005M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

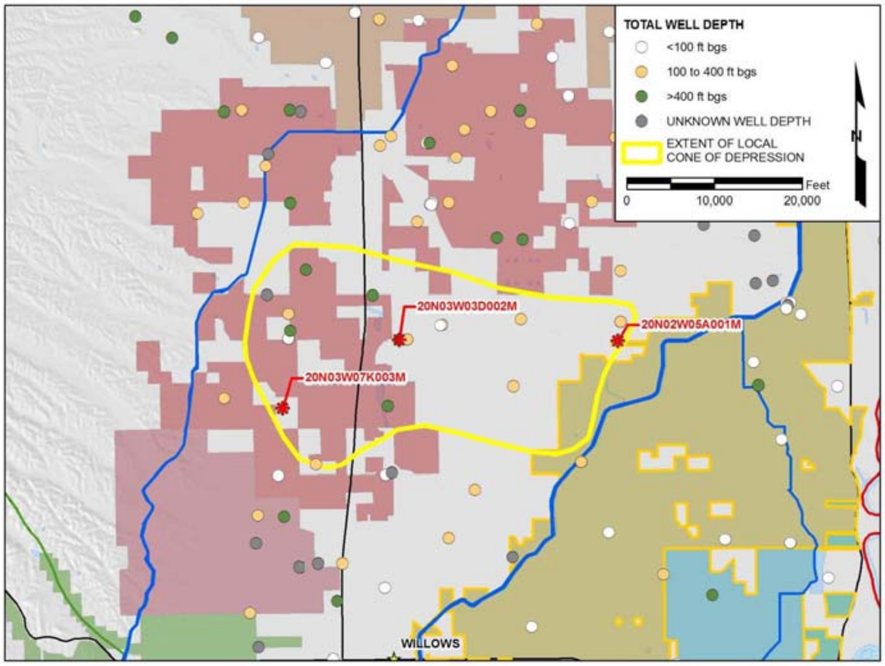


FIGURE 4-8
WELLS EVALUATED IN THE ORLAND-ARTOIS WATER DISTRICT AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

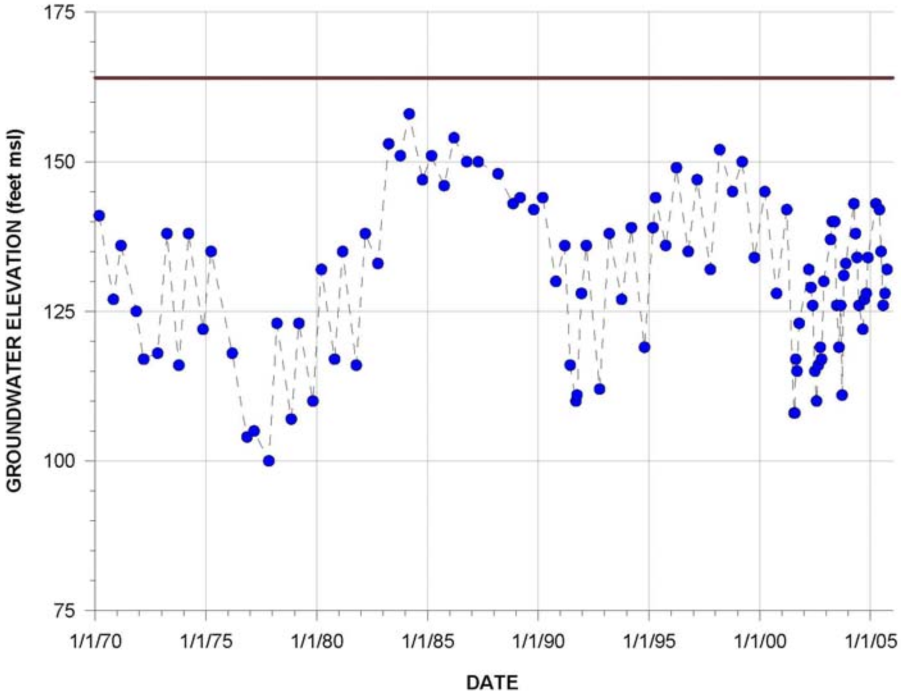


FIGURE 4-9
HYDROGRAPH OF WELL 20N03W03D002M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

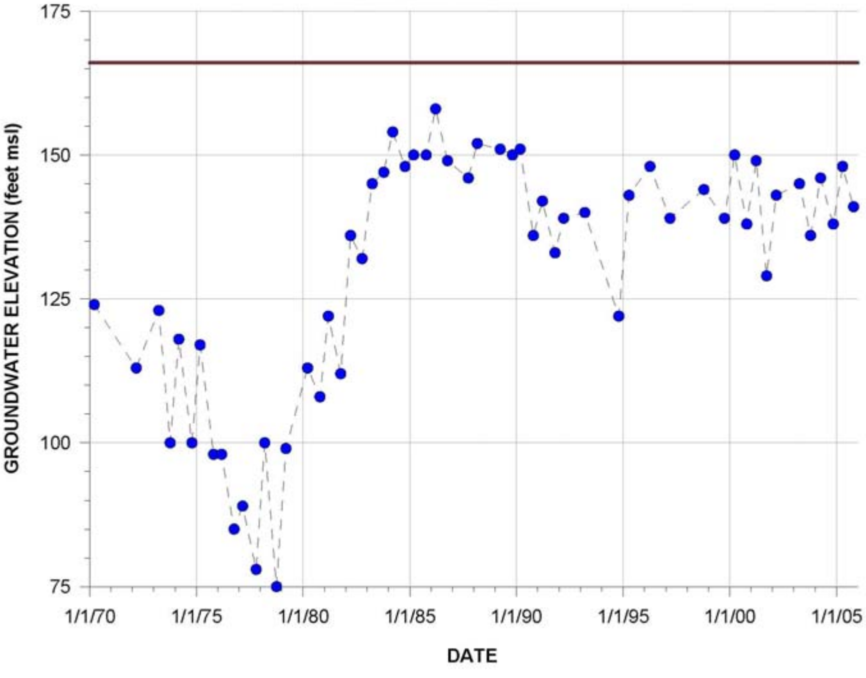


FIGURE 4-10
HYDROGRAPH OF WELL 20N03W07K003M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

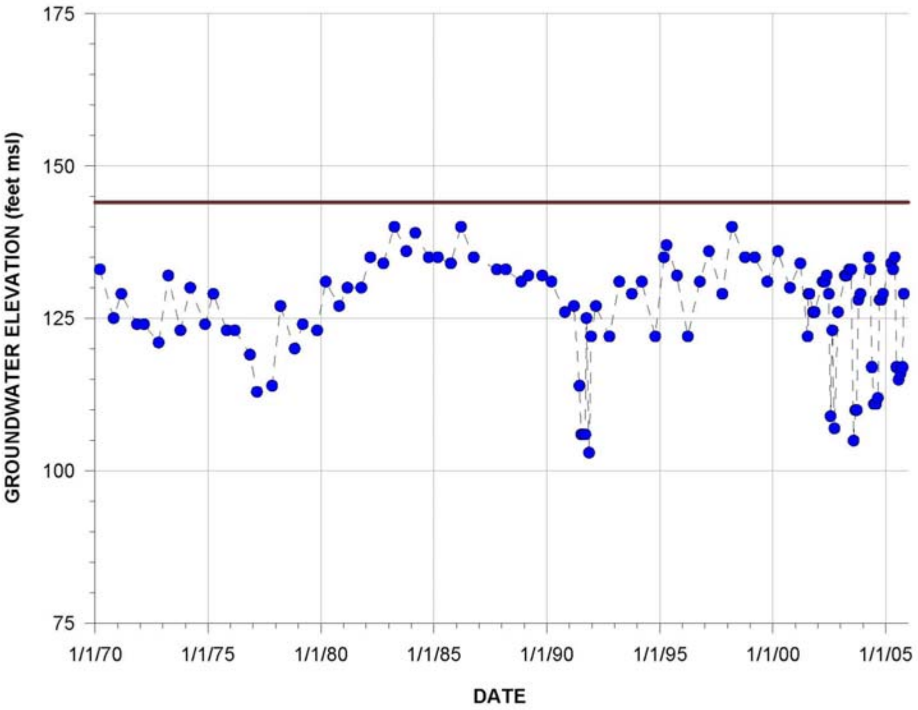


FIGURE 4-11
HYDROGRAPH OF WELL 20N02W05A001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

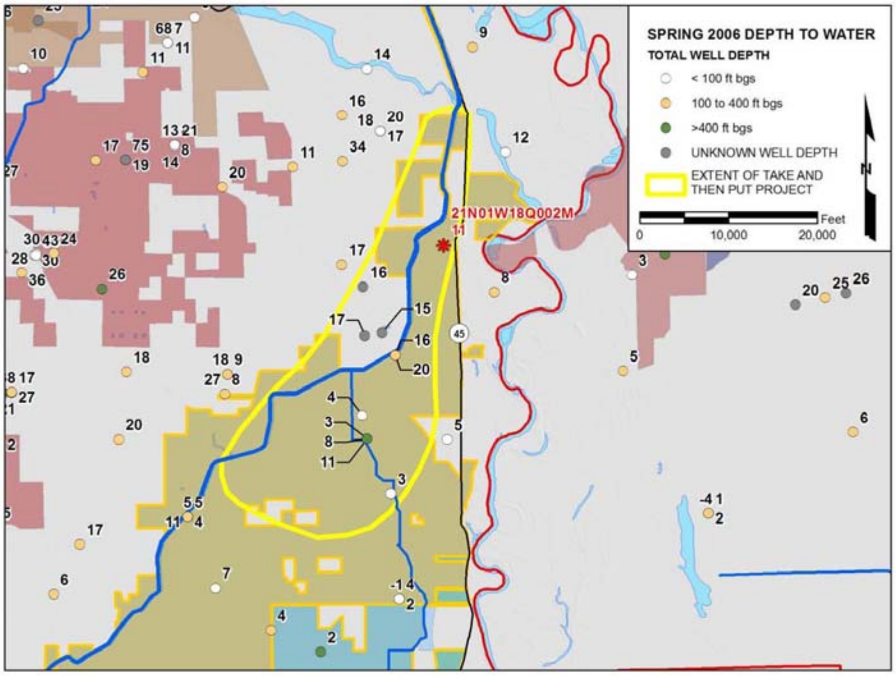


FIGURE 4-12
WELLS EVALUATED IN THE NORTHERN GCID WATER DISTRICT AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

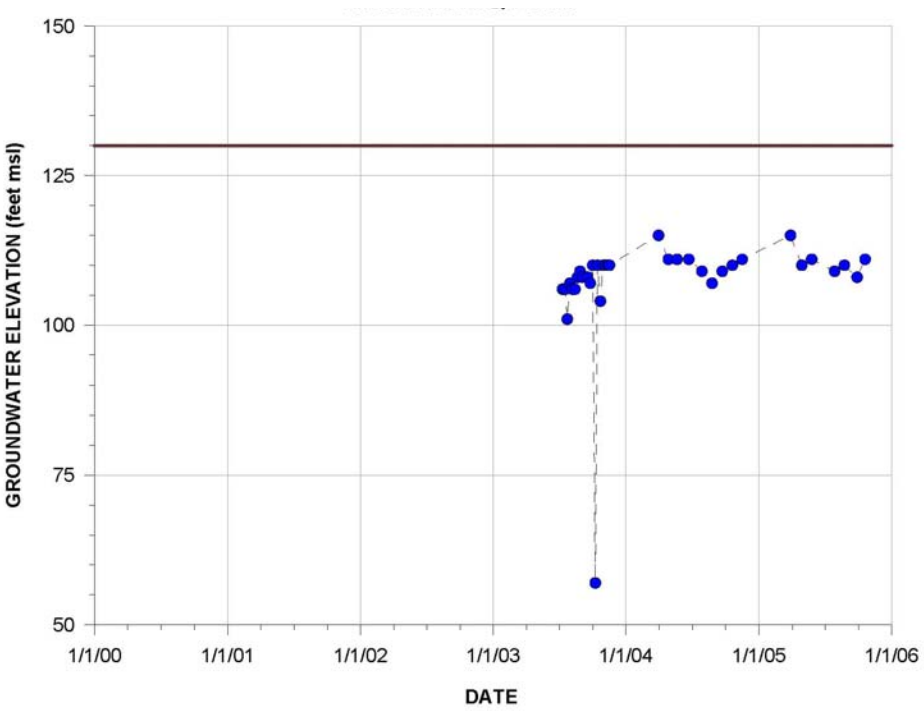


FIGURE 4-13
HYDROGRAPH OF WELL 21N01W18Q002M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

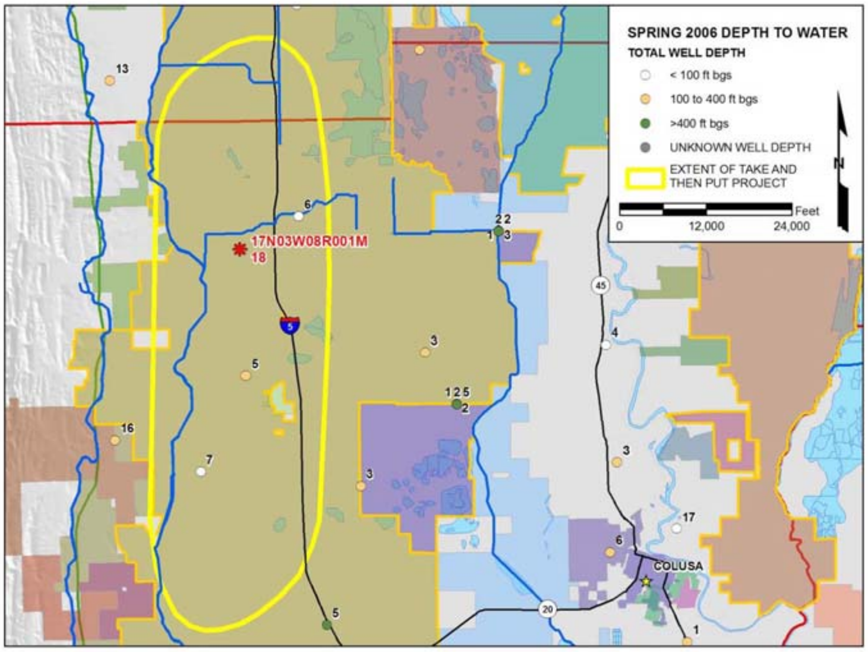


FIGURE 4-14
WELLS EVALUATED IN THE CENTRAL GCID WATER DISTRICT AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

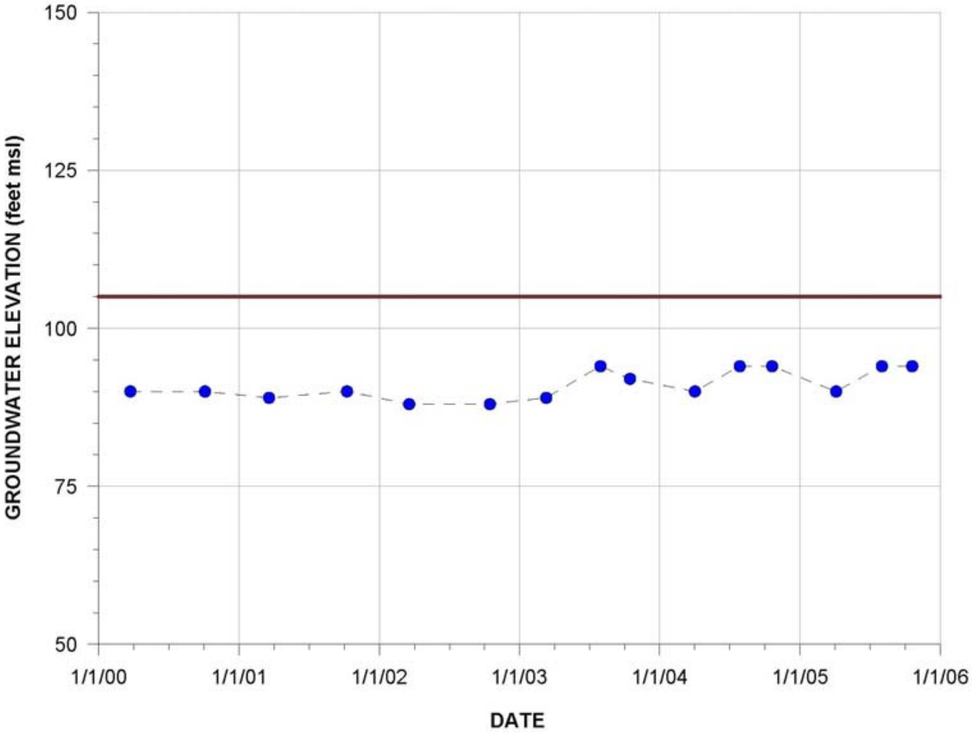


FIGURE 4-15
HYDROGRAPH OF WELL 17N03W08R001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

SECTION 5

General Operational Scenario

The team used its understanding of annual aquifer drawdown and recovery to develop a conjunctive operation configuration that relies primarily on re-operation of existing reservoirs to achieve the project objectives, drawing on groundwater as a backstop. The term "backstop" refers to the potential to use groundwater supplies on a temporary basis to make up for shortfalls in surface water supplies due to modified project operations. Groundwater provides an additional source of water to protect surface water reservoirs from being excessively depleted. This type of operation offers different opportunities and challenges than the conventional put-then-take groundwater banking discussed above. Surface water is not banked in the aquifer in wet years and recovered during dry years. Instead, additional water is released from surface reservoirs for delivery to meet Project objectives (unmet local irrigation demands and environmental flow targets). These releases result in lower end-of-year reservoir storage levels and more reservoir space available to capture winter runoff.

The goal of this operation is to develop additional water supply by refilling reservoir space vacated by additional Project releases with surplus surface water that otherwise is released for flood control. In years when refill is not complete, Project pumping produces groundwater for use in Project areas in lieu of surface water deliveries that would otherwise be made from reservoirs. This allows an equivalent volume of water to remain in reservoir storage to recover from prior year project releases.

This mode of conjunctive operation, in which reservoir operation is used as the primary means to develop new water supply and groundwater is used infrequently as a backstop, is highly efficient because it reduces the frequency and volume of pumping as compared to traditional banking operations. Groundwater pumping is relied upon only as needed to maintain reservoir storage when refill from surplus winter flows is insufficient.

In some years, conditions in the Sacramento Valley may be so critically dry that Project pumping would be suspended altogether. For instance, if groundwater levels were already at levels of concern (according to county Basin Management Objectives or other standards), Project wells would be turned off and the Project would generate no new supplies under these conditions.

SECTION 6

Initial Project Site Identification

The project team completed a systematic, qualitative assessment of conditions within the Sacramento Valley to identify particular areas in which conjunctive operations appear promising. This process did not conclusively identify the very best or most feasible sites, but did identify particularly promising sites for conjunctive operations.

The team examined fall groundwater elevation maps, water district maps, and water source maps. Initially it was assumed that conjunctive management operations would follow groundwater banking type operations wherein water is stored in aquifers during years of above normal precipitation and extracted during years of below normal precipitation. These operations are typical in the San Joaquin Valley and other areas in which aquifers have been depleted and appreciable storage space exists. Following this initial assumption, the following two types of sites were identified:

- Areas in which existing groundwater levels may be lower than surrounding areas and overlying lands are supplied almost exclusively from groundwater. This type of site may provide the potential for storage of surplus surface water in underlying aquifers.
- Areas in which minimal groundwater pumping exists because overlying areas are supplied almost exclusively from surface water. This type of site may provide a potential area for groundwater extraction.

6.1 Initial Project Sites

An initial list of project sites was developed from a review of groundwater maps and knowledge of the Sacramento Valley. Sites were identified by the overlying water district, though projects did not strictly conform to water district boundaries. Information considered in this analysis included the location, water source, existing surface water contracts, infrastructure available and additional infrastructure necessary for delivery of surface water and extraction of groundwater, conceptual operations, and information on existing groundwater conditions. Table 6-3 summarizes this information for the nine initial sites.

6.2 Selection Criteria

The main goal was to identify at least one site that is served by the CVP (Shasta), one by the SWP (Oroville), and one by the Orland Project. The CVP and SWP are the principal surface water systems in the Sacramento River basin and their operations are linked to the Sacramento and Feather Rivers, respectively, both of which are targeted for environmental restoration. The Orland Project, although not among the largest surface water systems in the Valley, is an area where conjunctive operations have been viewed as a possibility for many years.

TABLE 6-1
Initial Project Sites and Parameters
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Location	Water Source	Site Type	Annual Surface Water Contract	Project to Integrate With	Currently Integrated?
Butte Basin	Surface	Extraction	~ 300 TAF/yr	SWP	Yes
Orland-Artois WD	Mixed	Both	53 TAF/yr	CVP	Yes
Rancho Capay WD	Ground	Storage	None	CVP	No
Corning Canal Area	Mixed	Both	33 TAF/yr	CVP	Yes
Yolo-Zamora WD	Ground	Storage	None	CVP	No
Glenn-Colusa ID	Surface	Extraction	825 TAF/yr	CVP	Yes
Stony Creek Fan area	Surface	Extraction	~ 100 TAF/yr	Orland	No
Colusa County WD	Mixed	Both	68 TAF/yr	CVP	Yes
Olive Percy Davis Ranch	Surface	Extraction	32 TAF/yr	CVP	Yes

These nine sites were evaluated based on whether they could meet project objectives of providing additional water supply to meet agricultural and environmental objectives, an estimate of the volume of water that may be developed, and relative (compared to the other sites) ease and cost of integrating the project with existing surface water systems.

The following additional criteria were used to identify prospective sites:

- Availability of reliable surface water supplies that could be substituted with groundwater to enable conjunctive operations
- The presence of highly productive, underlying groundwater aquifers that could be economically developed
- The ability to locate and design production wells in a manner that would minimize effects on existing groundwater users and surface streams

6.3 Selected Project Sites and Operational Scenarios

Using the selection criteria described in Section 5.2, the Project identified two sites on which to conduct more refined analyses with surface and groundwater modeling tools. The GCID and Butte Basin Projects, supplied by the CVP and SWP, respectively, provided the potential to develop the largest quantity of water compared to other sites, and are already well integrated with the surface water system.

Additionally, the Stony Creek Fan and Orland Project was identified as a third potential project. However, upon further investigation into potential groundwater pumping capacities and the ability to integrate the project with the Sacramento River system, it was determined that this project would not be modeled during this phase of the project. This project is retained for additional analysis in future phases of investigation.

6.3.1 Glenn-Colusa Irrigation District Project

GCID is the largest, single Sacramento River diverter, serving about 141,000 acres of irrigated land and 20,000 acres of managed waterfowl habitat within its gross service area of 170,000 acres. GCID is served by the CVP (pursuant to underlying senior water rights) and is underlain by productive aquifers. There are about 200 existing private wells in GCID, but groundwater production in most years is small. Conjunctive management operations would utilize wells within GCID as a backstop for a more aggressive operation of Shasta Reservoir.

6.3.2 Butte Basin Project

The initial project site of Western Canal Water District was expanded to include neighboring Richvale Water District. These districts are all served by the SWP (pursuant to underlying senior water rights) and are adjacent to each other comprising a total irrigated area of roughly 110,000 acres. They are generally underlain by productive groundwater systems and there is limited existing use of groundwater. Conjunctive management operations would utilize wells within the two districts as a backstop for a more aggressive operation of Oroville Reservoir.

SECTION 7

Modeling Overview

Evaluating conjunctive management projects requires simulation of both surface water and groundwater systems. Simulating the surface water system is necessary to determine when water is available to refill reservoirs and estimate unmet agricultural demands, environmental objectives, and flow conditions. A groundwater model is necessary to estimate the effects of additional pumping on aquifer systems, including the spatial extent and magnitude of drawdown and potential change in stream-aquifer interaction. Changes in stream-aquifer interactions may affect the surface water system, depending on stream conditions when the changes occur. For example, if additional pumping results in more stream loss to the aquifer or less aquifer contribution to stream flow during the winter season of relatively wet years when the surface water system has surplus flow, there may be little or no impact. However, if pumping reduces stream flow during months and years when the surface water system is being operated to meet specific flow or water quality requirements, any reduction in stream flow will require a corresponding increase in reservoir release to ensure the flow requirement continues to be met. This decreases the water supply benefit of conjunctive management projects. Evaluating this aspect of conjunctive management projects requires interaction between surface water and groundwater models.

The main tool used to evaluate alternative conjunctive management operations strategies and test alternative environmental flow thresholds and priorities is a spreadsheet-based surface water model. It is set up to simulate changes in operation of Lake Shasta and Lake Oroville relative to conditions depicted in a baseline CalSim II simulation of CVP and SWP operations. The CalSim II baseline provides time series of reservoir storage levels, stream flows, and water deliveries which are used by the surface water model. Conjunctive management operations are simulated and layered onto baseline operations based on user inputs, while maintaining compliance with existing CVP and SWP rules, regulation, and operations.

The surface water model treats the groundwater system as a source of water and does not simulate groundwater flows or conditions. It does, however, include features to account for estimated effects of groundwater pumping on stream flow accretion and depletion through use of functions derived from complementary simulations of pumping in the groundwater model. These functions provided a coarse but adequate representation of stream-aquifer interaction so that the surface water model could be used for gaming sessions without having to operate the groundwater model. Final scenarios were evaluated using actual changes in stream-aquifer interaction based on complimentary groundwater model simulations.

Figure 7-1 illustrates inputs to the surface water model and resulting simulation of conjunctive management projects integrated into CVP and SWP operations.

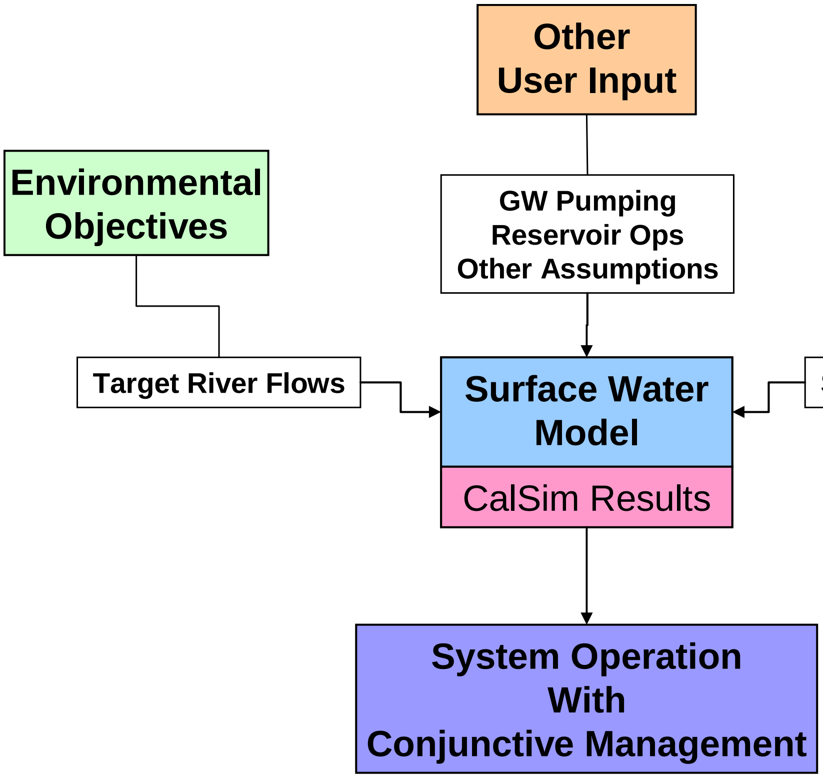


FIGURE 7-1
SURFACE WATER MODEL INPUTS AND OPERATIONS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Numerous improvements were made to previously existing modeling tools, and new tools were developed for this analysis of conjunctive management projects. For the groundwater analysis, an existing simplified groundwater modeling tool was completely re-designed and improved, to yield an extremely powerful analytical package now referred to as the Sacramento Valley Groundwater Model (SACFEM). The basis for the SACFEM model was a simplified superposition-based groundwater model previously developed to support the Sacramento Valley Water Management Program. That model represented a very simplified depiction of the Sacramento Valley aquifer system as no recharge components to the aquifer system (deep percolation of precipitation and applied water) or discharge components (regional agricultural pumping) were included, and therefore the model could only compute the incremental change in groundwater levels and streams flows during the irrigation season. It was assumed that the aquifer system fully re-filled every winter, and each year of pumping was independent of previous aquifer stresses.

The SACFEM model is a full water budget based transient groundwater flow model that incorporates all of the groundwater and surface water budget components on a monthly time step over the period of simulation. This model provides very high resolution estimates of groundwater level and streamflow effects due to conjunctive water management pumping across the valley.

The surface water model is a new tool designed specifically to analyze conjunctive management projects for agricultural and environmental benefits. Its flexibility for use in gaming sessions and for sensitivity and tradeoff analysis helped provide understanding of conjunctive management concepts, operations, and limitations.

The integration of surface water and groundwater modeling tools and the simulation of effects of additional groundwater pumping on the surface water system is a significant advancement over previous modeling tools. Simulation of changes in stream-aquifer interaction, the spatial and temporal variations in those changes, and conditions in the surface water system when changes occur are key components for evaluating conjunctive management projects and understanding their benefits and risks.

SECTION 8

Groundwater Model

MicroFEM© (Hemker, 1997), an integrated groundwater modeling package developed in The Netherlands, was chosen to simulate the groundwater flow systems in the Sacramento Valley Groundwater Basin. The current version of the program (3.60) has the ability to simulate up to 25 layers and 250,000 surface nodes. MicroFEM© is capable of modeling saturated, single-density groundwater flow in layered systems. Horizontal flow is assumed in each layer, as is vertical flow between adjacent layers.

MicroFEM© was the chosen modeling platform for both basins for the following reasons:

- The finite-element scheme allowed the construction of a model grids covering large geographic areas (over 5,955 square miles in the Sacramento Valley Groundwater Basin) with coarse node spacings outside of the simulated project areas and finer node spacings in areas of interest (e.g., near potential project areas). The finer node spacing near simulated production wells provides greater resolution of simulated groundwater levels and stream impacts.
- The graphical interface allows rapid assignment of aquifer parameters and allows proofing of these values by graphical means.
- The flexible post-processing tools allow for rapid evaluation of transient water budgets for model simulations and identification of changes to stream discharges and other water fluxes across the model domain.

8.1 Geologic Setting

The Sacramento Valley Groundwater Basin is a north-northwestern trending asymmetrical trough filled with as much as 10 miles of both marine and continental rocks and sediment (Page, 1986). On the eastern side, the basin overlies basement bedrock that rises relatively gently to form the Sierra Nevada, and on the western side, the underlying basement bedrock rises more steeply to form the Coast Ranges. Marine sandstone, shale, and conglomerate rocks that generally contain brackish or saline water overlie the basement bedrock. The more recent continental deposits, overlying the marine sediments, contain fresh water. These continental deposits are generally 2,000 to 3,000 feet thick (Page, 1986). The depth (below ground surface [bgs]) to the base of fresh water typically ranges from 1,000 to 3,000 feet (Bertoldi et al., 1991).

In the Sacramento Valley Groundwater Basin, groundwater users pump primarily from deeper continental deposits. Groundwater is recharged by deep percolation of applied surface water and rainfall, infiltration from streambeds, and lateral inflow along the basin boundaries. The quantity and timing of snowpack melt and precipitation events are the predominant factors affecting the surface water and groundwater hydrology, and peak runoff in the basin typically lags peak precipitation by 1 to 2 months (Bertoldi et al., 1991).

8.2 Hydrology

The Sacramento River is the main surface water feature in the Sacramento Valley Groundwater Basin. It has several major tributaries draining the Sierra Nevada, including the Feather, Yuba, and American Rivers. Stony, Cache, and Putah Creeks drain the Coast Range and are the main westside tributaries of the Sacramento River.

8.3 Model Construction

8.3.1 Spatial Grid

The SACFEM model grid consists of 88,922 nodes and 177,095 elements. Nodal spacing varies from as large as 5,800 feet (1,750 meters) near the model boundary and in areas with no water management projects to as small as 500 feet (150 meters) in areas where groundwater production is being investigated. Three zones of refined nodal spacing are located throughout the model domain in proximity to the areas that were previously identified as showing the greatest potential for successful conjunctive water management operations (NHI, 2007). These three areas are located in the west-central portion of GCID, the areas southwest of Chico encompassing the Western Canal and Richvale Water Districts, and the area east of Black Butte Lake on the Stony Creek Fan (see Figure 8-1).

The finer spacing in these areas of interest allows for a more refined estimate of the groundwater levels and groundwater-surface-water interaction in the potential project areas. The model boundary represents the extent of the freshwater aquifer in the Sacramento Valley.

8.3.2 Vertical Layering

The total model thickness represents the thickness of the freshwater aquifer (less than 3,000 micromhos per centimeter) as defined by Berkstresser (1973) and subsequently refined in the northern portion of the valley by the California Department of Water Resources (DWR) (2002). For the southern portion of the model area, defined by Berkstresser data, elevation contour lines of the base of fresh water, along with information from boring locations (point measurements of the elevation of the base of fresh water) were digitized and used to generate an x, y, z file containing the elevation of the base of fresh groundwater at regularly spaced intervals. For the northern portion of the model area, the locations of the geologic cross-sections were plotted, along with the estimated base of freshwater elevations obtained from the cross-section information, and a base of freshwater elevation contour map was constructed. These data sets were then merged to yield a single interpretation of the structural contour map of the base of freshwater across the Sacramento Valley. This map is presented on Figure 8-2.

Total Aquifer Thickness

To develop a total aquifer thickness distribution and, therefore, a total model thickness distribution, it was necessary to develop a groundwater elevation contour map and subtract the depth to the base of freshwater from the groundwater elevation contour map. The water level calibration targets for this groundwater modeling tool are the steady-state groundwater heads measured in calendar year 2000. Therefore, to develop a target groundwater elevation contour map, all available groundwater elevation measurements in the DWR Water Data Library were obtained from DWR central and northern district staff. These measurements were primarily collected biannually during spring and fall periods, and these values were averaged at each well location to compute an average water level at each well point. These values were then contoured, in conjunction with the streambed elevations for the 37 major streams included in the model, to develop a target groundwater elevation contour map for the year 2000. The distribution of the elevation of the base of freshwater was subtracted from this groundwater elevation contour map to yield an estimate of the distribution of the total aquifer thickness across the model domain.

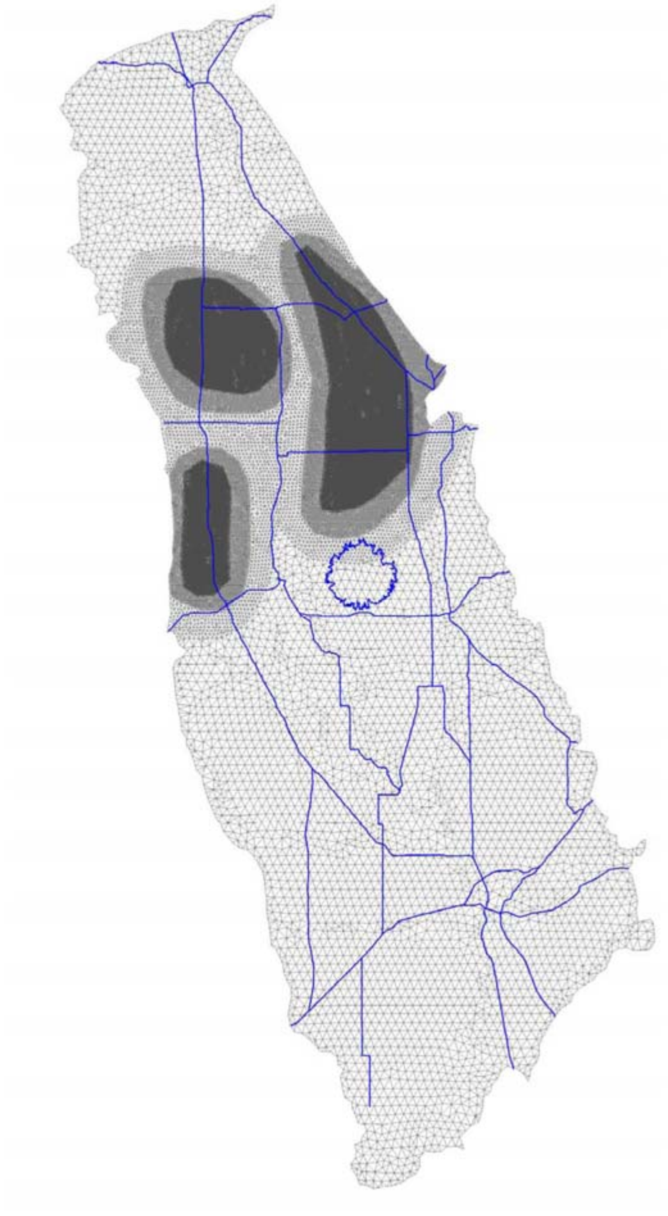


FIGURE 8-1
SACFEM FINITE ELEMENT GRID, LOWER TUSCAN CONJUNCTIVE WATER MANAGEMENT INVESTIGATION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

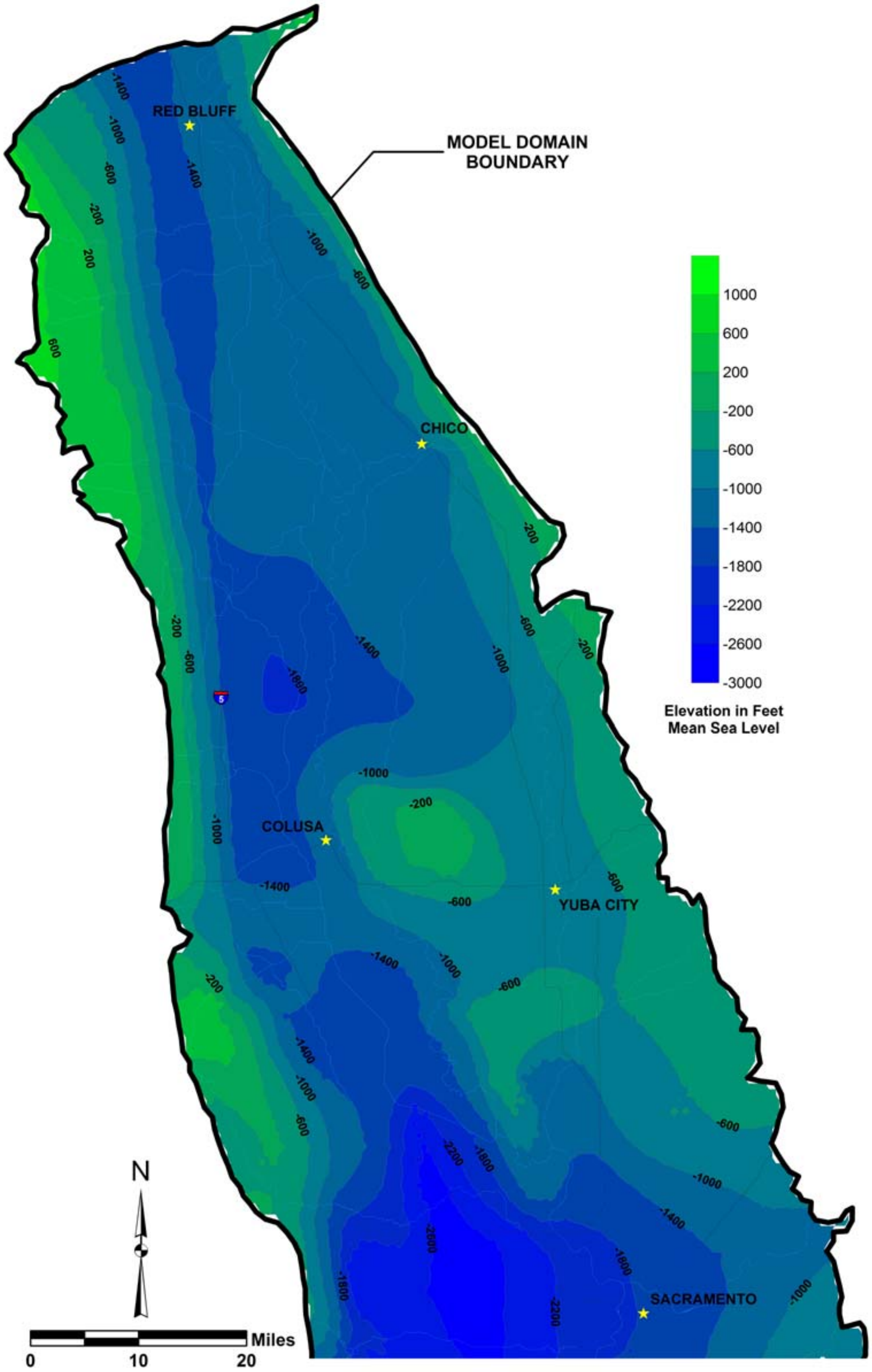


FIGURE 8-2
DEPTH TO FRESHWATER LOWER TUSCAN CONJUNCTIVE WATER MANAGEMENT INVESTIGATION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Model Layer Thickness

Because one of the primary objectives of this analysis was to investigate the potential to implement conjunctive water management projects within the lower Tuscan aquifer, the strategy used to layer the model was to assign two layers to explicitly represent this aquifer system: layers 6 and 7. Where the lower Tuscan is present, the elevation of the top of layer 6 was defined by the structural contour surface of the top of the lower Tuscan. Two layers were assigned to represent this unit because in many areas of the model, the depth to the base of freshwater (the base of the model) is as much as 900 feet below the upper surface of the lower Tuscan. Groundwater production wells drilled into the lower Tuscan would almost certainly be screened over a much smaller depth interval. To represent this condition in the model, layer 6 was assigned a thickness of between 200 and 250 feet, with the remaining lower Tuscan thickness assigned to layer 7. The exception to this convention is in the northeastern portion of the model near the City of Chico. The lower Tuscan outcrops in the foothills above Chico; therefore, in these areas, all layers of the model represent the lower Tuscan aquifer. Moving west from Chico, a transition zone exists where a decreasing number of layers represent the lower Tuscan until it is limited to layers 6 and 7. In areas where the lower Tuscan is not present, the thicknesses of layers 6 and 7 represent 18 and 27 percent of the total aquifer thickness, respectively.

Layers 1 through 5 represent shallower producing zones within the valley. The thicknesses of these layers were assigned based on a specified percentage of the available aquifer thickness at a given location, to provide multiple depth zones within which to assign regional pumping. The assumed layer thicknesses for layers 1 through 5 were also selected to reflect typical screened intervals of production wells in the Sacramento Valley. Layer 1 represents approximately 6 percent of the total aquifer thickness, except along certain portions of model perimeter where the total aquifer thickness became very small. In these areas, layer 1 thickness was increased to up to 24 percent of the total aquifer thickness to improve numerical stability of flow calculations. The thicknesses of layers two through four each represent approximately 10 percent of the total aquifer thickness, and the thickness of layer 5 represents approximately 15 percent of the total aquifer thickness.

8.3.3 Boundary Conditions.

A combination of no-flow, specified flux, and head-dependent boundary conditions were used to simulate the groundwater flow system within the Sacramento Valley.

Head-Dependent Boundaries.

Rivers. A head-dependent boundary condition was chosen to simulate the streams within the Sacramento Valley. The MicroFEM© wadi system was used to implement streams within the model domain. MicroFEM©'s wadi package calculates the magnitude and direction of nodal fluxes based on the relative values of the user specified stream stage (wh1) and the calculated head in the upper aquifer (h1), but is limited by a critical depth (wl1). When calculated groundwater elevations fall below this critical depth, it is assumed that the water table de-couples from the river system, and the leakage rate from the river to the aquifer becomes constant. The equations that govern operation of the wadi package are as follows:

Groundwater discharge to a stream is simulated if h1 >wh1:

$$Q_{inflow} = a * (h1 - wh1) / | wc1 | \quad (1)$$

In coupled streams (groundwater elevation is above the stream bottom elevation), groundwater recharge from a stream is simulated if h1 <wh1:

$$Qinflow = a * (wh1 - h1) / | wc1 | \quad (2)$$

In de-coupled streams (groundwater elevation is below the stream bottom elevation), groundwater recharge from a stream is simulated:

$$Qinflow = a * (wh1 - wl1) / | wc1 | \quad (3)$$

Where:

Q = volumetric flux

a = nodal area

h1 = simulated groundwater elevation in layer 1

wh1 = simulated stream stage

wl1 = stream bottom elevation

wc1 = resistance across the streambed

Nodal area is a grid-dependent parameter that can be automatically calculated within MicroFEM©. In general, the nodal area around a node that represents a discrete reach in a stream is greater than the surface area of that stream along the reach in the field. The effective resistance term (wc1) incorporates an areal correction factor to account for this discrepancy. Additionally, streambed resistance terms account for the relationship between the streambed sediments and aquifer properties in the upper half of model layer 1 when calculating stream seepage. River resistances are calculated as follows:

$$wc1 = ((Dr/Kr) +((0.5 * mt1)/Kv1))* (a/LW) \quad (4)$$

Where:

Dr = thickness of streambed sediments

Kr = vertical hydraulic conductivity of streambed sediments

mt1 = thickness of model layer 1

Kv1 = vertical hydraulic conductivity of model layer 1

L = stream length represented by the model node

W = field-width of the wetted river channel within the stream reach represented by L

Most major streams in the Sacramento Valley were included in the groundwater flow model. A total of 37 streams are represented. Stream locations and elevations were digitized from existing base maps and USGS topographic quad sheets and imported into the model domain. Stream length within a given node is a grid-dependent variable calculated by MicroFEM© at each river node. The stream-length term is generally overestimated by MicroFEM© at stream confluences. Manual corrections of this term were made where necessary. Streambed thickness was assumed to be 3.28 ft (1 meter) for all river nodes.

Assumptions of streambed Kv were based on the type of streambed deposits expected based on stream size. Wetted stream width was calculated from aerial photographs at two locations along each stream.

Drains. Drain boundary conditions were specified across the top surface of the model excluding nodes where wadi boundaries exist. Drain boundary conditions are head-dependent boundaries that allow the transfer of water out of the model domain only. The elevation of the drain boundaries were set at the land surface. The drain boundaries were included in the model to represent a combination of surficial processes that occur in areas of shallow groundwater including evapotranspiration and groundwater discharge to the surface.

Groundwater discharge to a drain is simulated if h1 >dh1:

$$Q_{outflow} = a * (h1 - dh1) / \mid dc1 \mid \text{ (where a = nodal area)} \quad (5)$$

Groundwater discharge to a drain if h1 <dh1:

$$Q_{outflow} = 0 \quad (6)$$

The parameter dc1 represents the drain conductance and is a measure of the resistance to flow across the drain boundary. The dc1 parameter is computed as:

$$dc1 = ((Td/Kd) \quad (7)$$

Where:

Td is the drain interface thickness and Kd is the hydraulic conductivity of the drain materials.

Specified Flux Boundaries. There are three sets of specified flux boundary conditions used in the SACFEM model. They represent the following three primary components of the agricultural water budget:

- Deep percolation of applied water and precipitation along with agricultural pumping
- Mountain front recharge
- Urban pumping

Deep Percolation of Applied Water and Precipitation and Agricultural Pumping. The first set reflects the deep percolation of precipitation and applied water across the valley, as well as the regional agricultural pumping. The deep percolation flux values were applied to every surface node in the model. The pumping stresses due to agricultural and urban pumping were applied at selected locations in model layers 2 through 4. These layers were selected as they represent the common depths of production wells within the valley. The spatial distribution and magnitudes of these fluxes were derived from the surface water budget calculations described in greater detail in the subsection titled Surface Water Budget.

Mountain Front Recharge. The second set of specified flux boundary conditions represent the subsurface inflow of precipitation falling within the Sacramento River Watershed but outside the extent of the model domain. To estimate these flux values, the USGS 10-meter Digital Elevation Model (DEM) along with existing hydrography geographic information system (GIS) coverages for the Sacramento Valley were used to delineate the drainage areas that are tributary to the model domain but fall outside of the rivers watersheds explicitly represented in the model. It is these areas that can contribute water to the model domain but are not accounted for in the wadi boundary conditions defined in the model. Once the areas of these watersheds were defined, they were intersected with (PRISM) rainfall data using GIS PRISM tools, and the volume of precipitation falling on the watershed computed. Based on the computed total volume of precipitation, the deep percolation to the groundwater system was calculated using the empirical relationship developed by Turner (1991).

$$DP = (PPT-2.32)*(PPT)^{0.66} \quad (8)$$

Where:

DP = Average annual deep percolation of precipitation (in/yr)
PPT = Annual precipitation (in/yr)

Following is a summary of the process that was used to estimate the quantity of subsurface inflow, otherwise known as mountain front recharge:

1. The area of each drainage basin tributary to the model domain that is not represented by streams explicitly simulated in SACFEM was computed using a GIS-based analysis of the land surface topography. The extent of these smaller watersheds is shown on Figure 8-3.

2. Each drainage area polygon was then intersected with a GIS coverage of annual average rainfall estimated using the PRISM model (reference). This distribution of annual average rainfall was then used to calculate the total volume of rainfall falling on the watershed, and an overall average rainfall rate computed (inches per year).

3. The average rainfall rate was then used to compute a deep percolation quantity using the relationship between annual rainfall and deep percolation rate developed by Turner (1991).

4. The annual volume of deep percolation computed in step 3 was then converted into monthly values based on the monthly distribution of stream flow measured in unregulated sections of Deer Creek. These monthly deep percolation quantities were then introduced at the model domain boundary of each small watershed polygon using injection wells into layer 1. The quantity applied to each model boundary node was proportional to boundary length of each element versus to the total boundary length of the drainage polygon.

Urban Pumping. The final set of specified flux boundary conditions reflect urban pumping within the model domain. The distribution of agricultural pumping developed using the surface water budgeting methodologies described in the Surface Water Budget subsection do not include urban pumping. To estimate the quantity of urban pumping to apply to the model the year 2000 census data were used. Each municipal area with a population greater than 5,000, that uses groundwater as a source of municipal supply, was assigned a pumping volume based on an annual average per capita value of 250 gallons per capita per day. The urban pumping assigned to the Chico area as well as several northern Sacramento County municipal areas required a higher per capita rate to match the observed groundwater elevations in those areas. The monthly variability in urban pumping quantity was distributed based on typical seasonal trends for municipal water use.

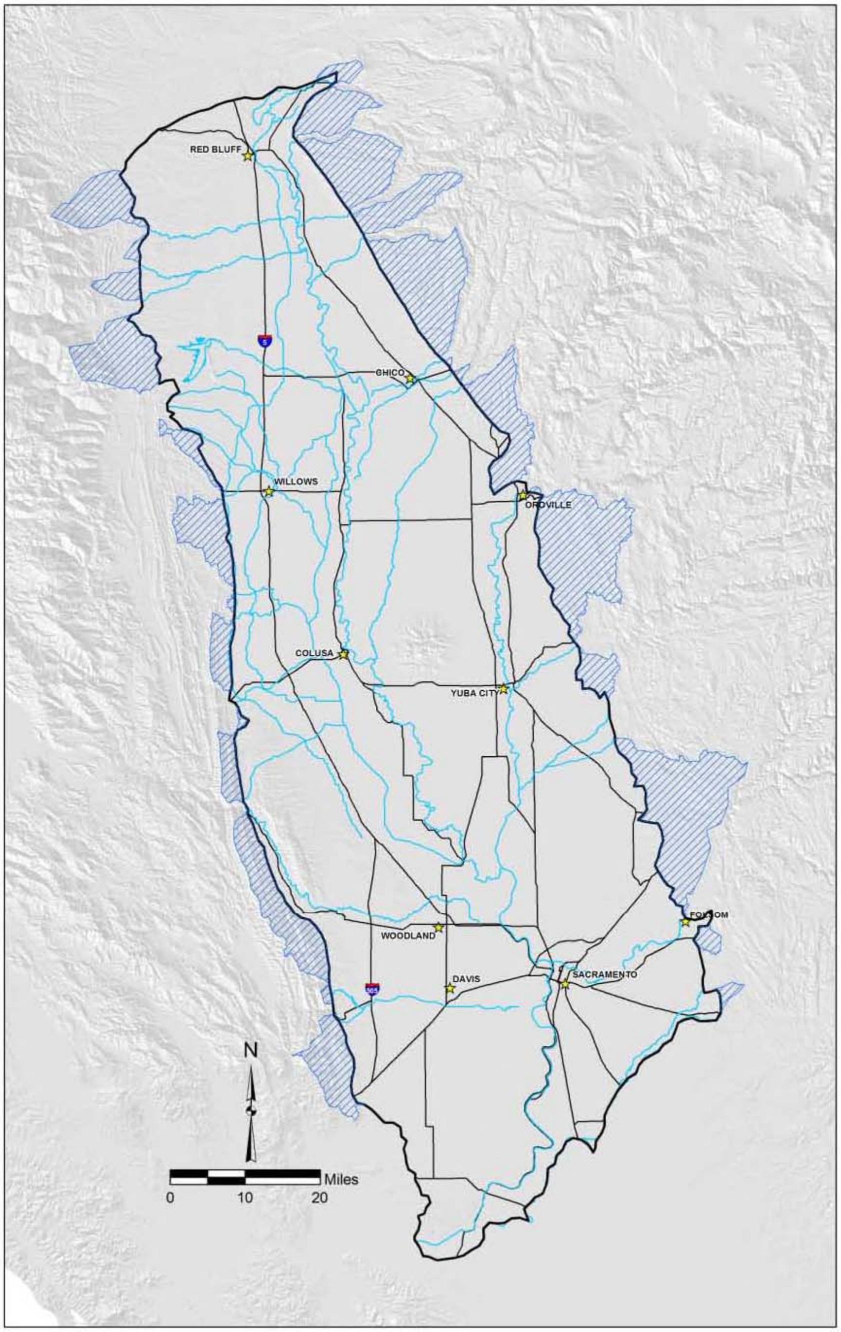


FIGURE 8-3
EXTENT OF POLYGONS USED TO ESTIMATE MOUNTAIN FRONT RECHARGE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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No-Flow Boundaries. A no-flow boundary was specified across the bottom boundary of the model, representing the freshwater/brackish water interface.

8.3.4 Surface Water Budget

One of the most critical components to the successful operation of the SACFEM model is computation of transient surface water budget components. These water budget components were estimated based on a variety of spatial information including land use, cropping patterns, source of irrigation water, surface water availability in different year types and locations, and the spatial distribution of precipitation. Surface water budget components included in the model are deep percolation of applied water, deep percolation of precipitation, and agricultural pumping.

Surface water budgets were developed by intersecting existing GIS data developed by DWR with the groundwater model grid to develop land use for each groundwater model node. Additionally, GIS data on water districts and surrounding areas were used to identify district and non-district areas. The resulting intersection provided land use, water district, and water source information for each of the approximately 89,000 groundwater model nodes.

A semiphysically based soil moisture accounting model and historical precipitation data were used to simulate the root zone and calculate applied water demand and deep percolation past the root zone for each node. Calculated deep percolation was split between applied water and precipitation based on the season and the availability of water from each source.

Calculated values for deep percolation were compared to estimated values prepared by DWR’s Northern District for the year 2000. Northern District staff calculated detail water budgets in 2000 that included some of the best available estimates of regional deep percolation. In some areas soil parameters in the root zone model were adjusted to provide similar volumes of deep percolation. However, considerable uncertainty still exists in any estimate of regional deep percolation because soil conditions vary widely and it is not possible to measure deep percolation on a regional basis.

The total demand for applied water was used in conjunction with the water source and water district attributes from the GIS intersection to estimate agricultural groundwater pumping. Some areas are supplied solely from groundwater and calculated total applied water demand represents groundwater pumping. Other areas are supplied by a mix of groundwater and surface water. For these areas, estimates of the availability of surface water each year were made to determine the fraction of applied water demand met from surface and groundwater. In these areas, additional information on the overlying water district was combined with district water rights and contracts to estimate available surface water. For example, districts within the Tehama Colusa Canal Authority have water contracts with the Bureau of Reclamation (Reclamation) that receive different allocations each year. An estimate of those allocations from an existing level of development simulation of CVP operations was used to calculate the availability of surface water for groundwater model elements within those districts. Any remaining applied water demand, after consideration of available surface water, is assumed to be met from groundwater pumping.

Annual values of calculated agricultural pumping for the Sacramento Valley were reviewed and compared well to the generally accepted estimate of approximately 2.5 million acre-feet (DWR, 2005).

8.3.5 Aquifer Properties

The distribution of aquifer properties across the Sacramento Valley is poorly understood. In certain areas with significant levels of groundwater production, the collection of aquifer test data, and the measurement of historic groundwater level trends in response to known groundwater production rates have provided valuable information on aquifer properties. However in the majority of the valley, these data are not available.

To estimate the spatial distribution of aquifer properties across the model domain for this numerical modeling effort, a database of well productivity information was used. In consultation with DWR staff, a database was obtained that included all of the specific capacity yield data that were available from well log records. These data were compiled along with well construction information for each production well to yield a representative data set of well productivity across the valley. Wells that did not have available construction data were omitted from further consideration. To protect owner privacy, the exact location of each well was modified by DWR staff to reflect the center of the section in which each well was located. This modification in well location did not adversely affect the use of the data to estimate the spatial distribution of aquifer properties, given the extremely large area encompassed by the model domain. The total number of wells in the database within the model domain used in this analysis was approximately 1,000 wells.

The intent of the modeling analysis described herein is to simulate the operation of high-productivity irrigation wells screened within the major producing zones in the valley to support conjunctive water management projects. Therefore, the aquifer properties that are of primary interest are those of the major aquifer zones tapped by large-diameter irrigation wells. The well database described above was filtered to remove data obtained from tests on low yield and/or shallow domestic type wells. All test data from wells that reported a well yield below 100 gallons per minute (gpm) were eliminated from consideration as was the test data from wells with a total depth of less than 100 feet. The only exception to this second consideration was for wells that were located along the basin margins, where aquifers are thin, that reported what appeared to be valid test results. Data from these wells was considered as they were often the only data available in the basin margin areas.

Once the data set for consideration was finalized, the reported specific capacity data for each well was used to estimate an aquifer transmissivity for that location. The relationship used to estimate aquifer transmissivity was the following form of a simplified version of the Jacob non-equilibrium equation:

$$Sc = T/2000 \tag{9}$$

Where:

Sc = specific capacity of an operating production well (gpm per foot of drawdown)
T = aquifer transmissivity (gallon per day [gpd] per foot)

After a transmissivity estimate was computed for each location, the transmissivity value was divided by the screen length of the production well to yield an estimate of the aquifer hydraulic conductivity. The final step in the process was to smooth the hydraulic conductivity field to provide regional scale information. Individual well tests produce aquifer productivity estimates that are local in nature, and may reflect small scale aquifer heterogeneity that is not necessarily representative of the basin as a whole. To average these smaller scale variations present in the data set, a FORTRAN program was developed that evaluated each independent hydraulic conductivity estimate in terms of the available surrounding estimates. When this program is executed, each K value was considered in conjunction will all other K values present within a user-specified radius, and the geometric mean of the available K values calculated. This geometric mean value is then assigned as the representative regional K value for that location. The radius used in this analysis was 10,000 meters, or approximately 6 miles. The point values obtained by this process were then kriged to develop a hydraulic conductivity distribution across the model domain. The aquifer transmissivity at each model node within each model layer was then computed at the geometric mean K values at that node times the thickness of the model layer. Insufficient data were available to attempt to subdivide the data set into depth varying K distributions and it was therefore assumed that the computed mean K values were representative of the major aquifer units in all model layers. Effectively this approach averages the aquifer K values at a given location. In reality, there is certainly vertical heterogeneity present in the Sacramento Valley aquifer system. However any inaccuracies in the assumed vertical distribution of K values will result primarily in local scale errors in computed vertical gradients. In the extremely heterogeneous aquifer system of the Sacramento Valley, it is the distribution of total aquifer transmissivity, along with the imposed water budget boundary conditions, that determine the regional distribution of hydraulic head. The efficacy of this approach at replicating the observed transient water level fluctuations across the valley will be demonstrated in the calibration section discussion below. The final distribution of hydraulic conductivity used in the SACFEM model is shown on Figure 8-4.

Model Calibration

Calibration Approach. The calibration approach used to develop the modeling tool described herein was significantly influenced by the resources available to fund the project. While a fully transient calibration approach, wherein the model is used to replicate groundwater levels and flow conditions throughout some period of record would be the more desirable approach, the resources were not available to fund such an effort. Instead, a more limited steady-state calibration approach was implemented. In a steady-state calibration process, the monthly water budget components for a selected period are averaged, and the model is calibrated to both average groundwater levels and stream discharges that occur during the calibration period. The calibration period selected for this effort was calendar year 2000. Calendar year 2000 was selected because it is the most recent year where water budget information is available that was characterized by average hydrologic conditions. A calendar year instead of a water year was used to facilitate the development of average groundwater elevation calibration targets. The available water-level data were obtained from DWR, and much of that data are collected in the spring and the fall. If a water year was used, the cut-off between water years is the end of September, which coincides with the mid-point of the fall sampling event. The result would be that when average groundwater elevation values were calculated, some of the measurements would be from October of the previous year and some would be from September of the subsequent year, which would introduce error in the data set, especially if the year types were different. The use of a calendar year eliminates this potential for error.

While a rigorous transient calibration was not possible as part of this effort, because the model was being used to simulated transient operation of conjunctive water management projects, simulated transient groundwater elevations were compared to observed groundwater elevation hydrographs from a collection of monitoring wells located throughout the model domain. The period of record over which the transient analysis was performed was water years 1982 through 2003. Therefore, simulated and observed transient groundwater elevations were compared over this period as well.

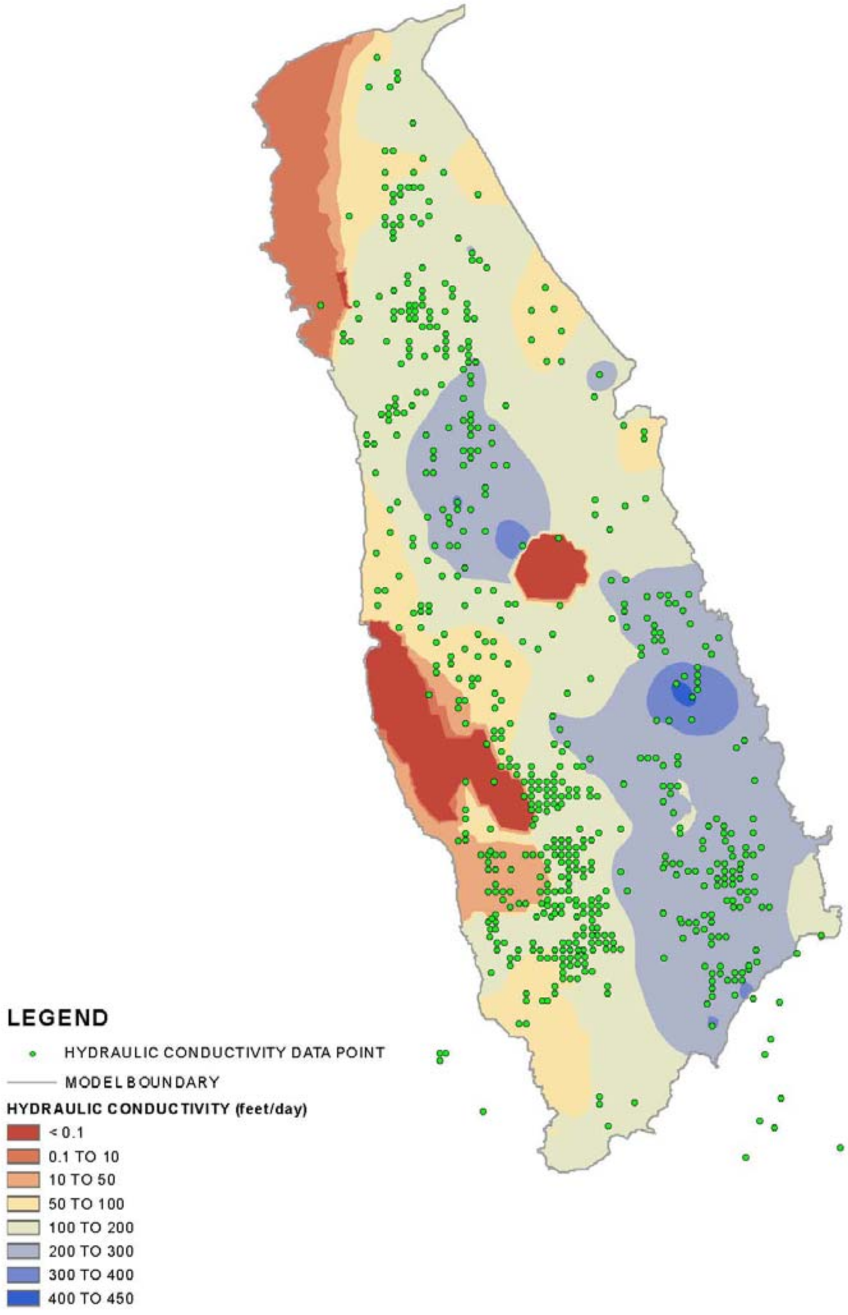

FIGURE 8-4
SACFEM HYDRAULIC CONDUCTIVITY DISTRIBUTION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Steady-State Calibration Targets. Several quantitative and qualitative calibration targets were used in the calibration process. These calibration targets are as follows:

- Average year 2000 groundwater elevations (257 wells used as calibration targets)
- Areas of gaining and losing streams (approximate)
- Approximate water budget quantities (order of magnitude comparison as no accurate estimates are available)
- Approximate calibration to transient groundwater levels measured between water years 1982 and 2003

Water Budget Modification. During the calibration process, it was anticipated that some adjustment to the water budget components computed using the previously described methodology would be necessary to obtain an acceptable degree of calibration. A water budget analysis performed on the raw input data provided by the root zone model, combined with simulated groundwater heads from model runs using that deep percolation data, suggested that the prescribed deep percolation rates in the northern (Red Bluff) and southern (Davis/Woodland) areas were too high. Deep percolation rates were reduced in these areas, resulting in a significant improvement in calibration residuals. To run the model is a transient mode, it was also necessary to make similar adjustments to the prescribed transient monthly deep percolation rates obtained from the root zone model. This was accomplished by computing the percent reduction in deep percolation that was required at each model node to obtain an acceptable steady-state calibration. It was then assumed that these same nodal reduction percentages were applicable to the monthly deep percolation estimates throughout the transient simulation period. While no rigorous transient calibration was performed, simulated groundwater levels over the 1982 though 2003 transient simulation period were compared to hydrographs of observed data at several locations across the model domain.

Steady-State Calibration to Year 2000 Groundwater Elevations. A graphical measure of the state of calibration is to develop a scattergram that plots the simulated versus the measured groundwater elevation at each target calibration well. A plot of this type is shown on Figure 8-5. A perfect fit between simulated and observed groundwater elevations would plot as a 45 degree line (slope = +1.0, Y-intercept=0). As can be seen on Figure 8-5, the simulated heads generated by the SACFEM model show good agreement between simulated and observed groundwater levels. This implies that the model is providing accurate estimates of the steady state groundwater elevations and flow directions that exist in the vicinity of the potential project sites evaluated under this conjunctive water management evaluation program.

Another quantitative measure of calibration that is commonly used is to calculate the root mean square error (RMS) divided by the range of observations. As a rule of thumb, a well calibrated regional model will have an RMS/range of less than 10 percent, and a well calibrated local scale mode will have an RMS/range of less than 5 percent. The RMS/range of the steady state calibration presented here is 4.6 percent, well below the 10 percent criterion.

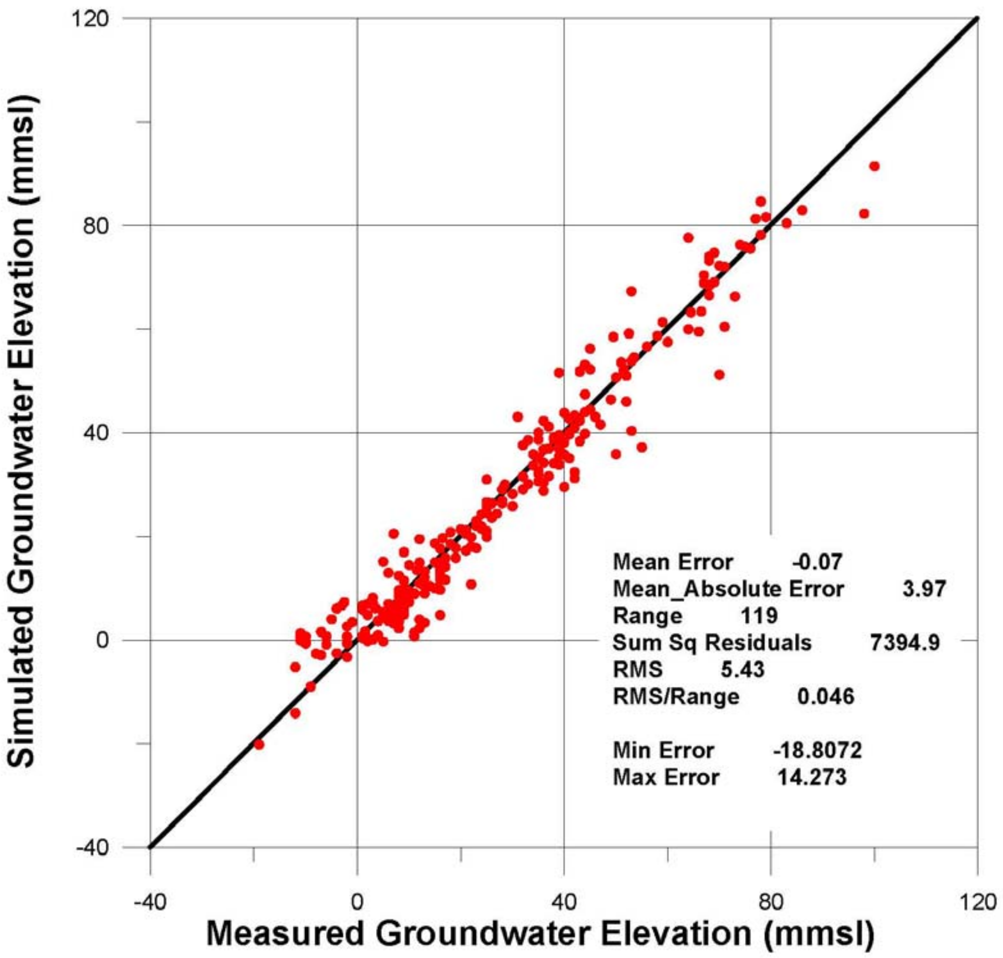

FIGURE 8-5
SACFEM CALIBRATION SCATTERGRAM
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Calibrations to Gaining and Losing Stream Segments. In the Sacramento Valley, a further qualitative calibration target is the identification of stream segments that are gaining flow through groundwater discharge versus losing flow to groundwater recharge. While the exact distribution of stream reaches that gain or lose flow due to surface water/ groundwater interaction are not fully delineated, and this relationship changes over time with fluctuating groundwater levels and stream stages, a general pattern can be observed. The major trunk streams such as the Sacramento, Feather, and American Rivers tend to gain flow, especially in their lower reaches, while the smaller upper tributaries near the basin margin tend to lose flow to the groundwater system. The stream reaches predicted by the model to gain or lose flow to the groundwater aquifer are shown on Figure 8-6. The pattern predicted by the calibrated groundwater flow model is reasonably consistent with the generally accepted pattern described above. The distribution shown on Figure 8-6 should be considered an average condition with greater stream lengths gaining groundwater during wet periods with higher groundwater levels and greater stream lengths losing water to the aquifer system during dry periods with lower groundwater levels.

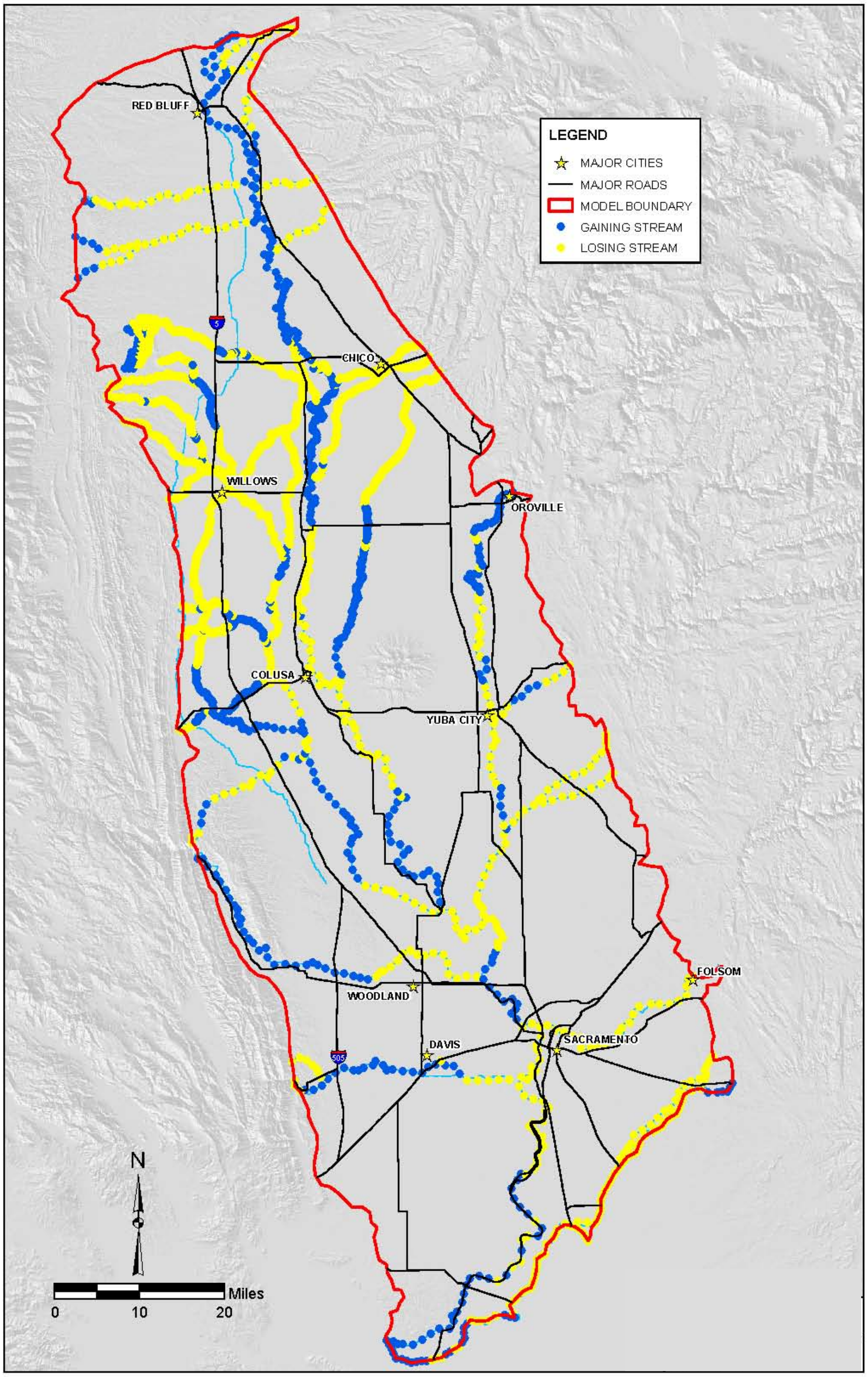

FIGURE 8-6
SIMULATED GAINING AND LOSING STREAM REACHES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Calibration to Steady-State Water Budget. The magnitude of the water budget components derived from the steady-state calibration run are summarized in Table 8-1. While exact comparative estimates are not available for most of these components, rough estimates are available. For example, the 2000 calibration simulation estimates a combined 2.5 million acre-feet (ac-ft) of groundwater pumping within the model domain, which agrees reasonably well with the generally accepted value of between 2.5 million and 3 million ac-ft of groundwater withdrawal in an average year. Similarly, while no independent estimates of the quantity of groundwater that discharges to the Sacramento River are available, the average simulated value of 975 cubic feet per second (cfs), which represents approximately 2 to 4 percent of mean annual flow measured at the Freeport gauge, seems reasonable.

TABLE 8-1
Average Annual or Year 2000 SACFEM Water Budget Summary
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	ac-ft	cfs
Recharge		
Deep Percolation of Precipitation	1,398,461	1,932
Deep Percolation of Applied Water	865,131	1,195
Mountain Front Recharge	495,507	684
Seepage from Streams to Groundwater	816,848	1,128
Total Recharge	3,575,947	4,939
Discharge		
Agricultural Pumping	2,417,506	3,339
Urban Pumping	451,507	624
Groundwater Discharge to Streams	705,999	975
Total Discharge	3,575,012	4,938

Preliminary Transient Calibration. While the SACFEM model has not undergone a rigorous transient calibration, a comparison of simulated and observed groundwater elevations from Water Year 1982 through 2003 was performed to assess the performance of the model at simulating historic groundwater elevation trends. This step was necessary because the SACFEM model is being used to forecast the performance of various conjunctive water management projects during the 1982 through 2003 period, and it was necessary to determine the accuracy of the model at replicating the transient groundwater elevations that occurred over that period. The ability of the model to match observed transient heads is also an indication of the accuracy of the assumed transient water budget components being used in the model. The period 1982 though 2003 was used because it includes wet periods, such as the winter of 1983, and dry periods, such as the 1988 through 1992 drought. Using a climatic period of this type allows assessment of the effects of highly variable climatic conditions on conjunctive water management project operations and subsequent effects on groundwater levels and stream flows.

The accuracy of the model running in transient mode was assessed using two different methods. The first was to evaluate the ability of the SACFEM model to replicate the results of the final steady-state calibration run within a longer transient simulation. This was done by running the transient model using a monthly time step from water year 1982 though 2003, retrieving the simulated monthly head values for calendar year 2000, and averaging them to obtain a data set that should theoretically match the steady-state calibration data. The comparison of the simulated calendar year 2000 steady-state heads with the head values obtained by averaging the simulated monthly head values obtained from the transient simulation over the same period is shown on Figure 8-7. It is clear from this figure that the average calendar year 2000 heads computed from the results of the transient simulation almost exactly match the simulated steady-state heads obtained from the final calibration run. This suggests that after running the SACFEM model for 19 years (1982 though 2000) using estimates of the historic transient monthly water budget stresses, the model is still capable of providing a very accurate calibration to the year 2000 conditions.

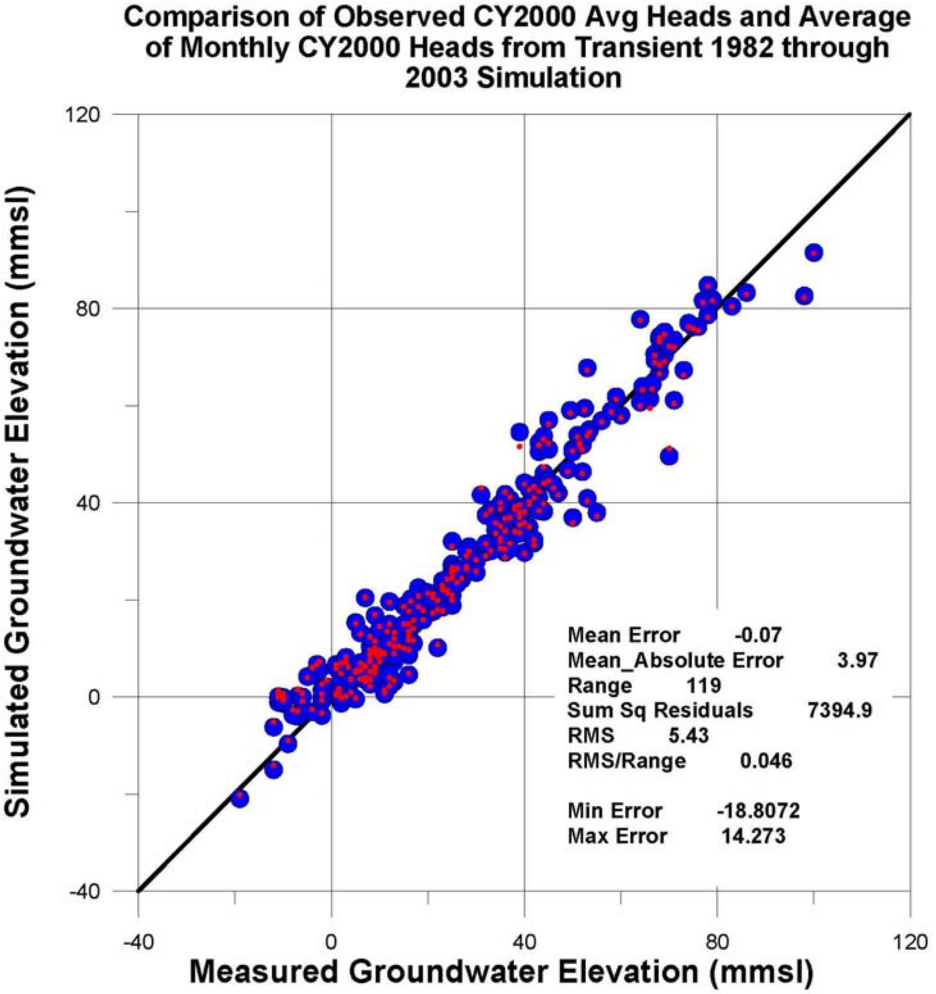

FIGURE 8-7
REPLICATION OF STEADY-STATE CALIBRATION HEADS WITHIN A 23 YEAR TRANSIENT SIMULATION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

The second method used to assess the accuracy of the SACFEM model of simulating transient groundwater elevations was to compare simulated monthly groundwater elevations with measured groundwater elevations in monitoring wells over this same 1982 though 2003 period. These comparisons are shown on Figures 8-8 through 8-15. These results suggest that in most cases, the model provides a fairly accurate depiction of transient groundwater elevations throughout the time period evaluated. Several of the hydrographs show differences between the simulated and measured heads, but in each case the trends of both data sets are similar but displaced by several feet. It is likely that small adjustments in water budget fluxes or aquifer properties in those areas will improve agreement.

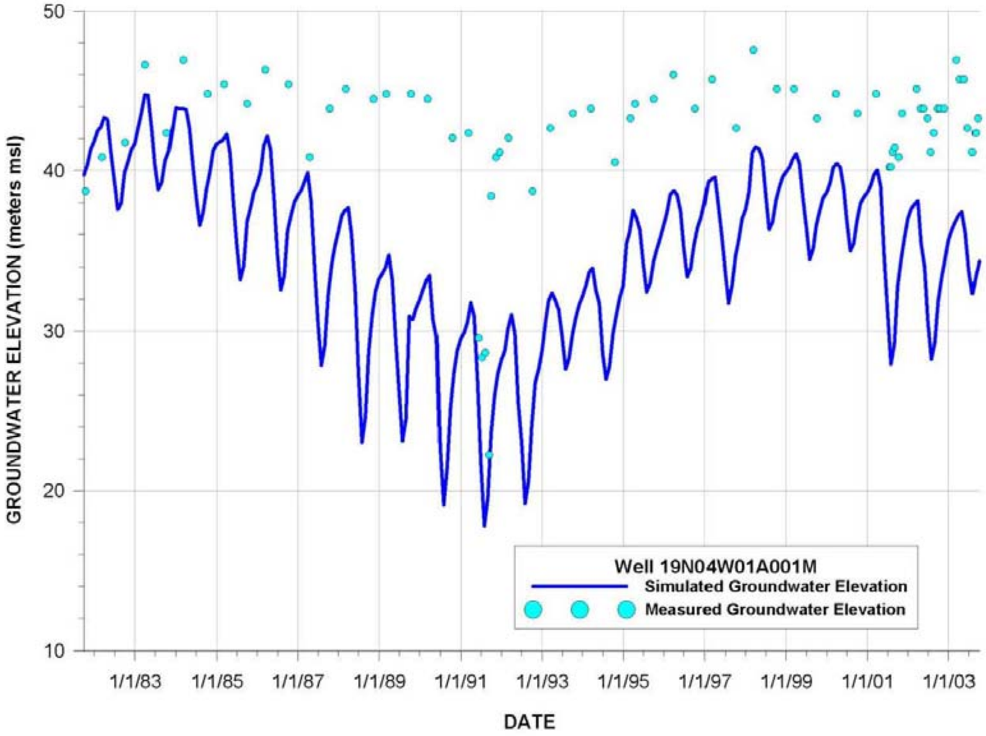

FIGURE 8-8
TRANSIENT CALIBRATION COMPARISON: WELL 19N04W01A001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

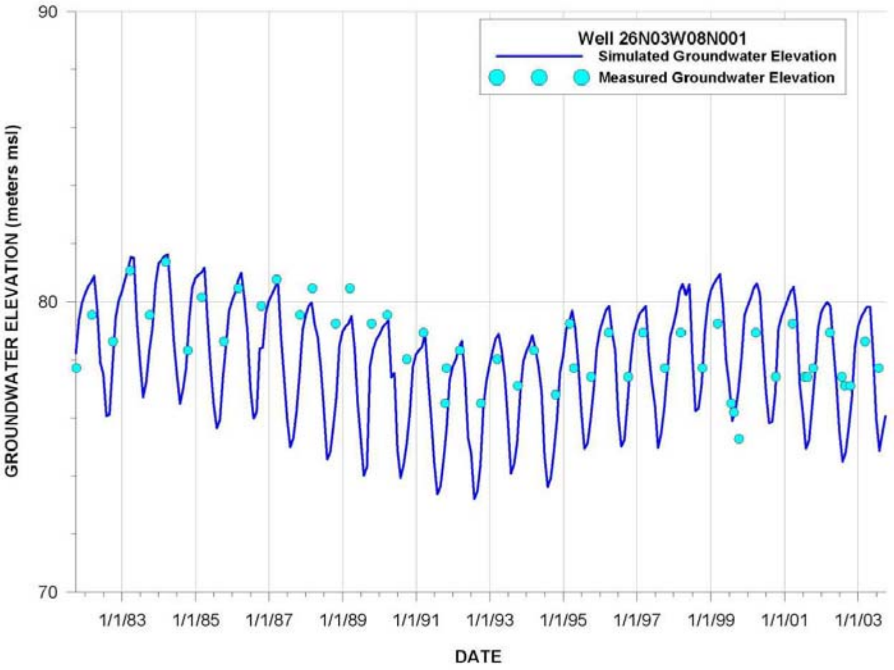

FIGURE 8-9
TRANSIENT CALIBRATION COMPARISON: WELL 26N03W08N001
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

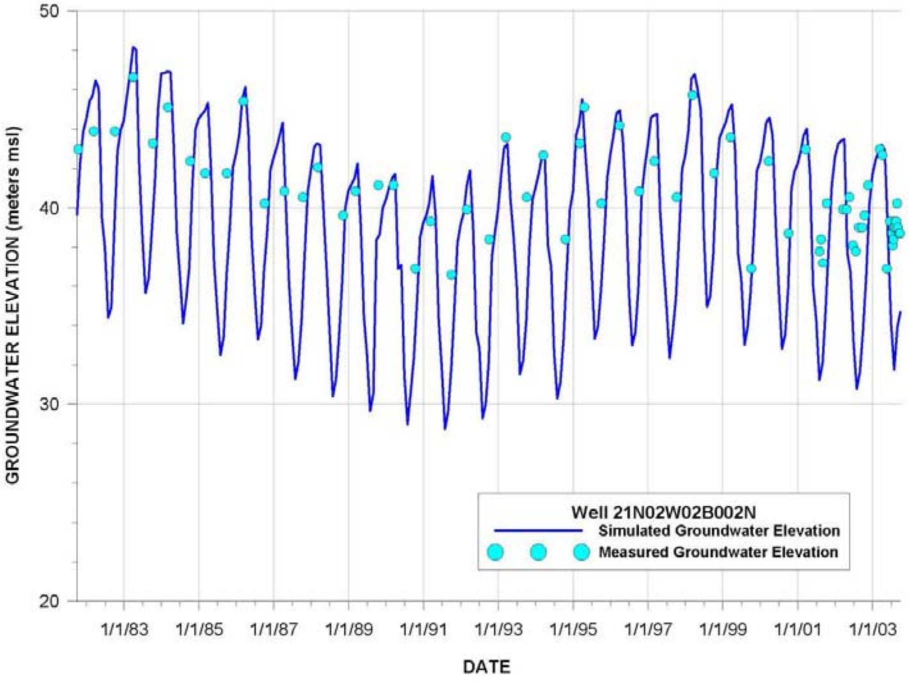

FIGURE 8-10
TRANSIENT CALIBRATION COMPARISON: WELL 21N02W02B0020N
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

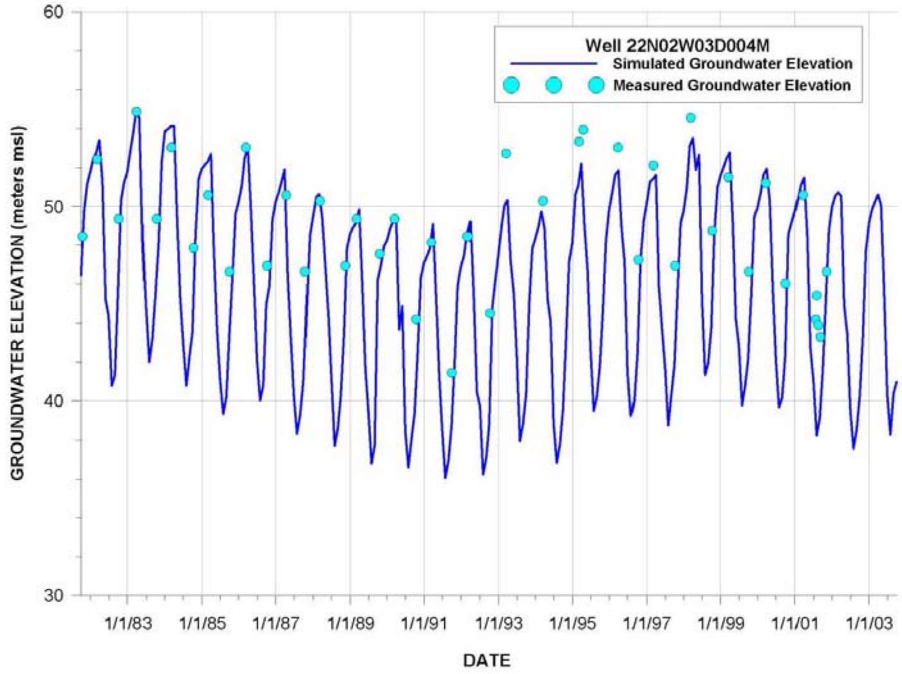

FIGURE 8-11
TRANSIENT CALIBRATION COMPARISON: WELL 22N02W03D004N
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

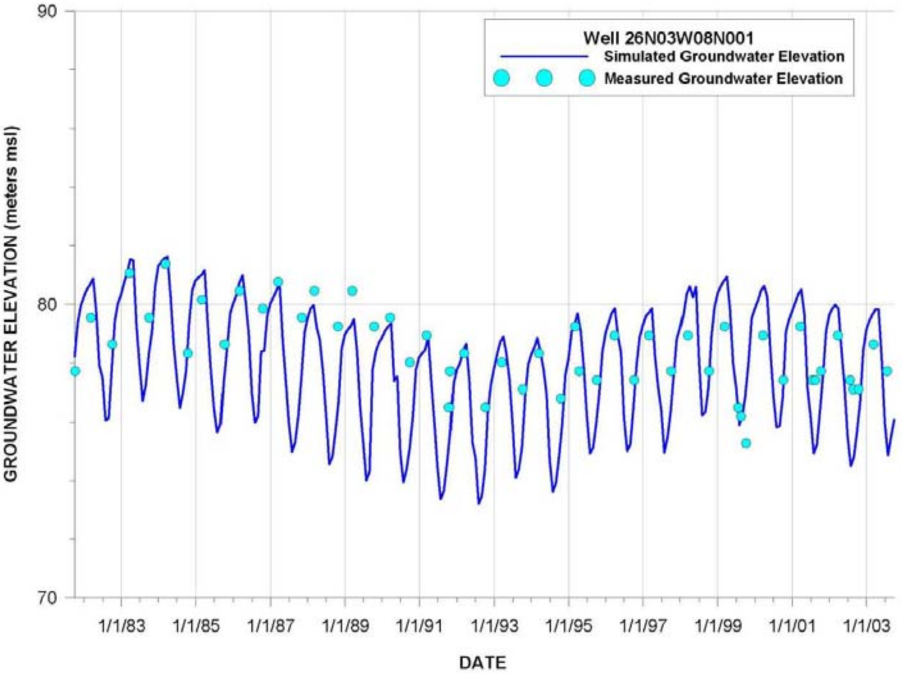

FIGURE 8-12
TRANSIENT CALIBRATION COMPARISON: WELL 26N03W08N001
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

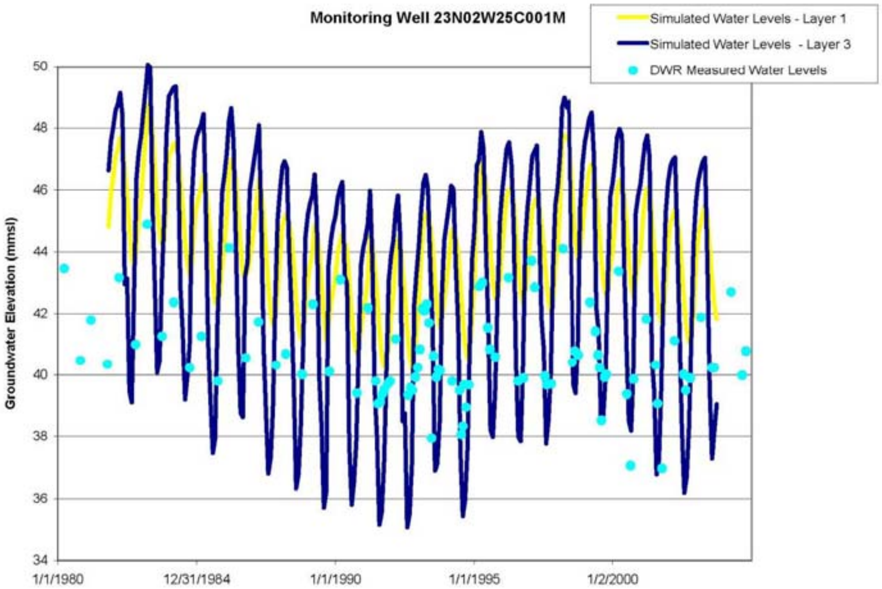

FIGURE 8-13
TRANSIENT CALIBRATION COMPARISON: WELL 23N02W25C001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

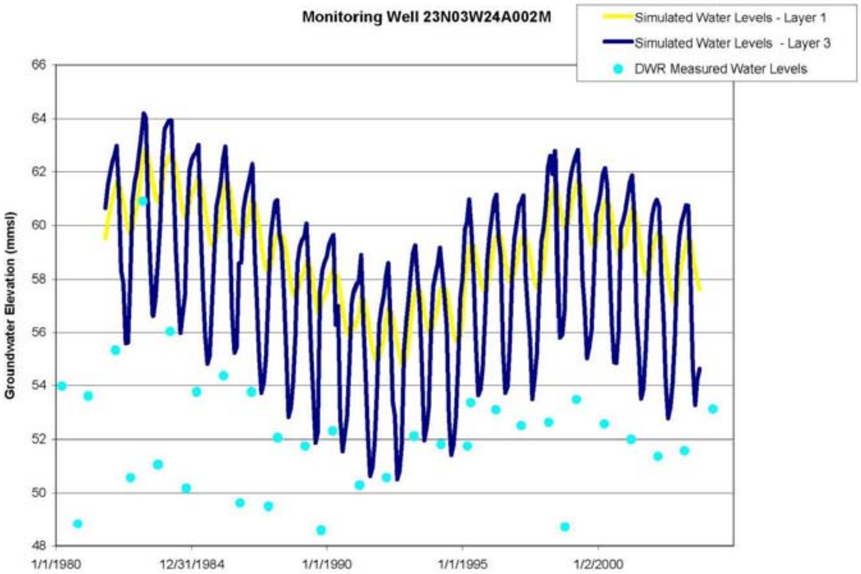

FIGURE 8-14
TRANSIENT CALIBRATION COMPARISON: WELL 23N03W24A002M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

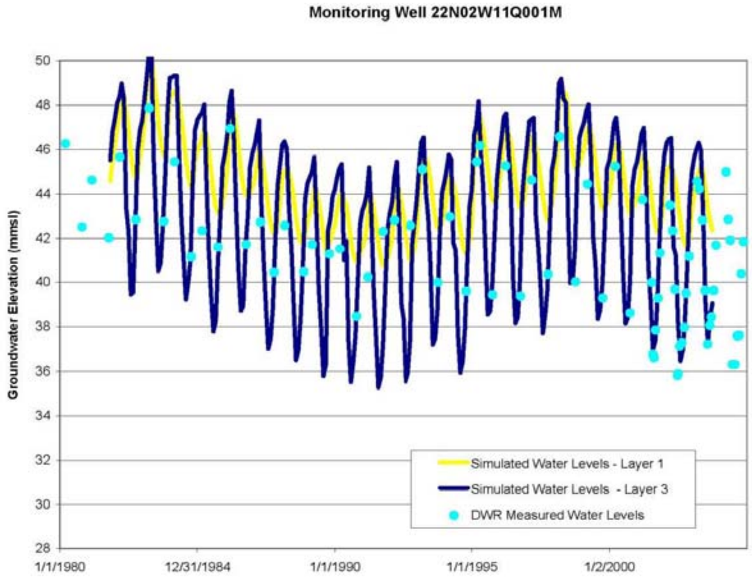

FIGURE 8-15
TRANSIENT CALIBRATION COMPARISON: WELL 22N02W11Q001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

SECTION 9

Surface Water Model

Effective analysis of conjunctive management projects and operations requires simulation of both the surface and groundwater systems. As described above, conjunctive management operations for this project are closely related to surface reservoir operations and conditions throughout the CVP and SWP. Therefore a surface water model that includes CVP and SWP reservoir operations and conditions was developed to evaluate conjunctive management projects.

9.1 Modeling Approach

The best tool currently available for planning level analyses of the CVP/SWP system is the CalSim II model, developed jointly by DWR and Reclamation. CalSim II is a planning model designed to simulate operations of CVP and SWP reservoirs and water delivery system, flood control operating criteria, water delivery policies, instream flow and Delta outflow requirements, and hydroelectric power generation operations. CalSim II is the main systemwide hydrologic model being used by DWR and Reclamation to conduct planning and impact analyses of potential projects.

CalSim II is a simulation by optimization model. The model simulates operations by solving a mixed-integer linear program to maximize an objective function for each month of the simulation. CalSim II was developed to simulate the operation of the CVP and SWP for defined physical conditions and a set of regulatory requirements. The model presently simulates these conditions using 82 years of historical hydrology from water year 1922 through 2003. CalSim II simulates regulatory conditions specified in State Water Resources Control Board (SWRCB) Decision 1641 (D-1641); the Central Valley Project Improvement Act b(2), including non-discretionary and discretionary actions; and limited water transfer operations.

CalSim II is a complex optimization model that can give surprising, unintended results when used to simulate complex operations. Additionally, runtimes for CalSim II models are typically several hours, making it inappropriate for use in gaming sessions and for rapid evaluation of many different scenarios.

The approach used for this project is to rely on CalSim II to depict CVP/SWP operations and system conditions and then model incremental changes in CVP/SWP operations that reflect possible conjunctive management projects. The result of this approach is a surface water model of the CVP/SWP system that layers conjunctive management operations for use in gaming sessions to quickly investigate numerous scenarios and operations, and can be used to test sensitivities and tradeoffs associated with certain key assumptions. The surface water model was designed to be easily adapted for use with various CalSim II simulations.

9.2 System Baseline Assumptions

A CalSim II simulation of the existing level of development (approximately 2004), regulatory conditions, and resulting operation of the CVP and SWP is the basis for surface water modeling. This simulation was developed by the Common Assumptions Project to provide a generally accepted model baseline for use in CALFED surface storage investigations. Key assumptions for the baseline CalSim II simulation are provided in Appendix A.

The existing level of development was used, as opposed to a future level of development, because of the need for consistency in land use data used in the surface water groundwater models. Existing level of development GIS land use data were used in the development of the surface water budgets for the groundwater model. Existing level of development information is also less speculative as to how land use may change in the coming decades. Simulation of a future level of development would require assumptions on future land use and the spatial distribution of that land use throughout the Sacramento Valley.

9.2.1 Surface Water Model Operations

The surface water model simulates operations of conjunctive management projects and their interaction with CVP and SWP reservoirs to meet project objectives (satisfying presently unmet agricultural water demands and targeted environmental flows and durations) based on results of a CalSim II simulation of existing system operations. The following sections define and describe individual aspects of model operation. This section concludes with a description of how the individual pieces interact to simulate system operations with conjunctive management.

9.2.2 Environmental Objectives

The surface water model simulates conjunctive management operations to increase water supply within the Sacramento Valley. The additional water supply can be used to meet a combination of agricultural water demands and environmental flow objectives. Environmental flow objectives were developed by National Heritage Institute staff and documented in *Developing Ecologically Based Flow Targets for the Sacramento and Feather Rivers* (Cain and Monohan, 2008). Different flow objectives were developed for the Sacramento and Feather Rivers.

All flow objectives are simulated as all-or-nothing thresholds, meaning the model will release water to meet the flow objective only if the full target flow can be sustained for the specified duration. As discussed in the NHI report, environmental objectives are based on the magnitude and duration of flows required to replicate certain ecological and geomorphic processes.

Environmental objectives are specified and prioritized by water year type. The Sacramento River Water Year Type Index (Sacramento River Index), sometime referred to as the 40-30-30 Index, is used to classify each year as either wet, above normal, below normal, dry, or critical.

Geomorphic

Geomorphic releases are short-duration, high-flow events for the purpose of sediment transport, channel migration, and flood plain processes, such as inundation and fine sediment transport. Geomorphic releases are targeted from March through April and are only required to last several hours. The surface water model simulates geomorphic events lasting one day due to the ramping requirements when making these large releases from reservoirs. Table 9-1 presents geomorphic flow objectives for Sacramento and Feather Rivers.

TABLE 9-1
Geomorphic Flow Objectives for Sacramento and Feather Rivers
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Sacramento River Index	Sacramento River (cfs)	Feather River (cfs)
Wet	105,000	50,000
Above Normal	85,000	35,000
Below Normal	65,000	20,000
Dry	35,000	10,000

No objective specified in critical year types.

Riparian Establishment

The purpose of riparian establishment flows is to recruit and grow cottonwoods in the riparian areas along the rivers. Riparian establishment flows are designed to assist in several phases of early cottonwood growth including seedbed preparation, seed germination, and seedling growth. These flows also create periodic large-scale disturbances of the riparian zone. Riparian establishment objectives (see Figure 9-1) are specified for the period of mid-April through mid-June to coincide with the cottonwood reproductive cycle. Riparian recruitment flows are large-magnitude flows for extended periods of time and are typically only possible during years of above average runoff. Therefore these objectives are only specified in years classified as wet or above normal by the Sacramento River Index.

Figure 9-1 illustrates the shape of the of riparian establishment objectives. The objective begins with a high-flow event held for a period of 5 days followed by a 60-day recession limb when the target each day is 5 percent less than the previous day’s target. Table 9-2 summarizes the objectives for both the Sacramento and Feather Rivers.

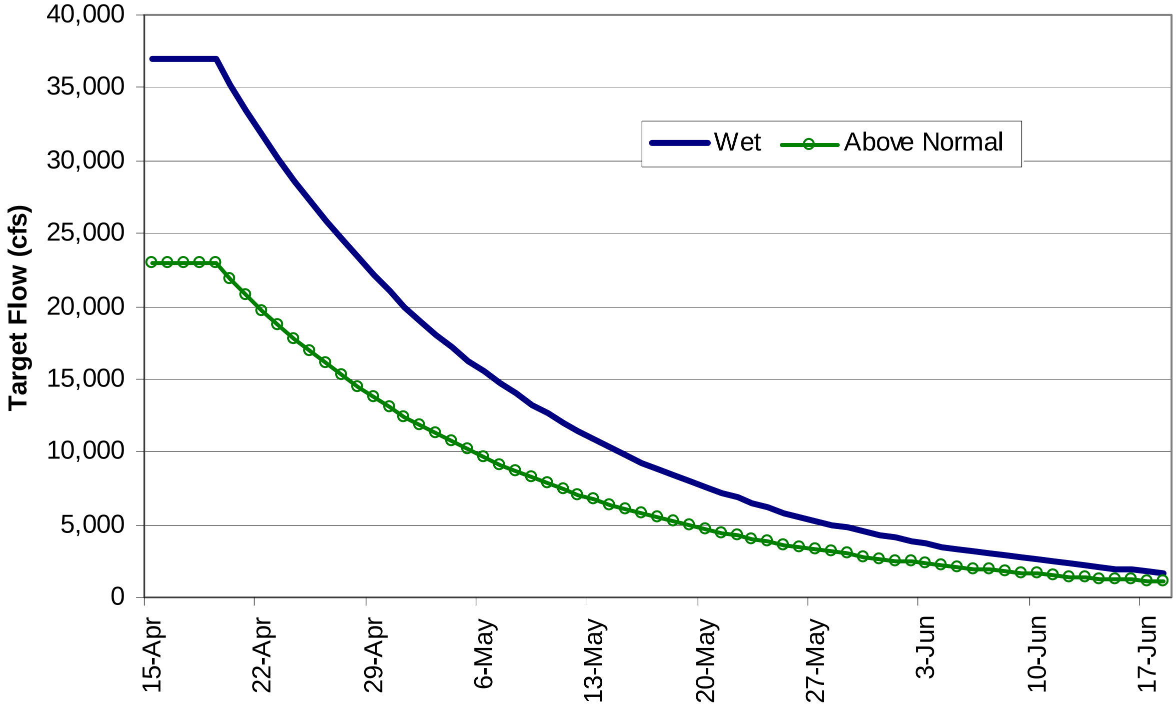

FIGURE 9-1
SACRAMENTO RIVER RIPARIAN ESTABLISHMENT OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

TABLE 9-2
Riparian Establishment Objectives
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Sacramento River		**Feather River**	
Sacramento River Index	**5-day Flow (cfs)**	**Recession Rate**	**5-day Flow (cfs)**	**Recession Rate**
Wet	37,000	5%	12,000	5%
Above Normal	23,000	5%	10,000	5%

Note:

No objective specified in below normal, dry, or critical year types

Spring Pulse

Spring pulse flows are designed to simulate a portion of the historic unimpaired runoff of the river to help create suitable flow conditions and temperatures for Chinook salmon migration. These flows also are designed to help maintain and recruit spawning habitat and avoid scour when eggs are in redds. Spring pulse flow targets are specified in all but critical year types, though the magnitude and duration of the target is reduced in years with less runoff. Tables 9-3 and 9-4 summarize the spring pulse objectives.

TABLE 9-3
Sacramento River Spring Pulse Objective
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Sacramento River Index	Flows (cfs) by Date					
	3/15-3/31	4/1-4/14	4/15-4/30	5/1-5/14	5/15-5/31	6/1-6/14
Wet	14,000	14,000	14,000	14,000	14,000	8,500
Above Norm	12,500	14,000	14,000	14,000	8,500	
Below Norm	12,500	12,500	12,500	8,500		
Dry	10,000	12,000	12,000	8,500		

Note: No objective specified in critical year types

TABLE 9-4
Feather River Spring Pulse Objective
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Sacramento River Index	Flows (cfs) by Date					
	3/1-3/14	3/15-3/31	4/1-4/14	4/15-4/30	5/1-5/14	5/15-5/31
Wet	8,000	12,500	12,500	11,000	6,000	4,000
Above Norm	6,500	6,500	10,000	10,000	5,000	3,000
Below Norm	3,200	3,200	8,000	8,000	3,200	
Dry	2,700	2,700	5,500	5,500	2,700	

Note: No objective specified in critical year types

Flood Plain Inundation

Inundation of the Sutter and Yolo Flood Bypass channels is another environmental objective. It is assumed for this study that the weirs that currently block flow into the bypasses below certain river stages can be modified to allow inundation at lower river stages and flows. Inundation of the flood bypasses provides rearing habitat for juvenile salmonids. These inundation flows are targeted to correspond with outmigration of salmonids in the spring months and designed to last for 45 days. Flood plain inundation flows can be set for one of three different time-periods in the surface water model: February 15 to March 30, March 1 to April 15, or March 15 to April 30. Table 9-5 presents flood inundation objectives for Sacramento and Feather Rivers.

TABLE 9-5
Flood Plain Inundation Objective for Sacramento and Feather Rivers
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Sacramento River Index	Sacramento River at Fremont Weir (cfs)
Wet	45,000
Above Normal	35,000
Below Normal	35,000
Dry	35,000

Note: No objective specified in critical year types

Cold Water Pool Management

The surface water model includes an environmental objective of increasing the flexibility of cold water pool management. This objective increases cold water pool volume in subsequent years by reducing summer reservoir releases (thereby increasing storage) in the current year by the volume of groundwater being pumped. This volume of water is then held in the reservoir through the winter and can increase cold water pool in following years. This operation occurs in years when fall reservoir storage is forecasted to be low. Low fall storage levels reduce the chance that any water stored will spill during the subsequent winter. However, operators may not be able to reduce summer releases in these years and still meet temperature control criteria in the current year. For example, summer releases from Lake Shasta in 2008 were typically controlled by temperature control criteria, not downstream irrigation demands. Therefore, it would not have been possible to offset reservoir releases with groundwater pumping. The surface water model is able to show the times and volumes of water potentially available to meet the cold water pool management objective, but a more thorough analysis with temperature models is needed to further evaluate the feasibility of this operation.

9.2.3 Agricultural Water Supply Objectives

The surface water model simulates the unmet agricultural demand within the Sacramento Valley based on hydrology, the underlying CalSim II simulation of CVP and SWP operations, and user input. Unmet agricultural demands are estimated to provide an understanding of the ability of conjunctive management to increase Sacramento Valley water supplies. Unmet agricultural demands are simulated differently for the Sacramento and the Feather River systems.

Sacramento River

Unmet demands of CVP contractors within the Tehama-Colusa Canal Authority (TCCA) are used to represent additional demands on the Sacramento River. Members of the TCCA, including contractors supplied from the Corning Canal, hold agricultural service contracts for approximately 320 TAF of contract supply from the CVP. Annual allocations to CVP contractors are simulated in CalSim II based on forecasted reservoir inflows, reservoir storage conditions, and the ability to deliver water. Simulated allocations range from 0 to 100 percent of full contract supply. When simulated allocations are less than 100 percent, it is assumed that the difference between simulated allocations and full contract supply is an unmet agricultural demand within the TCCA.

Figure 9-2 illustrates the annual unmet agricultural demand as a function of simulated allocations to the TCCA for each year of the study.

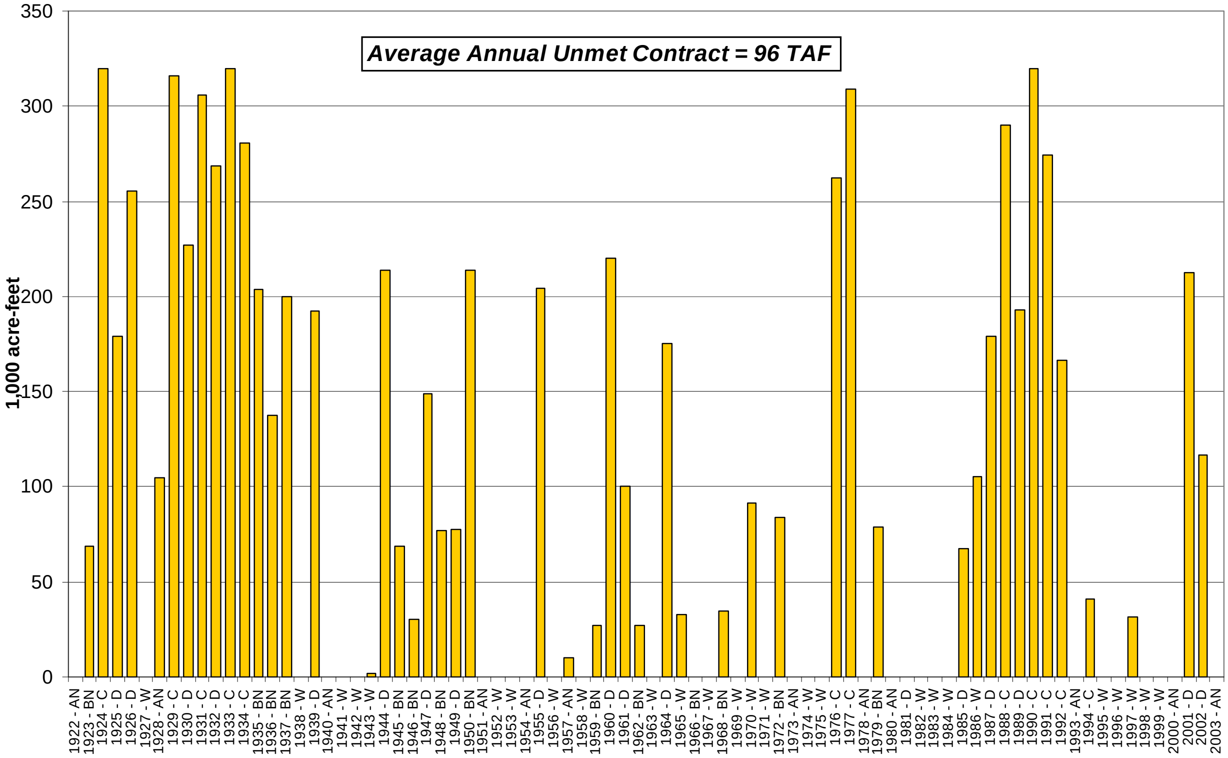

FIGURE 9-2
UNMET AGRICULTURAL DEMAND WITHIN TCCA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

The annual unmet demand illustrated above is assumed to occur on a typical agricultural demand pattern during the irrigation season. The gaming model simulates conjunctive management operations and attempts to meet all or a portion of this demand when it occurs from reservoir release of project assets.

Feather River

The majority of SWP contractors on the Feather River system have reliable water supplies with the exception of a few small contractors. There are no existing SWP contractors with large, frequently unmet agricultural demands in the Butte Basin. Therefore a more general unmet agricultural demand is defined for the Feather River based on user input. Table 9-6 summarizes the assumed unmet agricultural demand that can be met from Feather River supplies in the surface water model.

TABLE 9-6
Assumed Unmet Agricultural Demand within the Feather River System
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Sacramento Valley Index	Unmet Agricultural Demand (TAF)
Wet	0
Above Normal	40
Below Normal	75
Dry	90
Critical	100

Figure 9-3 illustrates the annual volume of demand based on the assumptions in Table 9-6.

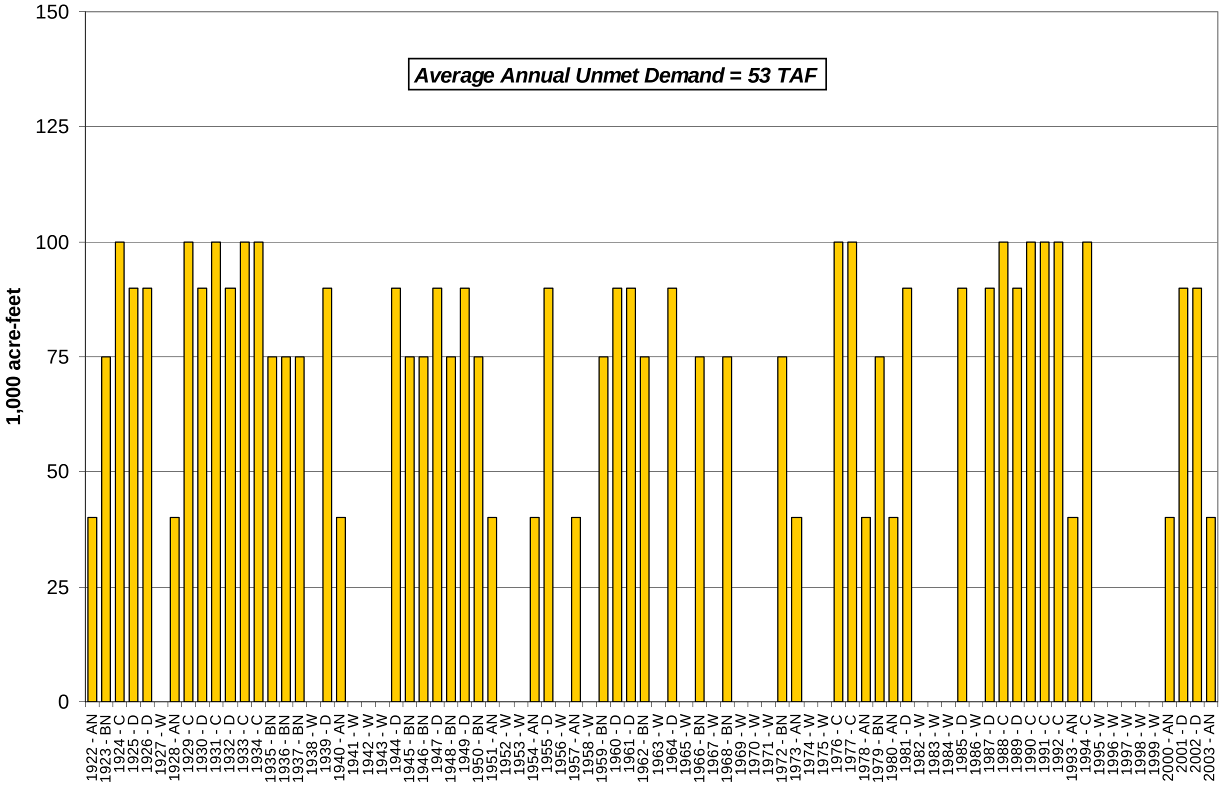

FIGURE 9-3
ASSUMED UNMET AGRICULTURAL DEMAND WITHIN FEATHER RIVER SYSTEM
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

9.2.4 Project Site Assumptions

Two project sites were selected for modeling. Project sites within GCID and the Butte Basin were simulated in the surface water model to determine the volume and timing of groundwater pumping and to better understand tradeoffs between groundwater pumping capacity and project benefits in the surface water system.

Each conjunctive management project site is defined in the model by several variables including maximum annual groundwater pumping capacity, monthly volumes of project pumping, and estimates of how pumping will affect stream-aquifer interactions. The estimated effects on stream-aquifer interaction were derived from iterative simulations between the surface and groundwater models.

The surface water model was developed to quickly evaluate a wide range of project pumping capacities and operations. Results of these sensitivity analyses (presented in later sections) led to evaluation of the following two different project pumping capacities or sizes: 1) 100 TAF in GCID and 50 TAF in Butte Basin, and 2) 200 TAF in GCID and 100 TAF in Butte Basin. Additionally, it was assumed that there would be no additional project pumping in years when surface water allocations are reduced in GCID or the Butte Basin. GCID's surface water allocations are reduced in years classified as "Shasta Critical" based on Sacramento River inflow into Shasta Reservoir. Feather River Settlement Contracts in the Butte Basin received reduced allocations under similar conditions on the Feather River.

Project Assets

Project assets are the volume of water that could potentially be made available through conjunctive management and the volume of additional water that could be released from CVP and SWP reservoirs to meet environmental flow targets or for additional agricultural water supply. Additional reservoir releases are possible because of the availability of groundwater pumping in the conjunctive management project, which serves as a "backstop" against drawing down reservoirs too far. Project assets are calculated each year considering reservoir storage conditions and available groundwater pumping capacity. A reservoir storage target table is used to determine how far operators may be willing to draw down reservoirs for different levels of available groundwater pumping capacity. Table 9-7 is an example for Shasta Reservoir that was a conjunctive management project in GCID with a maximum of 100 TAF of annual pumping capacity.

TABLE 9-7
Example Shasta Reservoir Storage and Project Assets
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

End of September Storage (TAF)	Project Asset (TAF)
Less than or equal to 2,400	0
Greater than 2,500	100

Table 9-7 shows that if end-of-September storage in Shasta Reservoir is forecasted to be less than 2,400 TAF, there are no project assets; therefore, no additional reservoir releases will be made. When forecasted end of September Shasta storage exceeds 2,500 TAF, additional reservoir releases up to the full 100 TAF of pumping capacity may be made to meet project objectives. The maximum project asset is the maximum annual pumping capacity because this represents the maximum backstop available to recover the reservoir in future years, if needed. The model interpolates if storage is between 2,400 and 2,500 TAF so that project operations do not draw Shasta Reservoir storage below 2,400 TAF. A conservative minimum end of September storage of 2,400 TAF was selected as a minimum to avoid any potential impacts.

Project assets also take into account any existing storage deficit, relative to baseline storage, in upstream reservoirs that may be carried over from project operations in previous years. Thus, the cumulative storage deficit over any series of years cannot exceed the annual groundwater pumping capacity of the conjunctive management project.

Water Cost

The surface water model compares environmental flow objectives with base flows that occur under existing system operations to determine additional reservoir releases necessary to meet each environmental objective. This additional release, calculated for the duration of the objective, is referred to as the water cost associated with meeting each environmental object. Water cost is expressed as a volume of water. Water cost for each objective is compared to available project assets to determine which objectives can be met. Figure 9-4 provides an example of water cost calculation for meeting a spring pulse objective.

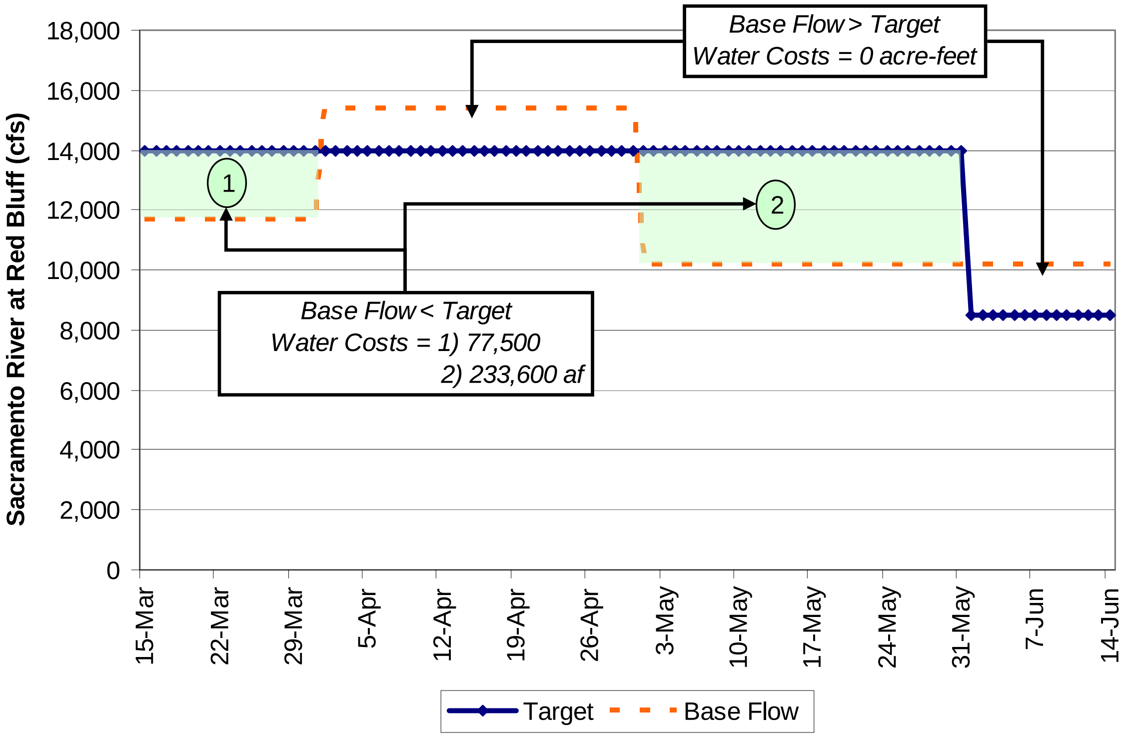

FIGURE 9-4
EXAMPLE WATER COST FOR MEETING SPRING PULSE OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

The water cost for meeting agricultural objectives is equal to the unmet agricultural demands for any year.

Prioritization

Environmental objectives are prioritized through a combination of user input and the frequency with which the various objectives are satisfied. Considering the frequency of when objectives have been satisfied places higher priority on objectives that have not been met in recent years relative to those that have. For example, if the spring pulse objective is typically the highest priority in an above normal year but was met in the previous year (either in the base condition or with a project release) it may be desirable to shift the highest priority to the flood plain inundation objective instead.

To implement this dynamic prioritization scheme that shifts the priority from one year to the next depending on year type and occurrence interval a user-specified relative priority value is combined with the number of years since an objective was last satisfied to determine the final priority of objectives each year.

Table 9-8 contains the relative priority matrix developed by the project team for use in the surface water model. Lower numbers are higher priorities.

TABLE 9-8
Relative Priority Matrix for Environmental Objectives
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Sacramento River			**Both Rivers**	**Feather River**		
Sacramento River Index	**Geomorphic**	**Riparian Recruitment**	**Spring Pulse**	**Flood Plain Inundation**	**Geomorphic**	**Riparian Recruitment**	**Spring Pulse**
Wet	10	2	10	10	10	2	10
Above Normal	15	6	2	4	15	5	2
Below Normal	2	99	1	3	2	99	1
Dry	5	99	2	90	5	99	2
Critical	80	99	1	90	80	99	1

Final priority is determined by subtracting the relative priority from the number of years since the objective was met and comparing the results for all objectives.

Table 9-9 provides an example prioritization calculation for a hypothetical wet year on the Feather River system.

TABLE 9-9
Example Prioritization of Environmental Objectives, Feather River, Wet Year
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Flood	**Geo**	**Rip.**	**Spring**
Years Since Met	6	1	4	25
Relative Priority	10	10	2	10
Final Priority	-4	-9	2	15

The objectives are prioritized by descending final priority scores, as follows: Spring Pulse, Riparian Recruitment, Flood Plain Inundation, and Geomorphic. In this example, because it had been 25 years since the spring objective had been met, Spring Pulse became the first priority objective, though its relative priority was lower than the Riparian Objective.

Decision Month

A decision must be made each spring to determine which objectives the model will attempt to meet that year. Several of the environmental objectives have variable start times and durations. To avoid always meeting the objective that starts earliest in the year or miss meeting an objective in hopes of satisfying a future objective, a user-specified decision month is used in the model. Project assets, water costs, and prioritization of environmental objectives are all determined during the decision month and results are used for operations that year. The decision month is used to determine what objectives the model will attempt to meet each year.

Agricultural Water Supply Objective

After determining which, if any, environmental objectives will be met from project assets the model calculates the remaining project assets available to meet any unmet agricultural demands. This operation wherein environmental objectives were met first and agricultural objectives second was used because environmental objectives are all-or-nothing thresholds, often with large water costs. In many years, all or a portion of project assets are available after making releases for environmental objectives. Simulations where agricultural water supply was prioritized first did not show significant increases in agricultural water supply deliveries, but significantly reduced the ability to meet environmental objectives. This analysis is presented in the section on sensitivity analysis.

Reservoir Release Logic

Figure 9-5 provides a flow chart of model decisions and operations for determining which objectives will be met from additional reservoir releases.

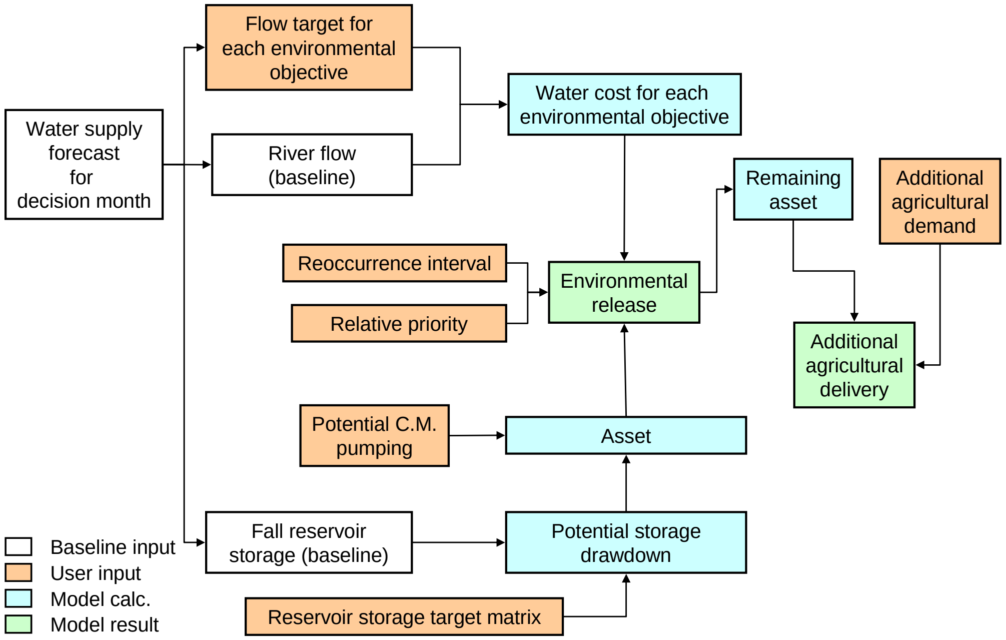

FIGURE 9-5
SURFACE WATER MODEL LOGIC FLOWCHART
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

The bottom of Figure 9-5 illustrates the steps associated with calculating project assets while the top illustrates the calculation of water costs and additional reservoir release. Assets and water costs are compared, according to the prioritized environmental objectives to determine any additional reservoir release for environmental objectives. Remaining assets and unmet agricultural demand are used to determine additional agricultural delivery from the reservoirs.

Groundwater Pumping Logic

Additional reservoir releases result in lower reservoir storage conditions relative to the baseline condition (without the conjunctive management project). Reservoir storage is refilled in the model from one of the following two sources: water that would have otherwise been released for flood control purposes or an increase in groundwater pumping to meet demands that otherwise would be met from the reservoir.

The surface water model simulates these operations by drawing down reservoir storages to make additional releases for project objectives and tracking the storage deficit relative to the baseline. In many instances storage deficits are refilled by water that would otherwise be released for flood control purposes (surplus surface water). Additional groundwater pumping is required when reservoirs are depleted prior to a series of dry years in which they do not fill. The surface water model uses fall reservoir trigger levels to determine when pumping is needed. These triggers are 2,400 TAF for Shasta Reservoir and 1,500 TAF for Lake Oroville. Therefore, if project operations result in reservoir storages below these levels pumping will occur to refill the minimum of any deficit caused by project operations or up to these levels.

Project pumping can be specified to occur over the summer season (May through August) the fall season (September through November) or a combination of both (May through November). Regardless of the selected season the total quantity of water to be pumped is spread evenly across the entire season to avoid turning pumps on and off and to reduce the number of groundwater production wells needed. Different seasons and pumping durations were selected to test the effects of pumping at different times and rates.

9.3 Surface and Groundwater Model Interaction

Evaluation of conjunctive management projects requires simulation of both surface water and aquifer systems. However, regional groundwater models with the needed level of refinement to adequately simulate pumping projects require run times that prohibit their use in gaming situations and for quickly evaluating multiple scenarios. Therefore, the surface water and groundwater model were used in an iterative fashion to simulate conjunctive management operations in both systems (see Figure 9-6).

An initial surface water model was developed to simulate project operations and develop the time series of groundwater pumping at each project site. Pumping time series were simulated in the groundwater model and results were reviewed, including changes in stream-aquifer interactions. These initial changes were used to develop response functions for use in the gaming model to quickly approximate changes in stream-aquifer interaction when simulating various conjunctive management operations. Response functions were used during the gaming sessions and when conducting tradeoff analyses to determine the final project scenarios. Pumping time series from the final project scenarios were then provided to the groundwater model for final simulation and resulting changes in stream-aquifer interactions associated with the pumping schedules were input back into the final surface water simulations.

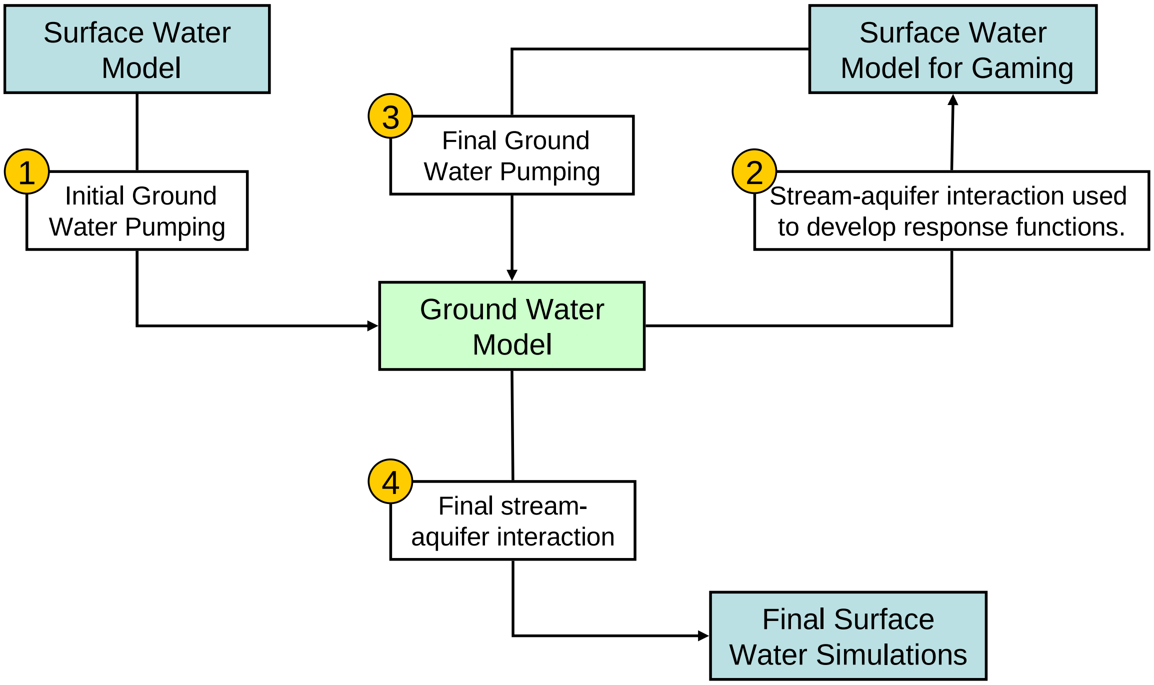

FIGURE 9-6
SURFACE WATER AND GROUNDWATER MODEL INTERACTION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

SECTION 10

Level of Analysis

Technical analyses were performed at a planning level to help prove concepts and define conjunctive management projects and operations. Analyses were conducted for general projects, locations, and operations. More specific and refined analyses may be required as specific projects are defined. Most analysis was conducted in a comparative, rather than absolute, manner and results must be interpreted as such.

Additionally, mathematical modeling tools typically report results at a level of precision that exceeds their level of accuracy. For example, planning-level surface water models may provide estimates of water supply accurate to within a range of several thousand acre-feet, but results with a precision down to an acre-foot. Surface water model results presented in subsequent sections are generally rounded to the nearest 1,000 acre-feet. Groundwater draw down is reported in approximately 10-foot increments, and changes in stream-aquifer interaction are reported to the nearest cfs. Results are reported to these levels of precision for comparison with results from other scenarios. Planning-level modeling tools used in this analysis are not necessarily accurate to this level.

SECTION 11

Project Scenario Results

The following section presents results from four different project scenarios. All scenarios are based on two conjunctive management projects, one in GCID and the other in the Butte Basin. Surface water modeling results are presented first and include the ability to meet environmental and agricultural objectives, the resulting effects on reservoirs, and how reservoirs are refilled with the capture of surplus surface water and conjunctive management pumping.

Groundwater model results are presented after surface water model results. Groundwater model results include plots of peak aquifer drawdown and changes in stream-aquifer interaction. For each scenario, the groundwater model was used to evaluate two different well fields. The first well field option uses existing wells screened in the current aquifer producing zones. The second well field simulates all new wells pumping from the deep aquifer. Figures 11-1 through 11-4 illustrate these well fields for the two different project pumping capacities simulated in the four scenarios.

Plots of additional reservoir releases to meet flow requirements after accounting for changes in stream-aquifer interaction are presented after groundwater model results.

11.1 Scenario 1 – 100 TAF GCID, 50 TAF Butte Basin, Summer Pumping

Scenario 1 is defined by two conjunctive management projects with maximum seasonal groundwater pumping capacities of 100 TAF in GCID and 50 TAF in the Butte Basin. Environmental objectives and unmet agricultural demands are as presented in preceding sections. The pumping season spans 4 months of the irrigation season from May through August. The model first determines ability to meet environmental objectives and then uses remaining project assets to meet agricultural demands. Sensitivity to prioritization of environmental objectives and agricultural demands was evaluated and is explained in subsequent sections of this report.

The following series of plots summarize the annual operations with conjunctive management. The first series of plots summarize Sacramento River and Shasta Reservoir operations and the second series summarize Feather River and Oroville Reservoir operations. Plots are arranged in order of how operations occur each year. In winter and spring months, additional water is released from reservoirs to satisfy environmental objectives. During summer months additional water is released to meet agricultural demands. The result is that fall reservoir storage levels are lower than they would be under operations without conjunctive management projects, as shown on Figure 11-5. Reservoir storage space is typically refilled with surplus surface water during subsequent winter and spring periods. If reservoirs do not refill with surplus surface water and fall reservoir storage levels are forecasted to be low, reservoirs are refilled by pumping groundwater in conjunctive management projects and holding a similar volume of surface water in the reservoir.

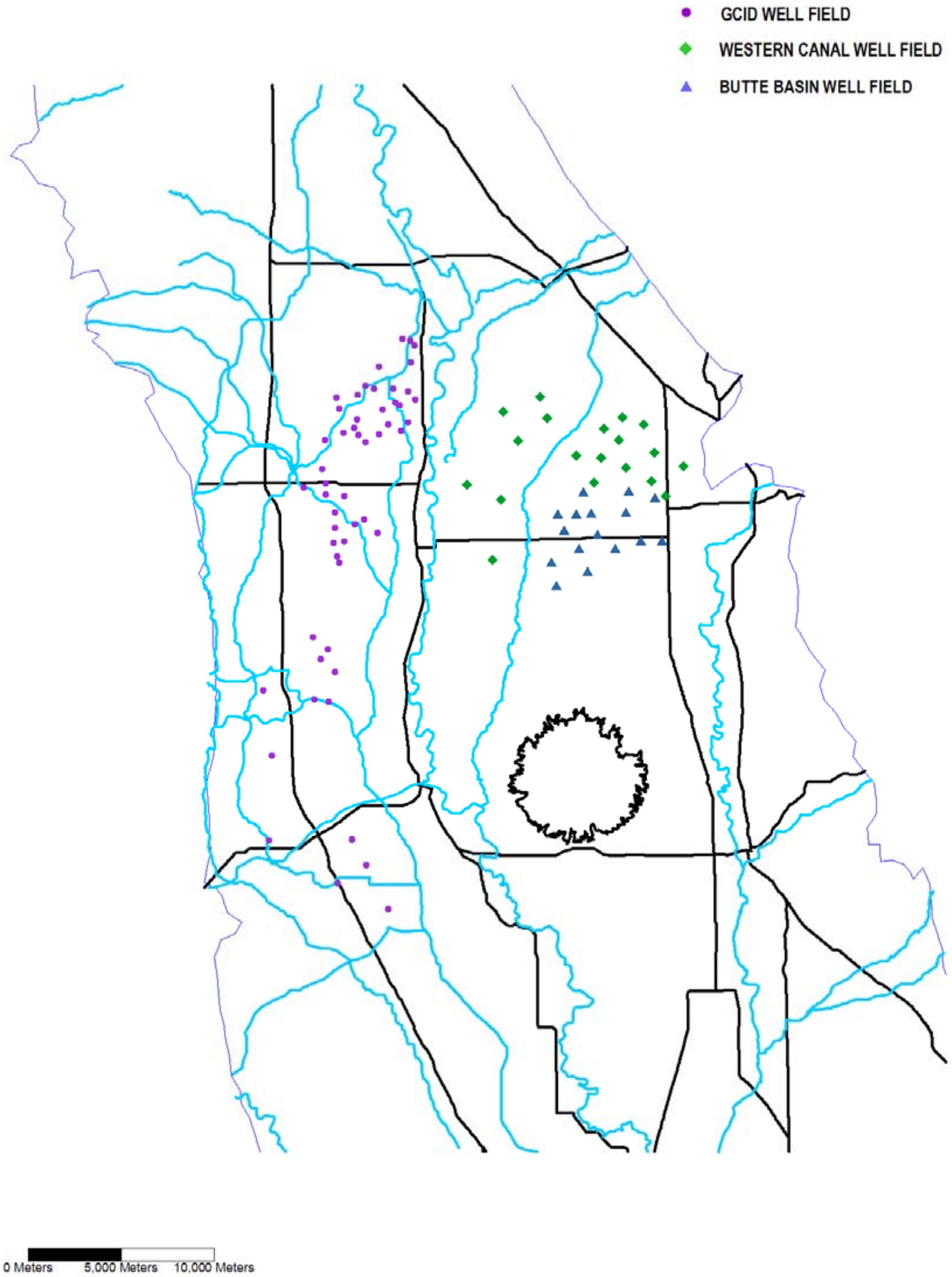

FIGURE 11-1
EXISTING WELL LOCATIONS, 150-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

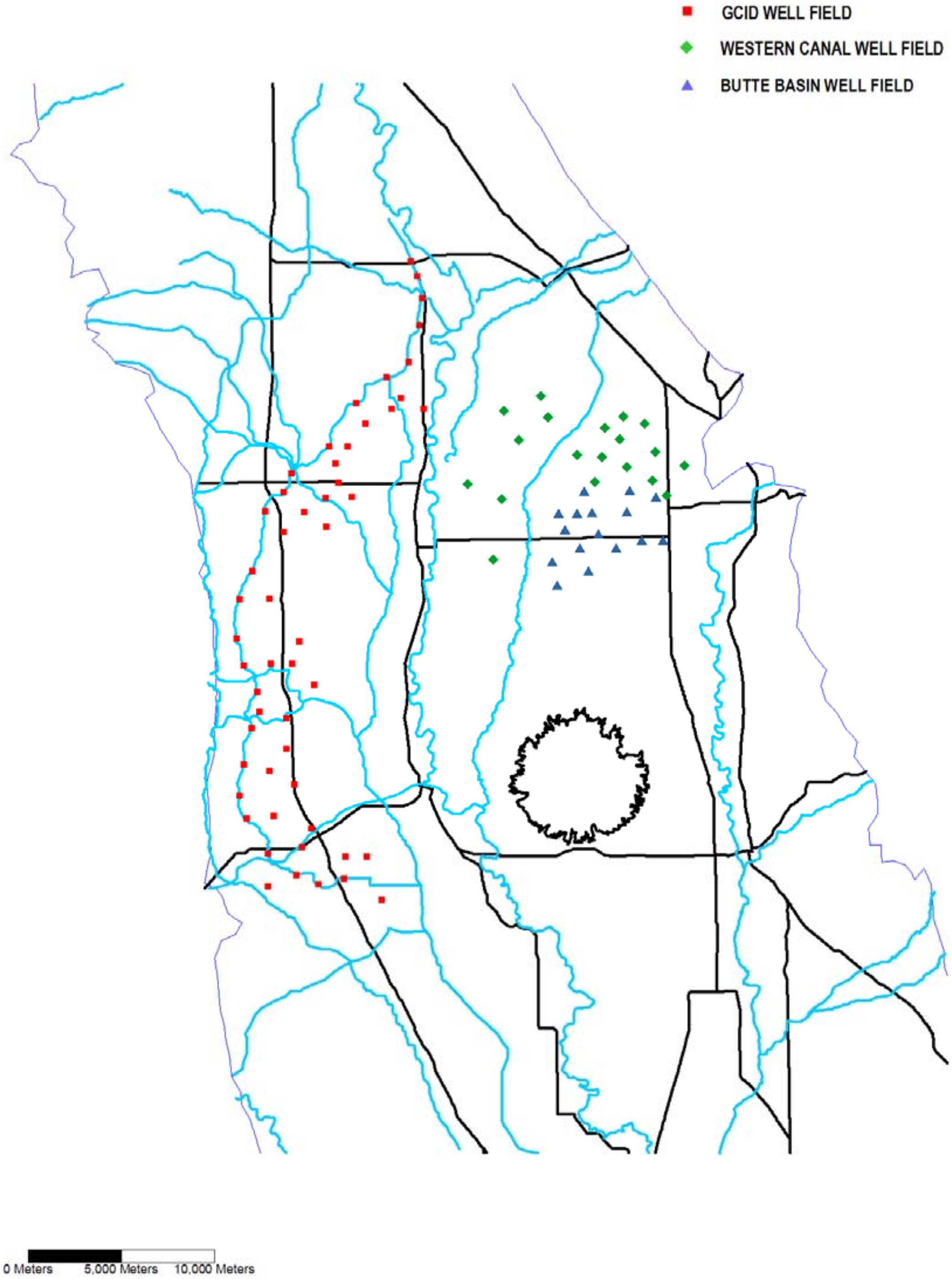

FIGURE 11-2
NEW WELL LOCATIONS, 150-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

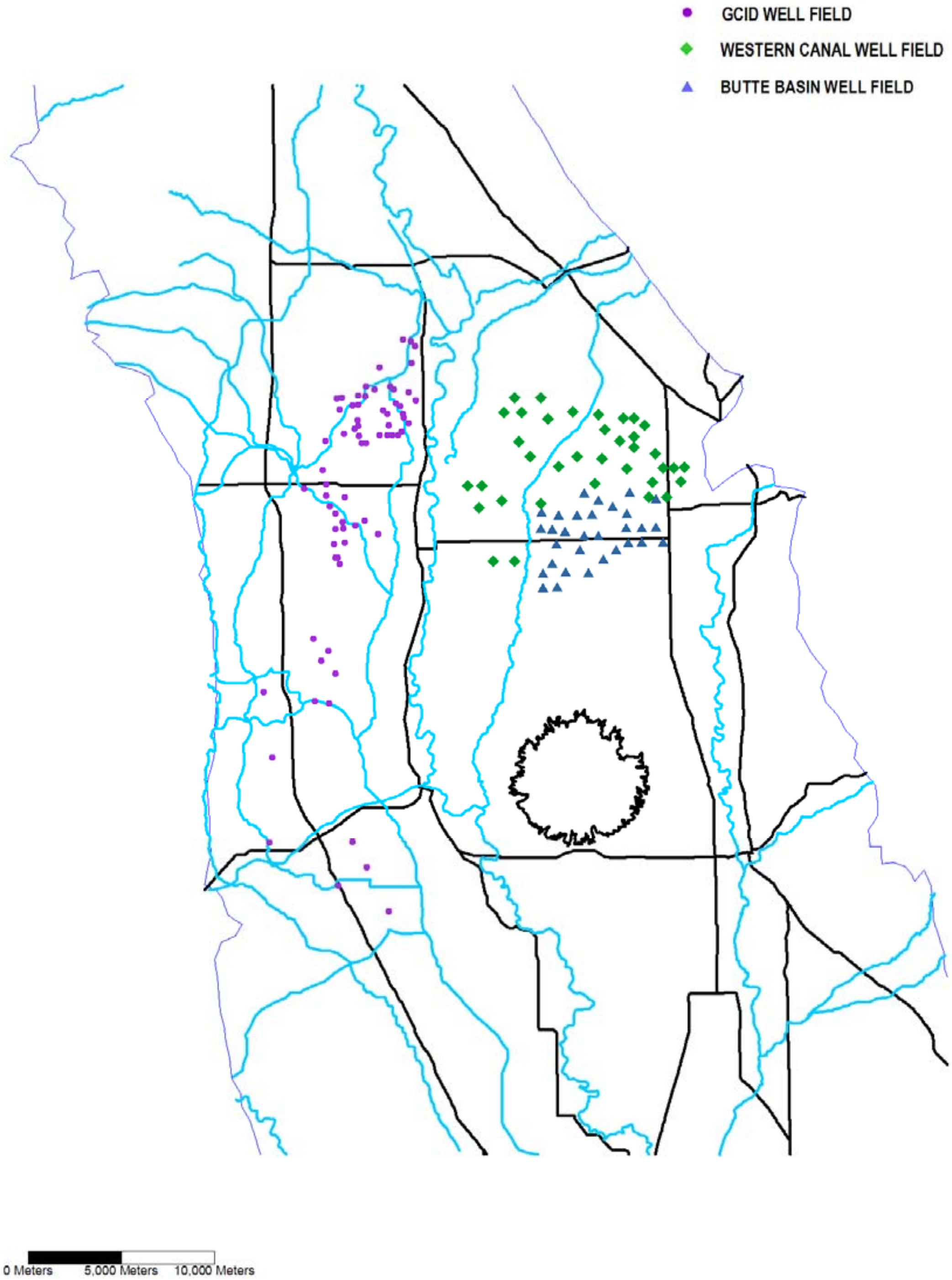

FIGURE 11-3
EXISTING WELL LOCATIONS, 300-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

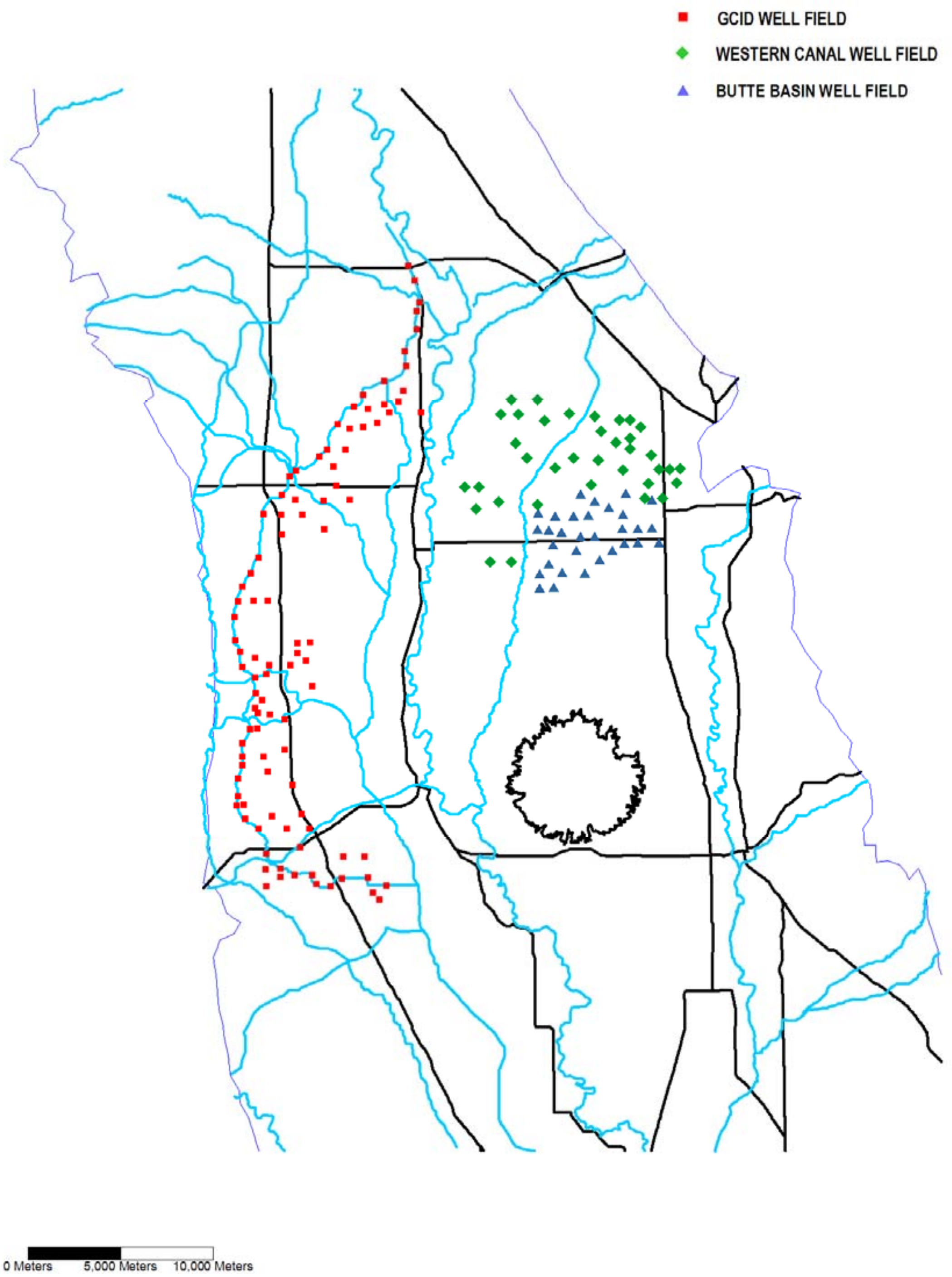

FIGURE 11-4
NEW WELL LOCATIONS, 300-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

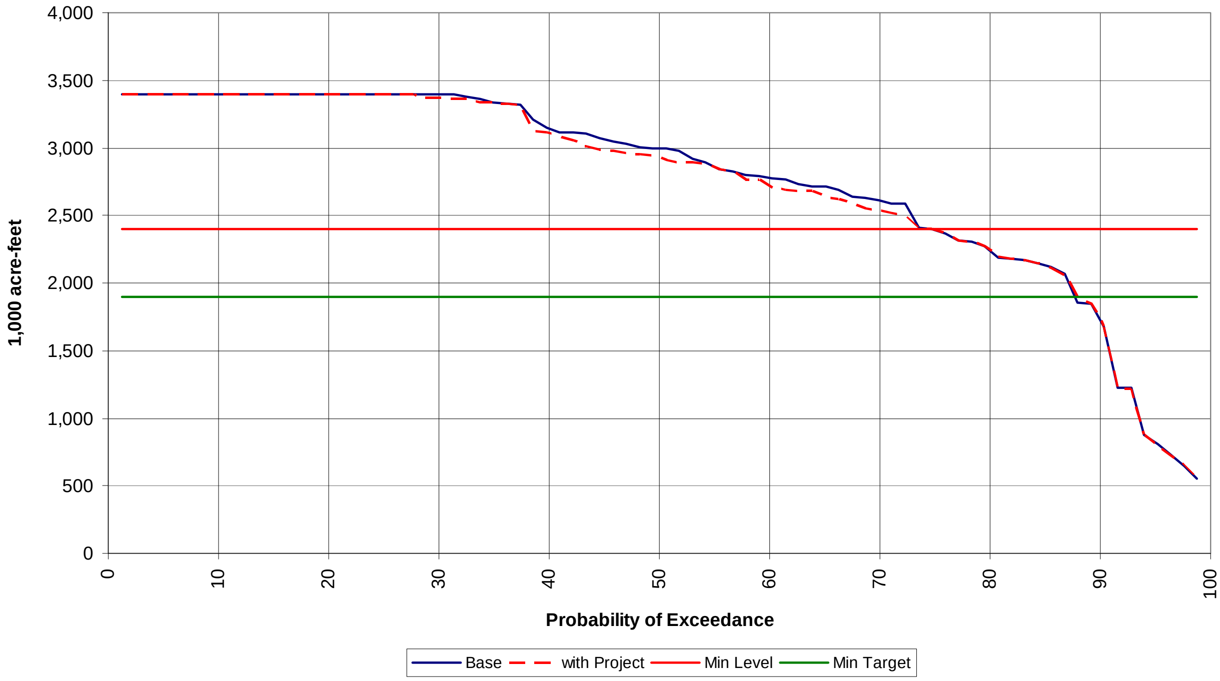

FIGURE 11-5
SHASTA RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.1.1 Shasta Reservoir and Sacramento River

Figure 11-6 illustrates annual volumes of water released to satisfy various environmental objectives on the Sacramento River. Color-coded bars and the legend refer to relative priority of objectives in each year. For example, in 1928 the red bar indicates that water was released to meet objective 4, the lowest priority objective. The type of objective, either geomorphic (Geo), riparian recruitment (Rip), spring pulse (Spring), or flood plain inundation (Flood) is labeled above the corresponding bar. Geomorphic objectives are met most frequently due to lower water costs associated with the short duration objective. Average annual release for environmental objectives is 13 TAF.

Figure 11-6 shows only years when environmental objectives are met through project release. Environmental objectives are also met at times under existing system operation. This information is summarized in Table 11-1. For the flood plain inundation objective, the project includes modifications to the Freemont Weir to allow inundation with less Sacramento River flow. The existing Fremont Weir crest limits inundation of the Yolo Bypass for flows less than approximately 62,000 cfs. The project assumes it is possible to modify the weir to allow inundation with flows of approximately 35,000 cfs. Therefore this objective can be met by the project; either under base condition flows between 35,000 and 62,000 cfs (base condition flows in excess of 62,000 cfs meet the objective in the base condition) or through additional reservoir release to create flows of approximately 35,000 cfs. Results presented in Table 11-1 show the flood plain objective is met in 20 years with the project, though there are only 2 years with releases for this objective illustrated on

Figure 11-6. This indicates that the objective was met with base condition flows between 35,000 and 62,000 cfs (without additional reservoir release) in 18 years.

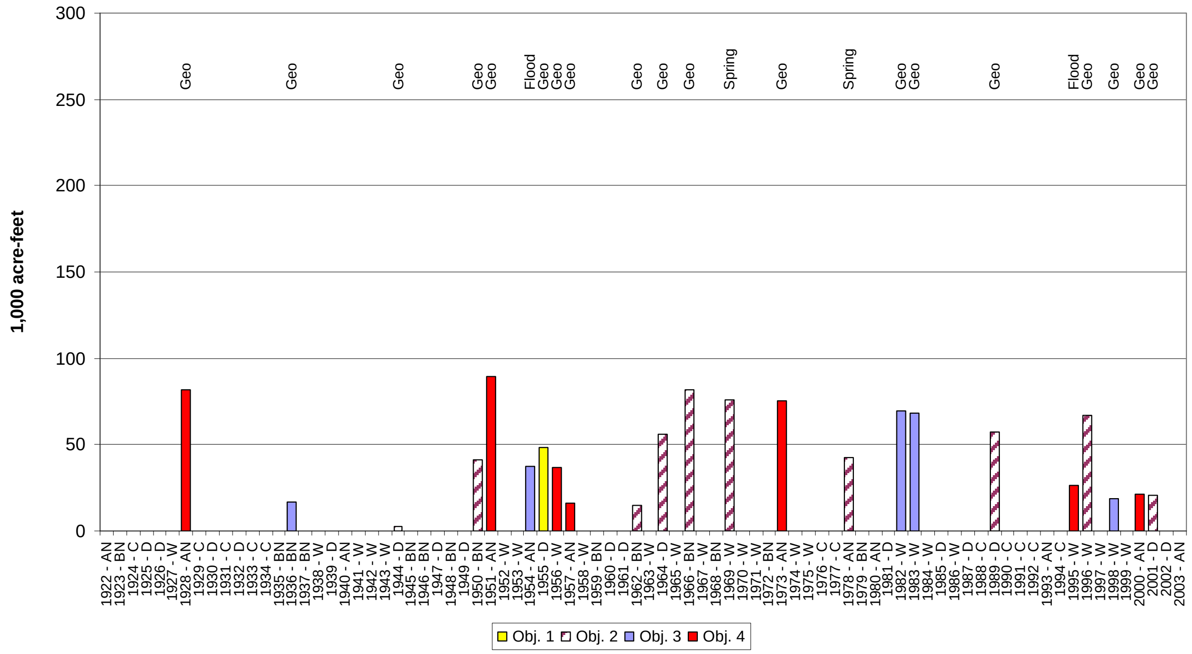

FIGURE 11-6
SACRAMENTO RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

TABLE 11-1
Number of Years Sacramento River Environmental Objectives are Met, Scenario 1
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Objective	Met with Base Conditions Flows	Met with Project Flows	Total
Spring Pulse	5	2	7
Riparian Recruitment	0	0	0
Geomorphic	25	18	43
Flood Plain Inundation	21	20	41

In some years, an objective may be met with base condition flows either before or after it is met with project releases during that same year. Results presented in Table 11-1 account for these occurrences and assume the objective is met in the base condition to prevent double counting in any year. For example, Figure 11-6 shows that releases were sufficient to meet the geomorphic objective in 19 of the 82 years analyzed. However, in 1 year (1956) the objective was met both under base conditions and then simulated to be met through project release. Results presented in Table 11-1 only show this objective being met during base condition flows to prevent potential double counting.

Figure 11-7 illustrates annual releases from Shasta Reservoir to meet additional agricultural demand in the TCCA service area. Dashed lines show unmet contract supply from CalSim II results and green bars illustrate the portion of unmet contract supply satisfied with conjunctive management operations. Additional agricultural releases are made in 24 of the 82 years simulated, or approximately 29 percent of the years. The average release in those years is 46 TAF, while the average annual agricultural delivery over the 82-year simulation period is 14 TAF.

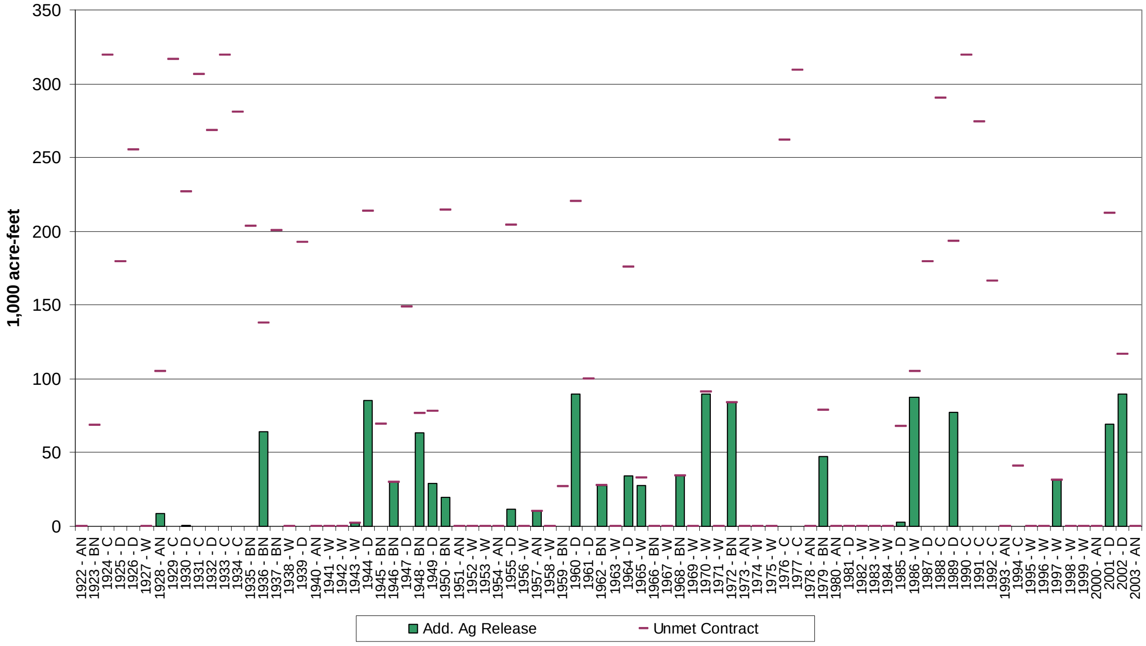

FIGURE 11-7
SACRAMENTO RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-7 illustrates that in many years when unmet contract supply for the TCCA is highest, there are no deliveries with conjunctive use. This is because in these years, project assets are typically low, either because fall reservoir storage is forecast to be low and no additional releases would be made or it is a Shasta Critical year and additional groundwater pumping for conjunctive management is assumed to be zero.

Additional reservoir releases for either environmental objectives or for additional agricultural delivery result in lower fall carryover storage in Lake Shasta. Figure 11-5 illustrates this with a probability of exceedance plot for end of September storage conditions. The solid blue line indicates fall storage conditions under base (without project) conditions. The red dashed line indicates conditions with conjunctive management. A solid red line at 2,400 TAF indicates the level when conjunctive management operations would not occur to limit the risk to cold water pool management in future years. Storage conditions below the solid green line at 1,900 TAF are when conjunctive management operations attempt to increase storage by pumping groundwater and holding water in Shasta above base levels.

Figure 11-5 illustrates that fall storage levels are lower in approximately 45 percent of the years and only when end of September storage is above 2,400 TAF. In wet years, when fall storage is at the flood control level of 3,400 TAF, releases in spring may refill in later months within the same year resulting in no change in fall storage conditions.

Figure 11-8 illustrates how storage deficits presented on Figure 11-5 are frequently refilled by the capture of surplus surface water. Surplus is water that would otherwise be released from the reservoir to maintain flood control storage and is not diverted downstream. This water is now stored in reservoir space created by making additional releases to meet agricultural and environmental objectives. Refill from surplus surface water occurs in 29 years with an average annual refill of 70 TAF in those years. Average annual refill with surplus surface water for the 82-year simulation is approximately 24 TAF.

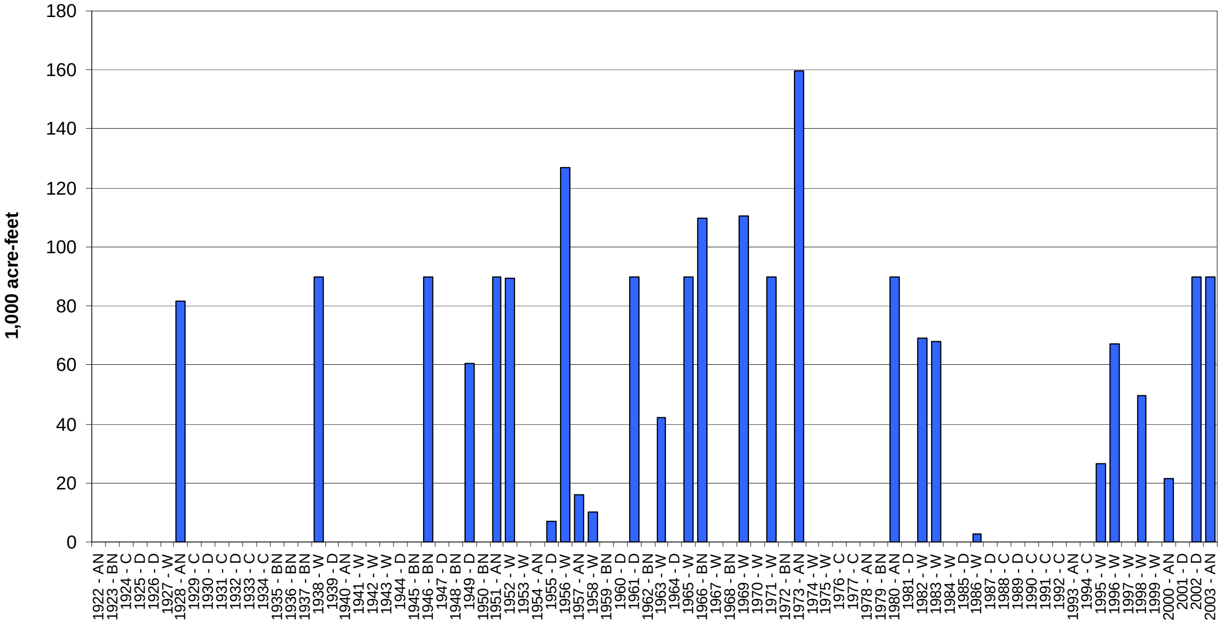

FIGURE 11-8
REFILL OF SHASTA RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

In some years, following additional reservoir releases for agricultural and environmental objectives, there is no surplus surface water, and reservoir storage levels continue to decline putting future water supplies and cold water pool management at risk. In these years groundwater pumping in the conjunctive management projects is used to recover reservoir storage levels. Figure 11-9 illustrates this annual pumping. Conjunctive management pumping occurs in 4 of the 82 years simulated, or 5 percent of years. The average annual pumping in those years is 70 TAF. The average annual pumping for the entire 82-year simulation is approximately 3 TAF with a maximum annual pumping of nearly the full 100 TAF of capacity. Pumping typically occurs in drier year types when reservoirs do not refill with surplus surface water.

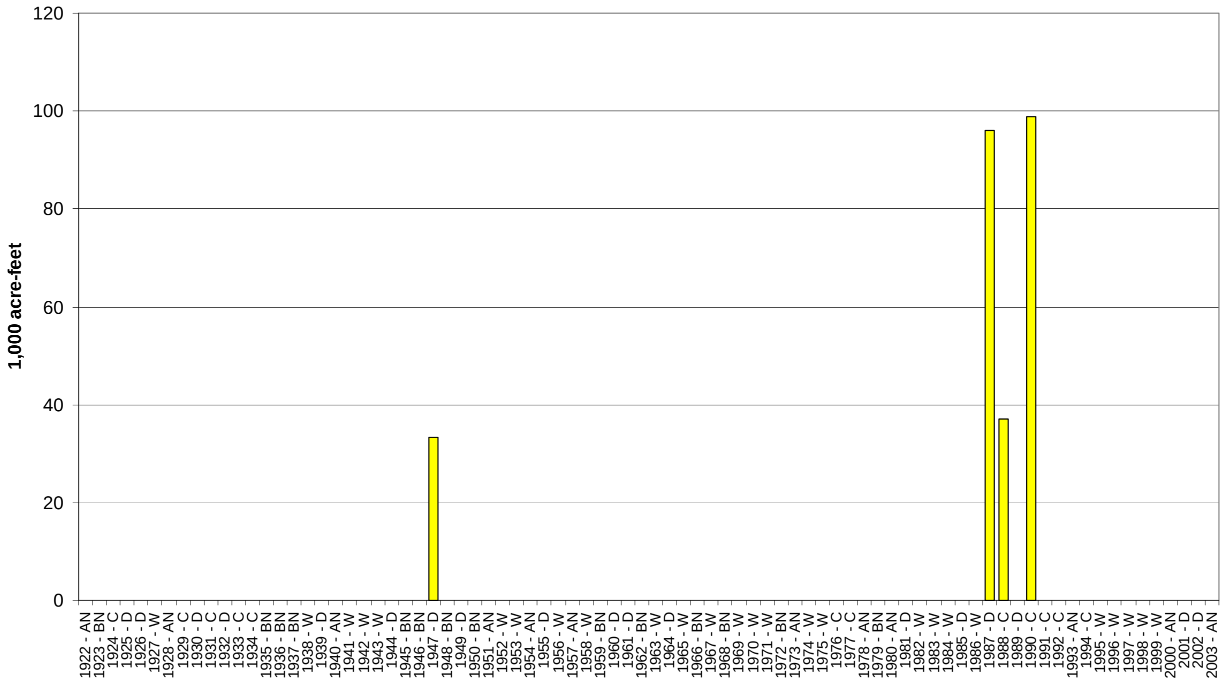

FIGURE 11-9
REFILL OF SHASTA RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Over the 82-year simulation period, additional reservoir releases are made in 37 years, or 45 percent of the years. Reservoir refill is accomplished with surplus surface flows in 29 years and with project pumping in 4 years. The number of years with additional releases exceeds the number of years with refill because reservoir storage deficits do not have to be completely refilled before making additional releases, as long as the total reservoir storage deficit does not exceed the capacity of the project to refill the reservoir in a single year. Of the total average annual additional releases of 27 TAF (14 TAF for agriculture and 13 TAF for environmental objectives), 24 TAF is refilled from surplus surface water and 3 TAF from conjunctive management pumping.

11.1.2 Oroville Reservoir and Feather River

Figure 11-10 illustrates annual volumes of water released to meet environmental objectives on the Feather River. Hydrology and operations on the Feather River result in meeting different objectives in different years compared to the Sacramento River. Similar to the Sacramento River operations, the geomorphic objective is satisfied most frequently due to lower water cost associated with meeting the shorter duration objective. Average annual release for environmental objectives on the Feather River is 7 TAF.

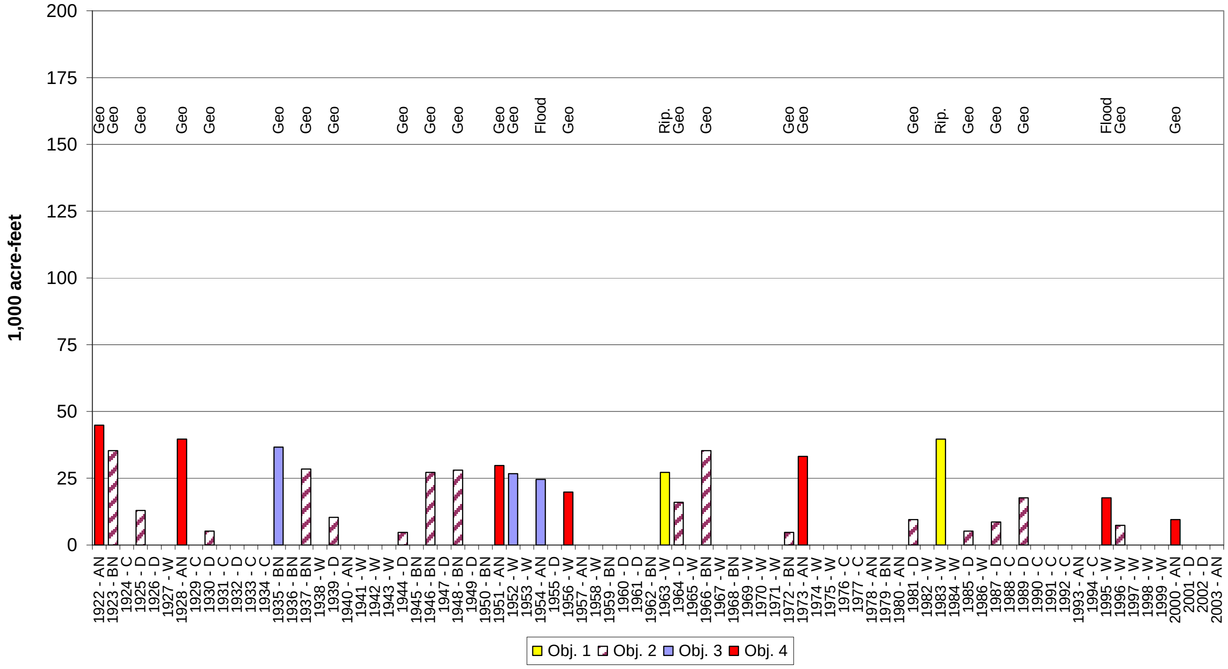

FIGURE 11-10
FEATHER RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Table 11-2 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 11-7. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

TABLE 11-2
Number of Years Feather River Environmental Objectives are Met, Scenario 1
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Objective	Met in Base	Met with Project	Total
Spring Pulse	3	0	3
Riparian Recruitment	1	2	3
Geomorphic	31	17	48
Flood Plain Inundation	21	20	41

Figure 11-11 illustrates additional agricultural deliveries possible with conjunctive management on the Feather River. Dashed lines relate to assumed unmet demands within the Feather River basin and correspond to the Sacramento Valley Index. Similar to operations on the Sacramento River, project assets do not allow additional releases for either environmental or agricultural objectives during drier year types when agricultural demands are higher. Additional agricultural releases are made in 30 of the 82 years simulated, or approximately 37 percent of the years. The average release in those years is 27 TAF, while the average annual agricultural delivery over the 82-year simulation period is 10 TAF.

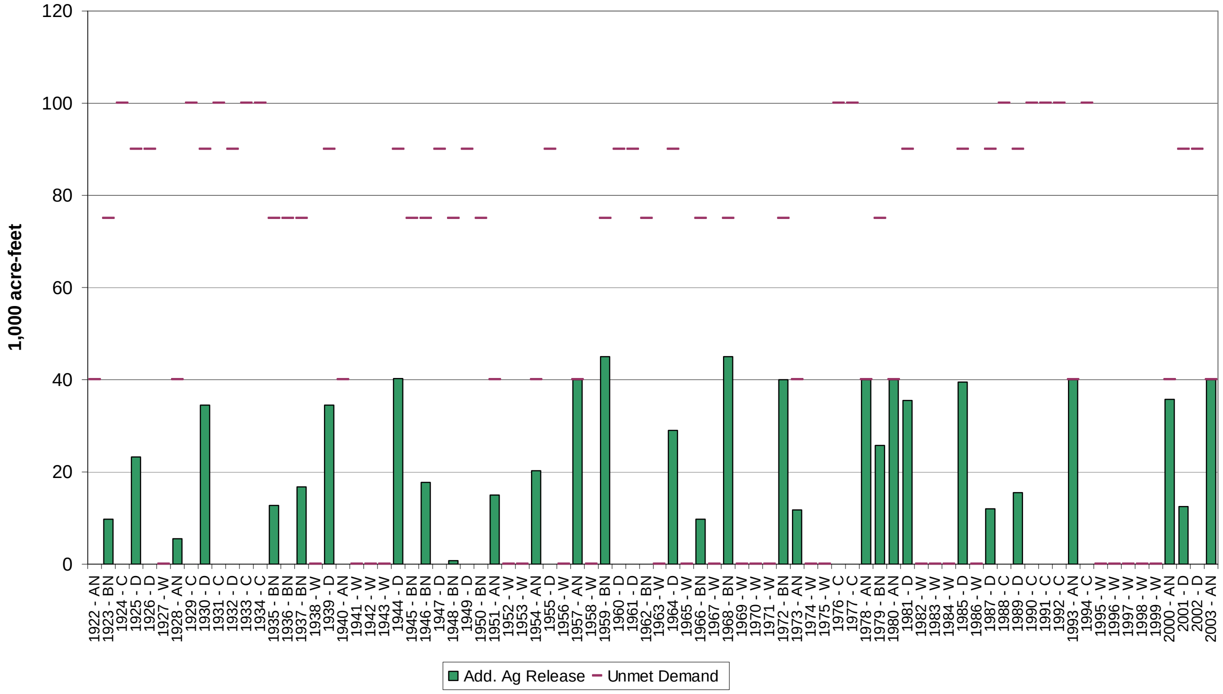

FIGURE 11-11
FEATHER RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Figure 11-12 illustrates how conjunctive management operations result in slightly lower Oroville Reservoir fall storage conditions in approximately 60 percent of the years. Fall storage is not affected below the minimum level of 1,500 TAF. The solid green line at 1,200 TAF denotes target storage for cold water pool management when conjunctive management may be used to increase storage.

Figure 11-13 shows how storage space created in Oroville Reservoir through additional releases for agricultural and environmental objectives is frequently refilled with surplus surface water. Refill from surplus surface water occurs in 37 years with an average annual refill of 32 TAF in those years. The average annual refill with surplus for the 82-year simulation period is 14 TAF.

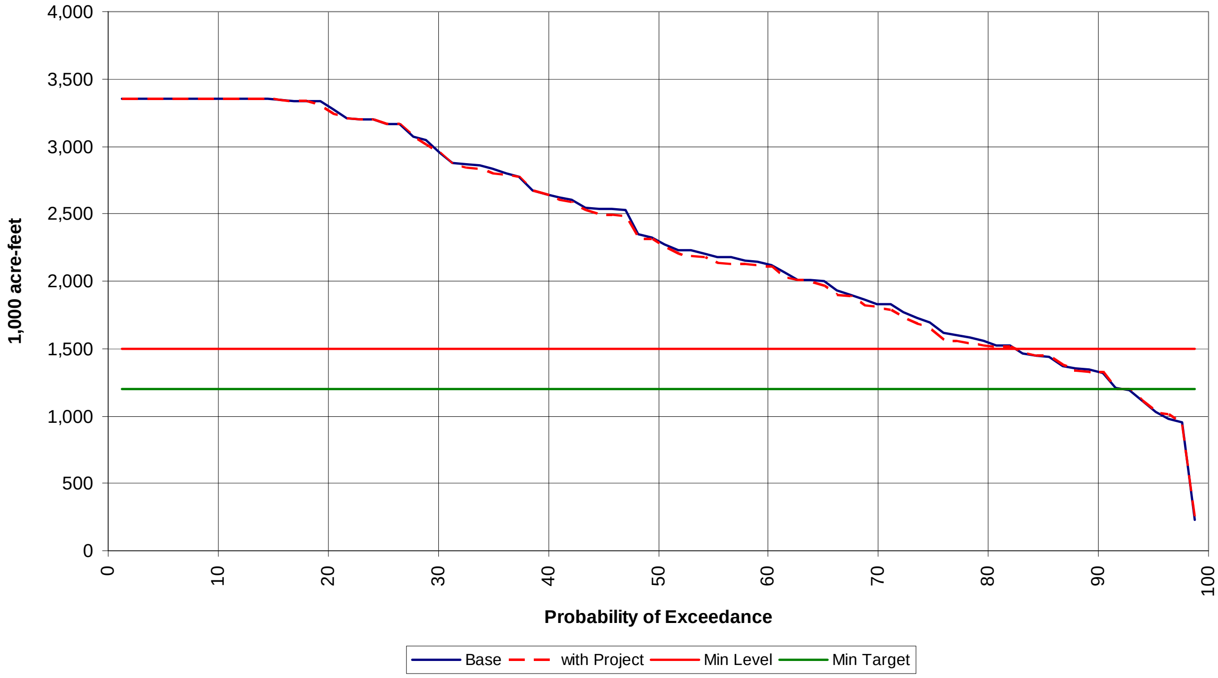

FIGURE 11-12
OROVILLE RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

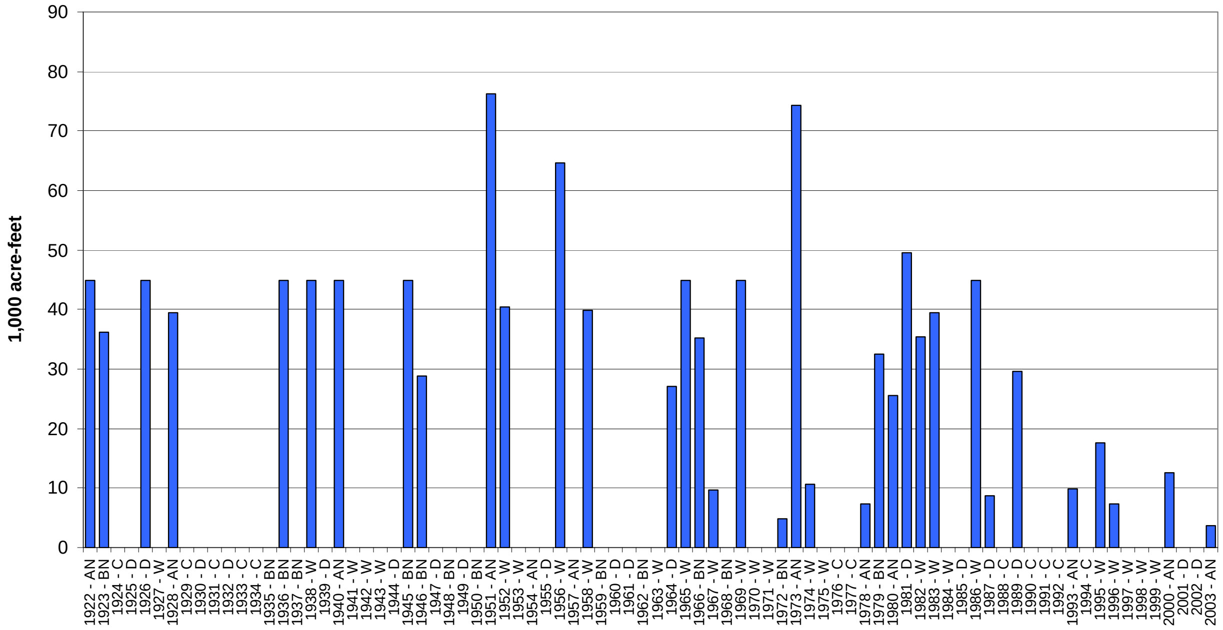

FIGURE 11-13
REFILL OF OROVILLE RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-14 presents annual conjunctive management pumping in the Butte Basin project. Conjunctive management pumping occurs in 6 of the 82 years simulated or 7 percent of the years. The average annual pumping in those years is 44 TAF. The average annual pumping for the entire 82-year simulation is approximately 3 TAF with a maximum annual pumping of the full 50 TAF of pumping capacity.

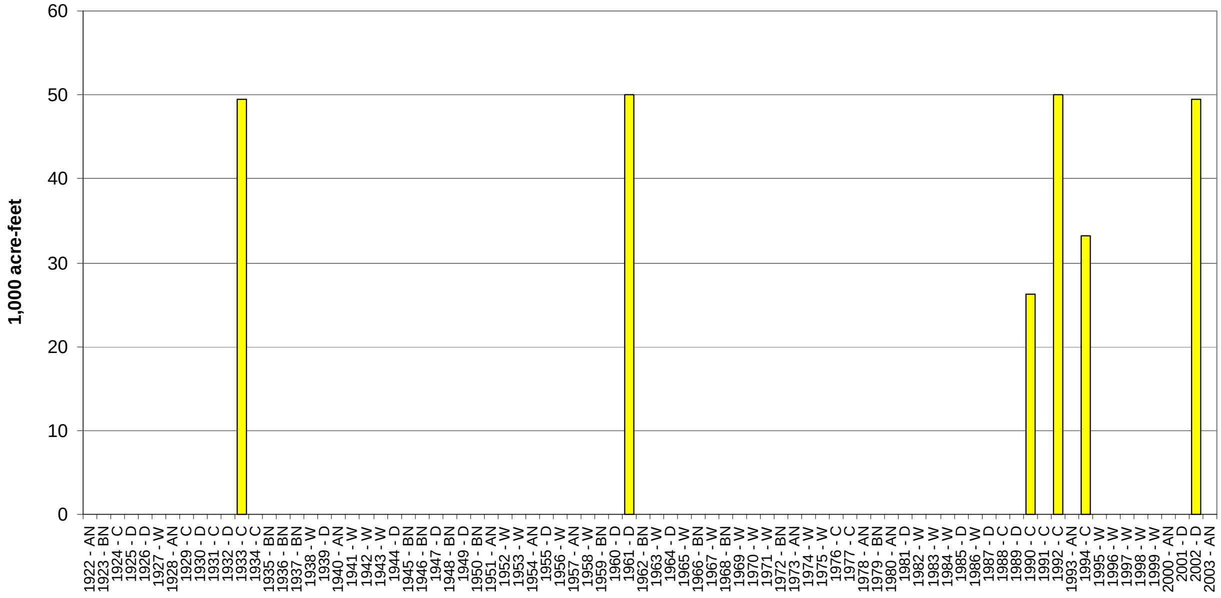

FIGURE 11-14
REFILL OF OROVILLE RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Over the 82-year simulation period, additional reservoir releases are made in 37 years, or 45 percent of the years. Reservoir refill is accomplished with surplus surface flows in 37 years and with project pumping in 6 years. The number of years with refill exceeds the number of years with additional release because reservoir storage deficits may not completely refill in a single year, but instead refill over the course of several years. In summary, of total average annual additional releases of 17 TAF (10 TAF for agriculture and 7 TAF for environmental objectives), 14 TAF is refilled from surplus surface water and 3 TAF from conjunctive management pumping.

11.1.3 Groundwater Results

Existing Well Field

Monthly pumping for Scenario 1, illustrated on Figures 11-9 and Figure 11-14 for the GCID and Butte Basin projects, respectively, was simulated in the groundwater model for the existing well field shown on Figure 11-1. All discussions provided in this section referring to the existing well field reflect simulated drawdown in the regional aquifer. All discussions referring to the new well field reflect simulated drawdown in the deeper aquifer. Production would occur through existing wells screened in the regional aquifer at depths of 100 to

500 feet. Results of this simulation are summarized on Figures 11-15 through 11-17. Peak drawdown in groundwater levels associated with implementation of this scenario is presented on Figure 11-15. This figure depicts simulated drawdown in the pumped aquifer during August 1990. Maximum pumping rates under this alternative occur during 1990 and the drawdown distribution at the end of August represent the approximate maximum drawdown that will occur under this scenario. Figure 11-15 shows that the area of greatest drawdown occurs in the northern GCID area at a magnitude of 30 to 40 feet. Drawdown in the Butte Basin is negligible and is confined to the close vicinity of the production wells.

Simulated impacts to surface streams under Scenario 1 for an existing well field are summarized on Figures 11-16 and 11-17. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-16 suggests that the peak cumulative impact to all surface water flows will be approximately 54 cfs in the summer of 1990, with a flow reduction of just more than 40 cfs forecasted to occur on the Sacramento River, and a flow reduction of approximately 13 cfs on Butte Creek. The peak impact to the Sacramento River will also occur in the late summer of 1990 while the peak impact on Butte Creek is forecasted to occur in early 1993. Peak impacts to stream flows on smaller tributary streams are less than about 6 cfs as shown on Figure 11-17.

The time of year in which impacts to rivers and streams are simulated to occur is a critical factor in assessing their significance. Typical flows in the Sacramento River at Wilkins Slough are on the order of 6,000 to 7,000 cfs in late summer and fall months with minimum flows for the historical period of 1980 through 2006 of 3,000 to 4,000 cfs. Therefore, the impacts reflected on Figure 10-16 represent a small percentage of total flow. Average summer and fall flows in the Feather River directly below Thermalito Afterbay are on the order of 2,000 to 3,000 cfs with minimum flows for the same historical period of approximately 1,000 cfs. Flows in Butte Creek near Chico average approximately 110 to 150 cfs with minimum flows of 50 cfs in some fall months. Therefore, simulated impacts to Butte Creek represent a larger percent of minimum or typical flows than impacts to the Sacramento or Feather Rivers.

Figure 11-16 illustrates stream flow reductions for the groundwater model simulation period. Reductions in the Sacramento River between GCID (Hamilton City) and Wilkins Slough show larger spikes during years with pumping in the GCID project and smaller increases during years with pumping in the Butte Basin project. Butte Creek reductions follow the opposite pattern with larger increases during years with pumping in the Butte Basin project and smaller increases in years with pumping in the GCID project. Reductions in all modeled streams show increases in years with pumping in either project. The annual cycle of increasing and decreasing reductions in all streams is due to the ephemeral nature of smaller streams. More reductions occur in winter months when smaller streams are simulated to be flowing and less reductions in summer when smaller streams are assumed to be dry.

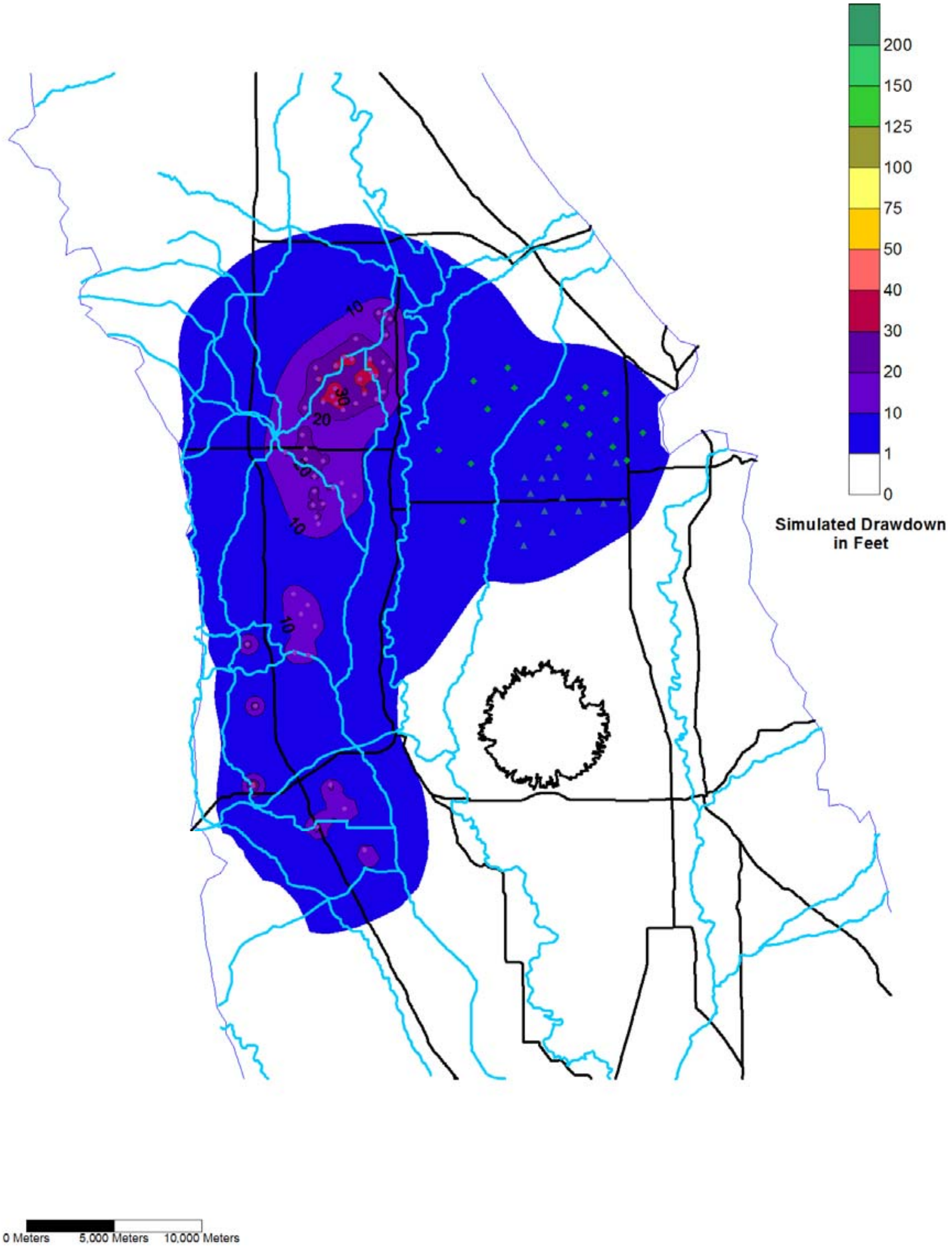

FIGURE 11-15
SIMULATED EXTENT OF DRAWDOWN IN THE REGIONAL AQUIFER IN AUG 1990, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

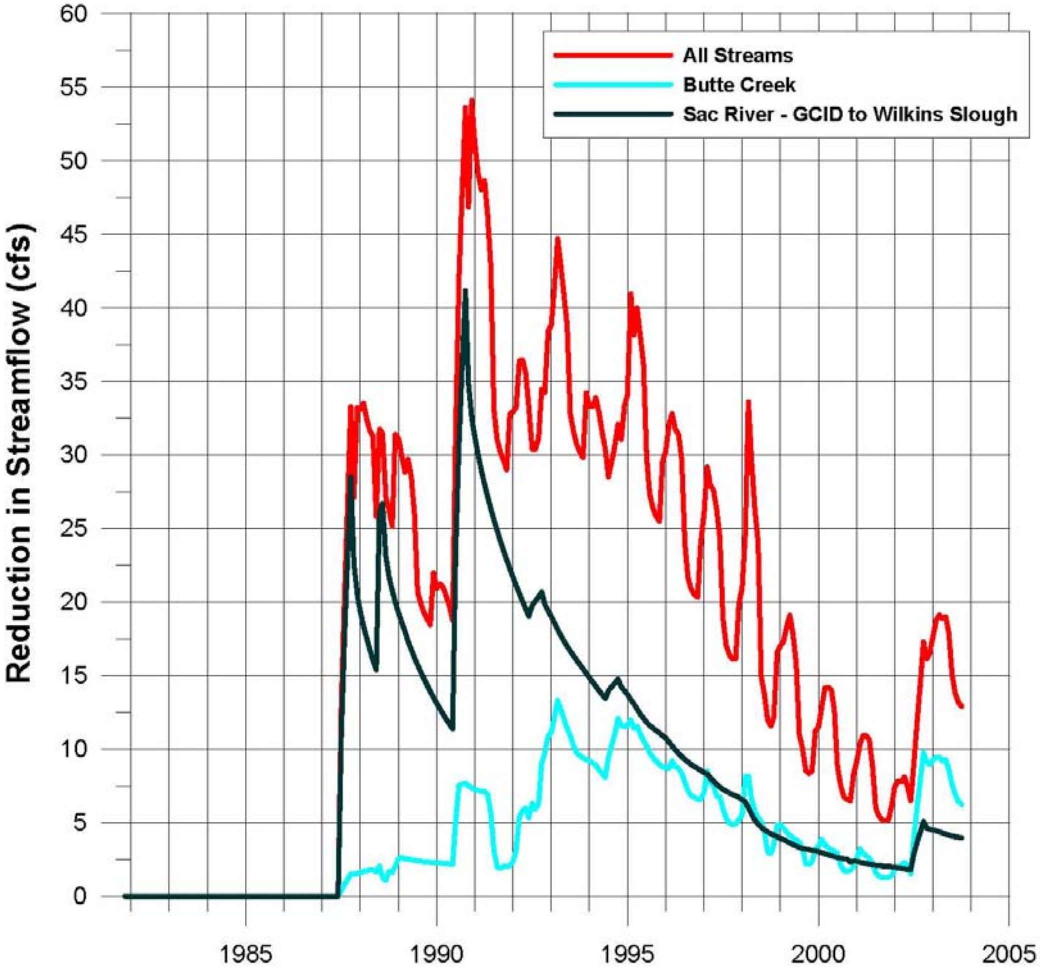

FIGURE 11-16
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

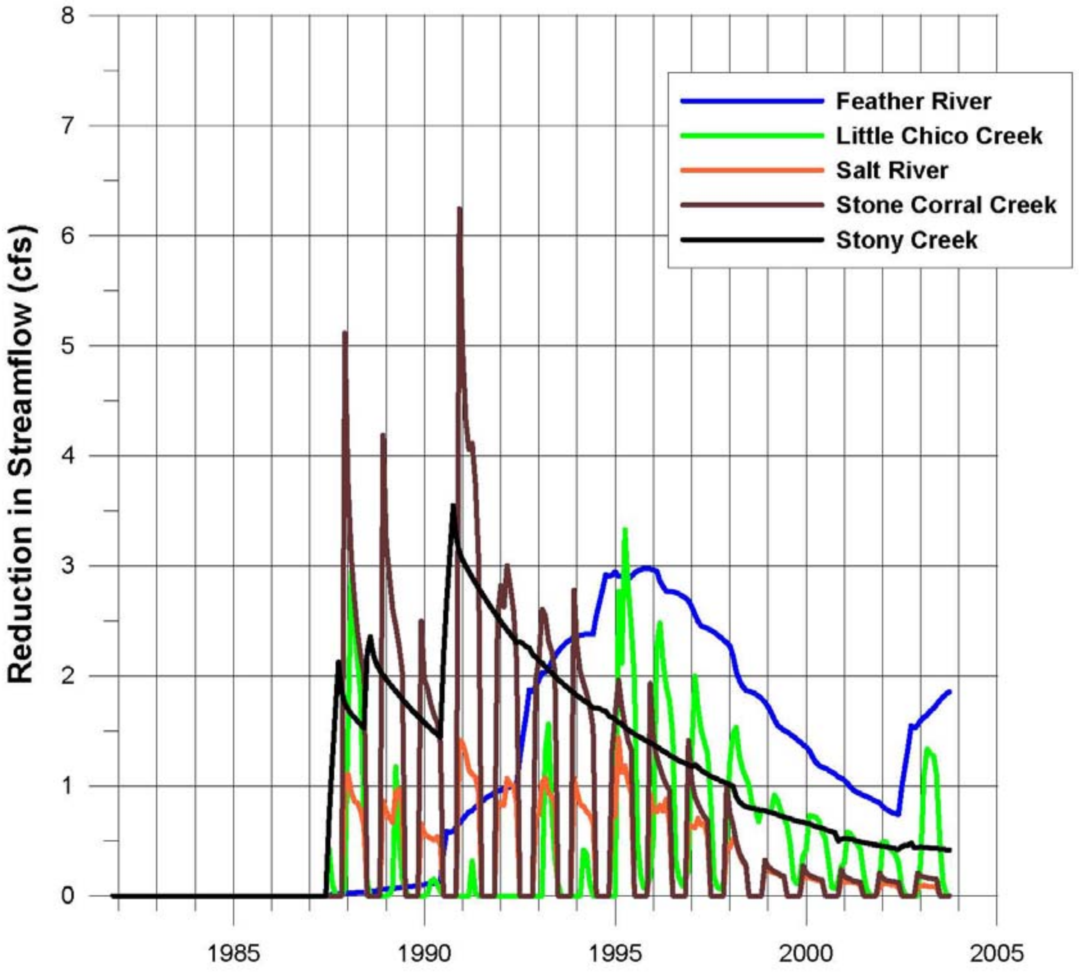

FIGURE 11-17
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Reservoir Release for Recharge

Stream reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. The timing of when stream reductions occur and conditions in the surface water system determine if and how the surface water system may respond. For example, if stream reductions tend to occur in winter months of years with above average precipitation there may be little or no response required by upstream reservoirs to a decrease in stream flow. Alternatively, if stream reductions occur during fall months of years with below average precipitation, upstream reservoirs may be required to make additional releases to ensure compliance with flow or water quality requirements in the surface water system.

The surface water system is sometimes referred to as being in a “balanced” or “surplus” condition. Balanced conditions occur when upstream reservoirs are releasing water to meet specific downstream requirements for flow, diversions, water quality, or to support Delta exports. Surplus conditions typically occur when upstream reservoirs are releasing water for flood control purposes or tributary inflow below reservoirs results in surplus conditions. It is possible for parts of the system to be in balanced conditions while others are in surplus conditions. For example, if Shasta Reservoir is releasing water to maintain minimum required flow at the navigation control point (a location near Wilkins Slough) the system is in balance between Shasta and Wilkins Slough and reduction in Sacramento River flow or its tributaries upstream of Wilkins Slough may require additional release from Shasta. Simultaneously there may be surplus flow in the Sacramento River below Wilkins Slough or the Delta, and reduction in stream flow downstream of Wilkins Slough may require additional release from Shasta.

Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-18 and 11-19 present annual additional releases from Shasta and Oroville, respectively, for Scenario 1 pumping from an existing well field.

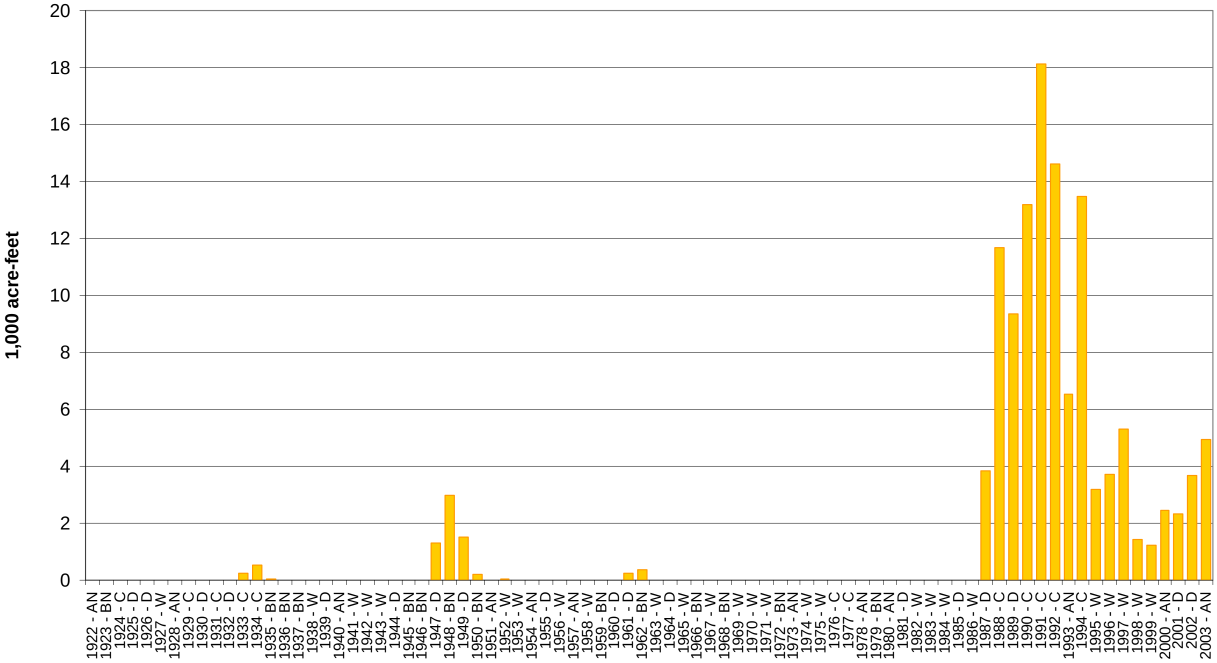

FIGURE 11-18
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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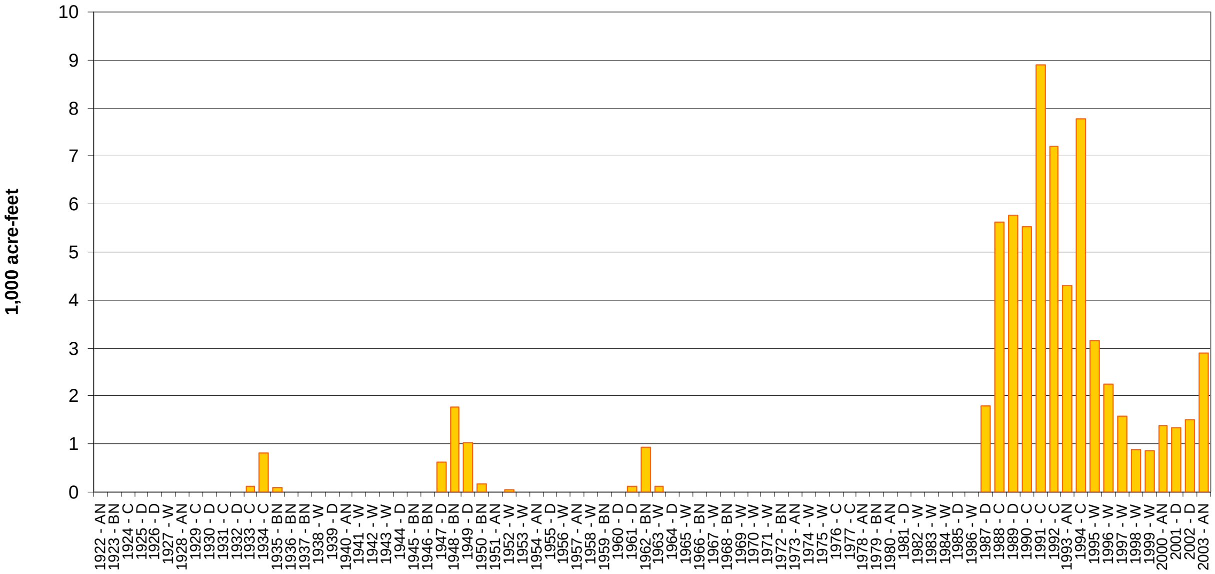

FIGURE 11-19
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - EXISTING WELL FIELD
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Figures 11-18 and 11-19 also illustrate that in multiple years with higher levels of pumping, such as the simulation from 1987 through 1994, upstream reservoirs may have to release a small volume of additional water to compensate for increases in streamflow reductions. These results reflect the precision of both the groundwater and surface water models but not necessarily the accuracy of these models. Annual releases from Oroville Reservoir of 3 TAF in any year are far beyond the accuracy of planning level models. Results are presented to demonstrate potential effects and to illustrate concepts.

New Well Field

The same monthly pumping time series for Scenario 1 was also simulated in the well field shown on Figure 11-2. Production would occur through new wells screened in the deeper aquifer units at a depth of 900 to 1100 feet. Results of this simulation are summarized on Figures 11-20 through 11-22. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-20. This figure depicts simulated drawdown in the pumped aquifer, during August 1990. The figure shows that the area of greatest drawdown occurs in the western GCID area at a magnitude of up to 100 feet. Drawdown in Butte Basin is the range of 10 to 20 feet.

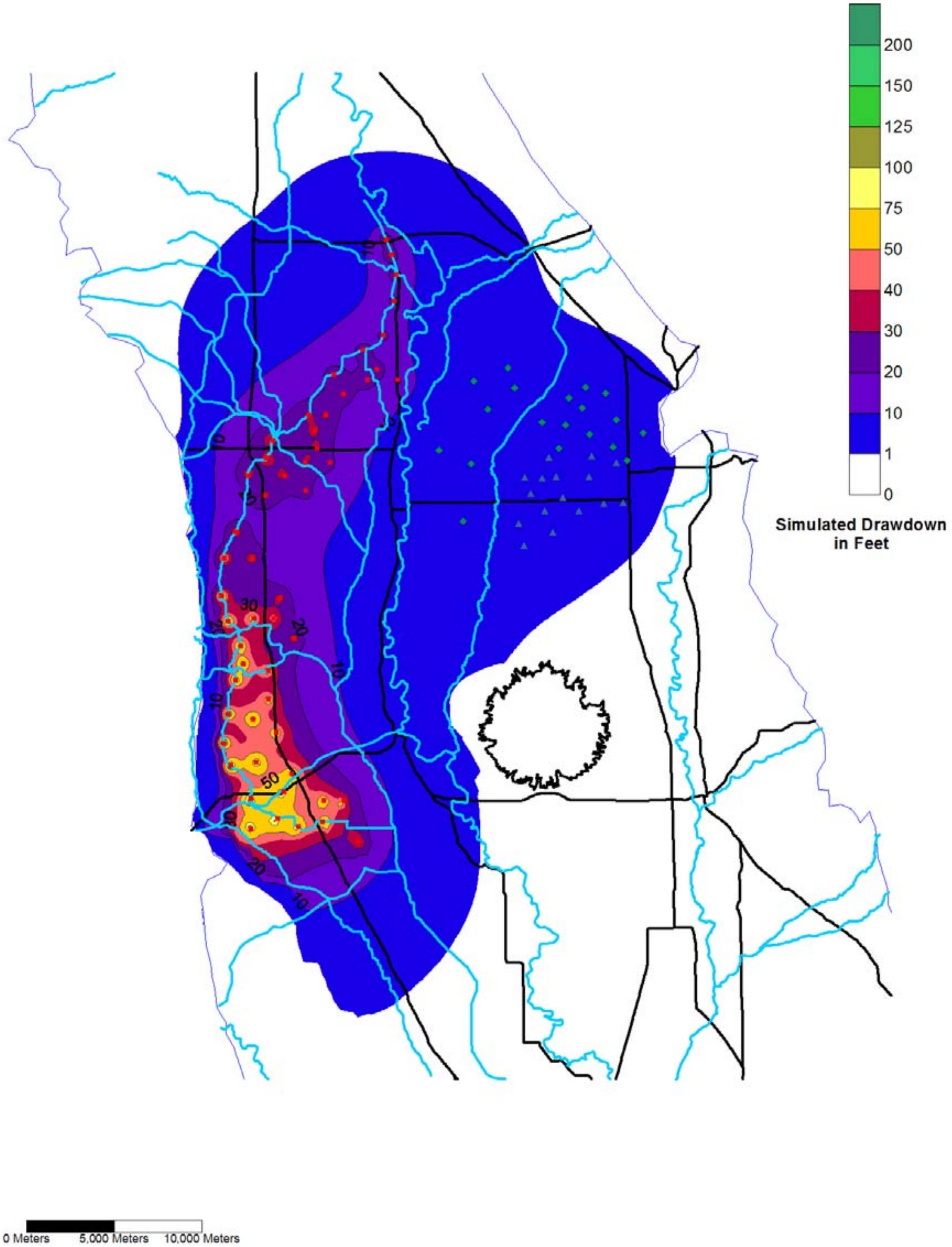

FIGURE 11-20
SIMULATED DRAWDOWN IN THE DEEP AQUIFER IN AUG 1990, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 1 for a new well field are summarized on Figures 11-21 and 11-22. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-21 suggests that the peak cumulative impact to all surface water flows will be a reduction of about 52 cfs in the late fall of 1990, while a flow reduction of just over 36 cfs is forecast to occur on the Sacramento River while a flow reduction of approximately 12 cfs is predicted on Butte Creek. The peak impact to the Sacramento River will also occur in the late fall of 1990, while two similar peak impacts occur on Butte Creek in early 1993 and the fall of 1994. Peak impacts to stream flows on smaller tributary streams peak at less than about 9 cfs as shown on Figure 11-22.

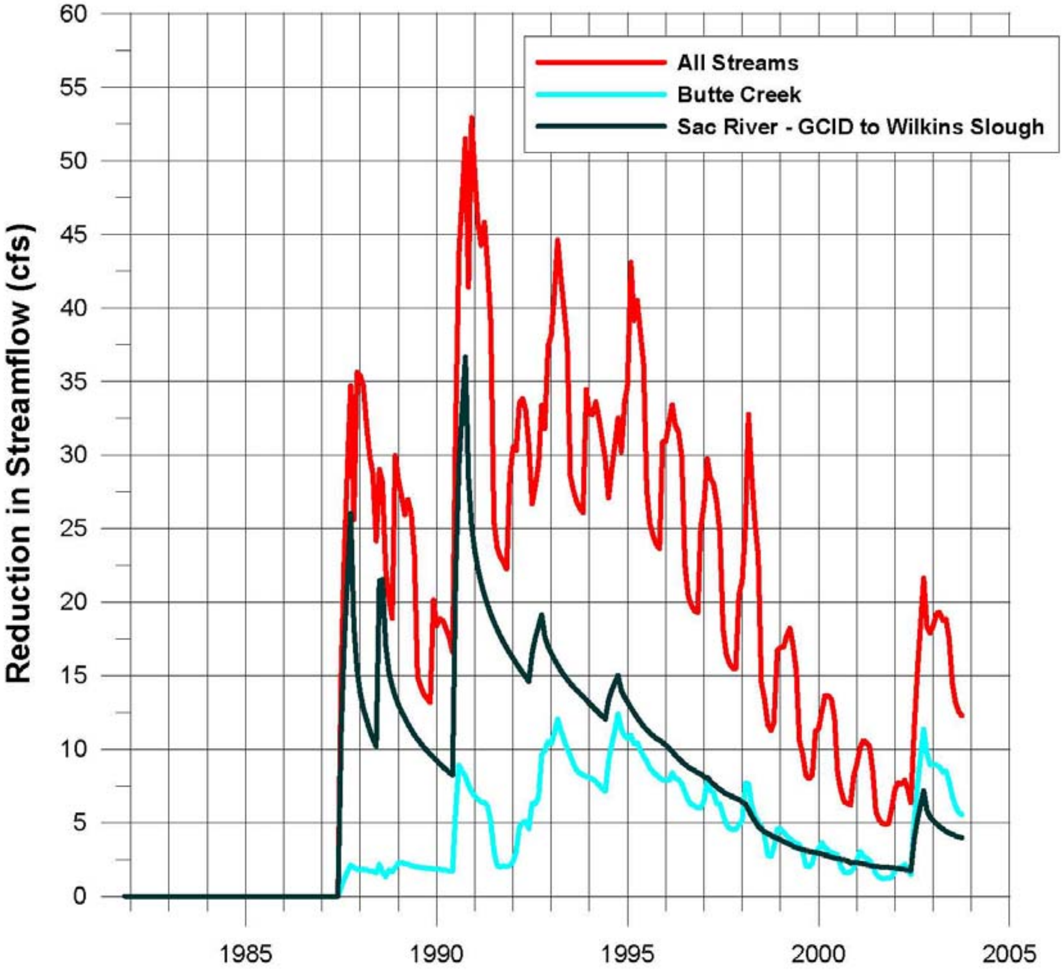

FIGURE 11-21
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

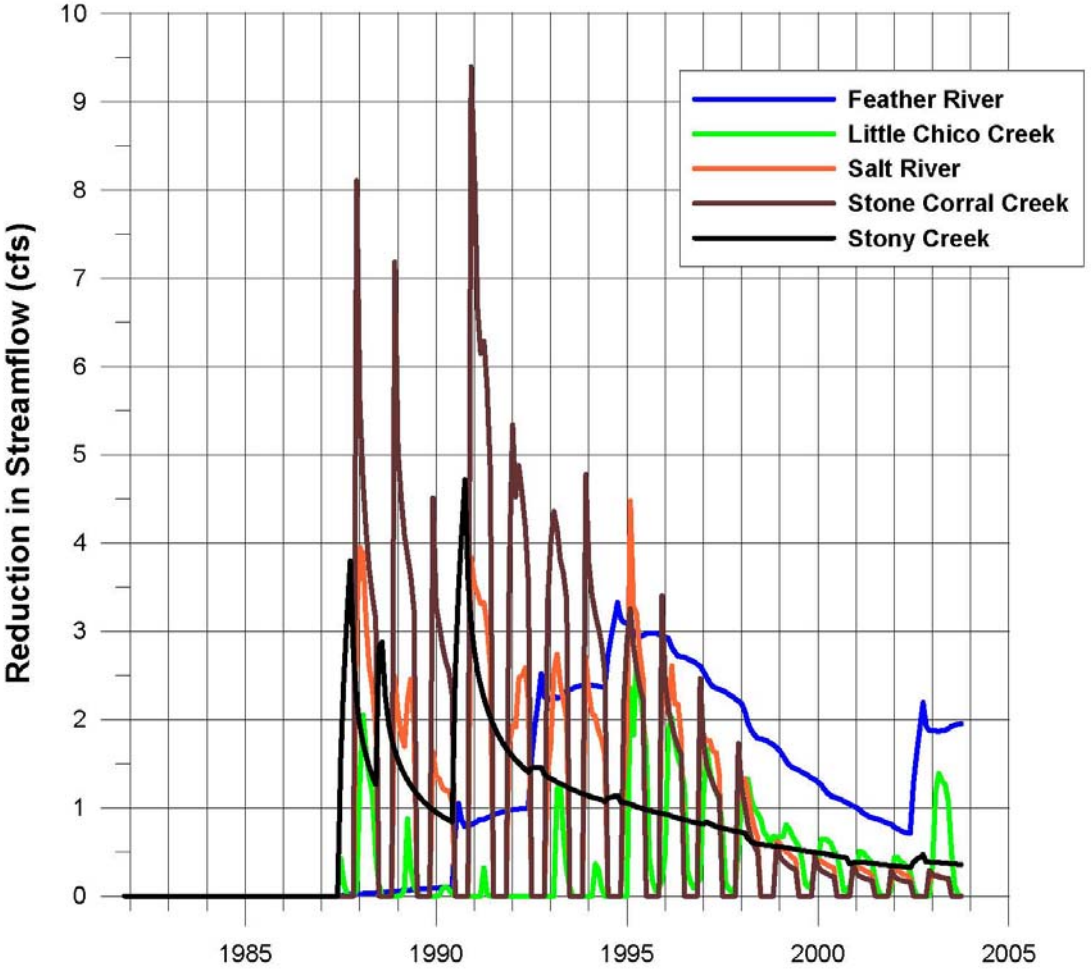

FIGURE 11-22
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-23 and 11-24 present annual additional releases from Shasta and Oroville, respectively, for Scenario 1 pumping from a new well field.

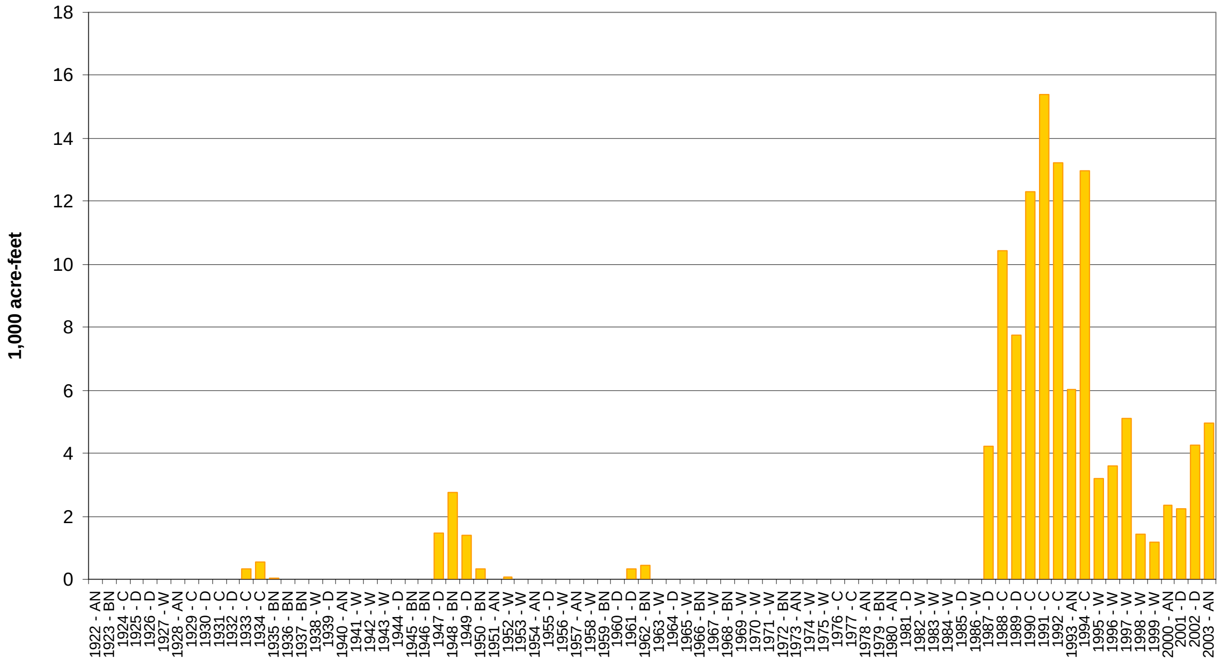

FIGURE 11-23
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

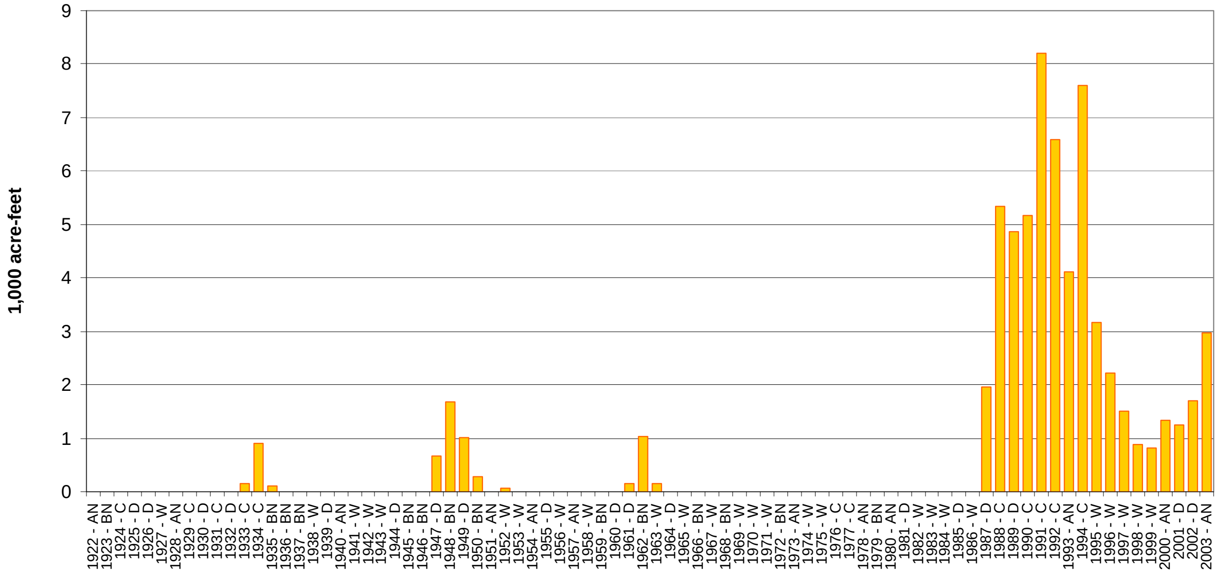

FIGURE 11-24
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figures 11-23 and 11-24 illustrate peak annual reservoir releases to compensate for stream reductions may be slightly less for a new well field than for the existing well field, but annual releases are similar for either well field.

11.2 Scenario 2 – 200 TAF GCID, 100 TAF Butte Basin, Summer Pumping

Scenario 2 is defined by two conjunctive management projects with maximum seasonal pumping capacities of 200 TAF in GCID and 100 TAF in the Butte Basin. This scenario is the same as Scenario 1 but with twice the pumping capacity at each project.

11.2.1 Shasta Reservoir and Sacramento River

Figure 11-25 illustrates annual volumes of water released to satisfy various environmental objectives on the Sacramento River. The geomorphic objective is met most frequently due to lower water cost associated with the short duration, but the larger pumping capacity increases project assets and allows other objectives to be met more frequently than in Scenario 1. Additionally, in some years more than one objective may be met as indicated by stacked bars. Average annual release for environmental objectives under Scenario 2 is 45 TAF.

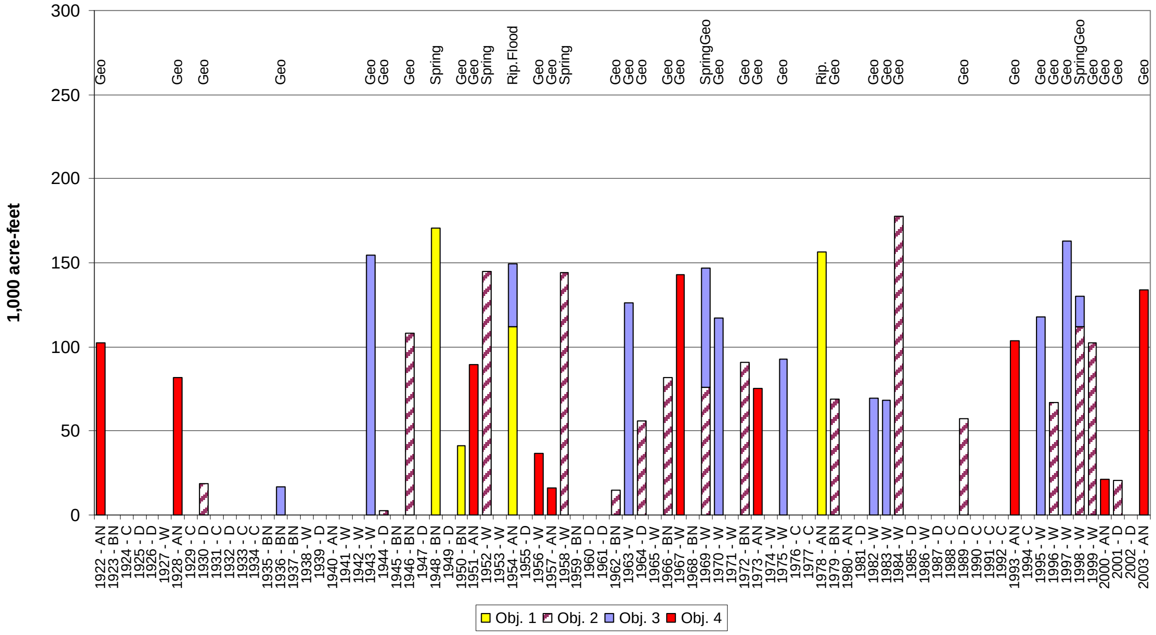

FIGURE 11-25
SACRAMENTO RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-25 shows only years when environmental objectives are met through project release. Environmental objectives may also be met under the base operations of the system.

Table 11-3 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include those years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 11-25. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

TABLE 11-3
Number of Years Sacramento River Environmental Objectives are Met, Scenario 2
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Objective	Met in Base	Met with Project	Total
Spring Pulse	5	5	10
Riparian Recruitment	0	2	2
Geomorphic	25	30	55
Flood Plain Inundation	21	20	41

Figure 11-26 illustrates annual release from Shasta to meet additional agricultural demand in the TCCA service area. Additional agricultural releases are made in 24 of the 82 years simulated, or approximately 29 percent of the years. The average release in those years is 75 TAF, while the average annual agricultural delivery over the 82-year simulation period is 22 TAF. Additional agricultural deliveries are made in many of the same years as in Scenario 1, but at higher volumes.

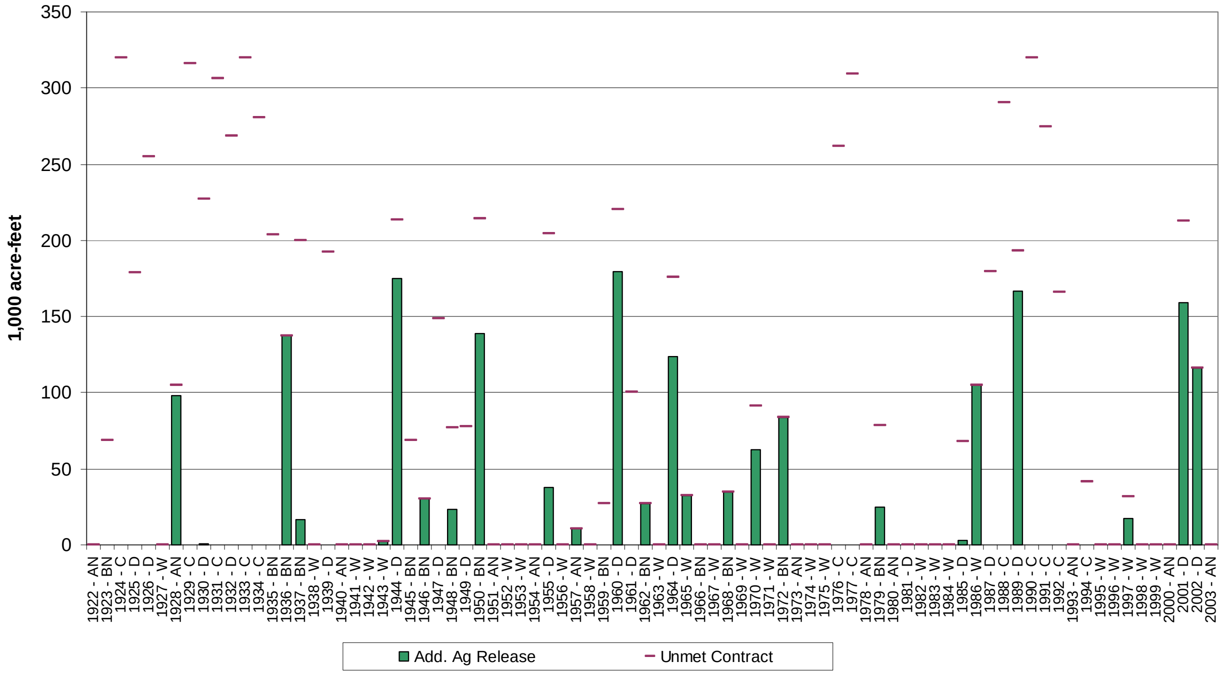

FIGURE 11-26
SACRAMENTO RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Additional reservoir releases for either environmental objectives or for additional agricultural delivery result in lower fall carryover storage in Lake Shasta. Figure 11-27 illustrates that fall storage levels are lower in approximately 45 percent of the years and only when end of September storage is more than 2,400 TAF. During these years fall storages are lower compared to Scenario 1 because larger pumping capacity allows for more aggressive operation of the reservoir. Additionally, a small increase in fall storage below the 1,900 TAF target may also be possible.

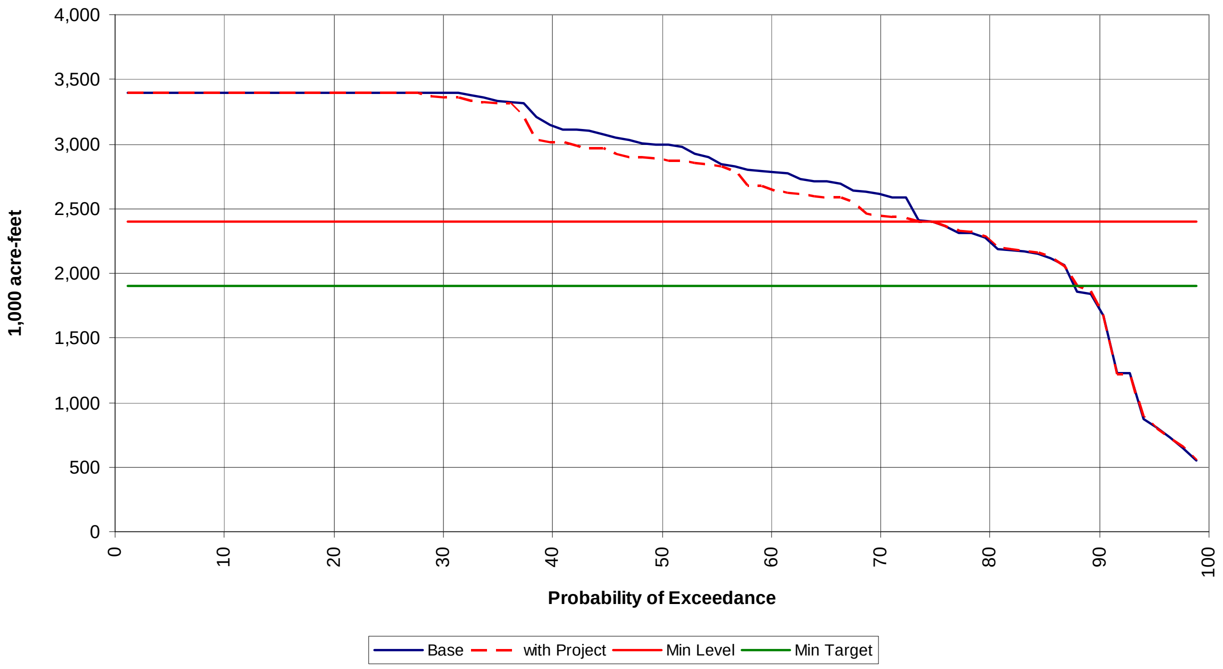

FIGURE 11-27
SHASTA RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 11-28 illustrates how storage deficits presented on Figure 11-27 are frequently refilled by capture of surplus surface water. Refill with surplus surface water occurs in 35 years with an average annual refill of 139 TAF in those years. Average annual refill with surplus surface water for the 82-year simulation is approximately 58 TAF.

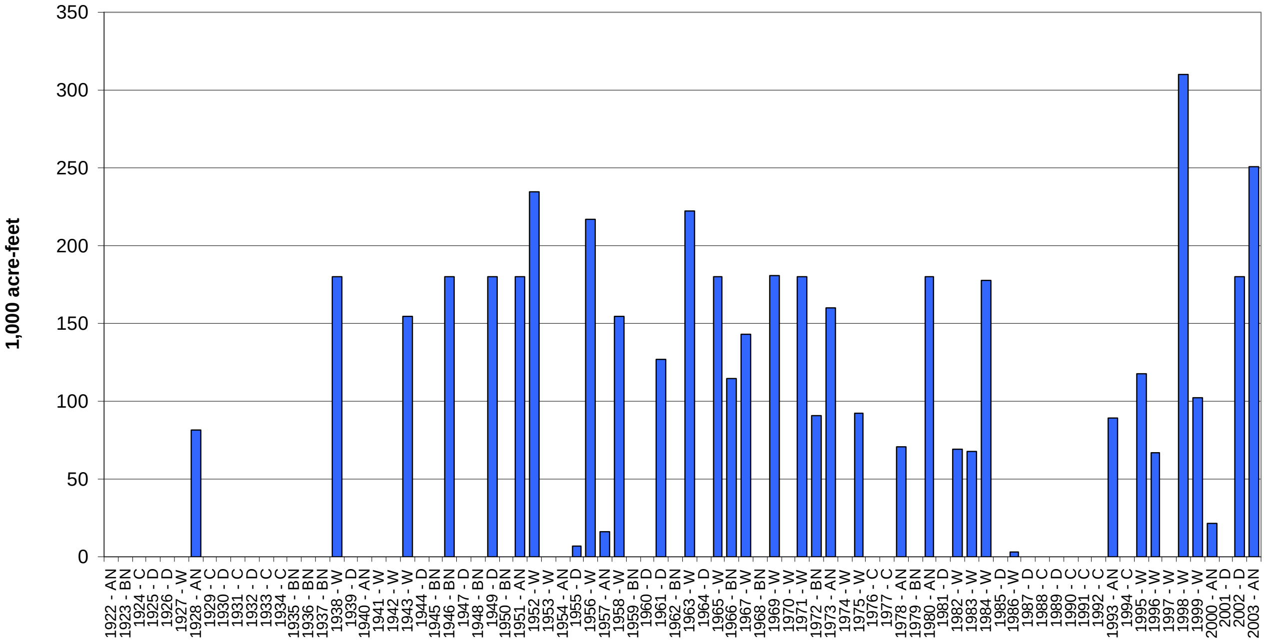

FIGURE 11-28
REFILL OF SHASTA RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 11-29 illustrates annual conjunctive management groundwater pumping for Scenario 2. Conjunctive management pumping occurs in 6 of the 82 years simulated, or 7 percent of years. The average annual pumping in those years is 123 TAF. The average annual pumping for the entire 82-year simulation is approximately 9 TAF with a maximum annual pumping of nearly the full 200 TAF of capacity. Pumping typically occurs in drier year types when reservoirs do not refill with surplus surface water.

Over the 82-year simulation period, additional reservoir releases are made in 48 years, or 59 percent of the years. Reservoir refill is accomplished with surplus surface flows in 35 years and with project pumping in 6 years. The number of years with releases exceeds the number of years with refill because reservoir storage deficits do not have to be completely refilled before making additional releases, as long as the total reservoir storage deficit does not exceed the capacity of the project to refill the reservoir in a single year. In summary, of total average annual additional releases of 67 TAF (22 TAF for agriculture and 45 TAF for environmental objectives), 58 TAF is refilled from surplus surface water and 9 TAF from conjunctive management pumping.

11.2.2 Oroville Reservoir and Feather River

Figure 11-30 illustrates annual volumes of water released to meet environmental objectives on the Feather River. Similar to the Sacramento River operations, the geomorphic objective is satisfied most frequently, but increased groundwater pumping capacity allows for more aggressive reservoir operations allowing other objectives to also be satisfied. Average annual release for environmental objectives on the Feather River is 23 TAF.

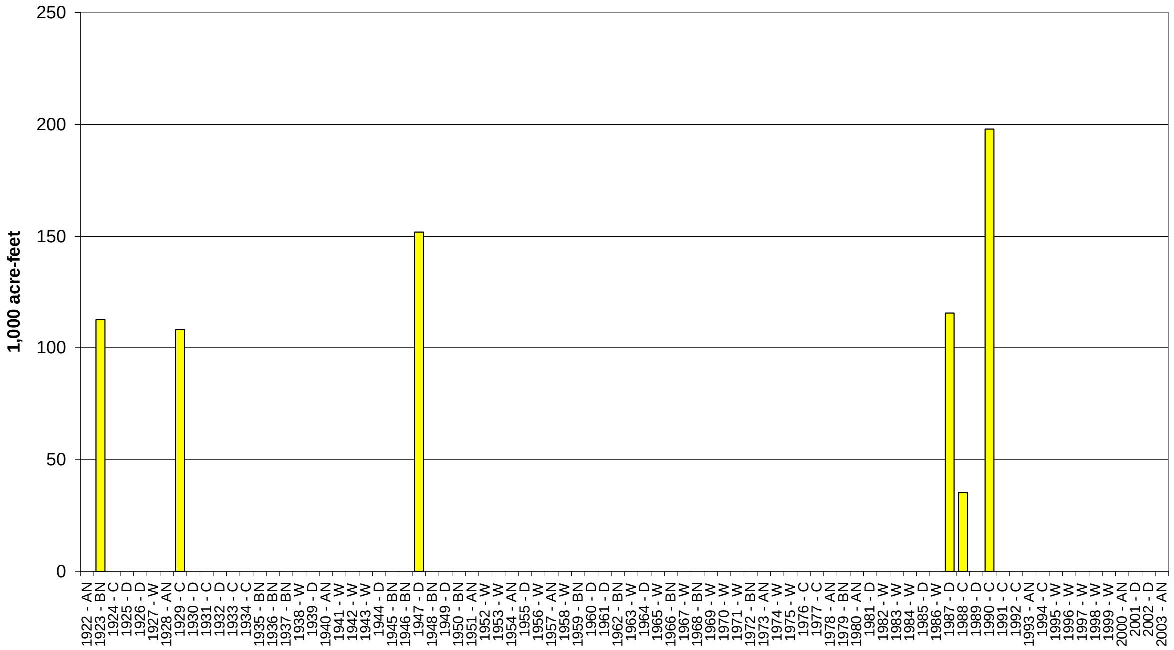

FIGURE 11-29
REFILL OF SHASTA RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

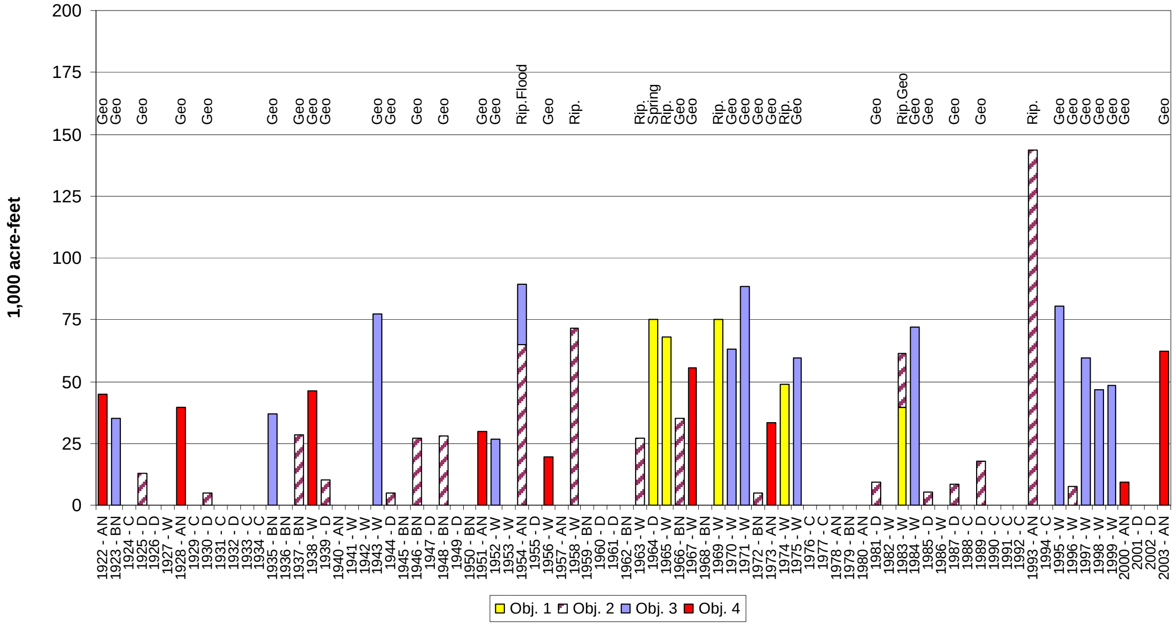

FIGURE 11-30
FEATHER RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Table 11-4 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include those years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 11-30. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

TABLE 11-4
Number of Years Feather River Environmental Objectives are Met, Scenario 2
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Objective	Met in Base	Met with Project	Total
Spring Pulse	3	1	4
Riparian Recruitment	1	8	9
Geomorphic	31	25	56
Flood Plain Inundation	21	20	41

Figure 11-31 illustrates additional agricultural deliveries under Scenario 2. Additional agricultural releases are made in 30 of the 82 years simulated, or approximately 37 percent of the years. The average annual release in those years is 52 TAF, while the average annual agricultural delivery over the 82-year simulation period is 20 TAF.

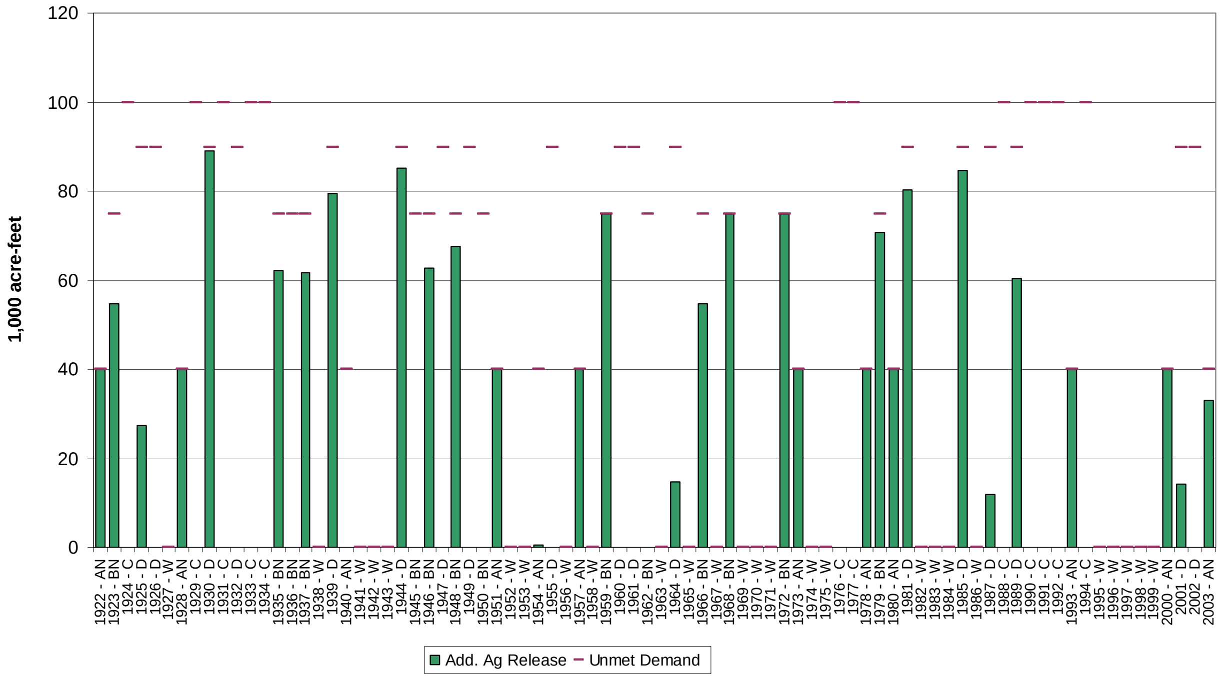

FIGURE 11-31
FEATHER RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-32 illustrates how conjunctive management operations result in lower Oroville fall storage conditions in approximately 60 percent of the years. Fall storage may be increased in a few years when it is below the minimum target level of 1,200 TAF.

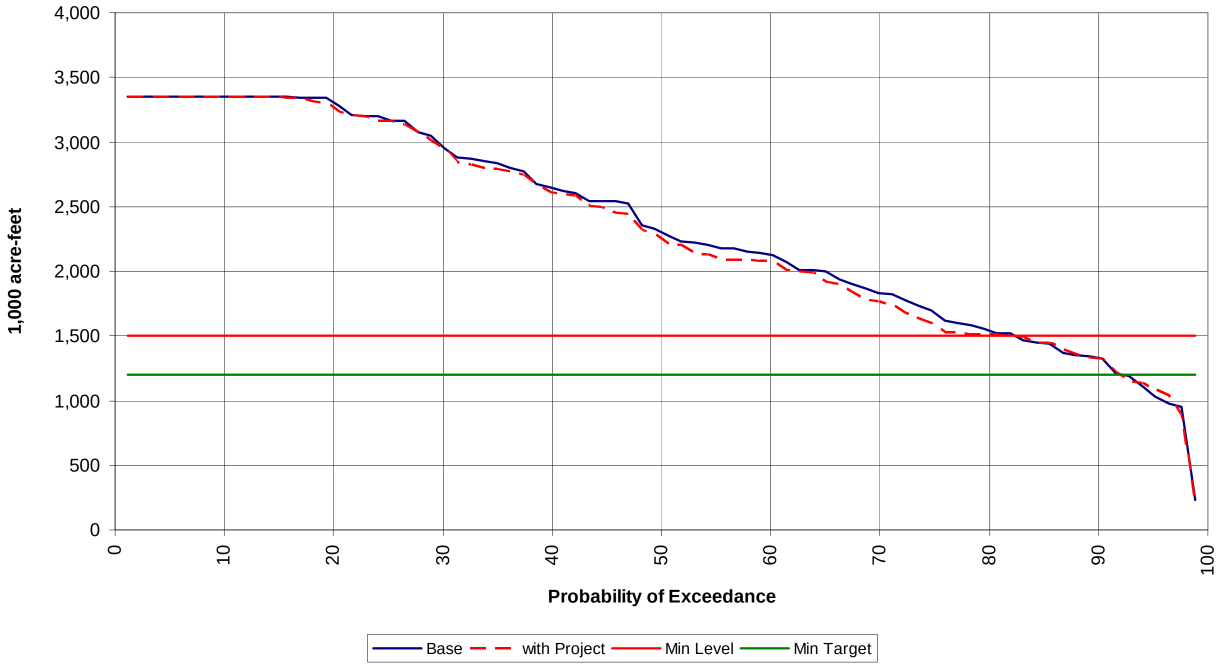

FIGURE 11-32
OROVILLE RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Figure 11-33 shows how storage space created in Oroville Reservoir through additional releases for agricultural and environmental objectives is frequently refilled with surplus surface water. This occurs in 43 years with an average annual refill of 72 TAF in those years. Average annual refill with surplus for the 82-year simulation period is approximately 36 TAF.

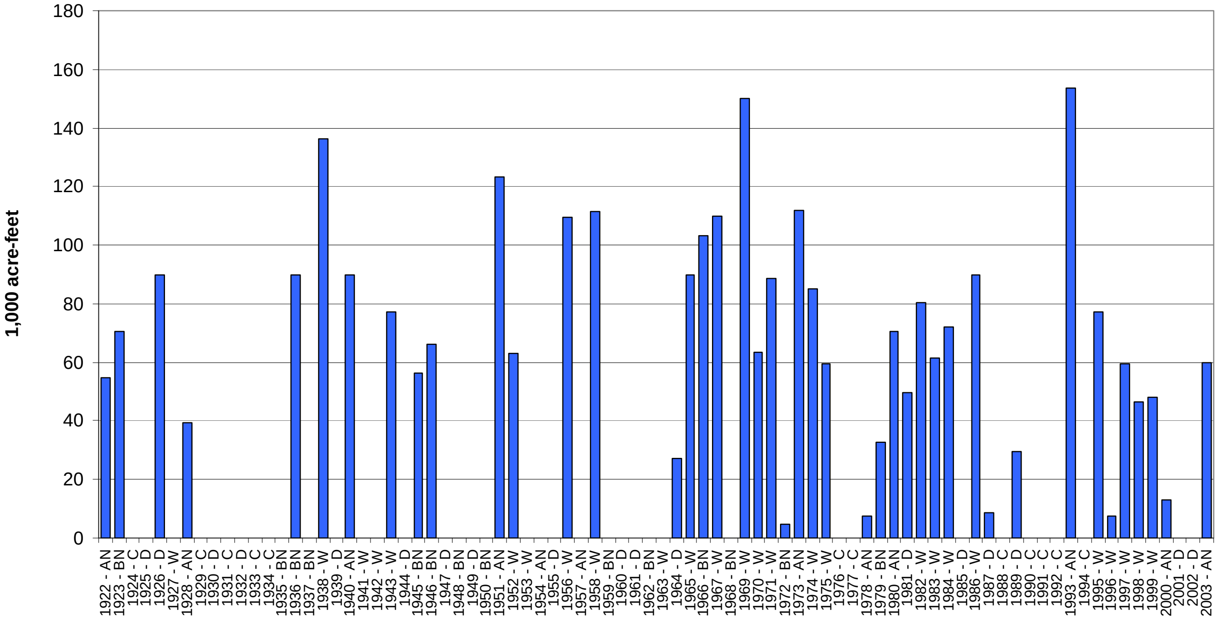

FIGURE 11-33
REFILL OF OROVILLE RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 11-34 presents the annual conjunctive management pumping in the Butte Basin project for Scenario 2. Conjunctive management pumping occurs in 8 of the 82 years simulated or 10 percent of the years. The average annual pumping in those years is 75 TAF. The average annual pumping for the entire 82-year simulation is approximately 7 TAF with a maximum annual pumping of the full 100 TAF of pumping capacity.

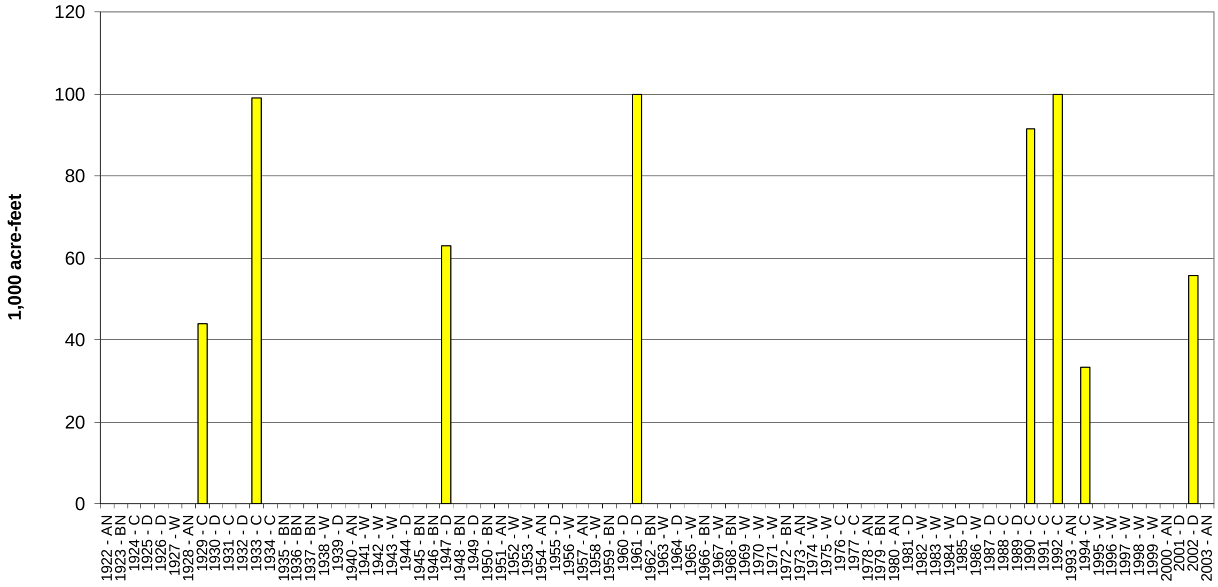

FIGURE 11-34
REFILL OF OROVILLE RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Over the 82-year simulation period, additional reservoir releases are made in 51 years, or 62 percent of the years. Reservoir refill is accomplished with surplus surface flows in 43 years and with project pumping in 8 years. For Scenario 2 on the Feather River system, out of total additional releases of 43 TAF (23 TAF for agriculture and 20 TAF for environmental objectives), 36 TAF is refilled from surplus surface water and 7 TAF from conjunctive management pumping.

11.2.3 Groundwater Results

Existing Well Field

Results of pumping for Scenario 2 using the existing well field shown on Figure 11-3 are summarized on Figures 11-35 through 11-37. Peak drawdown in groundwater levels associated with implementation of this scenario is presented on Figure 11-35. This figure depicts simulated drawdown in the pumped aquifer, during August 1990. Maximum pumping rates under this alternative occur during 1990. Figure 11-35 shows that the area of greatest drawdown occurs in the northern GCID area at a magnitude of up to 100 feet.

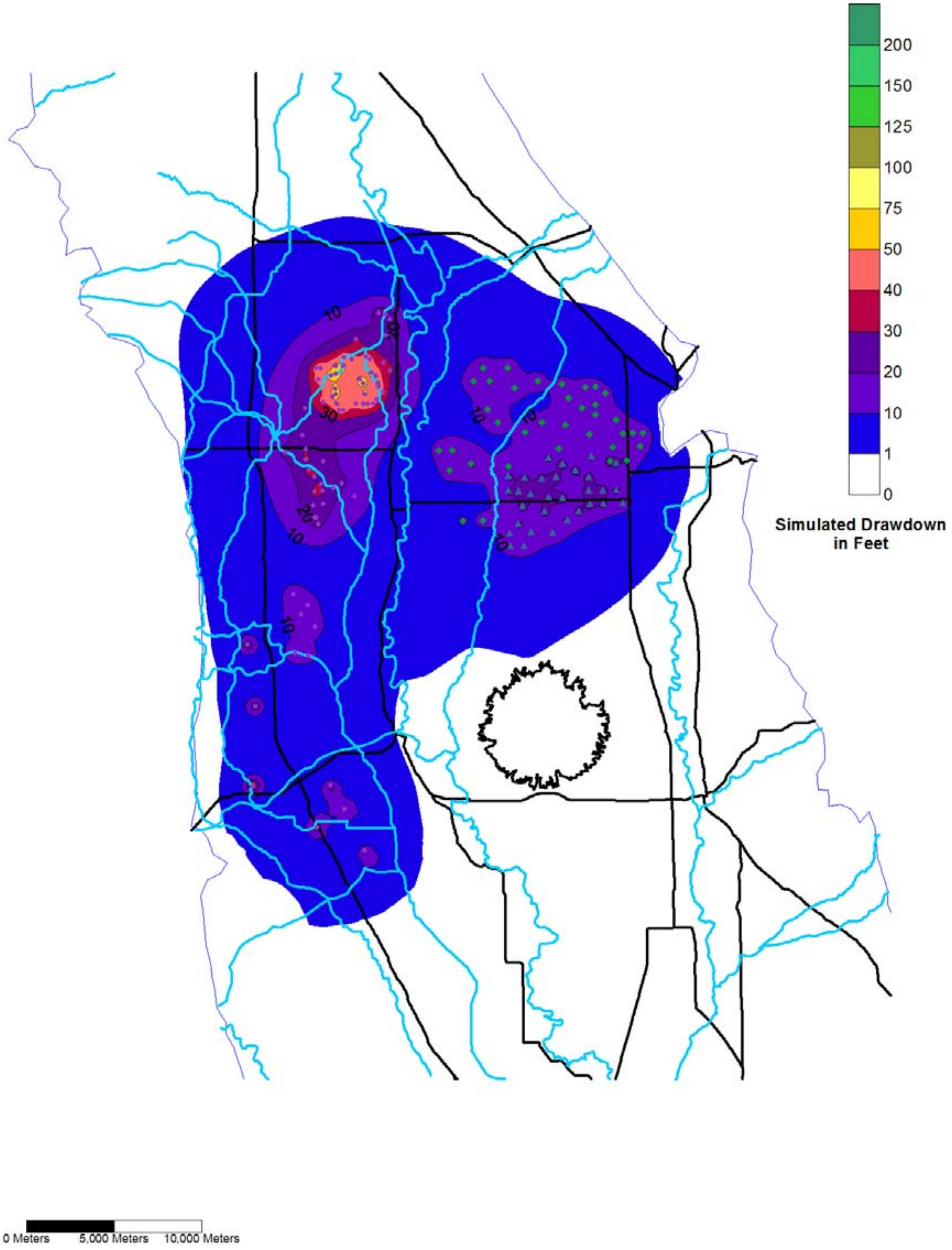

FIGURE 11-35
SIMULATED DRAWDOWN IN THE REGIONAL AQUIFER IN AUG 1990, SCENARIO 2 -EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 2 using an existing well field are summarized on Figures 11-36 and 11-37. These figures show that the greatest impact to surface streams will occur to the Sacramento River between GCID and Wilkins Slough and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-36 suggests that the peak cumulative impact to all surface water flows will be about 110 cfs in summer of 1990, while a peak impact of just over 70 cfs is predicted to occur on the Sacramento River and a peak impact of about 32 cfs is estimated to occur on Butte Creek. Peak impact to the Sacramento River will occur in late summer of 1990 while peak impact on Butte Creek is forecast to occur in early 1993. Peak impacts to stream flows on smaller tributary streams peak at less than about 11 cfs as shown on Figure 11-37.

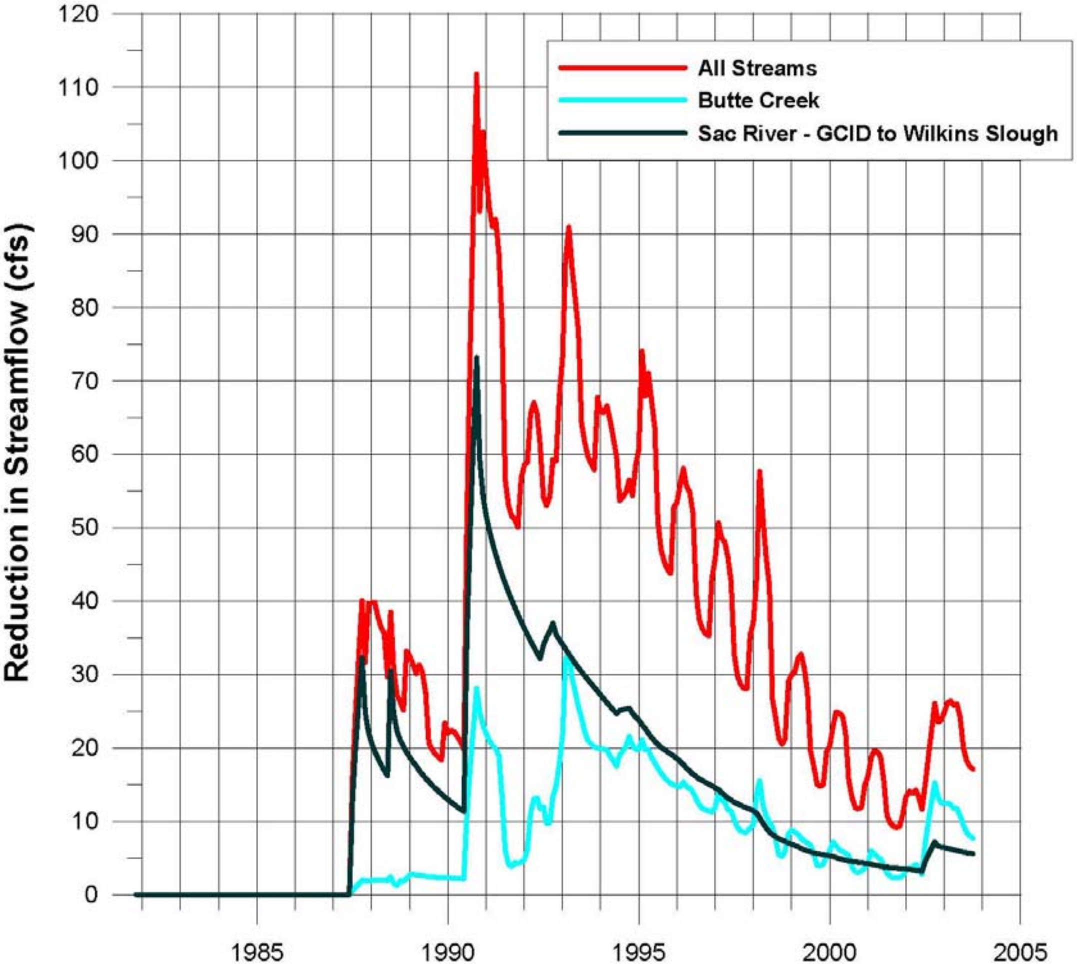

FIGURE 11-36
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 2 -EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

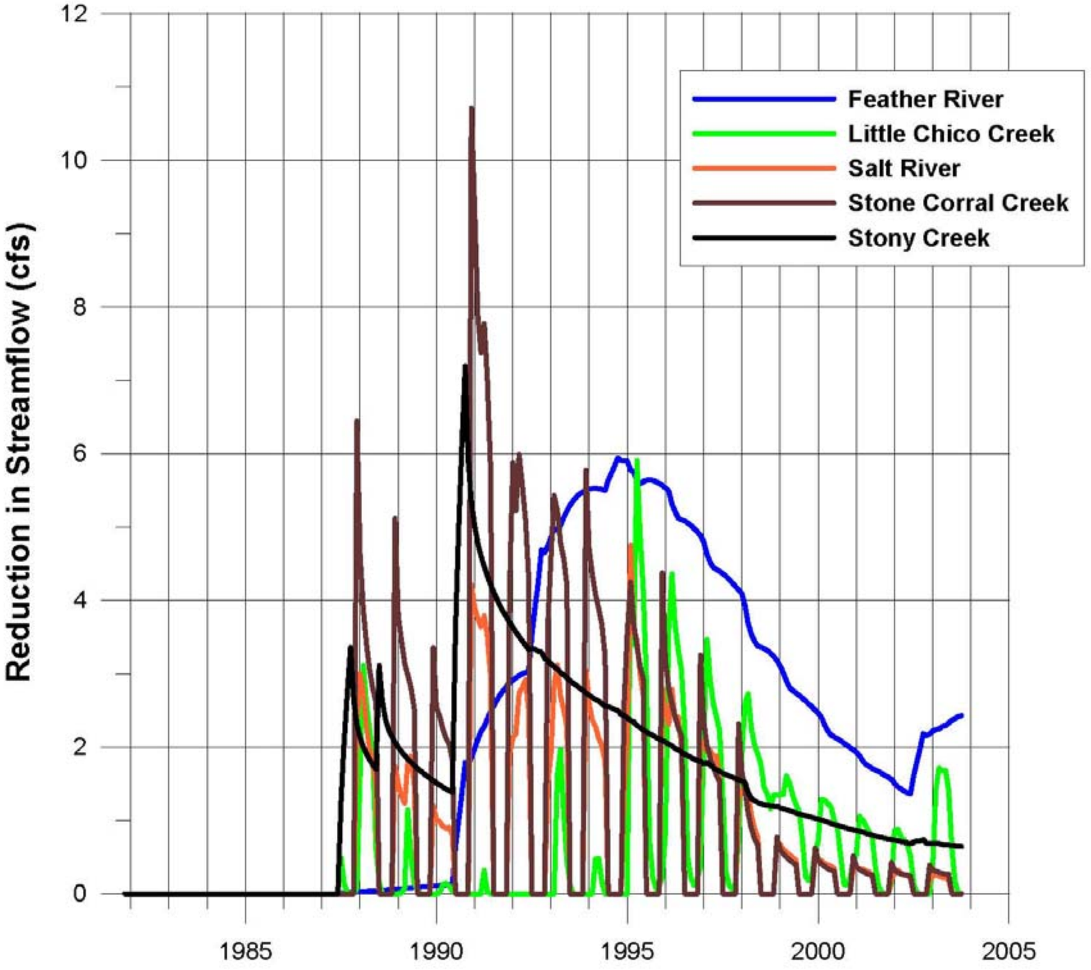

FIGURE 11-37
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 2 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.2.4 Reservoir Release for Recharge

Streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-38 and 11-39 present annual additional releases from Shasta and Oroville, respectively, for Scenario 2 pumping from an existing well field.

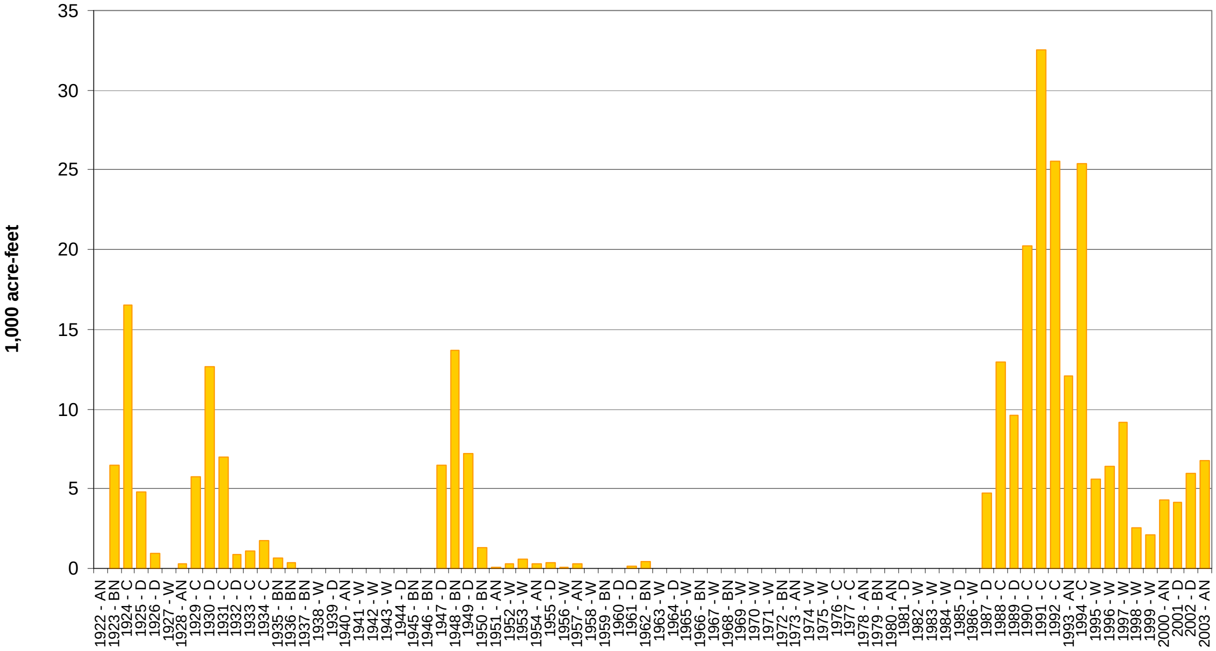

FIGURE 11-38
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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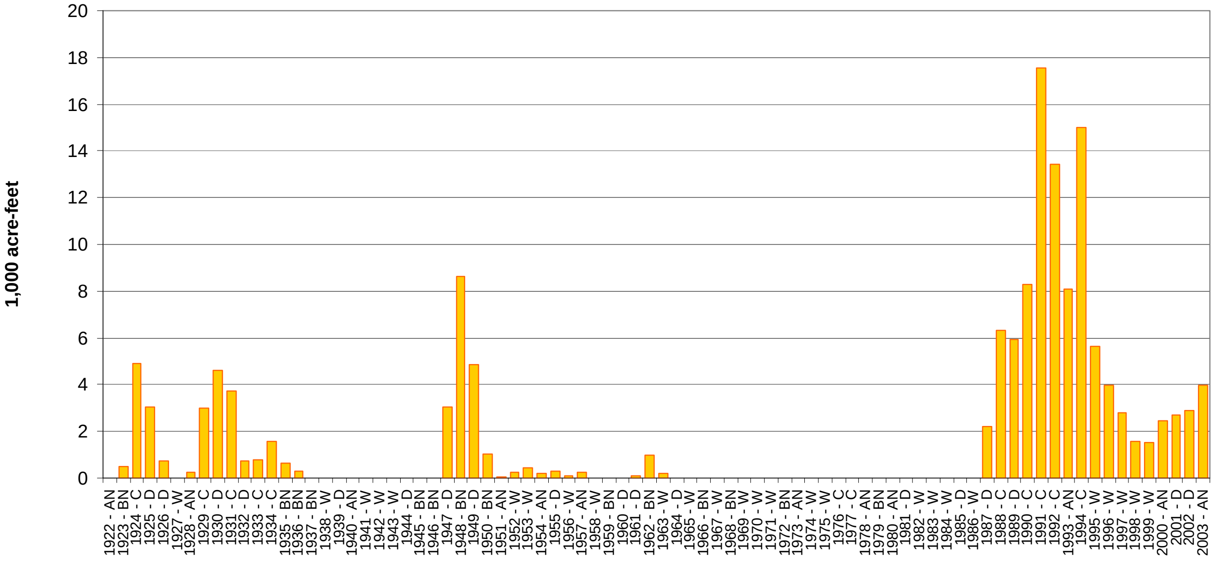

FIGURE 11-39
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Figures 11-38 and 11-39 illustrate that annual release from Shasta and Oroville to compensate for stream losses from conjunctive management pumping increase under Scenario 2 due to increased pumping frequency and quantity and the resulting increase in streamflow reductions.

New Well Field

Groundwater results for Scenario 2 using a new well field pumping from the deep aquifers are summarized on Figures 11-40 through 11-42. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-40. This figure depicts simulated drawdown in the pumped aquifer during August 1990; the area of greatest drawdown occurs in the western GCID area at a magnitude of up to 200 feet.

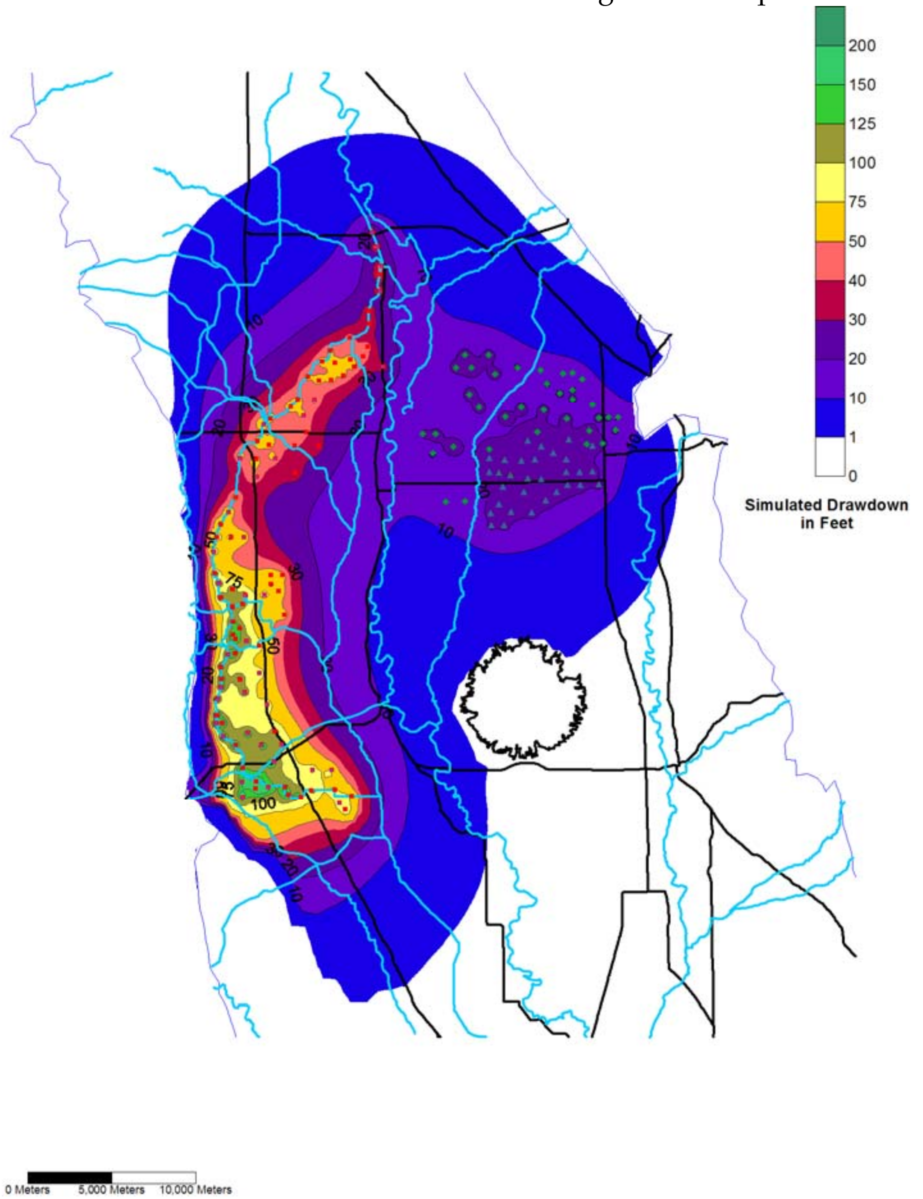

FIGURE 11-40
SIMULATED DRAWDOWN IN THE DEEP AQUIFER IN AUG 1990, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Simulated impacts to surface streams under Scenario 2 with a new well field are summarized on Figures 11-41 and 11-42. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-41 suggests that the peak cumulative impact to all surface water flows will be about 105 cfs in the late fall of 1990, and that a peak flow reduction of just less than 70 cfs will occur on the Sacramento River while a peak flow reduction of about 27 cfs will occur on Butte Creek. Peak impact to the Sacramento River will also occur in late fall of 1990 while two similar peak impacts occur on Butte Creek in early 1993 and the fall of 1994. Impacts to stream flows on smaller tributary streams peak at less than about 15 cfs, as shown on Figure 11-41.

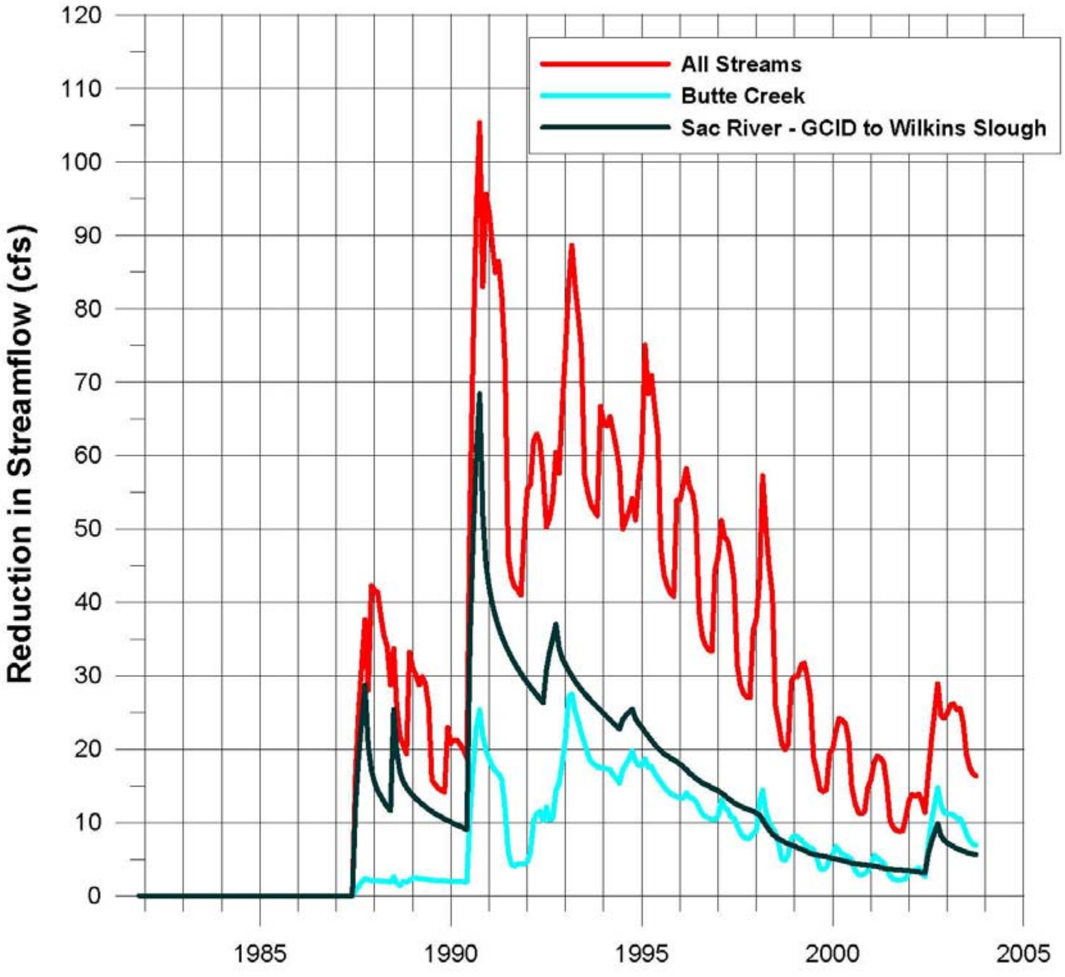

FIGURE 11-41
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 2 -NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

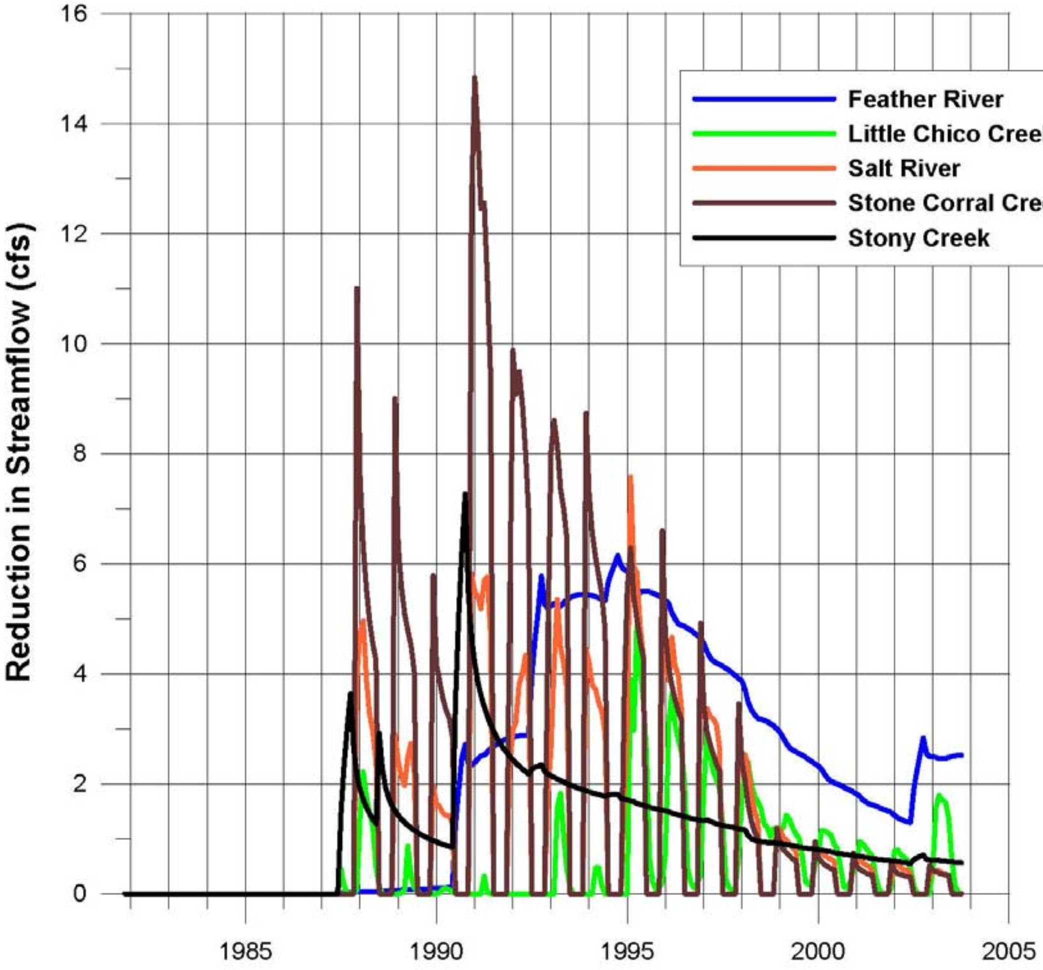

FIGURE11-42
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes to upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions upstream, reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-43 and 11-44 present annual additional releases from Shasta and Oroville, respectively, for Scenario 2 pumping from a new well field.

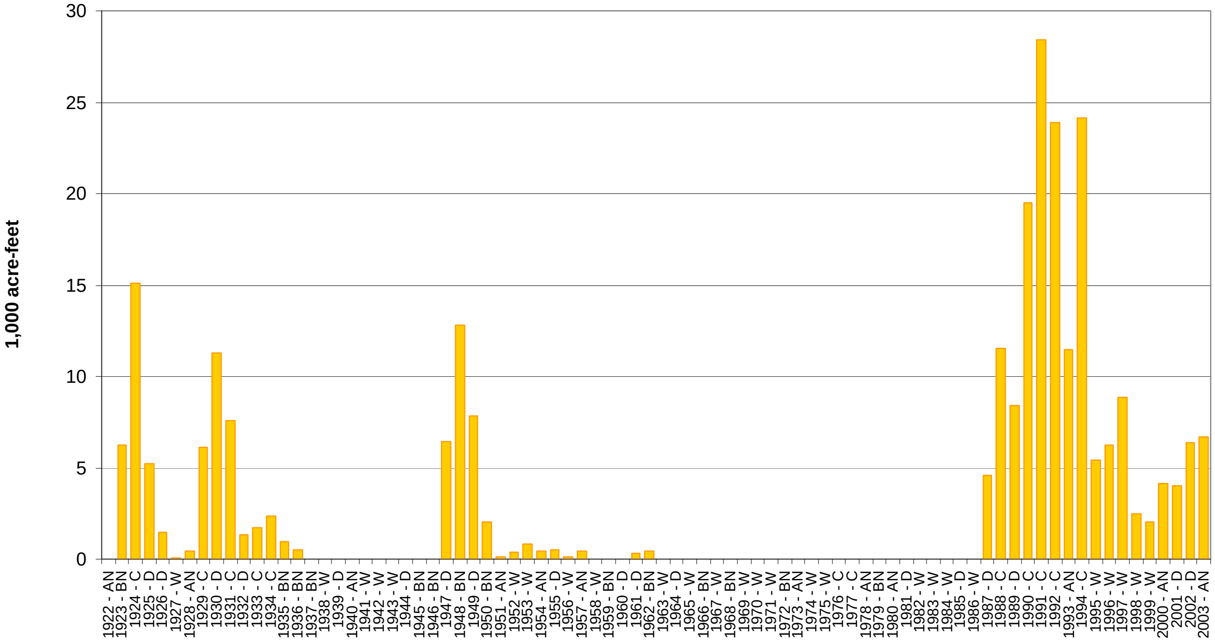

FIGURE 11-43
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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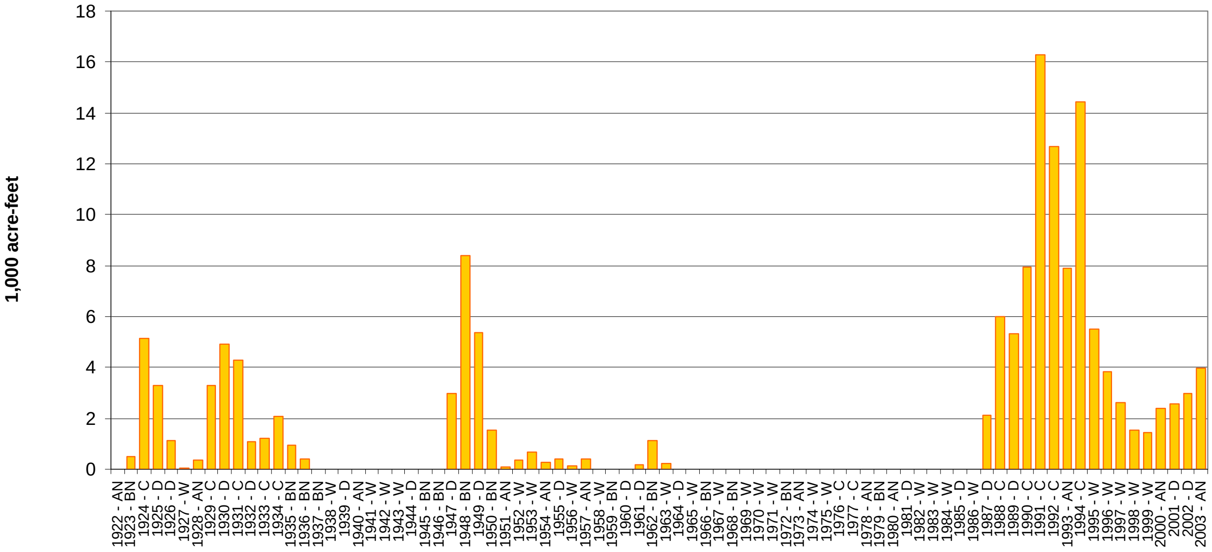

FIGURE 11-44
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Figures 11-43 and 11-44 show smaller peak reservoir releases to compensate for conjunctive management pumping for a new well field screen in the deep aquifer than for pumping existing wells. This reflects smaller streamflow reductions for a new well field at the higher pumping volumes simulated in Scenario 2.

11.3 Scenario 3 – 100 TAF GCID, 50 TAF Butte Basin, Fall Pumping

Scenario 3 has the same general reservoir release strategies and groundwater pumping capacities as Scenario 1. The difference is the season for conjunctive management pumping. Under Scenario 3 conjunctive management pumping for the purpose of recovering reservoir storage levels is conducted from September through November. Instead of offsetting irrigation season demands, this pumping is assumed to offset demands for rice straw decomposition and waterfowl habitat.

Shifting the conjunctive management pumping season may have several benefits. First, peak drawdown in the aquifers and resulting effects on nearby wells would occur outside of the primary pumping season for most existing wells. Second, a greater portion of aquifer recharge may occur during the winter rainy season when the surface water system is more likely to be in a surplus condition. Third, it may be easier to reduce fall reservoir releases to recover reservoir levels in the fall of dry years and still meet existing temperature control criteria on the Sacramento River.

A majority of results for Scenario 3 are the same as for Scenario 1 because spring and summer surface water operations do not change. The same environmental objectives are met, and the average annual releases for both environmental and agricultural objectives are the same. Reservoir refill for both Shasta and Oroville occurs with the same mix and timing of surplus surface water and groundwater pumping. There are minor differences in end of September storage in each reservoir under Scenario 3. These differences are in years when conjunctive management pumping occurs, but is not yet complete, by the end-of-September. Figures 11-45 and 11-46 illustrate this effect for both Shasta and Oroville.

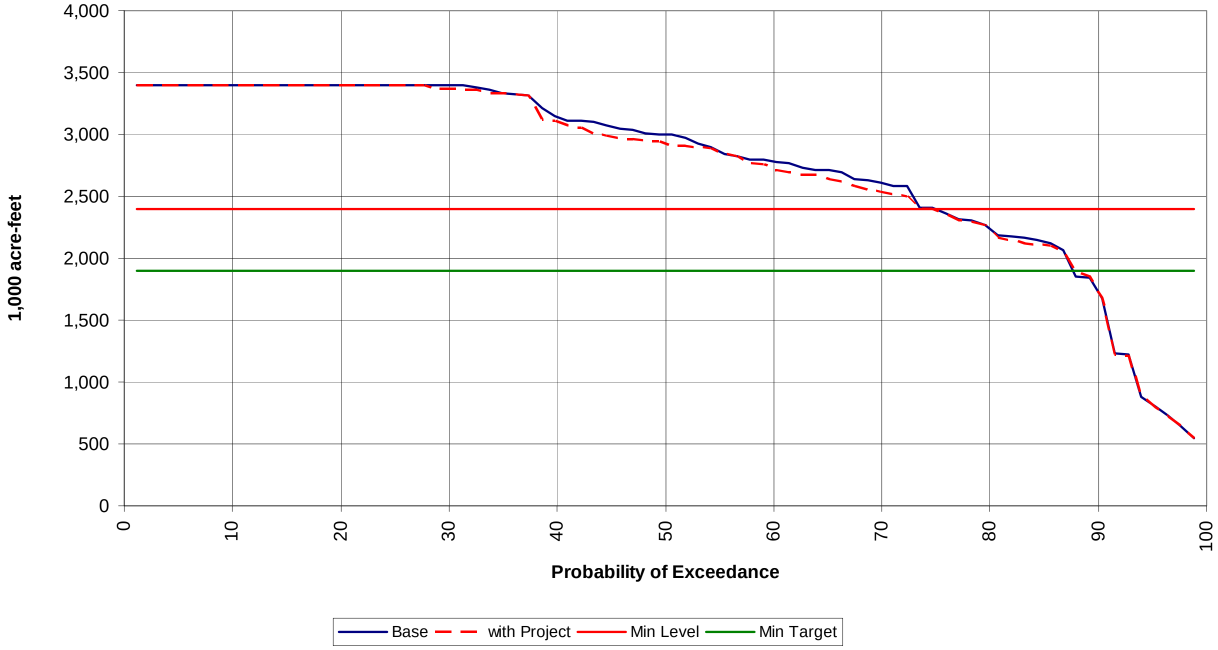

FIGURE 11-45
SHASTA RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 3
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-45 shows some minor differences between base conditions and Scenario 3 when end-of-September Shasta storage levels are below 2,400 TAF. In these years, conjunctive management pumping is occurring September through November so that the reservoir is recovered by the end of November and there is no risk to future water supplies or cold water pool.

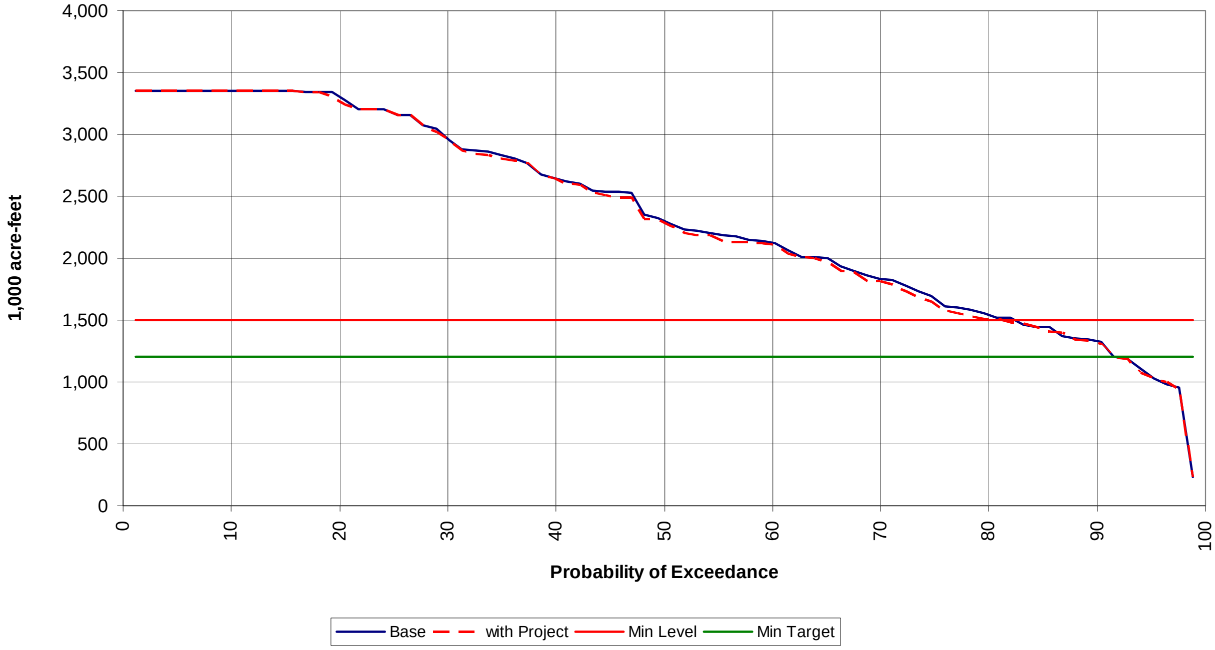

FIGURE 11-46
OROVILLE RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 3
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 11-46 illustrates a similar effect on Oroville Reservoir, but it is less clear due to the smaller difference between base and with project storages.

11.3.1 Groundwater Results

Existing Well Field

Results of pumping for Scenario 3 with an existing well field are summarized on Figures 11-47 through 11-49. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-47. This figure depicts simulated drawdown in the pumped aquifer during November 1990. Maximum pumping rates under this alternative occur during 1990. Figure 11-47 shows that the area of greatest drawdown occurs in the northern GCID area at a magnitude of up to 50 feet.

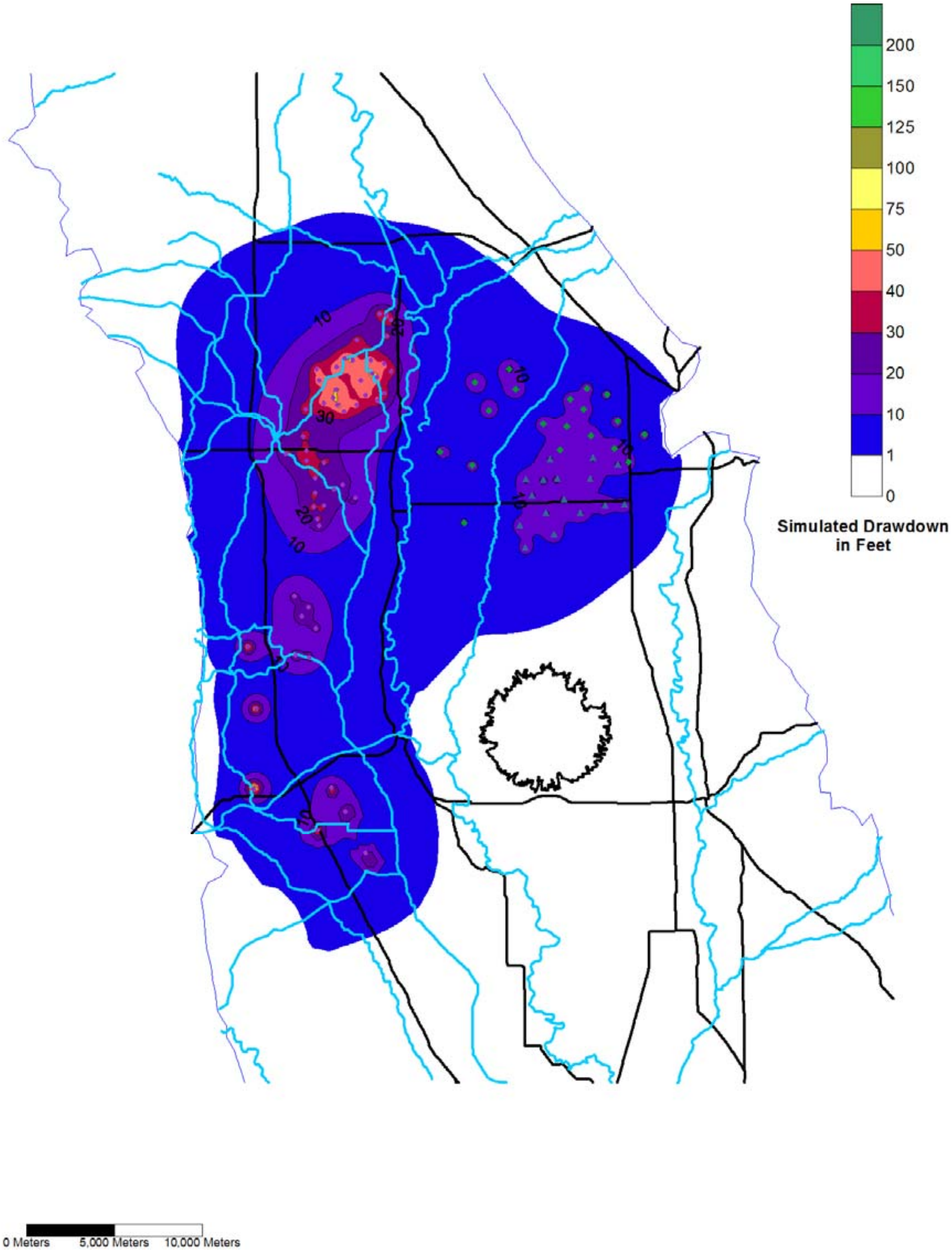

FIGURE 11-47
SIMULATED DRAWDOWN IN THE REGIONAL AQUIFER IN NOV 1990, SCENARIO 3 -EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Simulated impacts to surface streams under Scenario 3 with an existing well field are summarized on Figures 11-48 and 11-49. These figures show that the greatest impact to surface streams will occur to the Sacramento River (between GCID and Wilkins Slough) and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-48 suggests that peak cumulative impact to all surface water flows will be approximately 80 cfs in the summer of 1990, with a flow reduction of approximately 50 cfs forecast to occur on the Sacramento River and a flow reduction of approximately 18 cfs on Butte Creek. Peak impact to the Sacramento River will also occur in late summer of 1990 while peak impact on Butte Creek is forecasted to occur in late 1994. Peak impacts to stream flows on smaller tributary streams peak at less than approximately 7 cfs, as shown on Figure 11-48.

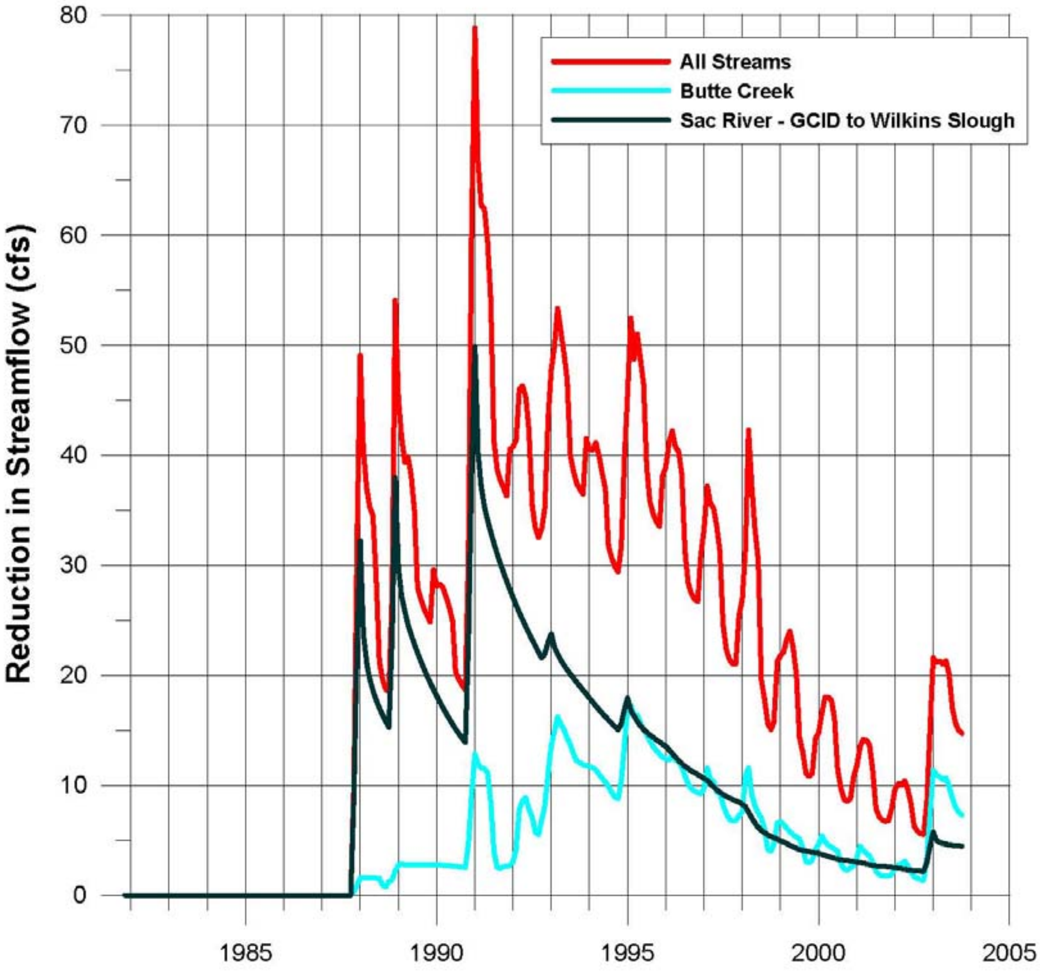

FIGURE 11-48
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

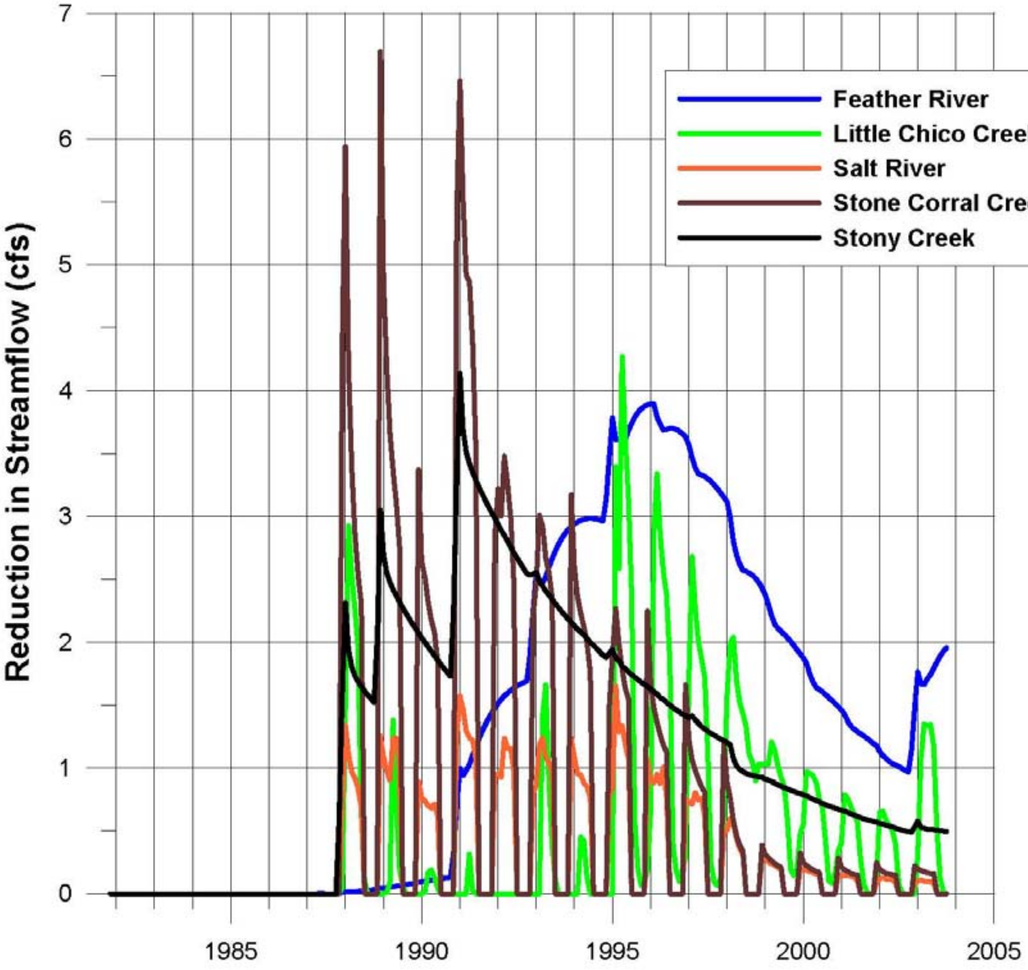

FIGURE 11-49
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes to upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-50 and 11-51 present annual additional releases from Shasta and Oroville, respectively, for Scenario 3 pumping from an existing well field.

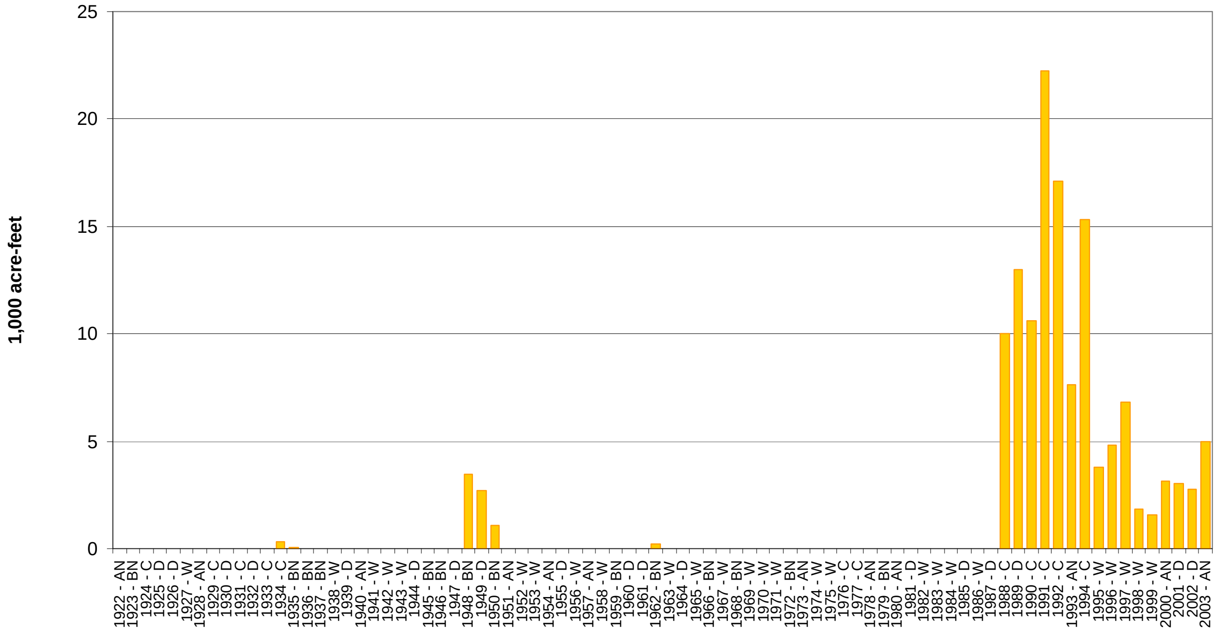

FIGURE 11-50

ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - EXISTING WELL FIELD

SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

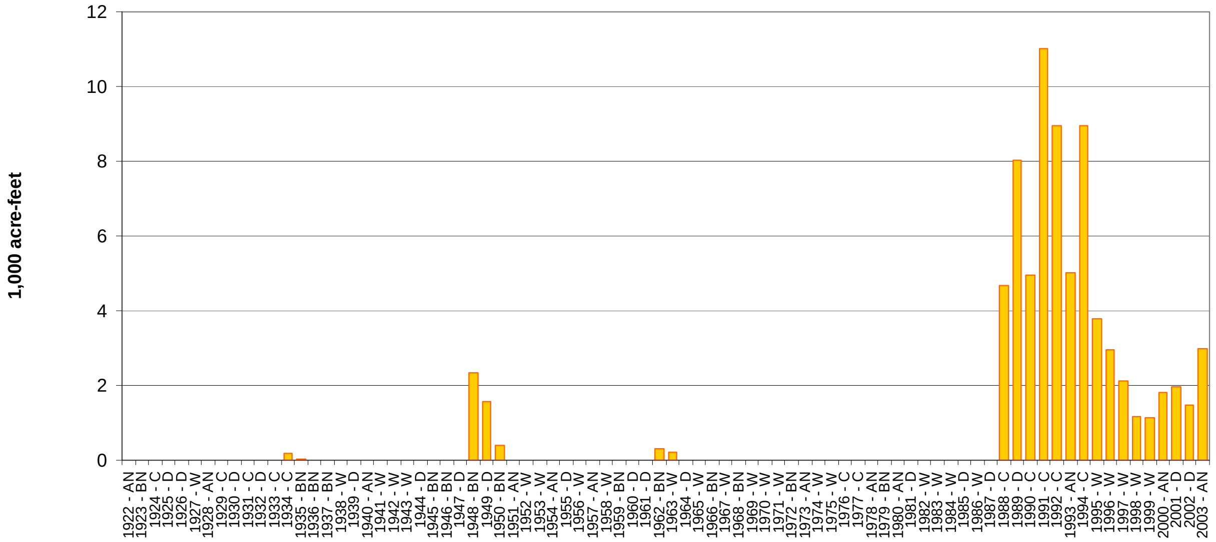

FIGURE 11-51

ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - EXISTING WELL FIELD

SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-50 and 11-51 show that peak annual releases are larger under Scenario 3 for the more condensed fall pumping season than under Scenario 1. General timing and volumes are similar between the two scenarios.

New Well Field

Results of Scenario 3 with a new well field are summarized on Figures 11-52 through 11-54. The peak drawdown in groundwater levels associated with the implementation of this alternative is presented on Figure 11-52. This figure depicts the simulated drawdown in the pumped aquifer, during November 1990. The maximum pumping rates under this alternative occur during 1990. It can be seen from the figure that the area of greatest drawdown occurs in the western GCID area at a magnitude of up to 125 feet.

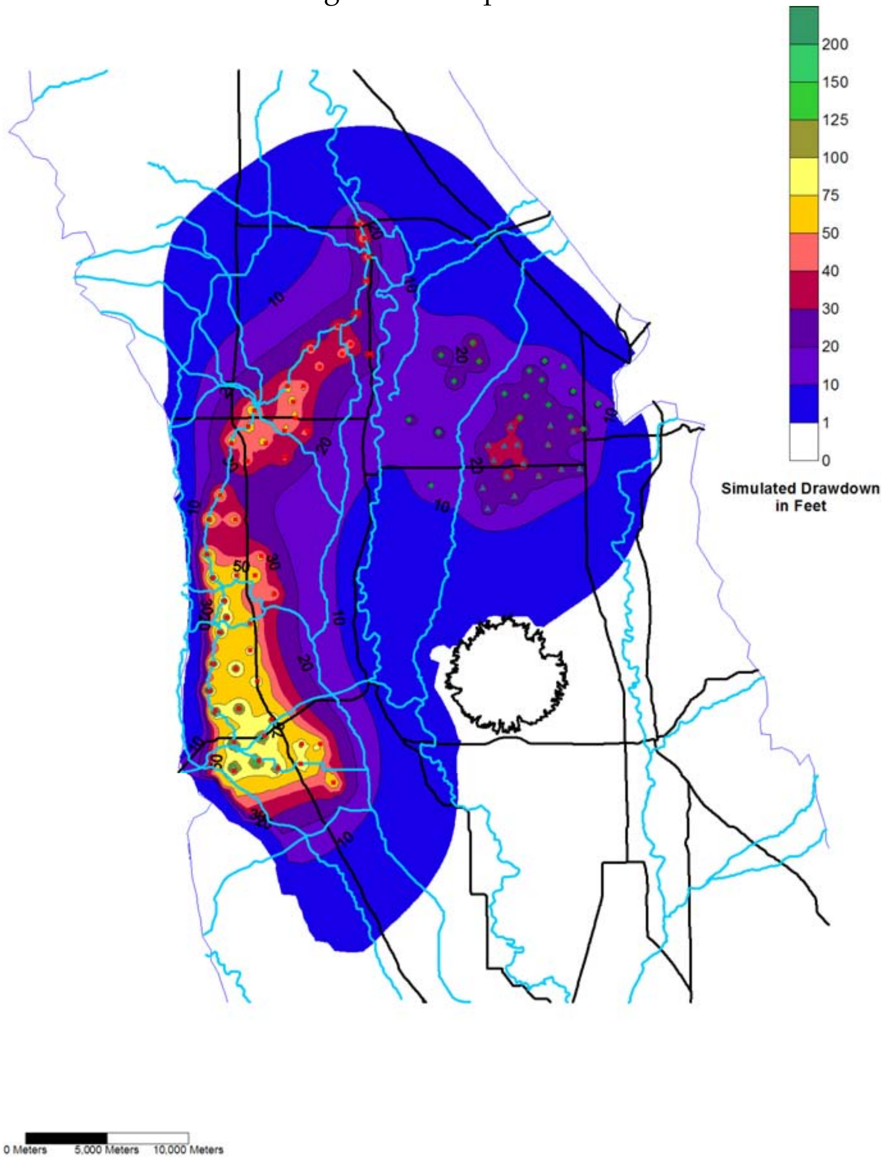

FIGURE 11-52
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 3 with a new well field are summarized on Figures 11-53 and 11-54. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-44 suggests that the peak cumulative impact to all surface water flows will be a reduction of about 90 cfs in December 1990, while a flow reductions of just more than 48 and 18 cfs is forecasted to occur on the Sacramento River and Butte Creek, respectively. Peak impact to the Sacramento River will also occur in December 1990 while peak impact predicted on Butte Creek will occur in December 1994. Peak impacts to stream flows on smaller tributary streams peak at less than about 10 cfs as shown on Figure 11-54.

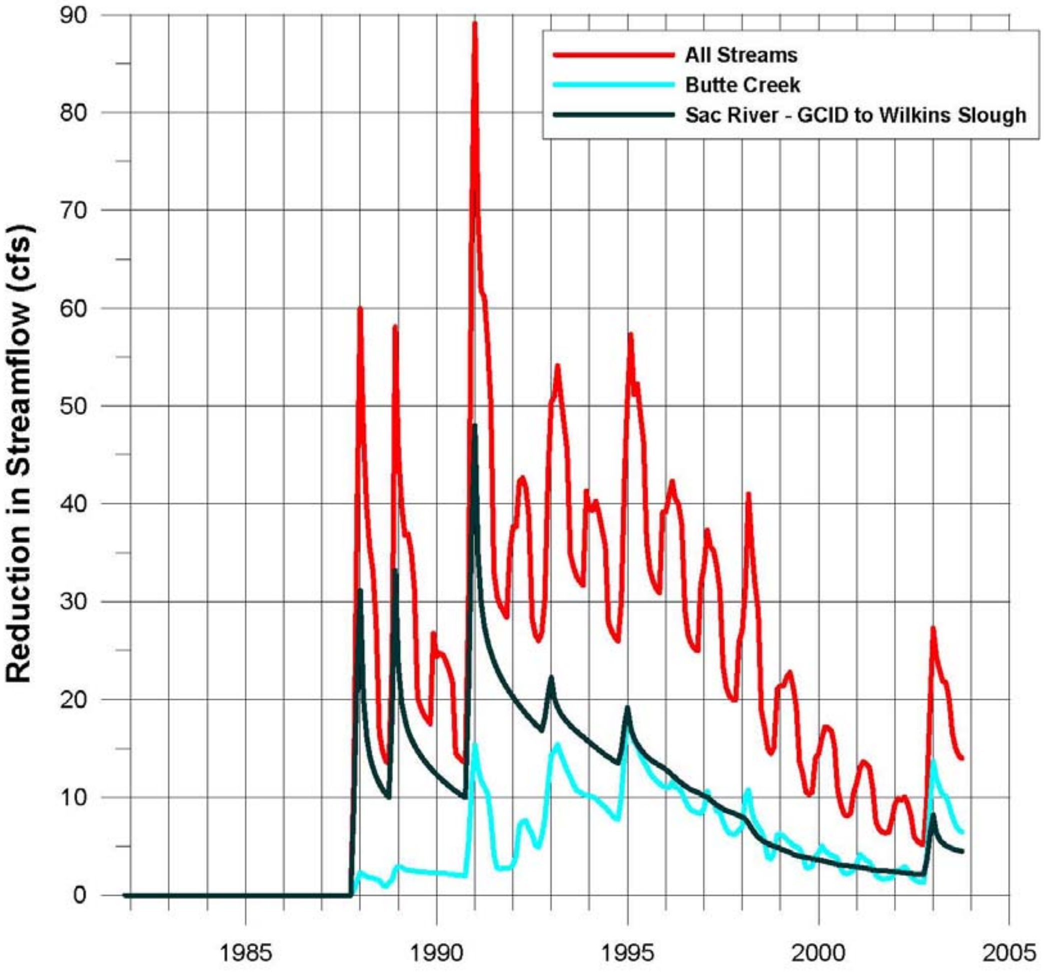

FIGURE 11-53
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 3 -NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

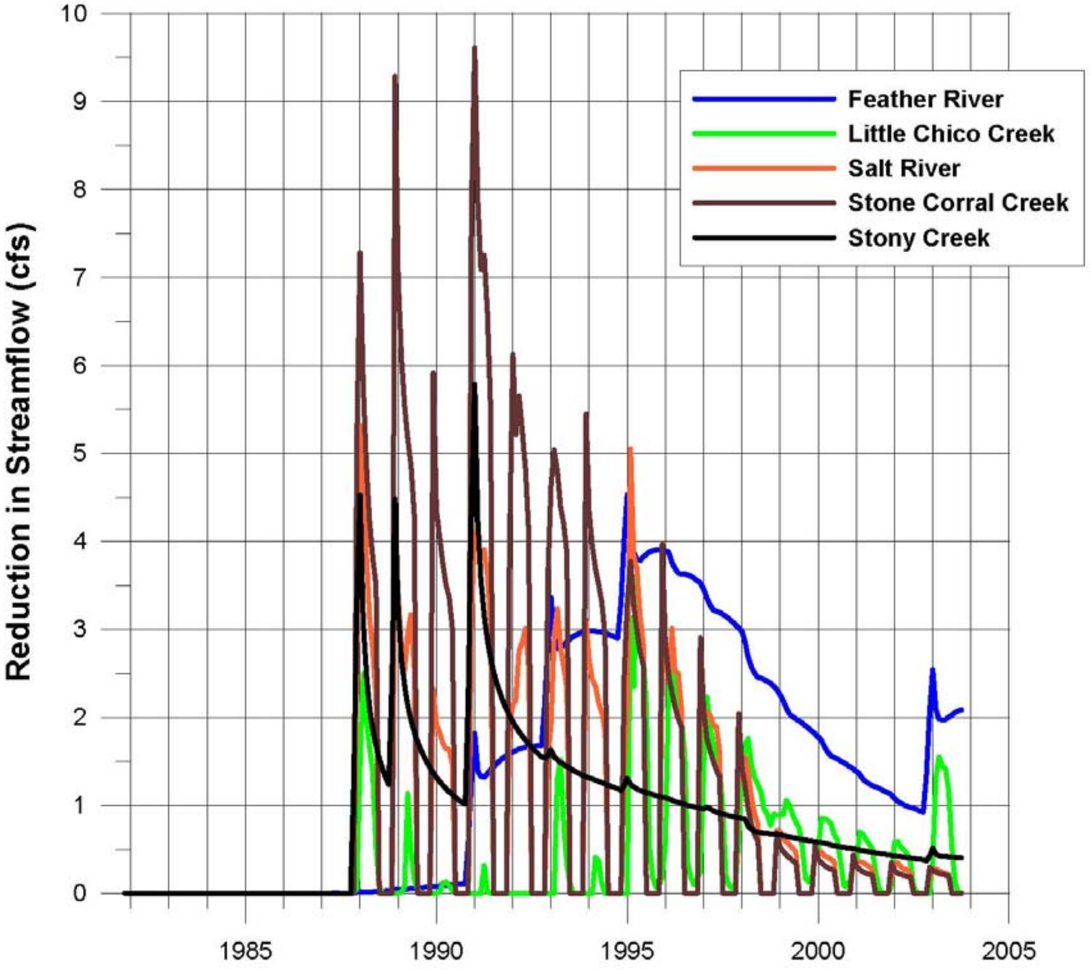

FIGURE 11-54
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 3 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Reservoir Release for Recharge

Streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-55 and 11-56 present annual additional releases from Shasta and Oroville, respectively, for Scenario 3 pumping from a new well field.

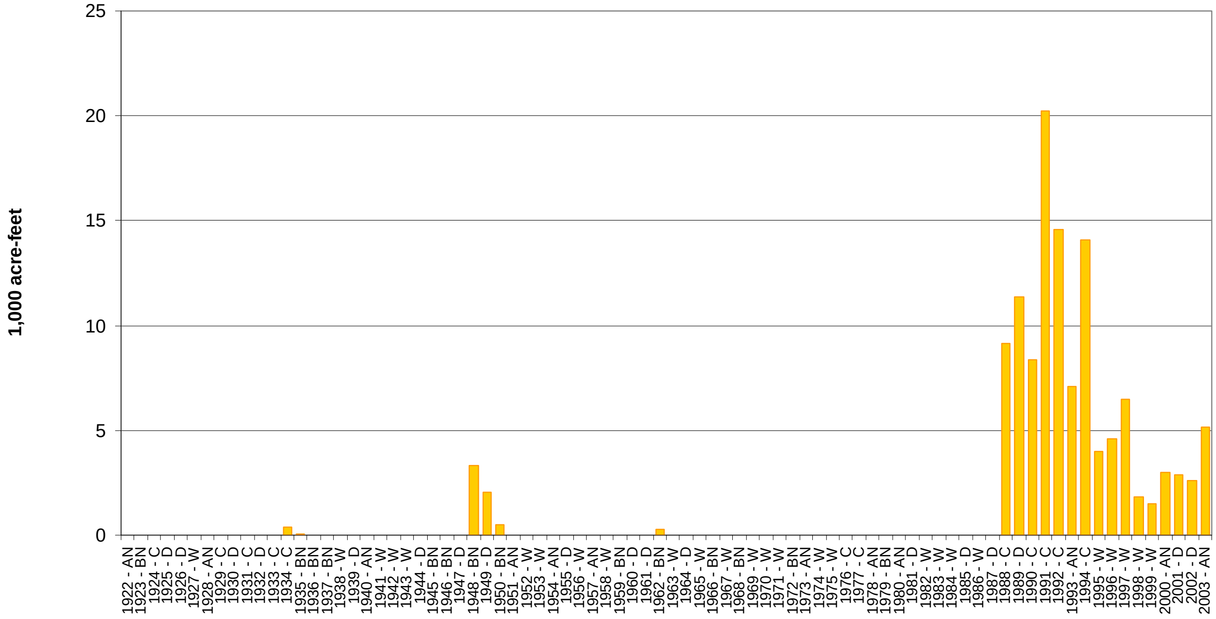

FIGURE 11-55
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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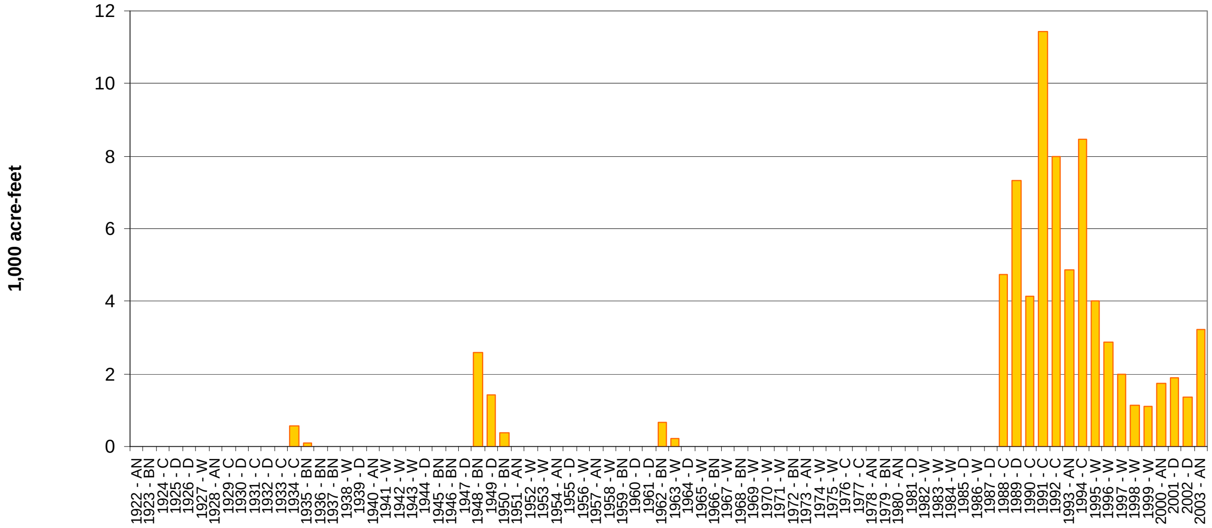

FIGURE 11-56
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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Figures 11-54 and 11-55 illustrate that maximum annual release from Shasta for a new well field is less than for the existing well field, while results are essentially the same on the Feather River.

11.4 Scenario 4 – 100 TAF GCID, 50 TAF Butte Basin, Summer and Fall Pumping

Scenario 4 has the same general reservoir release strategies and groundwater pumping capacities as Scenarios 1 and 3. The difference is again the season for conjunctive management pumping. Under Scenario 4 conjunctive management pumping is conducted in both the summer and fall from May through November. This pumping is used to offset both irrigation season demands and demand for rice straw decomposition water. Pumping over an extended period may provide benefits by reducing the quantity of water that must be pumped in any given month, thereby reducing the size and/or number of wells needed. Additionally, spreading pumping over a longer period may reduce drawdown and stream impacts.

Surface water results for Scenario 4 are similar to those presented for Scenario 1. The same environmental objectives are met, and the average annual releases for both environmental and agricultural objectives are the same. Reservoir refill for both Shasta and Oroville occurs with the same mix and timing of surplus surface water and groundwater pumping. Changes in end-of September storage in the reservoirs presented above for Scenario 3 are smaller in magnitude because under Scenario 4 the majority of conjunctive management pumping has occurred prior to the end of September. The minor differences seen under Scenario 4 are difficult to discern and are therefore not presented.

11.4.1 Existing Well Field

Results for Scenario 4 with an existing well field are summarized on Figures 11-57 through 11-58. Peak drawdown in groundwater levels associated with implementing this alternative is presented on Figure 11-57. This figure depicts simulated drawdown in the pumped aquifer, during November 1990. Maximum pumping rates under this alternative occur during 1990, and the drawdown distribution at the end of November represents approximately the maximum drawdown that will occur under this scenario. Figure 11-57 that the area of greatest drawdown occurs in northern GCID at a magnitude of less than 30 feet.

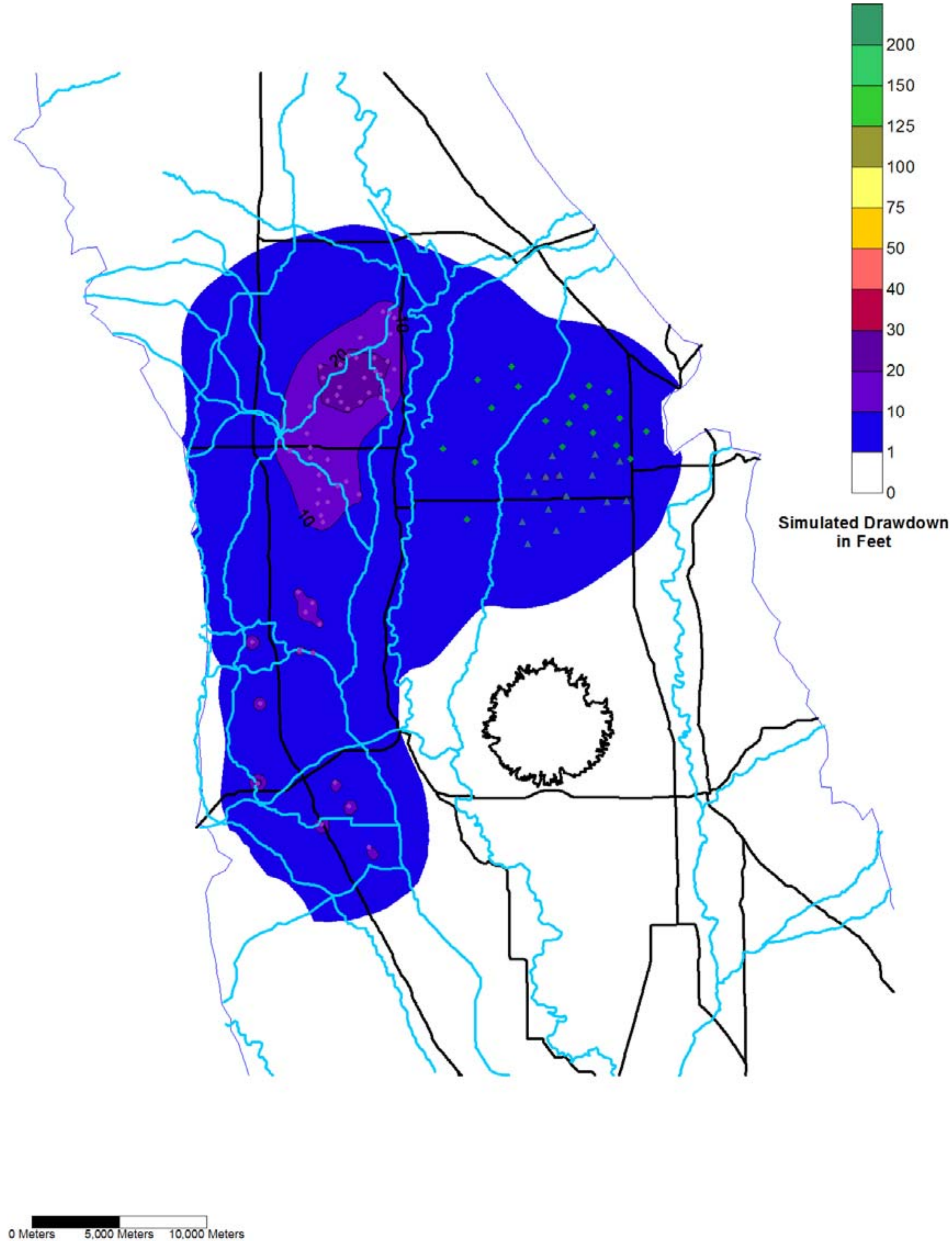


FIGURE 11-57
SIMULATED DRAWDOWN IN THE REGIONAL AQUIFER IN NOV 1990, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 4 with an existing well field are summarized on Figures 11-58 and 11-59. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-58 shows that the peak cumulative impact to all surface water flows will be approximately 64 cfs in December 1990, with a flow reduction of just less than 40 cfs forecasted to occur on the Sacramento River and a flow reduction of about 15 cfs on Butte Creek. Peak impact to the Sacramento River will also occur in December of 1990 while the peak impact on Butte Creek is forecast to occur in late 1995. Peak impacts to stream flows on smaller tributary streams peak at less than approximately 6 cfs, as shown on Figure 11-59.

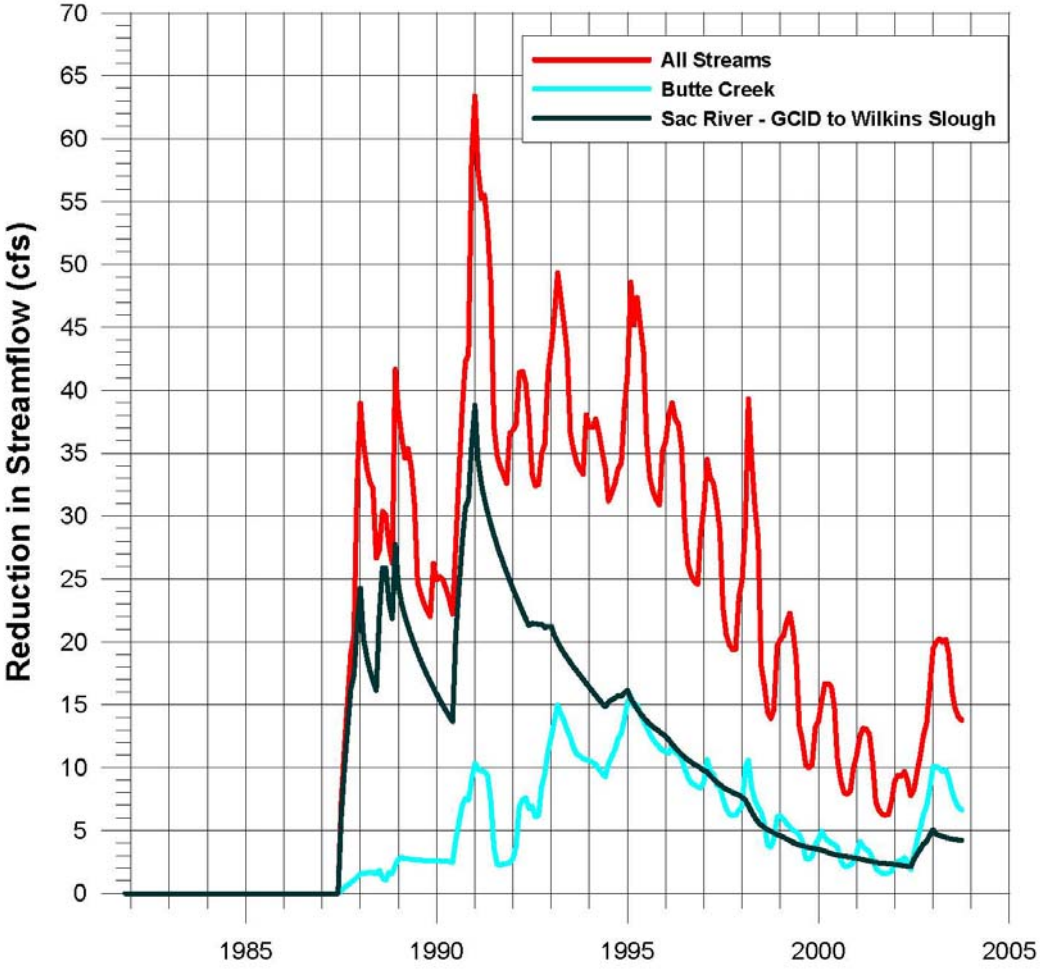


FIGURE 11-58
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

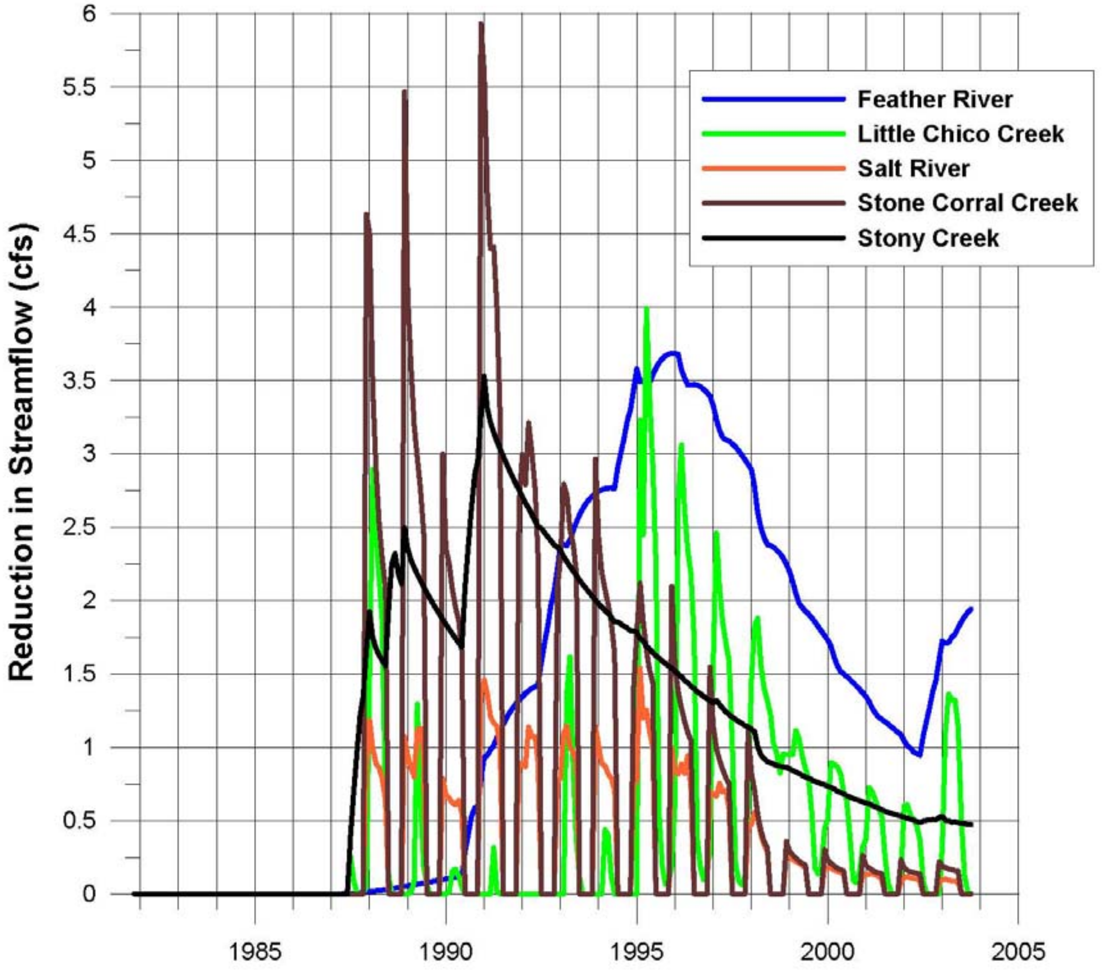


FIGURE 11-59
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.4.2 Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions upstream, reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-60 and 11-61 present annual additional releases from Shasta and Oroville, respectively, for Scenario 4 pumping from an existing well field.

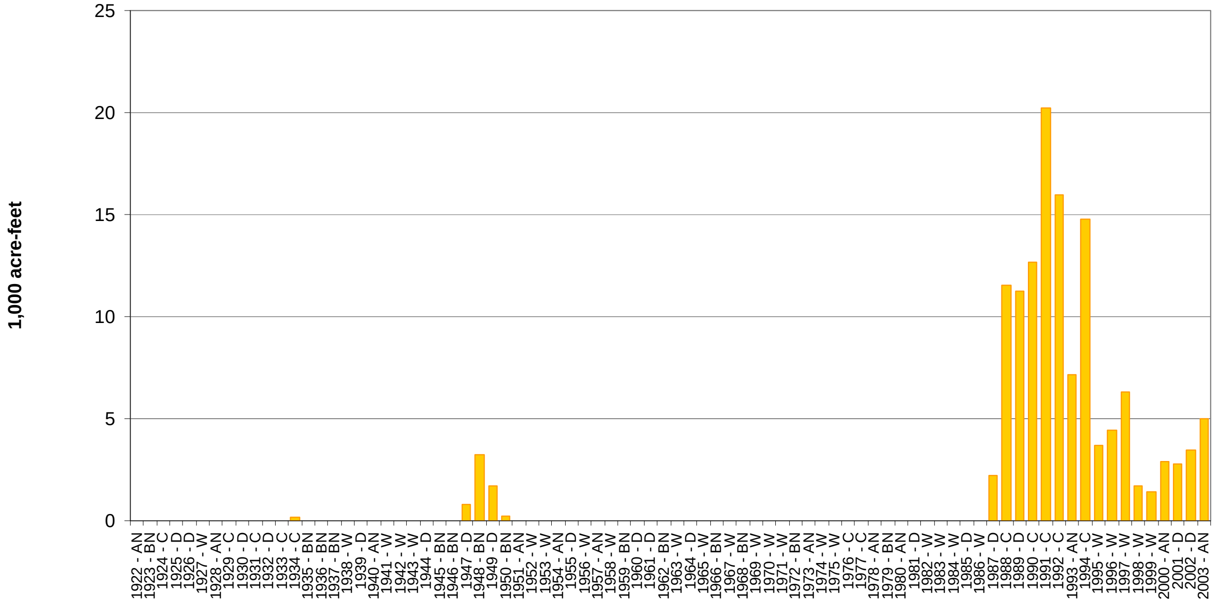


FIGURE 11-60
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

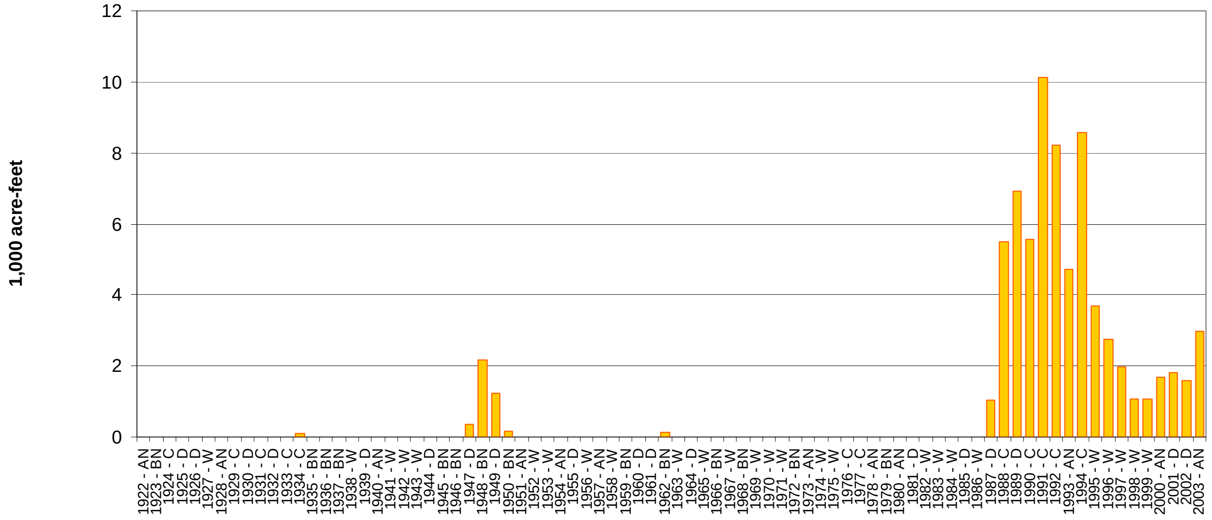


FIGURE 11-61
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-60 and 11-61 indicate that the pattern and volume of additional reservoir release for Scenario 4 is similar to that for Scenarios 1 and 3 with the maximum annual release approximately between those two scenarios.

11.4.3 New Well Field

Results of simulation of pumping from a new well field under Scenario 4 are summarized on Figures 11-62 through 11-64. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-62. This figure depicts simulated drawdown in the pumped aquifer during November 1990. Maximum pumping rates under this alternative occur during 1990, and the drawdown distribution at the end of November represents approximately the maximum drawdown that will occur under this alternative. It can be seen from the figure that the greatest drawdown occurs in the western GCID area at a magnitude of up to 50 feet.

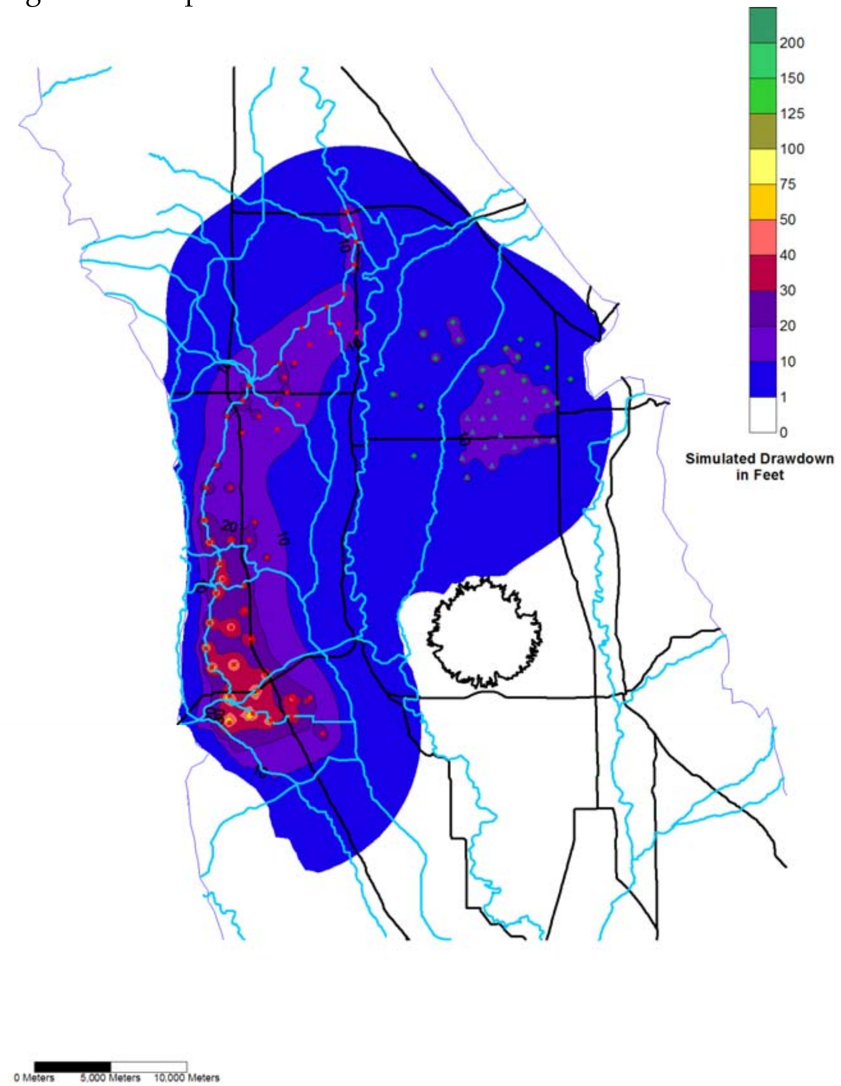


FIGURE 11-62
SIMULATED DRAWDOWN IN THE DEEP AQUIFER IN NOV 1990, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams for Scenario 4 with a new well field are summarized on Figures 11-63 and 11-64. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-63 shows that peak cumulative impact to all surface water flows will be a reduction of approximately 65 cfs in December 1990, while a flow reduction of just more than 33 cfs is forecasted to occur on the Sacramento River and a flow reduction of about 15 cfs is predicted on Butte Creek. Peak impact to the Sacramento River will also occur in December 1990 while peak impacts on Butte Creek occur in December 1995. Peak impacts to stream flows on smaller tributary streams peak at less than about 9 cfs, as shown on Figure 11-64.

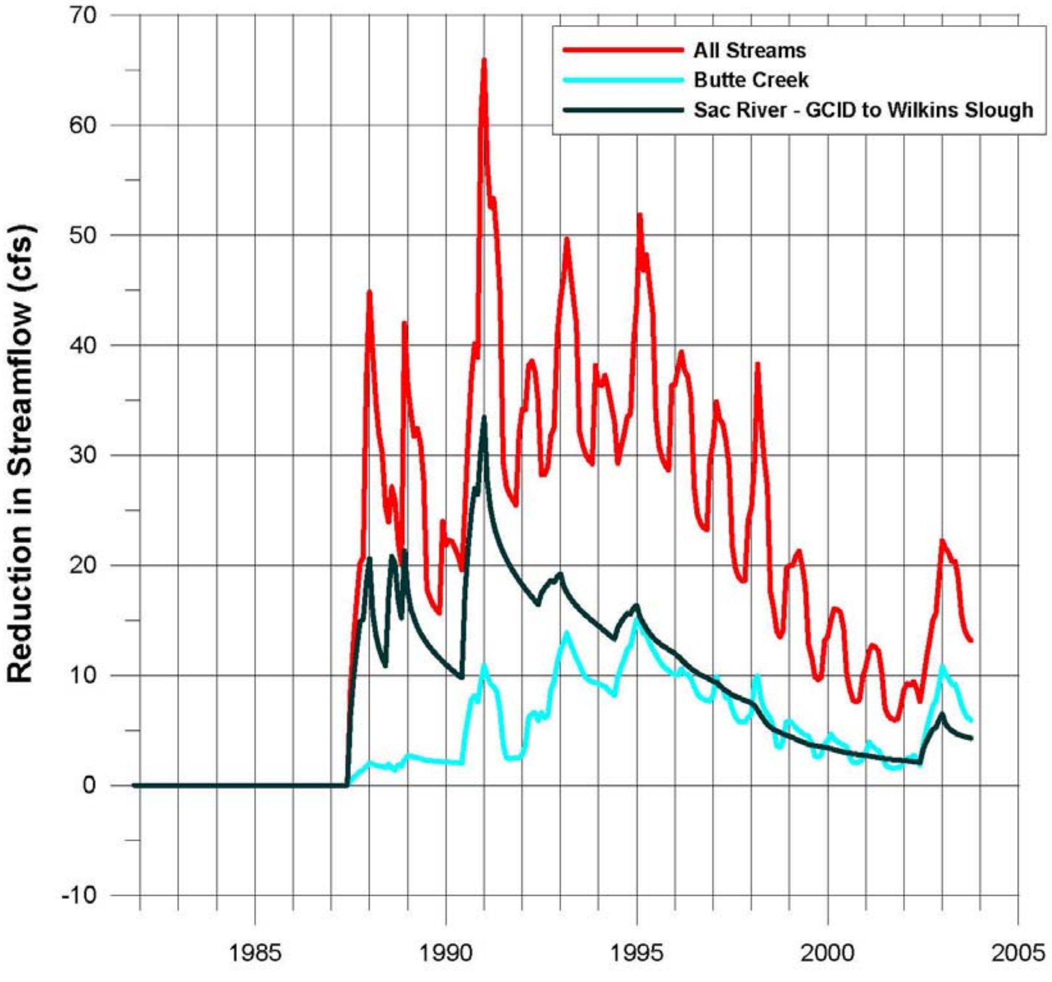


FIGURE 11-63
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 4 -NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

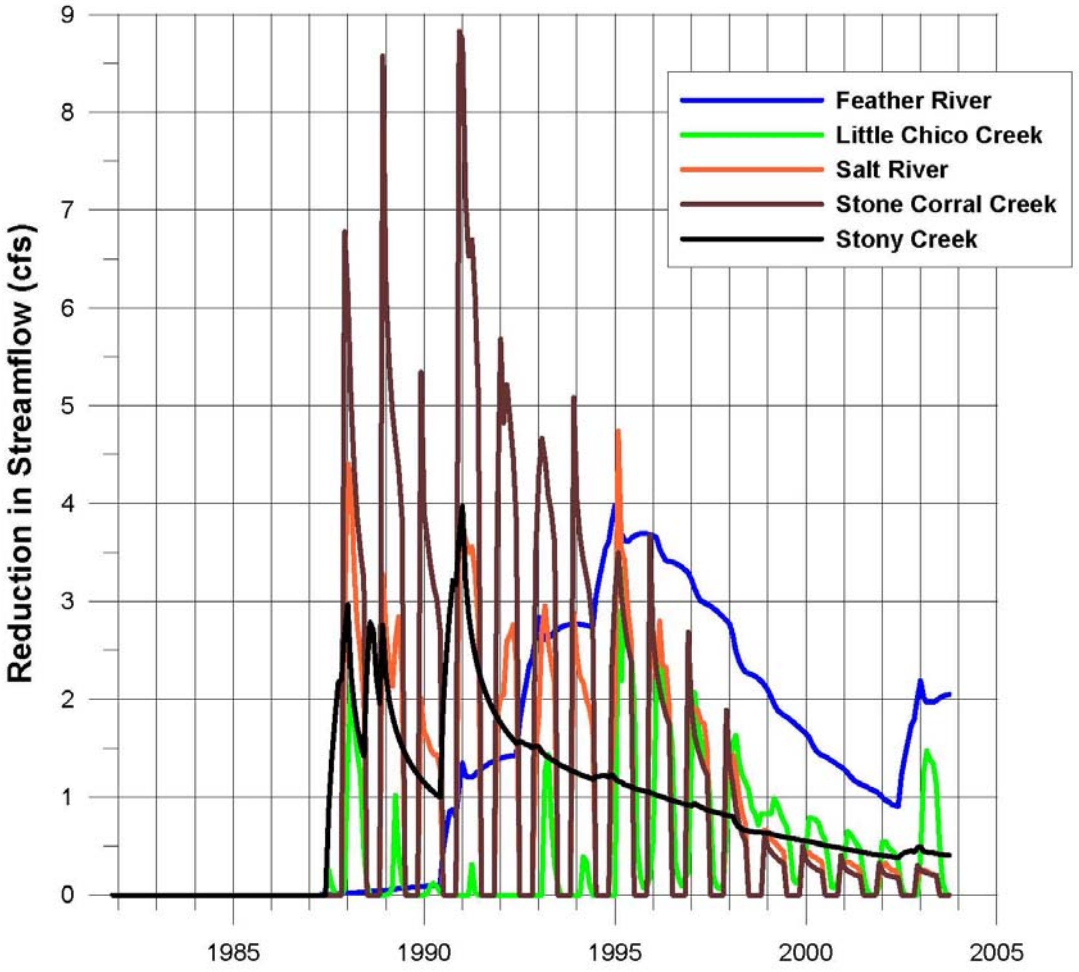


FIGURE 11-64
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.4.4 Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-65 and 11-66 present annual additional releases from Shasta and Oroville, respectively, for Scenario 4 pumping from a new well field.

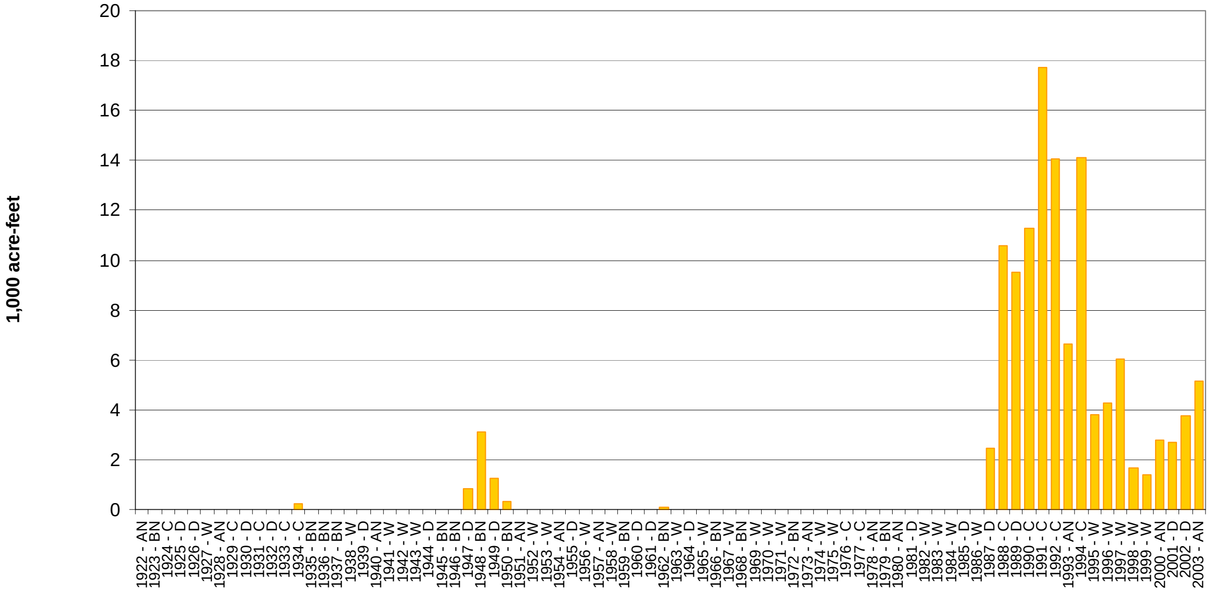


FIGURE 11-65
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

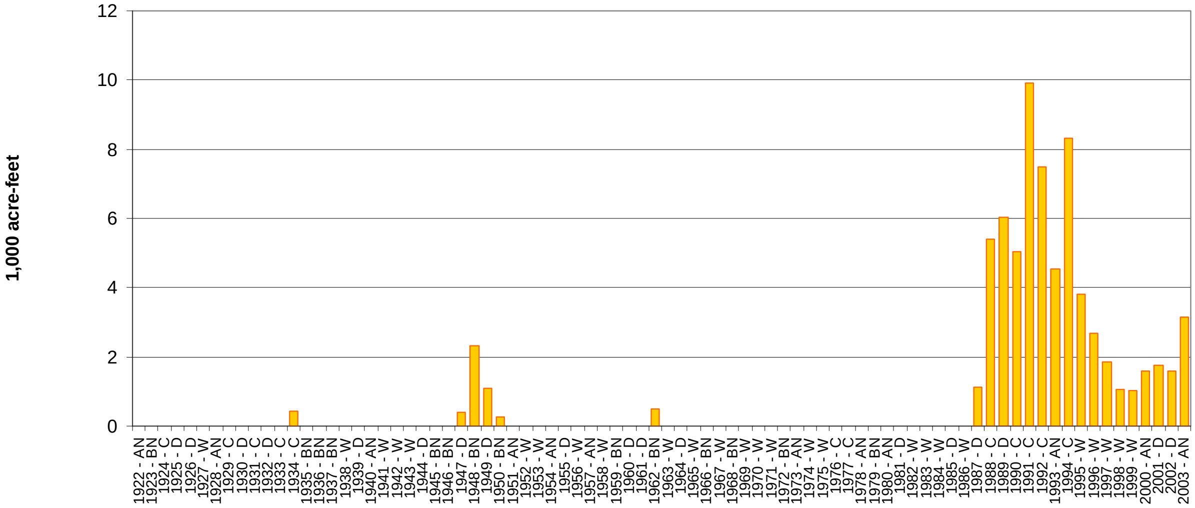


FIGURE 11-66
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

SECTION 12

Sensitivity Analysis and Tradeoffs

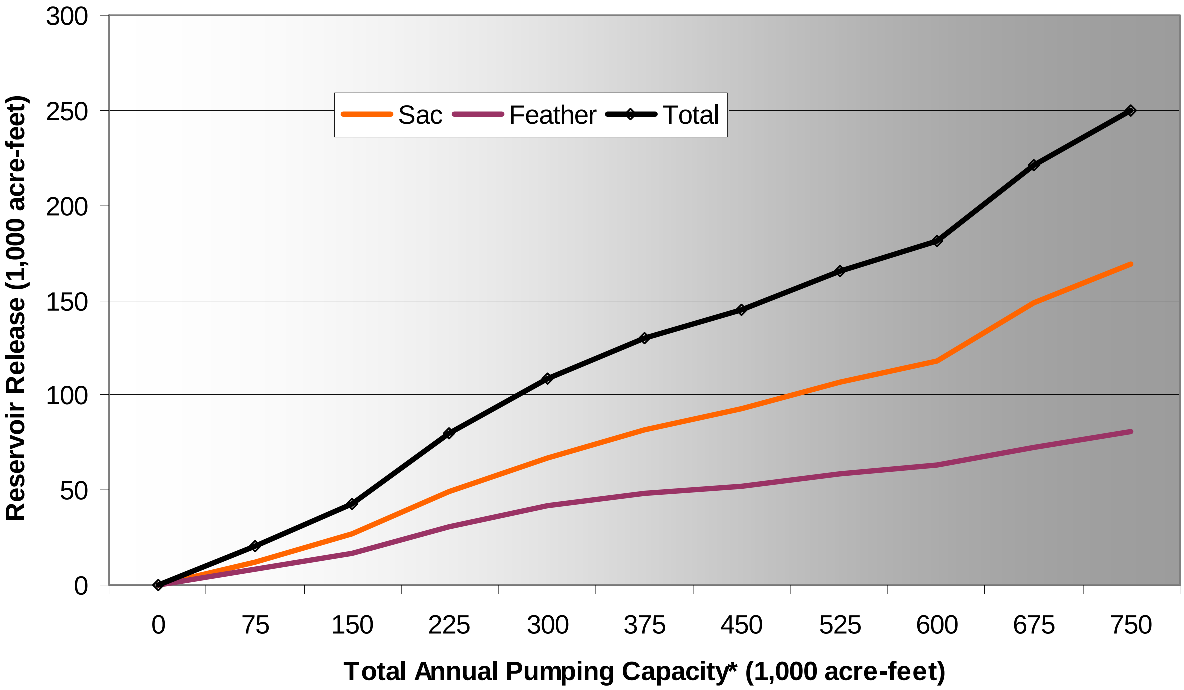
Simulation results presented in the previous section represent specific project sites and operations developed during the course of the analysis. Additional understanding of tradeoffs between certain key parameters and objectives can be gained from using the model in a sensitivity analysis mode in which or a limited number of parameters are varied while holding all other assumptions constant. This section presents results and conclusions for a limited set of model runs focused on better understanding key project inputs and assumptions.

Sensitivity analysis was conducted for several purposes. Sensitivity to parameters, such as project pumping capacity, was evaluated to assist in sizing potential projects. A range of environmental objectives were evaluated because considerable uncertainty exists in the development of objectives, and evaluating a range of possible objectives can help determine how much more or less conjunctive management could contribute to higher or lower flow targets. Evaluating various pumping periods and well field configurations was used to understand how aquifers respond to different pumping magnitudes and durations and the effects on stream-aquifer interactions.

12.1 Pumping Capacity

The surface water model was used to simulate a wide range of project pumping capacities and determine project benefits. Results of these simulations were one factor considered in determining final project capacities. The surface water model was used to simulate a range of pumping capacities to determine if certain capacities provided higher levels of project benefits. Project benefits were summarized as average annual reservoir release for both agricultural and environmental objectives.

Figure 12-1 illustrates that project benefits increase at different rates for different ranges of pumping capacities. For example, the incremental benefit of an additional 75 TAF of pumping capacity is greater when increasing pumping capacity from 150 to 225 TAF of total capacity than it is when increasing from 75 to 150 TAF, as illustrated by the steeper slope in the line. Benefits of incremental increases are smaller from 300 to 600 TAF (less steep line) and then increase again above 600 TAF. However, Figure 12-1, is shaded at the higher pumping capacities because projects of this size are not feasible and are not proposed for this project.



**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-1
TOTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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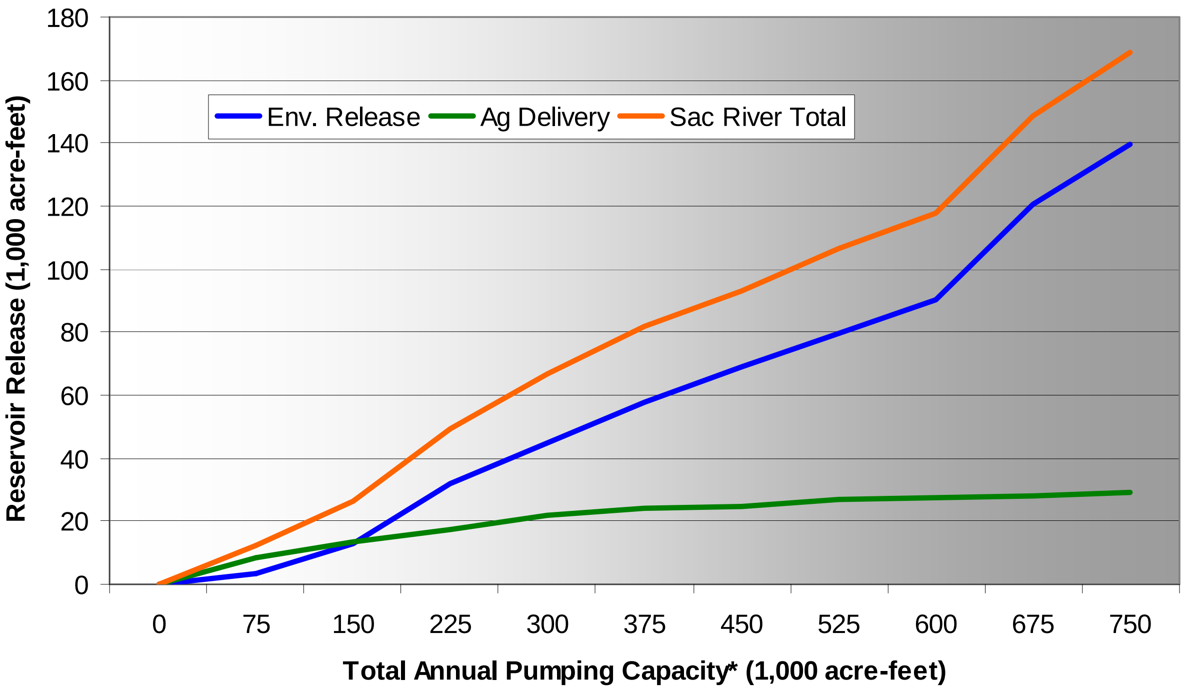
Figure 12-1 illustrates that projects between 75 and 150 TAF of pumping capacity have approximately the same marginal benefits when adding additional capacity. Figure 12-1 also illustrates that projects with 300 TAF may provide a good tradeoff at the upper end of the curve between pumping capacity and project benefits and that marginal benefits of increasing pumping capacity above 300 TAF are smaller than those realized by increasing from 150 to 300 TAF.

Project benefits presented on Figure 12-1 were compiled from reservoir releases to meet agricultural and environmental objectives. The model was set to first meet environmental objectives because of the all-or-nothing nature of those objectives. Figures 12-2 and 12-3 show the tradeoff between meeting agricultural and environmental objectives that occurs across a range of project pumping capacities.



**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-2
SACRAMENTO RIVER AGRICULTURAL AND ENVIRONMENTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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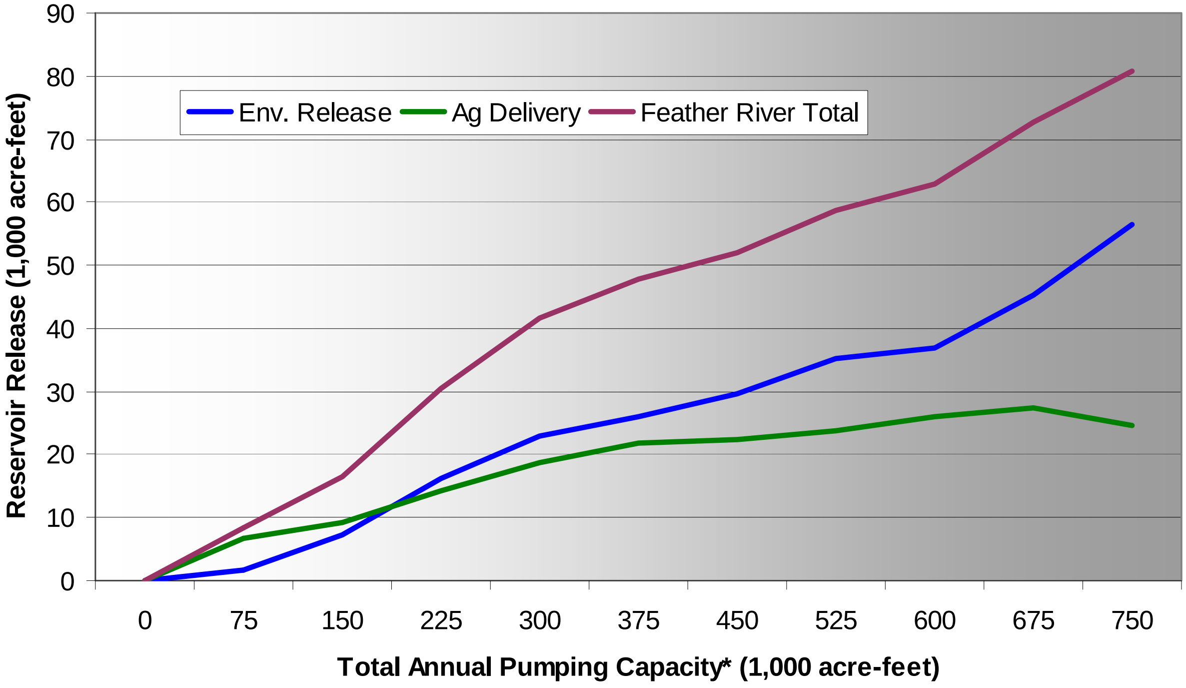
Figure 12-2 provides additional detail on the split between project benefits for agricultural demand and environmental objectives on the Sacramento River. Projects with smaller pumping capacities do not provide as much water supply for environmental objectives. This occurs because water costs for meeting environmental objectives typically exceeds project assets for lower pumping capacity projects. The result is smaller pumping capacity projects supply a greater portion of total benefits to agricultural demands because agricultural objectives are not constrained by a minimum threshold. As pumping capacity, and therefore available project assets increase, a greater portion of total benefits are directed toward meeting environmental objectives. However, this does not necessarily come at the sake of meeting additional agricultural demand. A project with 300 TAF of pumping capacity is providing an average annual agricultural supply increase of approximately 20 TAF, and pumping capacity would need to be significantly increased to provide additional agricultural water supply, up to a maximum of approximately 30 TAF per year. Maximum agricultural benefit is also constrained by the restriction on project operations during Shasta critical years. In these years, there is significant unmet agricultural demand that conjunctive management projects cannot satisfy under assumptions made for this analysis.

Figure 12-3 shows same relationships between pumping capacity and agricultural, and environmental benefits presented for the Sacramento River on Figure 12-2 also exist on the Feather River.



**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-3
FEATHER RIVER AGRICULTURAL AND ENVIRONMENTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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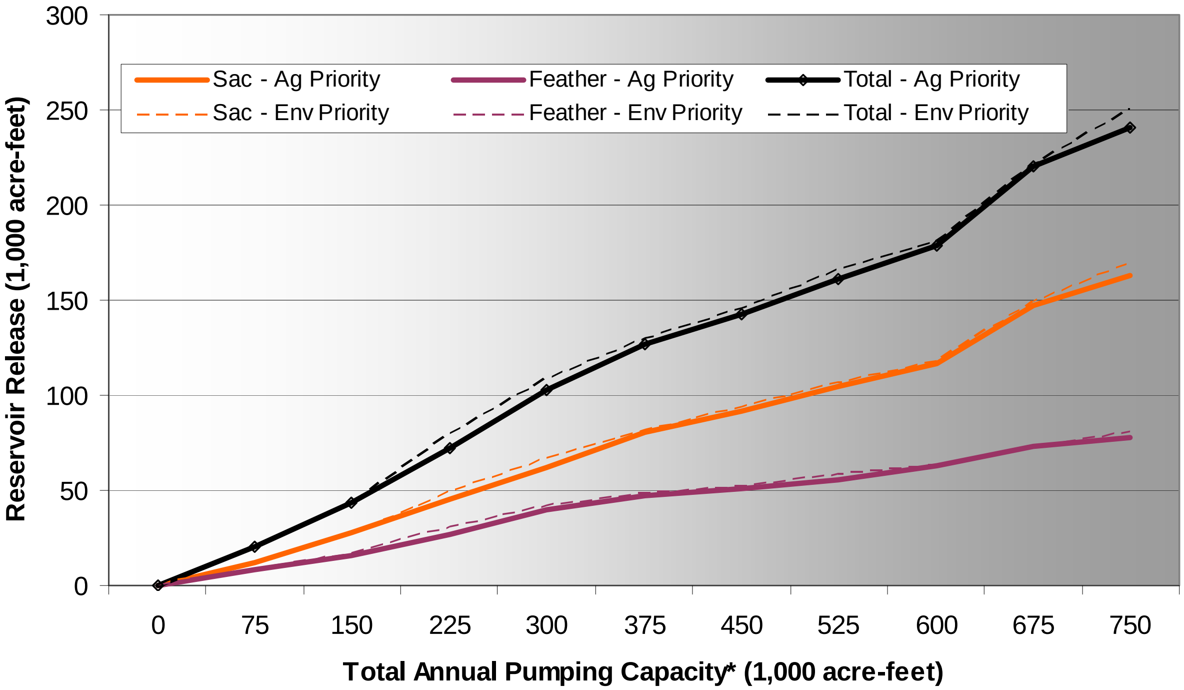
12.2 Prioritization of Objectives

The ability to direct additional water supply from conjunctive management toward meeting agricultural objectives first and environmental objectives second was also simulated. When environmental objectives are first priority, agricultural objectives are met more frequently for smaller capacity projects while environmental objectives are met more frequently for larger capacity projects. Figure 12-4 presents the same results as seen on Figure 12-1, with additional results that reflect when agricultural objectives are given first priority.



**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-4
TOTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES WITH HIGHER PRIORITY TO AGRICULTURAL OBJECTIVES (AG PRIORITY) AND HIGHER PRIORITY TO ENVIRONMENTAL OBJECTIVES (ENV PRIORITY)
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-4 illustrates model results are insensitive to prioritization of objectives for lower pumping capacity projects. However, as pumping capacity increases and conjunctive management projects are able to meet additional environmental objectives, total project benefits decrease when meeting agricultural objectives first. Table 12-1 compares average annual benefits for each objective on each river system with different priorities and the number of environmental objectives met by conjunctive management projects.

TABLE 12-1
Comparison of Average Annual Benefits for 300 TAF Pumping Capacity Project with Different Prioritization of Objectives
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Sacramento River			**Feather River**		
	Env. First	**Ag First**	**Change**	**Env. First**	**Ag First**	**Change**
Ag Benefit (TAF)	22	26	+4	20	23	+3
Env Benefit (TAF)	45	36	-9	23	18	-5
Env Obj. Met (#)	57	50	-7	54	40	-14

Table 12-1 shows when prioritizing agricultural objectives first average annual agricultural benefits increase, but not by the same volume environmental benefits decrease. Therefore there is a reduction in the total project benefits when prioritizing agricultural benefits first, as illustrated on Figure 12-4.

12.3 Reservoir Drawdown Targets

A reservoir storage matrix is used in combination with project groundwater pumping capacity to determine project assets available to meet objectives each year. Results previously presented for Scenarios 1 through 4 assume a minimum end-of-September storage of 2,400 TAF for Shasta Reservoir and 1,500 TAF for Oroville Reservoir. Model sensitivity to these assumptions was evaluated to better understand risk to water supplies and cold water pool management in subsequent years.

Figure 12-5 illustrates effects of changes in minimum fall storage levels on end of September storage. A line at 1,900 TAF is shown because this is the minimum level specified in the biological opinion for winter run Chinook salmon and changes in storage below this level can have significant impacts on Reclamation's ability to manage cold water pool and meet existing temperature control criteria. Setting minimum fall storage levels less than 2,400 TAF can impact storage in subsequent years when storage goes below 1,900 TAF. Setting minimum storage levels above 2,400 TAF reduces project benefits.

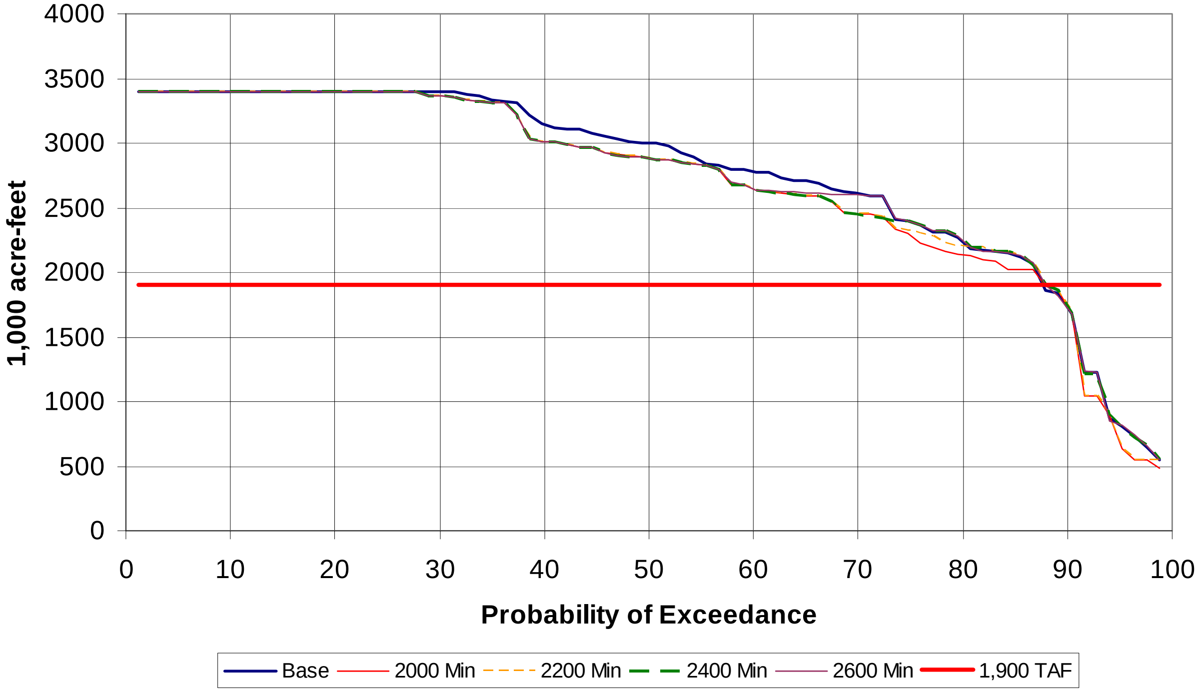


FIGURE 12-5
EXCEEDANCE PROBABILITY FOR END OF SEPTEMBER SHASTA STORAGE WITH SELECT MINIMUM STORAGE REQUIREMENTS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-6 illustrates similar results for Oroville Reservoir. There is no specified target for fall storage in Oroville, but it is understood that hydropower operations are affected when storage goes below 1,000 TAF. Results are less clear because of the smaller differences between base and project conditions; however, more aggressive operation of Oroville with a lower fall storage level may put operations in future years at risk. Therefore, 1,500 TAF was selected as a balance between achieving conjunctive management project benefits and operational risks.

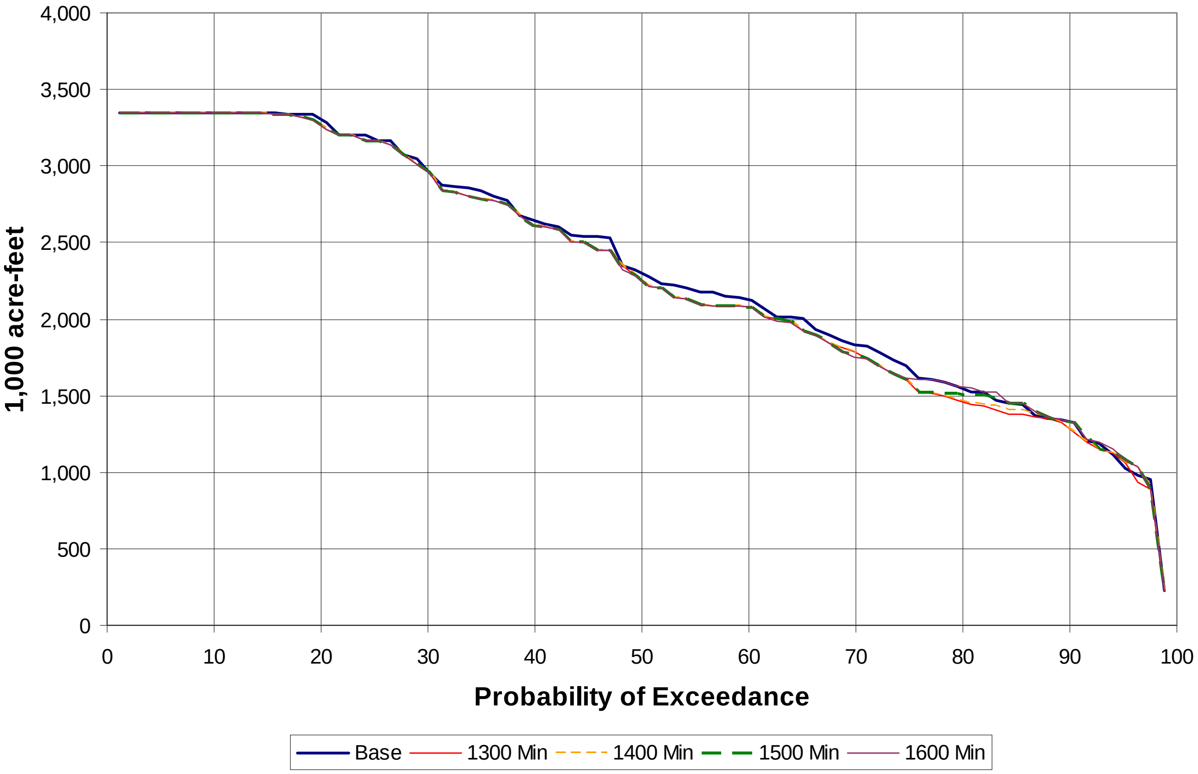


FIGURE 12-6
EXCEEDANCE PROBABILITY FOR SEPTEMBER OROVILLE STORAGE WITH SELECT MINIMUM STORAGE REQUIREMENTS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

12.4 Environmental Objectives

Considerable uncertainty surrounds developing of environmental objectives; therefore, limited sensitivity analysis was performed to determine if changes in environmental objectives resulted in significant changes in project benefits. For example, if a 10 percent increase in flow targets specified for each objective resulted in no objectives being satisfied for a given scenario, the results from this scenario would be interpreted to contain significant uncertainty. Likewise, if project benefits are consistent across a range of environmental objectives, conjunctive management projects are likely to provide a level of environmental benefit, even if flow targets are slightly different than those simulated.

Figures 12-7 through 12-10 present simulation results of varying environmental targets (presented in Tables 9-1 through 9-5, by more or less than 10 percent. Figures 12-7 through 12-10 show the years that objectives are met, either in the base condition or through project release, and total number of years met. Results are aggregated for both river systems.

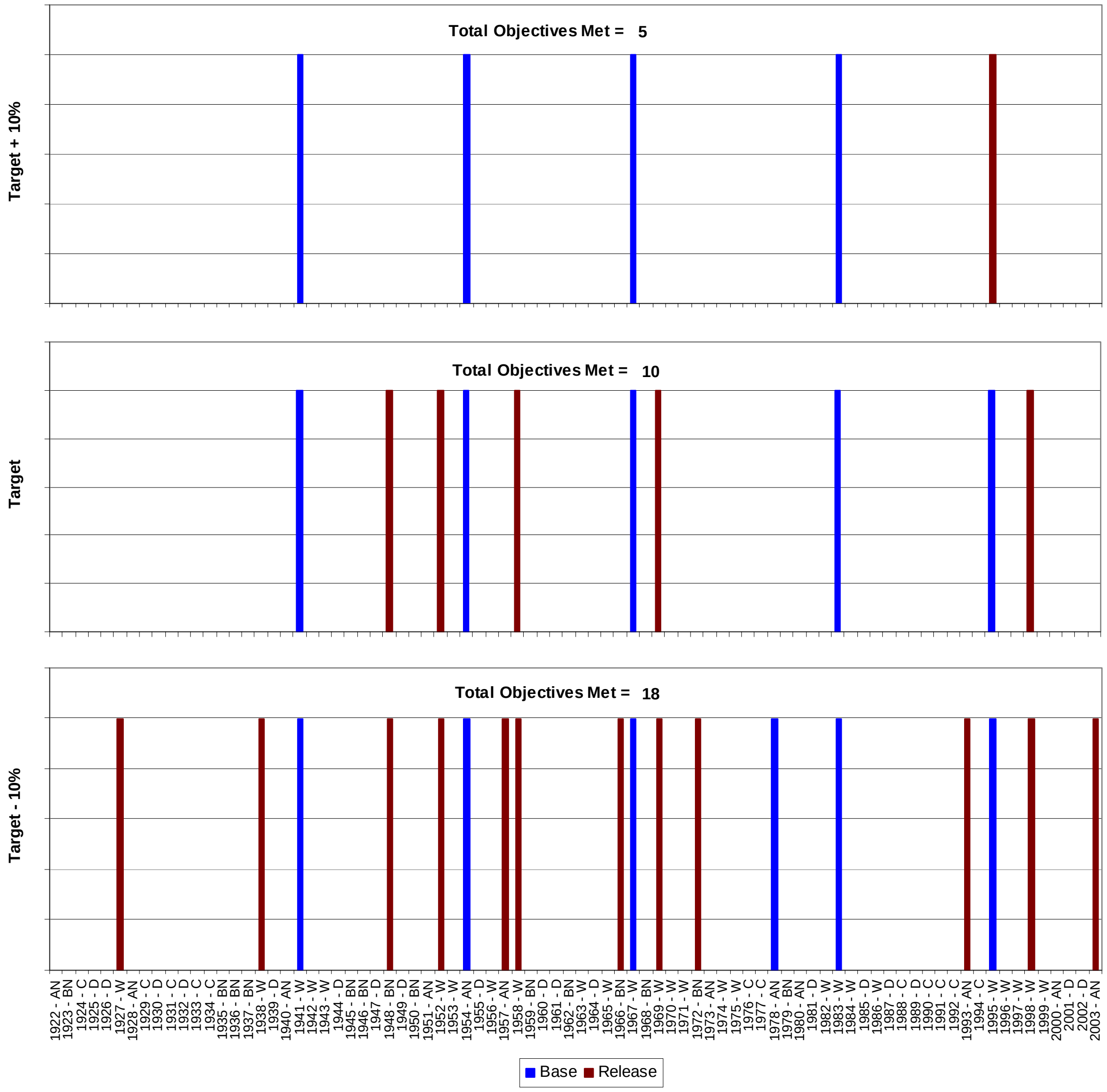


FIGURE 12-7
SENSITIVITY RESULTS FOR SPRING PULSE OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-7 shows that the larger water costs associated with meeting a larger spring pulse flow may decrease the ability of conjunctive management projects to satisfy the objective. Decreasing the flow target will increase the frequency of meeting the objective. The ability of conjunctive management projects to meet the spring pulse objective is sensitive to changes of more or less than 10 percent in the objective. Additionally, changes in the flow objective also change the frequency of meeting the objective with base operations.

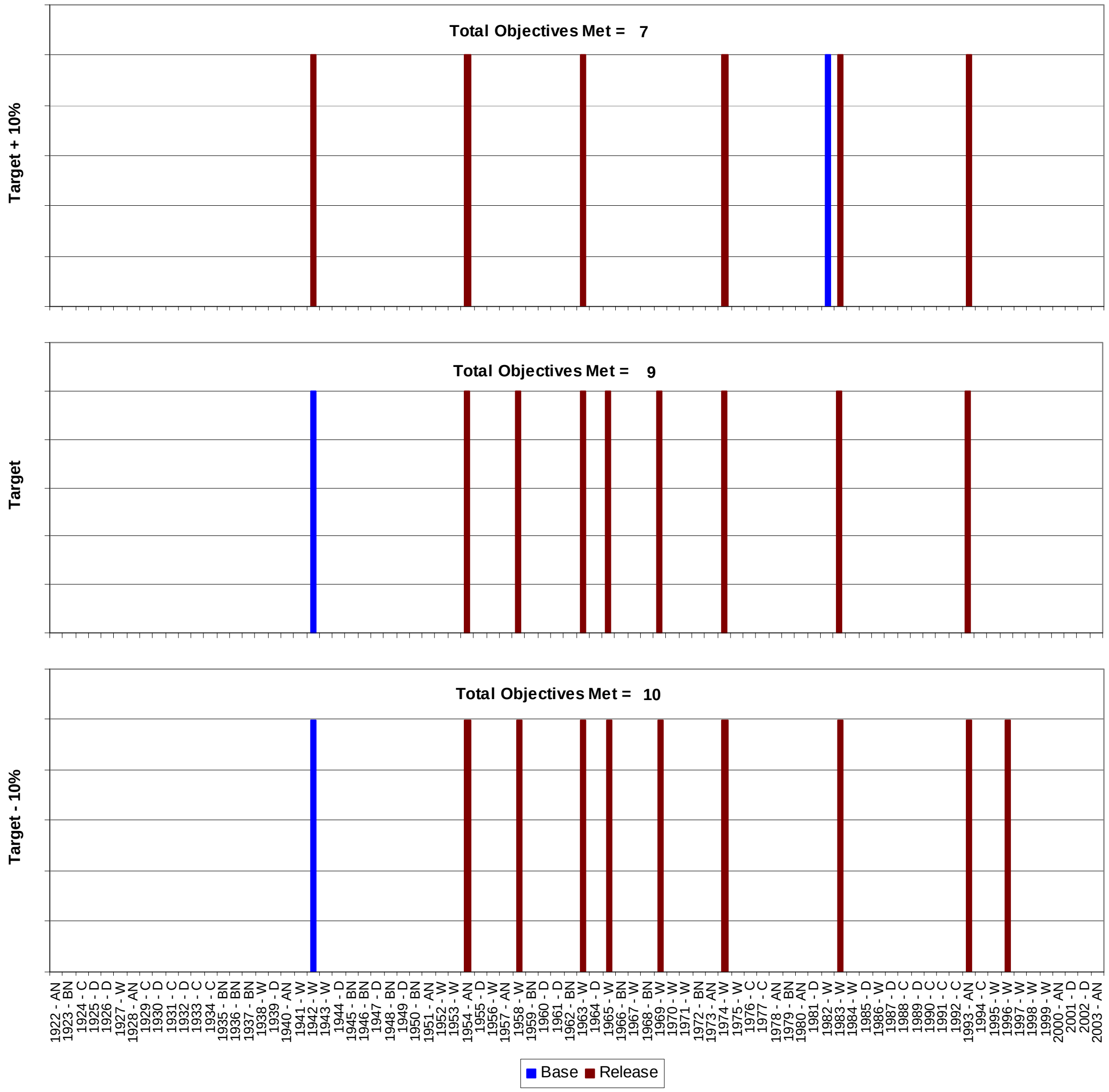


FIGURE 12-8
SENSITIVITY RESULTS FOR RIPARIAN RECRUITMENT OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 12-8 shows that riparian recruitment is less sensitive to changes in targets than the spring pulse objective. Changes in flow targets do not result in significant changes in the frequency of satisfying the objective.

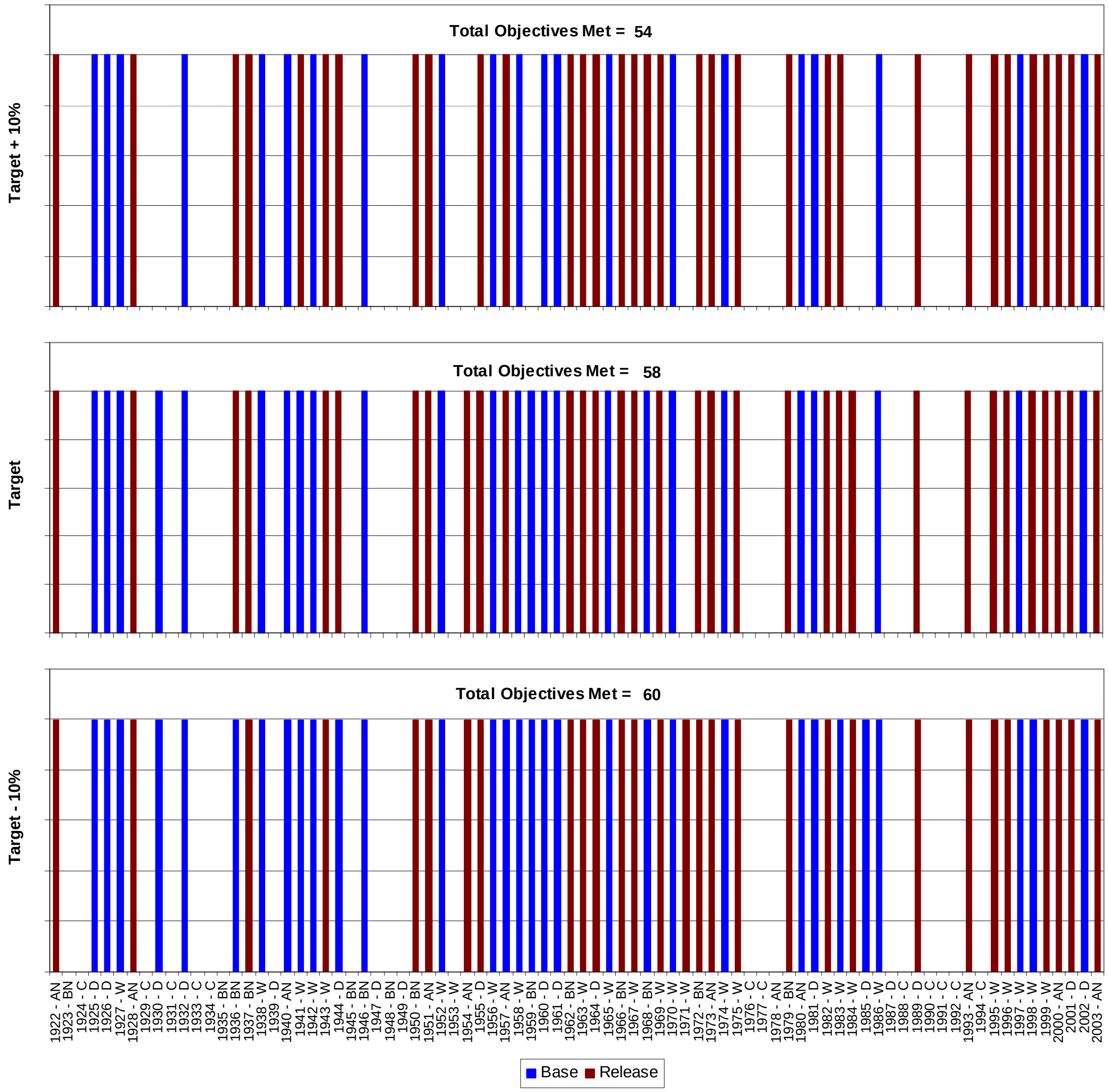


FIGURE 12-9
SENSITIVITY RESULTS FOR GEOMORPHIC OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-9 illustrates that the geomorphic objective is less sensitive to changes in targets than the spring pulse objective. Lower water cost of meeting a short duration objective results in being able to meet the objective, even when it is increased by 10 percent. Additionally, the objective is satisfied so frequently that reducing the flow target does not result in the objective being satisfied much more often.

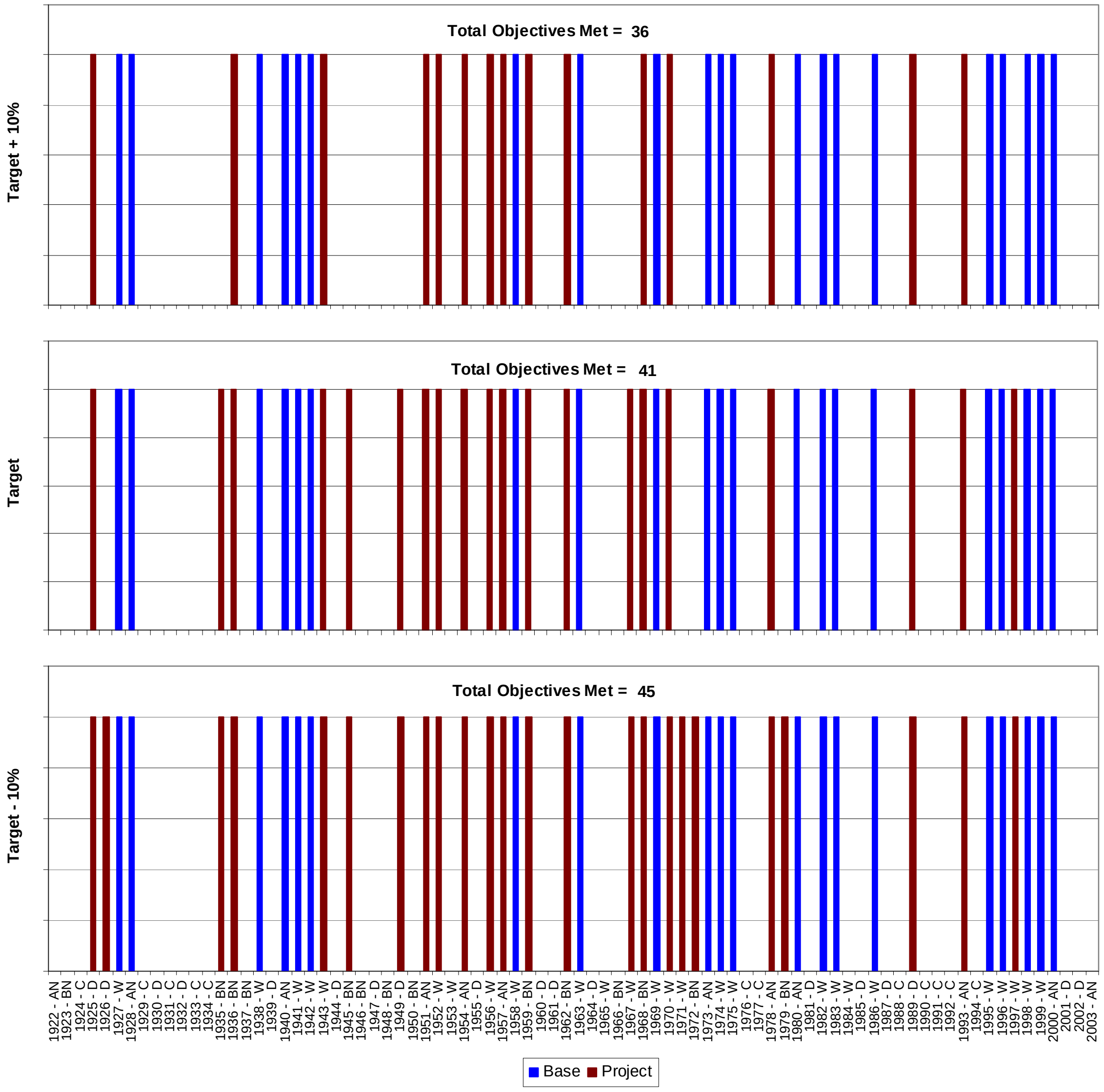


FIGURE 12-10
SENSITIVITY RESULTS FOR FLOOD PLAIN INUNDATION OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-10 illustrates that the flood plain inundation objective is also less sensitive to changes in the target than the spring pulse objective. Therefore, the conjunctive management project, including some form of weir modification, to allow inundation at lower river stages will allow the objective to be satisfied approximately 40 times if the flow target is within 10 percent of the target simulated in Scenarios 1 through 4.

SECTION 13

Systemwide Effects

This project focused operation of conjunctive management projects within the Sacramento Valley on developing water supply for uses within the Sacramento Valley. Developed water supply was split between environmental and agricultural objectives. However, water released to meet environmental objectives within the Sacramento Valley continues into the Sacramento-San Joaquin River Delta, where it may have additional environmental benefits or potentially be exported for delivery to CVP and SWP contractors south of the Delta.

13.1 Delta Salinity

Changes in Delta inflow, either increases from environmental releases or decreases when reservoirs or groundwater refill with surplus surface water, have the potential to change salinity conditions in the Delta. Formal simulation and analysis of expected changes is beyond the scope of modeling conducted to date. Generally, environmental releases will increase Delta inflow and improve salinity conditions, depending on how export operations respond to increased inflow. To the extent that environmental objectives can be met during drier periods those releases have potential to improve Delta salinity. Operations during wetter periods that either increased or decreased inflow may not result in large changes in Delta salinity. Overall, conjunctive management projects as described for this project will decrease average annual Delta inflow by the consumptive use of additional agricultural deliveries made possible by the project. Figures 13-1 and 13-2 present annual changes in inflow for Scenarios 1 and 2, respectively. Changes from Scenarios 3 and 4 are expected to be similar to those shown for Scenario 1.

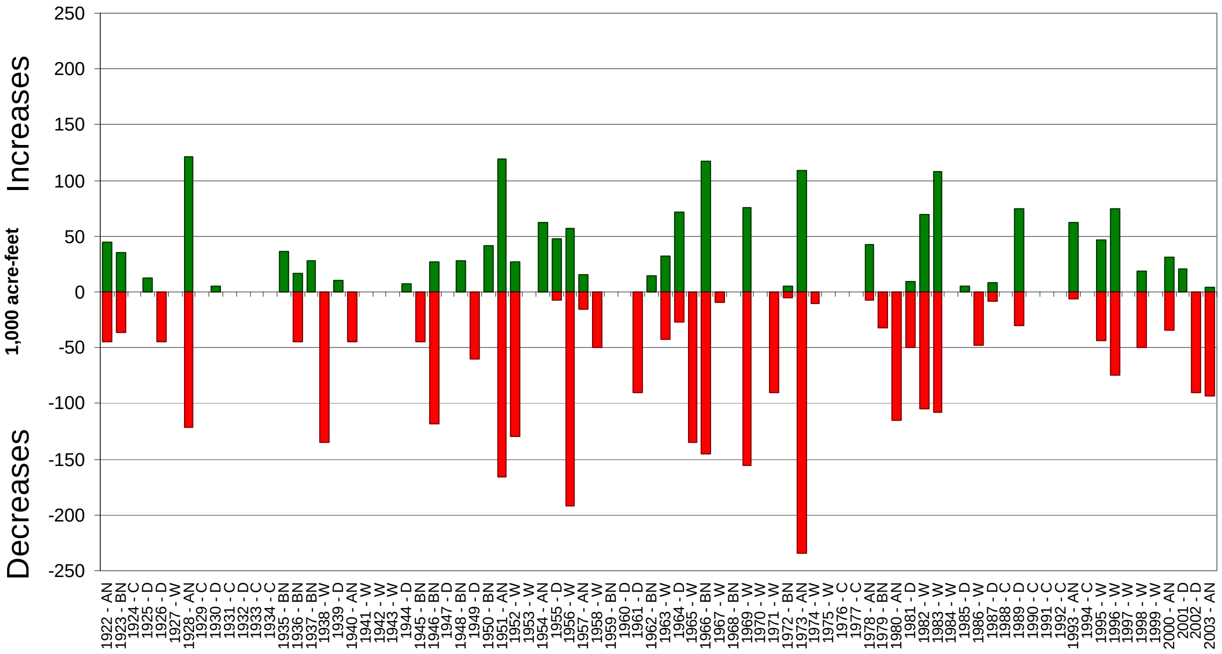


FIGURE 13-1
CHANGE IN ANNUAL DELTA INFLOW, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

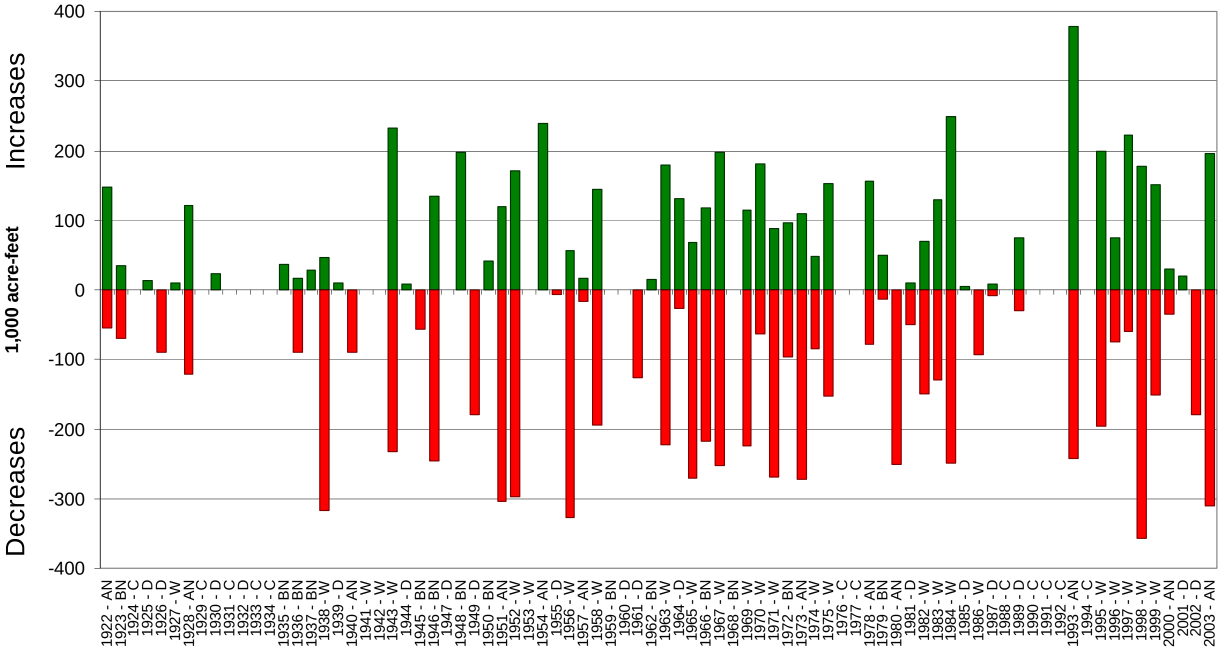


FIGURE 13-2
CHANGE IN ANNUAL DELTA INFLOW, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

13.2 South of Delta Water Supply

A preliminary analysis of the ability to export simulated environmental releases was made using the underlying CalSim II operations. This analysis considers the constraints imposed by D-1641 Delta flow and salinity standards, CVPIA b(2) restrictions, the Vernalis Adaptive Management Plan (2000), and export pumping capacity constraints. Analysis did not include pumping restrictions for protecting Delta smelt as proposed in the recent OCAP Biological Opinion (U.S. Fish and Wildlife Service, 2008). Export restrictions for protection of Delta smelt may significantly reduce ability to export environmental releases because smelt restrictions limit export operations during winter and spring months when environmental releases are made. Additionally, it was assumed that there is demand for any additional water that could be exported.

Figures 13-3 and 13-4 illustrate annual time series of total potential export of environmental releases made from Shasta and Oroville for Scenarios 1 and 2. Results for Scenarios 3 and 4 are essentially the same as for Scenario 1, because the timing and volume of environmental release does not change.

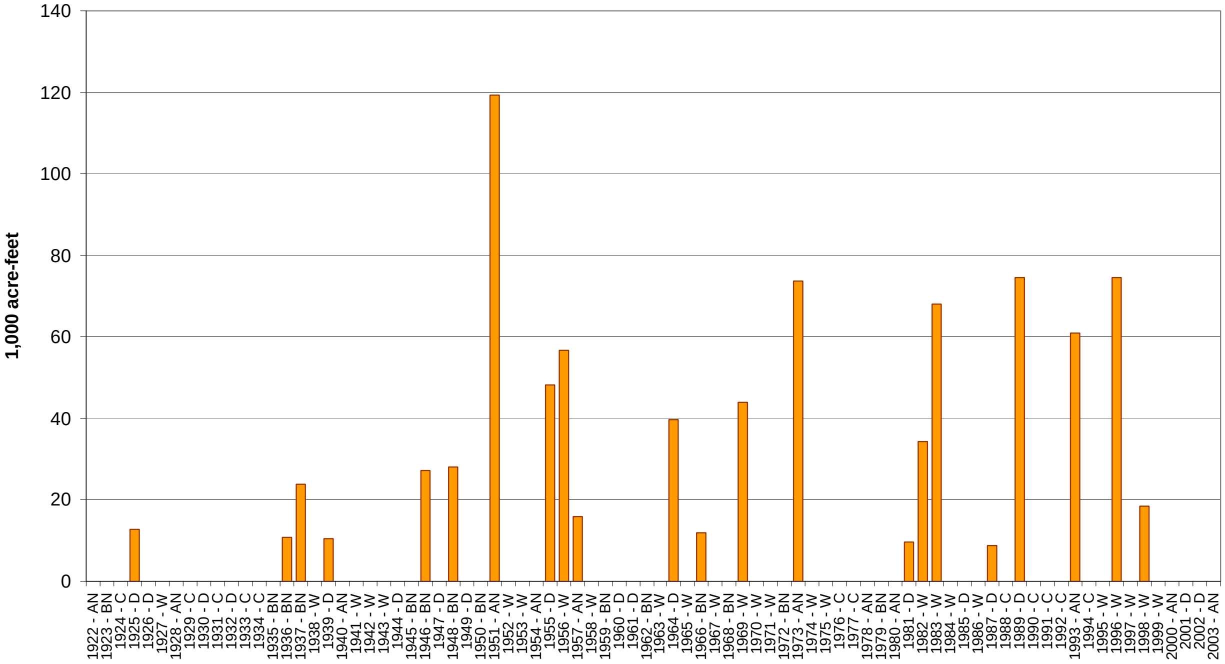


FIGURE 13-3
POTENTIAL EXPORT OF ENVIRONMENTAL RELEASES, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 13-3 illustrates the volume and timing of additional export that may occur with conjunctive management projects. Average annual exports increase by approximately 11 of the 22 TAF from environmental releases on the Sacramento and Feather Rivers. The majority of additional exports occur when CVP and/or SWP San Luis Reservoir storage is full and would therefore provide additional Section 215 water for CVP contractors and Article 21 water for SWP contractors.

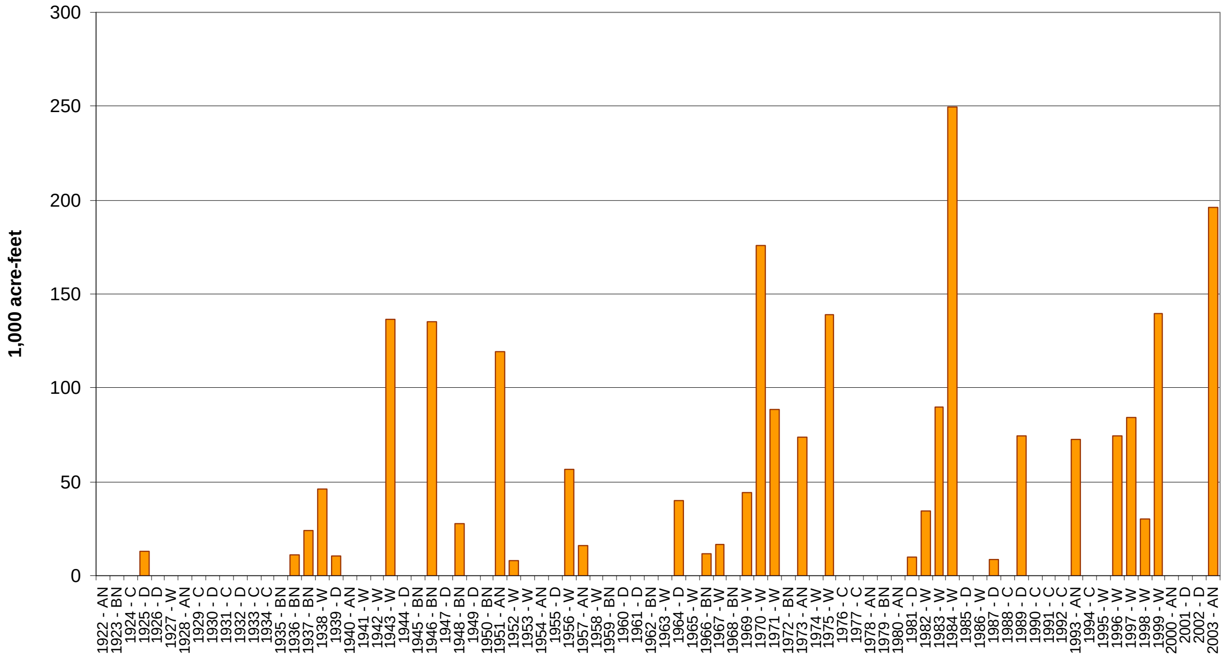


FIGURE 13-4
POTENTIAL EXPORT OF ENVIRONMENTAL RELEASES, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 13-4 presents the same results for Scenario 2 with an average annual export of 28 of the 68 TAF of environmental releases. Exports with Scenario 2 may increase by up to 250 TAF in a given year. In these years with large increases, exports and may be limited by the ability to use or store the water south of the Delta.

13.3 Other Changes

Analysis conducted to date focused on operations on the main stem of the Sacramento and Feather Rivers, and CVP and SWP reservoirs on those rivers. In reality, the water system in California is operated as a whole and changes in one area, particularly large components of the system, such as Shasta and Oroville Reservoirs, will ripple into other areas. While not addressed in this report, it is understood that these changes would require additional analyses at a feasibility level.

SECTION 14

Model Limitations and Areas for Refinement

14.1 Groundwater Model

While SACFEM is a powerful tool designed specifically to evaluate effects of conjunctive water management pumping on surface water and groundwater resources, several areas for refinement remain. Due to constraints on available resources for this project, it was not possible to perform a rigorous transient calibration of the model to observed historic water level hydrographs across the valley. This effort would help improve the level of confidence that the model is accurately simulating transient patterns in groundwater levels seen historically. However, a preliminary assessment of the accuracy of SACFEM at matching a limited number of historic hydrographs was performed, and the model appears to generally replicate historically observed water levels quite well over the 22-year period of simulation (1982 through 2003).

Another area of potential refinement is to further evaluate behavior of smaller unregulated tributaries across the valley, specifically to better understand timing and magnitude of groundwater recharge that occurs from these surface water features. In the current analysis, it was assumed that unregulated streams were dry from June through October. While this assumption is reasonable, it is likely that behavior of these streams is more complex. Further, some of these tributary streams are used as conveyance facilities to deliver water within various water districts. This would result in streams being active over summer months, and potential sources of recharge to the groundwater system. An analysis of these stream characteristics could improve the accuracy of the simulation of recharge sources to the groundwater system, especially over the summer months.

Forecasts provided by modeling tools contain some degree of uncertainty, due to limitations of replicating a complex physical system with a more idealized mathematical representation of that system. Analyses described herein should be considered a planning level analysis that tests the general viability of conjunctive water management strategies presented, and provides a general estimate of benefits that may be realized by implementation of these projects. However, these evaluations will need to be significantly refined, both in specificity of infrastructure and operational protocols and response of the natural system to these operations, before a project of this type could be carried to the design phase.

14.2 Surface Water Model

Surface water modeling and analysis was conducted at a pre-feasibility, planning level and required numerous simplifying assumptions.

14.2.1 Forecast-based Operations

The surface water model uses perfect foresight in operating reservoirs and determining ability to meet environmental objectives. This results in an ideal operation of system reservoirs and decisions to meet project objectives. In reality, project operators must rely on imperfect forecasts of water supply and demands when making daily decisions. In actual operations, there would be instances in which environmental objectives would be met or missed due to changing conditions that cannot be forecasted.

One method to address this uncertainty in future analyses would be to implement forecast-based decision logic that may help to illuminate some of the challenges in implementing environmental objectives in real-world operations. For example, because environmental objectives are specified for spring months, a forecast of the water year type (e.g., wet or above normal) is needed to estimate the flow target. In actual operations these forecasts will be uncertain and operations will need to respond to actual hydrology.

14.2.2 Temperature and Power Analyses

Conjunctive management operations as described and simulated for this report may have impacts on the ability to meet temperature control criteria, and the generation and use of CVP and SWP hydropower. For example, in some years, making releases for environmental objectives in spring may create challenges in meeting temperature control criteria in the fall, depending on how water is released from reservoirs. Additionally, large releases for certain objectives may be constrained by power plant capacities and may occur at times when power is less valuable. A better understanding of these constraints and simulation of resulting effects is necessary in future phases of the project.

14.2.3 System Response

Analysis presented in this report focused on operation of only part of the CVP/SWP system. Shasta and Oroville Reservoirs and the Sacramento and Feather Rivers are part of a larger system that is operated in a coordinated manner. Simulation of only part of the system may underestimate benefits or impacts to other areas of the system. Preliminary analysis of systemwide effects based on how conjunctive management operations change, Delta inflows need to be refined and expanded to other areas of the system.

SECTION 15

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Vernalis Adaptive Management Plan as described and implemented in State Water Resources Control Board Revised Decision 1641, State Water Resources Control Board, March 15, 2000.

Appendix A
CalSim II Common Assumptions

APPENDIX A

CalSim II Common Assumptions

Table A-1 summarizes assumptions used in CalSim II simulation of CVP and SWP reservoirs used in the surface water model at the existing level of development (Existing Conditions Assumption).

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
Planning Horizon	2004[a]	2030[a]	Same
Demarcation Date	June 1, 2004[a]	Same	Same
Period of Simulation	82 years (1922 through 2003)	Same	Same
HYDROLOGY			
Level of Development	2005 level[b]	2030 level[c]	Same
Sacramento Valley (excluding American River)			
CVP	Land-use based, limited by contract amounts[d]	Same	Same
SWP (FRSA)	Land-use based, limited by contract amounts[e]	Same	Same
Non-Project	Land-use based	Same	Same
Federal Refuges	Recent historical Level 2 deliveries[f]	Firm Level 2 water needs[f]	Same
American River			
Water Rights	2004[g]	Sacramento Area Water Forum[g,h]	Same
CVP	2004[g]	Sacramento Area Water Forum (PCWA modified)[g,h]	Same
PCWA	No CVP contract water supply	35 TAF CVP contract supply diverted at the new American River PCWA Pump Station	Same
San Joaquin River[i]			
Friant Unit	Limited by contract amounts, based on current allocation policy	Same	Same
Lower Basin	Land-use based, based on district level	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
	operations and constraints		
Stanislaus River	Land-use based, based on New Melones Interim Operations Plan[j]	Same	Same
South of Delta (CVP/SWP Project Facilities)			
CVP	Demand based on contracts amounts[d]	Same	Same
CCWD	124 TAF CVP contract supply and water rights[k]	195 TAF CVP contract supply and water rights[k]	Same
SWP	Demand varies based pattern used for 2004 OCAP Today studies; Table A transfers that occurred in 2005 and 2006 are not included	Demand based on full Table A amounts[e,l]	Same
Article 56	Based on 2002-2006 contractor requests	Same	Same
Article 21	MWD demand up to 100 TAF/month from December to March, total of other demands up to 84 TAF per month in all months[e,l]	MWD demand unlimited but subject to capacity to convey and deliver; KCWA demand of up to 2,555 CFS; others same as existing	Same
Federal Refuges	Recent historical Level 2 deliveries[f]	Firm Level 2 water needs[f]	Same
FACILITIES			
Systemwide	Existing facilities[a]	Same	Same
Sacramento Valley			
Shasta Lake	Existing, 4,552-TAF capacity	Same	Same
Colusa Basin	Existing conveyance and storage facilities	Same	Same
Upper American River	PCWA American River pump station not	PCWA American River pump station	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	**Future No Action Condition Assumption**	**Supplemental Future Condition (#1) Assumption**
	included	included	
Lower Sacramento River	Freeport Regional Water Project not included	Freeport Regional Water Project included	Same
Delta Region			
SWP Banks Pumping Plant	6,680 cfs capacity[a]	Same	8,500 cfs capacity[a]
CVP C.W. Bill Jones Pumping Plant (Tracy PP)	More than 4,200 cfs diversions upstream of DMC constriction	4,600 cfs capacity in all months (allowed for by the Delta-Mendota Canal–California Aqueduct Intertie)	Same
Los Vaqueros Reservoir	Existing storage capacity, 100 TAF, (AIP not included)	Existing storage capacity, 100 TAF; AIP included[m]	Same
San Joaquin River			
Millerton Lake (Friant Dam)	Existing, 520 TAF capacity	Same	Same
South of Delta (CVP/SWP Project Facilities)			
South Bay Aqueduct Enlargement	None	430 cfs capacity from junction with California Aqueduct to Alameda County FC&WSD Zone 7 diversion point	Same
California Aqueduct East Branch Enlargement	None	None	Same
WATER MANAGEMENT ACTIONS (CALFED)			
Water Transfer Supplies (available long term program)			
Phase 8	None	Supplies up to 185 TAF per year from new groundwater substitution, with 60% going to SWP and 40% to CVP[n]	Same
Lower Yuba River Accord	Not included	Not included	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	**Future No Action Condition Assumption**	**Supplemental Future Condition (#1) Assumption**
REGULATORY STANDARDS			
Trinity River			
Minimum Flow Below Lewiston Dam	Trinity EIS Preferred Alternative (369-815 TAF per year)	Same	Same
Trinity Reservoir End-of-September Minimum Storage	Trinity EIS Preferred Alternative (600 TAF as able)	Same	Same
Clear Creek			
Minimum Flow Below Whiskeytown Dam	Downstream water rights, 1963 Reclamation Proposal to USFWS and NPS, and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Upper Sacramento River			
Shasta Lake End-of-September Minimum Storage	SWRCB WR 1993 Winter-run Biological Opinion (1900 TAF)	Same	Same
Minimum Flow Below Keswick Dam	Flows for SWRCB WR 90-5 and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Feather River			
Minimum Flow Below Thermalito Diversion Dam	1983 DWR, DFG Agreement (600 cfs)	Same	Same
Minimum Flow Below Thermalito Afterbay outlet	1983 DWR, DFG Agreement (750-1,700 cfs)	Same	Same
Yuba River			
Minimum Flow Below Daguerre Point Dam	Interim D-1644 Operations[o]	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
American River			
Minimum Flow Below Nimbus Dam	SWRCB D-893[p] (see accompanying Operations Criteria), and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Minimum Flow at H Street Bridge	SWRCB D-893	Same	Same
Lower Sacramento River			
Minimum Flow Near Rio Vista	SWRCB D-1641	Same	Same
Mokelumne River			
Minimum Flow Below Camanche Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (100-325 cfs)	Same	Same
Minimum Flow Below Woodbridge Div. Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (25-300 cfs)	Same	Same
Stanislaus River			
Minimum Flow Below Goodwin Dam	1987 USBR, CDFG agreement, and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Minimum Dissolved Oxygen	SWRCB D-1422	Same	Same
Merced River			
Minimum Flow Below Crocker-Huffman Diversion Dam	Davis-Grunsky (180-220 cfs, Nov-Mar), Cowell Agreement, and FERC 2179 (25-100 cfs)	Same	Same
Tuolumne River			
Minimum Flow at Lagrange Bridge	FERC 2299-024, 1995 (Settlement Agreement) (94-301 TAF per year)	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
San Joaquin River			
San Joaquin River Below Friant Dam/Mendota Pool	None	None	None
Maximum Salinity Near Vernalis	SWRCB D-1641	Same	Same
Minimum Flow Near Vernalis	SWRCB D-1641, and Vernalis Adaptive Management Plan per San Joaquin River Agreement	Same[q]	Same[s]
Sacramento River–San Joaquin River Delta			
Delta Outflow Index (Flow and Salinity)	SWRCB D-1641	Same	Same
Delta Cross Channel Gate Operation	SWRCB D-1641	Same	Same
Delta Exports	SWRCB D-1641, USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
OPERATIONS CRITERIA: RIVER-SPECIFIC			
Upper Sacramento River			
Flow Objective For Navigation (Wilkins Slough)	3,500-5,000 cfs based on CVP water supply condition	Same	Same
American River			
Folsom Dam Flood Control	Variable 400/670 flood control diagram (without outlet modifications)	Same	Same
Flow Below Nimbus Dam	Discretionary operations criteria corresponding to SWRCB D-893 required minimum flow	Same	Same
Sacramento Area Water Forum Mitigation Water	None	Up to 47 TAF in dry years	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
Feather River			
Flow at Mouth of Feather River (Above Verona)	Maintain DFG/DWR flow target of 2,800 cfs for Apr-Sep dependent on Oroville inflow and FRSA allocation	Same	Same
Stanislaus River			
Flow Below Goodwin Dam	1997 New Melones Interim Operations Plan	Same	Same
San Joaquin River			
Salinity at Vernalis	D1641	San Joaquin River Salinity Management Plan[r]	Same
OPERATIONS CRITERIA: SYSTEMWIDE			
CVP Water Allocation			
CVP Settlement and Exchange	100% (75% in Shasta critical years)	Same	Same
CVP Refuges	100% (75% in Shasta critical years)	Same	Same
CVP Agriculture	100%-0% based on supply (South-of-Delta allocations are reduced due to D-1641 and 3406(b)(2) allocation-related export restrictions)	Same	Same
CVP Municipal and Industrial	100%-50% based on supply (South-of-Delta allocations are reduced due to D-1641 and 3406(b)(2) allocation-related export restrictions)	Same	Same
SWP Water Allocation			
North of Delta (FRSA)	Contract specific	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	**Future No Action Condition Assumption**	**Supplemental Future Condition (#1) Assumption**
South of Delta (including North Bay Aqueduct)	Based on supply; equal prioritization between Ag and M&I based on Monterey Agreement	Same	Same
CVP-SWP Coordinated Operations			
Sharing of Responsibility for In-basin-Use	1986 Coordinated Operations Agreement (2/3 of the North Bay Aqueduct diversions are considered as Delta Export, 1/3 of the North Bay Aqueduct diversion is considered as in-basin-use)	1986 Coordinated Operations Agreement (FRWP EBMUD and 2/3 of the North Bay Aqueduct diversions are considered as Delta Export, 1/3 of the North Bay Aqueduct diversion is considered as in-basin-use)	Same
Sharing of Surplus Flows	1986 Coordinated Operations Agreement	Same	Same
Sharing of Restricted Export Capacity for Project-specific Priority Pumping	Equal sharing of export capacity under SWRCB D-1641; use of CVPIA 3406(b)(2) restricts only CVP exports	Same	Same
Dedicated CVP Conveyance at Banks	None	SWP to convey 50 TAF per year of Level 2 refuge water supplies at Banks Pumping Plant (July and August)	SWP to convey 100 TAF/yr of Level 2 refuge water supplies at Banks Pumping Plant (July and August)
North-of-Delta Accounting Adjustments	None	CVP to provide the SWP a maximum of 37.5 TAF per year of water to meet in-basin requirements through adjustments in 1986 Coordinated Operations Agreement accounting (released from Shasta Reservoir)	CVP to provide the SWP a maximum of 75 TAF per year of water to meet in-basin requirements through adjustments in 1986 Coordinated Operations Agreement accounting (released from Shasta Reservoir)
Sharing of Export Capacity for Lesser Priority and Wheeling-related Pumping	Cross Valley Canal wheeling (max of 128 TAF/yr), CALFED ROD defined JPOD	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
San Luis Low Point	San Luis Reservoir is allowed to operate to a minimum storage of 100 TAF	Same	Same
CVPIA 3406(b)(2)			
Policy Decision	Per May 2003 Dept. of Interior Decision:	Same	Same
Allocation	800 TAF, 700 TAF in 40-30-30 dry years, and 600 TAF in 40-30-30 critical years	Same	Same
CVPIA 3406(b)(2) (continued)			
Actions	1995 WQCP, Upstream fish flow objectives (Oct-Jan), VAMP (Apr 15-May 15) CVP export restriction, 3,000 cfs CVP export limit in May and June (D-1485 striped bass cont.), Post-VAMP (May 16-31) CVP export restriction, Ramping of CVP export (June), Upstream Releases (Feb-Sep)	Same	Same
Accounting adjustments	Per May 2003 Interior Decision, no limit on responsibility for non-discretionary D-1641 requirements with 500 TAF target, no reset with the storage metric and no offset with the release and export metrics, 200 TAF target on costs from Oct-Jan	Same	Same

[a] A detailed description of the assumptions selection criteria and policy basis used is included in the Policy section of this Common Assumptions: Common Model Package (CACMP) report.

[b] The Sacramento Valley hydrology used in the Existing Conditions CALSIM II model reflects nominal 2005 land-use assumptions. The nominal 2005 land-use was determined by interpolation between the 1995 and projected 2020 land-use assumptions associated with Bulletin 160-98. The San Joaquin Valley hydrology reflects 2005 land-use assumptions developed by Reclamation to support Reclamation studies.

[c] The Sacramento Valley hydrology used in the Future No-action CALSIM II model reflects 2020 land-use assumptions associated with Bulletin 160-98. The San

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption

Joaquin Valley hydrology reflects draft 2030 land-use assumptions developed by Reclamation to support Reclamation studies.

[d] CVP contract amounts have been reviewed and updated according to existing and amended contracts as appropriate. Assumptions regarding CVP agricultural and municipal and industrial service contracts and Settlement Contract amounts are documented in Table 4 (North of Delta) and 6 (South of Delta) of Appendix B: CACMP Delivery Specifications.

[e] SWP contract amounts have been reviewed and updated as appropriate. Assumptions regarding SWP agricultural and M&I contract amounts are documented in Table 2 (North of Delta) and Table 3 (South of Delta) of Appendix B: CACMP Delivery Specifications.

[f] Water needs for federal refuges have been reviewed and updated as appropriate. Assumptions regarding firm Level 2 refuge water needs are documented in Table 4 (North of Delta) and 6 (South of Delta) of Appendix B: CACMP Delivery Specifications. As part of the Water Transfers technical memorandum (Appendix A: Characterization and Quantification), incremental Level 4 refuge water needs have been documented as part of the assumptions of future water transfers.

[g] Assumptions regarding American River water rights and CVP contracts are documented in Table 5 of Appendix B: CACMP Delivery Specifications.

[h] Sacramento Area Water Forum 2025 assumptions are defined in Sacramento Water Forum's EIR. PCWA CVP contract supply is modified to be diverted at the PCWA pump station. Assumptions regarding American River water rights and CVP contracts are documented in Table 4 of Appendix B: PFCMP Delivery Specifications.

[i] The new CALSIM II representation of the San Joaquin River has been included in this model package (CALSIM II San Joaquin River Model, Reclamation, 2005). Updates to the San Joaquin River representation have been included since the preliminary model release in August 2005. In addition, a dynamic groundwater simulation is currently being developed for San Joaquin River Valley, but is not yet implemented. Groundwater extraction/ recharge and stream-groundwater interaction are static assumptions and may not accurately reflect a response to simulated actions. These limitations should be considered in the analysis of results.

[j] The CACMP CALSIM II model representation for the Stanislaus River does not necessarily represent Reclamation's current or future operational policies.

[k] The Existing CVP contract is 140 TAF. The actual amount diverted is reduced due to supplies from the Los Vaqueros Project. The existing Los Vaqueros storage capacity is 100 TAF. Associated water rights for Delta excess flows are included.

[l] Table A and Article 21 deliveries into the San Francisco Bay Area Region–South and South Coast Region in the CACMP are a result of interaction between CALSIM II and LCPSIM. More information regarding LCPSIM is included in the following subsection of this document and the CALSIM-LCPSIM Integration technical memorandum (see Appendix C: Analytical Framework).

[m] The CCWD AIP is a new intake at Victoria Canal to operate as an alternate intake for Los Vaqueros Reservoir. This assumption is consistent with the future no-project condition defined by the Los Vaqueros Enlargement study team.

[n] This Phase 8 requirement is assumed to be met through Sacramento Valley Water Management Agreement Implementation.

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	**Future No Action Condition Assumption**	**Supplemental Future Condition (#1) Assumption**

[o] Interim D-1644 is assumed to be implemented.

[p] Sacramento Area Water Forum Lower American River Flow Management Standard is not included in the CACMP. Reclamation has agreed in principle to the Flow Management Standard, but flow specifications are not yet available for modeling purposes.

[q] It is assumed that either VAMP, a functional equivalent, or D-1641 requirements would be in place in 2030.

[r] The CACMP CALSIM II model representation for the San Joaquin River does not explicitly implement the CALFED Salinity Management Plan.

Notes:

PCWA = Placer County Water Agency
DMC = Delta-Mendota Canal
AIP = Alternate Intake Project
TAF = thousand acre-feet
cfs = cubic feet per second
EIS = environmental impact statement
Reclamation = Bureau of Reclamation
USFWS = U.S. Fish and Wildlife Service
NPS =
CVPIA = Central Valley Project Improvement Act
SWP = State Water Project
CVP = Central Valley Project

SWRCB = State Water Resources Control Board
DWR = Department of Water Resources
FERC = Federal Energy Regulatory Commission
CDFG = California Department of Fish and Game
FRWB =
EBMUD = East Bay Municipal Utility District
ROD = Record of Decision
CALFED = Calfed Bay-Delta Program
JPOD = Joint Point of Diversion
WQCB = Water Quality Control Plan
VAMP =
CACMP =

Sources:

Vernalis Adaptive Management Plan as described and implemented in State Water Resources Control Board Revised Decision 1641, State Water Resources Control Board, March 15, 2000.

U.S. Fish and Wildlife Service. 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) at State Water Project (SWP). Memorandum from Regional Director, Fish and Wildlife Service, Region 8, Sacramento, California, to Operation Manager, Bureau of Reclamation, Central Valley Operations Office Sacramento, California. December 15. 310 pages plus 3 attachments.

Appendix C
Project Site Screening
Technical Memorandum

DRAFT TECHNICAL MEMORANDUM

DATE: October 18, 2007

TO: Sacramento Valley Conjunctive Management Project Team

FROM: NHI Technical Team

SUBJECT: DRAFT Candidate Site Screening Methodology

This memorandum is a draft summary of the methodology used to select sites for the Conjunctive Use IRWMP technical scenario development. The California Department of Water Resources and the U.S. Bureau of Reclamation (project donors) have awarded funds to Glenn Colusa Irrigation District and the Natural Heritage Institute to develop an Integrated Conjunctive Water Management Plan (ICWMP) for Northern California surface water and groundwater resources. A description of the criteria used to select sites for the Conjunctive Use IRWMP technical scenario development is summarized below. The evolution of knowledge for candidate sites considered is summarized for all technical meetings held between February 2007 and August 2007. Technical meeting notes and a draft technical memo developed by MBK are included as appendixes.

Objectives and Benefits

The three fundamental objectives driving the plan's development are:

- To improve local water supply reliability by enlarging the firm yield of the basin and enhancing water management flexibility.

- To enhance the ecosystems in the region's rivers. Healthy rivers are not just environmentally attractive, they also are central to ensuring reliable, sustainable water supplies. Water supply systems that work in concert with the environment are less likely to be encumbered by court orders, water rights hearings, and other restrictions that can have drastic effects on water supplies for farming and other economic uses.

- To allow for meeting water demands outside of the Sacramento River basin. The Sacramento River basin is already a source of much of the State's water supply. A plan that allows for well-managed and regulated water transfers is preferable to shortsighted decisions made when drought emergencies arise and water transfer revenues could help stabilize a challenged agricultural economy and provide regional economic benefits.

Methods

Conjunctive water management essentially involves the coordination of storage and withdrawal of water from surface reservoirs and groundwater aquifers to produce firm water supplies through wet and dry cycles. This general concept can be adapted in a variety of ways to increase operational flexibility both to enlarge the firm water supply and improve the environmental performance of the state and federal water projects. During the study, various reservoir reoperation scenarios will be developed and evaluated for Lakes Oroville and Shasta, the centerpieces of the State Water Project and Central Valley Projects, respectively. Additionally, the Stony Creek system will also be evaluated as another option for potential reservoir reoperation.

The region to be addressed in the integrated plan is comprised of all of the lands overlying the Lower Tuscan and interconnected groundwater formations within Butte, Glenn, Colusa and Tehama counties whose access to this groundwater could be hydrologically affected by development of the aquifer system at any location. The Sacramento Valley Conjunctive Management Technical Team (The team) began by looking for sites that fell into one of two conjunctive management operational modalities; Put-then-Take or Take-then-Put. A Put-then-Take modality involves storing surface water in a groundwater aquifer and extracting that water at a later date. This modality increases water storage space in reservoirs and increases the flexibility of water delivery quantity and timing. A Take-then-Put modality involves creating water storage space in the groundwater aquifer by extracting water that can later be refilled with surface water. Under this modality the groundwater banking operation would be given rights to surface water in storage that it can call at any time, whatever the hydrologic conditions, and require groundwater replenishment on a cycle that guarantees no interference with wells outside that water district. The goal of the site selection process was to identify at least one site for each operational modality that could be implemented through the State water project and one that could be implemented through the Central Valley project and which are sufficiently promising to warrant further analysis to develop specific operational conditions for conjunct management. The team developed screening criteria for each conjunctive management modality:

<u>Put-then-Take Screening Criteria</u>

1. Persistent or permanent cone(s) of depression with no seasonal recovery, (i.e. groundwater areas with available storage space) within

2. Dual use water districts that use both groundwater and surface water deliveries from the state or federal projects or within

3. Unincorporated groundwater usage areas adjacent to state or federal water districts so that the extension of the State Water Project (SWP) or Central Valley Project (CVP) into these areas is practical.

Take-then-Put Screening Criteria

1. Groundwater production areas within or adjacent to state of federal water districts areas, where groundwater extraction can be increased during drier than average years, and which are

2. A significant distance from surface water features of concern; rivers, wetlands, etc to avoid flow depletion effects, and where the dewatered aquifers

3. Can be actively recharged during wetter than average years from the state or federal reservoirs, without losing banked water, or which recover from annual infiltration.

Summary of technical meetings held on Feb 15th, 2007

At a project team meeting on February 15, 2007, nine preliminary sites were selected based on review of a Spring to Fall change groundwater contour map for 2006 made by DWR and the collective knowledge in the room regarding current operations. Five sites were selected as potential Put-then-Take sites, and four sites were selected as potential Take-then-Put sites.

a. Put-then-Take
    - (1) Western Canal Water District
    - (2) M & T Chico Ranch
    - (3) Capay cone of depression
    - (4) Cone of depression that is north of Richfield and west of Tehama
    - (5) Yolo Zamora groundwater area

b. Take-then-Put
    - (1) GCID—Stony Creek Fan partnership
    - (2) Willow Creek Mutual Water District
    - (3) Colusa County Water District
    - (4) Olive Percy Davis Ranch

Summary of technical meeting held on June 19th, 2007 (See Appendix A)

For the June 19th, 2007 technical meeting MBK developed a brief description of each candidate site and how it might operate. This description was submitted to the project team in the form of a draft technical memorandum (Appendix B). For each site, current operations, current groundwater conditions, and the attributes of each water district were summarized in a table. These attributes included; general site information, operational concepts, aquifer characteristics, integration with surface water systems, infrastructure requirements, possible impacts and site screening criteria. There were several blanks in each attribute table, particularly for aquifer characteristics and potential impacts. These attributes required further research and development to be done during the full course of this study and would be used in future screening decisions. Based on each site's ability to meet the screening criteria they were either recommended to be retained for further analysis or to be dropped from the study. A brief summary of the nine sites considered is summarized below.

Put-Then-Take

WESTERN CANAL WATER DISTRICT - DURHAM CONE

Western Canal Water District (WD) extends surface water (SW) delivery system into the area overlying Durham cone of depression and operates a groundwater (GW) bank with Oroville providing the source water. One operation scenario would be to expand conjunctive management operations within Western Canal to increase surface water deliveries in wet years and reduce SW deliveries in dry years. Some of the augmented supply might be delivered to the refuges just west of Western Canal (Sac River Wildlife Refuge, Upper Butte Creek state reserve).

Groundwater levels fluctuate seasonally in response to agricultural and municipal pumping. The maximum measured fluctuation in the Chico-Durham area in 2006 was approximately 30 ft with an average value of approximately 20 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Big Chico Creek and other local streams. This site has the ability to contribute to Feather River flows and integrate with Oroville operations. It was proposed that we retain this site for further analysis.

ORLAND-ARTOIS WATER DISTRICT

Orland-Artois WD, a CVP Ag Service contractor, receives additional surface water from the Tehama-Colusa (TC) or Glen Colusa (GC) Canals, or directly from Stony Creek. Additional surface water reduces groundwater demand in current cone of depression. Water is returned to the system with additional groundwater pumping in dry years instead of Orland-Artois WD taking all or a portion of their CVP contract. (Note, the original discussion focused on this project with M&T Chico Ranch, but M&T is on east side of river while current cone of depression is on west side of the river, so a more likely project partner would be Orland-Artois WD.)

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the southern portion of Orland-Artois WD area in 2006 was approximately 25 ft, but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from streams tributary to Willow Creek. This site has the ability to contribute to Sacramento River flows and integrate with CVP operations. It was recommended that we retain this site for further analysis.

CAPAY RANCHO WATER DISTRICT

Capay Rancho WD would operate a groundwater bank by receiving surface water in wet years. Capay Rancho, a groundwater only district, is located over an existing cone of depression that may be utilized to store water. Methods for returning additional GW to the system in dry years are more complex, but may involve supplying water to areas in the TC Canal service area or GCID.

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Capay WD area in 2006 was approximately 50 ft with an average value of approximately 25 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Stony Creek and other local streams. Note that this is right next to the Sac river, therefore may be problems with gw/sw interactions. Because there was no perceived ability to contribute to Sacramento River flows and integrate with CVP operations it was recommended that we drop this site from the study.

CORNING CANAL SERVICE AREA

A portion of the Corning Canal Service Area overlies an existing cone of depression north of Richfield and west of Tehama. The overlying districts that could operate the groundwater bank include Elder Creek, El Camino ID, Tehama Ranch, and Thomes Creek. The Corning Canal runs though these districts and typically has unutilized capacity. CVP contractors along the Corning Canal include Proberta (3.5 TAF/yr), Thomes Creek (6.4 TAF/yr), and Corning (23 TAF/yr) WDs. These WDs have recently been pumping additional GW instead of taking CVP contract water due to the relative costs of CVP water to groundwater.

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Corning Canal Service Area in 2006 was in excess of 50 ft; but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Thomes Creek, Elder Creek, and other local streams draining the western foothills. This site has the ability to contribute to Sacramento River flows and integrate with Shasta operations and it was recommended that we retain this site for further analysis.

YOLO-ZAMORA WATER DISTRICT

The Yolo-Zamora WD overlies an existing cone of depression and relies on groundwater for irrigation. Surface water could be supplied by extending the Tehama Colusa Canal or constructing a canal from the Sacramento River. This has been studied in the past but rejected as prohibitively expensive as a substitute for groundwater for irrigation. Returning water to the system may be challenging.

Unable to evaluate due to lack of data from the Central District at this time. Awaiting receipt of groundwater level data from DWR. The option of extending the Colusa Canal would be economically impractical to distribute surface water in normal and non-normal water years in addition it would be impractical to extract groundwater. There is currently no ability to contribute to Sacramento River flows and integrate with CVP operations it was recommended that this site be dropped from study.

Take-Then-Put

GLENN-COLUSA IRRIGATION DISTRICT - STONY CREEK FAN
Glenn-Colusa Irrigation District (GCID) could operate a groundwater bank in the Stony Creek Fan, banking CVP water in wet years and reducing CVP surface water deliveries in dry years. This operation may be similar to recent groundwater substitution transfers.

The northern portion of GCID represents an area known to have high aquifer transmissivity. The area is currently served by surface water. The area is underlain by the lower Tuscan Aquifer as well as shallower producing zones in the Tehama Formation. Groundwater levels in this area are shallow, generally less than 10 to 15 ft in the spring. Hydrographs suggest very little seasonal fluctuation in groundwater levels.

The southwestern portion of GCID is still relatively high, but less than that of the northern portion due to the proximity to the margin of the groundwater basin. Well yields in this area are more than sufficient to meet the demands of a take then put project. The area is currently served by surface water. Groundwater levels in this area are shallow, generally less than 5 to 15 ft in the spring. Hydrographs suggest extremely little seasonal fluctuation in groundwater levels. This sites ability to contribute to Sacramento River flows and integrate with CVP operations led to the recommendation that it be retained for further analysis.

WILLOW CREEK MUTUAL WATER DISTRICT
Willow Creek Mutual Water District (MWD) is a mixed groundwater and surface water district located between the GC Canal and the Sacramento River southeast of Willows. Willow Creek MWD is located in close proximity to the Sacramento National Wildlife Refuge. The District is small and does not have substantial agricultural areas. Groundwater characteristics were not evaluated due to proximity to the Sacramento National Wildlife Refuge. There is limited ability to contribute to Sacramento River flows and no clear way to integrate with CVP operations; therefore, it was recommended that it be dropped from the study.

COLUSA COUNTY WATER DISTRICT
Colusa County WD is a CVP Ag Service contractor that takes delivery from the southern reaches of the Tehama Colusa Canal. Some areas within the district are noted to receive both surface and GW. (Note, the original discussion included extracting the water from RD 108, but RD 108 is primarily supplied from surface water and borders the Sac River. I don’t know that this is reasonable or necessary, though water banked under Colusa County WD may flow to RD 108.)

Wells to the east of I-5 indicate relatively shallow depth to water (<5 to 40 ft below ground surface [bgs]) in the spring of 2006. Depth to water increases to the west, in excess of 100 feet below ground surface along the western boundary of the water district. Wells in the eastern portion of the water district generally have higher seasonal fluctuations (up to 20 ft). Wells in the western portion of the district show little to no seasonal fluctuation in groundwater levels. Hydrographs further suggest that there is no long-term trend in groundwater levels since 2000. Aquifer transmissivity in this area decreases due to proximity to the margin of the groundwater basin. This site's ability to contribute to Sacramento River flows and integrate with Shasta operations led to the recommendation that it be retained for further study.

OLIVE PERCY DAVIS RANCH

The Olive Percy Davis Ranch (Ranch) has a Sacramento River Settlement Contract for water from the Sacramento River and CVP. The Ranch is located along the west bank of the river, east of Williams. The ranch has mixed water sources to include surface and groundwater.

Hydrographs in this area indicate that groundwater in this area is extremely shallow (up to 5 ft bgs) with very little seasonal fluctuation. Proximity to the Sacramento River could affect the implementability of a take then put project due to concerns regarding impacts on surface water resources. The aquifer in this area will likely yield large quantities of water to wells. This site has the ability to contribute to Sacramento River flows and integrate with Shasta operations. It is close in proximity to the Sacramento River and raises concerns over SW-GW interaction. Overall, it was recommended that this site be retained for further analysis.

Summary of technical meeting held on July 30, 2007 (See Appendix C)

In an attempt to identify viable put then take project sites in the northern valley, CH2MHill evaluated groundwater elevation data from the period 1970 though present. The objective of this analysis was to determine whether areas exists in the valley where cones of depression in the water table persist year-round such that they represent favorable sites where water could potentially be stored in the aquifer for later use during dry periods. The first step in the analysis was to evaluate spring-fall difference maps to look for seasonal cones of depression. Several areas with seasonal cones of depression exist, specifically the Chico-Durham area, the Capay area, and the area around the Corning Canal among others. Once areas with seasonal depressions were identified, longer term historic water level hydrographs covering the period 1970 to present were constructed for key wells defining the seasonal depressions. The results of this analysis indicated that the cones of depression were really only seasonal features, with almost complete recovery over the winter recharge period. The only exception was in some locations during the 1976-1977 and 1988-1992 drought periods. Some persistent cones of depression were suggested during these droughts but groundwater levels recovered as soon as normal rainfall returned to the valley. Overall, this groundwater level analysis suggests that no obvious locations for successful Put-then-Take scenarios exist in the northern Sacramento Valley.

Appendix A: Meeting Notes

Lower Tuscan Integrated Conjunctive Water Management Plan

Technical Team Meeting
June 19, 2007

Summary Notes

Following are brief notes from a meeting of the Lower Tuscan Technical Team at MBK Engineers on June 19th, 2007. The purpose of the meeting was to review progress on selection and screening of prospective conjunctive use sites, development of analytical tools and development of environmental flow targets.

Attendees:
Thad Bettner/GCID
Greg Thomas/NHI
Carrie Monohan/NHI
John Cain/NHI
Peter Lawson/CH2M HILL
Walter Bourez/MBK
Lee Bergfeld/MBK
Grant Davids/Davids Engineering

Site Selection and Screening

Peter presented well hydrographs from the nine candidate conjunctive management sites previously selected. He explained that while there are areas in the Sacramento Valley that experience seasonal depression of groundwater levels, these areas generally recover each year due to recharge from surrounding aquifers, precipitation, applied irrigation water, stream leakage and other sources. Contrary to initial assumption, there appear to be no areas in the valley where groundwater levels do not recover fully, except possibly in the very driest years or multi-year series. Thus finding conjunctive management sites where year-to-year groundwater banking is accomplished through initial cycles of “put” followed by “take” does not look promising. Instead, we are left with formulations where the take cycle occurs first, and recharge occurs primarily from natural sources, potentially including increased leakage from surface streams, or reduction of groundwater accretion to streams, induced by the lowering of groundwater levels.

With this sharpened perspective, it appears that promising conjunctive management sites would be irrigated areas where:

1) Surface water supplies are reliable (meaning appreciable entitlement in dry years) and form a substantial portion or all of the total irrigation water supply.

2) Underlying groundwater aquifers are productive and economically developed

3) Interaction between groundwater and surface streams, especially the Sacramento River and Feather River does not exist or is highly damped.

Given these attributes, the basic operational scenario would be to pump groundwater and forego use of an equivalent amount of surface water. The surface water could be withdrawn from storage on a schedule designed to meet environmental needs, or other needs. Another option would be to reoperate surface reservoirs to draw them down further and, if they did not refill, rely on groundwater to fill the resulting shortage. Additional yield would be produced by groundwater refilling from natural recharge or surface reservoirs refilling from water that otherwise would be released for flood control purposes.

A significant concern is the extent to which groundwater pumping affects streamflow, and when the effects occur. Effects occurring during balanced conditions would need to be addressed.

We discussed the need to revisit selection of the candidate conjunctive management sites given the additional considerations defined above, and to better document the selection criteria and process. However, no decisions were made.

Model Development

MBK demonstrated the current version of the conjunctive operations spreadsheet model, clarifying that it is still a work in progress. The basic simulation approach is to use outputs from selected CALSIM runs and impose the conjunctive operation on the CALSIM simulated conditions. The basic functionality of the model is complete, and remaining work will focus on adding data integrity and hydrogeologic characterization of the candidate sites.

The model is set up so that each of the nine sites is represented. They can be evaluated independently or in combination, although rules will be needed to establish priorities among sites for combined runs. Independent runs will be made first, and then combined runs explored.

Environmental Flows

NHI has made substantial progress toward establishing environmental flow objectives for the Sacramento River, drawing substantially on ongoing efforts by others, notably The Nature Conservancy and Stillwater Sciences. The objectives address flows for Freemont Cottonwoods, sustaining geomorphic processes, and floodplain inundation. Recognizing that the environmental flow needs may far exceed the additional supplies and timing modifications possible through conjunctive management, next steps will focus on prioritization among the Sacramento River flow objectives, and developing similar objectives for the Feather.

It was acknowledged that the existing Delta export pumping schedules pose significant constraints to reduction of Sacramento River summer flows; however, analysis of modified export schedules (such as might be possible with an isolated facility and additional south of Delta storage) are far beyond the scope of the current investigation.

Action Items

1) **Peter** to check with DWR and validate that there are no areas within the Sacramento Valley with persistent cones of depression where put-then-take operation might work.
2) **Peter** will review the nine sites identified initially, and advise the group as to whether and how site selection should be revisited, considering today's discussion and what is learned from DWR (see #1 above).
3) **Grant** will provide water balance information to Lee for GCID, Orland-Artois, and the Orland Unit.

Next Meeting

1) Next meeting is scheduled for Monday, July 30, 9:00 am at MBK.
2) Peter and Grant will meet at CH2M HILL in Redding on July 19 to discuss site selection.

Appendix B:

MBK ENGINEERS

DRAFT TECHNICAL MEMORANDUM

DATE: June 16, 2007

TO: Sacramento Valley Conjunctive Management Project Team

FROM: MBK and CH2M Hill Technical Team

SUBJECT: DRAFT Candidate Site Screening

This memorandum is a summary of nine potential project sites developed during a project team meeting at MBK Engineers on February 15, 2007. A brief description of how each site would operate and the current groundwater conditions is followed by a table listing site attributes relevant for conjunctive management and integration with the surface water system. The last section of each table summarizes the screening criteria used to rate the site to include ability to meet project objectives, volume of water that may be developed, and relative cost of developing the site. Information in the table was developed using existing data, tools, planning factors, and professional judgment to objectively evaluate all sites by consistent standards. The objective of this analysis is to screen the full list of sites and identify a maximum of six sites to carry forward in the study.

The tables are blank for several attributes, particularly for aquifer characteristics and potential impacts. These attributes will be researched and developed during the course of the study and used in future screening decisions. For example, aquifer characteristics will be determined during the next phase when water budgets are calculated for each project site. Aquifer characteristics and preliminary surface water modeling results will be used to further screen sites, and these sites may then be evaluated for possible impacts.

Western Canal Water District - Durham Cone

Project Operations

Western Canal Water District (WD) extends surface water (SW) delivery system into area overlying Durham cone of depression and operates a groundwater (GW) bank with Oroville providing the source water. An alternative operation would be to expand conjunctive management operations within Western Canal to increase surface water deliveries in wet years and reduce SW deliveries in dry years.

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural and municipal pumping. The maximum measured fluctuation in the Chico-Durham area in 2006 was approximately 30 ft with an average value of approximately 20 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Big Chico Creek and other local streams.

Table 1: Western Canal-Durham Cone Site Attributes

General Site Information	
Project Location:	Western Canal WD and northeast of Western Canal WD near Durham
Current Water Source:	GW
Approximate Area:	? acres over Durham cone; Western Canal = 58,800 ag acres
Existing Project Contracts:	Western Canal – 145 TAF/yr Settlement, 150 TAF/yr Project
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Supply SW thru Western Canal to GW users
Return (dry years):	Pump additional GW in Western Canal to reduce SWP diversions from Feather River and Oroville
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	Seasonally depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Butte Creek
GW Quality:	Localized high Ca, NO3, and TDS in the Chico Area
Integration with SW System	
Existing:	Western Canal with SWP; Durham area is not integrated
With Project:	SWP
Reservoir:	Oroville
Infrastructure Requirements	
Supply Water:	Extend Western Canal canals to include lifts, distribution system in current GW only area
Return Water:	Additional wells in Western Canal
Possible Impacts	
Surface Water:	

Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Feather River flows and integrate with Oroville operations
Est. Water Developed:	Existing ag demands and contracts > 250 TAF/yr
Relative Cost:	Low in Western Canal only; high to include Durham area
Site Status:	**Retain for further analysis**

Orland-Artois Water District

Project Operations

Orland-Artois WD, a CVP Ag Service contractor, receives additional surface water from the Tehama-Colusa (TC) or Glen Colusa (GC) Canals, or directly from Stony Creek. Additional surface water reduces groundwater demand in current cone of depression. Water is returned to the system with additional groundwater pumping in dry years instead of Orland-Artois WD taking all or a portion of their CVP contract. (*Note, the original discussion focused on this project with M&T Chico Ranch, but M&T is on east side of river while current cone of depression is on west side of the river, so a more likely project partner would be Orland-Artois WD.)*

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the southern portion of Orland-Artois WD area in 2006 was approximately 25 ft, but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from streams tributary to Willow Creek.

Table 2: Orland-Artois WD Site Attributes

General Site Information	
Project Location:	Between TC and GC Canals south of Stony Creek
Current Water Source:	GW and mixed within Orland-Artois WD
Approximate Area:	? acres in cone; Orland Artois WD = 25,000 ag acres
Existing Project Contracts:	Orland-Artois WD – 53 TAF/yr CVP Ag service
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Additional SW thru TC Canal, Stony Creek, or uphill from GC Canal
Return (dry years):	Pump additional GW to reduce surface water diversions and back water into Shasta and/or Stony Creek System

Aquifer Characteristics	
GW Recharge Concept:	In-lieu and natural recharge from Stony Creek
Existing GW Levels:	Seasonally depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Stony Creek and Sacramento River
GW Quality:	High nitrates occur in Arbuckle, Knights Landing, and Willows. Localized areas have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP with Orland-Artois WD
With Project:	Possibly expand integration with CVP thru TC or GC canals
Reservoirs:	Shasta (Folsom) and/or Stony Creek system
Infrastructure Requirements	
Supply Water:	Distribution system, extend canals and possibly lift water from GC canal
Return Water:	Additional wells within Orland-Artois WD; minimal to return water to GC Canal
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Existing ag demands and contracts > 50 TAF/yr
Relative Cost:	Medium
Site Status:	**Retain for further analysis**

Capay Rancho Water District

Project Operations

Capay Rancho WD would operate a groundwater bank by receiving surface water in wet years. Capay Rancho, a groundwater only district, is located over an existing cone of depression that may be utilized to store water. Methods for returning additional GW to the system in dry years are more complex, but may involve supplying water to areas in the TC Canal service area or GCID.

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Capay WD area in 2006 was approximately 50 ft with an average value of approximately 25 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Stony Creek and other local streams.

Table 3: Capay Rancho WD Site Attributes

General Site Information	
Project Location:	Between TC Canal and Sacramento River, north of Stony Creek
Current Water Source:	GW
Approximate Area:	? acres overlying cone; Capay Rancho WD = 7,700 ag acres
Existing Project Contracts:	None
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Provide surface water thru TC Canal, Stony Creek, or pump up from Sacramento River or head of GC Canal
Return (dry years):	Pump additional GW, possibly into GC Canal to reduce surface water diversions and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu and natural recharge in Stony Creek
Existing GW Levels:	Seasonally depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Project borders Sacramento River, near Stony Creek
GW Quality:	The Corning Subbasin has locally high calcium.
Integration with SW System	
Existing:	None
With Project:	CVP thru TC or GC Canals
Reservoirs:	Shasta (Folsom) and/or Stony Creek system
Infrastructure Requirements	
Supply Water:	Distribution system to take surface water from nearby canals; possibly lift from Sacramento River, Stony Creek, or GC Canal
Return Water:	Conveyance to pump GW into GC or TC Canals?
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Currently no ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Small ag area (demands) and no existing contracts
Relative Cost:	Medium

Site Status:	**Drop from study**

Corning Canal Service Area

Project Operations

A portion of the Corning Canal Service Area overlies an existing cone of depression north of Richfield and west of Tehama. The overlying districts that could operate the groundwater bank include Elder Creek, El Camino ID, Tehama Ranch, and Thomes Creek. The Corning Canal runs though these districts and typically has unutilized capacity. CVP contractors along the Corning Canal include Proberta (3.5 TAF/yr), Thomes Creek (6.4 TAF/yr), and Corning (23 TAF/yr) WDs. These WDs have recently been pumping additional GW instead of taking CVP contract water due to the relative costs of CVP water to groundwater.

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Corning Canal Service Area in 2006 was in excess of 50 ft; but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Thomes Creek, Elder Creek, and other local streams draining the western foothills.

Table 4: Corning Canal Service Area Site Attributes

General Site Information	
Project Location:	Corning Canal service area
Current Water Source:	Mixed
Approximate Area:	? acres overlying cone of depression
Existing Project Contracts:	Corning Canal contracts total 32.9 TAF/yr
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Supply SW thru Corning Canal and possibly TC Canal
Return (dry years):	Pump additional GW to reduce surface water diversions and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River and Thomes Creek
GW Quality:	Impairments in the Red Bluff Subbasin include high magnesium, TDS, calcium, ASAR, and phosphorus.

Integration with SW System	
Existing:	CVP Ag service contractors currently integrated
With Project:	Potential to integrate additional areas with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Minimal in Corning Canal area; significant in existing GW only areas
Return Water:	Additional wells and conveyance?
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with Shasta operations
Est. Water Developed:	Existing ag demands and contracts > 30 TAF/yr
Relative Cost:	Low Corning Canal area only; High to include other areas
Site Status:	**Retain for further analysis**

Yolo-Zamora Water District

Project Operations

The Yolo-Zamora WD overlies an existing cone of depression and relies on groundwater for irrigation. Surface water could be supplied by extending the Tehama Colusa Canal or constructing a canal from the Sacramento River. This has been studied in the past but rejected as too expensive as a substitute for groundwater for irrigation. Returning water to the system may be challenging.

Current Groundwater Conditions

Unable to evaluate due to lack of data from the Central District at this time. Awaiting receipt of groundwater level data from DWR.

Table 5: Yolo-Zamora WD Site Attributes

General Site Information	
Project Location:	Between southern end of Colusa Basin Drain (CBD) and north of Cache Creek
Current Water Source:	GW
Approximate Area:	? acres overlying cone; Yolo-Zamora WD = 19,000 ag acres
Existing Project Contracts:	None

Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Surface water thru TC Canal or possibly from Colusa Basin Drain
Return (dry years):	Challenging to return water to system
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	Depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River and Cache Creek
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	None
With Project:	Possibly with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Extend TC Canal or CBD; distribution system within Yolo-Zamora WD
Return Water:	Unknown
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Currently no ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Significant ag area (demands) but no existing contracts
Relative Cost:	High
Site Status:	**Drop from study**

Glenn-Colusa Irrigation District - Stony Creek Fan

Project Operations

Glenn-Colusa Irrigation District (GCID) could operate a groundwater bank in the Stony Creek Fan, banking CVP water in wet years and reducing CVP surface water deliveries in dry years. This operation may be similar to recent groundwater substitution transfers.

Current Groundwater Conditions

The northern portion of GCID represents an area known to have high aquifer transmissivity. The area is currently served by surface water. The area is underlain by the lower Tuscan Aquifer as well as shallower producing zones in the Tehama Formation. Groundwater levels in this area are shallow, generally less than 10 to 15 ft in the spring. Hydrographs suggest very little seasonal fluctuation in groundwater levels.

The southwestern portion of GCID is still relatively high, but less than that of the northern portion due to the proximity to the margin of the groundwater basin. Well yields in this area are more than sufficient to meet the demands of a take then put project. The area is currently served by surface water. Groundwater levels in this area are shallow, generally less than 5 to 15 ft in the spring. Hydrographs suggest extremely little seasonal fluctuation in groundwater levels.

Table 6: GCID-Stony Creek Fan Site Attributes

General Site Information	
Project Location:	Northern portion of GCID
Current Water Source:	Primarily surface water
Approximate Area:	Estimate area within GCID overlying Stony Creek Fan
Existing Project Contracts:	GCID - 825 TAF/yr Settlement Contract
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	In normal and wet years area takes existing surface water supply
Return (dry years):	Water returned to system by additional GW pumping to reduce surface water deliveries and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	Natural
Existing GW Levels:	Shallow and stable
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP thru GCID
With Project:	No change
Reservoirs:	Shasta (Folsom); potentially Stony Creek System
Infrastructure Requirements	
Supply Water:	None
Return Water:	Additional wells
Possible Impacts	
Surface Water:	

Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Existing ag demands and contracts > 800 TAF/yr
Relative Cost:	Low
Site Status:	**Retain for further analysis**

Willow Creek Mutual Water District

Project Operations

Willow Creek Mutual Water District (MWD) is a mixed groundwater and surface water district located between the GC Canal and the Sacramento River southeast of Willows. Willow Creek MWD is located in close proximity to the Sacramento National Wildlife Refuge. The District is small and does not have substantial agricultural areas.

Current Groundwater Conditions

Groundwater characteristics were not evaluated due to proximity to the Sacramento National Wildlife Refuge.

Table 7: Willow Creek MWD Site Attributes

General Site Information	
Project Location:	West of Willow Creek, east of Sacramento NWR and north of Delevan NWR
Current Water Source:	Mixed
Approximate Area:	Willow Creek MWD = 7,100 acres total, 2,900 ag
Existing Project Contracts:	None
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	
Return (dry years):	
Aquifer Characteristics	
GW Recharge Concept:	
Existing GW Levels:	Shallow and stable
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia,

	and phosphorus.
Integration with SW System	
Existing:	
With Project:	
Reservoirs:	
Infrastructure Requirements	
Supply Water:	
Return Water:	
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Currently no ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Small ag area (demands) and no existing contracts
Relative Cost:	Not evaluated
Site Status:	**Drop from study**

Colusa County Water District

Project Operations

Colusa County WD is a CVP Ag Service contractor that takes delivery from the southern reaches of the Tehama Colusa Canal. Some areas within the district are noted to receive both surface and GW. (*Note, the original discussion included extracting the water from RD 108, but RD 108 is primarily supplied from surface water and borders the Sac River. I don't know that this is reasonable or necessary, though water banked under Colusa County WD may flow to RD 108.)*

Current Groundwater Conditions

Wells to the east of I-5 indicate relatively shallow depth to water (<5 to 40 ft below ground surface [bgs]) in the spring of 2006. Depth to water increases to the west, in excess of 100 feet below ground surface along the western boundary of the water district. Wells in the eastern portion of the water district generally have higher seasonal fluctuations (up to 20 ft). Wells in the western portion of the district show little to no seasonal fluctuation in groundwater levels. Hydrographs further suggest that there is no long-term trend in groundwater levels since 2000. Aquifer transmissivity in this area decreases due to proximity to the margin of the groundwater basin.

Table 8: Colusa County WD Site Attributes

General Site Information

Project Location:	Southern reaches of TC Canal, west of RD 108
Current Water Source:	Mixed
Approximate Area:	Colusa County WD = 38,000 ag acres
Existing Project Contracts:	Colusa County WD - 68 TAF/yr
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	Supply additional surface water through TC Canal
Return (dry years):	Pump additional groundwater to reduce surface water deliveries and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	Stable since 2000. Depth increases from east-west (<5 ft bgs to >100 ft bgs).
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Local streams
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP
With Project:	Expanded integration with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Minimal
Return Water:	Minimal
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with Shasta operations
Est. Water Developed:	Existing ag demands and contracts > 65 TAF/yr
Relative Cost:	Inexpensive
Site Status:	**Retain for further analysis**

Olive Percy Davis Ranch

Project Operations

The Olive Percy Davis Ranch (Ranch) has a Sacramento River Settlement Contract for water from the Sacramento River and CVP. The Ranch is located along the west bank of the river, east of Williams. The ranch has mixed water sources to include surface and groundwater.

Current Groundwater Conditions

Hydrographs in this area indicate that groundwater in this area is extremely shallow (up to 5 ft bgs) with very little seasonal fluctuation. Proximity to the Sacramento River could affect the implementability of a take then put project due to concerns regarding impacts on surface water resources. The aquifer in this area will likely yield large quantities of water to wells.

Table 9: Olive Percy Ranch Site Attributes

General Site Information	
Project Location:	Between town of Williams and Sacramento River
Current Water Source:	Mixed
Approximate Area:	Ranch = 6,900 ag acres (9,110 per contract)
Existing Project Contracts:	Ranch = 31.8 TAF/yr Settlement Contract
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	Supply additional surface water from Sacramento River
Return (dry years):	Pump additional groundwater to reduce surface water deliveries and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP
With Project:	Expanded integration with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Potentially expand SW distribution system
Return Water:	Additional pumps?

Possible Impacts	
Surface Water:	Possible impacts to Sacramento River flows from increased GW pumping
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with Shasta operations; close proximity to Sacramento River raises concerns over SW-GW interaction and impacts
Est. Water Developed:	Existing ag demands and contracts > 30 TAF/yr
Relative Cost:	Inexpensive
Site Status:	**Retain for further analysis**

summary of site screening

A summary of the nine proposed sites and their respective status is provided in the following table.

Table 10: Summary of Site Status

Site Name	Status
Western Canal WD – Durham	**Retain**
Orland Artois WD	**Retain**
Capay Rancho WD	Drop
Corning Canal Service Area	**Retain**
Yolo-Zamora WD	Drop
GCID – Stony Creek Fan	**Retain**
Willow Creek MWD	Drop
Colusa County WD	**Retain**
Olive Percy Davis Ranch	**Retain**

The six sites that are retained will be carried forward for additional analysis to include calculation of water budgets, determination of aquifer characteristics, and preliminary surface water modeling.

Appendix C:

Lower Tuscan Integrated Conjunctive Water Management Plan

Technical Team Meeting
July 30, 2007

Summary Notes

Following are brief notes from a meeting of the Lower Tuscan Technical Team at MBK Engineers on July 30, 2007. These are not intended as meeting minutes, rather as a summary of key points, decisions and action items. The primary purposes of the meeting were to: 1) resolve issues related to project site selection and 2) reach consensus on the technical approach for the groundwater analysis. Environmental flows for the Feather River were also discussed. The full meeting agenda is attached.

Attendees:
Thad Bettner/GCID
Carrie Monohan/NHI
John Cain/NHI
Peter Lawson/CH2M HILL
Walter Bourez/MBK
Lee Bergfeld/MBK
Grant Davids/Davids Engineering
Maurice Hall/DWR

1. Revisit Potential "Put-then-Take" Sites

Peter reviewed the rationale that had been used to identify particular geographic areas for investigation of put-then-take (P-T) conjunctive operations. While there are areas in the Valley where cones of depression develop seasonally, those cones generally refill each year by natural recharge and therefore do not offer opportunity for inter-annual storage as is needed for conjunctive operations. Additionally, to the extent that groundwater levels in these areas do not recover completely, this tends to occur in dry years when there would be little surface water available for recharge.

Groundwater hydrographs were reviewed for three areas where seasonal cones of depression occur:

- Chico-Durham
- Capay
- Corning

Some long-term downward decline in groundwater levels is evident in some wells, but there are no persistent inter-annual cones of depression in these areas.

The Yolo-Zamora area was also discussed. Lee explained that while this area does have a local cone of depression that might be conducive to groundwater storage, there are two major shortcomings associated with this site. One is that it does not have an existing surface water supply to forego use of in dry years (and a new surface water supply would most likely be a CVP water service contract which would not provide a reliable dry year supply). The second is the need for extensive infrastructure improvements involving extension of the Tehama-Colusa Canal and construction of a completely new water distribution system.

The conclusion of the review was that there are no areas where a P-T strategy appears workable at this time on an appreciable scale. Therefore the investigation will proceed focusing on "take-then-put" (T-P) strategies, recognizing that natural recharge will play a significant role in refilling groundwater extracted for project purposes.

The degree of rigor and level of documentation needed in our screening process was discussed. It was agreed that our objective is not to conduct an exhaustive assessment of all possible conjunctive management sites in the Sac Valley, but to identify 2 or 3 most promising sites based on available information and professional judgment, and move ahead with characterization of those sites and development of our analytical tools. We also agreed that given the more detailed modeling approach we have adopted (see below), we should not conduct intermediate analyses of several sites (as originally planned) as a means of selecting the final 2 or 3.

The primary qualifications for candidate T-P sites (as discussed at our last meeting) are places where:

4) Surface water supplies are reliable (meaning appreciable entitlement in dry years) and form a substantial portion or all of the total irrigation water supply.

5) Underlying groundwater aquifers are productive and economically developed

6) Interaction between groundwater and surface streams, especially the Sacramento River and Feather River does not exist or is highly damped.

Additionally, sites that have potential to produce large quantities of groundwater are desirable.

The following three locales were discussed as having these basic attributes, and will receive primary attention as we move ahead with T-P analyses.

- Western Canal WD (potentially including the Chico-Dayton area)
- Stony Creek Fan-Northern GCID
- Central GCID

It was agreed that Carrie would spearhead documentation of our site screening and selection process. Our documentation needs to be clear that elimination of sites for our purposes at this time does not mean that those sites would not be attractive for other purposes or at other times.

2. Analytical Approaches and Tools

The ongoing Delta Vision process and its possible implications to our project were discussed at some length. It was acknowledged that it is as likely that future Delta operations will change, perhaps appreciably, as they are to remain the same. However, it was also acknowledged there is no reliable way to anticipate possible future Delta changes nor related changes to CVP and SWP reservoir operations. We agreed to continue the planned course of analysis within the context of existing Delta operating parameters. The tools and knowledge we are developing may be instructive for planning broader operational changes, but this is outside the scope of our current effort.

The three model improvement approaches formulated by CH2M HILL and MBK were discussed and a decision was made to pursue modifications to the existing superposition model (Option 3). This begins with MBK providing spatially distributed hydrologic time series to CH2M HILL for incorporation into the model. The model will be calibrated to historical groundwater levels.

The need to acknowledge and understand the nature of error and uncertainty in our analysis was discussed. Peter mentioned that sensitivity analyses could be conducted to assist in this process. We will need to track this and design appropriate analyses when we are further along.

Grant will review project budgets to identify where the necessary additional $40,000 can be found and review the necessary adjustments with GCID, NHI and DWR.

3. Environmental Flows

John and Carrie reiterated NHI’s basic approach of seeking operational changes that move toward pre-project flow regimes. This approach, rather than a species-specific approach, is thought to be most effective and defensible. Hydrographs for the Feather River were discussed. (This discussion occurred in conjunction with discussion of Item 2.)

Specific rules and priorities by month are needed to incorporate the environmental flows into the analysis. John and Carrie will work on this next.

4. Schedule

Peter, Lee and Walter will establish milestones and develop a proposed schedule for completion of technical tasks to be reviewed by the Team.

5. Summary of Action Items

- Carrie will initiate draft documentation of our site screening and selection processes drawing on the assistance of other team members as needed. A draft will be distributed before our next meeting.
- Lee to transfer hydrologic data to Peter ASAP.
- Grant to review project budgets and initiate task order revisions to CH2M HILL and MBK, in coordination with GCID, NHI and DWR, ASAP.
- John and Carrie to coordinate with Walter in expressing environmental flows in a form conducive to modeling.
- Peter, Lee and Walter will establish milestones and develop a proposed schedule for completion of technical tasks to be reviewed by the Team, ASAP.

6. Next Meeting

The next meeting was set for September 13 at 10:00 a.m. at MBK

Appendix D
Estimating Ecologically Based Flow Targets for the Sacramento and Feather Rivers

Estimating Ecologically Based Flow Targets for the Sacramento and Feather Rivers

THE NATURAL HERITAGE INSTITUTE

John Cain

Carrie Monohan

April 2008

PREFACE

This report was prepared as part of a collaborative investigation by the Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) to explore opportunities to expand water supplies in the Sacramento Valley through conjunctive management of surface water and groundwater supplies. These expanded supplies could contribute toward achieving three primary objectives: (1) improve local in-basin water supply reliability for farms, cities, and the environment; (2) contribute to improvement of statewide water supply reliability; and (3) enhance ecosystems in the rivers in the Sacramento Valley. The investigation was funded by the California Department of Water Resources and Bureau of Reclamation.

The Scope of Work of the federal and state grants includes a task to define a range of environmental flows to restore in stream and riparian ecosystem processes to the maximum extent compatible with the protection of the interests of the riparian landowners in the floodplain improvements. Flows shall be defined for both the Sacramento River below Shasta and Keswick dams, and the Feather River below Oroville and Thermalito dams, in terms of magnitude, duration, frequency, seasonality and reach. This will be defined in a manner to avoid any uncompensated risks to affected landowners. The range may include various assumptions about levee setbacks in the floodplains. Flood-routing models will be used to estimate the potentially inundated area and system capacity to carry environmental flows.

This report was prepared by the NHI in partial fulfillment of the above-defined task. It postulates hypothetical environmental flow regimes for the Sacramento and Feather Rivers that are significantly different from those that presently exist. It is not yet known to what extent the flows can be achieved through conjunctive water management or, potentially, by other means that are outside the scope of this investigation, while other existing and future water demands are satisfied. Also, the risks that the recommended flows may pose to affected landowners are not addressed in the report, but will be addressed in subsequent work. NHI has prepared this report for the purposes of this planning investigation only. To the extent this report is used or referenced for other purposes, it will be subject to review, modification, and acceptance by the larger number of entities and stakeholders necessarily involved in crafting water management policies, projects and practices in the Sacramento Valley and downstream affected areas.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

This study identifies an environmental flow regime for the Sacramento and the Feather Rivers in order to:

- Test the feasibility of reoperating terminal reservoirs in the Sacramento River Basin without diverting additional water away from agriculture,
- Develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River, and
- Use the environmental flow targets to inform and guide conjunctive use scenarios.

The development of environmental flow regimes is as much an art as a science, but we attempted, to the extent possible, to use established methods to develop a transparent and replicable approach for identifying and environmental flow regime. We conducted a detailed literature review of various methods and approaches previously utilized to develop environmental flow recommendations, and employ a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento and Feather Rivers. This approach relies heavily on hydrological evaluations, previous studies and modeling efforts analysis of historical hydrology, and expert opinion to estimate environmental flow requirements.

Our approach consists of five basic steps:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support achieve environmental objectives.
3. Compare and analyze existing and historical hydrology to understand natural hydrologic patterns and how they have been altered.
4. Identify obvious gaps between flows necessary to achieve objectives and existing flows.
5. Modify the existing hydrograph into an environmental flow hydrograph based on an understanding of natural hydrology and the flows necessary to achieve key objectives.

These five steps will ultimately need to be followed by an adaptive management research program to test and refine an improved environmental flow regime over time.

We designed the environmental hydrograph to achieve the following three types of objectives

- Geomorphic Functionality: Bed mobility, channel migration, and floodplain inundation.

- Riparian Habitat Sustainability: Recruitment and maintenance of Fremont Cottonwood.
- Chinook Salmon: Improved habitat, particularly rearing habitat, for all runs.

We relied on field data, modeling results, and studies , particularly the recent Nature Conservancy Study of the Sacramento River, to identify the minimum flows and critical thresholds to achieve each of our objectives. We then analyzed historical and existing hydrology to understand how the objectives may have been achieved under pre-dam conditions and to evaluate how existing hydrology may fall short of meeting those objectives.

A sharp reduction in the magnitude and duration of the late winter and early spring hydrograph and a corresponding reduction of inundated floodplain habitat is the most obvious and significant change in the hydrograph on both the Sacramento and Feather Rivers. The reduction in late winter and spring flows reduces the frequency of geomorphic and riparian flows and substantially reduces the extent and frequency of occurrence of inundated floodplain rearing habitat for salmonids. Restoring spring flows alone, however, will not be sufficient to dramatically increase the amount of floodplain habitat. Modifications of the levees and bypass system will also be necessary to enable high flows to inundate historical floodplains. We evaluate the amount of flow necessary to inundate the Yolo and Sutter Bypasses assuming modification of the weirs controlling flows into those bypasses in the interest of identifying water efficient strategies for creating large areas of inundated floodplain habitat.

The last chapter identifies an environmental flow regime for the Sacramento and Feather Rivers. An increase in late winter and early spring flow is the primary component of the environmental flow regime, but a corresponding reduction in summer base flows is also recommended. Reduced summer flows are primarily needed to free-up water needed to restore the spring hydrograph but may also provide ecological benefits by better approximating the natural hydrograph. Reducing summer base flows could, however, increase summer temperatures and harm salmonids including the endangered winter-run Chinook salmon. On the other hand, cool water temperatures in the upper Sacramento River are largely controlled by the volume of cold water storage behind Shasta Dam and the environmental flow regime identified here does not involve modifying coldwater pool management.

The summer temperature issue is one of several key uncertainties that must be addressed before any significant modifications to the flow regime can be refined and implemented for environmental purposes. Articulating a hypothetical environmental flow regime is the first step in identifying and addressing constraints and uncertainties associated with improving environmental flow regimes on regulated rivers. To that end, NHI welcomes comments and criticisms so that we can improve upon this report as we learn more about the rivers and the people who depend upon them for their livelihood.

2. INTRODUCTION

This study identifies environmental flow targets for the Sacramento River and the Feather River. The purpose of developing environmental flow targets is to:

- Test the feasibility of reoperating terminal reservoirs in the Sacramento River Basin without diverting additional water away from agriculture,
- Develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River, and
- Use the environmental flow targets to inform and guide conjunctive use scenarios.

Our thesis is that reservoirs operated today for a limited set of water supply and flood control objectives could be reoperated to achieve newly defined ecological objectives without compromising existing objectives. This opportunity was recognized by the authors of CALFED's Strategic Plan for Ecosystem Restoration:

> "There is underutilized potential to modify reservoir operations rules to create more dynamic, natural high-flow regimes in regulated rivers without seriously impinging the water storage purposes for which the reservoir was constructed. Water release operating rules could be changed to ensure greater variability of flow, provide adequate spring flows for riparian vegetation establishment, simulate effects of natural floods in scouring riverbeds and creating point bars, and increase the frequency and duration of overflow onto adjacent floodplains."

Clearly defining this new set of ecological objectives and estimating the flows necessary to achieve them is the first step toward evaluating the feasibility of restoring these flows. The biological and physical processes that support natural riverine functions are complex and the task of defining environmental flow regimes is enormously difficult. For the purpose of defining an environmental flow regime and assessing the feasibility of attaining it, we have identified a simplified but broad set of water intensive ecological objectives that best capture the full range and magnitude of environmental flow requirements in the Sacramento Basin. These objectives include:

- Geomorphic Processes: sediment transport, channel geomorphology, floodplain inundation.
- Riparian vegetation: cottonwood recruitment and maintenance flows
- Chinook and Steelhead: stream temperatures and adequate flow for various life stages.

This study focuses on the magnitude and timing of flows necessary to replicate key ecological and geomorphic processes, and considers the flows necessary to provide suitable conditions for various life stages of Chinook salmon and steelhead. This study does not identify specific population targets for salmonid restoration, nor does it address important non-flow objectives such as habitat area required for restoration of target species or augmentation of coarse sediment supplies necessary to restore full geomorphic structure and function. Rather this study focuses on magnitude, pattern, and quantity of water necessary to restore ecological functions assuming that adequate physical habitat exists or will be created to complement a suitable environmental flow regime. The rationale of this focus is to identify a hypothetical environmental flow regime for the purpose of evaluating whether it is possible to reestablish ecological and geomorphic flows on the rivers of the Sacramento Basin without reducing water supply deliveries to existing water users.

This report would not have been possible without the foundational analysis conducted by the Nature Conservancy and their consulting team, but it differs substantially from the Sacramento River Ecological Flows Study (SREFS) developed by the Nature Conservancy with funding from the CALFED Bay-Delta Program. The SREFS compiled information on the state of the Sacramento River ecosystem and developed a decision support tool to predict how changes in the flow regime of the Sacramento River might affect key attributes and species of the riverine ecosystem. The SREFS did not, however, attempt to develop an environmental flow prescription for the river and did not address ecological conditions or flow requirements for the Feather River. The SREFS decision support tool could be used to test and refine the flow regime developed for this report, but the SREFS did not and will not propose an environmental flow regime. We relied heavily on the information developed for the SREFS to generate the environmental flow regime described in this report.

Our study relies heavily on analysis of historical hydrology and the habitat it created to provide a reference point for identifying ecosystem restoration goals, but we recognize that it is not possible to restore historic conditions in highly altered systems such as the Sacramento River. Historical hydrologic analysis is useful for identifying patterns in the timing, magnitude, duration, and frequency of flows that may be important for maintaining native species, but it is less useful in developing specific flow prescriptions, because physical habitat has been so profoundly changed by dams and levees. We recognize that it is not possible to fully restore historical hydrology or habitat conditions in the Sacramento Valley, but ecosystem restoration will require reestablishment of a minimum threshold of both hydrologic and physical habitat conditions.

Although this study identifies hypothetical restoration flow regimes for the Sacramento and Feather Rivers, we recognize that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The hypothetical flow regime serves as a reasonable starting point for evaluating the economic feasibility of reoperating reservoirs and a long-term adaptive management program. The assumptions and uncertainties associated with the hypothetical flow regime are important to acknowledge and understand. To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of modeling, pilot flow studies, model calibration, and long-term implementation.

3. METHOD FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS FOR THE SACRAMENTO AND FEATHER RIVERS

We conducted a detailed literature review of various methods and approaches previously utilized to develop environmental flow recommendations, which is described in further detail in Appendix A. We have employed a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento River. This approach relies heavily on hydrological evaluations, previous studies, and expert opinion to estimate environmental flow requirements and develop a long-term adaptive management plan for implementing and refining an environmental flow regime over time. The results of the holistic approach provide a framework for increasing knowledge regarding the relationship between flow and environmental objectives and refining water management practices over time. The output of the holistic method envisioned here provides not only an estimate of environmental flow requirements, but more importantly, an explicit identification of key assumptions and uncertainties that need to be tested overtime to more accurately describe the flow requirements necessary to achieve environmental objectives.

We made two important assumptions in generally applying this method to the Sacramento River.

- Similarities in both the restoration objectives and the hydrologic, geomorphic, and ecological conditions on the Sacramento River will result in relatively similar prescriptions for environmental management flows. We believe this assumption is well supported by the environmental conditions and historical alteration of this river.

- The flow necessary to achieve restoration objectives may vary greatly depending on non-flow restoration actions such as improving spawning habitat, reconstructing degraded channel, removing levees to restore floodplain habitat, modifying and screening water diversions, reducing polluted run-off, managing ocean harvest, and other factors. In general, non-flow restoration actions will reduce the amount of water necessary to achieve restoration objectives.

The holistic approach applied in this study consists of the following 6-step process to identify an environmental flow regime:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.
3. Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.

4. Identify obvious gaps between objective flow requirements and existing flows.
5. Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.
6. Design an adaptive management program to further test and refine environmental flows.

1) Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).

Well-articulated target ecological conditions and desired species and communities are necessary for establishing environmental flows. Despite the correctly vogue concept of restoring ecosystem processes and avoiding species specific approaches, there is no getting around the fact that key species need specific hydrologic conditions at specific times. This analysis will include both aquatic and riparian communities and the flow parameters necessary to sustain these communities such as floodplain inundation, appropriate water temperature, or creation of structural habitat through geomorphic processes. These specific environmental objectives may vary by region, sub-basin, and reach of the river.

2) Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.

An environmental flow regime encompasses the adequate timing, magnitude, duration, and frequency of flows necessary to support target species and facilitate specific ecological processes encompassed in the stated environmental objectives. Where we understand the life cycle timing of various target species, it is relatively easy to identify the approximate timing and duration of flows necessary to support different life stages of target species. Estimating the required flow magnitude is far more difficult but can be informed by field data, results of numerical models, and general relationships described in the literature. Most short lived target species require adequate flows each year to reproduce, while longer lived species can sustain their populations with a lower frequency of flow conditions conducive to reproduction. For example, riparian forest species may only require recruitment flows every five to ten years to establish new seedlings.

Estimating the magnitude of flows necessary to support or optimize conditions for target species and processes is by far the most difficult element of the environmental hydrograph to approximate. Environmental engineers and biologists have developed relatively elaborate methods for determining ideal flow regimes such as physical habitat simulation (PHABSIM) and Instream Incremental Flow Methodology (IFIM) to identify optimum flow magnitudes based on known habitat preferences of target species, measured habitat conditions (velocity and depth) at various flows, and numerical models that predict habitat conditions at a range of flows. Numerical models that describe the width, depth, and velocity of the rivers at various discharges are useful for predicting river stage and temperature at various locations, factors that are important considerations for habitat or facilitating geomorphic and hydrologic processes. As discussed above, these models tend to focus on the needs of specific species and can sometimes produce results that are inconsistent with both holistic ecological process restoration and common sense. Furthermore, these models are often not calibrated, particularly at higher flows relevant to riparian recruitment, geomorphic processes, and spring outmigration temperatures. Nevertheless, we utilized the results of these models as a guide combined with other information to develop our environmental flow management hypothesis.

Where possible, we relied on actual data and measurements to estimate the flows necessary to achieve suitable conditions to support biological, riparian, and geomorphic objectives for temperature, floodplain inundation, and bed mobilization. In particular, we relied on USGS temperature gauges to characterize the relationship between temperature and flow. Similarly, we relied on previous studies of the rivers to characterize flows necessary to mobilize bed material and inundate the floodplain.

3) Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.

Analyses of historical hydrologic data is useful for describing natural patterns and identifying potential links between hydrology and the requirements necessary to maintain species and precipitate key processes. An analysis of historical patterns can provide clues about the timing, magnitude, duration, and frequency of flows under which target species have evolved. Identification of major changes between historical and hydrologic patterns combined with the life history requirements of various species can help generate hypotheses about how flow regulation may be limiting target species. We will use the an analysis similar to the Index of Hydrologic Alteration approach (Richter et al. 1996) and the Hydrograph Component Analysis (HCA) (Trush et al. 2000) to evaluate changes in flow patterns. The analysis similar to the IHA provides a quick statistical overview of how several important hydrologic attributes have changed. The analysis similar to the Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. While valid and useful, the statistical analysis in the IHA method is not substitute for visually comparing and evaluating key components of the pre- and post-dam hydrographs. Similarly, visual comparisons of pre- and post-alteration hydrographs don't always reveal important changes identified by the IHA method.

4) Identify obvious gaps between objective flow requirements and existing flows.

An analysis of historical flow patterns combined with an approximation of the TMDF of flows necessary to achieve objectives compared with the regulated flow regime can help illustrate obvious gaps between regulated flows and flows that may be necessary to achieve environmental objectives. We will plot TMDF flow requirements developed in Step 2 as an annual hydrograph and compare it with average regulated and historical conditions.

5) Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.

This project identifies hypothetical restoration flow regimes but recognizes that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The purpose of developing the hypothetical flow regime is to develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River. However, the assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself.

6) Design an adaptive management program to further test and refine environmental flows.

To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of numerical modeling, pilot flow studies, model calibration, and long-term restoration implementation.

4. IDENTIFY ENVIRONMENTAL OBJECTIVES AND UNDERLYING CONCEPTUAL MODELS

4.1. Environmental Objectives

The geomorphic, riparian, and salmonid objectives considered in this report are summarized below. A more detailed description of the objectives, background information, and the underlying conceptual models is included in Appendix B.

Geomorphic Objectives

- Sediment Transport: bed mobilization and bed scour
- Channel Migration
- Floodplain Processes: inundation and fine sediment deposition

Riparian Objectives

- Fremont cottonwood seedbed preparation
- Fremont cottonwood seed germination
- Fremont cottonwood seedling growth
- Periodic large-scale disturbance of the riparian zone
- Riparian stand structure and diversity

Chinook Objectives

- Chinnook salmon: suitable flow conditions and temperatures for all life stages.
- Provide inundated floodplain habitat for rearing juveniles during the later winter and early spring.
- Maintain and recruit spawning habitat, but avoid scouring gravels while eggs or alevon are present

We purposely did not identify population targets for salmonids. The extent and magnitude of restoration actions depends on the size of the population fish managers are attempting to restore. More fish require presumably require more habitat particularly for spawning and rearing. Creating more habitat may require both physical changes in channel conditions and increased flows. .

Appendix B describes the underlying assumptions and rationale (conceptual model) for environmental flow requirements. It describes the science of how and why river flows are necessary to achieve the objectives listed above, and identifies some of the challenges associated with developing environmental flow prescriptions.

5. ENVIRONMENTAL FLOW THRESHOLDS AND REQUIREMENTS

5.1 Geomorphic Thresholds

Flow requirements broadly fall into two categories: threshold and targets. Thresholds are flow prescriptions that only achieve their objective if the threshold is reached or exceeded. For example, bed mobility flows must be high enough to mobilize the bed. If they are below the threshold, the bed does not mobilize and no progress toward the objective occurs. In actuality, however, bed mobilization may occur at different flows in different reaches making it difficult if not impossible to name a single threshold number. Targets are flow requirements that are desirable but not essential to achieve. Benefits still accrue when there is progress toward the target even though the target is not actually reached. For example, a flow release to meet a target of 5,000 cfs to achieve an optimal water temperature for twenty four hours a day will still provide temperature benefits even if the release only achieves 4,000 cfs and optimal water temperatures eighteen hours per day. At some point, however, there is a minimum threshold or minimum flow below which temperatures are lethal or flows are insufficient to support fish.

This paper focuses on thresholds for key ecological and geomorphic objectives that generally require high flow thresholds, but also identifies flow targets to sustain salmon. We have not attempted to define minimum flow thresholds for salmon, but rather have identified more generous targets based on historical base flow conditions. We identify the basis for these thresholds and targets in this section and compile them into a environmental hydrograph in the final chapter of this report.

For each threshold, we have estimated the magnitude, duration, frequency, and timing of flows necessary to achieve a desired outcome and have organized table X and the following text accordingly.

5.1.1. Bed Mobilization:

Magnitude: There is limited information regarding the magnitude of flows required to initiate bed mobilization on the Sacramento River, but less information regarding flows necessary to precipitate full-scale bed mobilization. Under natural conditions the gravel bedded reaches of the Sacramento River were theoretically mobilized by peak flows exceeding the 1.5 to 2 year recurrence interval of the annual instantaneous peak (Leopold et al 1964), which is approximately 80,000 cfs to 120,000 cfs. For comparison, the post dam Q1.5 and 2.0 recurrence interval flow is approximately 65,000 and 80,000 cfs respectively. The Department of Water Resources estimated that the threshold for spawning gravel mobilization immediately below Keswick Dam was 50,000 cfs (CDWR 1981), but this is considered to be a minimum because it was based on observations of gravel that was artificially deposited below the dam *(Stillwater,* *2006).*[1] DWR added 13,300 yd^3 of gravel below Keswick Dam in 1978 and 1979, and estimated that 85% of it was eroded by high flows of 36,000 and 50,000 cfs during the winter of 1980 (CDWR 1981). Latter, Koll Buer of the USBR measured mobility and transport downstream of Keswick with “flower box” samplers – boxes placed into the channel bed before a high flow event. Buer’s measurements indicate that gravel transport begins at 24,000 cfs but did not provide information about when larger gravels and the entire bed begin to mobilize. The coarser riffles downstream of Keswick (small boulders and large cobbles) are probably armored due to years of erosion from sediment free water released from Shasta Dam. These armored riffles appear not to change and thus probably remain immobile even at flows exceeding 100,000 cfs (K. Buer, personal communication in Kondolf, 2000).

There are not empirical studies or observations regarding bed mobility on the Feather River. Historical flow data is the only information available to estimate the discharge necessary to mobilize the bed on the Feather River. The 1.5 to 2 year recurrence interval of the annual instantaneous peak prior to the construction of Oroville Dam was 33,000 to 50,000 cfs respectively.

Frequency: Relatively frequent bed mobilization is necessary to prevent vegetation establishment and encroachment on gravel bars. Willows can become well established and resistant to scour in three to four years (cite). Therefore, bed mobilization flows are necessary at a greater frequency then every three to four years to prevent vegetation establishment.

Duration: The duration of peak flows may vary depending on the objective. A short duration may be enough to clean gravels on a spawning riffle while a longer duration flow may be necessary to maintain overall transport of gravels. Because coarse sediment inputs are limited by the upstream dam and riffles already show signs of armoring, long duration peak flows may actually degrade riffles. For this reason and to both reduce flood hazards and economize water, a short duration bed mobilization flow of approximately 12 hours at the recommended peak flow and then ramping down thereafter consistent with historical patterns may be optimal.

Timing: Ideally, bed mobility flows should occur after fall run fry have emerged from the gravel and before swallows begin nesting on stream banks in late march. We therefore recommend a 30 day target window between February 20 and March 20.

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[1] These gravels may have mobilized at lower flows because of their unnatural position relative to the high flows or because they were not integrated into the gravel/cobble matrix of the natural bed

5.1.2 Bed Scour

Less is known about the bed scour process, flows exceeding the natural 5–10 year recurrence interval are probably necessary to precipitate bed scour (Trush et al. 2000). The pre-dam Q5 and Q10 recurrence interval on the Sacramento are 150,000 and 200,000 cfs respectively. During the post dam era, flows of 150,000 cfs or more occurred roughly once every 10 years. On the Feather River, the pre-dam Q5 and Q10 were 104,000 and 144,000 respectively. Flows of this magnitude have only occurred twice in the forty years since Oroville Dam was constructed. Because of the lack of information regarding bed scour and the probable flooding impacts of these flows, it is exceptionally difficult to develop and achieve a bed scour flow recommendation.

5.1.3 Bank Erosion and Channel Migration

Magnitude

Stillwater reports that there is general disagreement on the exact magnitude of flow to initiate substantial bank erosion, but claims there is growing evidence that flows between 20,000 and 25,000 cfs will erode some banks while flows above 50,000 to 60,000 cfs are likely to cause widespread bank erosion (Stillwater, 2007). Meander migration modeling analysis for the Sacramento River assumed that 15,000 cfs was the lower threshold for meander migration (Larsen, 2007). Total bank erosion and channel migration, however, is dependent on both the duration and magnitude of flows, which together produce a cumulative streampower in any given year. Analysis of cross section surveys (Buer, 1994a) over more than ten years shows that rates of bank erosion are closely correlated with cumulative annual stream power (Larsen, et al., unpublished in Stillwater, 2006). Bank erosion.

On the Feather River, there is very little information regarding flows necessary to initiate bank erosion and channel migration. The pre-dam Q1.5 on the Feather River (35,000 cfs) is approximately forty four percent of the pre-dam Q 1.5 on the Sacramento River (80,000) cfs. If channel migration flows on the Feather were similarly proportioned channel migration flows on the Sacramento (50,000 – 60,000 cfs), then one could expect significant and wide spread bank erosion on the Feather River at flows between 20,000 and 25,000 cfs. Instantaneous peak flows of this magnitude reoccur every 2.5 years on average, and large areas of channel revetment along the Feather River indicate that the unprotected bank is subject to erosion under the current flow regime.

Duration

The stream power relationship between magnitude and duration make it difficult to identify a specific threshold. Without modeling analysis, it is difficult to assess whether two weeks at 30,000 cfs could result in as much bank erosion as two days at 60,000 cfs.

Frequency

Bank erosion and channel migration are important for maintaining general riparian habitat, nesting habitat for bank swallows, and turbidity for juvenile fish cover. We are uncertain how often migration and erosion should occur but suspect that some bank erosion every year is a reasonable target. Slight but annual bank erosion may be beneficial for maintaining optimal bank swallow habitat. More significant and annual erosion events may be necessary for producing turbid water conditions. Moderate but less frequent bank erosion, every (2-4) years, may be adequate for generating new riparian habitat.

Timing
Erosive flows during the bank swallow nesting period, which generally begins in late March, can actually disrupt bank swallows. Therefore, it may be most beneficial to bank swallows to achieve bank erosion objectives prior to late march.

5.1.4 Floodplain Inundation and Rearing Habitat Flows

The occurrence of inundated floodplain habitat has been substantially altered by both levees and dams. Dams have reduced the frequency of high flows sufficient to inundate floodplains, while levees have prevented high flows, even very high flows, from inundating floodplains particularly in the lower reaches of the river below Colusa. It is not reasonable to reestablish inundated floodplains by overtopping levees, because it would require extremely, even unnaturally, high flows and would cause widespread flood damage.

Adequate duration of flooding in the designated flood bypasses generally occurs in the wet years and sometimes in normal wet years creating excellent conditions for salmon and splittail. But overtopping the weirs and flooding the bypasses in normal dry and dry years would require prohibitive amounts of water to achieve in normal dry and dry years. For efficiency sake, it is probably only realistic to achieve prolonged (30-60 days) floodplain inundation in normal dry and dry years by notching (or removing) the upstream weirs to allow a small amount of water to pass (3,000-5,000 cfs) and installing inflatable weirs in the low flow channels of the bypasses to back-up water.

Strategically breaching levees and flood control weirs to inundate flood bypasses and other undeveloped land is a much more prudent and achievable approach for creating inundated habitat. Although there may be many places to create inundated flood plain habitat with strategic levee modifications, we have focused on identifying flows that would create inundated habitat in the Yolo and Sutter Bypasses if modifications are made to the weirs that control flow onto the bypass. The area of inundation under a given flow is determined by topography and drainage. We assume changes in the topography and drainage of the bypasses (i.e. berms or inflatable wiers) to maximize the area of inundation at lower flows and minimize the potential for stranding. While it might be possible to create large areas of habitat at low flows, more flows may be necessary to optimize temperatures on the flood plain and conveyance of nutrients from the floodplain to the Delta.

Magnitude
We evaluated two questions associated with magnitude: the magnitude of flow necessary in the Sacramento or Feather Rivers necessary to inundate the bypasses and the magnitude of flow in the bypasses necessary to create large areas of suitable floodplain

habitat. It may be possible to inundate large areas of the bypass with relatively little flow by installing flow barriers in the bypass to back-up water onto the floodplain. While this may be suitable for creating large areas of inundation, it might not create the right residence time and temperature for optimal habitat. Habitat characteristics such as velocity, depth, temperature, residence time, primary productivity are negatively correlated with flow, while Diptera, an important food resource, was positively correlated with flow (Sommer et al, 2004).

According to DWR modeling analysis, large areas of the bypass become inundated with as little as 5,000 cfs flowing through the bypass (figure 5.1) (Harrell, B., 2008). Flows in excess of 25,000 cfs in the Sacramento River, however, may be necessary before it is possible to get 5,000 cfs down the bypass.

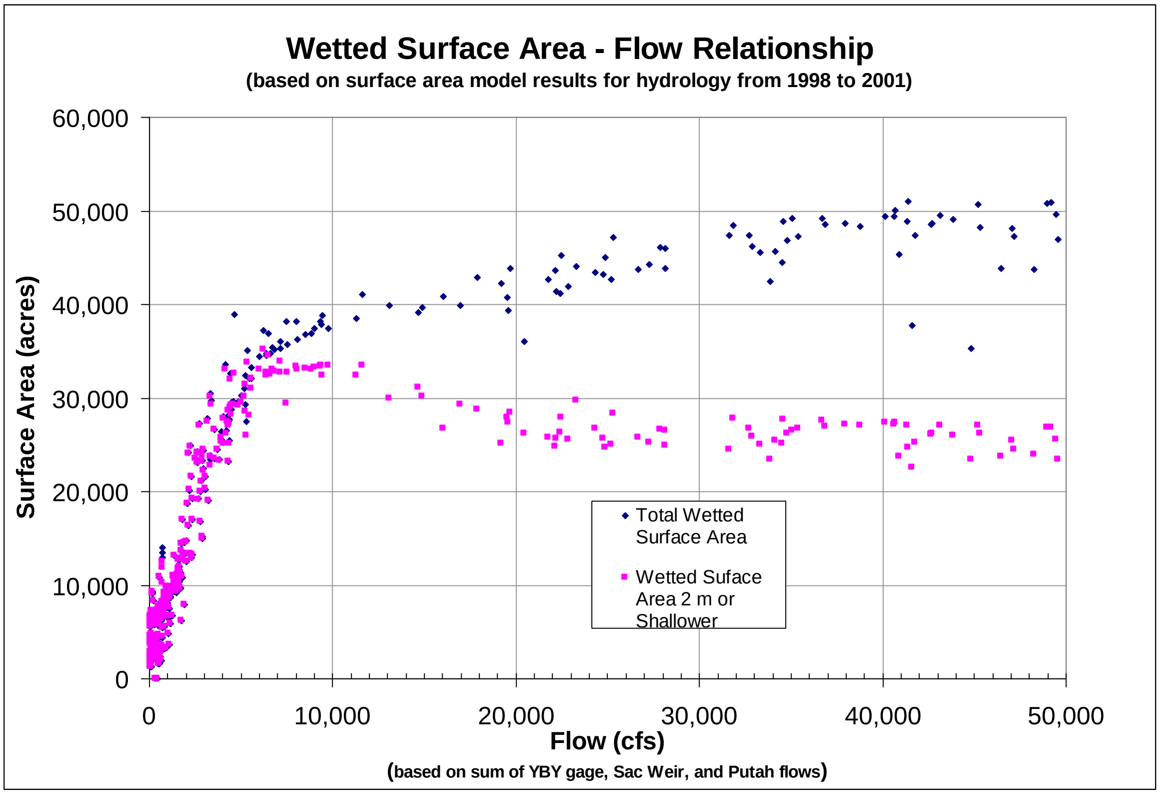


Figure 5.1: Wetter surface area-flow relationship for flows in the Yolo bypass (cite)

To estimate the amount of flow necessary to inundate the Sutter and Yolo Bypasses, we referred to USGS topographic maps to determine ground elevations at Tisdale and Freemont weirs which currently control flows onto the bypass, and then used stage discharge relationships for nearby gauges to estimate the amount of flow necessary to achieve a stage equal to the ground elevation at the weir – an overbank flow assuming the weir did not exist or was operable (table 5.1). The overbank flow, however, is not enough to push substantial amount of water down the bypasses. We therefore assumed that a minimum of 5,000 to 10,000 cfs above the overbank flow was necessary to create substantial inundated floodplain in the bypass.

Table 5.2 identifies flow recommendations for various year types at four key sites: Tisdale Weir, Freemont Weir, and Verona Gauge on the Sacramento River and Nicolaus Gauge on the Feather River. Tisdale Weir spills into the Sutter Bypass and then flows back into the Sacramento River near Freemont Weir. The sum of Freemont and Nicolaus should equal Verona. Note, however, that table 5.1 flows at Verona are lower then the sum of Freemont and Nicolaus. This is because large amounts of the Sutter Bypass (ground elevation of 25 feet) will flood with backwater from the Sacramento at flows above 27,000 cfs at Freemont Weir. In other words, if Freemont or Verona is greater then 30,000 cfs, then large amounts of the Sutter Bypass are flooded irregardless of flows in the Feather River or at Tisdale Weir.

Table 5.1: Overbank flows in the Yolo or Sutter Bypass assuming levees or weirs along the Sacramento and Feather Rivers are breached or removed

Gauge or Weir	Ground Elevation	Overbank Flow	Notes
Nicolaus Gauge (Feather)	30	10,500	
Freemont Weir	25	27,000	Approximate based on Verona Gauge
Freemont with Excavation	13	15,000	Invert of the Toe Drain
Tisdale Weir	40	25,000	Approximate
Sacramento Wier (I Street Bridge)	15	49,000	
Sac Weir with Excavation	10	31,000	Sac Weir with excavation
Right Bank at Verona	25	42,000	Remove right bank levee

Table 5.2: Recommended flows to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types.

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Duration and Timing

Provide floodplain inundation flows for 30 – 60 days between February 15 and April 30 into Sutter and Yolo Bypasses to provide rearing habitat for salmon and splittail and spawning habitat for splittail. Where possible, time releases to coincide with and extend duration of high releases on the Yuba and Sacramento.

Frequency

Ideally, it would be possible to inundate the bypass in every year to enhance foodweb productivity and improve rearing habitat for every year class of salmon. It may be possible to do this while economizing on water by inundating relatively small areas in dry years and very large areas in wet years with no inundation in critical dry years.

5.2 Riparian Flow Requirements

A sequence of hydrologic, geomorphic, and biologic phenomena is necessary to recruit cottonwood seedlings to the riparian forest. Under natural flow regimes, moderate 5- to 10-year flood events precipitate channel migration and the creation of point bars suitable for cottonwood seedling establishment (McBain and Trush 2000, Trush et al. 2000). Analysis of hydrologic data, dendrochronologic data, historic channel mapping, and aerial photography riparian recruitment appears to occur approximately once per decade in the post-regulation period (Roberts, 2003). But recruitment may now be limited to larger, less frequent events due to greater hydrologic modification in recent years. Recruitment did result from the recent large flood events of 1983-1986, and 1995-1997, (Roberts, 2003) but willows dominate while cottonwood recruitment is spatially limited.

In order to maintain or re-establish woody riparian vegetation using a process-based restoration approach, managed flows need to mimic natural hydrographs in the following key ways (Stillwater, 2007):

- High flow peaks, which should mimic to some degree the characteristics of peak flows associated with winter peak rain events in the unimpaired hydrograph are necessary to control vegetation encroachment by herbaceous and weedy species and prepare seedbeds prior to seedling recruitment flows in wet years (scouring or encroachment prevention flows) and seedbed preparation flows.
- High spring snow-melt peak flows with relatively gradual recession rates during wet years to moisten the seedbeds and induce seed germination on geomorphic surfaces suitable for long-term establishment (recruitment flows for seedling initiation).
- Summer and fall base flows are needed to ensure that new seedling cohorts and older cohorts of saplings and mature trees have adequate soil moisture for summer growth and survival during the annual dry season (seedling establishment and maintenance flows).

In regulated rivers it may also be necessary to limit unnaturally high summer flows. Summer base flows higher than spring flows may give a competitive advantage to non-native species that reproduce by seed during the summer months. Establishment of non-natives could impede later recruitment of natives such as cottonwood (cite).

5.2.4 Site Preparation

Large flows scour away herbaceous plants and/or deposit fine sediments on floodplains, preparing new seed beds for pioneer riparian species (Mahoney and Rood 1998). The magnitude of flows necessary to scour or deposit seed beds is presumably much larger then the amount of water necessary to inundate these sites. For this analysis, we assume that flows sufficient to mobilize the bed (80-100k cfs on the Sacramento and 35,000-50,000 on the Feather) are sufficient and that seedling establishment flows will only occur in wetter years after bed mobilization generally occurs.

5.2.5 Seedling establishment:

In order to assure long-term survival, seedlings must become established in a zone that is high enough on the bars and banks to avoid scour from peak flows, but low enough to avoid desiccation during low flows in summer and fall. Rood and Mahoney (2000) developed a recruitment box model that placed this zone at 2.5 to 4 feet above mean low (MLW) water for the St. Mary River in Alberta Canada. Roberts (2003) calibrated the recruitment box model on the Sacramento placing the recruitment zone at 3-6 feet above MLW and developed a stage discharge relationship at three representative sites to determine that recruitment zone is inundated at flows between 23,000 and 30,000 cfs. Roberts recruitment zone, however, is based on the artificially high summer flows in the Sacramento River. Under natural summer flow conditions the recruitment zone, and flows necessary to inundate it, may be somewhat lower.

Little to no information exists regarding seedling establishment elevation for the Feather River. Furthermore, it is difficult to identify a suitable recruitment zone at some distance from the mean low water, because mean low water levels in the summer are two to three times higher then pre-dam, natural levels. The stage discharge relationship for the Feather River at Nicolaus combined with topographic maps indicate that the Feather River overflows its banks at Nicolaus at approximately 12,500 cfs. The banks further upstream are higher and can convey more flow before overtopping. Since cottonwoods generally become established on the banks and gravel bars of alluvial rivers, it is reasonable to assume that the recruitment zone is below the stage of the bankfull discharge. The seedling establishment flow on the Sacramento (23,000 – 30,000 cfs) is twenty seven to thirty seven percent of the bankfull discharge (Q1.5 to Q2) on the Sacramento. Assuming a similar proportional relationship on the Feather River, flows in the range of 9,500 to 18,000 would be suitable for seedling establishment. Analysis of historical flow data (section seven of this report) indicate that flows in this range were common during April and May when germination is most likely to occur.

Post-germination decline of river stage, which is presumed to control adjacent groundwater levels, should not exceed approximately one inch per day (Mahoney and Rood 1998, Busch et al. 1992). This is the rate at which seedling root growth (0.16–0.47 inches/day; Reichenbacher 1984, Horton et al. 1960) can maintain contact with the capillary fringe of a receding water table in a sandy substrate. Cottonwood root growth and seedling establishment rates are higher in these soils than in coarser textured soils, which are more porous (Kocsis et al. 1991). In reaches with gravelly substrates, slower draw-down rates are necessary to support seedling establishment.

Information necessary to design a gentle recession limb is limited. Stage discharge data from gauging stations may not be representative of Cotonwood recruitment sites, because they are generally sited at geomorphically stable and simple sites while cottonwood recruitment often occurs on complex and dynamic sites. Kondolf and Stillwater (Kondolf, 2007) measured stage discharge relationships at several representative gravel bars along the Sacramento River and determined that stage drops 0.1 meter (.34 feet) per 1000 cfs at flows ranging from 7,000 to 15,000 cfs, but cautioned against extrapolating this relationship to flows outside the observed range. Within this range, however, a discharge decline of 250 cfs per day would yield a stage decline of one inch per day.

To estimate a suitable recession rate flow schedule, we assumed that cottonwood seedlings would become established six feet above the mean low water and then calculated that it would take 72 days to drop river stage six feet at a rate of one inch per day. On this basis, we recommend a 72 day recession period from the establishment flow to the summer base flow. The actual recession flow required may vary substantially depending where seedlings become established relative to the mean summer flows.

5.2.6 Recruitment stage:

After the second year, growth rates level. Despite extensive root development during this stage, cottonwoods are still somewhat susceptible to drought stress. Yearly flows must be sufficient to maintain groundwater levels within 10 to 20 feet of ground surface elevations (JSA and MEI 2002). Groundwater extraction and reduced flows can reduce groundwater levels and induce drought stress in cottonwood saplings (Jones & Stokes 1998. Acute draw down and corresponding drought stress is primarily a problem in arid river ecosystems and will probably not be a problem on the Sacramento River where summer flows are artificially high.

5.3 Chinook Flow Requirements

Adult Upstream Migration

If salmon migration is motivated by major storms, early freshets or pulses after the first rain, and most of the large flows from storm events are trapped behind dams, reservoir operators can simulate pulse events by releasing water from the reservoir. However, "There is [a] concern that pulse flow releases in mid October to attract salmon may cause the fish to enter the rivers earlier than normal, which may expose them to high water temperatures when the pulse flows cease." (CMARP). Therefore, if flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for migrating adults and subsequent spawning.

Spawning

In order to provide quality areas of spawning habitat, adequate flows need to be released from dams into the tributaries during the spawning period. Due to channel alteration from gravel mining, artificial gravel habitat construction and enhancement may be necessary. Over the long run, periodic high flows are necessary to mobilize gravels and flush-out fine sediments. However, large peak flow events that occur in channels that have been excessively incised and leveed cause excessive gravel mobilization, which can disrupt spawning and cause egg mortality (CMARP). Therefore, these flows should be released after mid-February so they reduce mortality to incubating salmon eggs (McBain and Trush, 2000). Increased flows may also be needed to decrease water temperatures in late October and early November to prompt earlier spawning, expand the area with suitable temperatures for spawning and incubation, to increase egg viability, and to reduce the probability of superimposition of redds. If flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for spawning and to prevent dewatering of redds.

Egg Development and Emergence

Dewatering of redds is a known mortality factor effecting development of alevins. (Becker et al., 1982, 1983 in Healey, 1991). Dewatering of redds can be minimized below dams by careful flow regulation.

Adequate base flows during the incubation and emergence period combined with periodic flushing flows outside the period should reduce the mortality factor of eggs and alevins. Instream flows, at or above spawning flows, should be maintained throughout the incubation and emergence period to avoid dewatering redds. Siltation and capping from fine sediments could be minimized with small reservoir releases timed to coincide with rainfall induced local run-off. These releases would help convey fine sediments out of the spawning reach.

Rearing and Outmigration

We hypothesize that increasing rearing habitat will improve growth rates and successful smolt outmgration and may also reduce mortality from diversions and predation, because larger fish are less vulnerable to these sources of mortality. Based on robust results from research in the Yolo Bypass, it appears providing seasonally inundated floodplain habitat is perhaps the best way to ensure adequate growth before outmigration to the Delta and Ocean. If nothing else, providing seasonally inundated floodplain habitat will provide better habitat for the young that migrate or are washed out of the gravel bedded reaches early. We describe the flow regimes necessary to create inundated floodplain in section 6.3 above.

In addition to inundated floodplain habitat, seasonally inundated off-channel habitats may also provide valuable rearing habitats for juvenile salmon. Kondolf and Stillwater (Kondolf, 2007) determined that secondary scour channels on gravel bars along the upper Sacramento River become inundated and connected to the mainstem at flows above 12,500 cfs. They also determined that these same secondary channels become disconnected and desiccated at flows below 8,500 cfs. To assist juvenile rearing, it may therefore be advantageous to maintain flows between 8,500 and 12,500 cfs or greater during winter and spring when fish are rearing. To prevent establishment of non-native, resident predator fish populations that thrive in shallow or warm water habitats, however, it may be beneficial to maintain flows below 8,500 cfs during the summer months. Preventing inundation and connectivity of the off-channel habitats during summer months could also reduce temperatures by significantly reducing wetted perimeter and surface area. Lower temperatures should favor native fish over exotic fish populations.

6. EVALUATION OF EXISTING AND HISTORIC FLOW REGIMES

To identify specific hydrograph component alterations between historical and current conditions which may limit the attainment of environmental objectives an analysis of existing and historical hydrologic patterns was conducted using daily flow data from USGS gages at multiple locations on the Sacramento and Feather Rivers. We used two approaches to compare existing and historical hydrologic patterns, a statistical approach similar to IHA whereby specific hydrograph components were graphed using box plots for different year types and a visual approach similar to HCA whereby median hydrographs for historical and current conditions were compared.

We evaluated pre- and post-project hydrology using statistical methods similar to IHA and HCA methods to generate hypotheses regarding the causal links between historical hydrograph components and ecological conditions relevant to our restoration objectives. The Index of Hydrologic Alteration (IHA) method (Richter et al. 1996) provides a statistical overview of how several important hydrologic attributes change between historical and regulated conditions. The Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. Instead of using a formal IHA and HCA analysis the fundamental principals of these methods were used to conduct an analysis based on first principles.

To conduct this analysis USGS daily discharge data was organized into water year types based on the Sacramento Four Rivers Index. The water year data was divided into pre project or post project data sets. The project id defined by the construction of a dam in the headwaters of the river under consideration. For the Sacramento River the project is Shasta Dam which was constructed in 1945. For the Feather River the project is defined by Oroville Reservoir which was constructed in 1968. Hydrograph components for each water year were compared for pre and post project periods using box plots. This statistical approach was coupled with a visual comparison of the pre and post project median flows hydrographs. The pre project period was further defined by the 25th and 75th percentile hydrographs. The 25th and 75th percentile captured the natural range of variability around the median hydrograph during the pre project period for each year type. When the current hydrograph was outside of this acceptable range of variability then a significant discrepancy between the historic and current flow regimes could be identified.

The hydrograph components that were considered for the statistical analysis were: 1) summer baseflow, 2) winter peaks, 3) winter baseflows and 4) spring peaks(Figure 5). A useful way to describe streamflow hydrology and relate it to geomorphic, riparian, and biological ecosystem components is by quantifying these hydrograph components. Kondolf et. al. 2000 described these four primary components of the annual hydrograph in the following way:

(1) Summer base flows extending from July through Spetember/October

(2) Large magnitude, short duration winter floods during December through April

(3) Sustained high winter base flows intermittent between high flow events

(4) Spring snowmelt flood and recession limb of long duration, but typically moderate magnitude

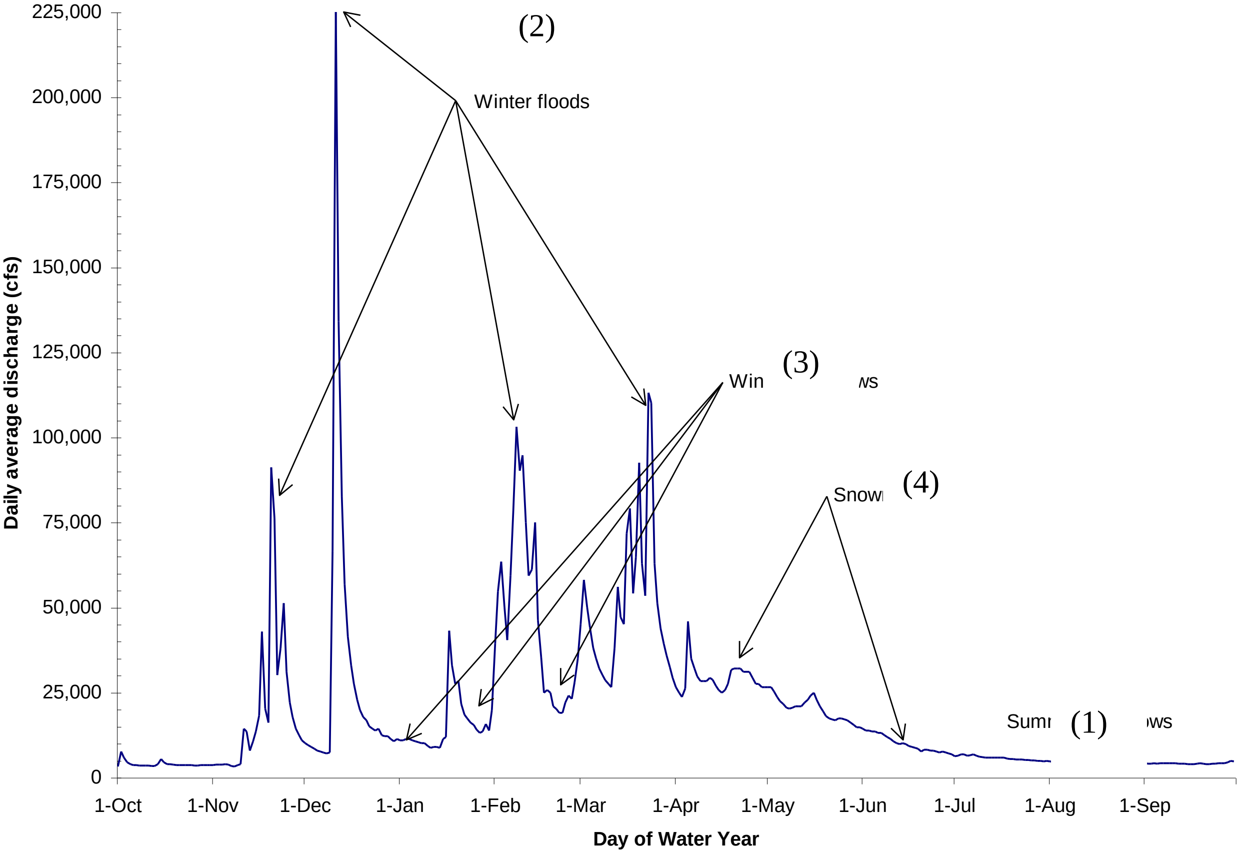


Figure 6.1: Sacramento River hydrograph components illustrated in the 1938 hydrograph for the Sacramento River above Bend Bridge, near Red Bluff gauging station. Modified from Kondolf et al. 2000.

a. Methods

Data Source

We analyzed hydrologic data for periods before and after dams were constructed on the Sacramento and Feather Rivers. Table 4 shows the gauges analyzed their period of record, and the pre and post-dam analysis periods. We divided data into five year types based on the Sacramento Basin Index: wet, above normal, below normal, dry, and critical.

Period of Analysis	River	Description	USGS Gage Number	Period of Record
Pre Shasta	Sacramento River	Bend Bridge	11377100	1906-1944
Post Shasta	Sacramento River	Bend Bridge	11377100	1945-2006
Pre Shasta	Sacramento River	Verona	11425500	1929-1944
Post Shasta	Sacramento River	Verona	11425500	1945-2006
Pre New Bullards Bar	Yuba River	Marysville	11421000	1944-1969
Post New Bullards Bar	Yuba River	Marysville	11421000	1970-2006
Pre Oroville	Feather River	Oroville	11407000	1906-1967
Post Oroville	Feather River	Oroville	11407000	1968-2006
Post Oroville	Feather River	Thermalito AfterBay	11406920	1968-2006

Table 6.1: USGS gauges used for hydrologic analysis, the period of analysis, location, description and the period of record.

Hydrographs

For each year type we compared post-dam median flows to pre-dam median flows. Median flows bounded by the 25th and 75th percentiles represent the natural range of variability during the pre-dam period for each water year type. Hydrographs provide a visual tool to identify portions of the current hydrograph that are outside of the historic range of variability. When the current hydrograph is outside of the natural range of variability we would expect the greatest potential loss of environmental flow benefits.

Box Plots

Box plots were used to statistically compare hydrograph components including summer baseflows, winter floods, winter baseflows, and spring peak flows. The lower edge of the boxes represent the 25th percentile and the upper end represents the 75th percentile, with the whiskers at the maximum and minimum values. The various components of the hydrograph were computed as follows.

- **Summer baseflows** were computed as average August discharge. Summer baseflows begin following the spring snowmelt recession in July and August and last through autumn when the first rainfall events occur.
- **Winter floods** were computed as the maximum daily average discharge over the course of the entire water year.
- **Winter baseflows** were computed as the median flow for February and March.
- **Spring peak flows** were computed as peak flows in April and June.

Flood Frequency Analysis

We conducted the food frequency analysis for a range of reoccurrence intervals for pre and post project periods using the peak instantaneous flow records at USGS. The flood frequency analysis enables further quantification of storm events and their geomorphic potential.

b. Results

The analysis utilized 100 years of daily flow data from the Bend Bridge gage near Red Bluff on the Sacramento River (11377100). This gage was selected for the analysis because it has a long period of record 1906-2006, and best characterizes flow conditions where salmon concentrate. The Bend Bridge gage is at the upstream end of what is considered the most valuable habitat in the Sacramento River. However, flows at Bend Bridge are not fully representative of downstream conditions, particularly in the irrigation season because irrigation diversions operate downstream. Four major diversions are listed below:

- The Glenn-Colusa Irrigation District (GCID) diversion, located just upstream of Hamilton City at RM 206, began diverting summer flows for irrigation around the turn of the century, and has a diversion capacity of about 3,000 cfs.
- The Anderson-Cottonwood Irrigation District (ACID) diversion, located on the north side of the City of Redding downstream of Shasta Dam, began diverting for irrigation during the summer months, around 1917.
- The Red Bluff diversion and Tehama-Colusa Canal at Red Bluff was built in 1964, and diverts during the summer months for irrigation.
- The Trinity River Division of the Central Valley Project was completed in 1963, and typically diverted over 1,000,000 acre-ft/yr of Trinity River flows into the Sacramento River basin just below Shasta Dam between 1963 and 2000. Due to new flow requirements for the Trinity River, substantially less flow is now diverted into the Sacramento River.

The hydrograph at Bend Bridge reflects operations at Shasta Reservoir in timing and magnitude, but it is only by looking at the hydrograph from a downstream gage that we can evaluate the impacts of diversions operations and the degree of hydrograph recovery from tributary inputs. It is for this reason that we used the eighty year record, from 1926-2006) daily discharge data at the USGS gage at Verona (11425500). Major tributary inputs to the Sacramento below Bend Bridge include Mill Creek, Deer Creek and the Feather River. The Feather River flow regime exhibits similar characteristics to the Sacramento below Red Buff because of the operation of Oroville Dam. The major tributary to the Feather is the Yuba River which also displays similar characteristics due to the operation of Bullards Bar. For this reason a hydrograph comparison for the Feather (11407000, 11406920) and Yuba River (11421000) was also conducted.

5.2.1 Sacramento River at Bend Bridge

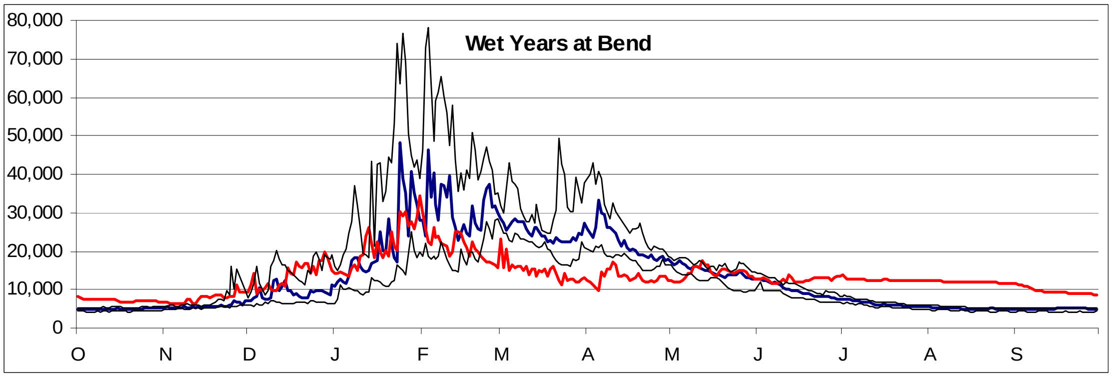
Hydrologic Changes
The hydrographs and box plots for pre and post Shasta at Bend Bridge (Figures 6 and 7) illustrate significant differences in all hydrograph components.

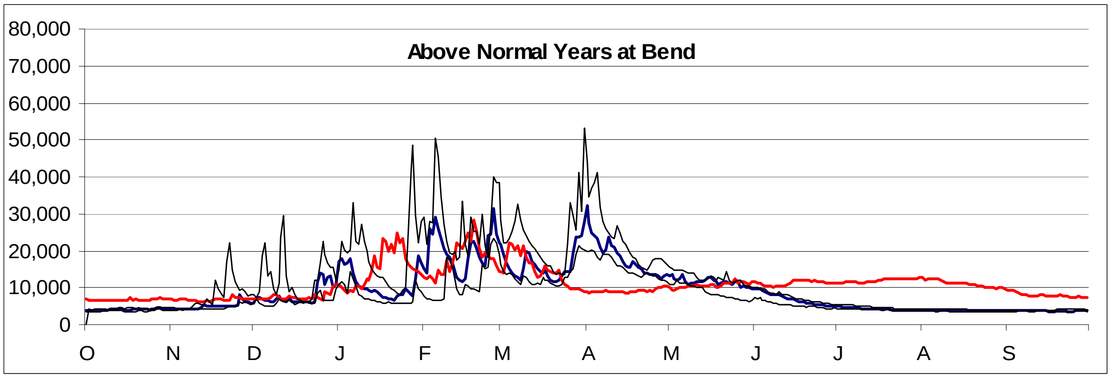
- Summer base flows are significantly higher post Shasta for all water year types. The average summer base flow pre-Shasta was 3,000-4,000 cfs which is significantly less than the current average of 10,000-12,000 cfs. These artificially high summer flows are driven by summer water supply demands for agriculture and power.

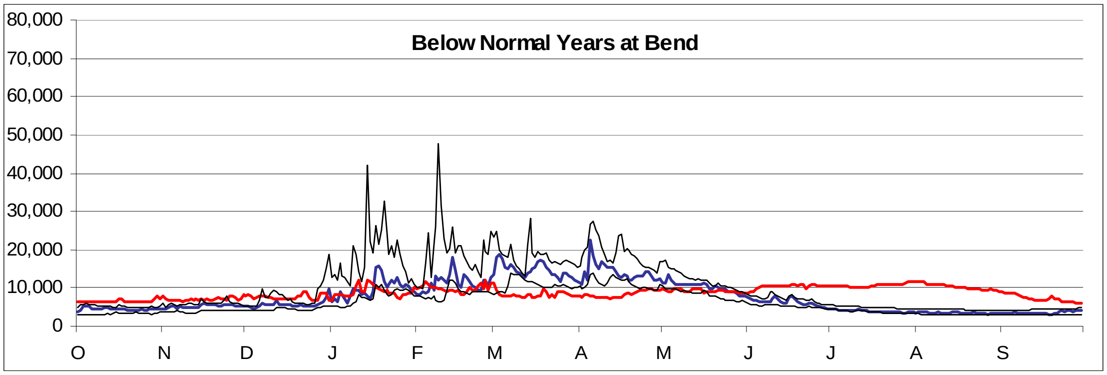
- Spring peak flow events are significantly reduced in the post Shasta era for below normal, above normal and wet year types and there is a truncated spring and early summer recession limb, particularly in wet years. The reduction in spring peak flows hampers cottonwood recruitment, seed establishment and germination.

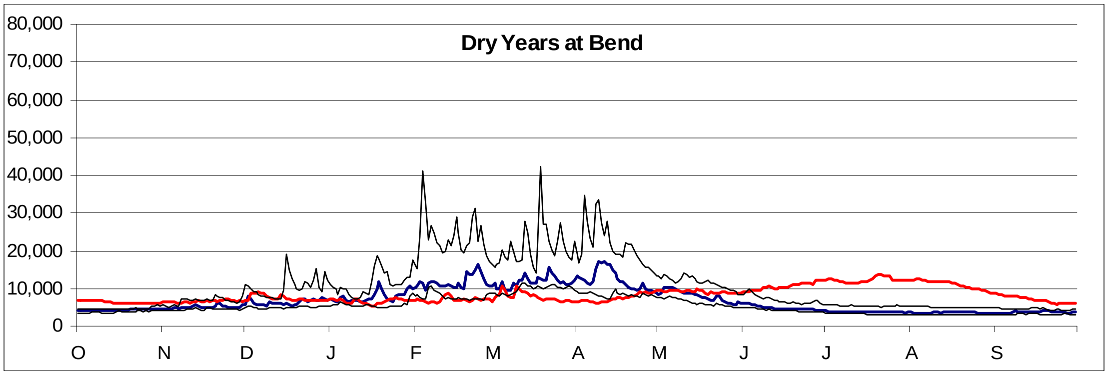
- Winter peak flows are significantly reduced in the post Shasta era. The magnitude and duration of winter peak flows are responsible for channel forming flows. Channel forming flows effect cottonwood recruitment and off channel habitat formation critical to Chinook Salmon rearing and survival.

- In addition to significantly altered hydrograph components there is also a general decline in hydrologic variability in the post Shasta era.









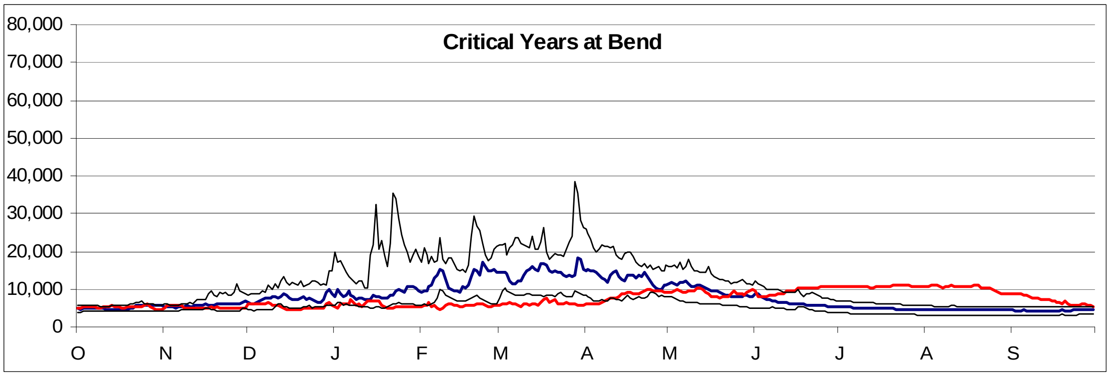


Figure 6.2: Bend Bridge median hydrographs : Historical data was used to construct hydrographs for five water year types at Bend Bridge (USGS Gage 11377100). The median hydrographs pre and post Shasta represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) See the table of the number of water year types below.

Water Year Type	Pre Shasta (1906-1944)	Post Shasta (1945-2006)
W	13	22
AN	5	10
BN	7	11
D	8	12
C	6	7
Total	**39**	**62**

Figure 6.3: Sacramento River Box Plots at Bend Bridge. Box plots display the median and the range of variability for each hydrograph component. Summer baseflows are represented by the average August discharge for each water year type. Winter floods are represented by the maximum daily average discharge for each water year type. Winter base flows are represented by the median discharge in February and March for each water year type. Spring peak flows are represented by peak average daily discharge value in April-June for each water year type. The top of the box plot is the 75th percentile and the bottom of the box is the 25th percentile. The 25th percentile means that 75% of the data is above this point. The wiskers represent the maximum and minimum values. The dark line inside the box is the median value, or 50th percentile. When the boxes do not over lap then there is a very highly significant difference between the data sets.

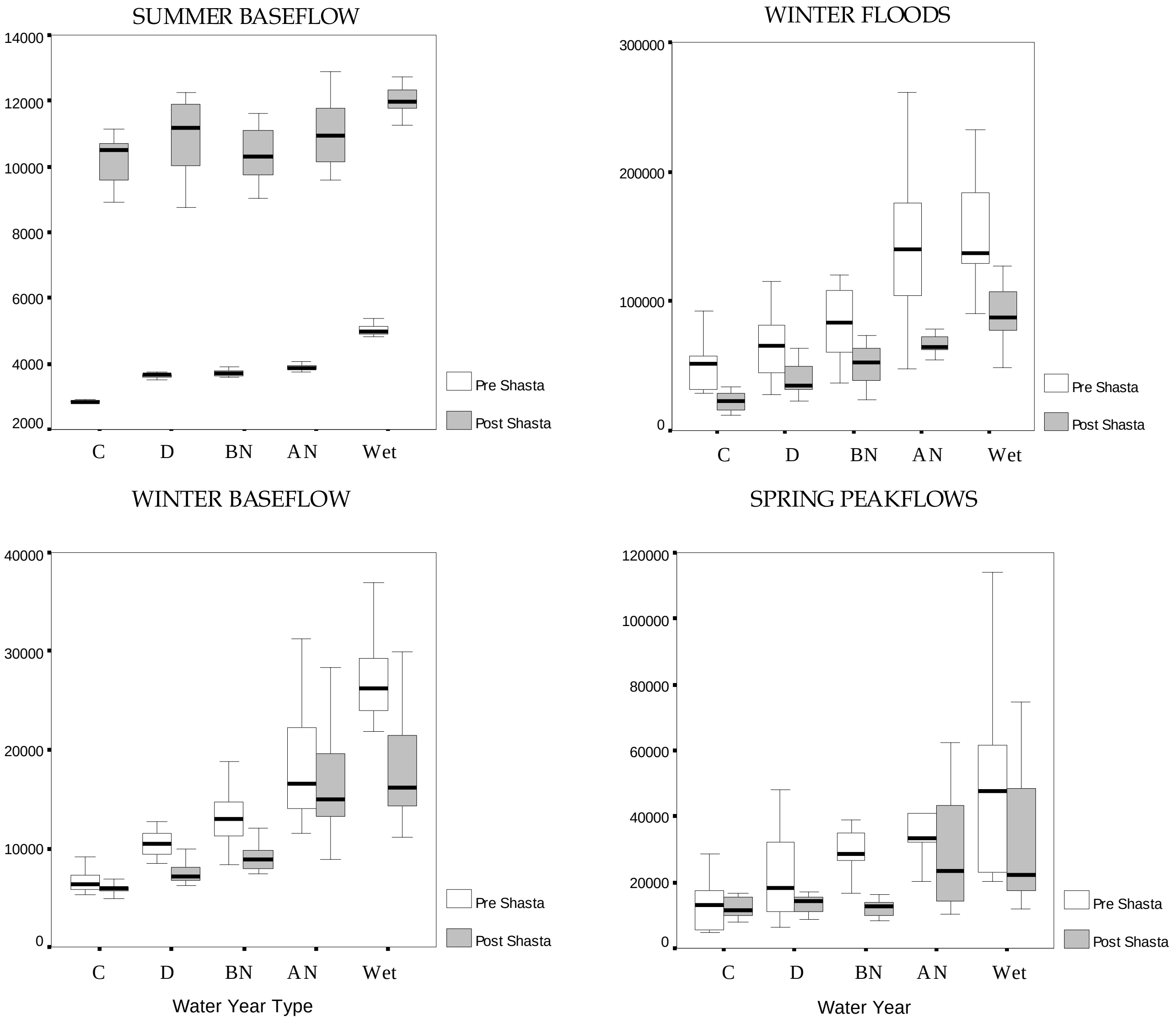


Figure 6.4: Flood frequency analysis at Bend Bridge Pre and Post-Shasta. The flood frequency analysis displays the magnitude of flows expected to occur in a 1.5, 2, 2.5, 5, 10, 20….year flood. The two year flood event in the pre Shasta era is ~100,000 cfs. Bed mobility is expected at the 1.5 year flood (Q1.5) or 82,795cfs.

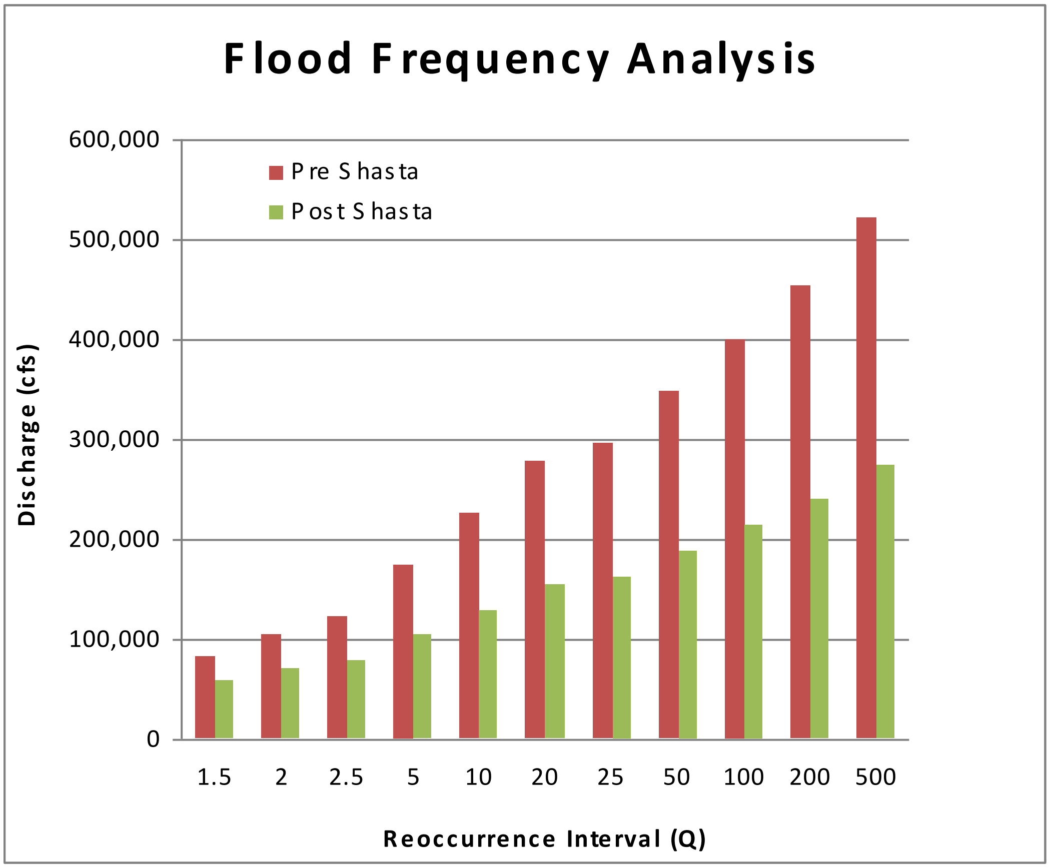


Table 6.2: Sacramento River Flood Frequency

Recurrence Interval (years)	Post 1939 (cfs)	Pre 1939 (cfs)
1.5	65,000	87,000
2	78,000	105,000
2.5	87,000	120,000
5	120,000	160,000
10	153,000	225,000
20	160,000	285,000
50	190,000	350,000
100	210,000	400,000

Table 6.3: Summary of Geomorphic Flow Thresholds

Sacramento River	Pre-Dam ($Q_{1.5}$)	Bed Mobility ($Q_{1.5}$)	Channel Scour and Migration (Q_{10})	Floodplain Inundation (Q_1)
Flows at Bend	82,795	82,795	226,476	52,087

6.2.1 Feather and Yuba Rivers

Introduction

Oroville Dam and Reservoir on the Feather River were completed in 1968 and have a storage capacity of 3.5 million acre feet (maf). It is managed for water supply, hydropower, and flood control. The average annual yield of the upstream Feather River basin at Oroville is about 4.2 maf. Due to several diversions in the upper watershed, average annual inflow into Oroville Reservoir is approximately 4.0 maf, but varies annually depending on precipitation. From 1979 to 1999, annual inflows ranged from a minimum of 1.7 maf to as high as 10 maf . Most of the water released from the dam, except during flood spills, is routed through the Thermalito diversion pool and afterbay and therefore bypass a 7 mile stretch below the dam known as the low flow channel. A minimum flow of 700-800 cfs is released into the low flow channel to maintain habitat for salmonids.

We evaluated change in hydrology that resulted from construction and operation of Oroville Dam. We compared pre and post dam hydrology at the USGS gauge below Oroville. In order to account for the water in the post-dam period that is discharged into the Thermalito diversion pool and bypasses the Oroville gauge, we summed daily values from the Thermalito (11406920) and Oroville (11407000) gauges to calculate the average daily flow for the river below the low flow channel.

Minimum instream flows below Thermalito Afterbay range from 1,000 cfs in the late spring and summer to 1,200 -1,700 cfs during the fall winter months. Minimum flows for the low flow channel are between 700 and 800 cfs all year. Minimum flows are slightly higher during the fall and winter to provide flow for spawning and incubating salmonids. Minimum flows in the summer are necessary to maintain cool temperatures for over summering juveniles and adult salmonids.

Most irrigation releases are made directly into irrigation canals, so relatively little water is conveyed to irrigators via the Feather River channel. Most irrigation water is released from Oroville Reservoir into Thermolito Diversion Pool, Forebay, and Afterbay where it is subsequently diverted into irrigation canals. Thus, it is possible to substantially meet summer irrigation demands without conveying water through the Feather River Channel.

The Feather River is joined downstream by a major tributary, the Yuba River. The hydrology of the Yuba River was modified early in the 19th century, but the first big storage reservoir, Bullards Bar, was not constructed until 1968. As a result, the hydrology of both the Yuba and Feather River were substantially altered at the same time by large reservoirs constructed in the late 1960s.

Hydrologic Changes

The construction and operation of Oroville dam and reservoir have significantly altered the hydrograph of the Feather River downstream of Oroville. Figures 10 and 11 depict the hydrologic patterns during different year types before and after 1968 when Oroville

Dam was completed. Figure 12 and Table 6 show changes in peak flow magnitude and duration. The most significant changes to the hydrograph are:

- Very significant reductions in spring flows during all year types, particularly during April and May. Storage of spring run-off and snow melt behind Oroville Dam has virtually eliminated any spring flows above a base flow of approximately 2,000 cfs.
- Increases in summer flows by 150-200% in all year types during July, August, and September.
- Reduction in the frequency and magnitude of peak flows, such as Q1.5[2] or channel forming flow by an order of magnitude. Substantially less reduction in the magnitude of the 5 year recurrence interval event (Table 6)
- Reduction in the frequency of short duration fall and winter flow pulses.

These hydrograph modifications are a result of Oroville Reservoir's water supply, flood management, and hydropower operations. Oroville Reservoir captures high flows in the winter and spring for use during the summer months. Stored water is released to meet minimum instream flows, irrigation demand in the Feather River region between April 1 and October 31, generate hydropower primarily in the summer, and meet water quality and export water demands in the Delta. Large volumes of stored water are periodically released during the winter months to create reservoir space for flood management purposes.

Most of the increases in summer flow in the Feather River channel are the result of Oroville releases to meet water quality and export demands in the Delta. As a unit of the State Water Project, Oroville is specifically operated to meet water quality and export demands in the Delta. An analysis of pre-1995 and post 1995 hydrology shows that Feather River flows changed significantly after the 1995 Water Quality Control Plan tightened restrictions on the timing of Delta diversions. After implementation of the plan, spring flow in the Feather River has been further diminished while summer flow has been further increased.

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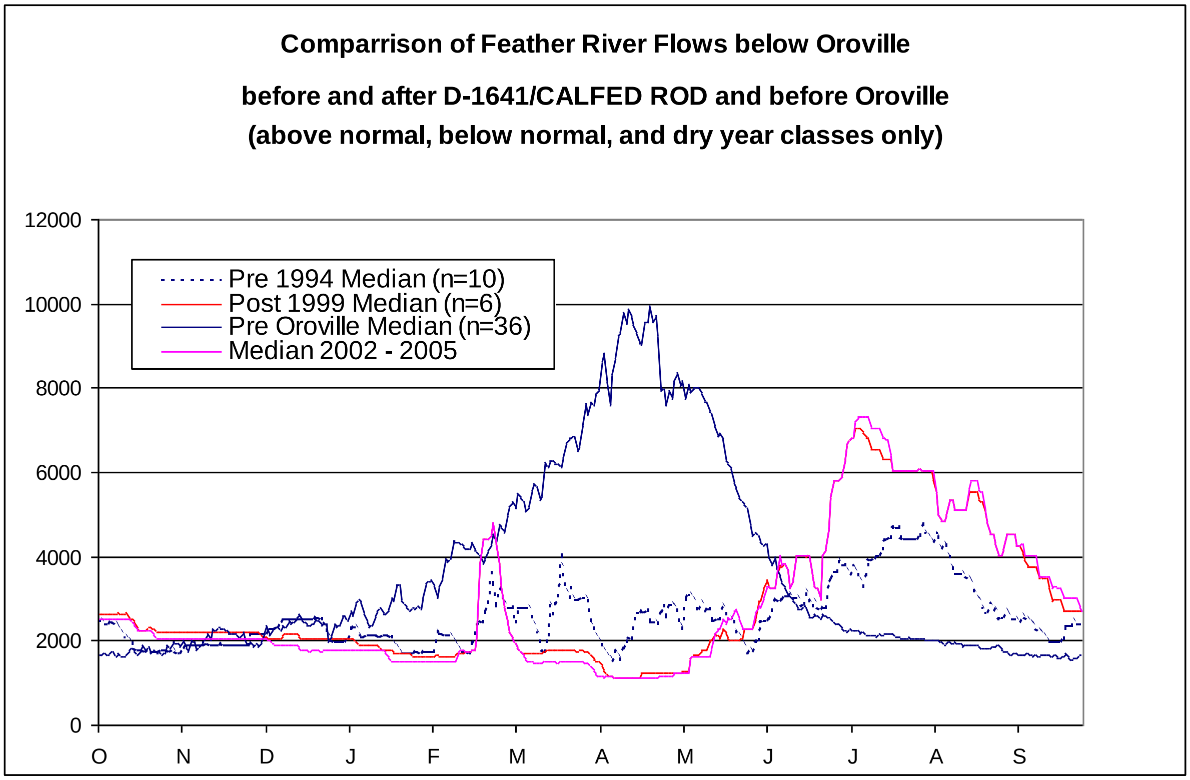
[2] The instantaneous peak annual flow with a recurrence interval of 1.5 years.

Figure 6.5: Influence of Sacramento-San Joaquin Delta Regulations on Feather River Hydrograph. The blue line of pre Oroville median flows represents the most natural hydrograph. In 1995 the Water Quality Control Plan tightened restrictions on the timing of Delta diversions. The pre 1994 hydrograph compared to the post 1999 illustrates how the hydrograph shifted spring flows to summer releases to meet Delta requirements.



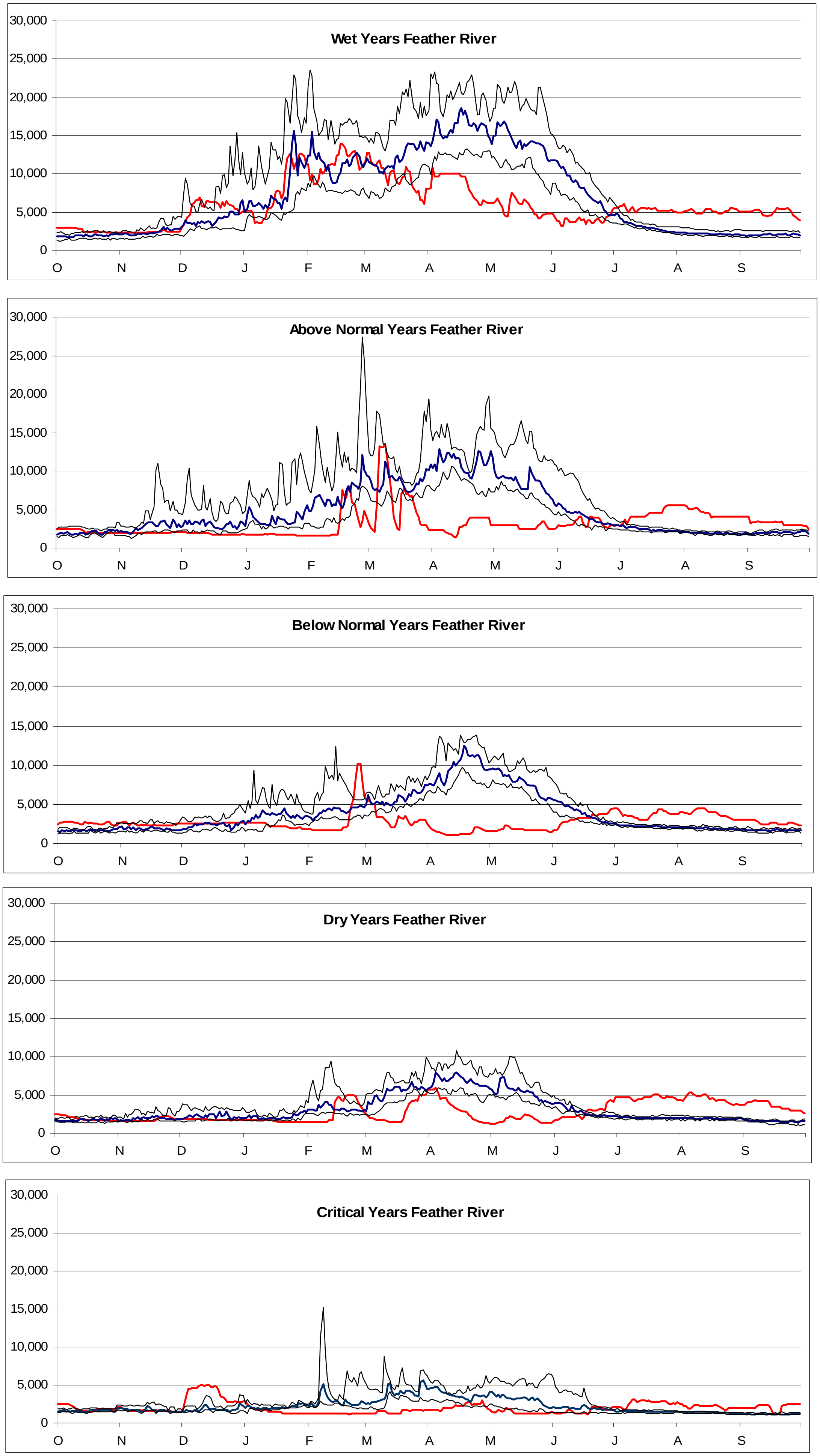


Figure 6.6: Feather River median hydrographs : Historical data was used to construct hydrographs for five water year types on the Feather River (USGS Gage11407000 and 11406920). The median hydrographs pre and post Oroville represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) The hydrographs post Oroville (1968-2006) are the sum of the Oroville (11407000) and Thermolito Afterbay gages (11406920). See the table of the number of water year types below.

Water Year Type	**Pre Oroville (1906-1967)**	**Post Oroville (1968-2006)**
W	20	15
AN	8	7
BN	14	4
D	14	6
C	6	7
Total	**62**	**39**

Figure 6.7: Feather River box plots for Oroville gauge. Box plots display the median and the range of variability for each hydrograph component. Summer baseflows are represented by the average August discharge for each water year type. Winter floods are represented by the maximum daily average discharge for each water year type. Winter base flows are represented by the median discharge in February and March for each water year type. Spring peak flows are represented by peak average daily discharge value in April-June for each water year type. The top of the box plot is the 75th percentile and the bottom of the box is the 25th percentile. The 25th percentile means that 75% of the data is above this point. The wiskers represent the maximum and minimum values. The dark line inside the box is the median value, or 50th percentile. When the boxes do not over lap then there is

a very highly significant difference between the data sets.

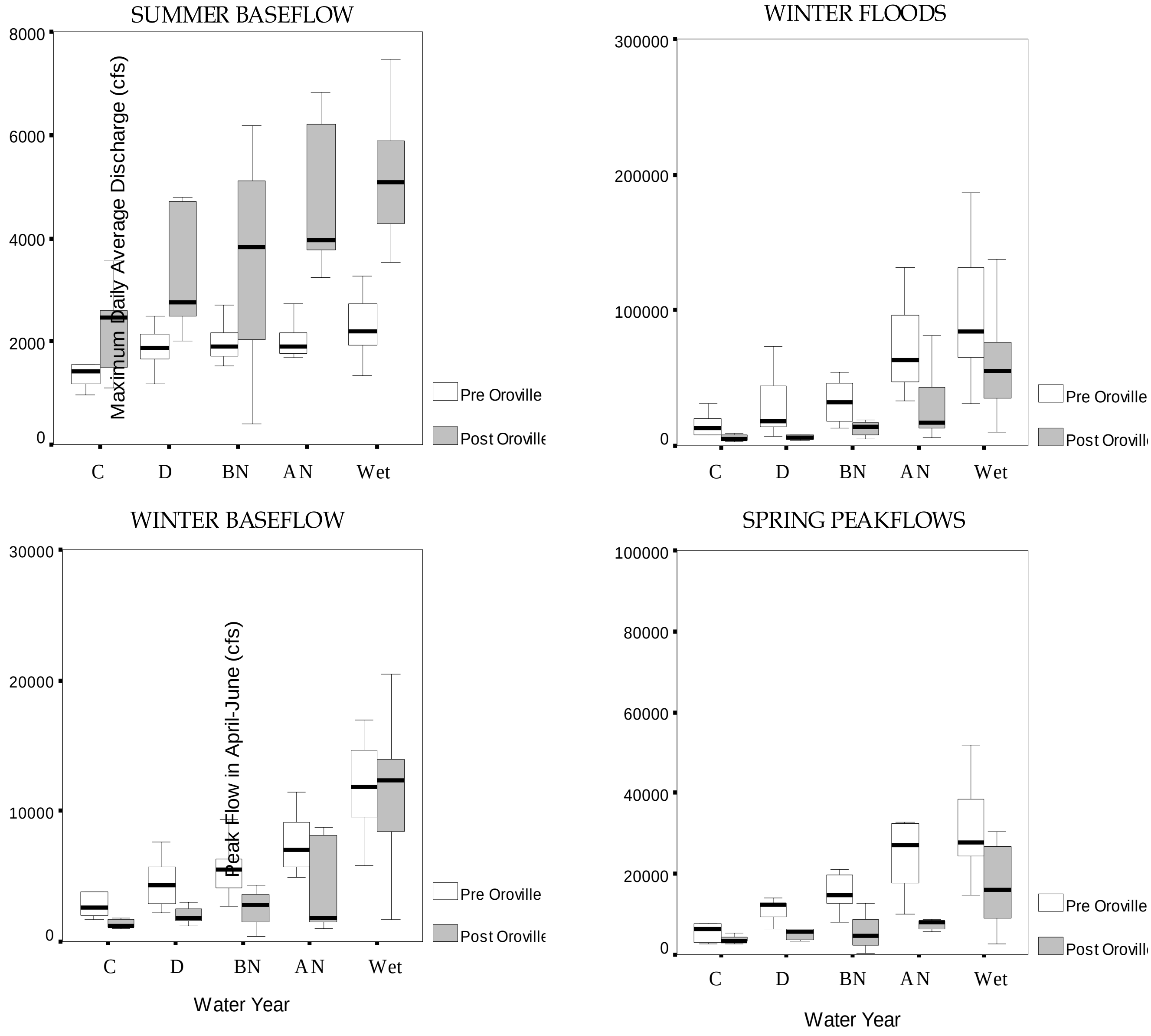


Figure 6.8: Flood Frequency Analysis for Feather River Flood frequency analysis at Bend Bridge Pre and Post-Shasta. The flood frequency analysis displays the magnitude of flows expected to occur in a 1.5, 2, 2.5, 5, 10, 20….year flood. The two year flood event in the pre Shasta era is ~50,000 cfs. Bed mobility is expected at the 1.5 year flood (Q1.5) or 33,224cfs.

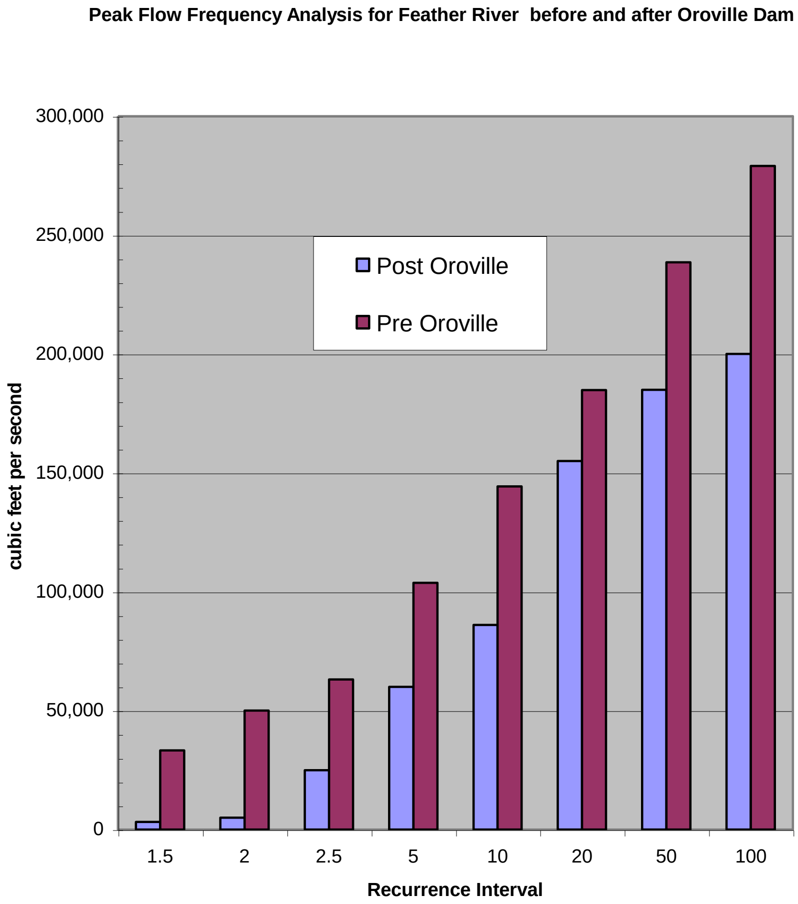


Table 6.4: Feather River Flood Frequency

Recurrence Interval (years)	Post 1968 (cfs)	Pre 1968 (cfs)
1.5	3,170	33,224
2	5,000	50,065
2.5	25,000	63,128
5	60,000	103,704
10	86,000	144,281
20	155,000	184,858
50	185,000	238,498
100	200,000	279,075

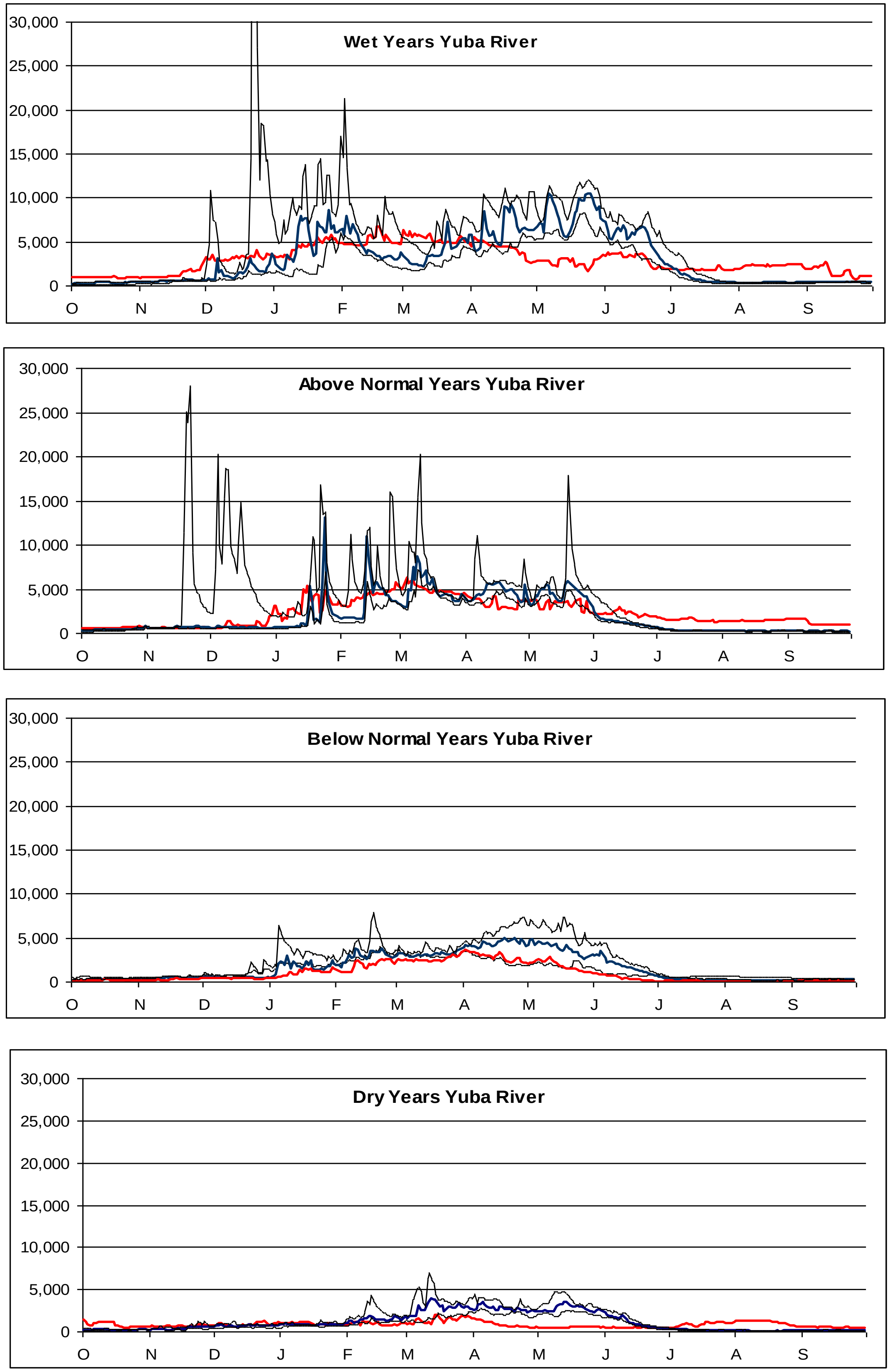


Figure 6.9: Yuba median hydrographs : Historical data was used to construct hydrographs for different water year types for the Yuba (USGS Gage 11421000). The median hydrographs pre and post New Bullards Bar represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.)There is no median hydrograph for the Critical Year type because there were no critical years between 1944 and 1969. See the table of the number of water year types below.

Water Year Type	Pre New Bullards Bar (1944-1969)	Post New Bullards Bar (1970-2006)
W	7	13
AN	3	7
BN	8	3
D	7	6
C	0	7
Total	**25**	**36**

6.3 Sacramento River at Verona

Analysis of the Sacramento and Feather Rivers at gauges near the large dams only tells part of the story. The Verona gauge is downstream of the confluence of the Sacramento and Feather River, and measures run-off from numerous large tributaries not measured by the gauges at Oroville and Bend Bridge. Several of these tributaries do not have large storage reservoirs and thus continue to exhibit relatively natural hydrographs. Figure 14 shows the hydrographs from Mill and Deer Creek which are characterized by large, gently receding spring flows. As a group, these less regulated tributaries tend to dampen the effect of Shasta, Oroville, and New Bullards Bar, but only to a limited extent.

Figures 16 shows hydrologic patterns for four periods: before Shasta, after Shasta but before Oroville Dam, after Oroville Dam, and after the implementation of the 1995 water quality control plan that established stringent limits on the timing of water exports from the Delta. The hydrology from all four periods shows a clear and consistent trend: progressively less spring flow and continuously increasing summer time flows. The decrease in spring flows and increase in summer flows is particularly striking after 2000 when the water quality control plan was in full effect in the Delta. Due to stringent export restrictions in the spring, the state water project, which operates Oroville Reservoir and controls the Harvey O'Banks pumping plant in the Delta, has apparently shifted operations to minimize spring time releases from Shasta and favor summer time releases so that it can deliver water to the Delta when pumping restrictions are less severe.

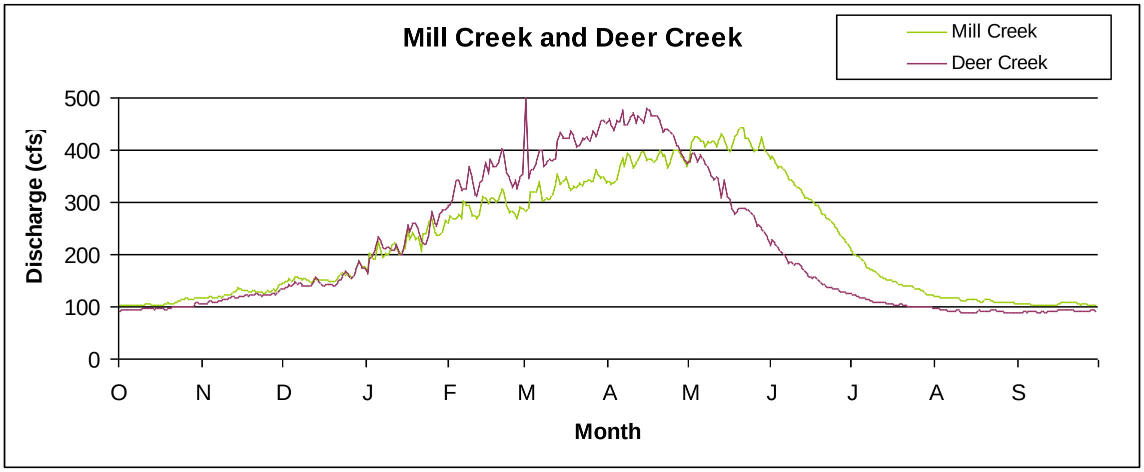


Figure 6.10: Median hydrographs for Mill and Deer Creek.

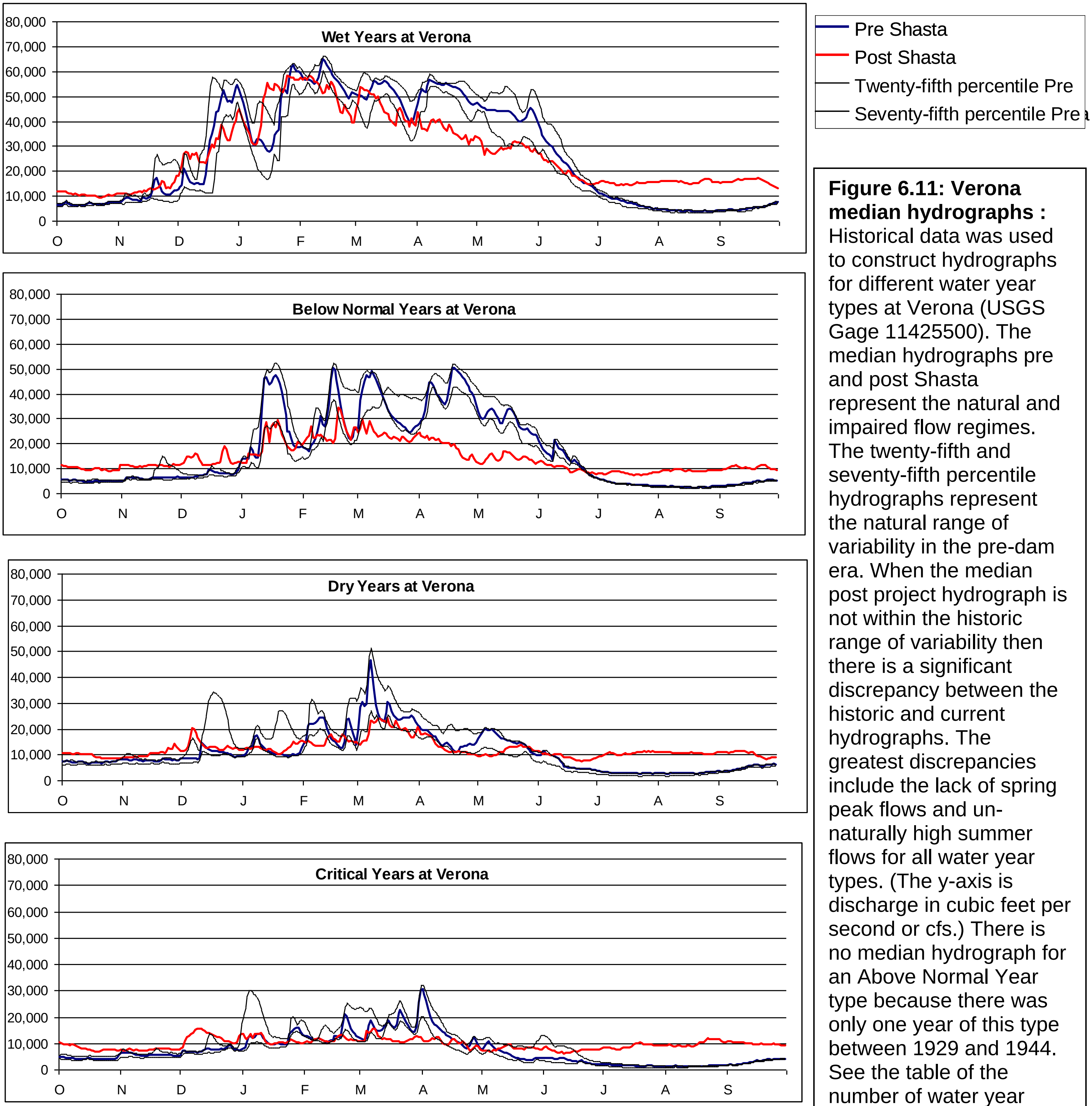


Figure 6.11: Verona median hydrographs : Historical data was used to construct hydrographs for different water year types at Verona (USGS Gage 11425500). The median hydrographs pre and post Shasta represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) There is no median hydrograph for an Above Normal Year type because there was only one year of this type between 1929 and 1944. See the table of the number of water year types below.

Water Year Type	Pre Shasta (1929-1944)	Post Shasta (1945-2006)
W	4	22
AN	1	10
BN	3	11
D	4	12
C	3	7
Total	15	62

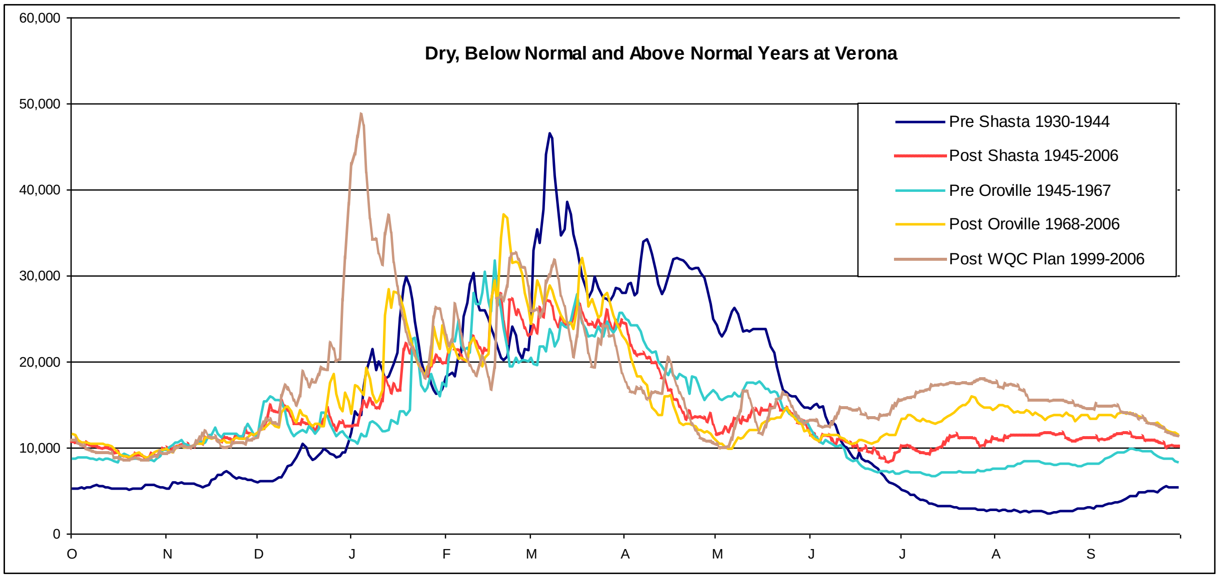


Figure 6.12: Median hydrographs for different time periods indicate a progression towards increased summer flows and decreased spring peaks. The increased regulation of the Sacramento and Feather Rivers with Shasta in 1945, Oroville in 1968 and the implementation of the Water Quality Control Plan in 1999 all had the effect of releasing increased flows during the summer when demands are high and as a consequence eliminated spring peak flows.

Summary of Results

From the hydrograph comparisons of current hydrographs to pre project, or natural hydrographs, a consistent trend immerges for all sites. This trend is the result of reservoir operations where by water is stored until periods of peak demand arise. In the Sacramento River basin peak demands occur in the summer months which means that reservoirs hold water through the spring, eliminating peak spring flows and augmenting summer base flows well above pre project levels. In this way reservoirs alter the timing and magnitude of the spring and summer hydrographs. In addition the presence large reservoirs in the headwaters dampen winter floods in all but the wettest of years. Loss of these geomorphic and riparian flows impacts riparian vegetation and Chinook Salmon habitat.

7.0 IDENTIFY OBVIOUS GAPS BETWEEN OBJECTIVES FLOW REQUIREMENTS AND EXISTING FLOWS

7.1 Gaps in Riparian Vegetation Objectives

Bed Mobilization

The frequency and size of large flows capable of mobilizing the bed have been reduced, but large flows occur in more than half of the years on the Sacramento River. The size of the Q1.5 has been reduced by twenty fiver percent. The pre-dam Q1.5 of 87,000 cfs now has a recurrence interval of every 2.5 years instead of every 1.5 years. While this is a significant reduction, it is a relatively small reduction in comparison to hydrologic alteration on other rivers such as the Feather or San Joaquin Rivers. The abundance of active riffles in the Sacramento River meander belt suggests that the river still periodically mobilizes its bed. Lack of bed mobility in the upper reach below Keswick Dam may be more a result of armoring due to coarse sediment trapping upstream then it is a result of reduced flows.

On the Feather River, the frequency and magnitude of peak flows has been reduced more substantially. The historical instantaneous Q1.5 – 2 has of 33,000 – 50,000 has been reduced by an order of magnitude to 3,000 – 5,000 cfs. The Q2.5, however, is 25,000 cfs. Under the post dam regime, several 4-5 years can pass without exceeding a bed mobilizing flow. This enable riparian vegetation to become established on gravel bars leading to long term stabilization and degradation of the channel.

Bed Scour

The frequency of very large, bed scouring events has been reduced substantially. The pre-dam Q5 of 160,000 cfs now has a twenty-year recurrence interval rather then a five-year recurrence interval. Similarly, the pre-dam ten-year flow now has a one hundred year recurrence interval. The physical processes and ecological function of these large events is not well understood. It is possible that smaller flows substantially scour the bed, rearrange the channel, and form new channel habitat. If so, the reduction in very large flows may not be as important. On the other hand, these very large events may be very important for creating and maintaining important habitats such as oxbow lakes and other off-channel habitats.

Bank Erosion and Channel Migration

We did not conduct an assessment of changes in stream power, but figure 5.2 illustrates that the occurrence of flows exceeding 15,000 or 20,000 cfs in dry, critical dry, and below normal years has been reduce substantially. Larson (2007) identified 15,000 cfs as the lower threshold for bank migration. Median flows frequently reached 15,000 cfs in these drier year types during the pre-dam period, but in the post-dam period median flows seldom rise above 10,000 cfs. During the wettest forty percent of years, wet and normal wet years, median flows frequently exceed 20,000 cfs and thus maintain some level of bank erosion and channel migration processes. Reduction in the frequency and duration of erosive events may have substantial impacts on the colonization and succession of riparian habitat over time. It definitely has habitat implications for bank swallow, a listed species that nests on recently eroded stream banks. Reduced bank erosion almost certainly lowers the suspended sediment levels and could therefore have significant impacts on instream fish habitat for juvenile salmon or Delta smelt that appear to prefer or concentrate in turbid waters (citation?). Although the reduction in the frequency or duration of bank erosion events may have significantly ecological impacts, it may be less important then the widespread presence of bank revetments along the Sacramento Rivers (Larson, 2007).

Inundated Floodplain and off-channel habitat during late winter and spring

The lack of prolonged flows of sufficient magnitude to inundate floodplain and off-channel habitats during the late winter and early spring months is perhaps the most significant ecological change to the Sacramento and Feather Rivers. Large, prolonged flows still occur in wet and normal wet years, but they are largely disconnected from the floodplains due to levees that prevent inundation of the vast historic floodplain of the lower Sacramento River. Large areas of the Sutter and Yolo Bypass become inundated in wet and normal wet years, but little or no floodplains become inundated for any length of time in the drier sixty percent of the years. This is a result of both levees and flow alteration, but flow alteration alone is sufficient to preclude floodplain inundation in the drier years.

Loss of shallow water habitats in secondary channels and floodplains not only reduces the amount of rearing habitat, it also may reduce foodweb productivity in the spring months when juvenile fish are rearing and moving downstream to the Delta. Increase connectivity between shallow water habitats and open water can substantially increase aquatic productivity in estuaries (Cloern, 2008).

Inundated off-channel habitat such as high flow channels can also provide rearing habitat for salmon (Peterson and Reid, 1984), but regulated spring flows are generally insufficient to inundate these habitats for prolonged periods (30-60) days. A recent study of these habitats in the Sacramento River determined that a large proportion of secondary channels between Red Bluff and Colusa become fully connected to the river at flows above 12,000 cfs (Kondolf, 2007). Regulated flows seldom exceed 10,000 cfs in the drier year types (dry and below normal) during late winter and spring when salmon are most likely to require spawning habitat. Even in normal wet years, median April flows are generally below 10,000 cfs.

7.2 Gaps in Riparian Vegetation Objectives

Peak spring flows are conspicuously absent under current conditions. On both the Sacramento and Feather River, median summer flows are significantly greater then median spring flows in all but wet years. As a result, any seeds that might germinate during the cottonwood seed release period in April and May are at risk of mortality from prolonged inundation throughout the summer months. If seeds to become established, they are less likely to grow deep roots during their first growing season due to high groundwater levels and therefore may be more vulnerable to desiccation mortality when water levels do drop.

In addition to the overall decapitation of the spring hydrograph, rapid flow declines during the spring months create a hostile environment for establishment of Fremont cottonwoods. Changes in the rate of the spring snowmelt recession are not obvious from the composite hydrographs depicted in figure 6 because they are of average spring flows over several years. The recession rate is more directly controlled by reservoir release operations in specific wet and above normal years. Our evaluation of hydrographs for individual years indicates that the recession rates are often characterized by abrupt changes in flow during the seed germination period on both the Sacramento and Feather rivers as illustrated in figures 6.1 and 6.2. Abrupt changes in reservoir releases during germination and initial seedling establishment period can limit recruitment by abruptly desiccating recently germinated seedlings before their roots reach the water table or by scouring and inundating newly established seedlings with high summer flows shortly after germination.

Even in wet years, median flows do not reach the documented threshold of 23,000 cfs on the Sacramento necessary to recruit riparian vegetation in a zone that is not vulnerable to subsequent channel scour. Similarly, the Feather River only reaches the assumed threshold of 8,000 -10,000 in median wet years. While it is true that the median numbers depicted in figure 6 obscure the variability that actually occurs in various years, figure 6 clearly illustrates how dramatically the critical spring and summer hydrograph has been altered in non-wet years. Even in wet years, the hydrographs are often not suitable due to the rapid fluctuation in flows (figures 6.1 and 6.2).

Figure 7.1: Annual hydrograph for Sacramento River at Bend Bridge illustrating abrupt flow decline in mid April during cottonwood germination period.

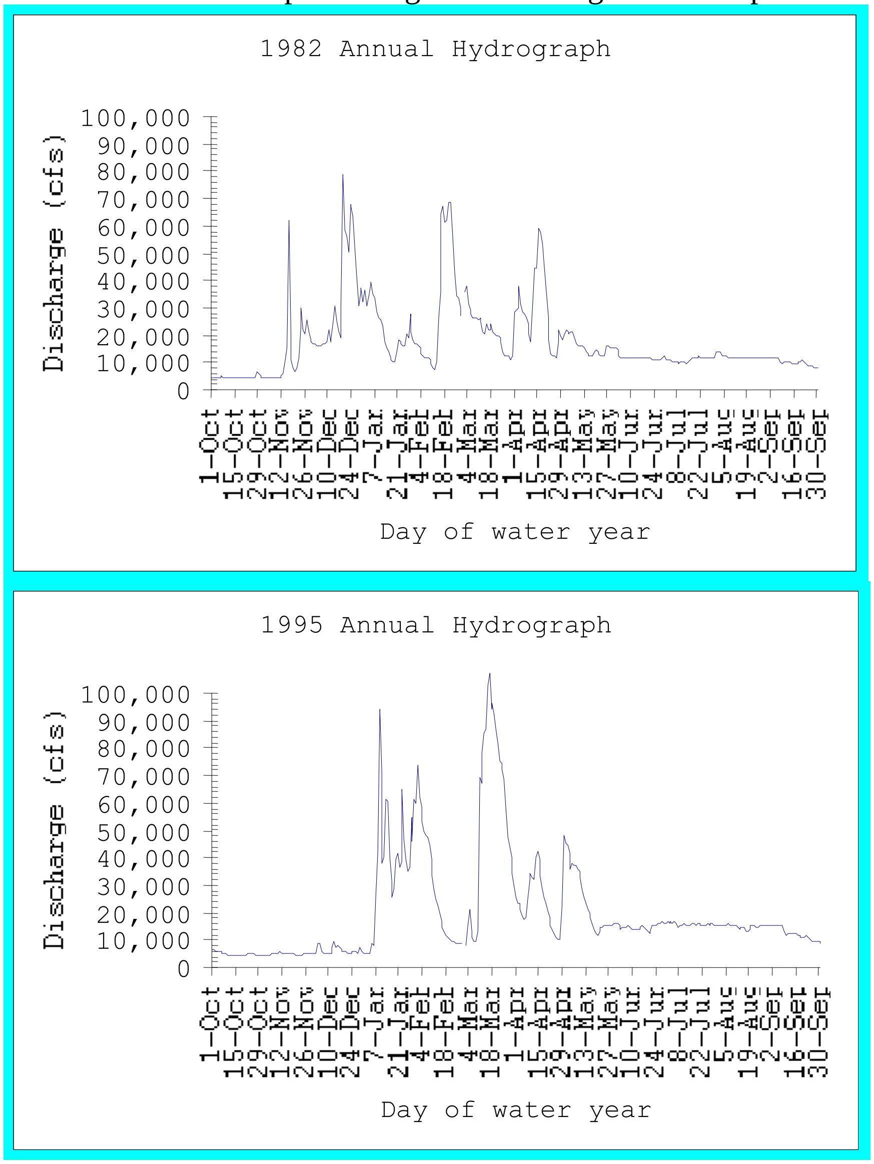
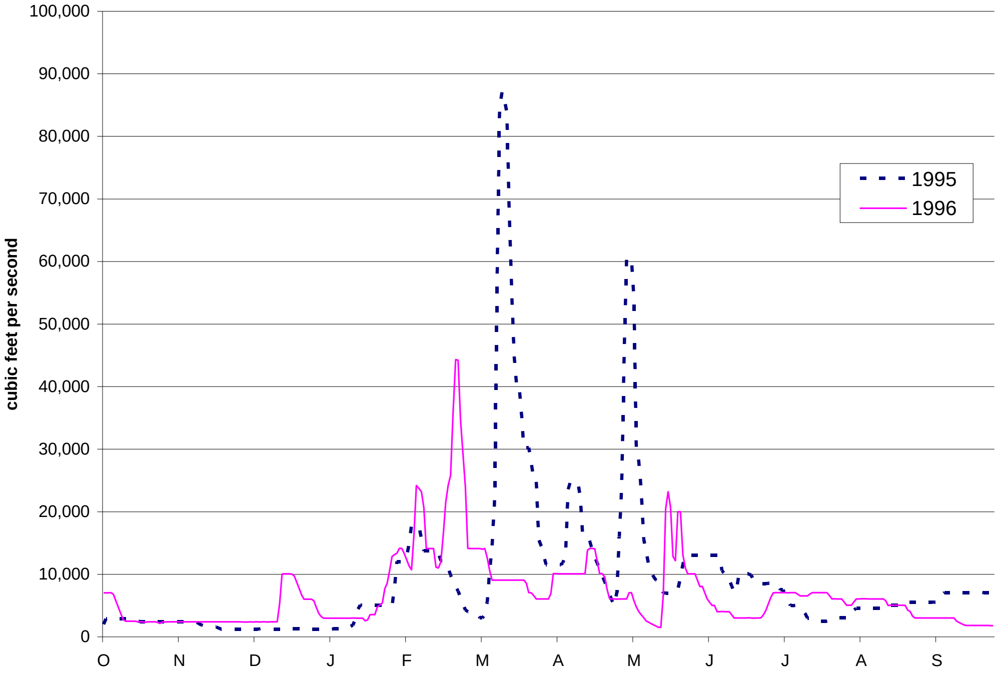


Figure 7.2: Annual hydrograph for Feather River at (sum of Oroville and Thermolito gauges) illustrating abrupt flow decline in mid April during cottonwood germination period.



7.3 Gaps in Chinook Salmon Objectives

Spring Pulse

Elimination of high winter and spring flows has substantially reduced the amount of rearing habitat on inundated floodplains and in off-channel habitats. A close examination of flow patterns indicate that later winter and early spring flows are increasingly the lowest flows of the entire year on both the upper Sacramento and Feather River. Under natural conditions, the highest prolonged flows of the year consistently occurred in the late winter and spring. This "spring rise" in flows inundated gravel bars, secondary channels and associated backwaters, and floodplains during the larger events.

Late winter and early spring flows at Bend Bridge on the Sacramento are about fifty to sixty five percent of what they were historically. A recent study of off-channel habitats on the upper Sacramento River (Kondolf and Stillwater, 2007) identified 12,500 cfs as an important threshold for inundating side channel habitats. On the Sacramento River, median spring flows at Bend Bridge seldom fell below 12,000 cfs between February and April prior to Shasta Dam. In the post dam era, median flows are consistently below 10,000 cfs in all but the wettest years. Meanwhile, summer flows which were historically below 5,000 cfs are now consistently above 10,000 cfs. The shift from spring to summer has become even more pronounced in recent years as dam operators have shifted operations to meet water quality and water supply demands for the Sacramento-San Joaquin Delta.

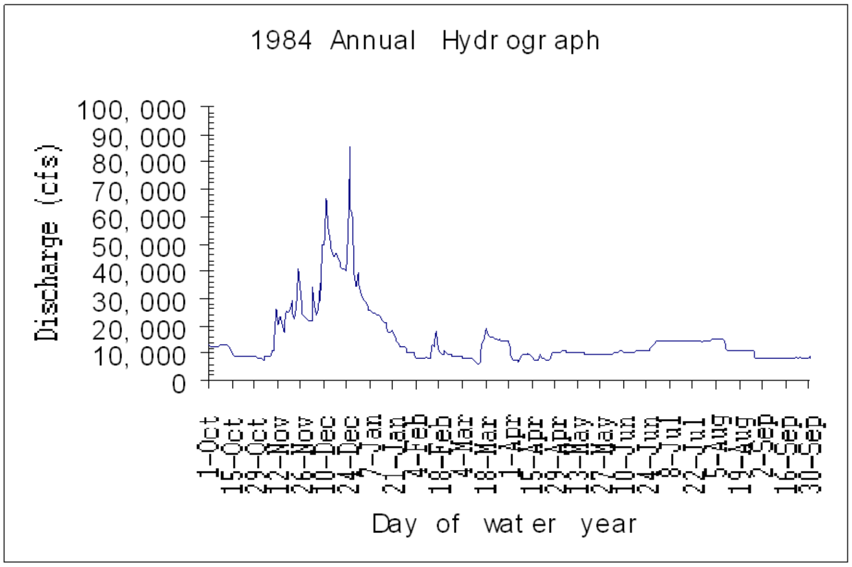
The pattern of reduced spring flows is even more pronounced on the Feather River where median spring flows are fifteen to thirty percent of what they were historically in most year types. The only exception is wet years when they are approximately fifty percent of the historical median. But even in these wetter years, the spring flows are characterized by abruptly fluctuating flood flows as illustrated in figure 6.2, rather then the prolonged spring pulse that characterized historic flows.

Fluctuating Flow Events

The median flow analysis presented in the previous chapter is not well suited for evaluating the frequency of abrupt flow changes, because the composite hydrographs depicted in figure 6 do not reveal individual flow events, which may harm salmon populations. The recent Nature Conservancy study of the Sacramento River (Stillwater, 2007, 2008 appendix F) hypothesized that abrupt increases or decreases in flows in the Sacramento may impact salmon and other species by scouring or dewatering reds, stranding fish, or eroding bank swallow nesting sites. Our cursory analysis of annual hydrographs, illustrated in figures x and xx, indicate that abrupt fluctuations in flow do occur in some years. The timing of these fluctuations may be a significant problem for fish in individual years. Large, rapid fluctuations in the winter or spring could strand juvenile salmon on floodplains or was juveniles downstream to poor habitat. Large reservoir releases in the fall, followed by declines to a significantly lower stage during the remainder of the winter, as illustrated in figure 6.3, could result in dewatering and stranding of redds. Large fall releases are usually limited to periods following very wet years when reservoir levels are high and need to be reduced prior to the rainy season for flood control purposes.

It is clear that large fluctuations in flow occurred under natural conditions on both the Feather and Sacramento Rivers. It is unclear how and whether individuals and populations of these salmon survived these events. Did very high flows that scoured the bed result in reproductive failure? How often did this occur? It is likely that today’s regulated flow regime fluctuates in the present day riverine conditions is more likely to harm salmon then fluctuating flows under historical conditions. Under historical flow conditions, high peak flows are often followed by subsequent peaks that might enable stranded fish to reenter the river. More habitat complexity under historical conditions increased the probability that salmon could spawn or take refuge in areas safe from the potential negative effects of high flows. In today’s environment, large peaks are often abruptly ended only to be followed by weeks of low flows. Levees and channelization have cut-off important refuge and foraging habitat that fish might have otherwise used during high flows.

Figure 7.3: 1984 annual hydrograph from the Sacramento illustrating high flow falls that could result in salmon redd stranding and reproductive failure.



Base Flows

Base flows in the Sacramento and Feather Rivers have been increased in most months except the spring, as previously discussed. Increased base flows during the summer and fall probably lower water temperatures and improve fish passage conditions. It is unclear whether unnaturally high base flows in the summer and fall have any deleterious impacts on fish such as harboring exotic species.

8 ENVIRONMENTAL FLOW REGIME RECOMENDATION

This chapter identifies flow recommendations for the Sacramento River based on the objectives and flow thresholds identified in chapters three and four, and the analyses of natural and regulated hydrology presented in chapters five and six.

Although this study identifies hypothetical restoration flow regimes for the Sacramento and Feather Rivers, we recognize that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program. The hypothetical flow regime that we have developed and identified is imperfect, but it serves as a reasonable starting point for evaluating the feasibility of reoperating reservoirs without impacts on existing reservoir functions.

The assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself. To cost effectively achieve restoration, managers will ultimately need to test these assumptions and address the uncertainties through a program of modeling, pilot flow studies, model calibration, and long-term restoration implementation. In the text below, we have explicitly identified some of these uncertainties so that they can be further evaluated.

8.1 Summary Recommendation

The key component of the environmental flow proposal for both the Sacramento and Feather Rivers is to restore higher flows during the late winter and spring. This period was once characterized by sustained, high flows. Under regulated conditions, however, spring flows are nearly half their historic volume and substantially below summer flows. We recommend restoring a stable spring base flow that is sufficient to inundate secondary channels, as well as, a spring pulse flow to inundated floodplains, particularly the Yolo and Sutter Bypasses.

A second key objective of the flow regime is to ensure adequate flows for the geomorphic and riparian processes that are necessary to sustain riverine and riparian habitat. We recommend short duration, high magnitude flows during the late winter to increase the frequency of hydrologic events that will mobilize the river bed or erode river banks. During late winter and early spring, we recommend prolonged duration moderately high flows to create inundated floodplain habitat for salmon. During the spring of wet and normal years, we recommend moderate duration, high flow evernts in wet and normal wet years to facilitate recruitment of Fremont cottonwoods and other riparian vegetation.

Restoring higher flows in the spring will necessarily reduce flows during other times of the year We propose reducing summer base flows to enhance spring flow, but realize that this could reduce suitable habitat for winter-run salmon during the summer months. We are not proposing any changes in the cold water pool management regime, which currently assures cold water releases from Shasta Reservoir. We recommend against diverting additional water away from the winter months, because we believe that existing winter flood events are necessary to create and maintain riverine and riparian habitat.

8.2 Sacramento River

Summary recommendations for Sacramento River base flows, key ecological flows, and a flow schedule are presented in tables 7.1 – 7.3. Illustrative flow recommendation hydrographs for each year type are presented in figure 7.2.

Table 8.1: Sacramento Environmental Flow Targets for Bend Bridge and Verona

	Critical	Dry	Below Normal	Above Normal	Wet	Location
Bed Mobilization		35,000	65,000	85,000	105,000	Bend
Floodplain Inundation			25,000	35,000	45,000	Verona
Riparian Establishment Flow				23,000	37,000	Bend
Bed Scour	No Recommendation					
Channel Migration						

Table 8.2: Sacramento River Base Flow Target Summary for Bend Bridge

	Critical	Dry	Normal Dry	Normal Wet	Wet
Fall base flow	5,250	5,250	5,250	5,250	5,250
Winter base flow	4,500	6,000	6,500	7,000	8,000
Spring base flow	10,000	12,000	12,500	14,000	14,000
Summer Base	8,000	8,000	8,000	8,000	8,000
Summer Base at Colusa	4,000	4,000	4,000	4,000	4,000

Table 8.3: General Timing and Duration of Sacramento Environmental Flow Targets

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Geomorphic				▨	🟨 2/15 -3/15	🟨	▨					
Floodplain Inundation					🟨 Only 45 Days	🟨	🟨					
Riparian Establishment Flow							🟨					
Riparian Recession Limb								🟨	🟨			
Spring Rise						🟨	🟨					
Fall Base Flow	🟨	🟨										🟨
Winter Base Flow			🟨	🟨	🟨							
Spring Base Flow						🟨	🟨	🟨				
Summer Base Flow									🟨	🟨	🟨	

8.2.1 Fall Base Flows

We propose stepping flows down from a stable summer base flow (see below) in late September in the upper river (between Keswick and Red Bluff). Under both natural and regulated conditions, flows in early fall are the lowest flows of the year. The primary purpose of lowering fall base flows closer to their historic levels is to economize on water and shift the saved water to the spring months when it is more important. The secondary purpose is to provide stable base flows for spring and fall-run spawning salmon and suitable rearing conditions for winter-run 5,500 cfs release from Keswick is about 1,000 – 1,500 cfs below existing fall base flows, but should be adequate for spawning habitat. The fall base flows must be stable to avoid dewatering or redds that may occur when flows are substantially dropped from the norm. Lower base flows in October could also potentially improve rearing habitat for winter run by creating slightly warmer fall water temperatures and thus an increased food supply.

Below Keswick	5,500
Below Red Bluff Diversion	5,250
Below GCID Diversion	5,000
Below Colusa	4,750

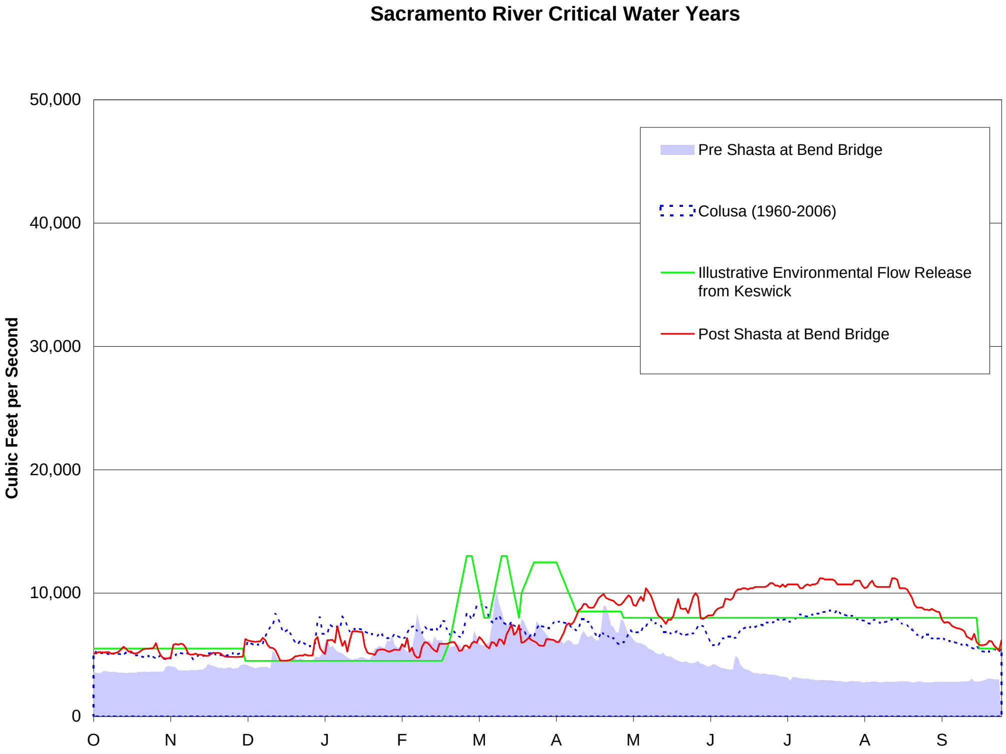
Key Uncertainties

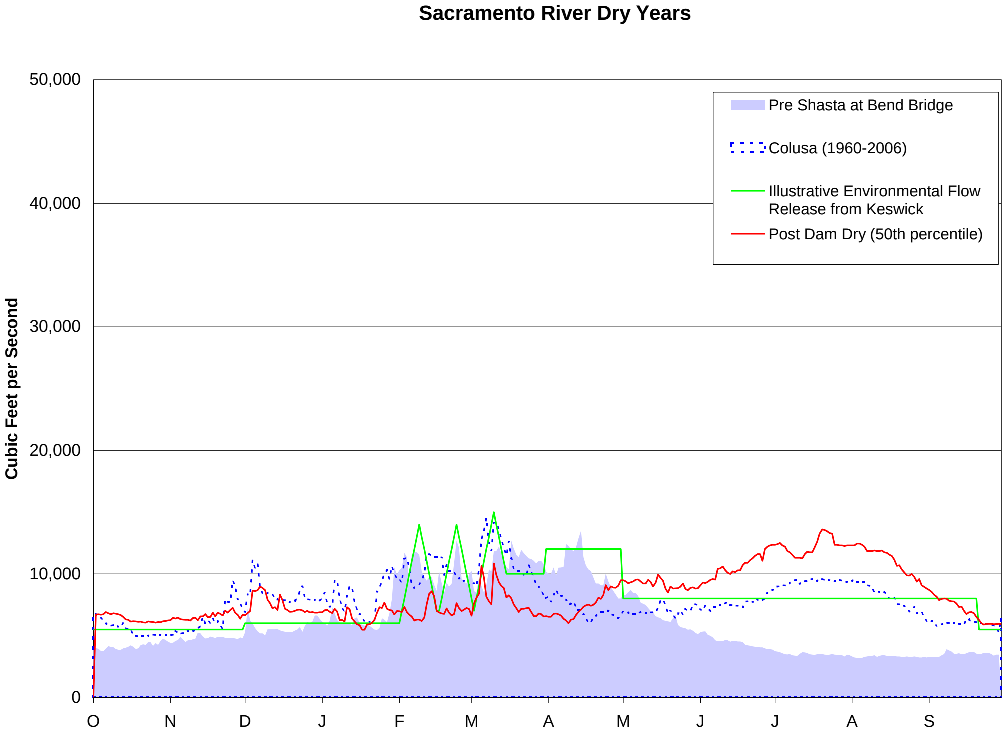
- Are proposed fall base flows sufficient for area of spawning habitat?
- Will lowering fall base flows provide warmer, slower velocity habitat for rearing winter run juveniles, and will this improve their growth and survival?
- Will reduce fall base flows cause adverse impacts in the Delta ecosystem?

8.2.2 Fall Pulse Flow

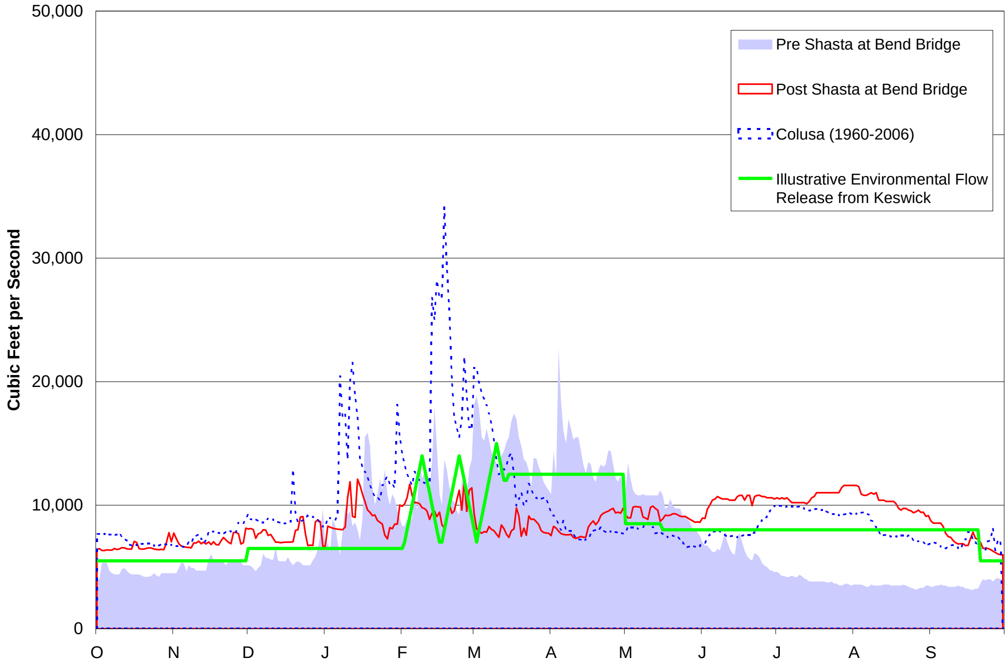
We considered a pulse flow to improve rearing conditions for juvenile salmon in the fall but did not include it in figure 7.2. The purpose of the fall pulse flow would be to improve food supply and rearing conditions for the winter run salmon and is loosely

Figure 8.2: Illustrative environmental hydrographs for five year types on the Sacramento River relative to existing regulated hydrograph and pre-Shasta hydrograph.

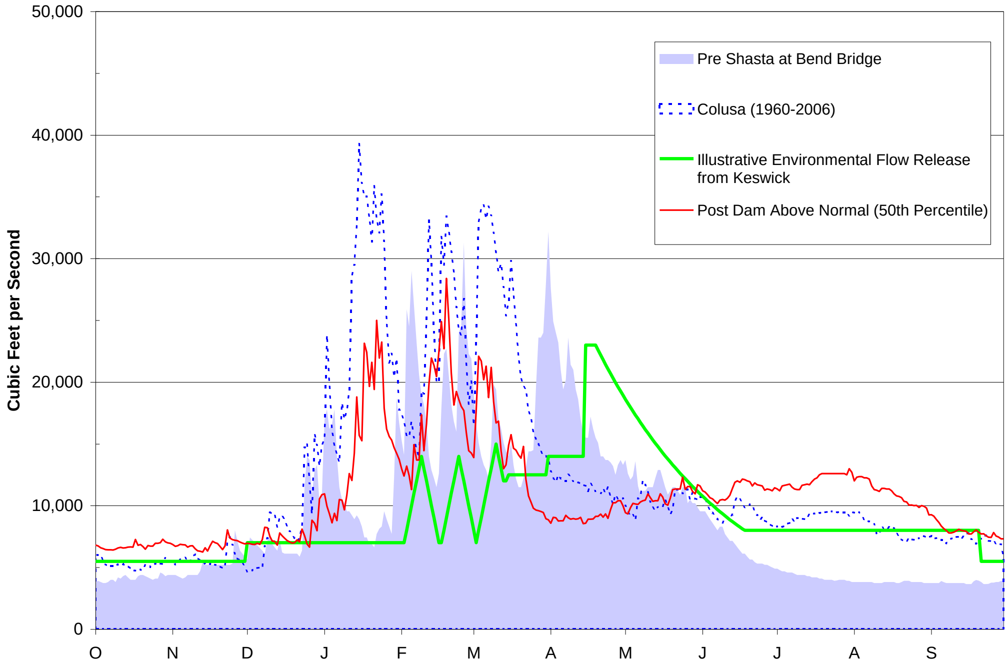


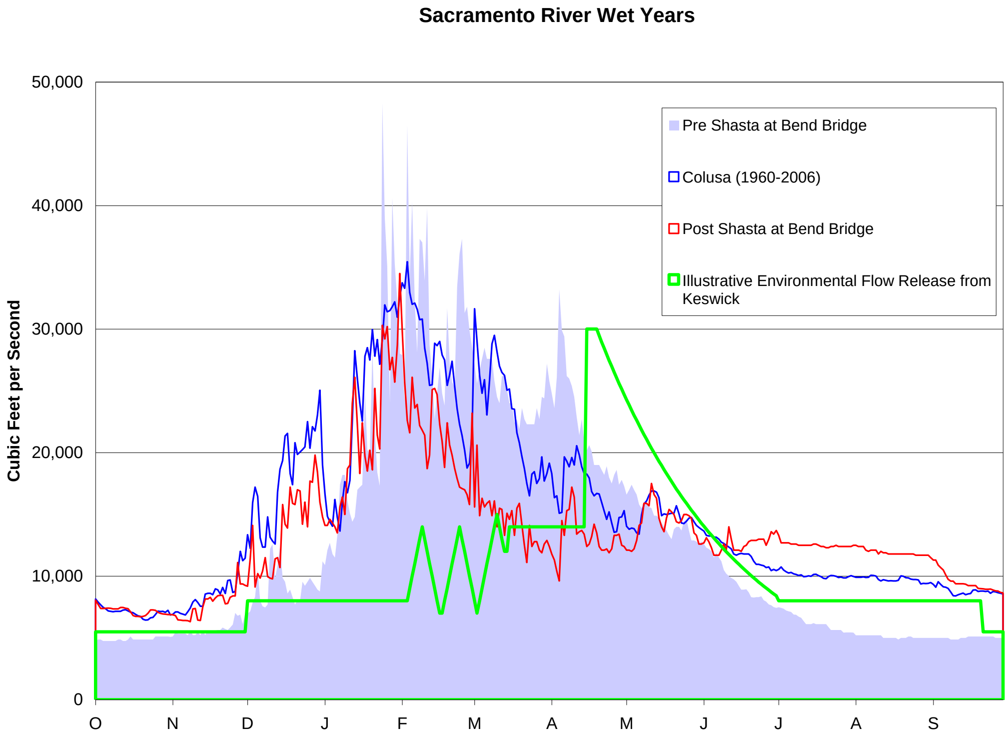


Sacramento River Below Normal Years



Sacramento River Above Normal Years



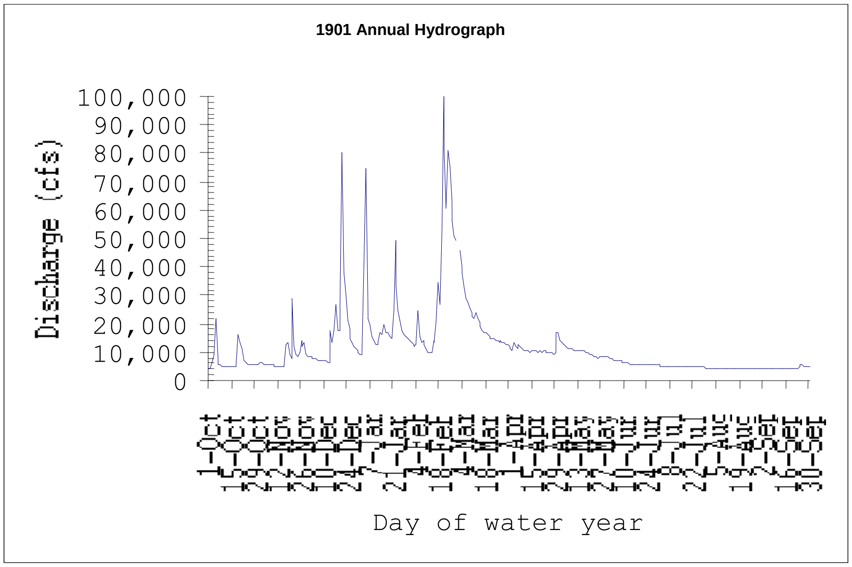


Sacramento River Wet Years

based on recommendations of the recently published Sacramento River Environmental Flows Report (Stillwater, 2007; ESSA Technologies, 2008). Rather then releasing a long duration rearing flow as proposed by Stillwater, it may be more economical to release two or three short duration pulses (3-5 days) of 12,000 cfs in late September and early October to inundate secondary channels and channel margins. The initial pulses would inundate the side channels and then be lowered to allow high residence times in the side channels. Each pulse would be followed by a subsequent pulse to flush food resources into the main channel and prevent fish stranding.

The main potential problem with a fall pulse flow would be to enable salmon, particularly spring run, to spawn on areas that would subsequently be dewatered. If the pulses are short enough, this problem may be limited. But the shorter the pulses will provide less potential for rearing habitat and food supply. Early fall pulse flows were rare under natural conditions, but they did occur occasionally as illustrated by the 1901 hydrograph (figure 7.1). Under regulated conditions, the winter run are confined to the mainstem river. The fall pulse, although largely unnatural, is designed to improve rearing conditions for them before cool winter months when food resources will presumably be less abundant.

Figure 8.1: 1901 hydrograph at Bend Bridge illustrating the rare, but natural occurrence of early fall pulse flows.



Key Uncertainties

- Will fall pulse flows for a few days result in dewatered reds once the pulse subsides?
- How long do secondary channel habitats need to be inundated in order to provide prolonged and substantial food supply benefits in the main channel?

8.2.3 Winter Base Flows

The purpose of the winter base flows is to provide stable conditions for incubating salmonids and reduce flashy regulated hydrology that can result when run-off from unregulated tributaries, primarily on the west side, is not modulated by less flashy natural hydrology from the larger, regulated watersheds. We recommend base flows of between 4,500 cfs in critical dry years and 8,000 cfs in wet years (table 7.4), which is similar to both existing regulated conditions and pre-dam historical conditions.

The winter base flows are a minimum base flow and are designed to occur in combination with unregulated run-off and flood control releases. Figure 7.2 shows the winter base flows as a straight line, but it is just a base flow that supports larger, unregulated peak flows. As a result, actual flows at Bend Bridge will be far more variable then depicted in figure 7.2.

Table 8.4: Winter base flow release from Keswick

	Critical	Dry	Normal Dry	Normal Wet	Wet
Winter base flow	4,500	6,000	6,500	7,000	8,000

Fairly substantial winter base flows combined with run-off events from less regulated tributaries will increase the frequency of inundation of channel margins and secondary channels that may serve as important rearing habitat.

8.2.4 Winter and Spring Peak Flows

The geomorphic flow targets discussed below may require additional releases from Shasta but are not explicitly included in figure 7.2 because they are short duration flow events that would be constructed upon unregulated run-off peaks. Smaller magnitude winter and spring peaks for fish rearing discussed below should be sufficient, particularly if reshaped, to achieve geomorphic targets below Red Bluff when combined with unregulated run-off.

Bed Mobilization

We recommend increasing the frequency of channel migration and bed mobilization flows during dry and below normal years for the reasons discussed in Appendix B. On the basis of thresholds discussed in chapter six, we recommend measures to achieve bed mobilization flows in most years (table 7.5). Based on the analysis of flow thresholds presented in chapter five, 35,000 cfs in dry years should be enough to initiate bed mobilization, at least locally, but it is probably not enough to precipitate widespread bed mobilization. The recommended peak flows in wetter years should be sufficient to precipitate significant bed mobilization in below normal, above normal, and wet years.

Table 8.5: Bed mobilization flow targets for Sacramento River between Keswick and Bend Bridge during different year types.

	Critical	Dry	Below Normal	Above Normal	Wet
Bed Mobilization		35,000	65,000	85,000	105,000

Some fish biologists have expressed concerns that high flow, even relative modest high flowss, could scour redds and thereby harm salmonid reproduction (ESSA, 2008; Stillwater, 2007). Based on our flow threshold analysis (chapter 5), we doubt that flows below 25,000 cfs will substantially mobilize the bed or scour redds. Much higher flows will significantly mobilize the bed, but the biological impact is not well documented and dependent on timing.

The ideal timing for bed mobilization is in early March after most salmon fry have emerged from the gravel and before bank swallow initiate nesting on cut banks. We expect that most mobilization events will result largely from unregulated run-off that humans are unable to control. While it seem logical that scouring flows would impair salmon reproduction, the natural hydrograph was characterized by multiple bed mobilization events in most years, raising the question of whether high, scouring flows actually limit salmonid reproduction. Under natural conditions, however, young fish would have had abundant floodplain and backwater habitat that is now scarce due to levees and reduced channel complexity.

Bed Scour

Information regarding the bed scour process and the magnitude of flow necessary to scour the bed is limited. While we recognize the potential importance of bed scour processes, we have not recommended any measures to precipitate bed scour due to the high level of uncertainty and the sheer magnitude of flow that may be necessary. We do, however, expect some bed scour to occur during the larges flow events once every ten years or more.

Channel Migration

Bank erosion and channel migration is a natural process that shapes the river ecosystem and provides habitats for riverine species. Bank swallows nest in recently eroded cut banks. Coarse and fine materials eroded from cut banks create substrates for growth of riparian vegetation and spawning salmon respectively. Turbid water resulting from bank erosion can provide important cover habitat for juvenile fish that would otherwise be very vulnerable to predation.

Some degree of bank erosion and channel migration will occur at the bed mobilization flows identified above and the spring pulse flows described below. Flows sufficient to erode unprotected banks already occurs and will continue to occur in wet and above normal years due to unregulated flows irregardless of a flow prescription. Furthermore, removal of bank revetment may be a more cost water efficient measure to facilitate natural channel migration then intentional flow releases. For all of these reasons, we have not developed a specific flow recommendation for bank erosion and channel migration at this time.

Key Uncertainties:

- How much does the bed need to be mobilized? Is it sufficient to barely move the gravel and cobble substrate on the surface of the bed, or is it necessary to achieve full scale mobilization.
- What duration of peak flow is necessary to adequately mobilize the bed?
- How much does or could natural rates of bank erosion contribute to the overall turbidity and sediment load of the Sacramento River.

8.2.5 Spring Base Flow

The purpose of the spring base flow is to substantially increase rearing habitat along channel margins and within high flow channels for 45 to 120 days. Under natural conditions, spring flows (March and April) were consistently the highest, prolonged flow of the water year and resulted in widespread inundation of flood plain habitats. Under existing conditions, spring flows are substantially reduced, and a system of levees prevents widespread floodplain inundations.

We propose base flows to inundate secondary channels for rearing habitat during the spring months (table x). According to a recent study, a large number of secondary channels become fully connected to the channel at flows above 12,000 cfs (Kondolf, 2007). In critical dry years, flows would average 10,000 for thirty days after March 15, but small pulses greater then 12,000 cfs would increase connectivity with rearing habitat. In wetter years, larger flows would presumably create more rearing habitat and connectivity for longer periods of time.

Figure 8.6: Spring Pulse Flows at Bend Bridge

	3/15 - 3/31	4/1 - 4/14	4/15 - 4/30	4/30 - 5/14	5/1 - 5/14	5/15 - 5/31	6/15 - 6/30
Critical	10,000	10,000	8,500				
Dry	10,000	12,000	12,000	8,500			
Below Normal	12,500	12,500	12,500	8,500			
Above Normal	12,500	14,000	14,000	14,000	8,500		
Wet	14,000	14,000	14,000	14,000	14,000	8,500	

Key Uncertainties:

- Do flows in excess of what is necessary to inundate high flow channels create better rearing habitat and more food then flows barely sufficient to inundate these habitats?
- What is the optimal flow and residence time to create ideal rearing habitat conditions (food supply, temperature, and depth) in the secondary channels.

- Is the secondary channel habitat significant enough to substantially improve rearing conditions relative to the rearing habitat in the channel.

8.2.6 Floodplain Inundation Flows

The purpose of the floodplain inundation flows is to inundate floodplains in the Sutter and Yolo flood bypasses for rearing habitat and food web productivity. The flow objective is to create substantial inundated floodplain habitat for 30-60 days between February 15 and April 15 in most year types. To economize on the amount of water necessary to inundate these bypasses, we propose modifying the Tisdale and Fremont weirs to created inundated flood plain habitat more frequently and for a longer duration. Based on the floodplain process analysis in chapter 5, we developed a schedule of flood flow targets for various year types to create good conditions for floodplain rearing and foodweb productivity in nearly all year types (table 7.7).

The floodplain inundation flows are not explicitly included in figure 7.2. The winter and spring pulse flows described above combined with unregulated run-off at Colusa and environmental flows from the Feather and Yuba should be sufficient to achieve the table 7.7 targets.

Table 8.7: Recommended average monthly flows at Verona and Nicolaus on the Feather to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types (30-60 days).

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Key Uncertainties:

- What magnitude of flow is necessary in the Sacramento and Feather Rivers to move water across the bypasses assuming a modified weir structure?
- What is the optimal timing and flow to create optimal habitat conditions on the bypasses (depth, velocity, temperature, residence time) and food web productivity for the estuary?

8.2.7 Spring Snowmelt Recession Limb

The purpose of the spring, snowmelt recession is to periodically provide conditions for recruitment of Fremont cottonwoods, a keystone species in the riparian ecosystem. As discussed in appendix A and chapter 5, recruitment of cottonwoods requires a high spring flow followed by a gradual decline in order to enable cottonwoods set roots into the groundwater on higher surfaces that are relatively immune from scour during subsequent winter floods. An earlier analyses (TNC, 2003) determined that a range of 23,000 cfs to 37,000 cfs inundates the appropriate seedbed for establishment of cottonwood.

Cottonwood trees need not be recruited in all years to ensure a sustained riparian forest ecosystem.

We recommend recruitment flows of 23,000 in above normal years and 37,000 cfs (or somewhere in that general range) in wet years for 4-7 days between mid April and mid May followed by a gradual recession for 8-10 weeks. This flow regime should enable seeds released in mid spring to germinate on relatively high surfaces and then gradually extend roots to the permanent water table before the subsequent growing season.

8.2.8 Summer Base Flow June 15 to September 15

We have designed summer base flows between Keswick and Red Bluff to economically provide suitable conditions for winter run, spring run, and steelhead that spend a temperature sensitive portion of their life cycle between Keswick Dam and Red Bluff diversion Dam (table 7.8). Under natural conditions, these fish would have migrated upstream of Keswick and Shasta, but there mainstem habitat is now limited to the cold tail water provided by reservoir releases. Current base flows are artificially high to deliver water to Sacramento Valley irrigation districts and the Delta. Ideally, these unnaturally high flows could be shifted to the early spring to restore a prolonged spring pulse flow for rearing habitat and aquatic productivity, but providing a more natural flow regime (3,000 to 5,000 cfs) could result in lethal water temperatures for incubating winter run-eggs. Furthermore, flows of only 3,000-5,000 cfs would not provide sufficient water for both diversion into the north valley canals and base flows all the way downstream to the Delta. Therefore, we have proposed an intermediate level summer base that falls at the mid-range between historic base flows and existing base flows between Keswick and Red Bluff.

Table 8.8: Summer base recommendation at various points on the Sacramento River for all year types.

Below Keswick	8,000
Below Red Bluff Diversion	6,000
Below GCID Diversion	4,500
Below Colusa	4,000

Below Red Bluff and the GCID diversions, we have proposed substantially reduced summer base flows in order to shift more flow to the early spring months without disrupting the cold water pool management regime. The primary purpose is to provide better habitat conditions in the spring, but restoring a more natural summer base flow may have environmental benefits in its own right. Summer base flows substantially below the 8,000 cfs needed to inundate off-channel backwaters will create more natural summer conditions and thus may discourage invasive plant and animal species that may out compete natives under the existing artificial summer base flow regime. Seasonally desiccated off-channel habitats may be more productive then perennially inundated wetlands and less likely to harbor exotics predators such as bull frogs and bass. Lower summer water levels may be less beneficial to late germinating invasive vegetation such as tamarisk that can out compete native cottonwoods.

Key Uncertainties:

1. Assuming no changes to the cold water pool management, what flow is necessary to maintain sufficient water temperatures for over summering life stages of winter-run, spring-run, late fall-run and steelhead?
2. Will low flows and corresponding higher temperatures increase populations of non-native warm water fish that prey upon or compete with native species?
3. Will summer base flows be sufficient between Red Bluff and GCID to maintain water temperature conditions suitable for juvenile salmonids or adult migrating salmonids?
4. Will more "natural" conditions provide better habitat and feeding conditions for native species?

8.3 Feather River

Summary recommendations for Sacramento River base flows, key ecological flows, and a flow schedule are presented in tables 7.1 – 7.3. Illustrative flow recommendation hydrographs for each year type are presented in figure 7.2.

Table 8.9: Feather River Environmental Flow Targets for Bend Bridge and Verona

	Critical	Dry	Below Normal	Above Normal	Wet	Location
Bed Mobilization		10,000	20,000	55,000	50,000	Bend
Floodplain Inundation		6,000	8,000	10,000	12,000	Verona
Riparian Establishment Flow				10,000	12,000	Bend
Bed Scour	No Recommendation					
Channel Migration						

Table 8.10: Feather River Minimum Base Flow Targets for Oroville

	Critical	Dry	Normal Dry	Normal Wet	Wet
Fall base flow	1,250	1,250	1,300	1,600	1,750
Winter base flow	1,500	1,700	1,850	2,750	3,500
Spring base flow	2,000	2,700	3,200	6,500	8,000
Spring rise	2,750	5,500	8,000	10,000	12,500
Summer Base	1,300	1,700	2,000	2,000	2,000

Table 8.11: Feather River Environmental Flow Targets (Timing and Duration)												
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
Geomorphic				▒	🟨	🟨	▒		Optimal 2/15 -3/15*			
Floodplain Inundation					Only 45 Days	🟨	🟨					
Riparian Establishment Flow							🟨					
Riparian Recession Limb								🟨	🟨			
Spring Rise							🟨	🟨				
Fall Base Flow	🟨	🟨										🟨
Winter Base Flow			🟨	🟨	🟨							
Spring Base Flow						🟨	🟨	🟨				
Summer Base Flow									🟨	🟨	🟨	

8.3.1 Fall Base Flows

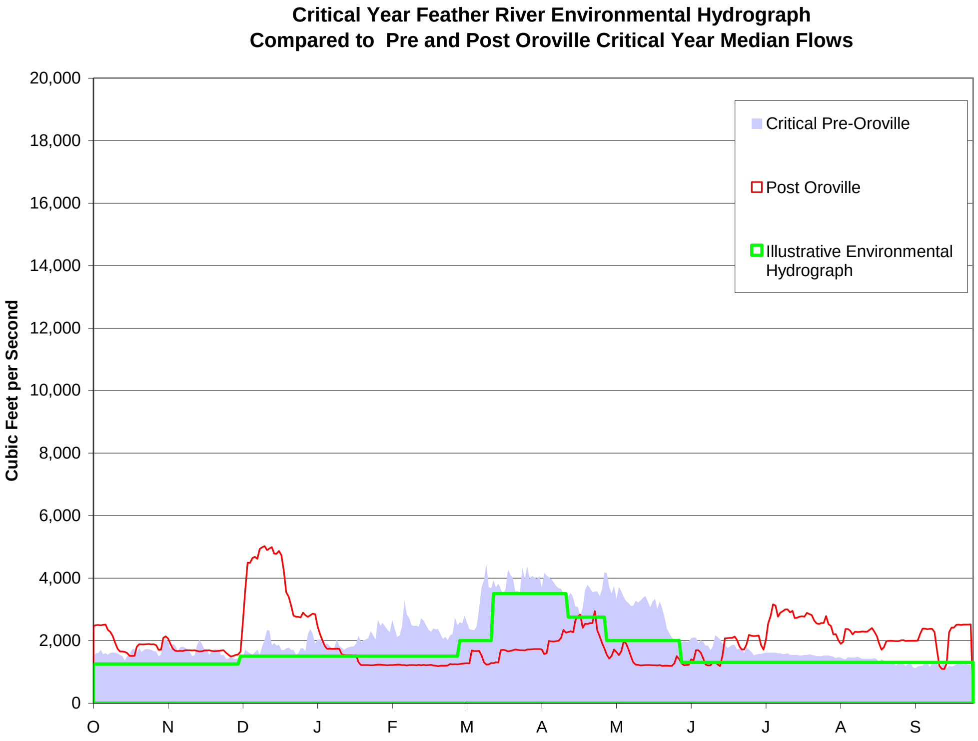
We propose stepping flows down from a stable summer base flow (see below) in late September (table 7.10) to fall spawning flows specified by the recent Oroville relicensing proceeding. The new minimum instream flows below Thermalito Afterbay range from 1,000 cfs in the late spring and summer to 1,200 -1,700 cfs during the fall winter months. Under both natural and regulated conditions, flows in early fall are the lowest flows of the year. The primary purpose of lowering base flows in the fall closer to their historic and regulatory minimum levels is to economize on water and shift the saved water to the spring months when it is more important. The secondary purpose is to provide stable base flows for spring and fall-run spawning and potentially to trigger spring-run spawning. The fall base flows must be stable to avoid dewatering or redds that may occur when flows are substantially dropped from the norm.

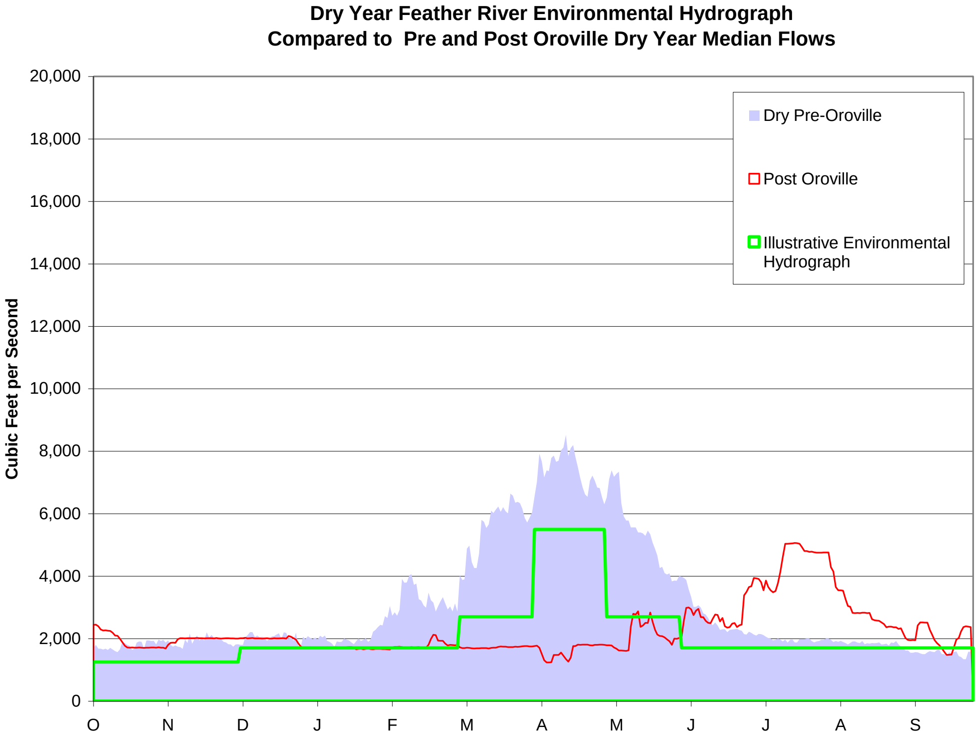
Key Uncertainties

- Are proposed fall base flows sufficient for area of spawning habitat?

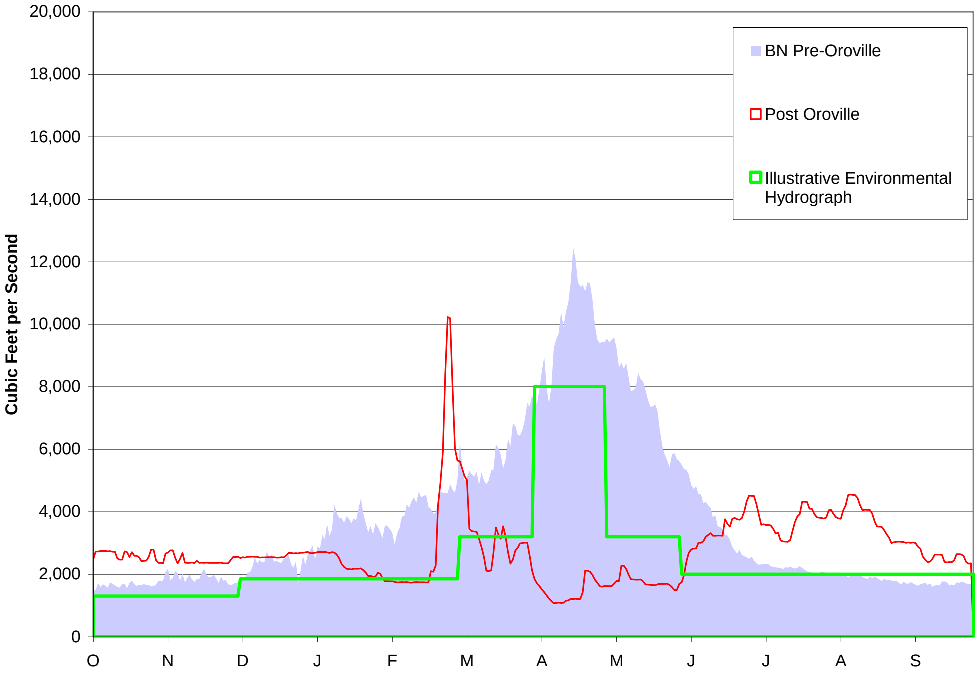
Will reduce fall base flows cause adverse impacts in the Delta ecosystem?

Figure 8.3: Illustrative environmental hydrographs for five year types on the Feather River relative to pre and post Oroville hydrographs.

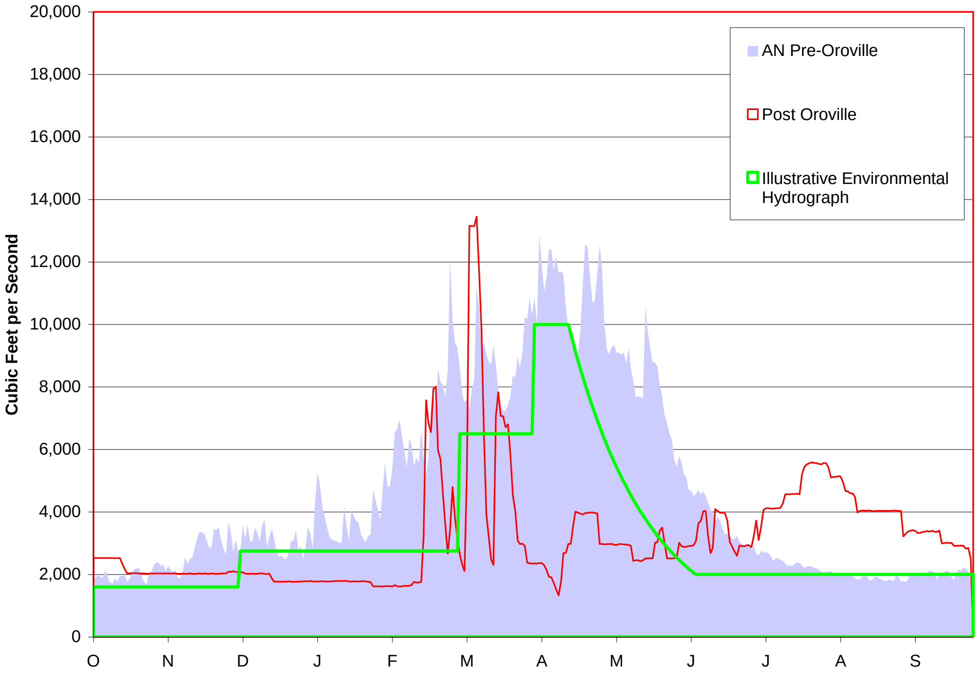


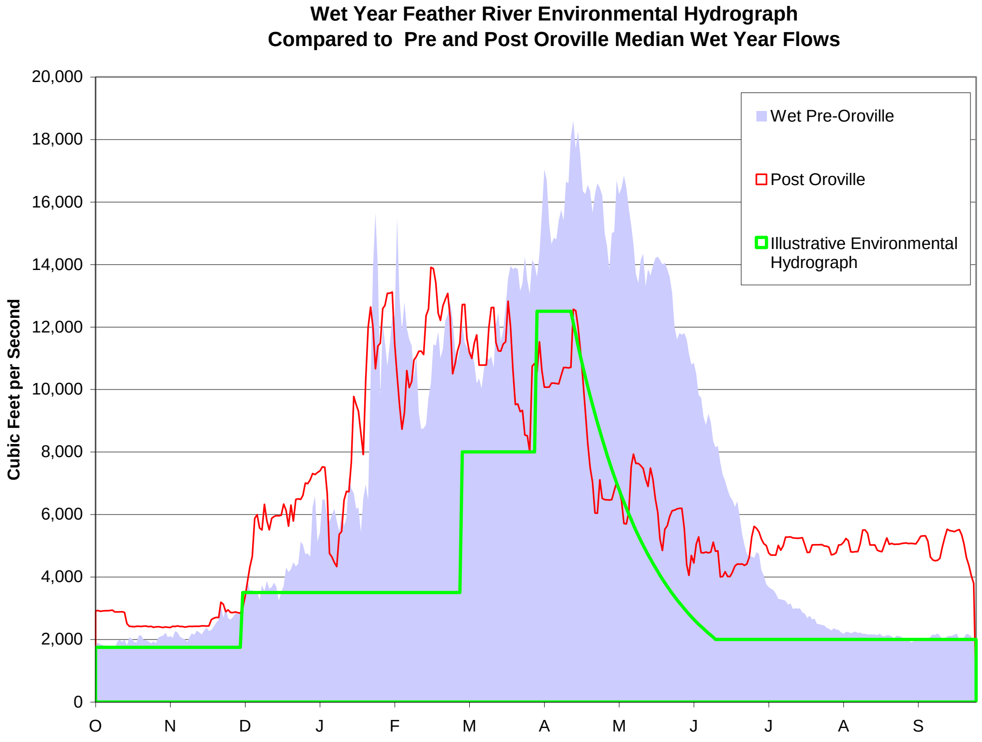


Below Normal Year Feather River Environmental Hydrograph
Compared to Pre and Post Below Normal Oroville Median Flows



Above Normal Year Feather River Environmental Hydrograph
Compared to Pre and Post Oroville Above Normal Median Flows





Wet Year Feather River Environmental Hydrograph
Compared to Pre and Post Oroville Median Wet Year Flows

8.3.2 Winter Base Flows

The purpose of the winter base flows is to provide stable conditions for incubating salmonids and reduce flashy regulated hydrology that can result when run-off from unregulated tributaries, particularly the South Fork Yuba, is not modulated by less flashy natural hydrology from the larger, regulated watersheds. We recommend base flows of between 1,500 cfs in critical dry years and 3,500 cfs in wet years (table 7.10), which is similar to both existing regulated conditions and pre-dam historical conditions.

The winter base flows are a minimum base flow and are designed to occur in combination with unregulated run-off and flood control releases. Figure 7.3 shows the winter base flows as a straight line, but it is just a base flow that supports larger, unregulated peak flows. As a result, actual flows below the confluence with the Yuba will be far more variable then depicted in figure 7.3.
Fairly substantial winter base flows combined with run-off events from less regulated tributaries will increase the frequency of inundation of channel margins and secondary channels that may serve as important rearing habitat.

8.3.4 Winter and Spring Peak Flows

The geomorphic flow targets discussed below may require additional releases from Shasta but are not explicitly included in figure 7.3 because they are short duration flow events that would be constructed upon the spring rise or ordinary flood control releases. Smaller magnitude spring pulse flows for fish rearing discussed below should be sufficient, particularly if reshaped, to achieve geomorphic targets.

Bed Mobilization

We recommend increasing the frequency of channel migration and bed mobilization flows during dry and below normal years for the reasons discussed in Appendix B. On the basis of thresholds discussed in chapter six, we recommend measures to achieve bed mobilization flows in most years (table 7.5). Based on the analysis of flow thresholds presented in chapter five, 35,000 cfs in dry years should be enough to initiate bed mobilization, at least locally, but it is probably not enough to precipitate widespread bed mobilization. The recommended peak flows in wetter years should be sufficient to precipitate significant bed mobilization in below normal, above normal, and wet years.

Table 8.12: Bed mobilization flow targets for Feather River below Oroville

	Critical	Dry	Below Normal	Above Normal	Wet
Bed Mobilization		10,000	25,000	35,000	50,000

Some fish biologists have expressed concerns that high flow, even relative modest high flowss, could scour redds and thereby harm salmonid reproduction on the Sacramento River (ESSA, 2008; Stillwater, 2007). Because are bed mobilization flows for the Feather River are based on statistical estimates rather then empirical evidence of bed mobility, the potential for red scour is a big uncertainty, but we doubt it will occur at 25,000 cfs or less and the greater magnitude flows prescribed for above normal and wet are likely to happen from flood control releases regardless of our flow recommendations.

The ideal timing for bed mobilization after late February when most salmon fry have emerged from the gravel. We expect that most mobilization events will result largely from unregulated run-off that humans are unable to control. While it seem logical that scouring flows would impair salmon reproduction, the natural hydrograph was characterized by multiple bed mobilization events in most years, raising the question of whether high, scouring flows actually limit salmonid reproduction. Under natural conditions, however, young fish would have had abundant floodplain and backwater habitat that is now scarce due to levees and reduced channel complexity.

Bed Scour

Information regarding the bed scour process and the magnitude of flow necessary to scour the bed is limited. While we recognize the potential importance of bed scour processes, we have not recommended any measures to precipitate bed scour due to the high level of uncertainty and the sheer magnitude of flow that may be necessary. We do, however, expect some bed scour to occur during the larges flow events once every ten years or more.

Channel Migration

Bank erosion and channel migration is a natural process that shapes the river ecosystem and provides habitats for riverine species. Bank swallows nest in recently eroded cut banks. Coarse and fine materials eroded from cut banks create substrates for growth of riparian vegetation and spawning salmon respectively. Turbid water resulting from bank erosion can provide important cover habitat for juvenile fish that would otherwise be very vulnerable to predation.

Some degree of bank erosion and channel migration will occur at the bed mobilization flows identified above and the spring pulse flows described below. Flows sufficient to erode unprotected banks already occurs and will continue to occur in wet and above normal years due to unregulated flows irregardless of a flow prescription. Furthermore, removal of bank revetment may be a more cost water efficient measure to facilitate natural channel migration then intentional flow releases. For all of these reasons, we have not developed a specific flow recommendation for bank erosion and channel migration at this time.

Key Uncertainties:

- How much does the bed need to be mobilized? Is it sufficient to barely move the gravel and cobble substrate on the surface of the bed, or is it necessary to achieve full scale mobilization.
- What duration of peak flow is necessary to adequately mobilize the bed?
- How much does or could natural rates of bank erosion contribute to the overall turbidity and sediment load of the Sacramento River.

8.3.5 Spring Base Flow

The purpose of the spring base flow is to substantially increase rearing habitat along channel margins and within high flow channels for 45 to 120 days. Under natural conditions, spring flows (March and April) were consistently the highest, prolonged flow of the water year and resulted in widespread inundation of flood plain habitats. Under existing conditions, spring flows are substantially reduced, and a system of levees prevents widespread floodplain inundations.

On the Feather River, we do not have good information regarding the flows necessary to inundate back-water channels. As a result we developed spring flow targets based on historical hydrology and an assessment of the flows necessary to inundate the Sutter Bypass (table 7.13). Wetter year spring flow pulses begin later in the spring and last longer, while dryer year targets economize on water early to get salmon out of the river before temperatures could become a problem in the lower Sacramento.

Figure 8.13: Spring Pulse Flows below Oroville

	3/1- 3/14	**3/14- 3/30**	**4/1- 4/14**	**4//14 - 4/30**	**5/1 - 5/14**	**5/15 – 5/31**
Critical	2,000	3,500	3,500	2,000		
Dry	2,700	2,700	5,500	5,500	2,700	
Below Normal	3,200	3,200	8,000	8,000	3,200	
Above Normal	6,500	6,500	10,000	10,000	5,000	3,000
Wet	8,000	12,500	12,500	11,000	6,000	4,000

Key Uncertainties:

- Do flows in excess of what is necessary to inundate high flow channels create better rearing habitat and more food then flows barely sufficient to inundate these habitats?
- What is the optimal flow and residence time to create ideal rearing habitat conditions (food supply, temperature, and depth) in the secondary channels.
- Is the secondary channel habitat significant enough to substantially improve rearing conditions relative to the rearing habitat in the channel.

8.3.6 Floodplain Inundation Flows

The purpose of the floodplain inundation flows is to inundate floodplains in the Sutter and Yolo flood bypasses for rearing habitat and food web productivity. The flow objective is to create substantial inundated floodplain habitat for 30-60 days between February 15 and April 15 in most year types. To economize on the amount of water necessary to inundate these bypasses, we propose modifying the Tisdale and Fremont weirs to created inundated flood plain habitat more frequently and for a longer duration. Based on the floodplain process analysis in chapter 5, we developed a schedule of flood flow targets for various year types to create good conditions for floodplain rearing and foodweb productivity in nearly all year types (table 7.7).

The floodplain inundation flows are not explicitly included in figure 7.3. The spring pulse flows described above combined with unregulated run-off from the Sacramento and Yuba Rivers will be sufficient to achieve the table 7.7 targets.

Table 8.14: Recommended average monthly flows at Verona and Nicolaus on the Feather to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types (30-60 days).

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Key Uncertainties:

- What magnitude of flow is necessary in the Sacramento and Feather Rivers to move water across the bypasses assuming a modified weir structure?
- What is the optimal timing and flow to create optimal habitat conditions on the bypasses (depth, velocity, temperature, residence time) and food web productivity for the estuary?

8.3.7 Spring Snowmelt Recession Limb

The purpose of the spring, snowmelt recession is to periodically provide conditions for recruitment of Fremont cottonwoods, a keystone species in the riparian ecosystem. As discussed in appendix A and chapter 5, recruitment of cottonwoods requires a high spring flow followed by a gradual decline in order to enable cottonwoods set roots into the groundwater on higher surfaces that are relatively immune from scour during subsequent winter floods. Since we did not have estimates of flows suitable for riparian recruitment on the Feather River, we estimated a seedling establishment flow target based on the Sacramento riparian recruitment target. We simply scaled down the Sacramento target based on the ratio of the seedling establishment flow to the Q1.5. The seedling establishment flow on the Sacramento (23,000 – 30,000 cfs) is twenty seven to thirty seven percent of the bankfull discharge (Q1.5 to Q2) on the Sacramento. Assuming a similar proportional relationship on the Feather River, flows in the range of 9,500 to 18,000 would be suitable for seedling establishment.

We recommend seedling establishment flows of 10,000 in above normal years and 12,500 cfsin wet years for 4-7 days between mid April and mid May followed by a gradual recession for 8-10 weeks. This flow regime should enable seeds released in mid spring to germinate on relatively high surfaces and then gradually extend roots to the permanent water table before the subsequent growing season.

8.3.8 Summer Base Flow June 15 to September 15

The purpose of the summer base flow is to provide suitable temperature and rearing conditions for over summering salmonids, both juvenile and adult spring-run and steelhead. We propose base flow targets ranging from 1,300 in critical dry years to 2,000 cfs in above normal and wet years. These flows are very similar to natural summer base flows and are higher then the minimum existing minimum flows established during the recent relicensing proceedings. Existing minimum regulatory flows are 1,000 cfs in the summer. Existing actual flows are far higher then are recommendation.

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APPENDIX A

LITERATURE REVIEW OF ENVIRONMENTAL FLOW METHODS

APPENDIX A

LITERATURE REVIEW OF ENVIRONMENTAL FLOW METHODOLOGIES

Over the past five decades, the development and application of environmental flow methodologies (EFMs) has rapidly progressed, as a means to help sustain or restore natural aquatic functions and ecosystems in the face of increasing demands for limited water resources. EFMs are science-based processes for assessing and/or recommending instream flows for regulated rivers. Their purpose may be as general as maintaining a healthy riverine ecosystem or as specific as enhancing the survival of targeted aquatic species. The growing prominence of EFMs in river management planning reflects a trend towards more sustainable use of the world's freshwater resources and a shift in focus from water quality to water *quantity* as a major factor in the degradation of rivers (O'Keeffe 2000).

In a comprehensive study of environmental flow methodologies, Tharme (2000) documented the existence of more than 200 EFMs, recorded worldwide. These included various modifications and hybrids of some commonly applied methods, site-specific approaches with limited applications, and procedures that are no longer in use. In actuality there are only a few dozen EFMs that are still widely applied. They can be divided into four major categories: 1) hydrological, 2) hydraulic rating, 3) habitat simulation, and 4) holistic methodologies (Tharme 2000). An overview of each of these categories is provided below, along with general strengths, weaknesses, and associated trends.

1.1. Hydrological Methods

Hydrological methodologies make up the largest proportion (30%) of environmental flow methodologies developed (Tharme, 2000). Hydrological methods are usually simple office procedures that recommend a proportion of a river's historical unregulated or naturalized flow regime as the minimum flow to maintain a fishery or other aquatic features. Recommended flows may be given on a monthly, seasonal, or annual basis. For example, the Tennant (Montana) method suggests 20% of mean annual flow (MAF) during the wet season and 40% MAF during the dry season to maintain "good" river conditions. Because of their simplicity and low resolution, Tennant and other hydrological methods are most appropriate for early reconnaissance-level project planning, to provide relatively quick and inexpensive estimates of flows to allocate for environmental purposes. Although biological factors are not explicitly considered in these methods, most were developed with some general biological basis (Caissie and El-Jabi 1995). In addition, hydrological methods assume that a minimum flow within the historic flow range for a river will sustain some proportion of native aquatic biota because the species survived such conditions in the past (Jowett 1997).

Hydrological methods have the primary advantages of being simple, straightforward, and relatively inexpensive to apply. Most require only historical flow records for a site, with little or no additional fieldwork. The simplicity of these methods, however, is also their greatest weakness. Because they do not incorporate site-specific habitat data, their ecological validity is often questionable (King et al. 2000). For example, these methods are frequently applied without regard to artificial changes in channel conditions (due to flow regulation or man-made structures) that may influence the ecological impact of recommended flows. EFMs in this category also should not be applied to river systems that do not approximate in size and type the reference river systems on which they were developed. Many hydrological methods do not address ecologically important intra- and interannual variations in flows. And unlike other methods, hydrologically based EFMs usually cannot be used to compare alternative flow regimes. Finally, for some river systems it may be difficult to obtain the unregulated or naturalized flow data necessary to calculate recommended flows.

Despite their many limitations, Tharme (2000) suggested that hydrological methods will continue to be the EFMs of choice for the foreseeable future. However, we can expect to see progress in their development towards more ecologically defensible and sophisticated methodologies. The Range of Variability Approach (RVA) is one such recently developed EFM that is considered to represent a significant advance over earlier hydrological methods. Unlike other EFMs in its category, the RVA captures the complex intra- and interannual variability of natural flow regimes over multiple temporal scales, incorporates a large number of ecologically based hydrologic indices in its analysis, and utilizes an adaptive management program for monitoring and refinement (Richter et al. 1996, 1997). Since its inception, the RVA has attracted considerable interest among river scientists and managers as a new class of ecologically grounded hydrologically based environmental flow methodologies (King et al. 2000).

1.2. Hydraulic Rating Methods

Hydraulic rating methodologies comprise 11% of the global total of EFMs. They differ from purely hydrology-based methods in that they incorporate site-specific information on hydraulic parameters, such as wetted perimeter or maximum depth, as measured across riffles or other limiting river cross sections. These parameters are used as surrogates for the habitat available for target biota such as fish or macroinvertebrate communities. Hydraulic rating methods assess changes in the habitat surrogates in response to changes in discharge. Recommended flows are commonly set at a breakpoint in the parameter-discharge curve, interpreted as the flow below which habitat decreases rapidly with a decrease in flow and above which habitat increases slowly with an increase in flow (Loar et al. 1986).

Although they require some fieldwork and data analysis, hydraulic rating methods enable a relatively quick and simple assessment of flows for maintaining habitat of target biota. They are considered more advanced and biologically relevant than hydrological methods. Their inclusion of site-specific field measurements better adapts them to different river systems. Hydraulic rating methods, however, are based on a number of simplistic assumptions that often cannot be verified. Key among these is that the chosen hydraulic variable(s) can be used to determine the flow requirements of the target species. In addition, the validity of results is highly dependent on appropriate sampling of critical river cross sections and proper identification of a breakpoint in the parameter-discharge curve. The latter is frequently complicated by the existence of multiple breakpoints or the lack of any defined breakpoint in the curve. And like most hydrological methods, EFMs in this category generally do not address ecologically important intra- and interannual variations in flows.

In the past decade there have been few advances in the development or application of hydraulic rating methodologies. Instead, this category of EFMs seems to have been superceded by the more advanced habitat simulation methodologies for which they are precursors. The Wetted Perimeter Approach, the best-known EFM in this category, is still widely applied in North America and globally (Reiser 1989, King et al. 2000). However, it is likely that many other hydraulic rating methods will gradually fall into obsolescence as the science of EFMs advances in alternate directions (Tharme 2000).

1.3. Habitat Simulation Methods

Habitat simulation methodologies (28%) rank second only to hydrological methods in proportion of total EFMs. This group of flow methodologies includes the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), which is the most widely used EFM in North America and the world (Reiser 1989, Tharme 2000). IFIM and many other habitat simulation methods comprise systems of highly sophisticated computer modeling techniques that integrate site-specific hydraulic and hydrologic data with species specific habitat preference data (in the form of habitat suitability curves). Computer outputs are usually in the form of habitat usability-flow discharge curves for the various factors of interest, e.g., different life stages of one or two fish species. Practitioners evaluate these curves and determine flow regimes based on the levels of protection (habitat usability) desired for each factor of interest. Because there is considerable potential for conflicting habitat requirements in this final step, it is necessary to have clear management objectives and a good understanding of the stream ecosystem when using IFIM and other habitat simulation methods to develop flow regimes.

Habitat simulation methods are flexible and adaptable. They incorporate site-specific and species specific information, so can be tailored for particular conditions and management goals. They can be used to analyze flow-related trade offs among multiple species and life stages. They may be modified to recommend flows for riparian vegetation, sediment flushing, recreation, and any number of other instream purposes. They are capable of addressing ecologically important intra- and interannual variations in flows for target species. Habitat simulation methods are also often perceived as scientifically objective and legally defensible; thus, they may be suitable for allocating instream flows in highly controversial situations (Estes 1996).

The focus of habitat simulation methods on specific target species and/or instream uses raises the risk that other essential components of the stream ecosystem may be overlooked (Prewitt & Carlson 1980). On the other hand, when these methods are used to address multiple management objectives for a river system, there are no set procedures for resolving conflicting flow requirements. The flexibility that habitat simulation methods provide make them among the most difficult EFMs to apply and interpret. Another important consideration, especially for developing countries, is that habitat simulation methods are often time-consuming, costly, and require considerable technical and scientific expertise for proper application. Modeling applications can be run without sufficient understanding of input and output processes; therefore, there is high potential for misuse by improperly trained persons. Other important sources of error or bias for modeling outputs include selection of representative cross sections for collecting hydraulic data, and construction of species-specific habitat suitability curves. Finally, a commonly cited criticism of PHABSIM, the modeling system used with IFIM, is the seeming lack of relation between fish and habitat usability estimates produced by the models (Orth and Maughan 1982).

Habitat simulation models, though the subject of much criticism, are still highly regarded by many river scientists. Current trends in their development are more advanced modeling techniques, multi-dimensional graphics, and integration of GIS display platforms.

1.4. Holistic Methods

These methods are relatively new to the science of environmental flow management. They were first documented by Tharme (1996) and currently make up 7.7% of total EFMs (Tharme 2002). Holistic approaches rely largely on multidisciplinary expert panels to recommend instream flows (Tharme 2000). They represent a significant departure from earlier environmental flow methods, in that their recommendations are almost wholly subjective. However, more advanced holistic methods, such as the Building Block Methodology (BBM), may utilize several of the analytical tools described for other EFMs to assist in the decision-making process (Tharme 2000). An early step in the BBM and some other holistic methods is identification of the magnitude, timing, duration, and frequency of important flow events for various ecosystem components and functions. The decision-making process for integrating these flow events may include a number of activities, including workshops, site visits, and limited data collection and analysis. The final output of the consensus process is a recommended flow regime to meet various specific management objectives.

Most holistic methods are relatively quick and inexpensive to apply. They have limited requirements for technical expertise and hydrologic data. And with appropriate interdisciplinary representation, these methods can comprehensively address all major components of the riverine ecosystem, including geomorphological, riparian, biological, water quality, social and other elements. Holistic methods can recommend flows at a variety of temporal scales. They are site-specific and allow for assessment of whole stretches of river rather than extrapolation from sample cross sections. The major weakness of holistic methods is the subjectivity of their approach, which may open their findings to controversy and criticism.

Holistic methods are still very much in the infancy of their development. Most of these methods have their roots in South Africa and Australia. Few have been applied outside of these countries of origin. Application of holistic methods for environmental flow management is expected to grow rapidly over the next decade, as EFMs become better established as river management tools in developing countries. Holistic methods are well suited for use in these countries, where data, finances, and technical expertise are frequently limited.

2. METHOD FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS FOR THE SACRAMENTO AND FEATHER RIVERS

We have employed a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento River. This approach relies heavily on hydrological evaluations, previous studies, and expert opinion to estimate environmental flow requirements and develop a long-term adaptive management plan for implementing and refining an environmental flow regime over time. The results of the holistic approach provide a framework for increasing knowledge regarding the relationship between flow and environmental objectives and refining water management practices over time. The output of the holistic method envisioned here provides not only an estimate of environmental flow requirements, but more importantly, an explicit identification of key assumptions and uncertainties that need to be tested overtime to more accurately describe the flow requirements necessary to achieve environmental objectives.

We made two important assumptions in generally applying this method to the Sacramento River.

- Similarities in both the restoration objectives and the hydrologic, geomorphic, and ecological conditions on the Sacramento River will result in relatively similar prescriptions for environmental management flows. We believe this assumption is well supported by the environmental conditions and historical alteration of this river.

- The flow necessary to achieve restoration objectives may vary greatly depending on non-flow restoration actions such as improving spawning habitat, reconstructing degraded channel, removing levees to restore floodplain habitat, modifying and screening water diversions, reducing polluted run-off, managing ocean harvest, and other factors. In general, non-flow restoration actions will reduce the amount of water necessary to achieve restoration objectives.

The holistic approach applied in this study consists of the following 6-step process to identify an environmental flow regime:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.
3. Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.
4. Identify obvious gaps between objective flow requirements and existing flows.

5. Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.
6. Design an adaptive management program to further test and refine environmental flows.

1) Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).

Well-articulated target ecological conditions and desired species and communities are necessary for establishing environmental flows. Despite the correctly vogue concept of restoring ecosystem processes and avoiding species specific approaches, there is no getting around the fact that key species need specific hydrologic conditions at specific times. This analysis will include both aquatic and riparian communities and the flow parameters necessary to sustain these communities such as floodplain inundation, appropriate water temperature, or creation of structural habitat through geomorphic processes. These specific environmental objectives may vary by region, sub-basin, and reach of the river.

2) Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.

An environmental flow regime encompasses the adequate timing, magnitude, duration, and frequency of flows necessary to support target species and facilitate specific ecological processes encompassed in the stated environmental objectives. Where we understand the life cycle timing of various target species, it is relatively easy to identify the approximate timing and duration of flows necessary to support different life stages of target species. Estimating the required flow magnitude is far more difficult but can be informed by field data, results of numerical models, and general relationships described in the literature. Most short lived target species require adequate flows each year to reproduce, while longer lived species can sustain their populations with a lower frequency of flow conditions conducive to reproduction. For example, riparian forest species may only require recruitment flows every five to ten years to establish new seedlings.

Estimating the magnitude of flows necessary to support or optimize conditions for target species and processes is by far the most difficult element of the environmental hydrograph to approximate. Environmental engineers and biologists have developed relatively elaborate methods for determining ideal flow regimes such as physical habitat simulation (PHABSIM) and Instream Incremental Flow Methodology (IFIM) to identify optimum flow magnitudes based on known habitat preferences of target species, measured habitat conditions (velocity and depth) at various flows, and numerical models that predict habitat conditions at a range of flows. Numerical models that describe the width, depth, and velocity of the rivers at various discharges are useful for predicting river stage and temperature at various locations, factors that are important considerations for habitat or facilitating geomorphic and hydrologic processes. As discussed above, these models tend to focus on the needs of specific species and can sometimes produce results that are inconsistent with both holistic ecological process restoration and common sense. Furthermore, these models are often not calibrated, particularly at higher flows relevant to riparian recruitment, geomorphic processes, and spring outmigration temperatures. Nevertheless, we utilized the results of these models as a guide combined with other information to develop our environmental flow management hypothesis.

Where possible, we relied on actual data and measurements to estimate the flows necessary to achieve suitable conditions to support biological, riparian, and geomorphic objectives for temperature, floodplain inundation, and bed mobilization. In particular, we relied on USGS temperature gauges to characterize the relationship between temperature and flow. Similarly, we relied on previous studies of the rivers to characterize flows necessary to mobilize bed material and inundate the floodplain.

3) Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.

Analyses of historical hydrologic data is useful for describing natural patterns and identifying potential links between hydrology and the requirements necessary to maintain species and precipitate key processes. An analysis of historical patterns can provide clues about the timing, magnitude, duration, and frequency of flows under which target species have evolved. Identification of major changes between historical and hydrologic patterns combined with the life history requirements of various species can help generate hypotheses about how flow regulation may be limiting target species. We will use the an analysis similar to the Index of Hydrologic Alteration approach (Richter et al. 1996) and the Hydrograph Component Analysis (HCA) (Trush et al. 2000) to evaluate changes in flow patterns. The analysis similar to the IHA provides a quick statistical overview of how several important hydrologic attributes have changed. The analysis similar to the Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. While valid and useful, the statistical analysis in the IHA method is not substitute for visually comparing and evaluating key components of the pre- and post-dam hydrographs. Similarly, visual comparisons of pre- and post-alteration hydrographs don’t always reveal important changes identified by the IHA method.

4) Identify obvious gaps between objective flow requirements and existing flows.

An analysis of historical flow patterns combined with an approximation of the TMDF of flows necessary to achieve objectives compared with the regulated flow regime can help illustrate obvious gaps between regulated flows and flows that may be necessary to achieve environmental objectives. We will plot TMDF flow requirements developed in Step 2 as an annual hydrograph and compare it with average regulated and historical conditions.

5) Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.

This project identifies hypothetical restoration flow regimes but recognizes that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The purpose of developing the hypothetical flow regime is to develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River. However, the assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself.

6) Design an adaptive management program to further test and refine environmental flows.

To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of numerical modeling, pilot flow studies, model calibration, and long-term restoration implementation.

APPENDIX B

CONCEPTUAL MODELS
FOR
GEOMORPHIC PROCESSES, FREMONT COTTONWOODS,
AND CHINOOK SALMON

APPENDIX B: CONCEPTUAL MODELS

Geomorphic Conceptual Model

1.0 Geomorphic Conceptual Model

Geomorphic processes are generally initiated at threshold flow levels. Bed mobilization and floodplain inundation do not occur until flows reach a threshold level sufficient to flow over bank or create sheer stresses necessary to mobilize gravel. Theoretically, no benefit occurs unless the threshold flow is achieved. No amount of flows less than the threshold will initiate bed mobilization or floodplain inundation, but in reality the actual threshold flow varies spatially from reach to reach. Research from several gravel bedded river systems indicates that a flow with a natural (unregulated) recurrence interval of every 1.5 years is generally needed to mobilize the bed and initiate over bank flows (Leopold et al. 1964). In reality, however, the threshold flows necessary to initiate geomorphic processes naturally vary from reach to reach depending on channel dimensions, slope, and the size of bed material. In general, sand bedded reaches mobilize at lower flows than gravel bedded reaches with larger particle sizes. Similarly, low gradient reaches flood at lower discharges than steeper reaches, particularly where large woody debris is allowed to accumulate.

Human modifications of the channels from their natural state have changed the relationship between flows and geomorphic processes and have therefore complicated the already difficult task of determining the flows necessary for precipitating various geomorphic processes. Gravel and channel restoration projects have changed and could continue to change the particle size of gravels and the channel dimensions and will thus further change the relationship between flow and geomorphic processes. More importantly, there is no single bed mobility threshold for any reach of the Sacramento River or any other river channel due to spatial vaiabilty in particle size and channel form (Kondolf et al, 2000; Wilcock, 1996).

There are varying degrees of bed mobilization, further complicating the definition of mobility and its distinction with bed scour. For this study, we attempted to estimate the flows necessary to mobilize and scour the bed. Bed mobility and bed scour are two different processes that occur at different flow thresholds. We use the term bed mobility to refer to mobilization of the surface of the channel bed. Bed scour is the process of scouring the bed deeper than its coarse surface layer. Incipient bed mobility is the threshold at which bed material begins to mobilize and occurs when the ratio of the critical sheer stress to the D_{50} equals 1. Incipient mobility can cause small movement of gravel across the top of the riffle without general mobilization of the riffle surface. Relatively frequent (every 1–2 years) incipient motion of gravels on a riffle may be adequate for certain objectives such as flushing fines from the gravels, but is probably not sufficient for certain geomorphic objectives such as restoring sediment transport or maintaining a dynamic, alternating bar sequence (Trush et al. 2000). General bed mobility mobilizes the entire riffle surface and occurs when the ratio of critical sheer stress to particle size D_{50} exceeds 1.3. General bed mobility may be necessary for restoring basic alluvial functions such as transporting coarse sediment from one riffle to the next.

Lastly, there is relatively little information regarding the flows necessary to perform various geomorphic objectives. Geomorphic processes associated with these objectives occur at very high flows, when field measurement is difficult. Hydraulic models and equations have been applied on the Sacramento to provide insight into the flows necessary to mobilize the bed and banks and inundate the floodplain, but in many cases these models have not been adequately calibrated at high flows or do not accurately describe the actual hydraulics at specific cross sections (Kondolf, 2000). Empirical observations are generally more reliable, but are often limited to specific study sites. In this study, we have relied on previously reported field measurements, modeling analysis, and general principles from the literature to roughly estimate the magnitude of flows necessary to initiate geomorphic processes.

For all of the reasons discussed above, it is not possible to estimate future flow levels necessary to initiate geomorphic processes across an entire river, but for the purposes of this study, a rough estimate will be sufficient to evaluate the feasibility of reoperating reservoir releases for the purpose of achieving geomorphic objectives. In this study, we have focused on the flows necessary to mobilize the gravel bedded reaches, because they are more relevant to salmon restoration and because they will also result in mobilization of the sand bedded reaches. For floodplain inundation, we have focused on the lowland floodplains because they can be inundated at lower flows with demonstrated fisheries benefits.

The geomorphic conceptual model in its most succinct form is that high flows exert sheer stress on and transport sediment over the many structural components of a river channel and floodplain (bed, banks, other exposed surfaces) causing them to change, erode, migrate, and otherwise respond in a qualitatively predictable manner.

The geomorphic conceptual model described below is based on inputs and outputs. Inputs into the model are in three categories: flow, topography, and sediment. The outputs of the model are physical functions that in turn support habitat and biotic responses in the river system.

The Sacramento River requires a variety of high flows ($Q_{1.5} – Q_{10}$) to clean sediment, rejuvenate alternate bar sequences, prepare the floodplain for vegetation recruitment, and drive channel migration. Each one of these functions supports a biotic or habitat response described previously in this chapter.

Figure 1 illustrates the relationships between flow, sediment, and topographic inputs, and ensuing geomorphic processes. The model has been simplified to focus primarily on restoration objectives of this project and the inputs we propose to modify to achieve these restoration objectives (outlined in bold).

Inputs

The driving inputs in the conceptual model fall into three categories: flow, topography, and sediment. In reality, the conceptual model is at least partly cyclic, where the outputs are also inputs into successive cycles.

Flow Inputs

Flow inputs can be divided into three broad categories: regulated runoff, unregulated runoff, and groundwater inputs. Regulated runoff refers to flow releases from reservoirs over which humans exert some control. This is of particular importance to this conceptual model because it is the input we propose to modify. Unregulated runoff refers to flow inputs on streams and rivers over which humans do not exert much control. As the distance between any point on a river and an upstream dam or diversion increases, so too does the influence of unregulated runoff. More tributaries enter the river and the unregulated drainage area increases downstream from the dam or diversion.

Groundwater refers to any inputs from subsurface flows. These are not, in fact, entirely independent of regulated or unregulated runoff. Interaction of high flows with floodplain surfaces, flow durations, and flow frequencies impact the quantity and timing of groundwater inputs. Similarly, groundwater inputs impact base flow levels in both regulated and unregulated systems. For the sake of simplicity and focus, groundwater is considered an independent input.

Topographic Inputs

The shape of the river channel and floodplain, the location of the levees, the amount and type of vegetation in the channel and on the floodplain, and other structural characteristics comprise the topographical inputs of the conceptual model. They determine the distribution and velocity of any given flow quantity. For example, if one hundred acre-feet of water enter into a river, the water will pass much more quickly and smoothly if the river channel resembles a pipe - smooth and straight. If the channel is small, the water may spill onto the floodplain. If the channel is flat and wide, the water may travel very slowly. If the channel is full of vegetation, it may impede the flow of water or concentrate it between walls of vegetation.

Upstream Sediment Inputs

Upstream sediment inputs refer to silts, sands, cobbles, gravels or boulders transported in the river system. The quantity and quality of upstream sediment input create the building blocks for depositional processes. Because dams capture most upstream sediment, in regulated rivers sediment inputs are mostly from unregulated tributaries and storage in banks and bars below the reservoir.

Flow Outputs

Regulated flow, unregulated flow, and groundwater establish the amount of water in a river system. The topographic features determine the surface over which the water flows, and how it flows over that surface. Together, they determine the discharge, stage, and velocity of the flows (producing sheer stress). Combined with the frequency of these flows, and the upstream sediment inputs, they drive various geomorphic processes in river systems (described below).

Process Responses

Gravel Bed Mobilization

Gravel bed mobilization refers to the entrainment of D50[1] gravels. This generally occurs in alluvial rivers during the historic annual or biannual floods or roughly the $Q_{1.5}$ flow or Q_2. The mobilization of the gravels "cleans" them by removing accumulated silt, algae and other fine particulates (Stillwater Sciences, 2001).

Floodplain Inundation

Floodplain inundation is a hydrogeomorphic process that serves important ecological functions. Floodplain inundation provides temporary access to floodplain habitat for aquatic species, recruits nutrients from the floodplain into the river, and helps to recharge groundwater levels in riparian zones. Inundated floodplains provide important spawning and rearing habitat for numerous species. Sacramento splittail are largely dependent on inundated floodplains for successful spawning and rearing. Juvenile salmon grow two to three times as fast on floodplains compared to channels. Due to large surface area, the volume of area in the photo zone, and relatively warm temperatures during cool winter and early spring months, floodplains generate larges amounts of phytoplankton and zooplankton during the critical spring months.

Determining the flow necessary to inundate floodplains is complicated by the fact that different types of rivers and river reaches overflow their banks at different flows. Floodplain inundation in gravel bedded streams generally occurs during flows at or above the historic biannual flood (Q_2) (Stillwater Sciences, 2001). However, floodplain inundation on lowland Rivers such as the lower Sacramento and Feather Rivers occurr far more often, creating extensive flood basins that were inundated for weeks or months in all but the driest years (Bay Institute, 1998). Even under post dam hydrology, many of these basins, such as the Yolo Bypass, would flood for weeks or days at flows far below the bankfull discharge.

It is not realistic to restore floodplain inundation to the historic flood basins of the Sacramento Valley. It would simply be too disruptive to the water supply and economic functions of the Sacramento River and its historical floodplains. It is, however, more realistic to intentionally inundate the system of flood bypasses designed to safely accommodate flood flows in the Sacramento River. The magnitude of flows necessary to inundate bypasses, as well as the frequency of bypass inundation is controlled by weirs at the upstream end of each bypass. Water does not enter the bypass and create inundated habitat until the river stage is high enough to overtop the weir. A study sponsored by the US Army Corps of Engineers, however, demonstrated that it is possible to inundate the bypasses at greater frequency and lower flows by intentionally notching the weirs (NHI, 2002). For the purposes of this study, we have assumed that you could inundate

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[1] D refers to the length of the intermediate axis of gravels in a gravel bed. The D50 refers to the gravels in the 50th percentile size class, relative to the other gravels in the bed.

floodplains in flood bypass areas using this method at multiple weirs in the Sacramento Valley.

Bed Scour and Deposition

Bed scour and deposition refer to the removal of sediment and the corresponding replacement of sediment that occurs during storm events. The bed scour and deposition process discourages the river channel from being "fossilized" by riparian encroachment, maintaining it in a dynamic alluvial state. It is a greater level of mobilization than simply gravel bed mobilization, in that the bed degrades during the ascending limb of the hydrograph and aggrades on the receding limb of the hydrograph. Q_5 to Q_{10} floods generally provide the necessary shear stress to scour beds and redeposit with little net change in channel elevation (Trush et al. 2000)

Floodplain Sediment Scour and Deposition

Floodplain sediment scour requires greater sheer stress than simply inundation and generally occurs during flows equivalent to the historic Q_{10}. By exerting sheer stress, scour prepares floodplain surfaces for recruitment of riparian vegetation by removing existing vegetation, depositing clean sand and transporting new seed across the floodplain. Depositional processes also require higher flows to transport sediment away from the channel onto the floodplain. As flows increase, they spill across the floodplain, velocities slow, and the river deposits its sediments. Most floodplain sediments are the result of this process (Leopold et al., 1964). Deposition on the floodplain further reshapes and prepares the surfaces for recruitment.

Channel Migration

Channel migration is a function of stream energy and substrate strength. By eroding, channel migration recruits gravels and large woody debris into the system and directly and indirectly creates habitat complexity in the channel and floodplain. By depositing, channel migration prepares surfaces for pioneer species allowing for a diversity of riparian habitats. The process of channel migration is responsible backwater areas, sloughs, oxbow lakes, and secondary or abandoned channels (Bay Institute, 1998).

Channel migration requires the greatest amount of stream energy and generally requires large flows for a prolonged period, which can require very large volumes of water. Flows larger than the bank full discharge may be necessary to cause major channel migration or channel avulsion, but gradual channel migration may occur each year at some bends with flows well below the bank full discharge.

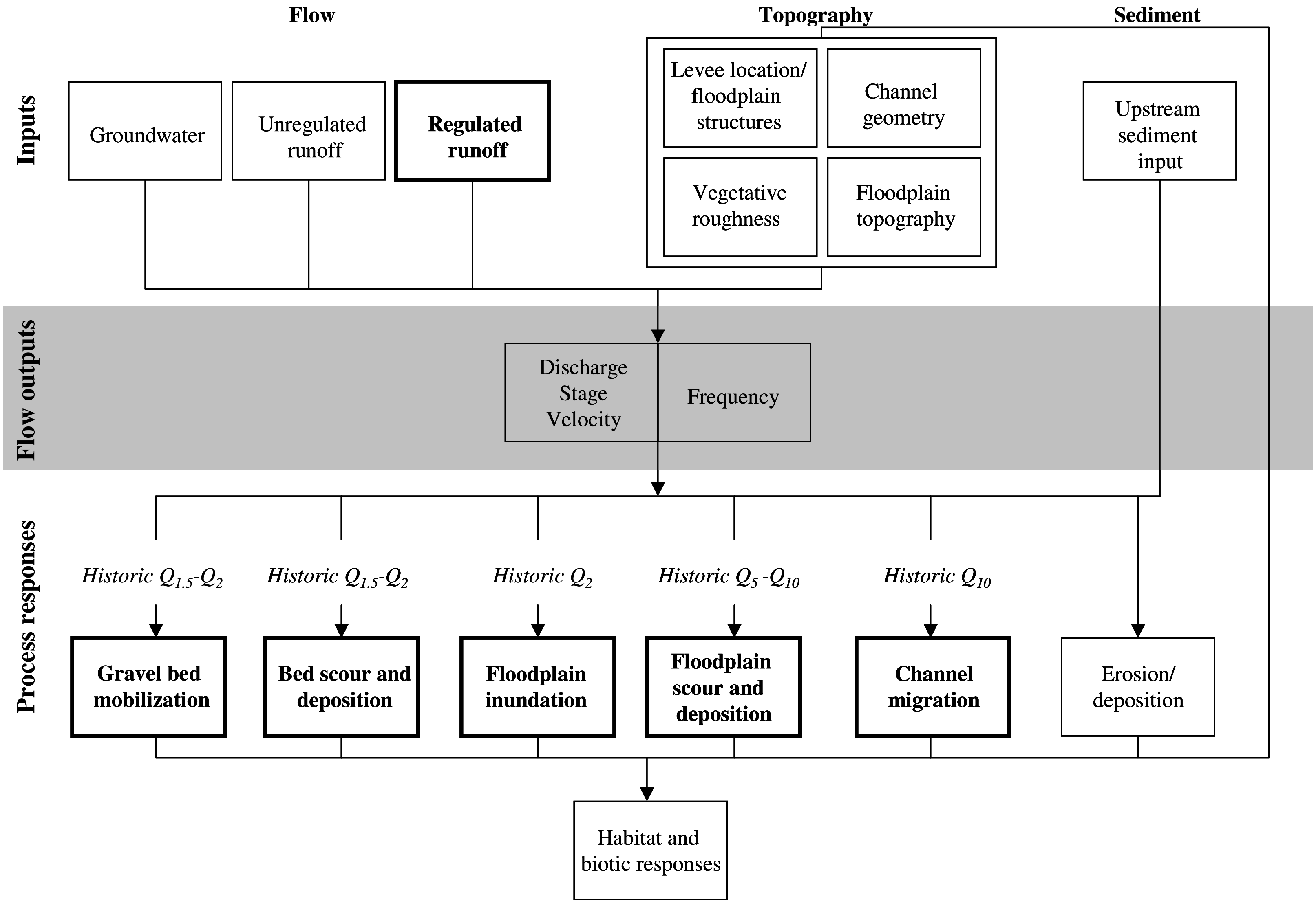


Figure 1. Geomorphic Conceptual Model. The figure above illustrates the relationships between flow, sediment, and topographic inputs, and ensuing geomorphic processes. The model has been simplified to focus primarily on restoration objectives of this project and the inputs we propose to modify to achieve these restoration objectives (outlined in bold).

Appendix C: Cottonwood Conceptual Model

4.2 Cottonwood Conceptual Model

Critical life history stages of cottonwoods and other pioneer riparian species in the Sacramento River basin are tightly linked with the hydrologic and geomorphic processes described in the previous conceptual model. Floodplain scour/deposition, channel migration, channel avulsion, and erosion/deposition processes generate new sites for cottonwood seedling establishment. Floodplain inundation provides moist substrates to sustain seedlings through their first growing season. Gravel and sand bed mobilization and bed scour/deposition help define a minimum elevation for cottonwood recruitment. Over time, these processes play a key role in determining the distribution, extent, and age structure of cottonwood communities in the Sacramento River basin. In turn, as cottonwoods mature, they have the potential to impact sediment deposition processes, channel stability, and channel dynamics. Both geomorphic processes and riparian habitat structure are important determinants of abundance and distribution of aquatic species such as chinook salmon, as described in the next section.

Land use activities and managed flow operations have greatly reduced the extent and integrity of riparian forests, particularly cottonwood forests, in the Sacramento Basin. Most existing cottonwood stands in the basin are mature, exhibiting older age structure than typical under natural conditions (McBain and Trush 2000, Stillwater Sciences 2002a, Jones & Stokes 1998). The absence of sapling cohorts in many reaches of the basin suggests that natural recruitment processes are not occurring under current conditions (McBain and Trush 2000, Jones & Stokes 1998, Stillwater Sciences 2002a). Without younger age classes, senescent trees cannot be replaced as they die, potentially leading to further substantial loss of this once dominant riparian vegetation community.

This conceptual model describes the ecological flows and geomorphic processes that drive establishment and recruitment of cottonwoods under natural conditions (Figure 2). The model identifies factors that currently limit cottonwood recruitment in the Sacramento Basin and opportunities for restoring this process through modification of flows and/or channel-floodplain geomorphology. Because channel attributes may differ widely among rivers and reaches of the Sacramento Basin, flow characteristics for restoration are described qualitatively in this model, with respect to channel and floodplain elevations.

Various species of cottonwoods share the characteristics discussed below. Any discussion specific to the Fremont cottonwood *(Populus fremontii),* the predominant species of the Central Valley (Stillwater Sciences 2002a, 2002b, 2006: McBain and Trush 2000), is noted as such.

4.2.1 Site Preparation

The creation of barren nursery sites through erosional and depositional processes is the first step in cottonwood seedling recruitment. Because cottonwood seeds contain very little endosperm, seedlings require full sunlight to produce photosynthates for growth and development; thus, cottonwood seedlings compete poorly on vegetated sites (Fenner et al. 1984). Under natural flow regimes, moderate 5- to 10-year flood events precipitate channel migration and the creation of point bars suitable for cottonwood seedling establishment (McBain and Trush 2000, Trush et al. 2000). Large flows scour away herbaceous plants and/or deposit fine sediments on floodplains, preparing new seed beds for pioneer riparian species (Mahoney and Rood 1998). In addition to point bars and floodplains, cottonwood forests may occur in high flow scour channels, oxbows, and other off-channel backwaters that receive scouring and sediment deposition (Stillwater Sciences 2002a).

Over the past century, continued agricultural and urban encroachment into riparian zones have greatly decreased the landscape area upon which cottonwood recruitment can occur (Stillwater, 2006; McBain and Trush 2000, Jones & Stokes 1998). In addition, flow regulation has reduced the intensity and frequency of winter and spring flood flows. The lower flows have led to a moderate reduction in the high-energy processes that, in less regulated river systems, create new seedbeds for recruitment—channel migration, point bar accretion, bed scour, and floodplain inundation. Levees and bank stabilization practices have reduced floodplain width and channel migration, in addition to isolating riparian backwaters (Stillwater, 2006). In addition, the loss of upstream sediment supply may have resulted in channel incision, requiring greater discharges for flows to inundate adjacent floodplains (TNC, 2003). The cumulative result of these processes has been a significant reduction in favorable germination sites for cottonwood seedlings.

There are several options for human intervention to increase availability of suitable recruitment sites for cottonwoods. Flood operations can be modified in wet years to allow shorter duration, but higher winter or spring peak flows sufficient to inundate floodplains and mobilize channel sediments (Jones & Stokes 1998). Reservoirs can be operated to release flows that mimic the 5- to 10-year flood events historically associated with cottonwood recruitment. Mechanical approaches include lowering floodplain surfaces for greater inundation frequency at current low flows, setting back or breaching levees to increase floodplain area, restoring the river's connection with abandoned side channels and backwaters, and artificially clearing floodplain sites to reduce plant competition.

Reductions in peak flows can lead to vegetation encroachment of more aggressive native riparian species into the formerly active river channel, further limiting cottonwood recruitment (Jones & Stokes 1998). Under natural hydrologic conditions, surfaces at the edge of low-flow channels were high-scour zones that generally prohibited the establishment of riparian vegetation. Under regulated conditions where the frequency of scouring flows has decreased significantly, vegetation —primarily alders and willows and forbes— can encroach along channel margins that were previously characterized by shifting and exposed gravel or sand bars (Stillwater Sciences 2002a, McBain and Trush 2000, FWUA and NRDC 2002). Vegetation encroachment can ultimately result in simplified and confined river channels resistant to fluvial geomorphic processes (e.g., channel migration) that create barren seedbeds for cottonwood recruitment. This does not appear to be a problem on the Sacramento River due to relatively frequent high flow events, but vegetation studies do indicate that recruitment is currently dominated by willows (TNC, 2003) to the potential detriment of cottonwoods. Therefore, maintaining the proper frequency and magnitude of high flows is necessary for maintaining habitats where cottonwoods are likely to become established and dominant.

4.2.2 Seedling Establishment

Establishment describes the process of seed release, germination, and growth through the end of the first year. This stage in the life cycle of cottonwoods is marked by high mortality rates, in both natural and regulated river systems (Mahoney and Rood 1998).

Most studies on Fremont cottonwood recruitment have focused on establishment of new stands through seed release, rather than vegetative sprouts. In the Sacramento Basin, mature female Fremont cottonwoods release hundreds of thousands to millions of seeds between April and June. Timing and duration of seed release are influenced by photoperiod and temperature, with maximal seed release generally occurring over a three-week period (FWUA and NRDC 2002, Stillwater Sciences 2002a). Seeds are dispersed by wind and water. They may travel up to a couple miles away, but more often they are deposited within a several hundred feet of the parent tree (Braatne et al. 1996). Dry Fremont cottonwood seeds are viable for one to three weeks (Horton et al. 1960). Once they are wet, their viability decreases to a few days (Braatne et al. 1996). Thus, for riparian restoration purposes it is important to understand the mechanisms that influence cottonwood seed release and dispersal, to ensure that timing of spring (snow-melt) pulse flows coincides with cottonwood seed dispersal. The spring pulse flows provide the moist nursery sites necessary for immediate germination of seeds (Mahoney and Rood 1998).

Cottonwoods germinate within 24–48 hours of landing on bare, moist substrates such as silt, sand, or gravel (John Stella, Stillwater Sciences, pers. com., 8 April 2003). For one to three weeks after germination, the upper layer of substrate must maintain moisture as the seedlings' root systems grow. Post-germination decline of river stage, which is presumed to control adjacent groundwater levels (JSA and MEI 2002), should not exceed approximately one inch per day (Mahoney and Rood 1998, Busch et al. 1992). This is the rate at which seedling root growth (0.16–0.47 inches/day; Reichenbacher 1984, Horton et al. 1960) can maintain contact with the capillary fringe of a receding water table in a sandy substrate. Cottonwood root growth and seedling establishment rates are higher in these soils than in coarser textured soils, which are more porous (Kocsis et al. 1991). In reaches with gravelly substrates, slower draw-down rates are necessary to support seedling establishment.

Mahoney and Rood (1998) describe the temporal and spatial window of opportunity for cottonwood seedling establishment as a "recruitment box", defined by timing of spring pulse ("establishment") flows/seed release and by seedling elevation relative to river stage. Optimal timing of seed release for successful establishment is during the gradually declining limb of a spring pulse flow. Optimal elevation relative to river stage is set at the upper end by the seedling's ability to maintain contact with the declining water table, and at the lower end by scouring and inundation flow levels in the first year, especially during the first winter.

The vast majority of cottonwood seedlings in this life stage die of drought stress because root growth is unable to keep pace with the decline in the water table (Mahoney and Rood 1998). Regulated ramp-down rates after spring pulse flows are often steep, in order to conserve water for human uses (Stillwater Sciences 2002b). Alternatively, decreased spring flows in regulated systems may cause seedlings to initiate at elevations too low to protect seedlings from flooding and scouring flows later in the growing season or during the winter (Mahoney and Rood 1998). In some rivers overwinter mortality of cottonwood seedlings is particularly high because flow regulation has reduced spring peak flows relative to winter peak flows (Stillwater Sciences 2002a).

High seedling mortality rates suggest that opportunities for improving cottonwood recruitment may be greatest in this life stage. In the first year of life, drought stress can be minimized by managing flood release flows for slow ramp-down rates after 5- to 10-year flood releases. Since reservoir spills often occur in wet years, reduced ramp-down rates may be accomplished by reshaping existing flood release flows without reducing water supply deliveries.

Artificial floodplain irrigation, either through flooding or a drip system, can also relieve summer drought stress for newly initiated seedlings. Agricultural irrigation close to the channel during the dry season would achieve similar gains in groundwater level. Grazing and trampling of seedlings by livestock can be minimized through grazing management practices or by building exclosures to protect cottonwood nurseries. To reduce winter mortality due to scouring and inundation, establishment flows can be discharged in spring rather than winter.

4.2.3 Vegetative Reproduction

In addition to seed dispersal and seedling establishment, vegetative reproduction is a potentially significant but commonly overlooked method for cottonwood recruitment along newly formed or previously established floodplains and point bars. Fremont cottonwoods can reproduce clonally through sprouting of buried broken or detached branches, or through development of suckers from shallow roots. This little-studied phenomenon has been alluded to in the riparian literature, and reported anecdotally and in unpublished studies (Tu 2000; Mike Roberts, TNC, pers. com., 27 February 2003). Additional insight into the process can be gained from studies of vegetative reproduction in other cottonwood species (Rood et al. 1994, Reed 1995).

Vegetative reproduction may be particularly important for sustaining Fremont cottonwood populations in altered hydrologic systems such as the Sacramento Basin. Tu (2000) reported that three years after the floods of 1996 established a new sandbar along the lower Cosumnes River, successful Fremont cottonwood recruits from vegetative branches outnumbered those from seeds by almost six to one. This is especially notable in light of the fact that the original 1996 cohort studied included 7,898 Fremont cottonwood seedlings compared to only 36 vegetative branches. Thus, the greater number of surviving 3-year-old recruits from vegetative branches compared to seedlings was due to their considerably higher survival rates rather than initial predominance. Most of the seedlings in this study died in their first year post-germination as a result of desiccation. Tu (2000) surmised that vegetative branches were better able to survive the critical first year by virtue of their greater nutrient storage, higher competitive ability for light, and greater proximity to declining water tables (most were partially buried in the soil).

In many parts of the Sacramento Basin, it is possible that the loss of natural recruitment processes under current conditions has increased the importance of vegetative propagation relative to seed propagation for sustaining cottonwood populations. An intervention opportunity based on natural vegetative reproduction is to plant cuttings collected from local cottonwood populations. Although this option would be time and labor intensive, cottonwoods have been successfully re-established by this method in Clear Creek and on the Sacramento and Merced Rivers (Mike Harris, USFWS, pers. com., 26 February 2003; John Stella, Stillwater Sciences, pers. com., 8 April 2003). Once a small number of individuals are successfully recruited to a new site, expansion of the population may subsequently occur via sprouting, suckering, or seed dispersal. Due to the uncertainties of seed dispersal timing, availability of flows, and high cost of flows (unless part of flood release flows), a dual strategy of vegetative reproduction and improved flow management may be the most cost effective option for improving rates of cottonwood recruitment in the Sacramento Basin.

4.2.4 Recruitment

The recruitment phase occurs from the end of the first year to sexual maturity, at five to ten years of age for Fremont cottonwoods (Reichenbacher 1984). Flow-related mortality is relatively low during this period because a plant has generally developed a sufficient root and shoot system to survive seasonal conditions of drought and flooding. Growth rates are very high in the second year, by the end of which roots may be almost ten feet deep (Ware and Penfound 1949). After the second year, growth rates level. Despite extensive root development during this stage, cottonwoods are still somewhat susceptible to drought stress. Thus, yearly flows must be sufficient to maintain groundwater levels within 10 to 20 feet of ground surface elevations (JSA and MEI 2002).

Groundwater extraction and reduced flows can reduce groundwater levels and induce drought stress in cottonwood saplings (Jones & Stokes 1998). In regulated river systems, low frequency of scouring flows may also allow exotics such as eucalyptus, tamarisk, and giant reed to establish and outcompete early successional native species such as cottonwood (Jones & Stokes 1998, McBain and Trush 2000). Relatively low flow-related mortality during this stage diminishes the importance of flow management opportunities. However, mortality due to herbivory (e.g., beavers, voles, mice) may be significant during this phase (John Stella, Stillwater Sciences, pers. com., 8 April 2003). Density-dependent mortality (self-thinning) may also occur if initial seedling density is high.

4.2.5 Maturity & Senescence

Maturity begins with the first flowering of a sexually mature adult. Senescence begins when reproductive capacity declines. Field studies indicate that a large proportion of existing cottonwood stands in the Sacramento Basin comprise mature and senescing individuals (McBain and Trush 2000, Stillwater Sciences 2002a, Jones & Stokes 1998). As these cottonwoods die (lifespan >130 years; Shanfield 1983), they are unlikely to be replaced by new generations of cottonwoods. Although cottonwood seedlings are readily germinating on the Sacramento River, most cohorts are not surviving to reproductive maturity, for the reasons outlined above. In addition, urban and agricultural conversion of mature cottonwood forests in the Sacramento Basin further reduces seed sources and threatens future prospects for this once-abundant riparian habitat (McBain and Trush 2000, Jones & Stokes 1998, Stillwater Sciences 2002a).

Cottonwood Conceptual Model

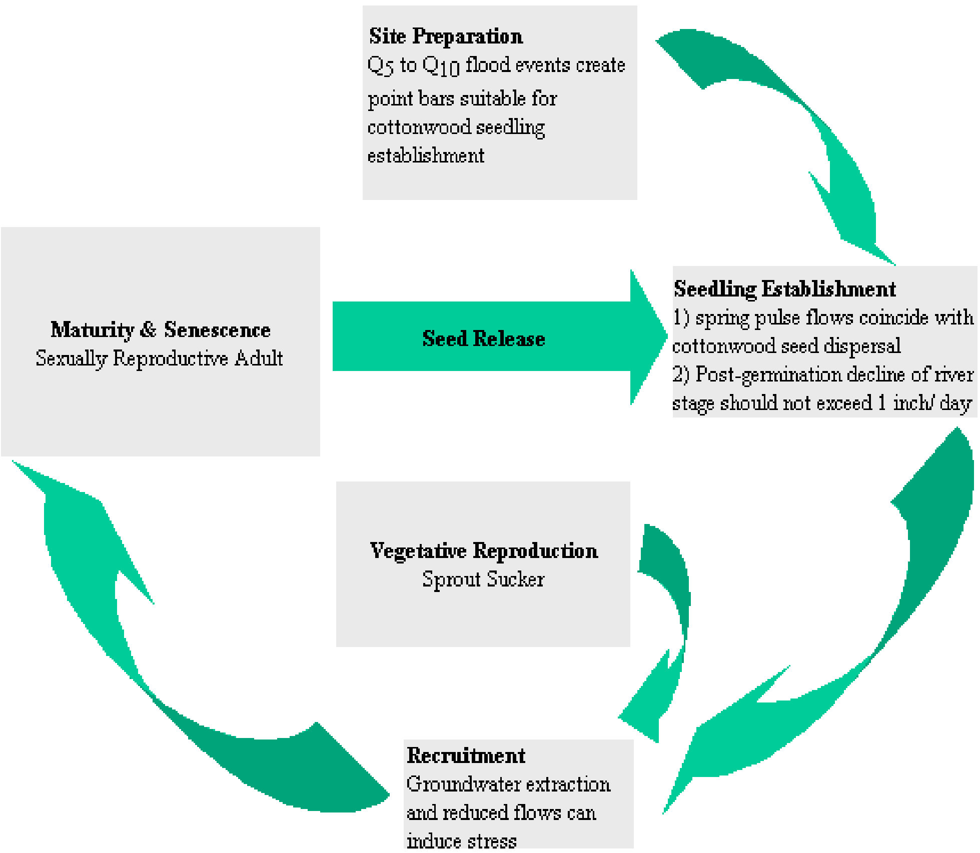
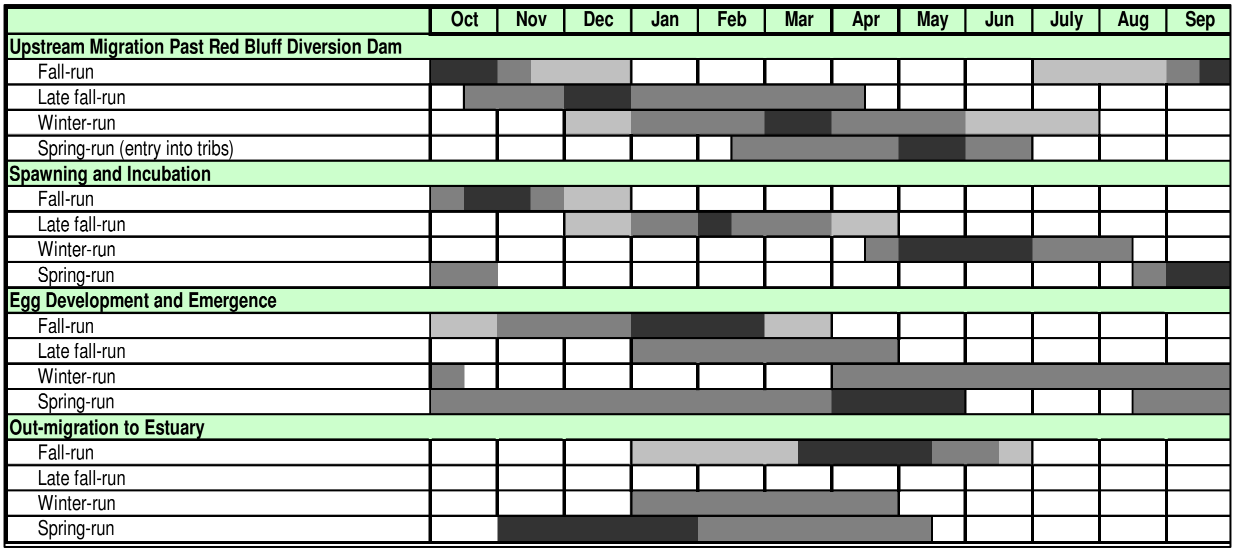


Figure 2. Cottonwood Conceptual Model for Sacramento Basin highlights characteristics of the flow regime that effect different life stages.

Chinook Salmon Conceptual Model

This conceptual model focuses on the flow related factors that affect populations of Chinook in the Sacramento and Feather Rivers. There are many non-flow factors that affect salmon populations, but we have only focused on the flow related factors for the purpose of developing an environmental flow regime. The model addresses flow-related factors for four runs of Chinook salmon and steelhead by life stage.

There are four distinct runs of Chinook salmon in the Sacramento River, the fall-run, the late fall-run, winter-run and spring-run. The different runs of Chinook differ in the timing of their life history. In general each run is named for the time that it begins migrating back to its natal stream. Table 1 shows that each run has the same life stages, but different runs move through the life-cycle at different times of the year and often employ different life stage strategies. For example, fall-run salmon are sometimes referred to as ocean type because they generally migrate to the ocean before their first year, while spring run generally spend a full year in the stream before migrating. Differences in timing and life history strategies mean that different runs can be vulnerable to different stressors. For example, winter run eggs incubate over the summer months and are therefore limited by summer water temperatures, while fall run eggs are much less likely to endure temperature stress since they incubate during the relatively cool winter months. The Chinook Conceptual Model lists the limiting factors that may impact the success of each life stage, the degree to which the limiting factor is relevant may depend on the particular run of Chinook which is being considered.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep
Upstream Migration Past Red Bluff Diversion Dam												
Fall-run	█	▒░	░							░	░	▒█
Late fall-run	□▒	▒	█	▒	▒	▒	▒□					
Winter-run			░	▒	▒	█	▒	▒	░	░		
Spring-run (entry into tribs)					□▒	▒	▒	█	▒			
Spawning and Incubation												
Fall-run	▒█	█▒	░									
Late fall-run			░	▒	█▒	▒	░					
Winter-run							□▒	█	█	▒	▒□	
Spring-run	▒										□▒	█
Egg Development and Emergence												
Fall-run	░	▒	▒	█	█	░						
Late fall-run				▒	▒	▒	▒					
Winter-run	▒□						▒	▒	▒	▒	▒	▒
Spring-run	▒	▒	▒	▒	▒	▒	█	█			□▒	▒
Out-migration to Estuary												
Fall-run				░	░	░█	█	█▒	▒░			
Late fall-run												
Winter-run				▒	▒	▒	▒					
Spring-run		█	█	█	▒	▒	▒	▒□				

Table 1: Salmon life history table. The timing and duration of the life history stage for each of the salmon runs; These are the periods of time that are most critical to the success of a particular life stage.

░	Period of light activity
▒	Period of acitivity
█	Period of peak activity

Table 2: Chinook Salmon (CHS) Thermal Tolerances. All lethal temperature data is presented as incipient upper lethal temperatures (IULT), which is a better indicator of natural conditions because experimental designs use a slower rate of change (1oC/d). (Modified from Moyle 2005, information largely from McCullough 1999.)

	Sub-Optimal	Optimal	Sub-Optimal	Lethal	Notes
Adult Migration	<10°C	10-20°C	20-21°C	21-24°C	Migration usually stops when temps climb above 21ºC. Under most conditions fish observed moving at high temps are probably moving to refugia.
Adult Holding	<10°C	10-16°C	16-21°C	10-20°C	Fish in Butte Creek experience heavy mortality above 21°C but will survive temperatures as high as 23.5°C for short periods of time. In some holding areas fish have been observed in temperatures of 20ºC for over 50 days during the summer.
Adult Spawning	<13°C	13-16°C	16-19°C	10-20°C	Egg viability may be reduced at higher temperatures
Egg Incubation	<19°C	9-13°C	13-17°C	10-20$_o$C	This is the most temperature sensitive phase of life cycle American River CHS experience 100% mortality in temperatures greater than 16.7°C; Sacramento River fall-run CHS mortality exceeded 82% in temperatures greater than 13.9°C
Juvenile Rearing	<13°C	13-20°C	20-24°C	10-20$_o$C	Past exposure (acclimation temperatures) has a large effect on tolerance. Fish with high acclimation temps may survive at 28-29ºC for short periods of time. When food is abundant, fish that live under conditions between 16 and 24ºC may grow very rapidly.
Smoltification	<10°C	10-19°C	19-24°C	10-20$_o$C	Smolts may survive and grow at suboptimal temps but are primarily avoiding predators

Temperature is one of the key factors that can limit salmon population numbers, but different life-stages display widely different temperature tolerances (Table 2). In general, salmon are most vulnerable to temperature stress in the egg life stage and least vulnerable in the juvenile life stage. Winter run are acutely sensitive to temperature, because their eggs are present during the summer months. Thus, different runs are effected differently by temperature stress due to the differences in run timing.

4.2.6 Life in the Ocean

All four runs of Chinook salmon spend approximately 1 to 5 years in the ocean before returning to spawn in their natal stream (Moyle, 2002), though historically, most Chinook salmon returning to the Sacramento River are approximately 4 years old (Clark 1929, in USFWS 1995).

Mortality of salmon in the ocean is based on natural and non-natural factors. Natural stressors include predation by other species, and ocean conditions, such as nutrient flow patterns (CMARP and CALFED Appendix C). The non-natural mortality factor affecting salmon is harvest. From 1967 to 1991, 60-80% of total salmon production was harvested (CMARP).

Changes in river management will do little to decrease natural mortality of salmon in the ocean. This study is not considering restoration of Chinook populations by limiting ocean harvest of salmon at this time. However, it is important to emphasize that large-scale harvesting of salmon in the ocean may be severely limiting salmon populations. If we could manage ocean stocks to increase the number of older fish, it may be possible to increase the ecosystem resilience against drought.

4.2.7 Adult Upstream Migration

Adult salmon migration can be limited by high temperatures and low dissolved oxygen. In the Sacramento River where flows are severely limited, adult salmon migration are delayed or disrupted by low flows and poor water quality. In particular, low levels of dissolved oxygen (DO) during summer and early fall at the Stockton Deep Water Ship Channel and high levels of ammonia from the Stockton wastewater plant in October cause poor water quality to delay adult Chinook migration up the lower San Joaquin, which causes an increase in poaching, lower egg and sperm viability and greater threats to outmigrating juveniles (Hallock et al, 1970 in CMARP). Fish migration does not appear to be limited by existing flow conditions, but reduced flows combined with polluted or warm water agricultural discharges could create problems for migrating fish.

Fall-Run
Adult fall-run Chinook salmon migrate into the Sacramento River and its tributaries from June through December (Yoshiyama, et al. 1998) Migration Peaks in September and October and spawning by mature adults begins shortly thereafter. Cool water releases in the Sacramento and Feather rivers are unnaturally high in late-summer and fall due to hypolimnetic discharge from

Shasta Reservoir (Stillwater, 2006). Increased summer and fall discharge, therefore may improve water quality and temperature conditions for migrating fall-run salmon. High ambient temperatures during late summer and early fall combined with warm or polluted agricultural drain water could become a problem for migrating salmon at lower stream flows (Domagalski, et al.). By mid October, however, water and ambient temperatures are cool enough for migrating salmon (Figure 4).

High water temperatures can prevent upstream migration, and can cause physiological damage and exhaustion (CALFED C-9). Temperatures above 70°F (21.1°C) prevented the upstream migration of adult Chinook salmon from the Delta to the Sacramento River, but the Chinook began migrating into the lower Sacramento as water temperatures fell from 72°F-66°F (22°C-18.9°C) (Hallock 1970 in USFWS, 1995). Temperatures ranging between 50°F and 67°F were found to be suitable for upstream migration of fall-run Chinook (Bell, 1986; Bell, 1973 in USFWS, 1995; and Bell, 1991 in Oroville). Although water temperatures below 38°F are reported to decreases adult survival (Hinze 1959 in USFWS, 1995), temperatures this low are not likely to occur in the Sacramento Basin tributaries.

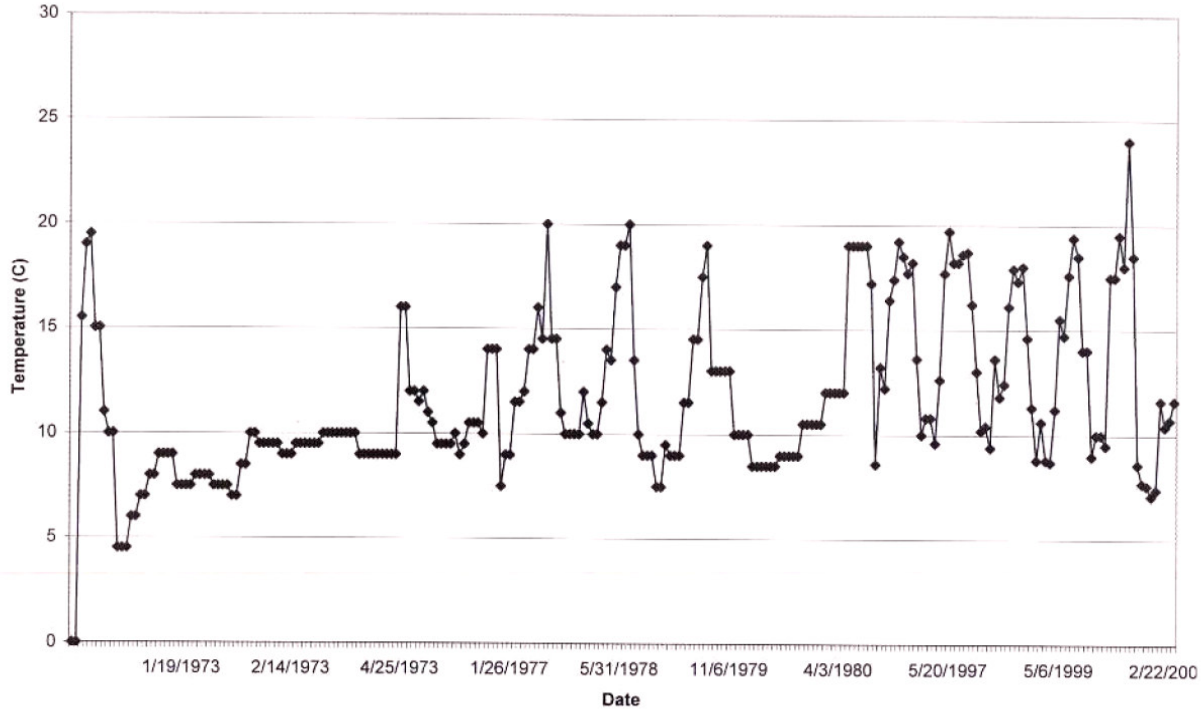


Figure 3: Temperature data collected on the Sacramento River downstream of Wilkins Slough (RM 118) between 1973 and 2000 at the Wilkins Slough gaging station (#11390500). Modified from Figure 4.2-7 in the Sacramento River Ecological Flows Study State of the System Public Review Draft.

A more natural flow regime in the late summer and fall could delay or impede the migration of fall-run salmon. Observations from the San Joaquin Basin where fall flows are lower and warmer suggest that the peak of the fall-run migration would shift to October and November. This may not reduce the overall population of fall-run salmon spawners, but it could create problems for recruitment by delaying emergence until the later spring months. Based on experience from the San Joaquin River (Stillwater, 2003) fall-run that emerge latter may have difficulty migrating out of the Sacramento and Feather Rivers before temperatures begin to rise in the late spring.

Increasing instream flows in the early fall in the Sacramento basin could improve conditions for migrating adult fall-run Chinook by reducing straying, improving water quality, improving passage barriers, decreasing water temperatures and decreasing the delay in migration. If salmon migration is motivated by major storms, early freshets or pulses after the first rain, and most of the large flows from storm events are trapped behind dams, reservoir operators can simulate pulse events by releasing water from the reservoir. However, "There is [a] concern that pulse flow releases in mid October to attract salmon may cause the fish to enter the rivers earlier than normal, which may expose them to high water temperatures when the pulse flows cease." (CMARP). Therefore, if flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for migrating adults and subsequent spawning.

Late-Fall Run

Adult late fall-run Chinook salmon migrate up the Sacramento River between mid-October and mid April, with peak migration occurring in December (Vogel and Marine, 1991). Water temperature and flow conditions within the natural range of variability will be suitable for late fall-run since water temperatures are within optimal levels.

Winter-Run

Adult winter-run Chinook salmon enter San Francisco Bay from November through June (Van Woert 1958, Hallowck et al. 1957 in NMFS 1997). Migration past Red Bluff Diversion Dam begins in mid-December and can continue into early August but the majority of winter run adults migrate past Red Bluff Diversion Dam between January and May with a peak in mid-March (Hallock and Fisher, 1985). Current RBDD operations facilitate upstream passage of winter-run adults by raising gates between September 15 and May 15.

Lower fall and winter flows are unlikely to create temperature adverse to winter-run migration, but lower spring flows could conceivably become a problem in drier years if spring flows are further reduced. Similarly, increased spring flows could be beneficial particularly for the latter part of the migration, but there is no evidence that the current adult migration is stressed by low flows or high temperatures.

Spring-Run

Although spring-run were probably the most abundant run historically in the Sacramento River (Mills and Fischer, 1994), most spring-run fish currently spawn in three tributaries: Deer, Mill, and Butte Creeks. Mainstem habitat was mostly blocked by Shasta Dam, but some spring-run still spawn below the dam, although they have apparently hybridized to some extent with the fall-run (Stillwater, 2006).

Adult spring-run enter the Sacramento-San Joaquin Delta beginning in January, entering their natal spawning streams from March to July (Myers et al. 1998). Adult spring-run migrate upstream to spawn in different tributaries at somewhat different times, suggesting some degree of life-stage flexibility. Butte Creek fish migrate up beginning in February and peaking March and April when flows peak in that stream. Adults from Deer and Mill Creek begin migration in March and peak in May, concluding in June.

Increased spring flows in the Sacramento during the late spring may provide some small benefits for migrating salmon in drier years, but there is no evidence that the adults are currently under stress during their migration. Increased flows in the Sacramento in drier years will not benefit conditions in the tributaries where most spring-run salmon migrate.

4.2.8 Spawning, Egg Incubation, and Emergence

Different runs spawn throughout the year and construct their redds in gravels that are typically 6 inches (15 cm) or less in diameter (Flosi et al., 1998). High water temperatures (greater than 56°F) due to low reservoir storage, high air temperatures and low flow releases could decrease available spawning habitat and affect sperm and egg viability. High temperatures cause spawners to concentrate in the upper reaches where water temperatures are lower, which increases the rate of superimpostion of redds (CMARP). "Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs" (USFWS, 1995) and water temperatures below 38°F also can result in lower egg viability (Hinze 1959 in USFWS, 1995).

In order to provide quality areas of spawning habitat, adequate flows need to be released from dams into the tributaries during the spawning period. Over the long run, periodic high flows are necessary to mobilize gravels and flush-out fine sediments. However, large peak flow events that occur in channels that have been excessively incised and leveed cause excessive gravel mobilization, which can disrupt spawning and cause egg mortality (CMARP). Therefore, these flows should be released during periods when most fry have already emerged from the gravels so they reduce mortality to incubating salmon eggs (McBain and Trush, 2000).

Eggs usually incubate in the gravel for approximately 6 1-64 days before hatching (Healey 1991) and it takes about 70 days for fry to emerge from the gravel (USFWS 1998 in SP Cramer, 2000). This is consistent with EA Engineering's findings, (1991 in CMARP) which found that eggs incubate for 40-60 days and remain in the gravel for 45-90 days. When fry first emerge from the gravel they are known as alevins and have an attached yolk sac that they depend on for food and nourishment.

The development of eggs into fry appears to be a difficult time for Chinook (Healey, 1991). High water temperatures, fine sediment capping, dewatered redds, poor quality gravel, and low substrate flow may contribute to the high mortality rate during egg and alevin development. High water temperatures (greater than 56°F), due to low reservoir storage, high air temperatures and low flow releases (CMARP, Loudermilk 1996) may cause egg mortality and decrease the incubation period when eggs are in the gravel (EA Engineering 1993 in CMARP). The late-fall and winter period of incubation combined with hypolimnetic discharge from the reservoirs generally maintains adequate water temperatures.

Low substrate flow through spawning gravels is known as an important cause of mortality in egg and alevin development. “Adequate water percolation through the spawning gravel is essential for egg and alevin survival. There is no doubt that percolation is affected by siltation and that siltation in spawning beds can cause high mortality” (Shaw and Maga 1943, Wickett 1954, and Shelton and Pollock 1966 in Healey 1991). Fine sediment capping occurs when redds become covered with fine silt (fines) due to small storm events that transport and deposit fines downstream. Shaw and Maga (1943) observed that siltation resulted in greatest mortality when it affected eggs in their early incubation stage (in Healey, 1991). Although common in steep coastal watersheds, fine sediment capping is relatively rare in the Sacramento basin due to sediment trapping in upstream reservoirs and the general lack of unregulated tributaries upstream of spawning areas.

Dewatering of redds is a known mortality factor effecting development of alevins. (Becker et al., 1982, 1983 in Healey, 1991). Dewatering of redds can be minimized below dams by careful flow regulation. Contaminated groundwater caused by seepage from agricultural or urban areas causes an increase in water temperature and reduces dissolved oxygen within spawning gravel, which may be harmful to incubating salmon eggs (CMARP).

Adequate base flows during the incubation and emergence period combined with periodic flushing flows outside the period should reduce the mortality factor of eggs and alevins. Instream flows, at or above spawning flows, should be maintained throughout the incubation and emergence period to avoid dewatering redds. Siltation and capping from fine sediments could be minimized with small reservoir releases timed to coincide with rainfall induced local run-off. These releases would help convey fine sediments out of the spawning reach.

Fall-Run, Late-Fall, and Spring Run

The mature adults spawn shortly after arriving at their spawning grounds between September and December. In the Sacramento and its tributaries, incubation and alevin development occurs from October through March (CMARP). Flow or temperature conditions are unlikely to be a problem except when Shasta Reservoir levels are drawn down. High water temperatures is probably not an important factor affecting fall, late fall and spring- run Chinook in the Sacramento Basin because incubation occurs between September and April when water temperatures do not rise above 14°C (57.2°F).

Winter-Run

Temperature stress induced by lower flows or lower reservoir levels in the summer, could be a significant problem for winter-run Chinook that incubate during the summer months. Temperatures in the winter-run spawning reach below Keswick Dam are largely controlled by the cold water pool in Shasta Reservoir and the Shasta temperature control device constructed in the 1990’s to manage cold water pool releases for the benefit of salmon. Currently, however, summer time flows are unnaturally high. Substantially reducing summer time flows, may result in elevated temperatures to the extent that it substantially increases travel time for cool water releases to reach the downstream end of the spawning reach, resulting in more time for the water to warm. However, stream temperatures will be controlled by a combination of cold water pool management in the reservoir j(reservoir level) and releases from that cold water pool (instream flows).

It is unclear how much, and at what point reduced flows in summer will increase temperature and how much that will negatively impact winter run. If substantially reducing flows creates negative impacts the endangered winter run irregardless of cold water pool management, then managers will be forced to maintain artificially high summer flows during winter run at incubation at the expense of increasing flows during other parts of the year for other species and other life-stages.

4.2.9 Juvenile Development and Rearing

Growth and rearing of juveniles is crucial to ensure that they grow fast enough to smolt before the onset of high temperature stresses common in the late spring. Smolts are typically >70-80mm and are able to survive in saltwater. Larger juveniles have a better chance of succeeding and surviving to the smoltification phase. “The rate of downstream migration of Chinook fingerlings appears to be both time and size dependent and may also be related to river discharge and the location of the Chinook in the river…Larger Chinook traveled downstream faster, and the rate of migration increased with the season” (Healey 1991). Growth is also important for avoiding other sources of stress and mortality such as lack of food, entrainment, predation, and disease. Larger fish are better able to compete for larger prey and avoid entrainment and predation. Larger juveniles have a competitive advantage over smaller fish in selecting prime positions in rearing areas (Fausch 1984 in Myrick and Cech), which can increase feeding rates (Alanara and Brannas 1997 in Myrick and Cech 2001). Larger fish also have more energy stores to withstand stresses imposed by disease.

There is great uncertainty about the suitability of the Delta for juvenile rearing and growth relative to rearing conditions farther upstream in the spawning reaches. The CALFED Strategic Plan for Ecosystem Restoration identified this question as one of the major uncertainties constraining the restoration planning process in the Bay-Delta watershed. Although Chinook salmon use other estuaries for rearing, most research and previous management actions on salmon in the Delta assume that juveniles suffer very high mortality in the Delta and has thus focused on moving smolt through the Delta as quickly as possible. Moyle (2002) found that “juveniles from other runs apparently do not spend as much time in the estuary, but pass through fairly rapidly on their way to sea. Whether or not this rapid passage is a recent phenomenon as the result of drastic changes in estuarine habitat or is the historical pattern is not clear”.

Fry appear to develop and grow in the tributaries, on inundated floodplains and in the Delta at different times until they become smolts and are large enough to migrate to the Ocean. There is strong evidence that juveniles rearing on inundated floodplains in the Yolo Bypass, a lowland transition zone between the spawning reaches and the Delta, had significantly higher growth rates than juveniles reared in the mainstem of the Sacramento River (Sommer et al. 2001). Sommer et al. (in preparation) attributed the higher growth rates to the increased area of suitable habitat, increased temperatures and increased food resources. Sommer et al. (2001) found that drift insects (primarily chironomids) were an order of magnitude more abundant in the Yolo

Bypass than the adjacent Sacramento River channel during 1998 and 1999 flood events. Seasonally inundated floodplains are also relatively free of exotic predators. “In the Central Valley during high flow periods, these fish historically moved into the floodplain, where they could rear for several months.” (Moyle, 2002). Today, however, most of the rivers in the Sacramento Basin have been cut off from their floodplains, decreasing the available habitat for juveniles to develop and grow.

Less is known about the value of inundated floodplains relative to the gravel bedded reaches of the tributaries, which produce abundant food resources from macro-invertebrate production. Numerous studies indicate that gravel bedded reaches are more productive than sand and clay bottomed reaches that characterize the lower Sacramento. The increased food resources in the gravel bedded spawning reaches may be somewhat offset by the constant cold water, hypolimnetic releases from the dams, which may dampen growth. Channel incision, degraded riparian vegetation and degraded streambed complexity have been found to reduce the supply of organic detritus that invertebrates depend on for food, which may limit growth and survival of juvenile salmon that depend on invertebrates (Allan 1995 in CMARP). Incised channels in the Sacramento basin have cut off the rivers from their floodplains, which further limit access to food supplies (CMARP). These incised channels combined with high flows can result in fry and juveniles being washed down stream into less productive lowland reaches with high predator populations. Despite lower macroinvertebrate production, warmer water temperatures in the low-lying rivers and in the Delta may result in higher growth rates similar to observations from the Yolo bypass. Healey (1991) found that fry grow more rapidly in the Sacramento-San Joaquin estuary than in the rivers. However, others report that “fry that rear in the upper rivers experience a higher survival to smolting than fry that rear in the delta” (Kjelson et al. 1982, Brown 1986 in Healey, 1991).

Temperature has a major impact on growth. High water temperatures were found to stimulate smoltification and growth (Kreeger and McNeil 1992 in CMARP and SP Cramer, 2000 and Castleberry et al., 1991 in Myrick and Cech, 2001). Myrick and Cech (2001) conducted an extensive review of temperature effects on growth of juvenile Chinook in the Central Valley (Table 3.6). Although they found conflicting results, generally temperatures in the 60-66°F (15-19°C) range lead to high juvenile growth rates. When juveniles are rearing in February and March, temperatures in the tributaries are relatively low, cooler than temperatures needed for optimal growth. SP Cramer (2000) found that “higher water years result in cooler river temperatures [in the spring], which in turn can slow growth rates…However, Cramer et al. (1985) concluded from a variety of growth measurements that warmer temperatures, rather than lower flows, were driving growth of juvenile Chinook” (SP Cramer 2000). Higher growth rates may be a factor of slightly higher temperatures on the floodplains and in the Delta during this early spring period.

Table 3. Effects of temperature on growth of Juvenile Chinook in the Central Valley (Myrick and Cech, 2001 and Moyle, 2002)

Source	**Location**	**Maximum Growth**
Moyle (2002 referencing Marine)		55-64°F (13-18°C)
Rich (1987)	Nimbus State Fish Hatchery on American River	56-60°F (13-15°C)
Marine (1997)	Coleman National Fish Hatchery on Sacramento River	63-68°F (17-20°C)
Cech and Myrick (1999)	Nimbus State Fish Hatchery on American River	66°F (19°C)

Water temperatures greater than 77°F (25°C) were found to be lethal to juveniles in the Central Valley when exposed to these high temperatures for a long period of time, but they could withstand brief periods of high temperatures up to 84.2°F (29°C) (Myrick and Cech, 2001).

Although the mid water trawl surveys at Chipps Island measure smolt outmigration from the Delta (Baker et al. 1995), there are no measurements that identify where these outmigrating fish reared. Without this information it is impossible to estimate the relative importance to the population of fry reared in the Delta and on lower river floodplains compared with fry that rear in the tributaries before outmigrating. It is fairly clear, however, that the majority of juveniles migrate to the lower river and Delta soon after emergence. Therefore, we hypothesize that improving rearing conditions in the lower river and the Delta should increase overall escapement. Present management seems to focus on the quality of rearing habitat in the tributaries, but if the majority of young are moving out of the tributaries, it seems prudent to improve conditions for them as well. In order to understand where to focus limited resources where they will have the most impact on successful rearing, we need better information on the relative success of fish rearing in the lower river and Delta relative to fish rearing in the gravel bedded reaches of the tributaries.

Entrainment in water diversion facilities and predation, particularly from non-native bass, are also a major problem for salmon during the juvenile life stage. “Predators are commonly implicated as the principal agent of mortality among fry and fingerlings of chinook…[and] other fish are generally considered to be the most important predators of juvenile salmon” (Healey, 1991). Entrainment and predation are less related to flow then morality associated with high temperatures during the outmigration period. Juvenile growth rates probably affects mortality from predation and entrainment because smaller juveniles are more susceptible to mortality. Juvenile growth rates may also affect ultimate survival because faster growing juveniles and smolts migrate out of the system earlier in the spring before temperature becomes a major source of mortality and because larger juveniles travel downstream faster (Healey 1991, CMARP).

Contaminated agricultural and urban runoff may also increase outmigrating juvenile salmon’s susceptibility to disease, such as *Ceratomyxa*, which causes a high mortality rate in Chinook and flourishes in organic sediments and possibly in mine pits (CMARP p 19 and 20).

We hypothesize that improving juvenile growth rates will improve the rates of successful smolt outmgration and may also reduce mortality from diversions and predation. Based on robust results from research in the Yolo Bypass, it appears providing seasonally inundated floodplain habitat is perhaps the best way to ensure adequate growth before outmigration to the Delta and Ocean. If nothing else, providing seasonally inundated floodplain habitat will provide better habitat for the young that migrate or are washed out of the gravel bedded reaches early.

Increased flows during the rearing period combined with floodplain restoration should help increase overall growth rates and potentially decrease predation. Increased flows during this period should also dilute poor water quality. Increased flow may also decrease negative effects on salmon from contaminants and disease. Agricultural return flow from the west side of the San Joaquin did not cause any detrimental effects on growth and survival of hatchery-born Chinook salmon when the return flows were diluted by 50% or more with water from the San Joaquin (Saiki et al., 1992, from CMARP p 19).

Fall-Run

Fall-run Chinook usually emerge from the gravel as fry between January and March. Large portions of fry are immediately dispersed downstream to the lower rivers and the Delta, while some fry remain in the tributaries to rear (Kjelson et al. 1982 in Healey 1991, Moyle, 2002, and SP Cramer, 2000). SP Cramer (2000) found that peak migration of fry on the Stanislaus was associated with an increase in daily average flows. Different studies have found that fry and smolts are more abundant in the Sacramento-San Joaquin Delta at different times, depending on how long they remain in the upstream tributaries, before migrating to the ocean. “Most rearing occurs in freshwater habitats in the upper delta area, and the fry do not move into brackish water until they smoltify” (Kjelson et al., 1981, 1982 in Healey, 1991).

Higher flows during January through March d are more likely to result in inundated flood-plain or channel margin habitat ideal for rearing.

Late Fall-Run

Due to their late emergence in April and May, late-fall run are not able to migrate downstream before summer temperatures in the lower river become lethal. Rather most escapement probably results from juveniles that rear and over summer in the upper river. Increasing late spring and early summer may improve conditions for those fish that attempt to migrate out in the late spring and early summer as juveniles. Very large flows, however, would be necessary to create suitable temperature conditions in the lower river.

Winter-Run

Winter-run fry emerge from the spawning gravels from mid-June through mid-October (NMFS 1997). Because winter-run salmon spawning is concentrated upstream in the reaches below Keswick Dam, the entire Sacramento River serves as a nursery area for juvenile winter-run Chinook as they migrate downstream. Downstream movement of juveniles typically begins in August soon after fry emerge from redds. Rotary screw traps at RBDD usually record peaks in the abundance of winter-run salmon fry in September and October. However, following these initial pulses of fry, winter-run juveniles steadily stream past RBDD through March (Kimmerer and Brown, in prep.). Most juvenile winter-run Chinook reach the Delta between January and April, when they pose a conflict with Delta pumping operations designed to increase South of Delta storage during winter months when conflicts with protections for Delta smelt are reduced.

Higher flows during the out migration period for winter run are likely to result in inundated flood-plain or channel margin habitat ideal for rearing. More food will reduce mortality to the extent food is limiting and faster growing fish will have higher survival against gape limited predators or through the smoltification process.

Spring-Run

The rearing and outmigration patterns exhibited by spring-run Chinook salmon are highly variable, with fish rearing anywhere from 3 to 15 months before outmigrating to the ocean (Fisher 1994). Variation in length of juvenile residence may be observed both within and among streams (e.g., Butte versus Mill creeks, USFWS 1995, as cited in Yoshiyama et al. 1998). Some may disperse downstream soon after emergence as fry in March and April, with others smolting after several months of rearing, and still others remaining to oversummer and emigrate as yearlings (USFWS 1995, as cited in Yoshiyama et al. 1998). Scale analysis indicates that most returning adults have emigrated as subyearlings (Myers et al. 1998). Calkins et al. (1940, as cited in Myers et al. 1998) conducted an analysis of scales of returning adults and estimated that greater than 90% had emigrated as subyearlings, at about 3.5 in (88 mm).

Spring-run that migrate early in their first year could benefit substantially from inundated floodplain habitat and channel margins that higher flows could provide. The excerpt below drafted by Stillwater (2003) clearly explains the phenomena:

> “As stream-type salmon, a fraction of spring-run juveniles may spend a summer rearing in natal streams before emigrating to the ocean. After emergence, spring-run juveniles display agonistic behavior, establishing and defending territories. This behavior means that summer rearing habitat can be quickly saturated, even if escapements are low, because of the area required to support each juvenile. Spring-run that migrate downstream as fry often represent those individuals displaced as a result of rearing habitat saturation in upstream reaches. Because these fry are forced to migrate downstream at a small size < 1.6 m (40 mm), they are vulnerable to predation, such that the fry component may not contribute significantly to future escapements. However, recent research conducted on the Butte Creek population of spring-run salmon suggest that successful rearing by spring-run fry in the Sutter Bypass may be stimulating the recent increase in escapements. Generally, the Deer and Mill creek populations spring-run do not seem to have the same success in fry rearing. To improve fry rearing potential for the Deer and Mill Creek populations, we recommend the creation of a dedicated floodplain/bypass area along the mainstem Sacramento River downstream of Deer and Mill creeks. A bypass in the vicinity of Deer and Mill creeks would provide rearing habitat to fry and juveniles outmigrating to the main stem from these important spawning tributaries for remaining wild-type spring-run Chinook. Such a bypass should be constructed to provide high-quality rearing habitat at relatively low flows, so that the habitat is available for a large portion of every winter, even during drier years.

4.2.10 Smolt Outmigration

As mentioned in the previous section, after fry emerge from the gravel the majority disperse downstream, especially during increases in flows or after storm events. Whether young fish migrate out of the tributaries soon after emergence or whether they rear in the tributaries, they eventually undergo smoltification and make their physiological transition to salt water. Several factors trigger smoltification, including changing hormone concentrations, increasing photoperiod, increasing temperature, and increasing body size (Myrick and Cech, 2001). While most of these factors cannot be influenced by changing management actions in the tributaries or the Delta and are not discussed in this report, temperature and body size are affected by flow and can be influenced by reservoir reoperation.

Smolts require lower temperatures than rearing juveniles. While higher temperatures in the 60-66°F (15-19°C) range can optimize growth of juveniles and better prepare them for smoltification earlier, lower temperatures are more optimal during the smoltification process. A comprehensive study by Myrick and Cech (2001) found that Chinook have a better chance of surviving in the Ocean if they undergo smoltification at lower temperatures, ranging from 50-63.5°F (10-17.5 °C). Warmer temperatures in the February –March period (which occur on floodplains) stimulate growth of juveniles so they are larger before they undergo smolification and therefore larger when they enter the Ocean (Myrick and Cech, 2001). Larger juveniles are also able to smolify before harmful high late spring temperatures set in. Cooler temperatures are necessary in the smolt outmigration period of April – June. The need for warmer temperatures in the early spring and cooler temperatures in late spring reflects the historical hydrograph, where large, cold snowmelt flows dominated the Sacramento Basin later in the spring.

Body size is an important function of the success of outmigrating smolts and the development to smoltification (Dlarke and Shelbourn 1985; Johnssson and Clarke 1988 in Myrick and Cech, 2001). It is important that Chinook reach an appropriate size for smolting before they arrive in saltwater. Relatively warm temperatures can be beneficial for growth provided adequate food supply. Increases inundated floodplain habitat provides the type of habitat that allow juveniles to grow larger before smoltification (Sommer et al, 1991).

High water temperatures, low flows and entrainment may cause increased mortality rates in outmigrating smolts and affect growth of juvenile Chinook. High water temperatures, particularly in May and June may pose the largest threat to juveniles that remain in the tributaries and in the Delta later in the spring. Baker et al (1995) found that 50% of Chinook smolt that migrate through the Delta die when temperatures reach 72-75°F (22-24°C) McCullough (1999 in Moyle) found that few fish can survive temperatures greater than 75.2°F (24°C) even for short periods of time.

Prolonged periods of high flows from January through June, especially from late February through mid-April, will reduce temperatures and help flush out outmigrating juveniles and smolt (CMARP). There are several programs underway and several measures that could be taken to improve juvenile outmigration and survival. Increased flows during outmigration improve juvenile/smolt survival in the Sacramento basin tributaries and Delta. Studies have shown that survival of fry and smolts passing through the Sacramento-San Joaquin River delta were highly correlated with discharge of the Sacramento River (Healey, 1991 and USFWS, 1998 in SP Cramer). Studies from the Stanislaus River shows that Smolt survival was high (about 78%) when releases from were increased in late April in 1986 and 1988, but were low (28%) when releases were lower in April 1989. A substantial increase in migrating juvenile was measured when flows were increased in the Stanislaus River for seven days in April 1995 (SP Cramer 1995 in CMARP).

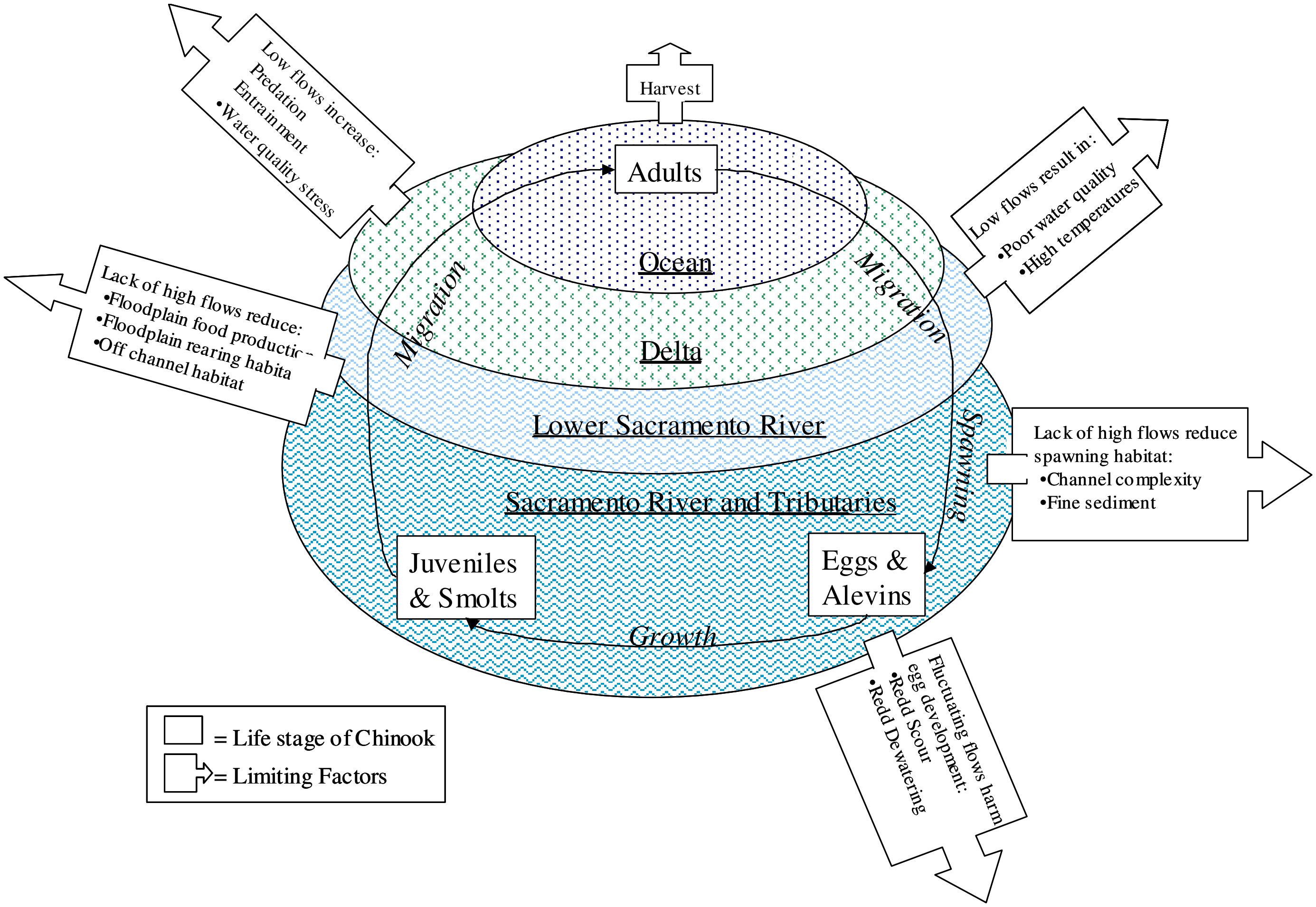


Figure 4: This conceptual model for Chinook salmon illustrates the life cycle of the Chinook in the Sacramento River, factors that increase Chinook mortality during their life cycle, and how restoration can improve the conditions of these fish.

Appendix E
Estimates of Project Costs
Technical Memorandum

DAVIDS
ENGINEERING, INC

Specialists in Ag Water Management

Technical Memorandum

TO: File

FROM: Davids Engineering, Inc.

DATE: October 4, 2011

SUBJECT: Estimation of Sacramento Valley Conjunctive Water Management Program Costs

Background and Objectives

The objective of this effort was to estimate implementation costs for Sacramento Valley Conjunctive Water Management Program. The cost estimates were developed based on an evaluation of capital, operations, maintenance, and mitigation costs associated with program. All costs were estimated in 2010 dollars.

The following pumping scenarios were evaluated:

- 300 TAF Summer Pumping, New Well Field
- 300 TAF Summer Pumping, Existing Well Field
- 150 TAF Summer Pumping, New Well Field
- 150 TAF Summer Pumping, Existing Well Field
- 150 TAF Fall Pumping, New Well Field
- 150 TAF Fall Pumping, Existing Well Field
- 150 TAF Summer and Fall Pumping, New Well Field
- 150 TAF Summer and Fall Pumping, Existing Well Field

This brief technical memorandum describes the estimation of implementation costs.

Summary of Program Implementation Cost Items

Capital, operations and maintenance, and mitigation cost items associated with the Program are summarized in Table 1. For each cost item, the nature of the cost is described, along with the basis upon which the associated cost was estimated.

Global Cost Parameters

The following cost parameters were assumed for the cost estimates:

- Contingency applied to all cost items: 20%
- Engineering and project management as a percentage of up-front capital costs: 12%
- Percent of normal maintenance required for Program wells in non-pumping years: 20%
    - Assumes that maintenance requirements are less in years the Program wells are not operated.
- PG&E energy rate paid for project pumping: $0.22/kWh

Table 1. Capital, O&M, and Mitigation Cost Items Associated with Sacramento Valley Conjunctive Water Management Program.

Cost Category	Cost Item	Item Description	Basis/Comment
Capital	Construct and equip shallow irrigation well	Construct new, typical ~450 foot deep irrigation production well in regional aquifer. Purchase land, electrical line extension, install well pad, pump, electrical motor and controls, discharge piping and connection to open canal, security enclosure.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Construct and equip deep irrigation well	Construct new, typical ~1,400 foot deep irrigation production well in deep aquifer. Purchase land, electrical line extension, install well pad, pump, electrical motor and controls, discharge piping and connection to open canal, security enclosure.	Recent SCF bids to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Rehabilitate existing shallow irrigation well (inspect and reinstall)	Remove existing pump and motor; perform downhole video and qualification assessment; reinstall existing pump and motor; discharge piping and connection to open canal, security enclosure. In some cases, well may require rehabilitation (acid wash) and/or upgrade of electrical. Also, conversion from Diesel to electric and electrical line extension may be required.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Rehabilitate existing shallow irrigation well (inspect and rebuild)	Remove existing pump and motor; perform downhole video and qualification assessment; rebuild existing pump and motor, upgrade electric controls; discharge piping and connection to open canal, security enclosure. In some cases, well may require rehabilitation (acid wash) and/or upgrade of electrical. Also, conversion from Diesel to electric and electrical line extension may be required.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Rehabilitate existing shallow irrigation well (inspect and replace)	Remove existing pump and motor; perform downhole video and qualification assessment; replace existing pump and motor; discharge piping and connection to open canal, security enclosure. In some cases, well may require rehabilitation (acid wash) and/or upgrade of electrical. Also, conversion from Diesel to electric and electrical line extension may be required.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Purchase and install SCADA equipment at production or monitoring well site	Furnish and install RTU, sensors, enclosure, radio, antenna, complete, installed.	Estimate unit costs based on data from ITRC. Estimate quantities based on number of project and monitoring wells required.
Capital	Construct dedicated monitoring well	Contruct new, typical 1,200-foot triple completion, dedicated monitoring well	Estimate unit costs based on input from DWR and well driller. Estimate quantites based on required number of project wells.
O&M	Electrical energy costs for project pumping	PG&E energy costs associated with project pumping.	Estimate unit costs based on PG&E rates, estimated lift from GW model and typical flow rates, OPPE from CIT APEP. Estimate quantities from SW model.

Table 1 (Continued). Capital, O&M, and Mitigation Cost Items Associated with Sacramento Valley Conjunctive Water Management Program.

Cost Category	Cost Item	Item Description	Basis/Comment
O&M	Water level monitoring, feedback and realtime management	During and following years of project pumping, conduct water level monitoring, operate and maintain GW model, manage pumping in real time to minimize or avoid impacts, confer with appropriate authorities, prepare periodic reports of project operations.	Estimate staffing requirements and costs for individual tasks during pumping and non-pumping years based on professional judgement.
O&M	Project operations	Operations forecasting and scheduling according to program objectives and operating rules.	Estimate staffing requirements and costs for individual tasks during pumping and non-pumping years based on professional judgement.
Mitigation	Construct domestic well	Replacement of domestic wells with yield impacted by project pumping.	Estimate unit costs based on well driller information. Estimate quantities based on analysis of yield impacted wells using GW model results from 1987 to 2003.
Mitigation	Payments for incremental agricultural pumping costs	Reimbursement for energy costs associated with increased lift caused by interference drawdown from the project.	Estimate unit costs based on PG&E rates, estimated lift from GW model and typical flow rates, OPPE from CIT APEP. Estimate quantities from GW/SW model.
Mitigation	Payments for incremental domestic pumping costs	Reimbursement for energy costs associated with increased lift caused by interference drawdown from the project.	Estimate unit costs based on PG&E rates, estimated lift from GW model and typical flow rates, OPPE from CIT APEP. Estimate quantities from spatially distributed Census data and USGS per capita water use rates.
Mitigation	Administration, outreach, complaint response and dispute resolution, mitigation operations, and legal counsel.	Provide administration of monitoring and mitigation, conduct public outreach regarding observed impacts, handle impacts complaints/disputes. Provide legal support.	Estimate staffing requirements and costs for individual tasks during pumping and non-pumping years based on professional judgement.

Domestic Well Replacement Quantities and Costs

Domestic Well Replacement Quantities

The number of domestic wells requiring replacement was estimated for each pumping scenario based on the analysis of peak drawdown relative to screened interval length for domestic wells in the project area with available screen length data, described elsewhere. The number of wells impacted was scaled up based on the total number of domestic, industrial, public, stock, and other potentially wells in the study area, as reported by DWR. The estimated number of wells requiring replacement is summarized in the table below.

		Impacted Wells[1]		
Pumping Scenario	Well Field	Min	Max	Average
300K Summer	New	63	172	118
	Existing	167	310	238
150K Summer	New	7	29	18
	Existing	99	189	144
150K Fall	New	7	32	19
	Existing	92	196	144
150K Summer and Fall	New	9	27	18
	Existing	69	142	105

1. Estimates of probable range of impacts based on analysis of peak interference drawdown relative to screened interval length for domestic wells in the project area with available screen length data. The number of wells impacted was scaled up based on the total number of domestic, industrial, public, stock, and other potentially impacted wells within the study area.

Unit Cost for Domestic Well Replacement

The unit cost of replacement for domestic wells was estimated to be $18,200, as summarized below. Based on an amortization rate of 3%, the annualized cost per well replaced was estimated to be $1,580.

Cost Item	Capital	Life (yr)	Amort. Rate	Annual Capital
Construction of New Domestic Well	$10,000	30	3%	$ 510
Installation of pump/motor/tank	$2,500	10	3%	$ 293
Abandon Old Domestic Well	$1,500	30	3%	$ 77
SUBTOTAL	$14,000			$880
Engineering and Project Management	$1,400		(10%)	$140
Contingencies	$2,800		(20%)	$560
TOTALS	$18,200			$1,580

NOTE: It is assumed that domestic wells replaced by the program will be maintained at the expense of the well owner.

Total Cost of Domestic Well Replacement

Combining the estimated quantity of domestic wells requiring replacement with the estimated unit cost of well replacement, the total cost of domestic well replacement was calculated and is summarized below.

		Total Capital			Annual Capital		
Pumping Scenario	Well Field	Min	Max	Average	Min	Max	Average
300K Summer	New	$1,151,660	$3,137,280	$2,144,470	$99,966	$272,322	$186,144
	Existing	$3,037,999	$5,639,161	$4,338,580	$263,705	$489,491	$376,598
150K Summer	New	$119,137	$536,117	$327,627	$10,341	$46,536	$28,439
	Existing	$1,806,914	$3,435,123	$2,621,018	$156,844	$298,176	$227,510
150K Fall	New	$119,137	$575,830	$347,484	$10,341	$49,983	$30,162
	Existing	$1,667,921	$3,574,116	$2,621,018	$144,779	$310,241	$227,510
150K Summer and Fall	New	$158,850	$496,405	$327,627	$13,788	$43,089	$28,439
	Existing	$1,250,941	$2,581,306	$1,916,123	$108,584	$224,063	$166,323

Project Well Construction and Rehabilitation Costs

Quantity of Project Wells Required

The number of project wells required was estimated based on estimates of the number and distribution of existing production wells in the study area, typical production well capacities in the study area, peak monthly pumping volumes for each pumping scenario, and assumptions regarding downtime for project wells. Estimated well capacities are summarized below.

Average Flow Rate per Well (gpm)[1]

	GCID	WCWD	Richvale
Existing Wells	2800	2400	2400
New Shallow Wells[2]	2800	2400	2400
New Deep Wells[2]	2800	2400	2400

1. GCID and WCWD average flow rates estimated based on average values from well surveys in each district. Richvale ID flow rate assumed to be similar to WCWD.
2. New wells assumed to have flow rates similar to existing wells.

Maximum monthly pumping volumes by scenario, estimated based on the reservoir operations model, are summarized below.

Maximum Monthly Pumping Volume (ac-ft)

Pumping Scenario	GCID	WCWD[3]	Richvale[3]
300K Summer	50,000	12,500	12,500
150K Summer	25,000	6,250	6,250
150K Fall	40,000	10,000	10,000
150K Summer and Fall	15,000	3,750	3,750

3. Equal pumping volumes assumed for WCWD and Richvale ID

The quantities of simultaneously operated project wells required to meet peak pumping requirements for each pumping scenario are summarized below.

Number of Simultaneously Operated Wells Required to Satisfy Project Pumping Requirements[4]

Pumping Scenario	Well Field	GCID	WCWD	Richvale
300K Summer	New	133	39	39
	Existing	133	39	39
150K Summer	New	66	19	19
	Existing	66	19	19
150K Fall	New	106	31	31
	Existing	106	31	31
150K Summer and Fall	New	40	12	12
	Existing	40	12	12

4. Assume pumps will operate every day, 24 hours per day at peak.

Due to periodic maintenance and other unknowns, it is likely that some project wells will be inoperable at times. As a result, the number of additional project wells required to ensure sufficient pumping capacity during peak production was estimated as described below.

Additional Wells Required to Allow for Downtime

Contingency for maintenance/repair of existing wells during peak pumping:	5%
Contingency for strategic shutdown of project wells to avoid yield impacts to domestic wells:	10%
TOTAL CONTINGENCY:	15%

Total Number of Project Wells Required to Satisfy Project Pumping Requirements

Pumping Scenario	Well Field	GCID	WCWD	Richvale
300K Summer	New	153	45	45
	Existing	153	45	45
150K Summer	New	76	22	22
	Existing	76	22	22
150K Fall	New	122	36	36
	Existing	122	36	36
150K Summer and Fall	New	46	13	13
	Existing	46	13	13

Quantity of Additional Production Wells Needed for Existing Well Field Scenarios

Even under the existing well field scenarios, additional production wells are needed to meet peak pumping demands in some areas.

Only a portion of existing wells are likely to enter the program due to lack of grower willingness, well condition, or other issues. As a result, the number of existing wells entering the program will be less than the total number of existing wells.

The estimated number of existing production wells in each area, the number of existing wells expected to enter the program, and the corresponding number of additional production wells required for the existing well field scenarios are summarized on the following page.

Existing Wells Potentially Available to Support Project Pumping

	GCID[5]	WCWD[6]	Richvale[7]
Existing Irrigation Wells	155	131	77

5. Estimated as number of wells listed in GCID well survey.
6. Estimated as number of wells listed in WCWD well survey, multiplied by 50%. It appears some wells listed may be domestic or abandoned.
7. Estimated based on number of wells in WCWD assuming equal number of wells per section.

Existing Wells Ultimately Included in Program

Existing wells not suitable for project due to nonideal location, owner unwillingness, or well unsuitable: 67%

	Existing Wells Entering Program		
Pumping Scenario	GCID	WCWD	Richvale
300K Summer	51	43	25
150K Summer	51	22	22
150K Fall	51	36	25
150K Summer and Fall	46	13	13

Additional New Shallow Irrigation Wells Needed for Existing Well Field Pumping Scenarios

Pumping Scenario	GCID	WCWD	Richvale
300K Summer	102	2	20
150K Summer	25	-	-
150K Fall	71	-	11
150K Summer and Fall	-	-	-

Existing Well Rehabilitation Quantities

Existing wells entering the Program will need inspection and in many cases rehabilitation. Estimates of the quantity of wells entering the program requiring rehabilitation are summarized below for each of the existing well field pumping scenarios.

Number of Existing Wells Requiring Upgrades or Repairs

Proportion of existing wells requiring down hole inspection:	100%	
Proportion of existing wells requiring rehabilitation:	30%	
Proportion of existing wells requiring well seal:	20%	(based on GCID well survey number of wells with no seal)
Proportion of existing wells requiring reinstallation of existing pump and motor:	50%	
Proportion of existing wells requiring rebuild of existing pump and motor:	30%	
Proportion of existing wells requiring replacement of pump and motor:	20%	
Proportion of existing wells requiring Diesel --> Electric conversion:	80%	

	Downhole Inspection			Well Rehabilitation			Construct Well Seal		
Pumping Scenario	GCID	WCWD	Richvale	GCID	WCWD	Richvale	GCID	WCWD	Richvale
300K Summer	51	43	25	15	13	8	10	9	5
150K Summer	51	22	22	15	7	7	10	4	4
150K Fall	51	36	25	15	11	8	10	7	5
150K Summer and Fall	46	13	13	14	4	4	9	3	3

	Reinstall Pump and Motor			Rebuild Pump and Motor			Replace Pump and Motor		
Pumping Scenario	GCID	WCWD	Richvale	GCID	WCWD	Richvale	GCID	WCWD	Richvale
300K Summer	26	22	13	15	13	8	10	9	5
150K Summer	26	11	11	15	7	7	10	4	4
150K Fall	26	18	13	15	11	8	10	7	5
150K Summer and Fall	23	7	7	14	4	4	9	3	3

	Diesel --> Electric Conversion		
Pumping Scenario	GCID	WCWD	Richvale
300K Summer	81	1	16
150K Summer	20	-	-
150K Fall	57	-	8
150K Summer and Fall	-	-	-

Unit Costs for Well Construction, Rehabilitation, Operation, and Maintenance

Unit costs for well construction and rehabilitation were estimated based on discussion with well drillers and based on recent well costs for test wells.

The estimated unit cost for construction, operation, and maintenance of a new deep project well is summarized on Page 9.

The estimated unit cost for construction, operation, and maintenance of a new shallow project well is summarized on Page 10.

The estimated cost for purchase, operation, and maintenance of an existing production well is summarized on Page 11.

It is anticipated that existing Diesel wells would be converted to electrical power upon entering the program. The estimated cost for conversion of existing Diesel wells to electrical drive is summarized on Page 12.

Estimated unit costs for well rehabilitation are summarized on Page 13.

It is anticipated that project wells will be equipped with SCADA to support monitoring of well operation, water level, and pumped volume. Estimated unit costs for SCADA are summarized on Page 14.

Estimated Cost to Construct, Maintain, and Operate New Irrigation Well (Lower Aquifer)

General Characteristics

Depth:	1200 ft	Estimated Specific Capacity:	50 gpm/ft	Total Dynamic Head:	138 ft
Diameter:	16 in	Estimated OPPE:	65%	Water Horsepower:	87 HP
Discharge:	2500 gpm	Estimated Static Water Level:	80 ft	Input Horsepower:	134 HP
		Estimated Friction Losses and Discharge Head:	8 ft		

Construction and Maintenance Cost

Discount Rate: 3%

Item		Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion		$ 250 per ft	1200	$ 300,000	60	$ 10,840	1%	$ 3,000	
Construct pad, install pump, electrical motor and controls, discharge piping		$ 100,000 ea	1	$ 100,000	30	$ 5,102	3%	$ 3,000	
Connection to distribution system (18" buried PVC)		$ 80 per ft	350	$ 28,000	50	$ 1,088	1%	$ 280	
Land purchase		$ 40,000 per ac	0.25	$ 10,000	100	$ 316		$ -	
Electrical service, 3-phase		$ 105,600 per mi	0.25	$ 26,400	50	$ 1,026		$ -	
Transformer and Power Drop		$ 12,500 ea	1	$ 12,500	30	$ 638		$ -	
Vandalism enclosure		$ 3,800 ea	0	$ -	20	$ -		$ -	(included in scada cost)
SUBTOTALS				$ 476,900		$ 19,010		$ 6,280	
Engineering and Project Management	(12%)			$ 57,228		$ 2,281			
Contingencies	(20%)			$ 95,380		$ 3,802		$ 1,256	
TOTALS				$ 629,508		$ 25,094		$ 7,536	

Operations Cost

Total Dynamic Head:	138	kwh per ac-ft:	217	Pumping energy cost:	$48 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

Estimated Cost to Construct, Maintain, and Operate New Irrigation Well (Regional Aquifer)

General Characteristics

Depth:	450 ft	Estimated Specific Capacity:	30 gpm/ft	Total Dynamic Head:	171 ft
Diameter:	16 in	Estimated OPPE:	65%	Water Horsepower:	108 HP
Discharge:	2500 gpm	Estimated Static Water Level:	80 ft	Input Horsepower:	166 HP
		Estimated Friction Losses and Discharge Head:	8 ft		

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250 per ft	450	$ 112,500	60	$ 4,065	1%	$ 1,125	
Construct pad, install pump, electrical motor and controls, discharge piping	$ 100,000 ea	1	$ 100,000	30	$ 5,102	3%	$ 3,000	
Connection to distribution system (18" buried PVC)	$ 80 per ft	350	$ 28,000	50	$ 1,088	1%	$ 280	
Land purchase	$ 40,000 per ac	0.25	$ 10,000	100	$ 316		$ -	
Electrical service, 3-phase	$ 105,600 per mi	0.25	$ 26,400	50	$ 1,026		$ -	
Transformer and Power Drop	$ 12,500 ea	1	$ 12,500	30	$ 638		$ -	
Vandalism enclosure	$ 3,800 ea	0	$ -	20	$ -		$ -	(included in SCADA cost)
SUBTOTALS			$ 289,400		$ 12,235		$ 4,405	
Engineering and Project Management (12%)			$ 34,728		$ 1,468			
Contingencies (20%)			$ 57,880		$ 2,447		$ 881	
TOTALS			$ 382,008		$ 16,151		$ 5,286	

Operations Cost

Total Dynamic Head:	171	kwh per ac-ft:	270	Pumping energy cost:	$59 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

Estimated Cost to Purchase, Maintain, and Operate Existing Irrigation well

General Characteristics

Depth:	450 ft	Estimated Specific Capacity:	30 gpm/ft	Total Dynamic Head:	171 ft
Diameter:	16 in	Estimated OPPE:	65%	Water Horsepower:	108 HP
Discharge:	2500 gpm	Estimated Static Water Level:	80 ft	Input Horsepower:	166 HP
		Estimated Friction Losses and Discharge Head:	8 ft		

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost		Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250	per ft	450	$ 112,500	60	$ 4,065	1%	$ 1,125	
Construct pad, install pump, electrical motor and controls, discharge piping	$ 100,000	ea	0.5	$ 50,000	30	$ 2,551	3%	$ 1,500	(motor, pad, panels not purchased with wel
Connection to distribution system (18" buried PVC)	$ 80	per ft	350	$ 28,000	50	$ 1,088	1%	$ 280	
Land purchase	$ 40,000	per ac	0.25	$ 10,000	100	$ 316		$ -	
Electrical service, 3-phase	$ 105,600	per mi	0	$ -	50	$ -		$ -	(not purchased with well)
Transformer and Power Drop	$ 12,500	ea	0	$ -	30	$ -		$ -	(not purchased with well)
Vandalism enclosure	$ 3,800	ea	0	$ -	20	$ -		$ -	(included in SCADA cost)
SUBTOTALS				$ 200,500		$ 8,021		$ 2,905	
Engineering and Project Management (12%)				$ 24,060		$ 962			
Contingencies (20%)				$ 40,100		$ 1,604		$ 581	
TOTALS				$ 264,660		$ 10,587		$ 3,486	

PURCHASE COST (ASSUME 1/2 COST OF NEW WELL DUE TO WEAR ON COMPONENTS) $ 132,330

Operations Cost

Total Dynamic Head:	171	kwh per ac-ft:	270	Pumping energy cost:	$59 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

Estimated Cost to Convert Diesel to Electric Irrigation Well

General Characteristics

Depth:	450 ft	Estimated Specific Capacity:	30 gpm/ft	Total Dynamic Head:	171 ft
Diameter:	16 in	Estimated OPPE:	65%	Water Horsepower:	108 HP
Discharge:	2500 gpm	Estimated Static Water Level:	80 ft	Input Horsepower:	166 HP
		Estimated Friction Losses and Discharge Head:	8 ft		

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250 per ft	0	$ -	60	$ -	1%	$ -	(included in purchase cost)
Construct pad, install pump, electrical motor and controls, discharge piping **(pad, motor, and controls only)**	$ 100,000 ea	0.5	$ 50,000	30	$ 2,551	3%	$ 1,500	(pad, motor, and controls only)
Connection to distribution system (18" buried PVC)	$ 80 per ft	0	$ -	50	$ -	1%	$ -	(included in purchase cost)
Land purchase	$ 40,000 per ac	0	$ -	100	$ -		$ -	(included in purchase cost)
Electrical service, 3-phase	$ 105,600 per mi	0.25	$ 26,400	50	$ 1,026		$ -	
Transformer and Power Drop	$ 12,500 ea	1	$ 12,500	30	$ 638		$ -	
Vandalism enclosure	$ 3,800 ea	0	$ -	20	$ -		$ -	(included in SCADA cost)
SUBTOTALS			$ 88,900		$ 4,215		$ 1,500	
Engineering and Project Management (12%)			$ 10,668		$ 506			
Contingencies (20%)			$ 17,780		$ 843		$ 300	
TOTALS			$ 117,348		$ 5,563		$ 1,800	

Operations Cost

Total Dynamic Head:	171	kwh per ac-ft:	270	Pumping energy cost:	$59 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

Estimated Costs for Rehabilitation of Existing Wells

Discount Rate: 3%

Cost Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Downhole Inspection	$ 3,000 ea	1	$ 3,000	25	$ 120			(includes pump and motor removal)
Well Rehabilitation	$ 5,000 ea	1	$ 5,000	25	$ 200			(rehab screen, acid wash and brush)
Construct Well Seal	$ 5,000 ea	1	$ 5,000	25	$ 200			
Reinstall Pump and Motor	$ 3,000 ea	1	$ 3,000	25	$ 120			
Rebuild Pump and Motor	$ 15,000 ea	1	$ 15,000	25	$ 600			
Replace Pump and Motor	$ 60,000 ea	1	$ 60,000	25	$ 2,400			

These represent upfront costs of bringing existing wells into the program. Cost associated with ongoing well maintenance have been estimated separately for newly constructed wells and will also apply to rehabilitated wells once brought in to program.

Estimated Cost to Equip Production Well with SCADA

Construction and Maintenance Cost

Discount Rate: 3%

Item		Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.
RTU, monitoring only		$ 12,500 ea	1	$ 12,500	15	$ 1,047	10%	$ 1,250
Antenna, mast, and cable		$ 3,000 ea	1	$ 3,000	15	$ 251	10%	$ 300
Vandalism enclosure		$ 3,800 ea	1	$ 3,800	25	$ 218	2%	$ 76
Water level sensor		$ 2,000 ea	1	$ 2,000	15	$ 168	10%	$ 200
Panametrics flow meter		$ 8,100 ea	1	$ 8,100	15	$ 679	10%	$ 810
SUBTOTALS				$ 29,400		$ 2,363		$ 2,636
Engineering and Project Management	(12%)			$ 3,528		$ 284		
Contingencies	(20%)			$ 5,880		$ 473		$ 527
TOTALS				$ 38,808		$ 3,119		$ 3,163

In addition to production wells, it is anticipated that monitoring wells will be installed as part of the project to support monitoring of water level impacts and mitigation activities. The estimated unit cost for construction and maintenance of a triple-completion monitoring well is summarized on Page 16, along with the estimated unit cost to equip the well with SCADA and to maintain the SCADA system.

Estimated Cost to Construct and Maintain Dedicated Monitoring Well

General Characteristics

Max Depth: 1400 ft
Completions: triple

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.
Triple completion monitoring well	$ 100,000 ea	1	$ 100,000	50	$ 3,887	1%	$ 1,000
SUBTOTALS			$ 100,000		$ 3,887		$ 1,000
Engineering and Project Management (12%)			$ 12,000		$ 466		
Contingencies (20%)			$ 20,000		$ 777		$ 200
TOTALS			$ 132,000		$ 5,130		$ 1,200

Estimated Cost to Equip Monitoring Well with SCADA

Construction and Maintenance Cost

Discount Rate: 3%

Item		Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.
RTU, monitoring only		$ 12,500 ea	1	$ 12,500	15	$ 1,047	10%	$ 1,250
Antenna, mast, and cable		$ 3,000 ea	1	$ 3,000	15	$ 251	10%	$ 300
Vandalism enclosure		$ 3,800 ea	1	$ 3,800	25	$ 218	2%	$ 76
Water level sensor		$ 2,000 ea	3	$ 6,000	15	$ 503	10%	$ 600
Panametrics flow meter		$ 8,100 ea	0	$ -	15	$ -	10%	$ -
SUBTOTALS				$ 25,300		$ 2,019		$ 2,226
Engineering and Project Management	(12%)			$ 3,036		$ 242		
Contingencies	(20%)			$ 5,060		$ 404		$ 445
TOTALS				$ 33,396		$ 2,665		$ 2,671

Total Costs for Well Construction, Rehabilitation, and Maintenance

Total capital costs for well construction or purchase for each pumping scenario are summarized below for each pumping scenario.

	300 TAF Summer Pumping, New Well Field					300 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	243	ea	$629,508	$152,970,444	$ 6,097,745	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	123	ea	$382,008	$47,016,781	$ 1,987,795
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	120	ea[1]	$117,378	$14,076,252	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	120	ea	$132,330	$15,869,278	$ 1,269,641
Construct Triple-Completion Monitoring Well[2]	24	ea	$132,000	$ 3,207,600	$ 124,665	24	ea	$132,000	$ 3,207,600	$ 124,665
Equip Production and Monitoring Wells with SCADA	267	ea	$ 38,316	$ 10,241,867	$ 822,612	267	ea	$ 26,450	$ 7,069,978	$ 822,612
TOTALS				$166,419,911	$ 7,045,022				$87,239,889	$ 4,204,712

	150 TAF Summer Pumping, New Well Field					150 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	120	ea	$629,508	$ 75,540,960	$ 3,011,232	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	25	ea	$382,008	$ 9,492,899	$ 401,345
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	95	ea[1]	$117,378	$11,168,555	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	95	ea	$132,330	$12,591,200	$ 1,007,374
Construct Triple-Completion Monitoring Well[2]	12	ea	$132,000	$ 1,584,000	$ 61,563	12	ea	$132,000	$ 1,584,000	$ 61,563
Equip Production and Monitoring Wells with SCADA	132	ea	$ 38,316	$ 5,057,712	$ 406,228	132	ea	$ 22,266	$ 2,939,106	$ 406,228
TOTALS				$ 82,182,672	$ 3,479,023				$37,775,759	$ 1,876,510

	150 TAF Fall Pumping, New Well Field					150 TAF Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	194	ea	$629,508	$122,124,552	$ 4,868,159	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	81	ea	$382,008	$31,110,732	$ 1,315,313
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	113	ea[1]	$117,378	$13,212,113	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	113	ea	$132,330	$14,895,065	$ 1,191,698
Construct Triple-Completion Monitoring Well[2]	19	ea	$132,000	$ 2,560,800	$ 99,527	19	ea	$132,000	$ 2,560,800	$ 99,527
Equip Production and Monitoring Wells with SCADA	213	ea	$ 38,316	$ 8,176,634	$ 656,735	213	ea	$ 25,085	$ 5,353,092	$ 656,735
TOTALS				$132,861,986	$ 5,624,421				$67,131,801	$ 3,263,272

	150 TAF Summer & Fall Pumping, New Well Field					150 TAF Summer & Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	72	ea	$629,508	$ 45,324,576	$ 1,806,739	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	0	ea	$382,008	$ -	$ -
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	72	ea[1]	$117,378	$ 8,451,245	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	72	ea	$132,330	$ 9,527,760	$ 762,280
Construct Triple-Completion Monitoring Well[2]	7	ea	$132,000	$ 950,400	$ 36,938	7	ea	$132,000	$ 950,400	$ 36,938
Equip Production and Monitoring Wells with SCADA	79	ea	$ 38,316	$ 3,034,627	$ 243,737	79	ea	$ 20,070	$ 1,589,567	$ 243,737
TOTALS				$ 49,309,603	$ 2,087,414				$20,518,971	$ 1,042,954

1. Quantity and unit costs are calculated by the proportion of wells requiring each rehabilitation activity (well rehabilitation, pump and motor rebuild, etc.).
2. It has been assumed that one monitoring well will be constructed for each 10 project wells, on average.

Annual maintenance costs for project wells, including monitoring wells and SCADA are summarized on Page 19 for each pumping scenario.

	300 TAF Summer Pumping, New Well Field					300 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	243	ea	$ 7,536	$ 1,831,248	$ 1,831,248	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	243	ea	$ 5,286	$ 1,284,498	$ 1,284,498
Monitoring Well Maintenance[3]	24	ea	$ 1,200	$ 29,160	$ 29,160	24	ea	$ 1,200	$ 29,160	$ 29,160
SCADA Maintenance[3]	267	ea	$ 3,119	$ 833,577	$ 833,577	267	ea	$ 3,119	$ 833,577	$ 833,577
TOTALS					$ 2,693,985					$ 2,147,235

	150 TAF Summer Pumping, New Well Field					150 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	120	ea	$ 7,536	$ 904,320	$ 904,320	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	120	ea	$ 5,286	$ 634,320	$ 634,320
Monitoring Well Maintenance[3]	12	ea	$ 1,200	$ 14,400	$ 14,400	12	ea	$ 1,200	$ 14,400	$ 14,400
SCADA Maintenance[3]	132	ea	$ 3,119	$ 411,643	$ 411,643	132	ea	$ 3,119	$ 411,643	$ 411,643
TOTALS					$ 1,330,363					$ 1,060,363

	150 TAF Fall Pumping, New Well Field					150 TAF Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	194	ea	$ 7,536	$ 1,461,984	$ 1,461,984	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	194	ea	$ 5,286	$ 1,025,484	$ 1,025,484
Monitoring Well Maintenance[3]	19	ea	$ 1,200	$ 23,280	$ 23,280	19	ea	$ 1,200	$ 23,280	$ 23,280
SCADA Maintenance[3]	213	ea	$ 3,119	$ 665,490	$ 665,490	213	ea	$ 3,119	$ 665,490	$ 665,490
TOTALS					$ 2,150,754					$ 1,714,254

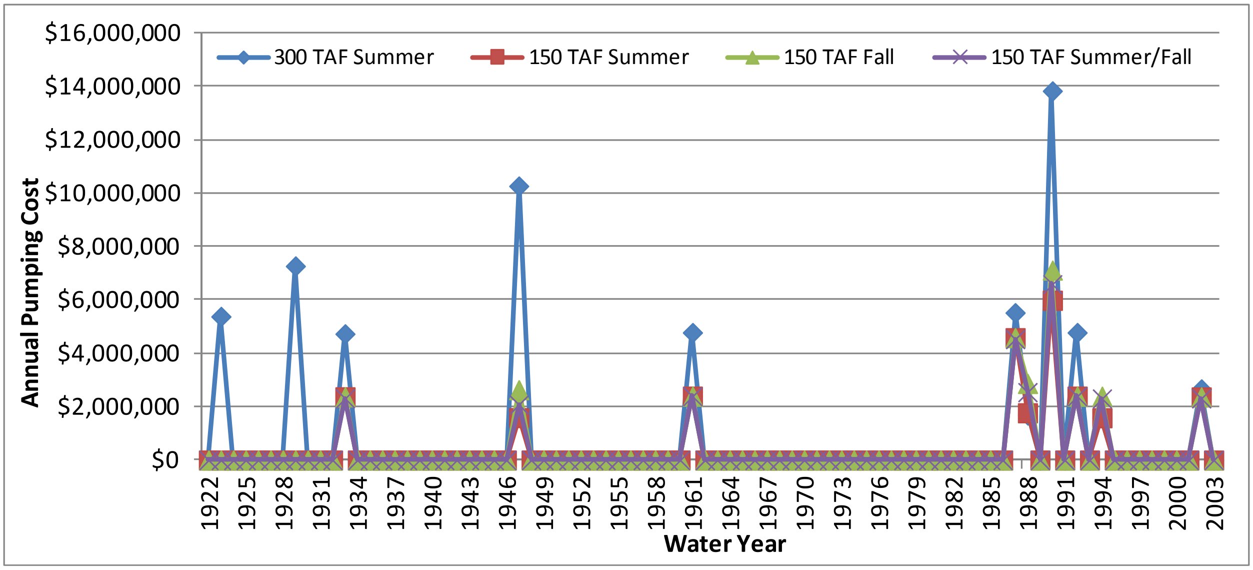
	150 TAF Summer & Fall Pumping, New Well Field					150 TAF Summer & Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	72	ea	$ 7,536	$ 542,592	$ 542,592	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	72	ea	$ 5,286	$ 380,592	$ 380,592
Monitoring Well Maintenance[3]	7	ea	$ 1,200	$ 8,640	$ 8,640	7	ea	$ 1,200	$ 8,640	$ 8,640
SCADA Maintenance[3]	79	ea	$ 3,119	$ 246,986	$ 246,986	79	ea	$ 3,119	$ 246,986	$ 246,986
TOTALS					$ 798,218					$ 636,218

3. Maintenance costs represent annual amounts estimated as a percent of initial capital cost.

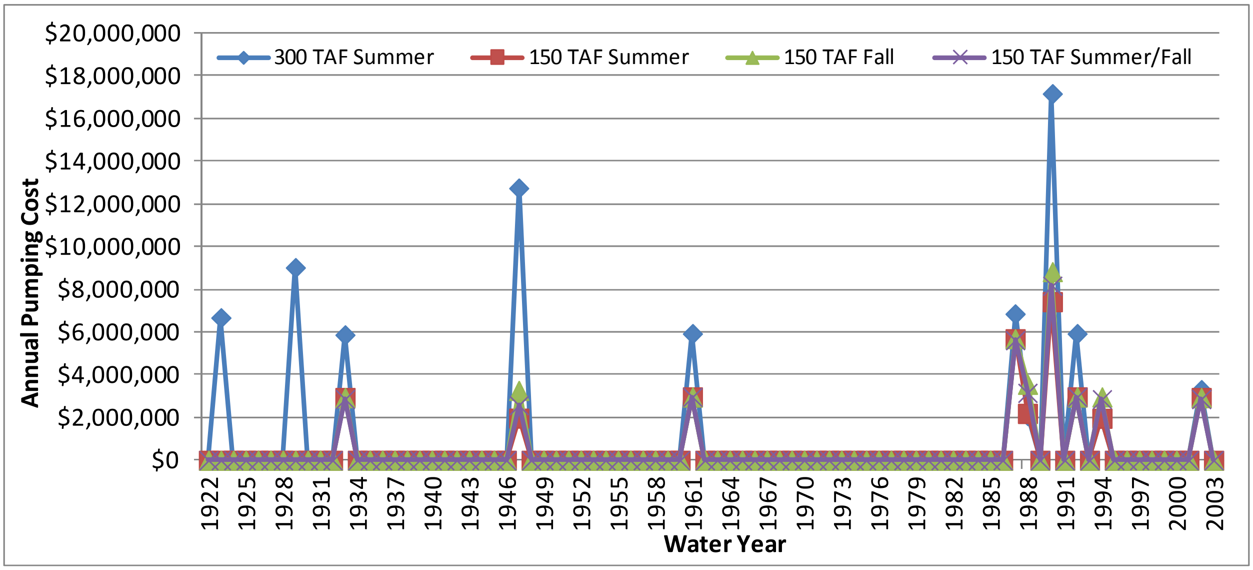
Annual Pumping Costs

Annual pumping costs were calculated based on pumped volumes and estimated cost per acre-foot pumped for shallow and deep production wells. Total pumping costs for the full study period are summarized in the table below. The time series of annual pumping costs for new well field pumping scenarios is shown in the following figure.

Pumping Scenario	Well Field	Pumping Costs	
		Total (full study period)	Average (years with pumping)
300 TAF Summer	New	$ 30,060,829	$ 5,010,138
	Existing	$ 37,321,899	$ 6,220,316
150 TAF Summer	New	$ 18,672,745	$ 3,112,124
	Existing	$ 23,183,070	$ 3,863,845
150 TAF Fall	New	$ 21,708,314	$ 3,618,052
	Existing	$ 26,951,868	$ 4,491,978
150 TAF Summer/Fall	New	$ 20,657,963	$ 3,442,994
	Existing	$ 25,647,809	$ 4,274,635



The time series of annual pumping costs for existing well field pumping scenarios is shown in the following figure.



As indicated, pumping costs tend to be greater for the existing well field scenarios as compared to the new well field scenarios. This is due to the lower aquifer having a greater specific capacity, which results in less pumping drawdown and required lift as compared to pumping from the shallow regional aquifer.

Project Operations Costs

The cost of operating the project was estimated based on the estimated level of effort required to operate the project and estimated salaries and overhead for project operators. Estimated operation costs for years with and without pumping are provided on the following page.

Estimated cost for project operations. Responsibilities include forecasting and scheduling project pumping according to program objectives and operating rules; coordination with USBR, DWR, and other agencies; and overall project management.

Estimated Time Required in Pumping Years

	Summer	Fall	Summer & Fall	
Pumping Duration (months):	6	5	9	(2 months added to account for ramp up/down)
Working Days per Month:	22			
Estimated Time Requirement (hr/day) During Pumping:	2		(25%)	
Estimated Time Requirement (hr/week) During Non-Pumping Period:	2			

	Summer	Fall	Summer & Fall
Total Hours Required per Year:	313	278	452
	15%	14%	22%
Base Salary:	$120,000		
Multiplier:	2.5		

	Summer	Fall	Summer & Fall
Total Cost (Pumping Years):	$ 45,966	$ 40,854	$ 66,401

Estimated Time Required in Non-Pumping Years

Estimated Time Requirement (hr/week) During Non-Pumping Period:	2

	Summer	Fall	Summer & Fall
Total Hours Required per Year:	104	104	104
	5%	5%	5%
Base Salary:	$120,000		
Multiplier:	2.5		

Project Monitoring Costs

Monitoring costs were estimated based on the estimated level of effort required for monitoring of water levels, groundwater modeling, managing pump operation to minimize or avoid impacts, and providing coordination and reporting, along with estimated salaries and overhead for project operators. Estimated monitoring costs for years with and without pumping are provided below.

Estimated cost for water level monitoring, feedback, and real-time program management. Responsibilities include conducting monitoring, operating and maintaining GW model, managing pump operation in real time to minimize or avoid impacts, conferring with appropriate authorities, and preparing periodic reports of project operations.

Estimated Time Required in Pumping Years

	Summer	Fall	Summer & Fall	
Monitoring Duration (months):	12	12	12	(assumes full year of monitoring in any year of operation)
Working Days per Month:	22			

Task	Position	Salary	Multiplier	Hourly	Hours per Week Required	
					Pumping Period	Non-Pumping Period
Water Level Monitoring	Eng. Tech	$60,000	2.5	$72.12	20	10
Data Quality Control	Eng. Tech	$60,000	2.5	$72.12	10	5
Monitor Pump Operation	Eng. Tech	$60,000	2.5	$72.12	10	0
Analysis of Monitoring Data	Engineer	$90,000	2.5	$108.17	20	4
Real Time Strategic Operation Decisions	Engineer	$90,000	2.5	$108.17	10	0
Confer with Appropriate Authorities	Engineer	$90,000	2.5	$108.17	2	0
Preparation of Monitoring and Operations Reports	Engineer	$90,000	2.5	$108.17	2	2

Position	Monthly Cost	
	Pumping Period	Non-Pumping Period
Engineering Technician	$12,500	$4,688
Engineer	$15,938	$2,813
TOTALS	$28,438	$7,500

Position	Annual Cost		
	Summer	Fall	S & F
Engineering Technician	$150,000	$150,000	$150,000
Engineer	$191,250	$191,250	$191,250
TOTALS	$341,250	$341,250	$341,250

Estimated Time Required in Non-Pumping Years

Task	Position	Salary	Multiplier	Hourly	Hours per Week
Water Level Monitoring	Eng. Tech	$60,000	2.5	$72.12	10
Data Quality Control	Eng. Tech	$60,000	2.5	$72.12	5
Monitor Pump Operation	Eng. Tech	$60,000	2.5	$72.12	0
Analysis of Monitoring Data	Engineer	$90,000	2.5	$108.17	4
Real Time Strategic Operation Decisions	Engineer	$90,000	2.5	$108.17	0
Confer with Appropriate Authorities	Engineer	$90,000	2.5	$108.17	0.5
Preparation of Monitoring and Operations Reports	Engineer	$90,000	2.5	$108.17	1

Position	Annual Cost
Engineering Technician	$56,250
Engineer	$30,938
TOTALS	$87,188

Annual GW Model Update

Task	Consultant Rate ($/hr)	Hours	Total
GW Model Update (incorporate new data, calibrate, operate, report)	$200	160	$32,000

Project Administrative and Legal Costs

Costs for administration of mitigation aspects of the program, including legal costs, were estimated based on the estimated level of effort required in pumping and non-pumping years, combined with estimated salaries and overhead for program administrators and legal staff. Estimated administrative and legal costs are summarized below.

Estimated cost for administration of mitigation aspects of the program. Costs will be incurred in greater amounts in pumping years, but residual effects of pumping will lead to a need for mitigation in non-pumping years as well.

Estimated Time Required in Pumping Years

	Summer	Fall	Summer & Fall
Mitigation Duration (months)	12	12	12

Working Days per Month:	22

					Hours per Week Required	
Task	Position	Equiv. Salary	Multiplier	Hourly	Pumping Period	Non-Pumping Period
Interface with Monitoring Team; Review Data	Manager	$120,000	2.5	$144.23	2	2
Conduct Outreach Regarding Observed Impacts	Manager	$120,000	2.5	$144.23	2	2
Handle Disputes Over Impacts	Manager	$120,000	2.5	$144.23	4	4
Legal Support	Attorney	$250,000	2.5	$300.48	5	5

	Monthly Cost	
Position	Pumping Period	Non-Pumping Period
Manager	$5,000	$5,000
Attorney	$6,510	$6,510
TOTALS	$11,510	$11,510

	Annual Cost		
Position	Summer	Fall	S & F
Manager	$60,000	$60,000	$60,000
Attorney	$78,125	$78,125	$78,125
TOTALS	$138,125	$138,125	$138,125

Estimated Time Required in Non-Pumping Years

Task	Position	Salary	Multiplier	Hourly	Hours per Week
Interface with Monitoring Team; Review Data	Manager	$120,000	2.5	$144.23	1
Conduct Outreach Regarding Observed Impacts	Manager	$120,000	2.5	$144.23	1
Handle Disputes Over Impacts	Manager	$120,000	2.5	$144.23	1
Legal Support	Attorney	$250,000	2.5	$300.48	1

Position	Annual Cost
Manager	$22,500
Attorney	$15,625
TOTALS	$38,125

Natural
Heritage
Institute

Feasibility Study of a Maximal Program of Groundwater Banking

December, 1998

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Acknowledgements

This report would not have been possible without the sustained support of the Ford Foundation. Recognizing the enormous contribution which groundwater banking could make towards diffusing water allocation conflict in California, indeed around the world, Ford was willing to underwrite several years of foundational research. By necessity, this research focused on framing the broad structural considerations and the general legal and institutional tenets of a maximal program of groundwater banking. Thanks to their generous financial assistance, however, we have also succeeded in adding form to the frame. The exciting payoff from the Ford Foundation's investment are the explorations of site-specific details of groundwater banking opportunities which are recounted in this report. Extending this analysis to the full suite of opportunities is now possible.

Our explorations have been facilitated by the availability of the Water Evaluation and Planning system (WEAP). This innovative river basin planning software, developed by the Tellus Institute in Boston, Massachusetts, underwent a major upgrade thanks to the financial support of the CalFed Bay-Delta Program, the U.S. Fish and Wildlife Service, the U.S. Bureau of Reclamation, and the Metropolitan Water District of Southern California. We sincerely appreciate the contribution of each of these valued partners and look forward to additional collaboration in the area of groundwater banking.

Finally, we would like to acknowledge you, the reader, for your willingness to read this document. We cannot promise that it will always make for gripping reading, although we are confident that it is an important contribution to the ongoing discussion of groundwater banking. Whatever your position in the California Water Community, it is in this context that we thank you. Only an open exchange of ideas will transform groundwater banking into a water management reality and we look forward to continued dialogue in the months and years to come.

Preface

Periodically since 1957, the California Department of Water Resources has published *The California Water Plan*. A review of these documents reveals that what began as an inventory of existing water supply and demand patterns, and projected future changes, has evolved into planning document which recommends options for balancing water demand and supply in the future. Bulletin 160-93, the 1993 version of *The California Water Plan Update*, was particularly noteworthy in terms of its recognition of the need to integrated the management of the state's surface water and groundwater resources (conjunctive use). According to *The Plan* (DWR 1994):

> In the future, carefully planned conjunctive use will increase and become more comprehensive because of the need for more water and the generally higher cost of new surface water facilities. Conjunctive use programs generally promise to be less costly than new traditional surface water projects because they increase the efficiency of water supply systems and cause fewer negative environmental impacts than new surface water reservoirs (page 103).

This statement is full of promise and expectation, positive tones which have sustained a conceptual discourse on conjunctive use and groundwater banking in California for many years. The end result of this promise and expectation is that groundwater banking has become an element of the standard litany of water management strategies for California, and is often held up as a win-win alternative for the state's disparate stakeholders.

When an attempt is made, however, to translate the conceptual model into actual yield enhancing projects, promise and expectation often give way to concern and uncertainty. Focusing attention on the conjunctive management of specific rivers and groundwater basins consistently raises "red flags" for those whose livelihoods depend on these resources. NHI does not seek to discredit these reactions. Given the level of investment in the current water management system and the hydrologic and economic uncertainly associated with conjunctive use, most are legitimate. Nonetheless, this report adopts the perspective that these concerns should catalyze analysis and dialogue, not extinguish them. The research we have conducted to date flows from this perspective and responds to many of the regularly waved red flags. In the interest of catalyzing increasingly site-specific analysis, the pages of this document report that:

- Re-operation of the terminal reservoirs on each of the major rivers between the Lake Shasta and Millerton Lake as part of a maximal groundwater banking program, in coordination with reservoirs located upstream, could generate approximately 1 MAF of average annual yield and increase the overall performance of the surface water infrastructure.
- Under existing law, there is no proscription against importing surface water for storage in a groundwater basin and eventual recovery for use off site.
- An inventory of potential aquifer storage sites discovered over 10 MAF of available storage a various places around the Central Valley, much of which could be accessed by re-operating and/or modifying conveyance infrastructure.
- Modification of conveyance infrastructure in a portion of the Sacramento Valley could enhance the yield of Shasta Dam by up to 40 TAF during dry years, while assisting water managers in Yolo County forestall future groundwater overdrafts.
- By increasing yield on the San Joaquin River, aquifer storage at Gravelly Ford could allow for downstream releases of approximately 144 TAF to restore the anadramous fishery while largely preserving the important agricultural economy in the southern San Joaquin Valley which currently diverts nearly the entire flow of the river.
- The proximity of a significant aquifer storage resource to the east of the Delta in San Joaquin County could increase the reliability of water supply south of the Delta, relieve chronic groundwater overdraft conditions and allow for enhanced Delta outflow when integrated with enhanced Delta conveyance infrastructure.
- At a cost which is generally less than $300 per acre-foot, groundwater banking projects similar to the examples cited above are must more affordable that surface water development projects which can cost up to $3000 per acre-foot.

These findings are an exciting step in the translation of a conceptual model of groundwater banking into actual programs which produce new water for both water supply and environmental restoration. We are optimistic that they are sufficiently compelling to allow some red flags to be lowered, if not furled. In keeping with this optimism, NHI anticipates that the analysis presented in this report will launch a useful dialogue about fulfilling the promise of groundwater banking. This analysis employs several innovative analytical tools which we expect will assist in developing a consensus around this management strategy. These including:

- The Conjunctive Use Potential model, or CUP, which can be used to assess the yield potential of the Central Valley reservoirs under a variety of assumptions regarding reservoir operating rules, conveyance capacities, and aquifer storage space.
- A legal matrix which weighs the relative strength of claims to various types of water stored in groundwater banking sites.
- A matrix of criteria which can be used to rank the suitability of specific groundwater banking sites.
- The Water Evaluation and Planning system, or WEAP, a monthly time-step water allocation model which allows for operational simulations which place specific groundwater banking sites in the context of surface water infrastructure and distributed water demand.
- An extensive database of existing groundwater banking activity in California which can be mined for important insights about avoiding potential pitfalls in the path towards groundwater banking.

We recognize that the task of fulfilling the promise of actual groundwater banking opportunities will only come from site-specific analysis which sufficiently resolves local details to allay the concerns of local actors and regional water managers alike. Our next phase of analysis will involve extending preliminary operational analysis similar to that conducted in Yolo and San Joaquin Counties and along the San Joaquin River to the other potential sites depicted on the cover of this report (also Figure 8). In all cases further refinement of site specific analysis will include:

- Facilitating stakeholder consultations;
- Defining operational changes required to practice groundwater banking;
- Assessing the suitability of groundwater banking in light of competing land uses;
- Evaluating potential environmental complications;
- Addressing local socio-economic and political realities;
- Optimizing the economic value of the site; and
- Resolving legal and institutional barriers.

The end result of this effort will be a suite of the most compelling groundwater banking opportunities ready for presentation to policy makers. The importance of this step cannot be underestimated. The policy making community must have this analysis in hand before making any final decisions about groundwater banking. Absent a well articulated strategy for capitalizing on this storage modality, it is unlikely that any storage enhancement program can be advanced. NHI offers ours analysis as an important contribution to this articulation.

I. Introduction

California's Central Valley watershed, made up of the San Francisco Bay-Delta Estuary and its upstream tributaries, is an extraordinary environmental resource for fish and wildlife. At the same time, the watershed provides much of the water that fuels California's enormous economy. Experience gained during the 1987-1992 drought indicates that operating the installed hydraulic infrastructure in the Central Valley under existing rules and proposed regulations will increasing bring economic and environmental water management objectives into conflict. The hard reality is that under rigid adherence to antiquated management arrangements, the Central Valley watershed cannot shoulder the enormous burden of simultaneously satisfying environmental and economic needs. Both the economy and the environment will ultimately suffer if this incompatibility remains unresolved.

One path towards resolution is increased water use efficiency and demand management. Environmentally benign water development which capitalizes on the storage capacity available in California's chronically dewatered aquifers is another. While in no way discounting the potential benefit of the first approach, this paper reports the findings of a feasibility study which rigorously explored the second path, specifically the potential for increasing both environmental and economic water supplies through an aggressive, maximal scale program of groundwater banking in the Central Valley water system. The results are very promising. Based on hydrologic considerations alone groundwater banking has the potential to provide approximately 1 MAF of additional annual yield, with the greatest benefit coming in new opportunities to supply consumptive demands and to enhance stream flows.

NHI's specific mission is to seek out and define opportunities for the conservation of natural resources. In responding to this objective, we cannot ignore the environmental benefit which an annual 1 MAF augmentation of water supplies in California would create. Cognizant of the pressing need to rededicate water back to the rivers and estuaries whence it has been diverted over the past century and a half, we have viewed this potential yield increase largely through the optic of environmental restoration. NHI, however, is also very pragmatic. Recognizing that powerful interests will naturally seek to defend the economic developments made possible through historic water diversion, ***we sought to demonstrate that groundwater banking can become one of the elusive win-win alternatives long desired by the California water community***. To make this case we adopted a very systematic approach towards analyzing and surmounting the physical, legal and institutional barriers which could stymie full realization of the yield potential associated with groundwater banking. The intent of this reductionist approach is to preemptively respond to the visceral reactions which are sure to greet a call to strengthen the ties between the management of California's surface water and groundwater resources. By addressing, and hopefully dispelling, some of these concerns in advance, this report lays the groundwork for to the full realization of the wide-spread benefit made possible through groundwater banking.

Funding from the Ford Foundation enabled NHI to produce this feasibility study. Although the work is the most comprehensive collection of analysis on the various aspects of groundwater banking in California produced to date, much work remains if we are to witness on the ground changes which capture the potential benefits of 1 MAF of new annual yield. NHI will use this feasibility study as a vehicle to actively solicit supplemental support from foundations, as well as from interested agencies and private sector beneficiaries, so that implementation of groundwater banking can help reduce the burden on the Central Valley water system.

I.1 The Problem: Imbalance Between Existing Stocks and Anticipated Flows

In the parlance of systems analysis, system reliability is a function of stock and flow characteristics. Systems where the desired flows are a large fraction of available stocks are vulnerable to disruption. This general axiom is true whether the system in question is a warehouse which furnishes goods in satisfaction of retail demand or a system of reservoirs which furnish water to cities and farms. Just as the warehouse which barely keeps up with retail demand in June will not satisfy the December rush, so a system of reservoirs which just covers demand under average hydrologic conditions will have difficulty providing adequate water supplies during times of drought. Municipal supply organizations have long understood the importance of system reliability. A survey conducted for the California Urban Water Agencies estimated the statewide value of water supply reliability to urban consumers at more than one billion dollars annually (Barakat & Chamberlin 1994). The Metropolitan Water District of Southern California began its recent Integrated Resource Planning process with the establishment of water supply reliability goals (MWD 1995). Only having set these goals did MWD begin to evaluate the anticipated levels of water supply and demand.

In California, the anticipation is that municipal demand will increase in response to population growth. The important agricultural industry in California would like to preserve historic production levels while at the same time emerging environmental standards respond to the critical need for additional water to enhance stream flow, particularly during dry years. Once again in the parlance of systems analysis, the desired flows in the California water system are likely to increase. Historically, the response to increased demand has been to increase stocks by constructing massive surface reservoirs. This approach, however, has fallen out of favor due to its high economic and environmental costs and it is unlikely to prove useful in the future without exhaustive consideration of alternatives. However, when the existing stocks fail to capture the excess wet year supplies needed to satisfy higher anticipated system flows, both economic and environmental values will be threatened. To reduce future disruptions, the desired system flows should be regulated via demand management. In addition, however, opportunities for increasing stocks, to the mutual benefit of economic and environmental interests, should be explored. This report focuses on one particularly compelling strategy for enlarging the stock, groundwater banking.

I.2 A Solution: Groundwater Banking to Increase Future Stocks

Relative to the construction of surface water reservoirs, enlarging the stock via groundwater banking, the storage of excess wet year supplies in subsurface aquifers, is a less controversial, lower cost, more environmental benign approach. Groundwater banking has numerous economic and environmental advantages compared to surface water storage: it reduces losses from evaporation, thus allowing for long-term storage; it allows for greater regulation of natural inflows, without the construction of a huge new network of reservoirs;[1] and it is generally less expensive than surface storage. As with all water storage systems, however, the main purpose of groundwater banking is to convert a fluctuating input of water from precipitation and snowmelt, into a steady supply stream which responds to a water demand pattern which differs from the input stream. Also in keeping with other forms of storage, groundwater banking occurs when water is plentiful, and produces stocks to tap when water is scarce.

Based on this operational definition, the natural hydrologic system is the preeminent practitioner of groundwater banking. During wet years, excess precipitation and elevated stream flows result in high levels of infiltration. As a result, aquifer recharge exceeds pumping, which has been suppressed by well endowed surface water supplies, and there is a net inflow into the aquifer. Groundwater has been banked. When dry hydrologic conditions return, suppressing both infiltration and surface water supplies, pumping by those overlying the aquifer will exceed recharge and the bank will be tapped. Natural groundwater banking, which cycles volumes of water which are orders of magnitude larger than those contemplated here, is not the focus of the maximal program of groundwater banking. Nor will the program rely on shaving the peaks off of the relatively infrequent and limited duration large flow events which already occur below California’s surface water reservoirs during wet years.

In order to increase the available stock, the maximal program of groundwater banking will start by intentionally transferring water from surface water storage to a groundwater bank during the late spring and summer. As this is the period of time when storage in California’s reservoirs is generally highest, the transfers can be aggressive and sustained. They can be accomplished either directly, through percolation at spreading basins, or through "in lieu" surface water deliveries in areas which rely heavily on groundwater pumping . The result of several months of intentional transfer will be an increment of additional storage in an aquifer and the equal increment of potential storage space in the surface water reservoir. Final

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[1] New facilities would be required but the unacceptable environmental and economic costs associated with primary dependence on surface storage could be reduced.

augmentation of the available stock in the system will be accomplished during subsequent winter storms and early spring runoff when the extra available reservoir space enable flood control operations which capture an increased volume of the reservoir inflow. Should a reservoir emerge from the wet season full, then the increment of water in the groundwater bank represents yield which would have otherwise gone unrealized. With these additional supplies in place, when the next dry year inevitably comes, economic demand for water may be satisfied from the groundwater bank, leaving the available surface water to be used to respond to the critical environmental need for enhanced stream flow.

1.3 Building a Case

This type of groundwater banking, which can help satisfy both economic and environmental water supply needs, has not developed on a significant scale in the Central Valley. The workplan which was implemented in carrying out this feasibility study was conceived to systematically address the barriers which have prevented aggressive groundwater banking from occurring. First among these is the perception that surface water reservoirs must be operated to serve only a narrow set of project beneficiaries. This parochial attitude towards the State's hydraulic infrastructure has discouraged the type of hydrologic analysis needed to determine the full water supply potential of a maximal program of groundwater banking. In a similar manner, the dependence of anadramous fish in the Central Valley on cold water releases from the major foothill reservoirs has forestalled consideration of aggressive reservoir re-operation.

Workplan Step 1: <u>Hydrologic Potential Analysis</u>
Assuming perfectly efficient storage and recovery potential, investigate the magnitude, frequency, and location of water that, absent reservoir re-operation as part of a maximal program of groundwater banking, would be released for flood control purposes and would otherwise be unavailable for environmental or consumptive purposes. Constrain the analysis only by the need to maintain suitable temperatures for fisheries downstream of the major foothill reservoirs.

The fear that this re-operation could further imperil Central Valley fisheries is not without merit. In one case where intentional transfers of surface water to aquifer storage have been accomplished, the environmental effects have been extreme. Because of the relatively small size of its central reservoir, the beneficiaries of the Friant-Kern unit of the Central Valley Project aggressively maximize pre-delivery from Millerton Reservoir on the San Joaquin River to the aquifers below their service area, to the point that a stretch of the San Joaquin below Friant Dam is frequently dry. The Friant-Kern example illustrates both of the potential for groundwater banking to enhance stocks, and the risk posed when the sole beneficiaries of the enhance groundwater storage are the local consumptive uses. This scenario is possible because water in groundwater storage in the Central Valley is viewed differently than surface storage. Whereas surface storage is endowed with specific user rights, even for distant beneficiaries, groundwater it is generally perceived of as a local resource, available only to overlying landowners. As a result, the use of groundwater storage to provide economic and environmental benefits for areas remote from the aquifer storage site is relatively rare in the Central Valley.

Workplan Step 2: <u>Legal and Institutional Analysis</u>
Investigate the legal support for the perception that the benefit of all water stored in a aquifer is the sole possession of overlying land owners and describe institutional arrangements, including voluntary contractual arrangements, that would be necessary to get overlying landowners and water districts to cooperate in a program of groundwater banking with broad economic and environmental benefit.

And yet, in the San Joaquin Valley the potential for maximal groundwater banking is massive. Past dependence on groundwater has produced areas where the water table is depressed, creating opportunities for storage. Moreover, heavy groundwater development has catalyzed a number of detailed hydrogeologic studies and information on aquifer characteristics is widely available. In the Sacramento Valley there are fewer areas of long term overdraft as there exists a high degree of interaction between rivers and groundwater. Thus, groundwater elevations tend to recover relatively quickly during wet period following dry years when heavy pumping occurs. While this natural interaction between river and groundwater is useful for local water users, it complicates

Workplan Step 3: <u>Site Analysis</u>
Identify groundwater basins which are well suited for direct recharge and retrieval and/or in lieu recharge and retrieval based on the physical characteristics of groundwater basin as well as land use patterns, ownership, water district jurisdiction and water supply systems. Display sites on a map.

efforts to use Sacramento Valley aquifers as a storage medium for non-local beneficiaries. While areas do exist within the Sacramento Valley where groundwater levels have been permanently depressed by pumping, there is less local incentive to pursue intentional groundwater storage north of the Delta. As a result the hydrogeology of the Sacramento basin remains poorly documented and accounting for the water stored can be a significant problem. In both the Sacramento and San Joaquin Valleys, however, detailed inventories of potential groundwater banking sites need to be elaborated and presented. Of particular interest should be the degree to which integration of a particular groundwater basin into the Central Valley water system facilitates the efforts of overlying water managers as compared with strictly local water management initiatives.

Even with this inventory in hand, however, developing an operational strategy to capitalized on specific groundwater banking opportunities will remain problematic. Surplus surface water for groundwater banking is most commonly available in the Sacramento Valley. The Mokelumne River, and the San Joaquin tributaries, while endowed with excess surface waters, have less substantial hydrologic potential. Hydrogeologically, however, many of the most promising storage sites lie in the San Joaquin Valley. Moving excess Sacramento Valley surface water to these sites may involve transit through the Delta, from which exports are increasingly constrained. Overcoming this potential barrier will turn upon the ability to investigate the operational details of linking reservoir operations to groundwater storage and recovery. This type of investigation requires a simulation tool which is both flexible and robust so that the scope of potential operating regimes can be defined.

Workplan Step 4: <u>Operational Analysis</u>
Investigate if changes in the current operating regime in the Central Valley can overcome constraints on moving water from re-operated reservoirs to groundwater banking sites, and from there to points of economic and environmental use. These changes may be both physical (e.g., the capacity and availability of conveyance facilities) and regulatory (e.g., Delta pumping standards) in nature.

In addition to operational considerations, economic obstacles to the realization of a maximal program of groundwater banking must be identified and overcome. As both the physical and institutional arrangements for aquifer storage differ from surface storage, so to must the financial considerations. In terms of planning and construction costs, aquifer storage and recovery is significantly less expensive then dam construction. However, some of the ancillary benefits of surface storage, such as hydroelectric power generation, flood control and recreation, which have been used to offset these costs are not associated with groundwater banking. In fact, reservoir re-operation as part of the program may either enhance or detract from these uses of California's reservoirs. In order to build a case for the program, these issues must be studied.

Workplan Step 5: <u>Economic Analysis</u>
Investigate the costs of groundwater banking programs relative to surface water development and define the potential benefits. Comment on unique economic aspects of capturing the available surface water supply, conveyance to a groundwater banking site, and storage and recovery for a prescribed end-use.

NHI began this groundwater banking feasibility study with the hypothesis that: (1) It is physically possible to generate substantial amounts of new water for the environment and the economy using groundwater storage; (2) The environmental and economic benefits of such a program outweigh the costs; and (3) any institutional barriers to the use of groundwater for this purpose can be overcome. By implementing of the five broad programmatic workplan steps described above, NHI sought to test whether this hypothesis is true and under what conditions. NHI recognizes that local concerns over the possible local impacts of groundwater banking **<u>must be</u>** overcome before a maximal scale program can become a reality. Prior to engaging in the difficult negotiations needed to address local concerns, however, some sense of the ultimate payoff is needed. By describing the outcome of the five program steps, this report provides that sense. It is intended to be eminently practical, not theoretical in its approach; it is not an academic exercise, but is intended to lead to action. Our premise is that this convincing portrayal of the potential of a maximal program of groundwater banking will generate an action plan which is useful to the governmental entities and stakeholder groups empowered to craft and implement such an ambitious, yet promising program.

II. The Context

Prior to presenting the conclusions of the five workplan steps, a description of the physical setting for a maximal program of groundwater banking is required. The following sections provide a context and a rationale for elaborating the link between the management of California's installed surface water hydraulic infrastructure and potential groundwater banking sites.

II.1 Surface Water Supply

On average, California is not short of water. Annual runoff averages roughly 71 MAF (78 MAF when out of state supplies are included). In 1990, a relatively dry year, environmental uses such as instream flow standards and wild and scenic river designations accounted for 24 MAF, irrigated agriculture for 24 MAF, urban use for 6 MAF, and "other uses" for 1 MAF. Roughly 30 MAF of the 1990 total was accounted for as "other outflow" -- e.g. not allocated to any specific use (DWR 1994).[2] These long-term averages, however, mask the variability which characterizes California hydrology. Consider that:

- Extended droughts are common. Over the six year periods from 1929-34 and 1987-92, cumulative runoff in the Sacramento and San Joaquin Rivers was slightly above half the long-term average. Runoff in 1976-77 was only 33% of the long-term average for the two rivers.
- Much year to year variability exists. In the period between 1906 and 1993, 27 years were dry to critical while 34 were wet.
- Runoff in California is highly seasonal. Much of the flow occurs during a few months when snow melt and rainfall coincide.
- Surface water supplies are spatially non-uniform. Roughly 75% of the natural runoff is north of Sacramento while 75% of the demand is south (DWR 1994).

The existing storage and conveyance infrastructure is designed to "even out" this variability in surface water supply. However, given the location and intensity of current and anticipated water demand, DWR projects a supply shortfall of between 2.1 and 5.2 MAF by the year 2020 if the capacity of the system remains static.[3]

II.2 Groundwater Supplies

Under current working assumptions one method of covering the anticipated shortfall will be an increased reliance on groundwater. Already, during dry years such as 1990, increased pumping results in a statewide groundwater overdraft of roughly 1.3 MAF. Future increases in demand would suggest that these overdrafts will continue at high levels indefinitely unless major changes in water management occur, particularly in the San Joaquin Valley (DWR 1994). Plans to cope with these changes must be tempered by hydrogeologic realities.

Table 1: Estimated Central Valley Groundwater Storage

Aquifer	Estimated Storage (MAF)
Sacramento Valley	170
Delta	130
San Joaquin Valley	160
Tulare Basin	370
Total Central Valley	830

Structurally, the deposits which form the aquifer system in the Central Valley range from a few tens to a few thousands of feet in depth. Total estimated fresh water within the upper 1,000 feet of these sediments is 830 MAF (Table 2). Traditionally the Sacramento Valley has been thought to consist of

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[2] It is important to recognize that this "other outflow" probably generates environmental benefits and should not be viewed entirely as surplus. The outflow is simply excess to minimum environmental flow standards that have been established for various streams and wetlands

[3] In reality, such shortages would not occur. Rather, water demand would be brought into balance with supply by some means -- water conservation, water recycling, water transfers, or desalinization. However, the economic and social costs and the political consequences of such a large reduction in demand make it highly likely that other means would be found to meet demands, such as additional diversions from the environment. The point of groundwater banking is to find ways to meet growing economic and environmental needs in ways that are acceptable to each side.

a single unconfined aquifer while the San Joaquin Valley was conceived of as an upper unconfined system and a lower confined system below the dense Corcoran Clay member of the Tulare formation. More recent studies conclude, however, that the Central Valley ground water reservoir is more accurately portrayed as a single heterogeneous aquifer, characterized by water bearing sediments interspersed with clay lenses.

Largely according to the nature of local interactions between surface water and groundwater, this vast water bearing reservoir has been divided into four hydrographic subregions: Sacramento Valley, Delta, San Joaquin Valley, and Tulare Basin. In each of the sub-region, all significant streams emerge from the Sierra Nevada or Cascade Mountains to the east. The sole exception is the Sacramento Valley where Stony Creek, Cache Creek, and Putah Creek flow into the valley from the Coast Range Mountains to the west. The mean annual runoff into the Central Valley from the surrounding mountains is about 32 million acre feet. Under historic conditions, the Central Valley rivers recharged the aquifers below the valley floor during periods of high flow and the groundwater sustained the low flow stage in rivers. By comparison, recharge via direct precipitation on the valley floor was a relatively minor component of the historic water balance (± 1.5 MAF/year according to Williamson et al 1989).

The regulation of high flows in the rivers of the Central Valley, combined with extensive groundwater pumping, substantially altered this annual cycle. In many parts of the Central Valley, groundwater no longer contributes to low stage stream flow, which is now comprised primarily of agricultural return flows. Across the region, current groundwater flow patterns are linked to the confounding alterations of the natural system which have accompanied decades of groundwater extraction and the hydraulic manipulation of surface water. In the western San Joaquin Valley, for example, the arrival of imported surface water from the Sacramento Valley raised the water table by as much as 170 feet. Further south in the Tulare Basin, where groundwater remains the primary source of irrigation water, the free surface has fallen as much as 400 feet. In the Sacramento Valley, where the interaction between rivers and the underlying aquifer remains closer to the natural regime, groundwater levels are generally stable. Even this general observation is violated, however, in the rapidly urbanizing regions around Sacramento and in numerous locations along the relatively dry west side of the valley.

The overall impression one gains is that the condition of the Central Valley aquifer has evolved through time and is at present extremely variable across the landscape. Williamson and other (1989) documented the steps leading to this dynamic situation:

- The total flow through the aquifer system increased from about 2 million acre-ft/yr prior to hydraulic development to nearly 12 million acre-ft/yr at the current time.
- Increased groundwater pumping prior to the 1960's, to nearly 11.5 million acre-ft/yr, drove the increase in groundwater flow.
- The groundwater pumping prior to the 1960's depleted total groundwater storage by some 20 MAF and was accompanied by increased pumping costs and dramatic land subsidence.
- Increased importation of surface water to some areas of the Central Valley, beginning in the 1960’s, prompted local declines in groundwater pumping.
- During the early 1980's, groundwater pumping decreased to a level approximately equal to the estimated rate of aquifer recharge.
- Since the arrival of surface water, groundwater levels have risen in most areas benefiting from imported surface water, and elsewhere further decreases in ground-water storage have been arrested.
- From a valley-wide perspective the system has achieve a state of quasi equilibrium where persistent zones of dewatered aquifer are largely in balance with adjacent zones of net aquifer recharge from overlying streams and imported surface water. In this context, any additional increment of groundwater pumping will eventually reduce surface flows.

This is not a system which can sustain the practice of satisfying increases in demand in the coming decades with a steadily increasing reliance on groundwater pumping. Such a strategy would likely return the system to the period of rapidly falling water tables, increased pumping cost, and land subsidence which plagued the first epoch of groundwater dis-equilibrium. There must be some consideration given to the need to increase storage in order to avoid a potentially destabilizing increase in groundwater pumping.

II.3 Storage Opportunities

The ability to store additional water and further "even out" natural variability would ease the predicted water availability shortfalls. Although California has a network of some 1400 major reservoirs, total storage in these reservoirs is approximately 42 MAF – only 60% of the average annual runoff (DWR 1994). The creation of sufficient additional surface storage to substantially even out variability is unrealistic. For example, proposals to build Auburn dam, a facility capable of storing 2.3 MAF, have been so controversial that funding has been blocked since Congress initially authorized the project in 1965. Even if Auburn dam were constructed, it would only increase the total system storage from 60 to 62.5% of annual runoff. Construction of all the new proposed surface storage facilities identified in Table 2 would increase the total capture of the system to 71% of annual runoff – and at an unacceptably high financial and environmental cost. Enlargement of the existing facilities in Table 2 would increase the system capture to just above the average annual runoff. As with new facilities, however, the financial and environmental costs of facility enlargement would be high.

Table 2: New/Enlarged Surface Storage

New Facilities	**Storage (MAF)**	**Cost ($/acre-ft)**
Cottonwood	1.6	480
Auburn	2.3	420
Marysville	1.05	1240
Los Banos Grande	1.73	660
Facility Enlargement		
Shasta	14.3	430
Folsom	1.34	1080
Friant	1.4	2920
Pardee	0.36	1640
Farmington	0.16	300
Berryessa	13.0	610
Total	30.56	

That underground aquifer storage is the primary supply-side alternative to the construction of new surface water reservoirs is widely recognized. As stated by the Department of Water Resources: "In the future, carefully planned conjunctive use will increase and become more comprehensive because of the need for more water and the generally higher cost of new surface water facilities." (DWR 1994). Groundwater banking was also recognized as one of the least cost sources in a review of yield enhancement opportunities undertaken under the Central Valley Project Improvement Act (USDOI, USBR et al., 1995) with cost estimates ranging from $60/acre-ft to $120/acre-ft of yield at source – greatly below the $300-$2920 unit cost of new surface storage.

This then is the hydrologic context for a maximal program of groundwater banking. Adequate surface water supplies exist in California if they can be further "even out" in space and time. Absent an effort to accomplish this management change, future anticipated growth in the State's water demand will likely lead to an increased reliance on groundwater pumping, disrupting the quasi-equilibrium currently in place and re-initiating problems with rapidly falling water tables and land subsidence. As the will to accept the high financial and environmental costs of additional surface water development has dissipated, the most viable alternative is to capitalize on the existence of regions of aquifer dewatering which developing prior to the 1970's, and which continue to plague overlying landowners. This is a scenario which can produce widespread benefit across the spectrum of water interests and which is the focus of the programmatic analysis which follows.

III. Workplan Step 1: Hydrologic Potential Analysis

A maximal program of groundwater banking seeks to divert surplus surface water to storage in suitable groundwater basins. This diversion would permit immediate storage and eventual recovery of water which would otherwise flow out to sea. The image most frequently conjured up by the aforementioned description is one of massive pumps and diversion canals, installed and ready to capture water during peak winter and spring flow events. Direct diversion during peak flows is depicted in the hypothetical example in Figure 1. In this case when the average daily flow in the Tuolumne River at Modesto exceeds 4000 cfs, 300 cfs of the large flow event is diverted to groundwater banking. Over the course of the 1994 and 1995 water years this approach generates approximately 80 TAF of storage. The important thing to note about this approach is that it involves manipulation of the hydrograph in the lower Tuolumne River while the storage in New Don Pedro Reservoir upstream remains unaltered.

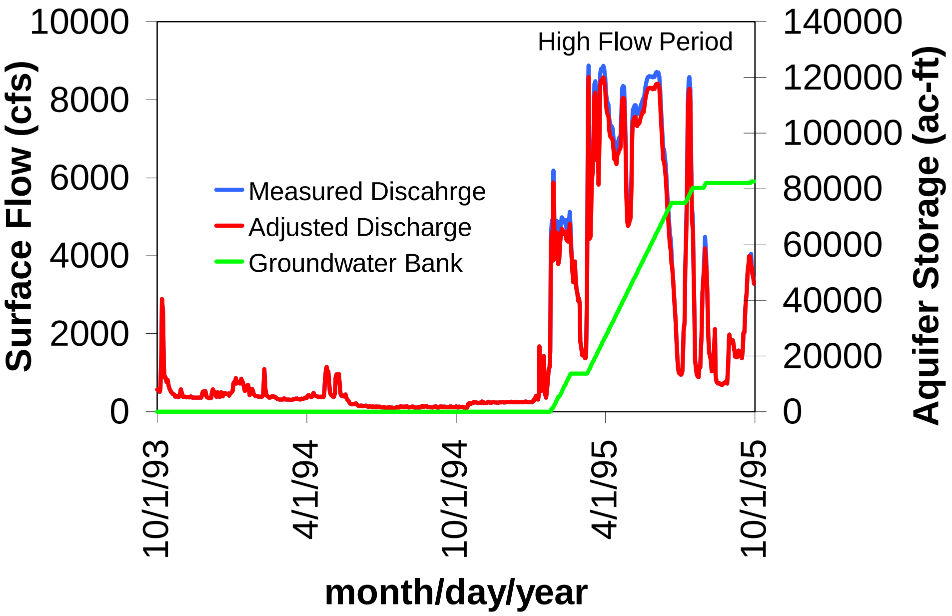

Figure 1: Banking Groundwater by Diverting Peak Flows from the Tuolumne River near Modesto

An alternate, and potentially complementary, strategy for groundwater banking involves the pre-delivery of water from surface water reservoirs to groundwater banking sites. Under this arrangement, water would be released from storage in California's major foothill reservoirs for transfer to aquifer storage during the summer and fall. This transfer could be accomplished directly through percolation at spreading basins or indirectly through *in lieu* deliveries to farms which would otherwise rely on groundwater for irrigation. Instead of directly altering downstream hydrographs during peak flow events, pre-delivery results in a decline in upstream reservoir storage levels. In the hypothetical example in Figure 2, each day between March and September, 1994 a supplemental release of 300 cfs is pre-delivered to groundwater banking from New Don Pedro Reservoir on the Tuolumne River. This re-operation causes a decline in reservoir storage relative to the historic trace which is balanced by a 130 TAF increase in aquifer storage. This aquifer storage becomes "new" water when, during the 1995 water year, measured reservoir releases in excess of 4000 cfs are cutback by 300 cfs. In effect, the excess available flood control capacity in New Don Pedro Reservoir allows for the eventual recovery of surface storage back to the historic trace.

Once storage in New Don Pedro recovers back to historic levels, the water stored in the groundwater bank becomes yield which would have otherwise been released during the peak flow events. It should be pointed out that a 300 cfs pre-delivery is relatively conservative as *in lieu* deliveries to farms could far exceed this level if a suitable distribution network were in place. The subsequent cutback of reservoir releases could also have been more aggressive than assumed in this example. Finally, the re-operation of surface reservoirs is a much more intentional and approach to groundwater banking than the periodic capture of peak flows as it does not require the installation of large diversion capacity which will only be used during short time windows. By "evening-out" the transfer of surface water to aquifer storage, pre-delivery allows for continual benefit to be derived from the physical and operational changes associated with groundwater banking.

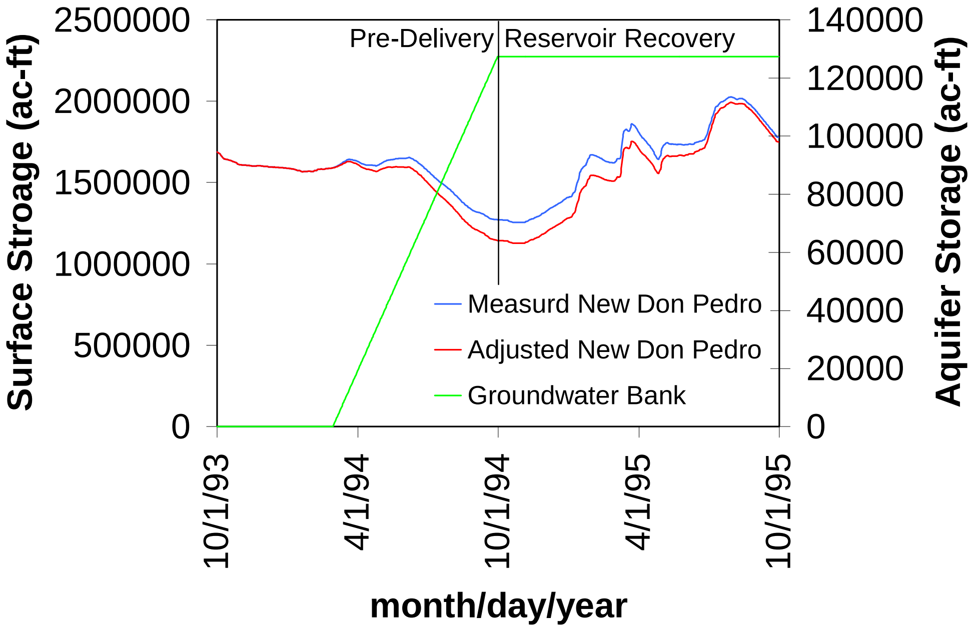

Figure 2: Banking Groundwater by Re-Operating New Don Pedro Reservoir on the Tuolumne River

III.1 Conjunctive Use Potential (CUP)

To estimate the hydrologic potential of the pre-delivery of surface water to groundwater banking in the Central Valley watershed, NHI developed the Conjunctive Use Potential model, or CUP (see the model methodology in the sidebar, parameters in bold italics must be provided by the user). CUP, which was developed for each of the river systems described in Table 3, is based on liberal assumptions about: (1) the existence of infrastructure; (2) a limited scale investment in the direct diversion of high flows to aquifer storage (as in Figure 1); and (3) the availability of suitable groundwater banking sites. On the other hand, CUP adopts a very conservative posture towards the need to preserve adequate cold water in the major foothill reservoirs. This cold water resource is needed to maintain suitable temperatures in the spawning and rearing reaches downstream of the reservoirs in Table 3. The conservative posture should help allay concerns over impacts to hydropower production targets or lake recreation opportunities, although these uses of surface

CUP Model Methodology

1. Compare ***historic daily reservoir releases*** to minimum ***required economic and environmental flows***. Historic releases in excess of required flows are considered "surplus", while smaller historic releases create a "deficit". Accumulate daily differences over the entire year to determine whether the year is wet or dry.
2. When environmental requirements create a deficit, adjust September 30 reservoir storage levels by this increment. Should the adjusted storage falls below a ***minimum carryover storage target*** set to preserve adequate cold water for anadramous fish below the dam, a shortage equal to the amount needed to meet the minimum carryover is applied to economic uses.
3. When a net surplus exists, the adjusted storage from Step 2 is compared to the ***target carryover storage***. If adjusted storage exceeds this parameter, water is pre-delivered to aquifer storage at a rate dictated by user defined ***transfer and storage constraints***. Surface storage is reduced by the same amount. Pre-delivered water is initially "provisional" storage as it can be recalled if needed.
4. Subsequent surplus flows will be held in surface storage until the Step 2 storage trace has been regained, transforming a similar amount of "provisional" storage to banked groundwater. If sufficient surpluses exist to transform all "provisional" storage to banked groundwater, additional surpluses can be transferred into the provisional groundwater account, provided that space is available in the bank.
5. Subsequent deficits which result in adjusted storage below target carryover initiate a search for replacement water and, if necessary, the recall of "provisional" storage at a rate dictated by ***user defined recovery constraints***. A shortage is declared when reservoir storage remains below the minimum target.

reservoirs are not specifically considered in the CUP analysis. The most important lesson to derive from Table 3 is that in six of the ten important rivers in the Central Valley, annual flows exceed the available storage and the improved flood control flexibility made possible through pre-delivery can help capture "new" water without imperiling anadramous fish below the dam.

Table 3: Details of the Major Foothill Reservoirs in the Central Valley

River	Reservoir/Dam	Operator	Storage (TAF)[4]	Mean 1921–1983 Unimpaired Flow[5]
American	Folsom	USBR/CVP	974	2,660
Calaveras	New Hogan	USBR	317	163
Feather	Oroville	DWR/SWP	3,538	4,441
Merced	New Exchequer	MeID	1,025	967
Mokelumne	Camanche	EBMUD	417	730
Sacramento	Shasta	USBR/CVP	4,552	8,303
San Joaquin	Millerton Lake	USBR/CVP	520	1,740
Stanislaus	New Melones	USBR/CVP	2,420	1,131
Tuolumne	New Don Pedro	MoID/TIDD	2,030	1,841
Yuba	New Bullards Bar	YCWA	966	2,333

III.1.1 Protecting Anadramous Fish

Prior to the development of the major foothill reservoirs, listed in Table 3, anadramous fish generally spawned in California's mountain streams. Construction of the dams which impound these reservoirs blocked passage to these sites, forcing fish to spawn in foothill and valley reaches which were historically warm during the summer and early-autumn. Figure 3 compares the water temperature in the Sacramento River downstream of the current Shasta Dam site. Before dam construction the summer water temperature was in excess of 70 ^oF and remained around 60 ^oF well into the autumn. Temperature moderation following dam construction resulted from the release of cold water found on the bottom of the reservoir. Similar temperature changes have been observed downstream of the other major Central Valley reservoirs.

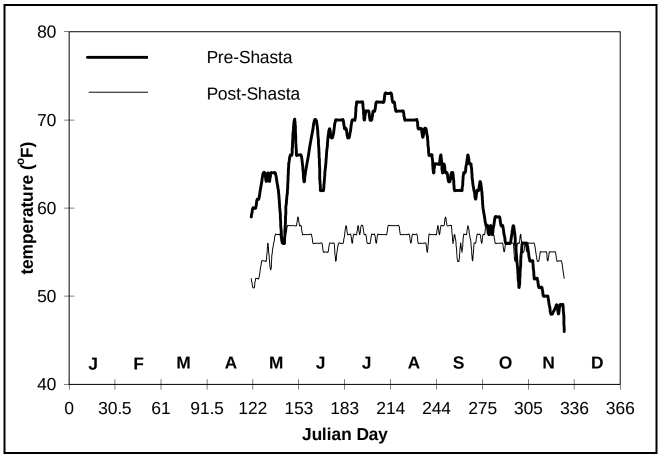

Figure 3: Sacramento River Water Temperature Downstream of Shasta Dam Site
(heavy line: Anderson-Cottonwood Diversion Dam; light line: Balls Ferry)

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[4] Draft of the California Water Plan Update, Department of Water Resources, California Water Commission, November 1993.
[5] California Central Valley Unimpaired Flow Data, 2nd Edition, California Department of Water Resources, Division of Planning, February 1987

The Central Valley Project Improvement Act (CVPIA) enacted in 1992 sought to elevate fish and wildlife protection, and restoration to a level of parity with the other project purposes (U.S. Fish and Wildlife Service 1995). The act also called for a "program which makes all reasonable effort to ensure that, by the year 2002, natural production of anadromous fish in Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991" (CVPIA 1992). For the rivers evaluated using CUP, a variety of temperature related actions were proposed as part of the U.S. Fish and Wildlife Service's Anadramous Fish Recovery Plan (AFRP). Some of these were specific prescriptions, others vague recommendations (see the adjacent sidebar). Table 4 describes specific reservoir carryover targets included in the AFRP.

Relevant USFWS Temperature Prescriptions

In order to maintain water temperatures below 56°F in the **Sacramento River**, Shasta Reservoir should be operated to attain a minimum October 1 carry over storage of 1.9 MAF under all runoff conditions except the driest 10% of water years.

In the **Feather River** pulse releases from Lake Oroville are needed to reduce the temperature difference between the low flow channel and the reach immediately downstream of the Thermalito outlet.

In the **Yuba River**, colder temperatures for chinook salmon could possibly be maintained by drawing Englebright Reservoir down in August and refilling with cold water from New Bullards Bar. Reservoir

In the **American River**, by re-operating the reservoir release shutters to provide greater flexibility, downstream releases during October would be 1-9°F colder than the temperature attained under current protocols and shutter configurations.

In the **Mokelumne River**, a minimum pool in Camanche Reservoir of 190 feet from April through September and a minimum pool of 170 feet from October through March, should be maintained to protect anadramous fish.

In the **Calaveras River**, temperatures could be kept cool enough for chinook salmon production with a minimum New Hogan Reservoir pool size of 85,000 ac-ft.

Water temperature in the **Stanislaus River** should be maintained below 56°F between October 15 and February 15 and below 65°F between April 1 and June 30 in order to enhance salmonid productivity below Goodwin Reservoir.

Water temperature in the **Tuolumne River** should be maintained below 56°F between October 15 and February 15 and below 65°F between April 1 and June 30 in order to enhance salmonid productivity below LaGrange Dam.

In the **Merced River** the same river temperature standards as for the Stanislaus and Tuolumne Rivers are suggested in order to enhance salmonid productivity below the Crocker-Huffman Diversion.

Table 4: AFRP Reservoir Carryover Targets in the Rivers Evaluated Using CUP

River	Specific Carryover Targets	No Clear Carryover Targets
Sacramento	1.9 MAF	
Feather		**X**
Yuba		**X**
American		**X**
Mokelumne	~108 TAF	
Calaveras	85 TAF	
Stanislaus		**X**
Tuolumne		**X**
Merced		**X**

In CUP, constraining the pre-delivery of water from reservoir storage to a groundwater bank based on the need to preserve the cold water pool requires the definition of both minimum and target carryover parameters. These parameters should be defined based on analysis of the physical juxtaposition of warm water in the Central Valley reservoirs with the release works on the face of the impounding dams, and on the thermal requirements of downstream fisheries. The carryover storage levels contained in Table 4 can be used as targets values in CUP. The remaining target parameters and all minimum carryover parameters must be set by the user.

III.1.2 Setting Carryover Targets

The derivation of these carryover parameters rests on physical principles, particularly a solid understanding of the tendency of reservoirs to stratify into warm and cold water pools during the summer and early autumn, and the potential for wind driven oscillation or *seiches* in stratified reservoirs. The limnological basis for this analysis is presented in Appendix I.

III.1.2.1 Required Data

The data required to carry out the required limnological analysis for the major foothill reservoirs in the Central Valley include:

- Historic EOM storage levels;
- Late summer vertical temperature profiles collected when the reservoirs were in a drawn down state;
- Late summer wind speed data from the vicinity of these reservoirs; and
- Information of the physical configuration of each reservoir and the impounding dam's release works.

Table 5 presents a matrix describing the data availability for each of the systems under investigation. In general, data for the Central Valley and State Water Project facilities was more easily acquired than in the case of projects managed by local-agencies. Gaps in the data availability were overcome by substituting the most appropriate data set available.

Table 5: Data Availability Matrix for Analysis of Minimum Carryover Storage Values of the Major Foothill Reservoirs

Reservoir	Operator	EOM Storage	Temperature	Wind Speed	Configuration
Shasta	USBR	✓	✓	✓	✓
Oroville	DWR	✓	✓	✓	✓
New Bullard Bar	YCWA	✓	✓	✓	✓
Folsom	USBR	✓	✓	✓	✓
Camanche	EBMUD	✓	✓	✓	✓
New Hogan	USACE	✓	✓	✓	✓
New Melones	USBR	✓	✓	***Use New Hogan***	✓
Don Pedro	TID	✓	***Use New Melones***	✓	✓
McClure	MID	✓	***Use New Melones***	✓	✓

III.1.2.1.1 Reservoir Storage

Figures 4A (Sacramento Valley) and 4B (San Joaquin Valley) depict the yearly October 1st reservoir storage values, for each of the major foothill reservoirs in Table 3, ranked in ascending order. The five lowest storage values are labeled, excluding the first five years of operation when filling could have influenced the storage levels as much as hydrologic conditions. The severity of the 1976-1977 drought is revealed in the fact that October, 1977 represents the lowest recorded level in eight of the nine reservoirs. The impact of the 1987-1992 drought is also revealed as many of these years also figure among the lowest measured storage levels. By examining the disposition of the cold water resource under these drawn down conditions appropriate carryover parameters can be established.

III.1.2.1.2 Vertical Temperature Profiles

Unlike reservoir storage data, data on the water temperature as a function of depth in the major foothill reservoirs is not collected and reported in a regular fashion. Every attempt was made to acquire temperature data corresponding to the lowest measure reservoir storage (see Figures 4A and 4B). Given the irregular character of this data, however, such a correspondence was not universally achieved. Table 6 summarizes the quality of the vertical temperature profile data collected for this analysis.

Table 6: Availability of Vertical Temperature Data for the Major Foothill Reservoirs Under Drawn Down Conditions

Reservoir	Measurement Date	Storage Rank	% Above Minimum
Shasta	Sept, 1976	3	8.9
Oroville	Sept, 1992	3	8.9
New Bullards Bar	Oct, 1992	>5	112.7
Folsom	Oct, 1977	1	0
Camanche	Oct, 1990	>5	28.0
New Hogan	Aug, 1990	3	1.6
New Melones	Sept, 1992	1	0
Don Pedro	N/A	N/A	N/A
McClure	N/A	N/A	N/A

Figure 4A: Ranked Historic October 1st Storage in the Major Sacramento Valley Foothill Reservoirs with Values of the First Operational Year (bold) and the Five Lowest Years Identified

(A: Shasta; B: Oroville; C: New Bullards Bar; D: Folsom)

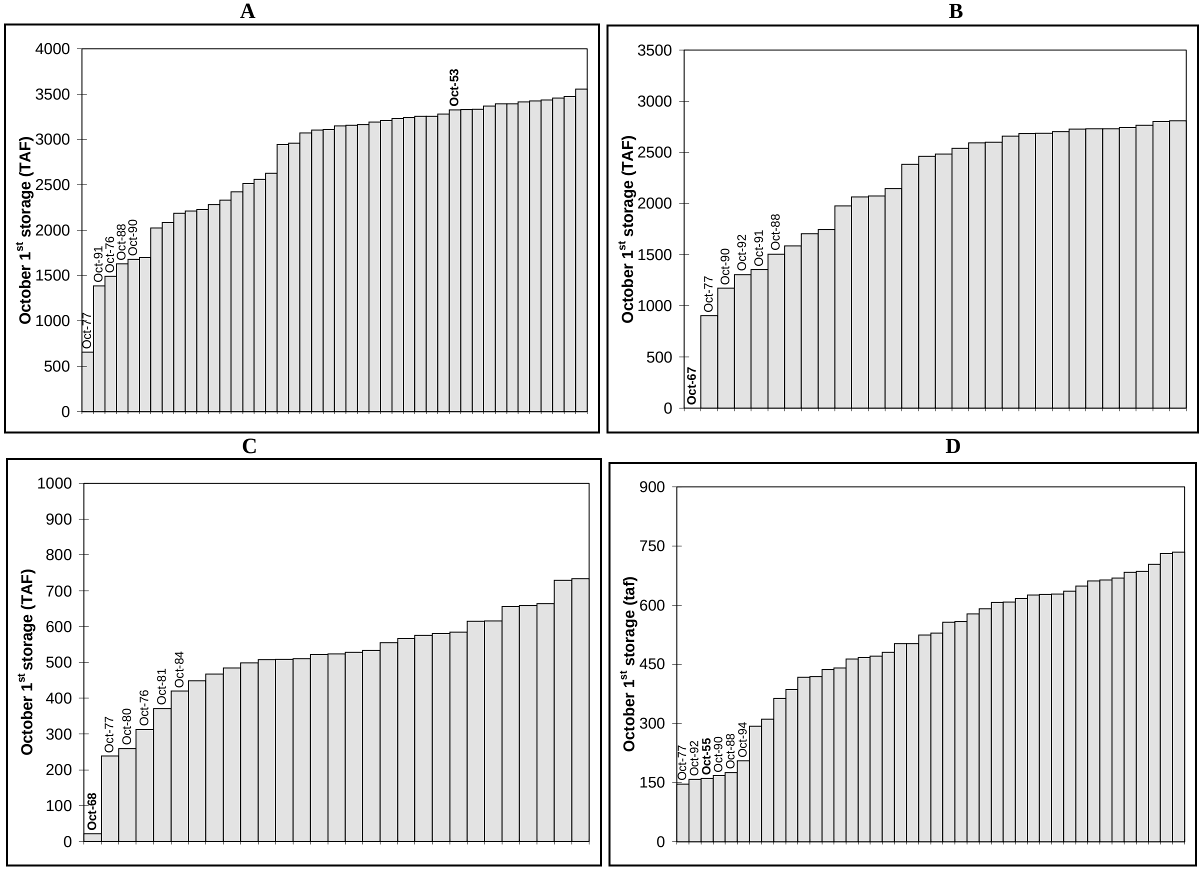
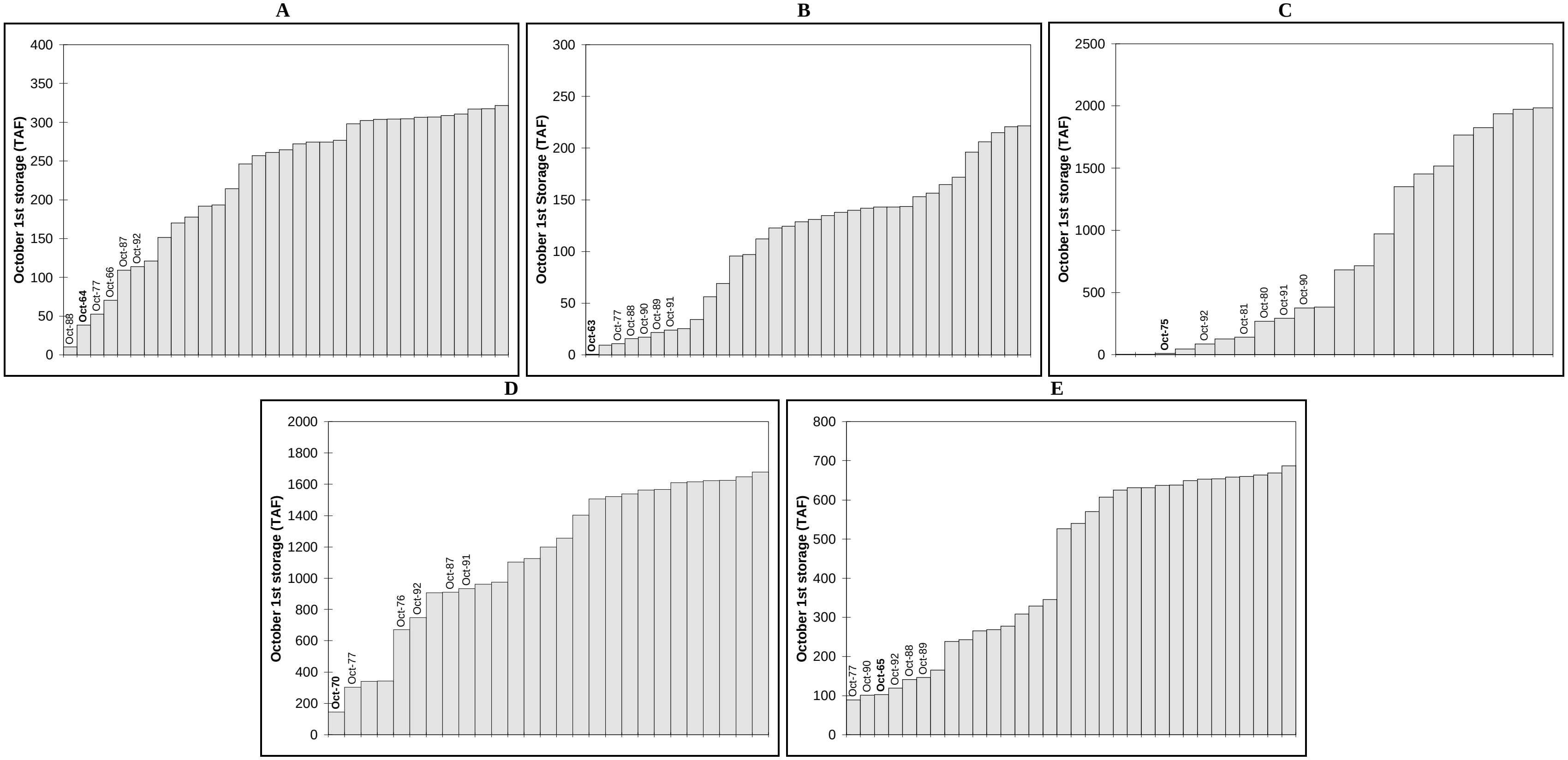


Figure 4B: Ranked Historic October 1st Storage in the Major San Joaquin Valley Foothill Reservoirs with Values for the First Operational Year (bold) and the Five Lowest Years Identified

(A: Camanche; B: New Hogan; C: New Melones; D: Don Pedro; E: McClure/Exchequer)



Using these data to establish acceptable carryover levels relies on the implicit assumption that the interaction between the incoming solar radiation, the prevailing wind, and the volume of the body of water behind the dam remains essentially constant across the range of drawn down conditions. Given the fairly uniform climatic patterns which characterize Central Valley summers, applying this assumption to the two climatic factors seems reasonable. The last column of Table 5 contains the percent increase in reservoir storage at the time of the temperature sounding, relative to the minimum observed October 1st storage reported in Figure 4. With the exception of New Bullards Bar and Camanche Reservoirs, the storage levels at the time of the temperature sounding were not substantially above the minimum observed storage level. Figure 5 contains the vertical temperature profiles plotted as a function of the depth below the lake surface for each of the reservoirs where data was available. The soundings reveal the well developed nature of temperature stratification in these reservoirs during the late summer/early autumn. Any appropriate carryover parameters used in CUP must consider the disposition of the cold water pool in the hypolimnion relative to the physical works controlling downstream releases.

III.1.2.1.3 Wind Speed

The disposition of the cold water resource in the major foothill reservoirs cannot be considered static. Shear stress generated by wind passing over the lake surface performs work on the water body which can disrupt the patterns of thermal stratification observed in Figure 5. In order to assess the potential for disruption, or mixing, the wind speed in the vicinity of the major foothill reservoirs must be characterized. The major foothill reservoirs generally lie somewhere between the elevations of two common wind speed databases containing data collected in the Central Valley (CIMIS) or at higher elevations in the Sierra (CDEC). In order to minimize the potential error associated with the use of this data, the maximum available measured daily average wind speed for each reservoir was used to assess the potential for wind driven mixing. These are shown in bold in Table 7.

Table 7: Wind Speed Measurement Stations Associated with the Major Foothill Reservoirs

(stations with maximum daily average wind speed in bold)

Reservoir	Station	CDEC	CIMIS	Reservoir	Station	CDEC	CIMIS
Shasta	McCloud	✓		Camanche	Beaver	✓	
	Thomes Creek	✓			Mt. Zion	✓	
	Whitmore	✓			**Lodi**		✓
	Gerber		✓	New Hogan	Esparanza	✓	
Oroville	**Butte Meadows**	✓			**Manteca**		✓
	Chester	✓		Don Pedro	**Green Springs**	✓	
	Quincy Road	✓			Tuolumne Meadows	✓	
	Westwood	✓			Modesto		✓
	Durham		✓	McClure	**Crane Flat Lookout**	✓	
New Bullards Bar	Bangor	✓			Mariposa Grove	✓	
	Dorris Ranch	✓			Mariposa Ranger Station	✓	
	Browns Valley		✓		Merced River	✓	
Folsom	**Buffalo Creek**	✓			Modesto		✓
	Camino		✓				
	Linclon	✓					

From the maximum data set, the highest single daily average wind speed was extracted. The assumption implicit in the use of the peak value is that energy imparted to the system by a steady wind blowing for a single day will be sufficient to fully induce wind-driven water movement in the reservoir. The time series of wind speed data from these most windy sites are shown in Figure 6.

Figure 5: Late Summer/Early Autumn Vertical Temperature Profiles for the Major Foothill Reservoirs

(A: Shasta; B: Oroville; C: New Bullards Bar; D: Folsom; E: Camanche; F: New Hogan; G: New Melones)

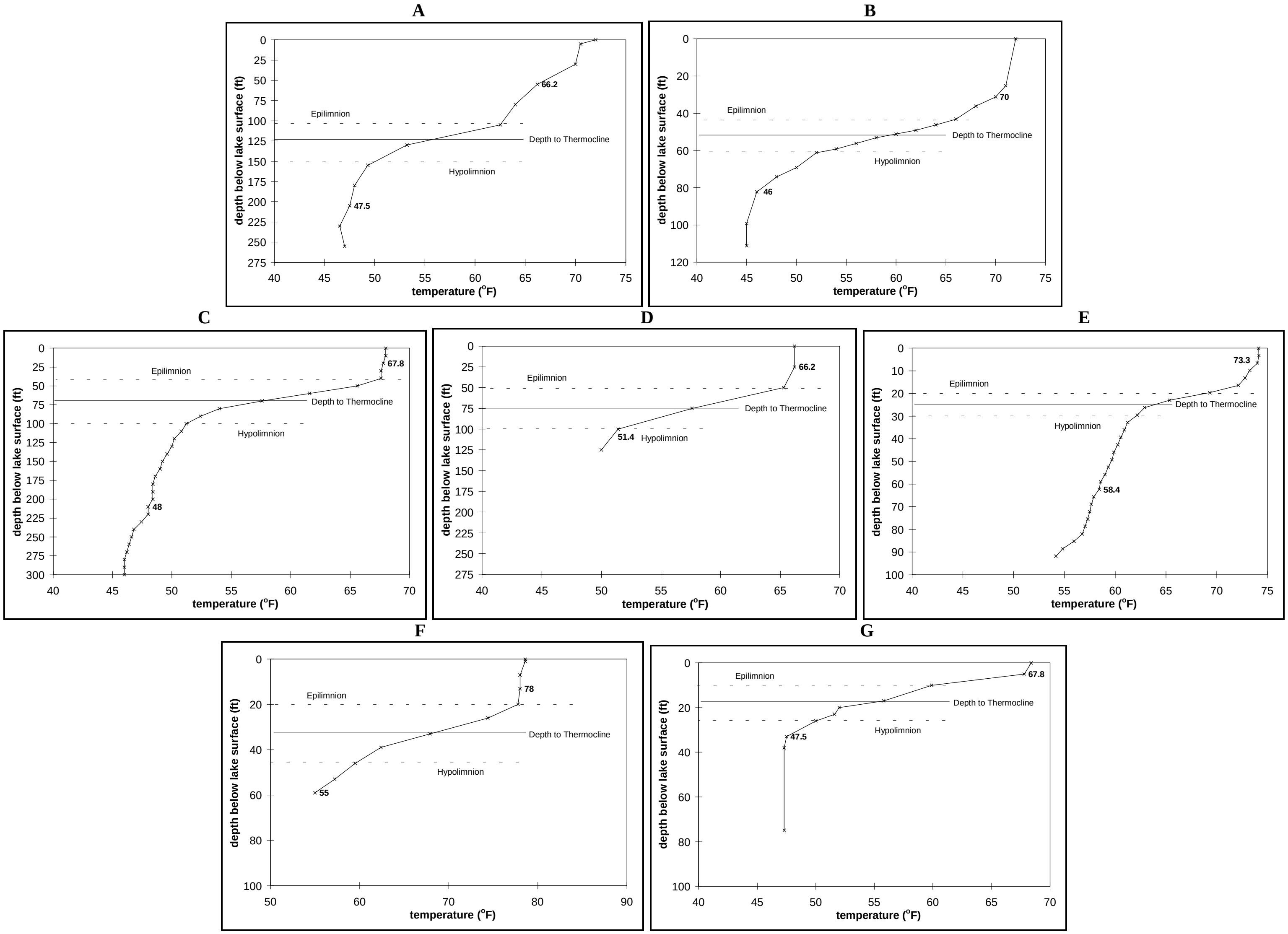
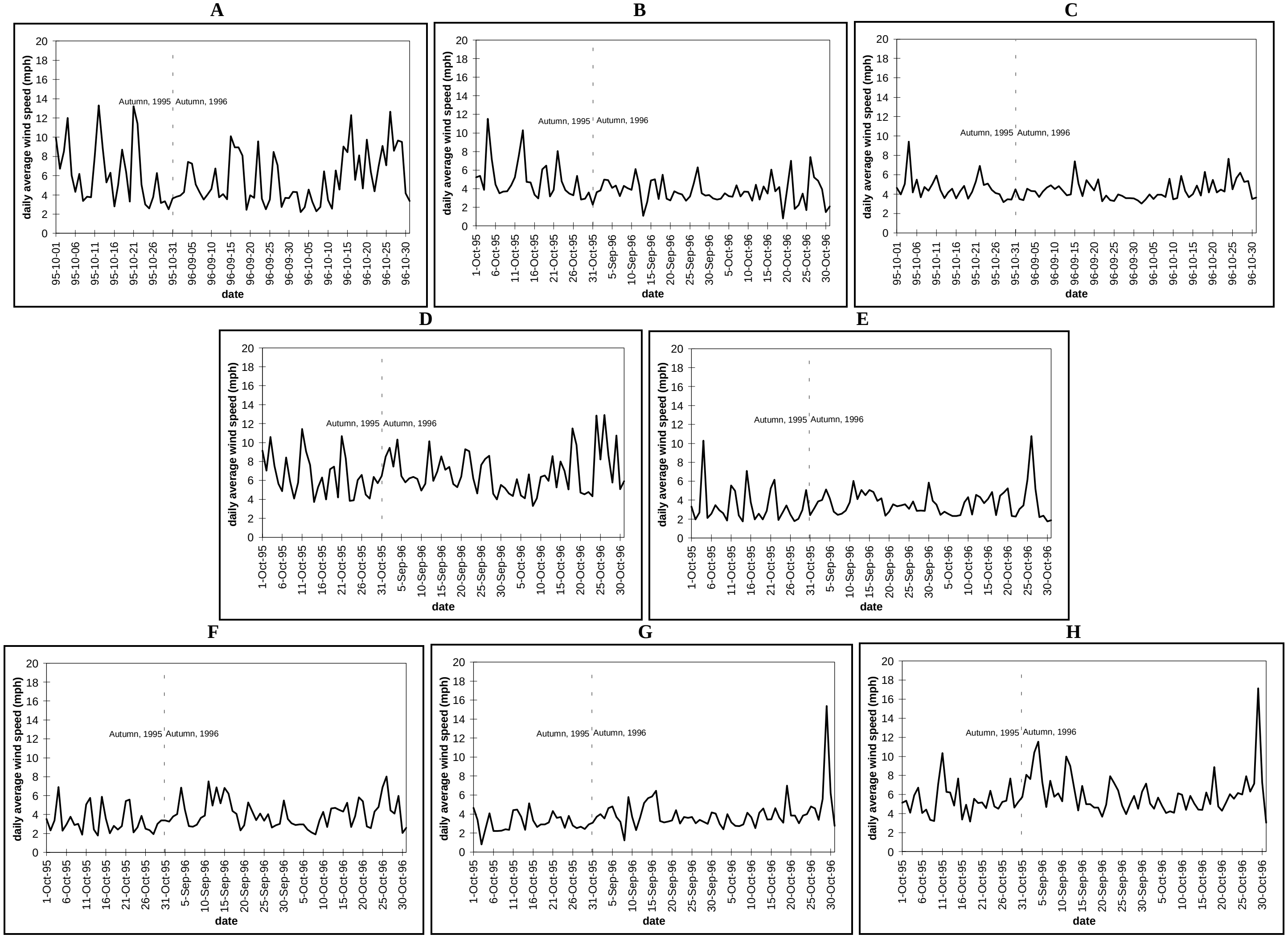


Figure 6: Recent Maximum Late Summer/Early Autumn Daily Average Wind Speed Date for the Major Foothill Reservoirs

(A: Shasta; B: Oroville; C: New Bullards Bar; D: Folsom; E: Camanche; F:New Hogan; G: Don Pedro; H: McClure)



III.1.2.1.4 Physical Configuration

In order to evaluate the disposition of the cold water resource with respect to the release works of a given dam, data describing the physical configuration of the reservoir system is required. This data set includes information on the length of the lake, the elevation of the foot of the dam and the elevation of the release works used to discharge water downstream. Two complications influence the compilation of this data set. First, the major foothill reservoirs are not uniformly long and narrow, which makes it difficult to define the length of the lake corresponding to the fetch of open water above the dam. For this analysis the length was defined as the longest unobstructed distance over water which can be traced at high water from the dam itself. Second, stating the elevation of the release works was complicated by the fact that many of the major foothill reservoirs include installed hydroelectric generating capacity. The elevation from which water is released to the powerhouse is usually higher then the low level release works used for flood control. In order to minimize the potential impact on hydroelectric power production, in this analysis the elevation at which water is released to the powerhouse served as the reference for a comparison with the disposition of the cold water pool. Table 8 summarizes the requiired information for the reservoirs of interest.

Table 8: Physical Configuration Data for the Major Foothill Reservoirs

Reservoir	Length (mi)	Elevation Foot (ft)	Elevation Release (ft)
Shasta	5.9	576	725
Oroville	4.7	180	640
New Bullards Bar	2.3	1400	1622
Folsom	7.8	200	218
Camanche	6.8	100	104
New Hogan	2.0	525	534
New Melones	3.3	500	760
Don Pedro	4.1	290	600
McClure	3.1	400	477

III.1.2.2 Computational Steps

In this analysis, the evaluation of the ability to release cold water downstream from a stratified lake relies upon three sequential calculations carried out for an assumed reservoir storage level and vertical temperature profile. These are

- Determine the set-up of the lake caused by the passage of wind over the lake surface;
- Determine the displacement of the warm water pool, in response to the set-up; and
- Determine the juxtaposition of the warm water relative to the reservoir release works.

Appendix II examines these three computational steps in greater detail, focusing on the physical rationale behind each step.

III.1.2.3 Defining the Minimum and Target Carryover Parameters

Table 4 contains carryover storage targets for Shasta, Camanche, and New Hogan Reservoirs as defined in the Anadramous Fish Recovery Plan (USFWS 1995). These will be used as target carryover parameters in CUP. Appropriate carryover targets for the remaining facilities, as well as the minimum carryover levels for all of the reservoirs, remain unresolved. These values are set according to the following criteria:

$$CS_{\text{target}} = \left| \begin{array}{l} CS_{AFRP} \\ CS \text{ where } HT \approx 50\text{ft} \end{array} \right. \text{ or if none} \qquad (1)$$

$$CS_{\text{minimum}} = CS \text{ where } HT \approx 20\text{ft} \qquad (2)$$

where CS is the carryover storage and HT is the minimum thickness of the cold water pool lying above the release works during wind driven oscillations. In those cases where no carryover standards are available, storage levels were adjusted in a trial and error fashion until conditions yielding HT values of 20 ft and 50 ft were identified. Table 9 presents the final CUP carryover parameter values for each of the nine simulated rivers (The San Joaquin was omitted from this analysis as extensive pre-delivery of surface water already takes place in the Friant Unit). These parameters were not based on political considerations, the sole consideration was the difference between the maximum downward displacement of warm water under *seiche* oscillations and the release works of a given facility. Obviously dams where the power plant intake is located well down the dam face are found to have much lower carryover requirements.

Table 9: CUP Carryover Parameters Developed According to Analysis of the Juxtapostion of Warm Water Relative to Reservoir Release Works (in ac-ft)

River	Carryover Target	Minimum Carryover
Sacramento	1,900,000	910,000
Feather	1,705,00	1,507,000
Yuba	210,000	190,000
American	190,000	100,000
Mokelumne	108,000	70,000
Calaveras	85,000	17,000
Stanislaus	382,000	268,000
Tuolumne	750,000	570,000
Merced	50,000	30,000

III.1.3 Tapping Upstream Storage

In CUP, when the re-operated storage falls below the minimum carryover parameter the model seeks to redress the deficit. The first place where CUP looks for replacement water is upstream towards storage in Sierra Nevada reservoirs. A time series of combined upstream storage for each river has been input into CUP and the user can specify the percentage of the upstream storage which can be tapped to make up any deficit. In CUP, water is returned to the surface reservoir from “provisional” storage only when the available upstream storage is insufficient to fill the gap. Figure 7 presents the time series of available upstream storage volumes.

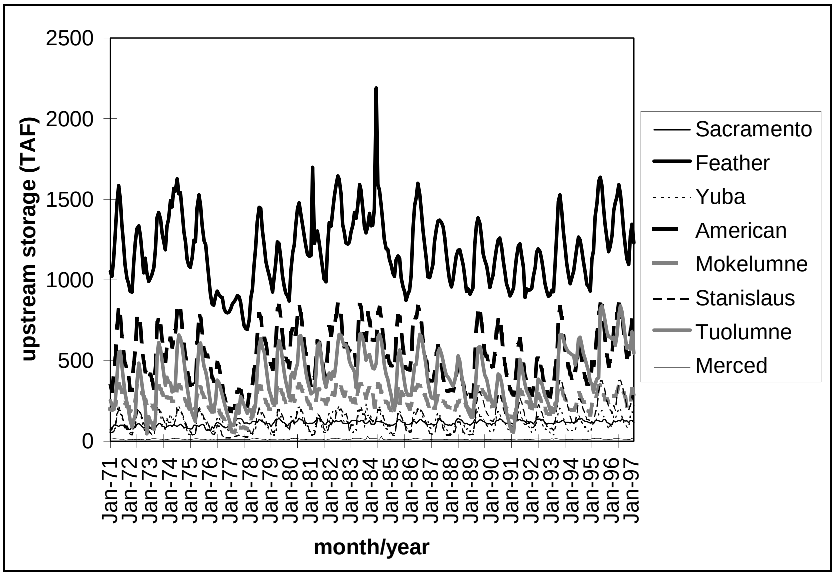


Figure 7: Time Series of Total Storage Upstream of the Major Foothill Reservoirs

III.1.4 CUP Simulations

Four different scenarios were simulated using CUP. These are summarized in the matrix shown in Table 10. The base case represents the case where instream flow standards are set to the highest possible level, carryover standards set in the AFRP are used where available to define the carryover target parameter, and 20% of the upstream storage can be tapped to make up any deficit relative to the minimum carryover. The other three simulations are departures from this base case. Scenarios 2 through 4 are designed to evaluate the sensitivity of the estimated average annual yield to various management strategies. Scenario 2 in particular merits some explanation. In this simulation the AFRP prescribed carryover targets are set aside in favor of the more aggressive targets derived from the application of the equations (1) and (2) to Shasta, New Hogan, and Camanche Reservoirs. Under each of these scenarios, a small simulated capacity to capture flow during peak winter and spring flow events was included (as depicted in Figure 1). It is important to keep in mind, however, that this approach is considered secondary to reservoir re-operation in CUP.

Table 10: Simulation Matrix for Revised CUP Model

Scenario	Carryover Target	Instream Standard	% Upstream Available
1. Base Case	AFRP if available, otherwise HT =50 ft	HIGH	20%
2. Set Aside AFRP	HT =50 ft everywhere	HIGH	20%
3. Relax Standards	AFRP if available, otherwise HT =50 ft	MEDIUM	20%
4. Full Upstream	AFRP if available, otherwise HT =50 ft	HIGH	100%

III.1.5 Results

The estimated average annual yield in the base case simulation is 894.4 TAF, a significant quantity of water which could contribute mightily to the quest for consensus in California's water sector. In addition, the alternative management strategies described in scenarios 2 through 4 improve the performance of the groundwater banking program. Table 11 summarizes the results for each simulated river under each of the management scenarios.

Table 11: Average Annual Yield Estimates from Revised CUP Model (in TAF)
(CU: conjunctive use re-operation; HP: capture of hydrograph peak)

	Base Case			**Set Aside AFRP**			**Relax Standards**			**Full Upstream**		
River	CU	HP	Total	CU	HP	Total	CU	HP	Total	CU	HP	Total
American	64.8	15.6	80.4	64.8	15.6	80.4	72.9	17.4	90.3	137.1	15.2	152.3
Calaveras	12.8	12.6	25.4	15.9	11.5	27.4	14.7	13.2	27.9	12.7	12.6	25.3
Feather	107.3	19.6	126.9	107.3	19.6	126.9	122.8	21.7	144.5	117.1	19.6	136.7
Merced	92.9	15.2	108.1	92.9	15.2	108.1	134.7	22.4	157.1	93.0	15.2	108.2
Mokelumne	53.7	15.7	69.4	51.6	15.7	67.3	77.6	23.3	100.9	59.6	15.0	74.6
Sacramento	170.8	26.0	196.8	184.5	26.0	210.5	195.3	31.2	226.5	170.8	26.0	196.8
Stanislaus	51.6	13.4	65.0	51.6	13.4	65.0	79.5	26.4	105.9	58.3	13.4	71.7
Tuolumne	65.3	12.6	77.9	65.3	12.6	77.9	116.4	24.8	141.2	72.1	12.4	84.5
Yuba	117.5	27.0	144.5	117.5	27.0	144.5	157.8	31.3	189.1	122.6	27.1	149.7
Total			894.4			908.0			1183.4			999.8

Relative to the base case, the most dramatic improvements come from reducing the simulated instream flow standards from high to medium. Even without relaxing the instream flow standards, however, the performance of the system can be improved by taking full advantage of the opportunity to release water from storage in upstream reservoirs when it is needed to re-establish the minimum carryover level on October 1st. Table 12 details the pattern of reliance on upstream storage which emerges from this simulation. Although the use of this water affords extra benefit to the ground water banking program, any advantage gained must certainly be weighed against power generation potential which might be lost in the process. This analysis suggest, however, that the notion of integrating storage upstream of the major foothill reservoirs into the maximal statewide groundwater banking program is certainly worth pursuing. This type of integration, however, would involved a wide array of actors running from the electric utilities which operate the upstream reservoirs, the water agencies which operate the major foothill reservoirs and their customers, and the land owners overlying the potential aquifer storage sites. The complexity of negotiating arrangements acceptable to all these parties will require a keen eye towards the legal and institutional nuances governing groundwater in California. Given the enormous potential payoff, however, there should be ample incentive to address any potential problems.

Table 12: Simulated Transfers from Upstream Storage to the Major Foothill Reservoirs under the Full Upstream Scenario (transfers in ac-ft)

River	No. of Transfers	Average Transfer
American	10	182,649
Calaveras	0	0
Feather	7	182,764
Merced	5	9195
Mokelumne	9	55,427
Sacramento	6	106,904
Stanislaus	3	87,343
Tuolumne	8	131,810
Yuba	3	53,935

IV. Workplan Step 2: Legal and Institutional Analysis

The infusion of approximately 1 MAF of new water into the California water system on an annual basis would undoubtedly help water managers in the state to meet water supply and environmental objectives. Realizing this hydrologic potential, however, requires that legal and institutional barriers be identified and surmounted.

IV.1 Basic Premise

Basically, the incentives for a maximal program of groundwater banking would be as follows, landowners overlying the storage site would agree to store the water as part of the program in exchange for a portion of the “new” water, or for a cash payment. Water will be regarded as “new” water if it would otherwise have been released for flood control purposes and flowed out to sea. Well monitoring may be necessary in selected areas to prevent increased pumping by overlying and adjacent landowners in storage areas, who could be tempted to irrigate new lands, avoid higher surface water costs, and/or to compensate for unrelated market transfers of surface water rights. Opportunities may exist to incorporate storage entities as a part of AB 3030 groundwater management plans for districts throughout the state, indeed in the case of *in lieu* storage this may be the preferred approach. Potential beneficiaries of the groundwater banking program would be invited to participate in the arrangement under agreements that would give them access to purchase a specified amount of the banked groundwater. The funds collected from the beneficiaries would be used to defray the costs of the program, which are expected to include the construction of new infrastructure and electricity for pumping the stored water.

IV.2 Basic Approach

A preliminary analysis of California groundwater law has been conducted to explore how a groundwater banking program could be set up so that the rights to the program water stored in groundwater basins could be protected against claimants which are not participating in the program. In pursuing this legal research two program designs were considered: (1) groundwater banking through active recharge and (2) groundwater banking through *in lieu* arrangements. Both designs would tap flood control releases that otherwise escape beneficial use. Thereafter the program designs diverge somewhat as they are predicated on different legal entitlements to extract and use the stored groundwater. The details of this legal research are included in an August, 1994 NHI document entitled *Analysis of Preferences in Rights to Groundwater Under California Law & Implications for Design of Conjunctive Water Use Programs*.

In this analysis NHI defined a number of distinct “types” of groundwater. While from a hydrologic perspective, a molecule of groundwater in a basin is not physically distinguishable from any other molecule, our analysis suggests that from a strictly legal perspective there are multiple groundwater types in the State. Our conception of a maximal scale groundwater banking program will focus on Groundwater Type 5, where the organizer of a groundwater banking program would seek to obtain rights to groundwater that is *percolating, used off-tract, imported to the watershed of use, and required for reasonable beneficial use, where area of origin statutes are inapplicable*. In more practical terms, this is groundwater which was imported from outside the groundwater basin, which has not become the underflow of a surface stream nor an underground stream, and which will be put to beneficial use at a location physically removed from the land overlying the basin. This type of groundwater offers several important protection to the organizers of a groundwater banking program. The most salient details of the legal analysis on the active and *in lieu* program designs are framed as responses to pertinent questions.

IV.3 Legal and Institution Questions

The questions posed below go right to the heart of perceptions that the benefit of water stored in an aquifer is the sole possession of overlying landowners. The responses assert that for groundwater of Type 5, at least, this perception is not universally valid. Having established this conclusion, questions related to how to best capitalize on potential storage opportunities can be posed.

IV.3.1 Could parties with potential claims on Groundwater Type 5 hamper the eventual recovery of stored groundwater?

IV.3.1.1 In the Case of Active Recharge

The universe of parties with potential claims to Groundwater Type 5 includes: the people of California through the public trust, as well as importers, prescribers and appropriators--both private and public.

The public trust is omnipresent. No disadvantage is incurred by using water of this type, since no type of water escapes the reach of the trust.

Prescribers, overlying users, and other importers are not of concern, if water of this type is used. If the organizer of the groundwater banking program is a public entity, as described below, prescribers are eliminated from competition for water imported by the organizer. The only colorable claim of overlying groundwater users to water of Type 5 would result if the importer abandoned the imported water once it was in the ground. Spreading does not constitute such abandonment.[6] Other importers can claim only rights to a quantity of water attributable to their own imports--a situation that does not threaten the operation of a groundwater banking program. Thus, a public importer of water of this type need only be concerned about being displaced by appropriators.

Appropriators have a superior claim to water of this type only if the importer fails to require the water for reasonable beneficial use--that is, if the water is considered "surplus." The burden of proof would be on the would-be appropriator to show that such water was, in fact, surplus.[7] Storage of groundwater for domestic, irrigation, and municipal purposes is typically considered a reasonable beneficial use.[8] Storage of groundwater is a beneficial use if the water is later applied to the beneficial purposes for which the water was first appropriated on the surface.[9] Thus, it is important that, in addition to manifesting an intent to recapture imported waters stored in the ground, the organizer of the groundwater banking program demonstrate that such waters are being stored for later application to reasonable beneficial uses. In this way, the storage itself will be considered beneficial.

Thus, if the organizer of the groundwater banking program holds rights to groundwater of Type 5, the program should be able to deposit water in the ground and, by right, withdraw it again.

IV.3.1.2 In the Case of *In Lieu* Arrangements

Under an in lieu system, the program would enter into arrangements with overlying landowners who already have access to groundwater. During periods when the program desires to recharge groundwater, the landowners would forego pumping and accept a substitute surface delivery from the program instead. In the case where the landowner has access to surface water, when the program desires to withdraw groundwater, the landowner would curtail its surface water use and substitute groundwater pumping. When the landowner has no independent claim to surface water, recovery by the program would rely on the physical extraction of stored groundwater.

The basic problem with such an arrangement is that the program will not be withdrawing groundwater that it has physically put into the aquifer through an active recharge program. Instead, it will require groundwater rights holders to forego pumping water that they are otherwise legally entitled to

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[6] City of Los Angeles v. City of Glendale, 142 P.2d 289, ___, 23 Cal.2d at 76-78 (Cal. 1943).

[7] Miller v. Bay Cities Water Co., 107 P. 115, ___ (Cal. 1910); Allen v. California Water & Tel. Co., 176 P.2d 8, ___ (Cal. 1947) (burden on appropriator to show existence of surplus); Monolith Portland Cement Co. v. Mojave Public Utilities Dist., 316 P.2d 713, ___ (Cal. Ct. App. 1957) (burden on off-tract user to show existence of surplus); 62 Cal. Jur. 3d, Water § 410 (1981).

[8] Rank v. Krug, 142 F.Supp. 1, 111-12, 113-14 (S.D. Cal. 1956), *affirmed in part and reversed in part*, California v. Rank, 293 F.2d 340 (9th Cir. 1961), *modified upon rehearing*, 307 F.2d 96 (9th Cir. 1962), *affirmed in part*, City of Fresno v. California, 372 U.S. 627 (1963), *overruled*, California v. FERC, 495 U.S. 490 (1990).

[9] CAL. WATER CODE § 1242 (West 1971).

extract in some years and to offset that forbearance by drawing more heavily on the aquifer in other years. The problem is that the contracting landowners have no better right to the underlying groundwater than do all of the other landowners overlying that same aquifer. The rights are "correlative", that is, of equal stature and limited by the principle of mutual avoidance of harm. Thus, in years of forbearance, the other pumpers would be entitled to extract the water that the program intended to store. In years of extraction, the contracting landowner's rates of withdrawal may impair the rights of the correlative pumpers.

Recognizing in the organizer a superior right to groundwater stored when surface water is used in lieu, could involve upsetting an established set of property rights and investment-backed expectations, something courts are typically loathe to do. Fortunately the only colorable claim of overlying groundwater users to water of Type 5 would result if the importer abandoned the imported water once it was in the ground. Delivery for surface use does not constitute such abandonment.[10] The important point when imported water is used is that the mass balance in the groundwater basin will be the same whether the water is actively recharged or delivered *in lieu* of groundwater pumping. In both cases during years or storage, more water is contained within the basin than would have been stored absent the program.

Of course, the problem associated with *in lieu* recharge may be avoided where groundwater basins have been adjudicated such that the particular extraction rights have been quantified. This is the situation with a number of groundwater basins in Southern California. A potential shortcoming of adjudication, other than the time and cost associated with the process, is that the final judgements in Southern California often proscribe out of basin transfers of groundwater. This may hinder the ability to recover groundwater of Type 5.

The technique of in lieu storage can be also used outside adjudicated groundwater basins, but special arrangements will be necessary. There are several potential approaches:

- The correlative rights problem can be avoided by bringing all of the correlative rights holders into the contractual arrangement, or mitigated by bringing most of them into it. The ability of any one rights holder to upset the program by withholding consent remains, however. This is were incorporation of storage entities as part of AB 3030 management plans could prove particularly beneficial.

- The program could be operated in a manner that would presumptively avoid injury to correlative rights holders by foregoing pumping for a period sufficient to assure that when accelerated pumping occurred, it would not disadvantage the correlative rights holders compared to the status quo. That might mean designing the program so that the number of sequential years of accelerated pumping was limited.

- Special legislation might be enacted to preclude suits against the program by non-contracting landowners where the groundwater that the program causes to be extracted in any one year was limited to amounts that could have been extracted in any previous year but for the forbearance imposed by the program. This would be a legislative interpretation of the "no harm" rule as applied in the narrow context of an in lieu groundwater banking program. While a general groundwater management regime may be beyond reasonable legislative expectations, a modest enactment of this sort may be realistic.

IV.3.2 What sort of entity should operate the program?

The organizer of the groundwater banking program will enjoy the best legal position to recover the groundwater that it has stored if it is a public agency managing groundwater of Type 5. Under these circumstances, the right to extract the stored groundwater enjoys a high priority. Such a right prevails over all rights except in the following circumstances:

(1) It is inferior to the state-held public trust interest of the people of California, as are all usufructory rights;

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[10] City of Los Angeles v. City of Glendale, 142 P.2d 289, ___, 23 Cal.2d at 76-78 (Cal. 1943).

(2) It is of equal priority with pueblo rights, but, since pueblo rights apply only to native water, disputes between the two result in apportionment to the importer of the quantity of groundwater attributable to imports;[11]

(3) It is of equal priority with other public and private importers in the watershed of destination and use, but disputes between these parties are also resolved by apportioning to each importer "the amounts attributable to the import deliveries of each."[12]

An importer's right to recapture imported recharge water is established by manifesting such intent prior to importation.[13] A groundwater banking program is predicated upon such an intent.

The advantage of the program organizer being a public entity is that that status precludes the potential for adverse rights attaching to the program's stored groundwater through prescription. While CAL. CIVIL CODE § 1007 (West 1982) literally protects "any public entity" from prescription, the courts have been reluctant to afford the statute its broadest application[14] and may try to limit the definition of "public entity" to exclude some marginal parties. Therefore, care should be exercised in choosing or establishing the program organizer. Further research is needed regarding the outer bounds of the "public entity" definition. For instance, it would be useful to know whether a groundwater banking program organizer that was the creature of a memorandum of understanding between the state and federal government might qualify.

IV.3.3 Where should the program store the imported water?

In the most general sense, in order to simplify the legal situation, the target groundwater storage basin should be composed of percolating strata and be isolated from surface waters, such as streams or the underflow of streams. This would minimize the interplay of various legal doctrines, avoid factual disputes, and make the legal outcomes more predictable. As a result, the participants in the program will feel more secure about their rights and about the investments required to implement active recharge.

Under the groundwater banking arrangements explored here, however, water might be introduced into a groundwater basin at one location and extracted at another some distance away. This raises the question of the hydrologic interconnections that must be maintained between the imported recharge water and the extracted water in order to preserve the importer's preference right. "Imported water" is "foreign water imported from a different watershed."[15] The advantage of obtaining the rights of an importer is that California law gives high priority to these rights in order "to credit the importer with the fruits of his expenditures and endeavors in bringing into the basin water that would not otherwise be there."[16] Under this rationale, it would appear that the area of recharge must be hydrologically connected to the area of discharge such that the program is pumping groundwater that "would not otherwise be there" but for the recharge. In other words, the two areas much be sufficiently proximate and interconnected so that the recharge water would be expected to replenish the area of discharge within the timeframe of the two events.[17]

Establishing proximity and interconnectedness is very important. Many California cases determining groundwater rights turn on geohydrologic characteristics of the groundwater aquifers. In

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[11] City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 288 (Cal. 1975).
[12] City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 260-62 (Cal. 1975).
[13] City of Los Angeles v. City of Glendale, 142 P.2d 289, ___, 23 Cal.2d at 78 (Cal. 1943); City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 257-58 (Cal.1975).
[14] *See* City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 272, 274, 276 (Cal. 1975).
[15] City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 261 n.55 (Cal. 1975).
[16] City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 261 (Cal. 1975).
[17] One of the cases holds that it is possible to establish a right to imported water by making deliveries and withdrawals within one's own reservoir and alleging in a complaint that one intended to capture return flow from waters imported into the basin. City of Los Angeles v. City of Glendale, 142 P.2d 289, ___, 23 Cal.2d at 78 (Cal. 1943); City of Los Angeles v. City of San Fernando, 537 P.2d 1250, ____, 14 Cal.3d at 257-58 (Cal.1975). The issue, then, is whether the conjunctive use program would be viewed as delivering and withdrawing water from within the same underground reservoir.

addition to locating a storage site that is factually simple, it would be useful to locate one that is scientifically well-studied; ideally, one where the pertinent scientific facts have been determined in prior judgements. Such prior judicial fact finding may not be binding on parties to any future suit but would at least serve as an advance indicator of what the program might expect from future litigation.

IV.3.4 From what source(s) should the program obtain surface water for storage?

One consideration in selecting a source of program water is the fixed capital requirements of the program. If the program requires appreciable new physical infrastructure, as will likely be the case for a maximal program of groundwater banking, the costs of those capital investments will presumably have to amortized by the project itself over a period of time. In that circumstance, the program will require a reliable source of water over that same time horizon. If, by contrast, the program requires only limited capital investment, the program water can be intermittent or less reliable. Therefore, an early question to be resolved is whether the program can be based on an interruptible source of water, or does it require a durable source? The hydrologic distinction between capturing peak floods (intermittent) and re-operating reservoirs (reliable) will certainly bear on the appropriate response to this question.

IV.3.5 What parties should be involved?

The program organizer should seek contractual arrangements with parties owning land overlying groundwater since they may possess both spreading grounds and a right to extract groundwater. Their participation and cooperation may be secured by sharing the benefits of the program with them, either in terms of new water or monetary compensation. The presumption in this case is that the sharing of benefits made available to the overlying landowners will be sufficient to surpass the water management opportunities afforded by strictly local opportunities.

V. Workplan Step 3: Site Analysis

The hydrologic potential analysis described in Section III relied upon making assumptions about the ability to convey surface water and to store it in a suitable groundwater banking site. The assumed conveyance and groundwater storage capacities input for the simulated foothill reservoirs in CUP are presented in Table 13. By virtue of is large flows and significant existing surface water storage capacity, the Sacramento-Shasta system was accorded the largest portion of the assumed 2 MAF storage capacity. The relatively small Caleveras-New Hogan system lies at the other end of the conveyance/storage spectrum.

Table 13: Partition of System Capacity Among the Nine Simulated Rivers in CUP

River	Conveyance Capacity (cfs)	Provisional Storage (TAF)
Sacramento	648	370
Feather	518	296
Yuba	387	222
American	387	222
Mokelumne	260	148
Calaveras	130	74
Stanislaus	387	222
Tuolumne	387	222
Merced	387	222

At first glance, the values in this table may seem to indicate that conveyance infrastructure and potential storage sites are located in close physical association with each surface water system. Any such impression is an artifact of the way CUP operates as it simulates each river as an independent system. Given the highly engineered character of the Central Valley water system, it is more likely that surface waters from various rivers diverted as part of the groundwater banking program will co-mingle during the aquifer storage process. This section deals with identifying the sites which can provide the required aquifer storage resource.

Much work in this area has already been carried out by the CalFed Bay-Delta Program. as part of its Storage and Conveyance Component, the ongoing water planning forum produced and inventory of 17 potential groundwater storage sites. These were described in a matrix which included a number of attributes, including: the active storage capacity; the extent to which groundwater banking will alter groundwater elevations; required infrastructure; long-term regional groundwater conditions; and environmental concerns. Details of the active storage attribute, which total over 10 MAF are shown in Table 14.

Table 14: CALFED Estimates of Active Groundwater Storage Capacity

North of Delta Storage	Potential Storage	South of Delta Storage	Potential Storage
Butte Basin	470 TAF	Folsom S. Canal (east S.J. County)	860 TAF
Cache Creek Fan (Cache-Putah)	450 TAF	Kern River Fan	930 TAF
Colusa County	320 TAF	Gavelly Ford/Madera Ranch	350 TAF
Eastern Sutter County	470 TAF	Medota Pool (Westside)	900 TAF
Sacramento County	260 TAF	Mojave River	200 TAF
Stony Creek Fan	640 TAF	Semitropic WSD	1000 TAF
Sutter County	1180 TAF	Tuolumne/Merced Basin	1250 TAF
Thomes Creek Fan	220 TAF		
Yuba County	540 TAF		
Total North of Delta	**4,550 TAF**	**Total South of Delta**	**5,490 TAF**

The spatial distribution of these sites, along with other potential storage targets located in Southern California, is depicted in Figure 8. When compared with the hydrologic potential of the rivers considered in CUP (Table 11), the first observation one makes is that while most of the yield associated with reservoir re-operation will be generated in the Sacramento Valley, much of the potential storage is located south of the Delta. This raises the issue of how best to convey water across that keystone of the California water system. It should not be assumed that the ability to realize the full potential of groundwater banking in the Central Valley is neutral with regards to the three Delta conveyance opportunities under consideration by CalFed. What is required is operational analysis of specific groundwater banking opportunities which can explore the full implications of various assumption about the existence and operation of conveyance infrastructure. This sort of operational analysis which is presented in the Section VI.

By virtue of their inclusion in the CalFed inventory, the storage sites listed in Table 14 likely comprise a likely constellation of potential groundwater banking sites. NHI has neither the resources nor the desire to redevelop the CalFed list. From our vantage point, however, there are issues other than the active storage capacity which go to the relative merits of a particular groundwater banking site. In fact, prior to the release of the CalFed inventory NHI had already completed a first assessment of promising groundwater banking sites. Based on consultation with experts,[18] and on a literature review,[19] we chose several criteria for selecting candidate sites for new or enhanced artificial or *in lieu* recharge of ground water:

1. Aquifer storage capacity available for groundwater banking
2. Opportunities to solve collateral problems
3. Impact on habitat and species of fish and wildlife
4. Infiltration characteristics of soils and water courses
5. Hydraulic properties of aquifers
6. Extent of well development and yields of wells
7. The magnitude of surface water/groundwater interaction
8. Water quality effects of recharge
9. Land use effects of recharge

Figure 8: Spatial Distribution of Potential Groundwater Storage Sites in California

This listing has been selected to cover the broad range of conditions occurring in California with respect to groundwater banking. Appendix III contains the results of a survey conducted by NHI which sought out examples of where the convergence of these criteria have already generated interest or activity in groundwater banking. It is important to keep in mind that each site listed in the inventory could

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[18] Bertoldi, Gilbert, 1993, Senior Scientist, U.S. Geological Survey, Sacramento, California; Durbin, Tim, 1993, Professional Engineer, vice-president, Hydrologic Consultants, Inc., Davis, California; Fielden, John R., Hydrologist, 1993, California Dept. of Water Resources, Sacramento, California; Wilson, Laurence, April, 1993, Ground Water Protection Supervisor, Santa Clara Valley Water District, San Jose, California.

[19] Asano, Takashi, and others, 1985, Artificial Recharge of Groundwater, Butterworth Publishers, Boston.

potentially become more productive with an infusion of new yield derived from reservoir re-operation. The nature and importance of these criteria are explored in greater detail in the following comments.

The volume of water which can be stored in the subsurface is dependent on the **aquifer storage capacity**. At an given moment, however, most of the water in storage will be the result of basin scale hydrologic processes. An intentional program of groundwater banking seeks to capitalize on the increment of storage capacity which could be integrated with the yield estimated in Section III. The challenge is defining the increment of storage capacity available to the groundwater banking program.

In areas of severe groundwater depletion that increment of storage clearly exists in the form of a persistent cone of depression. The presence of a cone of depression on the water table surface, a fairly common phenomenon in the Central Valley south of the Mokelumne River drainage, indicates that local pumping historically exceeded the natural recharge to the aquifer. If the cone is stable, then a water balance has likely been re-established via enhanced seepage from overlying rivers and streams in response to the increased hydraulic gradients associated with the drawdown feature. Defining the increment of groundwater storage in this case involves a fairly straight forward computation of filling the basin with known quantities of water and discounting the reduction in the induced seepage from overlying rivers and streams. This increment of enhanced stream flow would be a direct environmental benefit of the program. In addition, the net rise in the water table during periods of aquifer storage would have direct and quantifiable local benefit relative to the persistent cone of depression currently plaguing local groundwater users. The primary disadvantage of utilizing this increment of storage are the pumping costs associated with recovery from a deep cone of depression and the need to carry out a period of storage before any recovery can be achieved.

A second increment of storage available for groundwater banking should be viewed in more speculative terms. In locations where there has been no sustained, long-term imbalance between basin scale hydrologic process, as is commonly the case in the Sacramento Valley, the water table is generally more stable and closer to the surface than in zones of persistent dewatering. In order to create the increment of storage required for groundwater banking, recovery, either through increased local reliance on groundwater pumping or though the export of groundwater, must precede storage. This is somewhat akin to the situation in the drought water bank of the early 1990's when Sacramento Valley farmers sent groundwater to water strapped communities in Southern California in exchange for monetary compensation. Achieving this increment of storage essentially involves treating the aquifer as a direct extension of the reservoir. As in a reservoir where the lake surface fluctuates from month to month, the end result of this integration would be a water table which fluctuates within a prescribed management range. While a case can be made that the optimal overall system yield will emerge from this integration it is more difficult to demonstrate the local benefit of this type of storage and recovery.

For that reason we initially focused our attention in this feasibility study on zones where groundwater overdraft has already created a cone of depression. This focus should not be understood as completely discounting the potential role of the more integrated form of groundwater banking. In fact, given the imbalance in hydrologic potential towards the Sacramento Valley (Table 11) and the potential complexity of conveying water across the Delta, it may ultimately be necessary to explore the full range of Sacramento Valley alternatives. The premise of the program, however, should remain the same whether storage takes place in persistently de-watered or stable hydrologic regimes. Namely the use of any available aquifer storage resource must provide sufficient local benefit to inspire substantial local enthusiasm.

The best way to motivate local enthusiasm for groundwater banking is to demonstrate that implementation of the program might help **solve collateral water problems**. Our starting premise for this assertion is that even in relatively stable hydrogeologic provinces, water managers face challenges which call for action. These challenges often involve water quality consideration, the desire to resolve emerging conflicts between municipal and agricultural water use sectors, or the need to redress the degradation of aquatic habitat. In all such cases, controlling the rate and place of ground water recharge and pumping may create opportunities to accomplish local water management goals which would go unrealized save for the introduction of new yield into the system. Examples of the types of collateral problems which could be resolved in this manner include land subsidence and ground water quality degradation in Yolo County and increasing pumping lifts in eastern San Joaquin County.

Attention must also be paid to the **impacts, both positive and negative, which groundwater banking can have on fish and wildlife**. Appendix IV includes our assessment of some potentially negative impacts of groundwater banking which must be resolved. Commonly, groundwater recharge sites are viewed as wetlands conducive to enhanced wildlife management opportunities. Wildlife experts[20] remind us that to be beneficial to wildlife, water must be provided to an environment, in the right amount, at the right time, in suitable quality; and, the supply must be reliable. It would seem that specific benefits to wildlife could be built-in to many recharge projects, to create and maintain wetlands, where needed, or to increase the base flow of small streams through raising ground water levels. Another, perhaps more far reaching, environmental benefit of groundwater banking goes beyond the local impact of a flooded recharge basin. This benefit goes to the aquatic eco-system restoration opportunities which would have otherwise been missed without the added water management flexibility associated with the potential yield increase from groundwater banking. An examples of this type of benefit include the potential to enhance Delta outflow by storing groundwater in San Joaquin County and to restore the anadramous fishery in the San Joaquin River by banking groundwater near the Gravelly Ford reach of the river.

Aquifer recharge, the first of two central operations in a groundwater bank, occurs primarily by spreading water on land and in stream beds, or, or by filling percolation ponds. In all cases, **the infiltration characteristics of soils and sediments** determine the rate at which surface water becomes ground water. Clayey soils and sediments tend to inhibit infiltration. Generally, suitable soils must overlie permeable sediments in order to provide the physical environment essential to recharge the water table. Soil surveys developed by the U.S. Natural Resources Conservation Service provide information adequate to evaluate the recharge potential of soils, but, information on underlying sediments usually does not extend beyond the description of parent material.[21] Work conducted by the USGS in the Tulare Lake Basin, for example, identified large areas in which shallow clays underlying surface soils[22], precluding the development of any effective program for recharging ground water reservoirs, even though surface soils accept water readily. Other USGS studies in eastern San Joaquin County and along the Gravelly Ford reach of the San Joaquin River reveled conditions conducive to groundwater banking. When aquifer recharge is accomplished via *in lieu* substitution the pre-existence of extensive groundwater pumping is required. By substituting surface water for this pumping, ground water storage can be increased. In order to estimate the potential for *in lieu* groundwater recharge, information must be developed on the amount of pumping which is likely to occur during years of normal or above normal precipitation. An inventory of agricultural pumping in Yolo County is an example of information required in this case[23].

The rate at which aquifers can be discharged by pumping wells, the second of the two central operations of a groundwater bank, is dependent on **the hydraulic properties of the aquifers**, the spatial extent of these aquifers, and on the hydraulic head created by pumping.[24] Although specific investigations are required to quantify these properties, a history of groundwater use in target areas is a good indication that under natural hydrologic conditions these conditions favor aquifer storage and recovery. In selecting a site, the presence of groundwater wells should be the minimum threshold for consideration. **The extent of well development and the long term yield** of large volumes of ground water to wells suggests a favorable physical environment for recovery.

The magnitude of surface water/groundwater interaction at any given site may influence groundwater banking opportunities. In the San Joaquin Valley, where past overdrafts have dropped

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[20] Moore, S.B., and others, September 1990, "Fish and Wildlife Resources and Agricultural Drainage in the San Joaquin Valley, California: Technical Report of the San Joaquin Valley Drainage Program, Sacramento, California.

[21] Bullard, Gary, 1993, Senior Soil Scientist, U.S. Natural Resources Conservation Service, Davis, California, personal communication.

[22] San Joaquin Valley Drainage Program, September, 1990, "A Management Plan For Agricultural and Subsurface Drainage and Related Problems on the Westside San Joaquin Valley": Sacramento, California.

[23] Borcalli, Fran, 1992, "Yolo County Water Plan Update,"Report to Yolo County Board of Supervisors, Woodland, California; Jenkins, Mimi, Sept., 1992, "Yolo County, California's Water Supply System: Conjunctive Use Without Management," MS. Thesis, Dept. of Civil Engineering, University of California, Davis, California.

[24] Freeze, R.A. and Cherry, J.A., 1979, Groundwater, Prentice-Hill, Englewood Cliffs, NJ.

groundwater levels far below ground level, the degree to which adding groundwater storage may impact streamflow levels is relatively small. However, in many locations within the Sacramento Valley, groundwater storage may lead to increases in surface flows. Conversely, groundwater withdrawals could lead to reductions in surface flows. These kinds of interactions reduce the benefits of groundwater banking and increase the complexity of storage accounting. What is required is a thorough understanding of basin hydrogeology. Within California, there is a wide range in the certainty of knowledge of the hydraulic properties of specific aquifers.[25] Some water user organizations, such as the Turlock and Modesto Irrigation Districts, are well-armed with information to plan and operate an artificial recharge program, as part of a conjunctive use strategy. Others, like the Butte Basin Water Users Association, are in the process of developing the quantitative models and monitoring devices useful for participation in such programs. This information is lacking in regions such as Tehama County.[26] Wherever groundwater banking ultimately occurs, detailed hydrogeologic analysis will be required.

A review of the history of irrigation and ground water recharge in California,[27] shows the importance of considering **the water quality effects of recharge**--whether that recharge is coincidental or planned. Positive or negative effects can be produced in soil water or in underlying ground water reservoirs through the introduction of surface water of a certain quality. For example, some of the soils of the eastside San Joaquin Valley (Fresno area) are too sodic to be recharged effectively with Sierra water, without the addition of gypsum to the soils.[28] Looking for a "win-win" situation, the San Joaquin Valley Drainage Program, [29] analyzed the feasibility of exporting gypsiferous drainage water to irrigate these lands and recharge ground water. The concept was feasible, technically, but could not overcome political objections.

Most information on **land use effects of ground water recharge** is anecdotal, obtained from discussions with various water experts. In San Bernadino County, artificial recharge was halted in one locale, when rising ground water levels caused clays to swell and threaten the structural integrity of piers in a highway overpass.[30] In highly urbanized Santa Clara County there have been chronic complaints, and lawsuits, from residents adjacent to percolation ponds.[31] Nearby residents have alleged the creation of mosquito problems, marshy soils, and dangerous nuisances from open water bodies. Because of these and associated cost factors, ground water recharge in urban areas is most effectively conducted in natural or modified stream courses.

In light of resource limitations, NHI did not conduct detailed analysis of each of these attributes at all of the twenty potential sites in Figure 8. Our reconnaissance of the landscape, however, lead us to three locations where a convergence of groundwater banking attributes seems to exist. While by no means claiming that these are the sites which must ultimately store yield generated through pre-delivery[32], these are striking examples of the ability of groundwater banking to help meet: 1.) water management objectives; 2.) eco-system restoration objectives; and 3.) a combination of both these objectives.

Cache-Putah Basin. Cache and Putah Creeks are significant westside tributaries of the Sacramento River. Historically, flows in these creeks recharged groundwater below Yolo County through instream hydraulic connection with the aquifers which provide much of the county's municipal and agricultural water supply. Recently the intensity of local reliance on groundwater has combined with the out-of-basin export of water from Putah Creek and the mining out of the instream gravel in Cache Creek to create nagging problems

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[25] Durbin, Tim, 1993, Professional Engineer, vice-president, Hydrologic Consultants, Inc., Davis, California, personal communication.
[26] Durbin, Tim, 1993, Professional Engineer, vice-president, Hydrologic Consultants, Inc., Davis, California, personal communication.
[27] Prokopovich, Nikola P., April, 1989, "Irrigation History of the West-Central San Joaquin Valley" : U.S. Bureau of Reclamation Contract Report No. 7-PG-20-03920, Sacramento, California.
[28] Sposito, Garrison, and others, 1987, "Chemical Effects of Saline Drainage Waters on Irrigated San Joaquin Valley Soils": Calif. Water Resources Center, Univ. of Calif. Contribution No. 196.
[29] Hansen, B.R., and others, June, 1990, "An Assessment of Blending Westside Drainage Water with Friant-Kern Canal Water for Increasing Infiltration Rates": U.S. Bureau of Reclamation Contract Report No. 9-FC-20-08070.
[30] Fletcher, G. Louis, December, 1992, General Manager and Chief Engineer, San Bernadino Valley Municipal Water District, San Bernadino, California, personal communication.
[31] Wilson, Laurence, April, 1993, Ground Water Protection Supervisor, Santa Clara Valley Water District, San Jose, California.
[32] Tocay Dudley of the DWR Central District has been directing studies of groundwater storage opportunities in Yuba, East Placer, Yolo, and Sacramento counties. These may supplement the preliminary list outlined here.

with groundwater overdraft, land subsidence, and deteriorating ground water quality.[33] Despite the high cost and political uncertainty, these challenges have prompted both agricultural and municipal water providers to initiate planning to secure a Sacramento River water right. Such a claim would certainly be facilitated by increasing the available yield through reservoir re-operation. This could be accomplished by developing new off-stream percolation ponds or negotiating *in lieu* arrangements with local farmers which would be supplied through an extension of the Tehama-Colusa Canal. In exchange for this introduction of water, the Yolo water users could continue to allow the Yolo County ground water reservoir to be used as part of the drought water bank which performed well during the heart of the 1987-92 drought. To garner local support for such a scenario, however, this approach needs to be compared with purely local opportunities to meet water management objectives.

<u>Gavelly Ford/Madera Ranch</u>. As mentioned in Section II, operation of the Friant Unit on the San Joaquin River has lead to the virtual de-watering of the river below Friant Dam. Other then during occasional flood flows which spill from Millerton Lake, nearly all of the water in the San Joaquin in diverted to provide water for irrigation. Obviously this severe alteration of the hydrograph in the San Joaquin River has had a dramatic impact on fish. In particular, runs of anadramous fish were decimated. Enter the Anadramous Fish Recovery Act spawned by the CVPIA and its call for a doubling of the number of anadramous fish in the Central Valley, and restoration of the San Joaquin emerges as a promising management alternative. The challenge is to achieve this eco-system objective in a manner which minimizes negative impacts on existing water users. Groundwater banking opportunities in an expansive cone of depression below the Gravelly Ford reach of the San Joaquin and the adjacent Madera Ranch site could assist in removing political opposition to an environmental goal.

<u>East San Joaquin County</u>. Two associated ground water basins in this area are overdrafted and the northernmost basin, which is used directly for water supply by the city of Stockton, is experiencing intrusion of brackish water from the Sacramento-San Joaquin Delta. There is an overall shortage of both ground water and surface water, particularly surface water for environmental releases to the Stanislaus River Basin. Plans to extend the Folsom South Canal in order to use imported Ameircan River surface water for aquifer recharge have been discussed for many years although a consulting firm hire by local water districts[34] found that the structural modifications needed to facilitate large-scale groundwater banking would be formidable. Nevertheless, the strategic location of the ground water basins with respect to the Delta, make this a viable candidate area because water stored in this location would be well placed to help improve the export and environmental water management objectives in the Delta which may be compounded by certain Delta conveyance options under consideration by CalFed.

It is our hope that detailed operational analysis of the Cache-Putah, east San Joaquin, and Gravelly Ford/Madera Ranch groundwater banking sites, which is found in Section VII, will motivate additional support to bring the remaining sites under similar scrutiny.

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[33] Jenkins. Mimi, September 1992, "Yolo County, California's Water Supply System: Conjunctive Use Without Management," M.S. Thesis, Department of Civil Engineering, University of California, Davis.

[34] California Department of Water Resources, 1990, "Stanislaus and Calaveras Conjunctive Use Program," unpublished paper by Don Fisher, Senior Engineer, Sacramento, California.

VI. Workplan Step 4: Operational Analysis

In order to analyze both how any specific groundwater banking interventions might function and how they might interact with other features of the Central Valley water system, a simulation model is required. One of the key elements of an intentional program of groundwater banking will certainly be specific distribution and conveyance arrangements of both a structural and an institutional nature. An exploration of the ramifications of these arrangements is needed. In California, the type of exploration envisioned for this operational analysis has traditionally relied on the use of DWRSim, a simulation model of the State Water Project which has evolved into the standard reference for modeling the Central Valley water system.

In the current planning context, where the California water community is being encourage to pursue "fresh thinking rather than entrenched ideologies"[35] DWRSim is somewhat constrained by its attention to the details and nuances of the current system. It is not easy to reprogram DWRSim to model radical departures from the current system such as reservoir re-operation and the integration of the groundwater banking site in Table 14 into the Central Valley water system. To accomplish this exploratory analysis NHI initiated a collaborative program with several California water partners to identify an appropriate screening level river basin simulation model. The goal of the effort was to develop a tool which could help identify water management arrangements which show promise and which merit further attention. The premise behind this search was that identifying a sub-set of promising arrangements could provide a sharper focus for subsequent refinement of the more cumbersome DWRSim model.

To develop this screening tool NHI joined with the CalFed Bay-Delta Program, the US Bureau of Reclamation, the US Fish and Wildlife Service, and the Metropolitan Water District of Southern California to form the Joint Technical Unit (JTU). This grouped selected and guided the enhancement of the Water Evaluation and Planning system, or WEAP, developed by Tellus Institute. WEAP is a flexible water balance modeling tool conducive to the initial evaluation of management options at a system level. Unlike most river basin models, it effectively integrates supply, operation and demand. It is also highly flexible in that it can be easily reconfigured to screen emerging management options and to flesh-out those which appear promising.

In order to make WEAP more appropriate for the Central Valley, the JTU funded two phases of model enhancement. Phase I included the development of a conjunctive use node to simulate the intentional transfer of water from the surface water system to a target groundwater banking site. The magnitude of the simulated transfer is the minimum of the excess surface supply during a given month, the available storage capacity in the aquifer, and the transmission capacity available to effectuate the transfer. A second Phase I modification involved the development of an active diversion feature. This feature mimics the operation of a single canal which services multiple points of demand; a common feature in the water management landscape of California. A second phase of modifications funded by the JTU fell into three categories: graphical output enhancements, water year type controls, and refinement of the conjunctive use node. The enhanced version of WEAP was delivered to the JTU in April, 1998.

Since receiving the enhance software, NHI has carried out operational analysis on the three specific groundwater banking opportunities identified as the end of Section V: 1.) the Cache-Putah Basin; 2.) the Gravelly Ford/Madera Ranch reach of the San Joaquin; and 3.) east San Joaquin County. Respectively, these were selected as particularly strong examples of how groundwater banking can help meet: 1.) local and regional water management objectives; 2.) eco-system restoration objectives; and 3.) a combination of both these objectives. It must be reiterated that NHI chose these examples only to demonstrate the far-reaching benefit which can be realized through the implementation of a maximal scale program of groundwater banking. The analysis presented in this section should not be interpreted as an endorsement of these particulate sites over the other contained in Table 14. In fact, NHI hopes that the following demonstration of WEAP's ability to screen potential groundwater banking sites will motivate the additional resources required to complete operational analysis on all potential storage sites.

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[35] Deep Water Thinking, Sacramento Bee Editorial, November 18, 1998.

VI.1 Meeting Water Management Objectives: The Cache-Putah Basin

Located in the southwestern Sacramento Valley between Cache and Putah Creeks, the Cache-Putah Basin (Figure 9) serves as an important source of water for both the agricultural and urban communities of Yolo County. Under current operating arrangements, surface water from Cache Creek, regulated by dams at the outlet of Clear Lake and on Indian Valley Reservoir and diverted at Capay, provides irrigation water for farms west of Davis and Woodland. The water in Putah Creek has been developed for use in Solano County and much of the flow is exported from the basin towards the south at a point east of Winters. In the extreme north of Yolo County, surface water is also available from the Tehama-Colusa Canal, and the Colusa Drain which convey Sacramento River water from points of diversion located in the Sacramento Valley to the north of the county. In the eastern portion of the Yolo County, water is taken directly from the Sacramento River for both irrigation and the municipal supply for the City of West Sacramento.

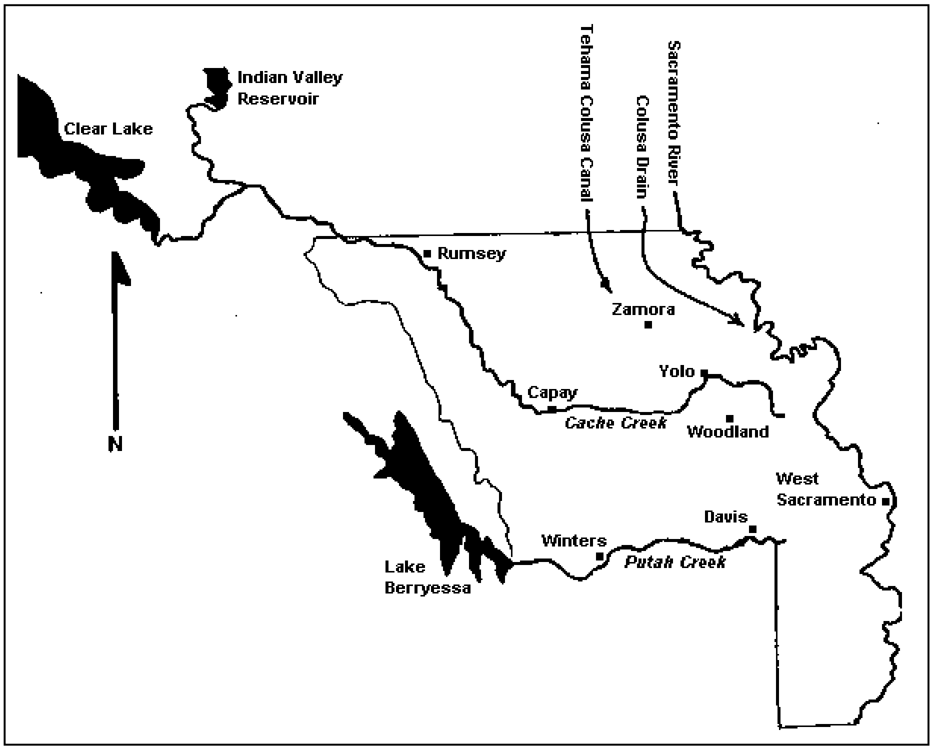


Figure 9: The Cache-Putah Basin

In spite of the availability of surface water from Cache Creek and the Sacramento River, there remain regions of Yolo County which rely exclusively on groundwater for supply. Overlying a map of the areas in which surface water is available with a map of the primary groundwater sub-basin of the Cache-Putah aquifer (Figure 10) reveals that a substantial portion of the land overlying the Lower Cache-Putah Sub-Basin has no access to surface water. This region includes Yolo County's principle cities, Davis and Woodland, as well as some of the most productive agricultural land in the Central Valley.

The result of this heavy reliance on pumped groundwater has been the development of a cone of depression in the water table of the Lower Cache-Putah Sub-Basin. The dimensions of this feature following the wet winter of 1993 are shown in Figure 11. Water table elevation data suggest that depending on hydrologic conditions this cone of depression will vary in size and depth, although it remains persistent. This feature is a remnant of the much more extensive depression which plagued the county prior to the construction of Indian Valley Reservoir on the North Fork of Cache Creek in the 1975. The enhancement of surface supplies afforded by the reservoir has allowed for a reduction in groundwater pumping, improving the water balance in the county. Nonetheless, the nagging persistence of this overdraft feature continues to create concern over land subsidence, the initiation of groundwater flow patterns which threaten water quality, and increasing pumping costs.

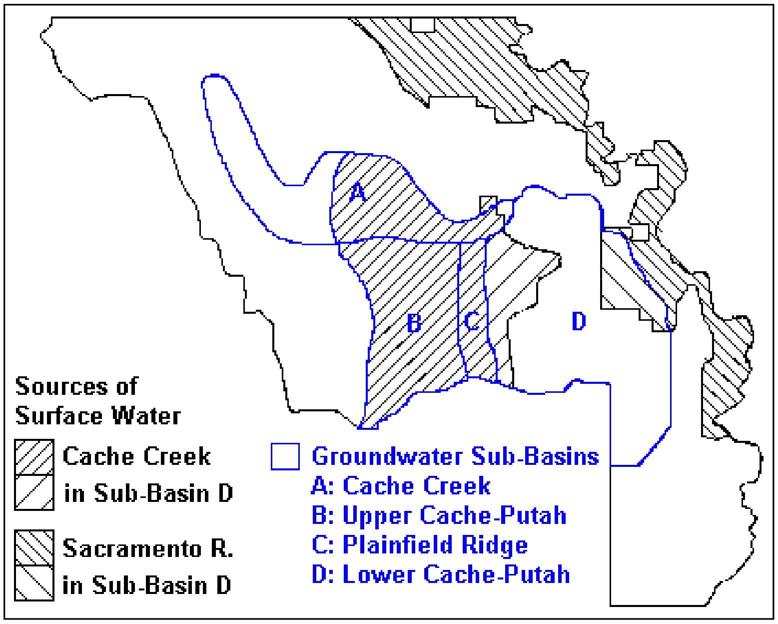


Figure 10: Composite Map of Groundwater Basins and Surface Water Service Areas

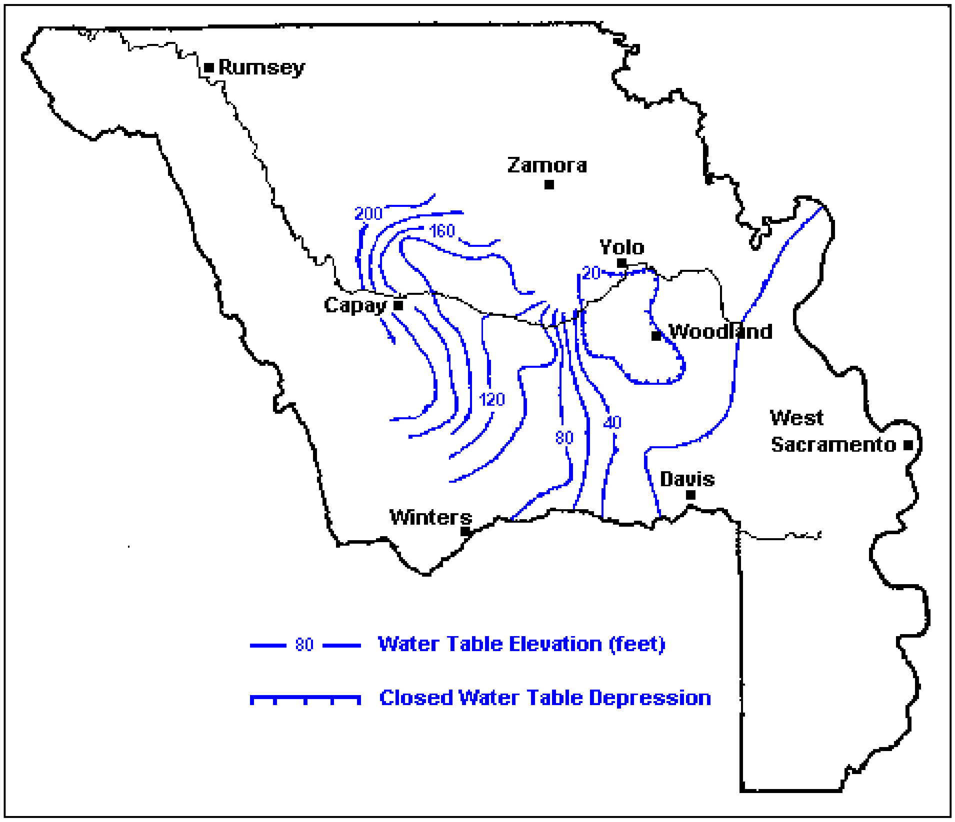
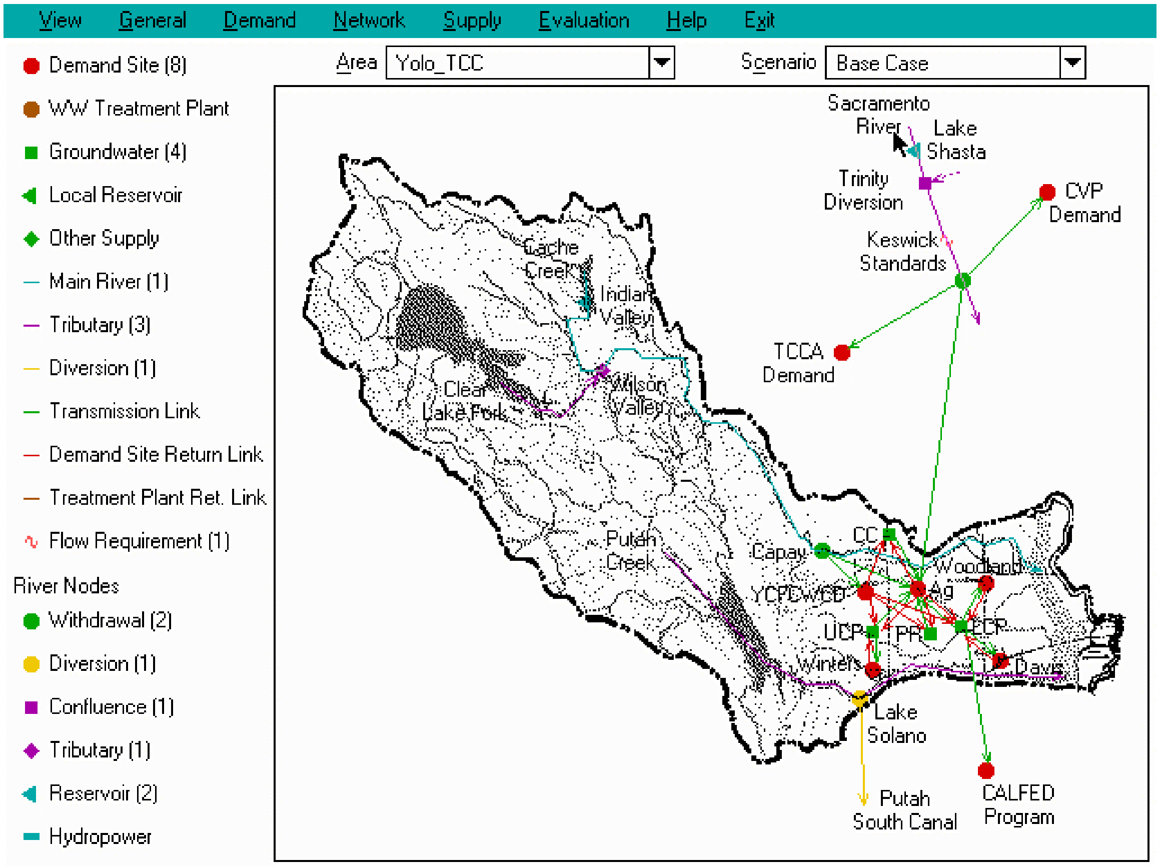


Figure 11: 1993 Cone of Depression in the Lower Cache-Putah Sub-Basin

In response to these threats, local water managers have proposed many alternatives. One is expand the area receiving surface water from Cache Creek as part of a local *in lieu* substitution program.

An alternative to this purely local response might be integration of the aquifer storage resource in the Lower Cache-Putah Sub-Basin into the broader Central Valley water system. Such integration could potentially assist in capturing some of the yield which could be generated through re-operation of Shasta Dam. It could be accomplished by implementing the long discussed extension of the Tehama-Colusa Canal into central Yolo County. With the connection in place, imported surface water could be used to implement *in lieu* transfers with farms overlying the dewatered portion of the Lower Cache-Putah Sub-Basin. Operational analysis using WEAP was conducted to explore the relative advantages and dis-advantages of these two water management strategies.

This was accomplished by configuring WEAP to represent the major features of the hydrologic system. Within the Cache-Putah Basin the essential features include the major sources of water supply, the principle points of demand, and existing and proposed hydraulic infrastructure. These are depicted in the WEAP Network Configuration shown in Figure 12. The data used to define these nodes was gathered primarily from the pages of the detailed inventory of Yolo County water developed by Jenkins (1992)



Area: Yolo_TCC

Scenario: Base Case

Figure 12: WEAP Cache-Putah Basin Network Configuration

The network configuration in Figure 12 includes all of the elements required to simulate three scenarios: the current base case; *in lieu* groundwater banking using surface water from Cache Creek; and *in lieu* groundwater banking using surface water from the Sacramento River. In the base case the transmission links joining the Capay and T-C Canal withdraw nodes with the Ag demand node in Yolo County are inactive. For the Cache Creek *in lieu* scenario the Capay link is activated and Indian Valley Reservoir is re-operated to pre-deliver water to the Ag node when surface water is available. In this scenario, the operation of Clear Lake Dam does not change as the YCFCWCD annually takes as much water as it can from that resource. By activating the transmission link between the T-C Canal and the Yolo County Ag demand node, Central Valley scale integration can be simulated. In this case Lake Shasta is re-operated to transfer available surface water to Yolo County for *in lieu* substitution. Broad water supply benefit can be achieved by activating the transmission link between the Lower Cache-Putah Sub-Basin and the CALFED Program demand node which calls for supplemental supplies during dry and critical water years.

Realization of either scenario will require the support of Yolo County water managers, stakeholders and politicians. From this perspective there are two essential question in evaluating the relative merits of the various approaches. Does a the water management intervention reduce the threats posed by the existence of a persistent aquifer draw down feature? How do existing stakeholders fare under the modified arrangements? Responds to both questions relies upon the establishment of a base reference.

Figure 13 is a simulated forecast of storage in the Lower Cache-Putah Sub-Basin under existing management arrangements and projected demand, assuming that the hydrologic record from 1972-1992 recurs between 1990 and 2010. The implication is that absent management intervention there will be a continued depletion of the groundwater resource in Yolo County. This change would likely strength the water quality and land subsidence threats faced by the county.

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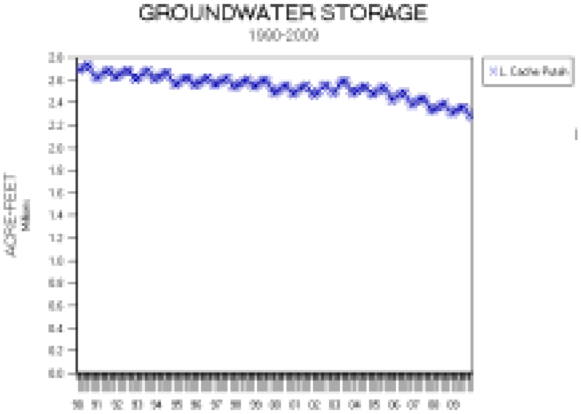


Figure 13: Simulated Groundwater Storage in the Lower Cache-Putah Sub-Basin Under Existing Arrangements

Recognizing this likely trend, local water managers have proposed the Cache Creek *in lieu* substitution scenario as a potentially beneficial strategy. In terms of the first essential question, by reducing groundwater pumping at the Ag demand node through the delivery of surface water the simulated decline in aquifer storage substantially reduced (Figure 14). In this case, rather than demonstrating a steadily decreasing trend, aquifer storage appears to fluctuate within an acceptable management range. The decline in storage at the end of the simulation corresponds to the recurrence of the 1987-1992 drought.

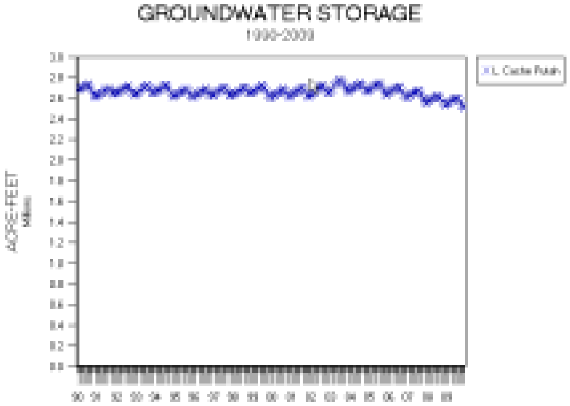


Figure 14: Simulated Groundwater Storage in the Lower Cache-Putah Sub-Basin Under Local *In Lieu* Arrangements

Increasing the area which receives water from Cache Creek, however, will presumably place a heavier burden on the surface water infrastructure on Clear Lake and Indian Valley Reservoir. In terms of the second essential question, this could make it more difficult to supply water to existing YCFCWCD customers. Figure 15 compares the difference in supply requirement coverage, or the extent to which demand is satisfied, under the proposed local *in lieu* substitution program as compared with the current arrangements. Relative to the base case, the heavier draw on the local surface water system would apparently cause the existing YCFCWCD customers to experience a decline in service relative to the level they would have received absent the program. Building a case for local *in lieu* substitution could be hampered by the decline in service experienced by an important group of stakeholders.

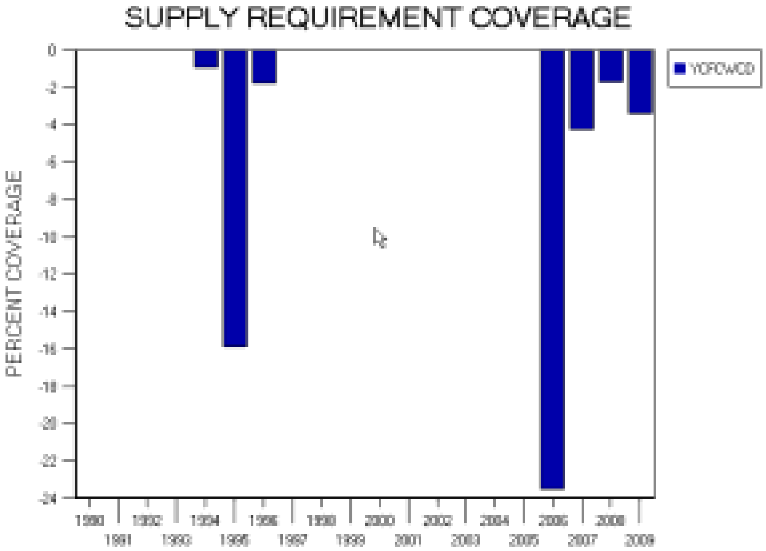


Figure 15: The Difference Between the Percent of the Supply Requirement (Demand) Coverage in the Base Case and the Local *In Lieu* Program Using Surface Water from Cache Creek

Carrying out *in lieu* arrangements with agricultural interests overlying the Lower Cache-Putah Sub-Basin using surface water made available through re-operation of Shasta Dam also mitigates the steady decline in aquifer storage predicted under the base case (Figure 16). The wider fluctuations in storage experienced under this arrangement relative to the local approach are the result of the more aggressive storage and recovery program carried out under integration into the Central Valley water system.

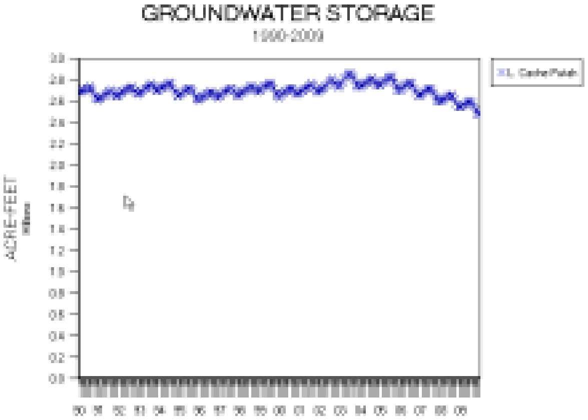


Figure 16: Simulated Groundwater Storage in the Lower Cache-Putah Sub-Basin Under Central Valley *In Lieu* Arrangements

Under this integration, no re-operation of the Cache Creek surface water system occurs and therefore existing YCFCWCD customers would experience no decline in service relative to the base case. Under this scenario, however, statewide water stakeholders would anticipate gaining some water supply advantage. In the simulation this is achieved by activating a 100 cfs transmission link between the Lower Cache Putah aquifer and the CALFED Program demand node. This node calls for 20 TAF of water during dry water years and 100 TAF during critical years. Under these arrangements the pattern of water supply enhancement which could be generated is shown in Figure 17.

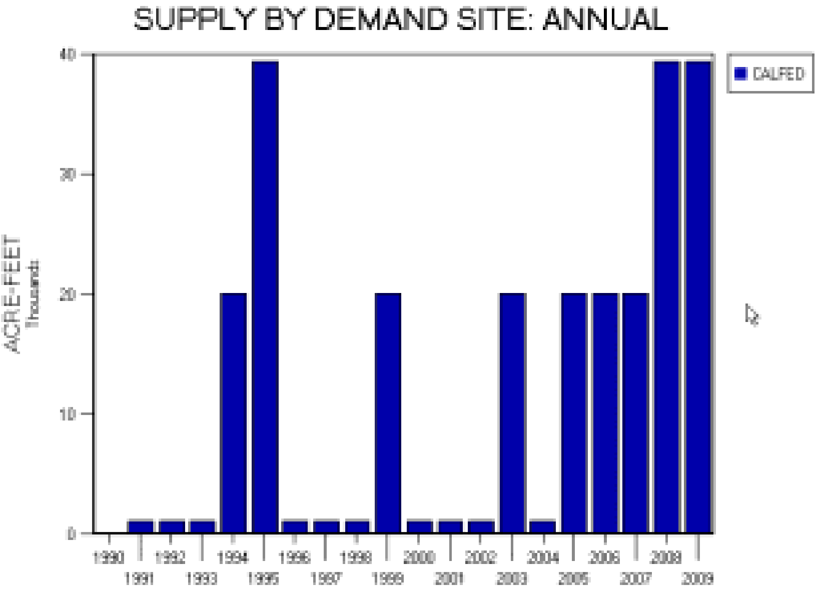


Figure 17: Simulated Water Supplies Enhancement for the CALFED Program Under a Central Valley *In Lieu* Substitution Program in the Lower Cache-Putah Sub-Basin

Increasing the capacity of the transmission link between the aquifer storage and the CALFED demand node could enable more complete coverage of the dry year demand, although potentially at the expense of stabilizing groundwater storage in the Lower Cache Putah Sub-Basin. As it is, there is a net transfer of water from the CVP storage system into the Yolo County groundwater system. Achieving a more balanced distribution could be achieved by fine tuning the capacities of important transmission links. The important implication of these simulations, however, is that without some sort of intervention groundwater levels in Yolo County will likely continue to decline and that the opportunity to negotiate storage and recovery arrangements with the managers of the Central Valley water system could provide water supply benefits both locally and a broader scale.

VI.2 Meeting Environmental Objectives: Gravelly-Ford/ Madera Ranch

In addition to facilitating the achievement of water supply objectives, groundwater banking can also assist in achieving important eco-system restoration objectives. One particularly exciting opportunity would be the restoration of the anadramous fishery in the San Joaquin River below Friant Dam. This fishery was completely decimated when the U.S. Bureau of Reclamation impounded the San Joaquin River and diverted it for use outside the basin. The hydrologic impact of this manipulation is depicted in Figure 18 which presents measured flows at the USGS *San Joaquin R Bl Friant Ca* gauge. Once the Friant Unit of the Central Valley Project went on-line, base flows in the San Joaquin were drastically reduced, with only peak event spills from Millerton Lake passing downstream. This flow regime proved incapable of supporting spawning and rearing salmon and steelhead. Reversing the loss of this fishery could provide substantial momentum towards meeting the AFRP anadramous fish doubling narrative standard. NHI believes this could be achieved by integrating the substantial groundwater banking opportunity at the Gravelly Ford/Madera Ranch into the surface water system in the San Joaquin Valley.

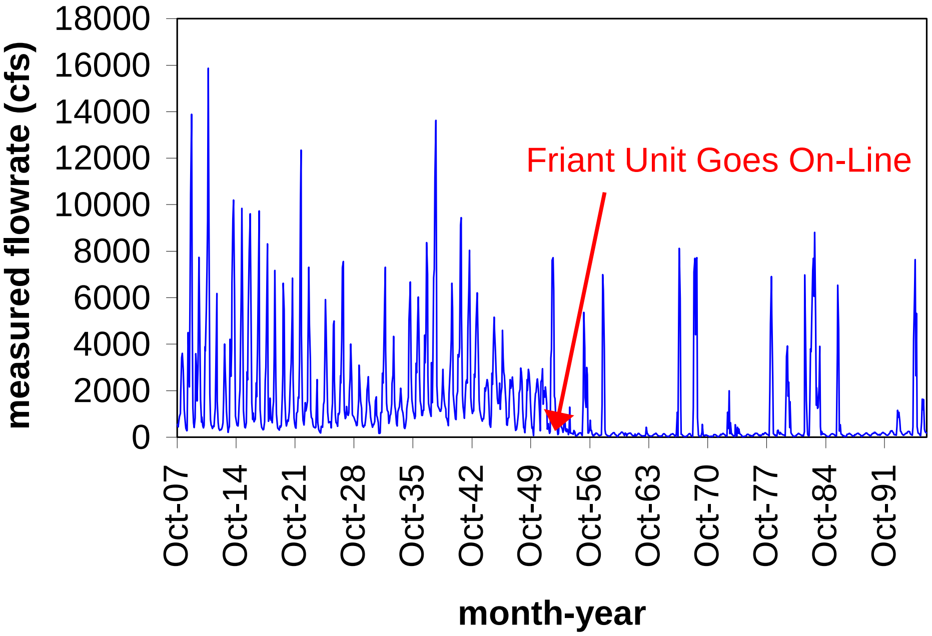


Figure 18: Measured Flows at the USGS *San Joaquin R Bl Friant Ca* Gauge Before and After the Construction of the Friant Unit of the Central Valley Project.

This system, depicted in Figure 19, includes the Delta-Mendota Canal which was constructed at the same time as the Friant Unit to provide roughly 800 TAF of replacement Delta water to exchange contractors holding water rights on the de-watered San Joaquin River. Later, the California Aqueduct system, including the Delta pumps at Clifton Court, the regulating facility San Luis Reservoir, and various pumping plants, was constructed by the State of California to convey water to the southern San Joaquin Valley and then over the Tehachapi Mountains to Southern California. The Cross Valley Canal, financed by Kern County interests, was constructed to capitalize on the water management flexibility which could be achieved through exchanges between the Delta and San Joaquin River systems.

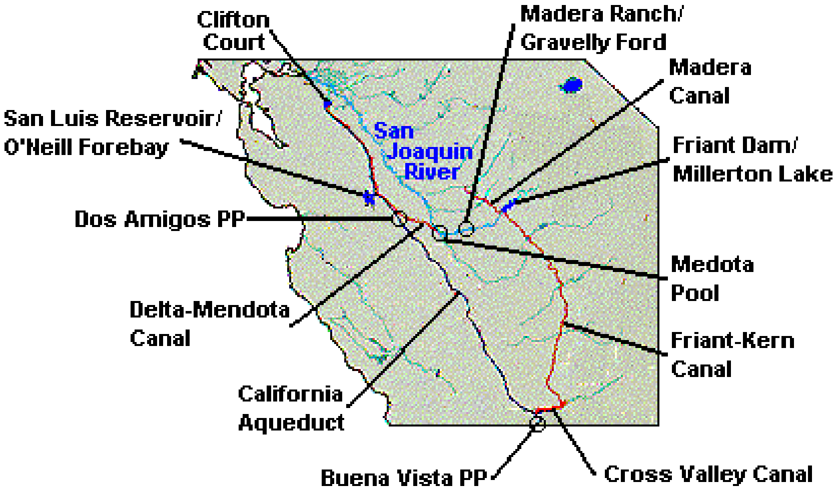


Figure 19: Important Elements of the San Joaquin Valley Water System

It is this type of flexibility which NHI would like to expand upon into order to profit from the substantial groundwater storage potential located below the de-watered Gravelly Ford reach of the San Joaquin. Figure 20 depicts the evolutions of the water table below the Central Valley over the first half of the 20th century based on simulations conducted by the USGS (Willamson et al. 1989). Where once groundwater flowed smoothly towards the valley outlet through the Carquinez Strait, by 1960 this surface was interrupted by numerous depressions related to the long-term imbalance between aquifer recharge and discharge. One of the most substantial depressions, located underneath the San Joaquin River downstream of metropolitan Fresno, developed in response to the elimination of seepage from the overlying San Joaquin River and the steady increase in groundwater pumping in this region. The decline was particularly acute given that the historically high seepage rate afforded by the coarse bed material in the Gravelly Ford reach was virtually eliminated by the closure of Friant Dam.

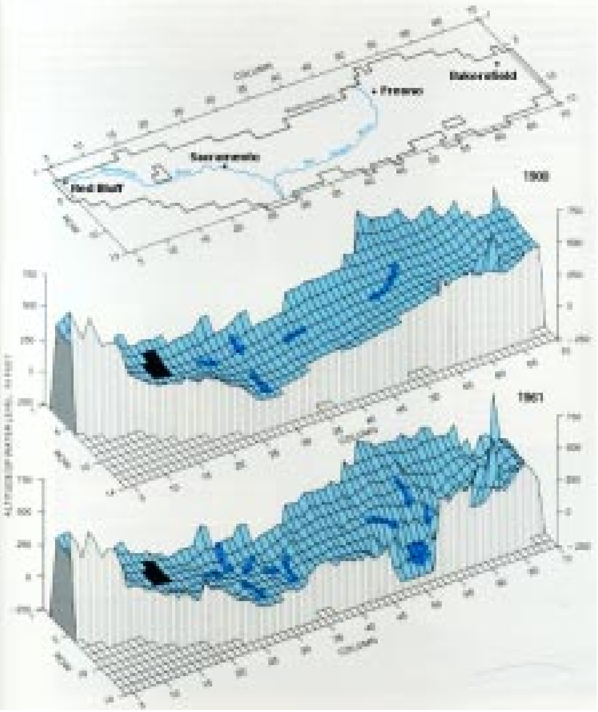


Figure 20: Water Table Evolution Below the Central Valley

There are those who discount any thought of restoring salmon to the San Joaquin precisely because of the heavy seepage losses at Gravelly Ford. They argue that the flows require to overcome these losses and to reconnect the Upper San Joaquin with the tributaries between Mendota Pool and the Delta would cripple the important agricultural economy in the southern San Joaquin Valley which rely the Friant Unit for irrigation water. Viewing the drawdown feature below Gravelly Ford as a groundwater banking site instead of as a hydrologic sink, however, provides the flexibility to restore the San Jaoquin with a minimum of disruption to the agricultural economy. This would be accomplish by re-routing water as depicted in Figure 21.

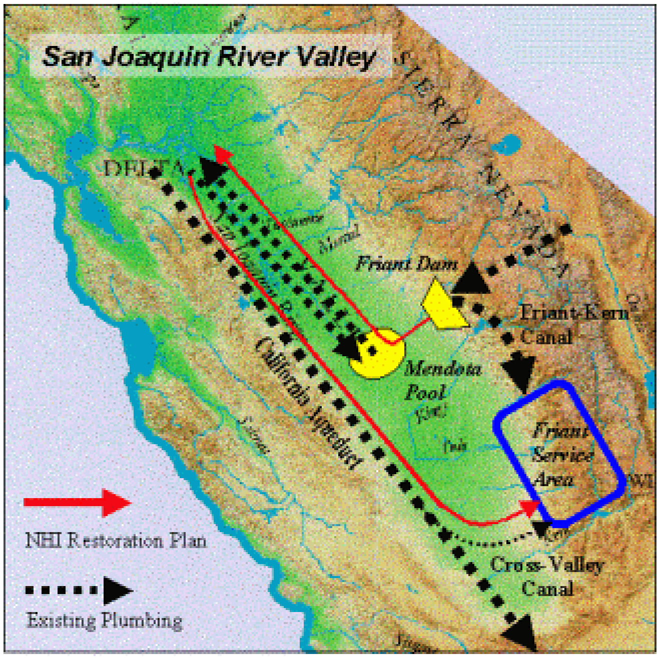


Figure 21: Proposed Arrangement for Restoring a Flow Regime in the San Joaquin River Suitable for Anadramous Fish

The basic premise of the arrangement involves wheeling Delta water currently delivered to the exchange contractors through the Delta-Mendota Canal to the southern Friant Unit via the California Aqueduct and an appropriate cross valley link. Relieving some of the demand for San Joaquin water would allow the exchange contractors to compensate for lost Delta water with releases from Millerton Reservoir. During passage over the Gravelly Ford reach, a portion of these releases would seep through the river bed and become stored in the groundwater banking site. This storage could be reclaimed by the exchange contractors should the surface water system fail to meet their demand.

In order to avoid disrupting the use of the California Aqueduct facilities by its current beneficiaries, an analysis was conducted to determine what excess capacity was available in the system between 1975 and 1996. Using monthly reports of operation for the State Water Project, the minimum capacity available to move historical deliveries from the Delta-Mendota Canal to the California Aqueduct through the O'Neill Pumping Plant and to convey these transfers through the Dos Amigos Pumping Plant was calculated. Figure 22 depicts the time series of the wheeling through the California Aqueduct which could have been accomplished using available capacity alone. This is a conservative trace as future restrictions on Delta exports may limit pumping into the California Aqueduct at Clifton Court while the exchange contractors, by virtue of their superior export right, will likely continue to have access to their 800 TAF annual allotment of Delta water delivered though the Delta-Mendota Canal.

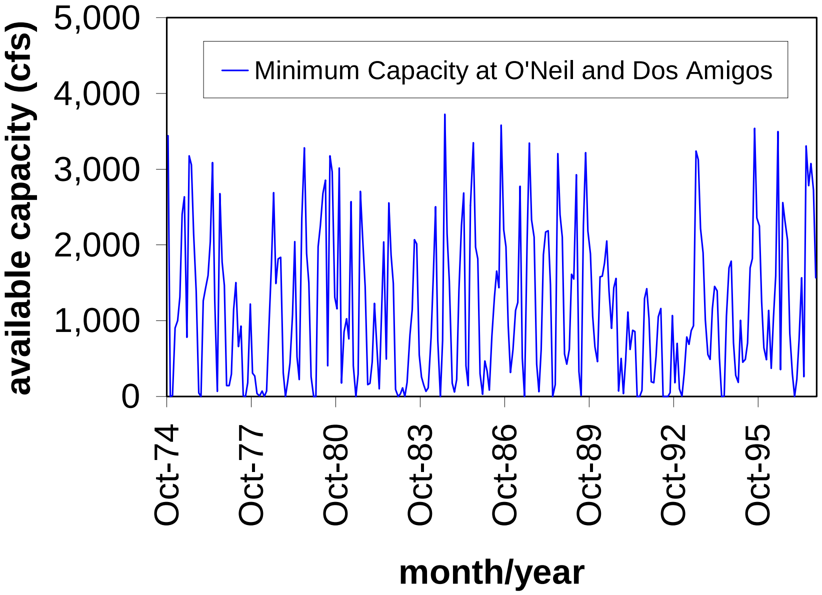


Figure 22: Historical Available Wheeling Capacity in the California Aqueduct System to a Point Below the Dos Amigos Pumping Plant.

Transfer of this Delta water into the Friant Unit could be accomplished through a variety of means. These could included the expansion of the Cross Valley Canal, the construction of some form of a Mid-Valley Canal, or institutional arrangements which would offer the wheeled water to agricultural interest in the Tulare Basin in exchange for the right to divert some of their Kings River water to the southern Friant Unit. In the context of this feasibility study, how the wheeling would be completed is of less interest then the opportunity which it would create to profit from the groundwater banking opportunity at Gravelly Ford.

The WEAP network configuration for this opportunity is presented in Figure 23. Three scenarios are simulated in this analysis. In a base case, which mimics the current arrangements, the exchange contractors receive water from the Act. DMC supply node while all other transmission links to the node are inactive. Transmission links emanating from the Wheel DMC supply node are also inactive under this scenario, as are those associated with Mendota Pool node and the Gravelly Ford groundwater banking site. In essences the exchange contractors receive their water from the Delta while the irrigation districts serviced by the Friant Unit receive water from Millerton Lake on the San Joaquin. Under a salmon recovery scenario a set of instream flows are imposed below the Mendota Pool. These standards, which were developed based on analysis by Cain (1997), are in keeping with the screening scope of this analysis.

As the analysis of this groundwater banking opportunity evolves these standards will be submitted to prominent fish biologists for review. Anticipating that the imposition of these standards will adversely impact the important agricultural interests in the Friant Unit, a final scenario integrates the Gravelly Ford groundwater banking site into the surface water system. Under these arrangements those transmission links which were inactive during the base case become active, the exchange contractors receive a smaller supply of Delta water though the Adj. Wheel DMC tributary, with the wheeled water being sent into the southern Friant Unit trough the Wheel DMC node. Groundwater is stored in the groundwater banking site both by simulated seepage in the river reach between Gravelly Ford and Mendota Pool and through intentional transfers of water from Millerton Lake to the Gravelly Ford groundwater node through the Gravelly Ford withdraw node.

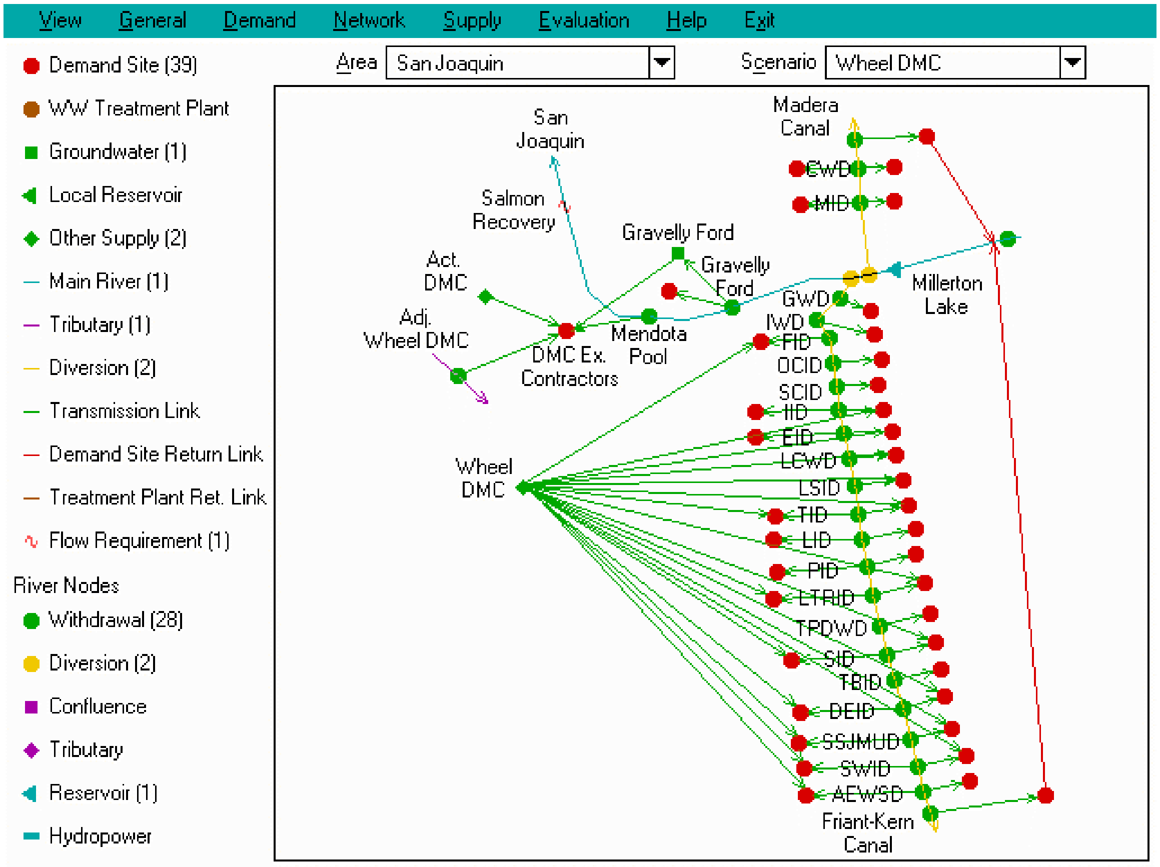

Area: San Joaquin
Scenario: Wheel DMC

Figure 23: WEAP Gravelly Ford/Madera Ranch Network Configuration

In these simulations, an active salmon recovery standard is met prior to any San Joaquin River water being diverted for consumptive use. The implication of this logic is that the desired eco-system objectives will be achieved under both the salmon recovery and wheeling scenarios. What is most relevant to this analysis is the degree to which groundwater banking can mitigate any impact which existing water users would experience by virtue of losing access to the San Joaquin River water released downstream to meet the standard. Figure 24 depicts the supply requirement coverage for the Class 1 contracts of two representative water districts in the Friant Unit, the Ivanhoe Irrigation District on the Friant-Kern Canal and the Chowchilla Water District on the Madera Canal. The negative economic impacts of imposing standards would apparently be most severe during drought periods. In 1977 for example, the degree to which demand was satisfied under the base case would have been reduced by nearly 14 % because of the reduction in Millerton storage associated with downstream releases. In this simulation however, the Delta-Mendota Canal exchange contractors would have experienced no decline in their level of service as deliveries from the Delta do not change. Under wheeling arrangements on the other hand, Friant Unit districts experience less severe reductions in service relative to the base case, even with the imposition of the salmon recovery instream standard. The exchange contractors also fare well under these arrangements. In the simulation, the critically dry 1977 was difficult for both the exchange contractors, which suffered reduced Delta deliveries without being able to tap into a fully recharged groundwater bank, and the Chowchilla WD which did not have access to the wheeled DMC supply. With access to this Delta water, the Ivanhoe Irrigation District actually benefited from improved service.

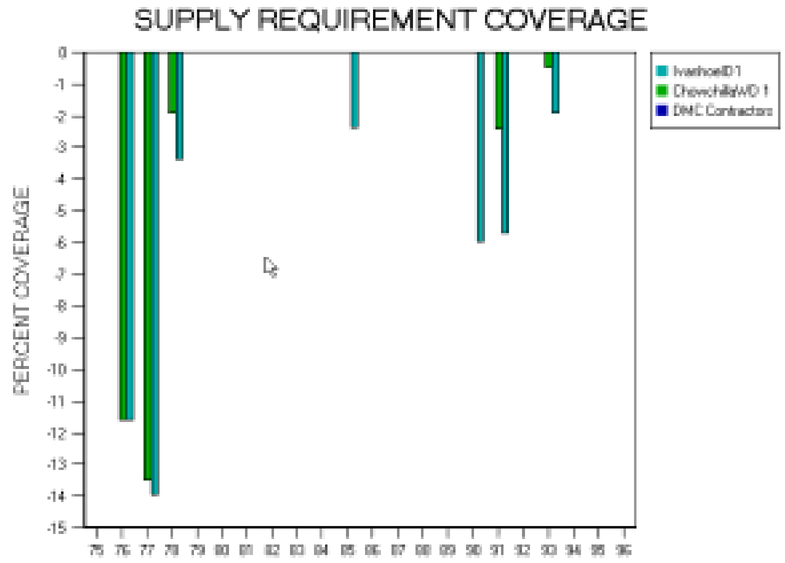


Figure 24: Change in Supply Requirement Coverage Between the Base Case and the Salmon Recovery Scenarios

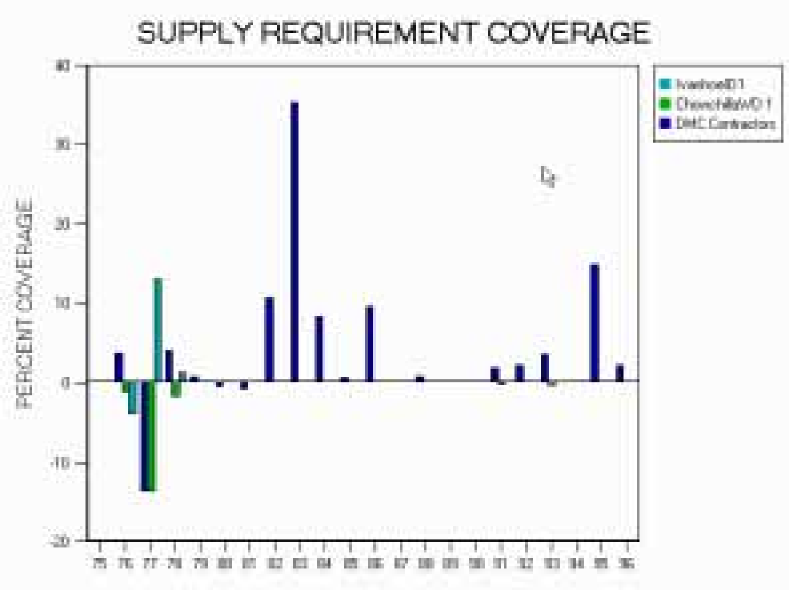


Figure 25: Change in Supply Requirement Coverage Between the Base Case and the Wheeling Scenarios

Figure 25 is a compelling example of how groundwater banking can transform potentially contentious environmental goals such as the restoration of the San Joaquin River into achievable objectives. Although water quality considerations, which could potentially prove problematic, have not been explicitly considered in this analysis, from a purely water supply perspective it appears that the salmon restoration releases can be made without overly taxing existing interests. This can occur because of the extra storage available in Gravelly Ford Groundwater Bank allows for greater flexibility in flood control operations at Millerton Lake which reduce the magnitude of the peak spill events in the San Joaquin River (Figure 26).

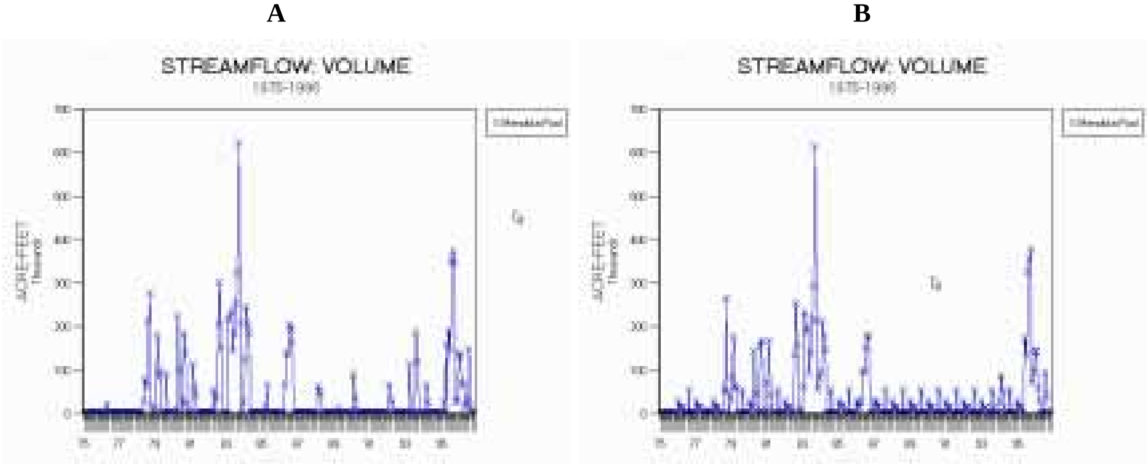


Figure 26: Simulated Streamflow Volumes in the San Joaquin River Below Mendota Pool Under the Base Case and Wheel DMC Sceanrios

The groundwater banking opportunity in Yolo County was framed as an approach for increasing both local and regional water management opportunities, while the Gravelly Ford opportunity was explored for its environmental restoration potential. By virtue of its strategic location relative to the Delta, the next suite of operational analysis highlights the real opportunity which maximal scale groundwater banking creates to achieve the full range of water supply and environmental benefits.

VI.3 Achieving Broad Benefits: East San Joaquin County

A WEAP network configuration which integrates the east San Joaquin County aquifer into the Central Valley water system is shown in Figure 27. A full a description of each of the features in the network is contained in Table 17.

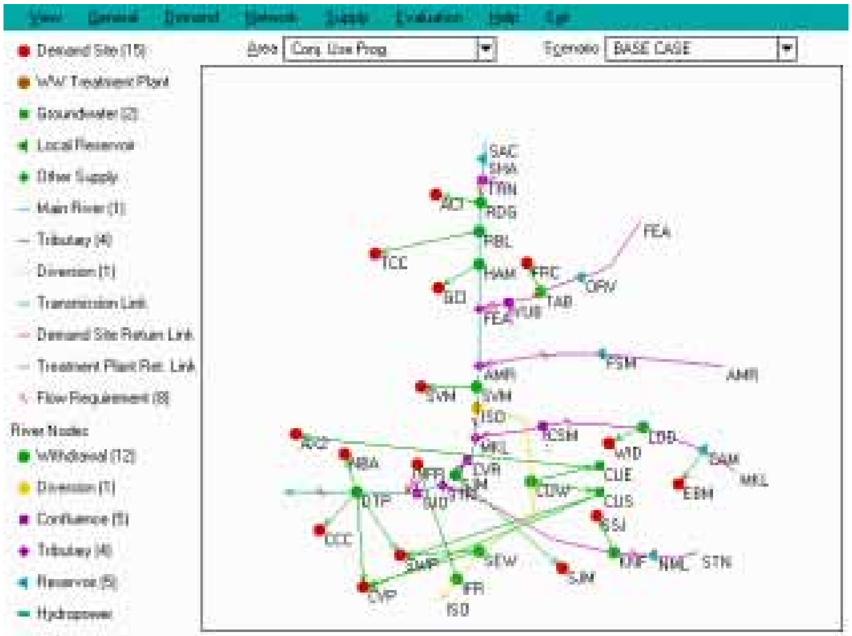

Area: Conj. Use Prog
Scenario: BASE CASE

Figure 27: WEAP East San Joaquin County Network Configuration

Table 15: List of Features Included in the Case Study Network Configuration

(refers to Figure 27)

Feature Type	Name	Abbreviation
Main Stem	Sacramento River	SAC
Tributary	Feather River	FEA
	American River	AMR
	Mokelumne River	MKL
	Stanislaus River	STN
Reservoir	Lake Shasta	SHA
	Lake Oroville	ORV
	Folsom Lake	FSM
	Camanche/Pardee Reservoir System	CAM
	New Melones Reservoir	NML
Confluence	Trinity Diversions	TRN
	Yuba River	YUB
	Cosumnes River	CSM
	Calaveras River	CLV
	San Joaquin River	SJO
Active Diversion	Cross-Delta Isolated Faciity	ISO
Withdraw Node	Redding	RDG
	Red Bluff	RBL
	Hamilton City	HAM
	Thermalito Afterbay	TAB
	Sacramento Valley Municipal	SVM
	Lodi	LOD
	Knights Ferry	KNF
	Conjunctive Use	CUW
	Southern Export	SEW
	X2 from Isolated Facility	X2I
	Isolated Facility Return	IFR
	San Joaquin Valley Municipal	SJM
	Delta Pumps	DTM
	X2 from River	X2R
Conjunctive Use Node	Environmental Aquifer Storage	CUE
	Water Supply Aquifer Storage	CUS
Actual Demand Node[1]	Anderson-Cottonwood Irrigation District	ACI
	Tehama-Colusa Canal Authority	TCC
	Glenn-Colusa Irrigation District	GCI
	Feather River Canals	FRC
	Sacramento Valley Municipal	SVM
	East Bay MUD	EBM
	Woodbridge Irrigation District	WID
	South San Joaquin Irrigation District	SSJ
	San Joaquin Valley Municipal	SJM
	North Bay Aqueduct	NBA
	Contra Costa Canal	CCC
	Central Valley Project	CVP
	State Water Project	SWP
Fictitious Demand Node[2]	Isolated Facility Return Flow	IFR
	Additional X2 Water	AX2

Notes

1. An actual demand node refers to one meant to represent an actual off-stream demand site for which data on water consumption has been collected and evaluated
2. A fictitious demand site refers to a feature which has been added to “trick” the program into carrying out a water transfer not explicitly included in the allocation algorithm.

This configuration represents a large-scale view of the northern portion of the Central Valley which encapsulates two management scenarios: a base case and an enhanced Delta conveyance/ groundwater banking alternative. When the 8500 cfs ISO active diversion feature and the groundwater banking nodes are active, unallocated surface water in the Sacramento Valley is pre-delivered to a severely overdrafted groundwater banking site in eastern San Joaquin County. This water can be used to raise the level of the groundwater system during times of abundant water supply and to supplement local and south of Delta demand or enhance Delta outflow during times of shortage. When no unallocated water is available or when the groundwater banking site is full, the active diversion feature can be used to meet south of Delta demand. By shutting off the active diversion labeled ISO, all of the features which branch from the enhanced conveyance system, including the groundwater banking site and the links to the southern export demand sites are deactivated, leaving the system in roughly its current form.

The hydraulic infrastructure currently in place in California developed progressively over the course of the 20th century. By the 1970s, however, the current hydraulic infrastructure in California was largely built out. Therefore the actual flow measurements made at various points around the State during this period already reflect the modifying influence of the fully developed water system. By limiting the simulated time horizon to the period between 1970 and 1992, historical hydrologic data can be used to drive the simulation. The proposed simulated time horizon contains some of the wettest years in the historical record, the 1974 water year for example, and the strongest, 1976-1997, and longest, 1987-1992, recorded droughts in the region. The placement of the protracted drought at the end of the simulated time horizon allows for direct comparison between the current arrangements and the proposed scenario.

The California Water Plan Update (DWR, 1994) estimated that 6.0 MAF of aquifer storage capacity exists in San Joaquin County. Rather than except this extremely optimistic assessment, whose derivation is not fully explained, our analysis adopted a very conservative view on the actual storage potential present in the field. A realistic available capacity of 600 TAF was derived following close evaluation of the drawdown feature shown in Figure 28, and was allocated equally to water supply and environmental restoration storage.

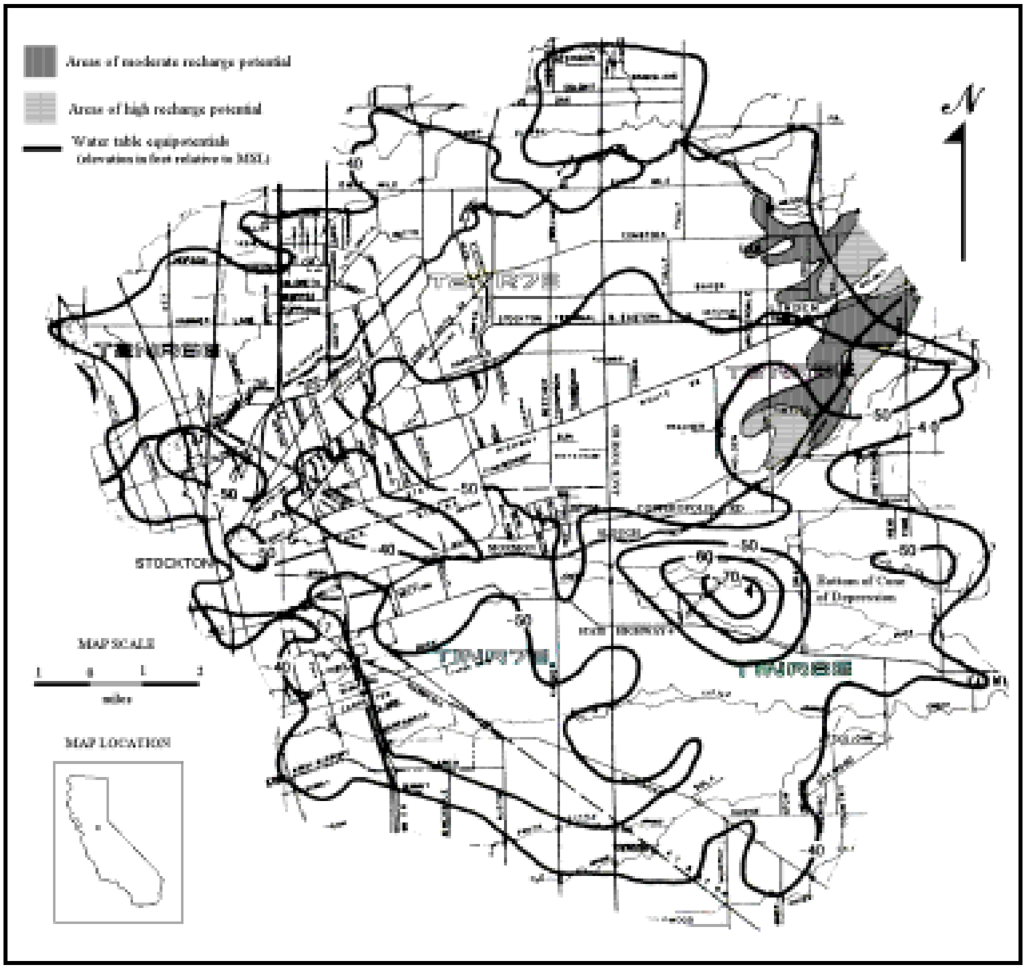


Figure 28: Spring 1995 Water Table Elevation Map East of Stockton, California

One basic result of the simulation has to do with the degree to which the enhanced Delta conveyance/ groundwater banking alternative improves the ability to deliver water to points of demand which can be supplemented by tapping storage in the groundwater bank. These include the SWP and CVP actual demand sites which access water supply storage and the Additional X2 demand which accesses environmental storage. The water supply benefit is seen clearly in Figures 29 and 30 which depict the temporal pattern of deliveries to the SWP and CVP nodes respectively. Under the proposed alternative, during 1977, surface water deliveries through the Delta pumps under the Base Case are largely replace by surface deliveries through the Isolated Facility with supplemental water being drawn from aquifer storage to help make up the simulated shortfall (Figures 29B and 30B). During 1988, the decrease in surface storage means that little or not deliveries of surface water take place under the proposed alternative, either through the Delta pumps of the Isolated Facility. In the extreme case, July 1988, the only water going to meet supply is from aquifer storage (Figures 29C and 30C). It seems likely that the generally poorer performance of the CVP relative to the SWP is related to the smaller amount of transmission capacity dedicated to the Federal project in the Isolated Facility and in the links issuing from the aquifer storage site. The results would have been different had the percent participation of the State and Federal projects been reversed. Adjusting the distribution of capacity is the type of screening exercise to which WEAP is ideally suited.

Figure 31A depicts the total Delta outflow in the Base Case and under the enhanced Delta conveyance/ groundwater banking alternative. Under the proposed alternative Delta outflow is the sum of the simulated flow at the bottom of the river system and the transfer from aquifer storage to the Additional X2 node. The curves reveal that in extremely wet years, outflow in is higher in the Base Case, presumably because some of the excess water is being transferred to aquifer storage. In the driest years, on the other hand, the proposed alternative offers a small supplement over and above the minimum standards which have been imposed. This is a logical result. It also seems reasonable that the Export:Import regime in the Delta improved under the proposed scenario (Figure 31B). In dry years water is delivered for southern export primarily through the Isolated Facility prior to entering the Delta. In this case the ratio of southern export to Delta inflows drops to nearly zero.

On balance, the results of this simulation reinforce the notion that the proposed alternative could improve the performance of the Central Valley water system. What is particularly attractive about this specific opportunity is how it could help both local and regional water managers to respond to both water supply and environmental challenges. Located as it is at the nexus of the Central Valley water system, the east San Joaquin County groundwater banking site offers flexibility which may be unparalleled in California. The staggering effects of the dewatered local aquifer also provide enormous potential for collateral local benefit in terms of reducing energy expenditures for pumping and protecting the water quality of one of the States important metropolitan centers. All of the actors, both locally and regionally, should be assembled to further investigate how this potential benefit of this site could be realized.

VI.4 Concluding Thoughts

The three preceding examples of operational analysis clearly demonstrate the array of issues which must be addressed in working out the operational details of a specific groundwater banking opportunity, and the enormous benefit which can be gained in so doing. These examples also demonstrate the utility of the WEAP model for exploring the site specific nuances of these opportunities. Developing WEAP network configurations for the other potential sites will be a major focus of future work on this project. These models will allow for an exploration, in concert with all interested actors, of the implications of site specific management decisions. NHI is convinced that this dialogue will allow the most promising sites to emerge from the pack, so to speak, so that further requisite analysis using DRWSim and other suitable tools can proceed apace.

Figure 29: Deliveries to the SWP Demand Node for the Base Case (red) and Isolated Facility/1.2 MAF Conjunctive Use Alternative (green)
A: Over the Entire Simulated Time Horizon; B: During the 1977-1978 Drought; and C: During the 1987-1992 Drought
(heavy solid line: total deliveries; light solid line: Delta pumping; short dashed line: Isolated Facility; long dashed line: aquifer storage)

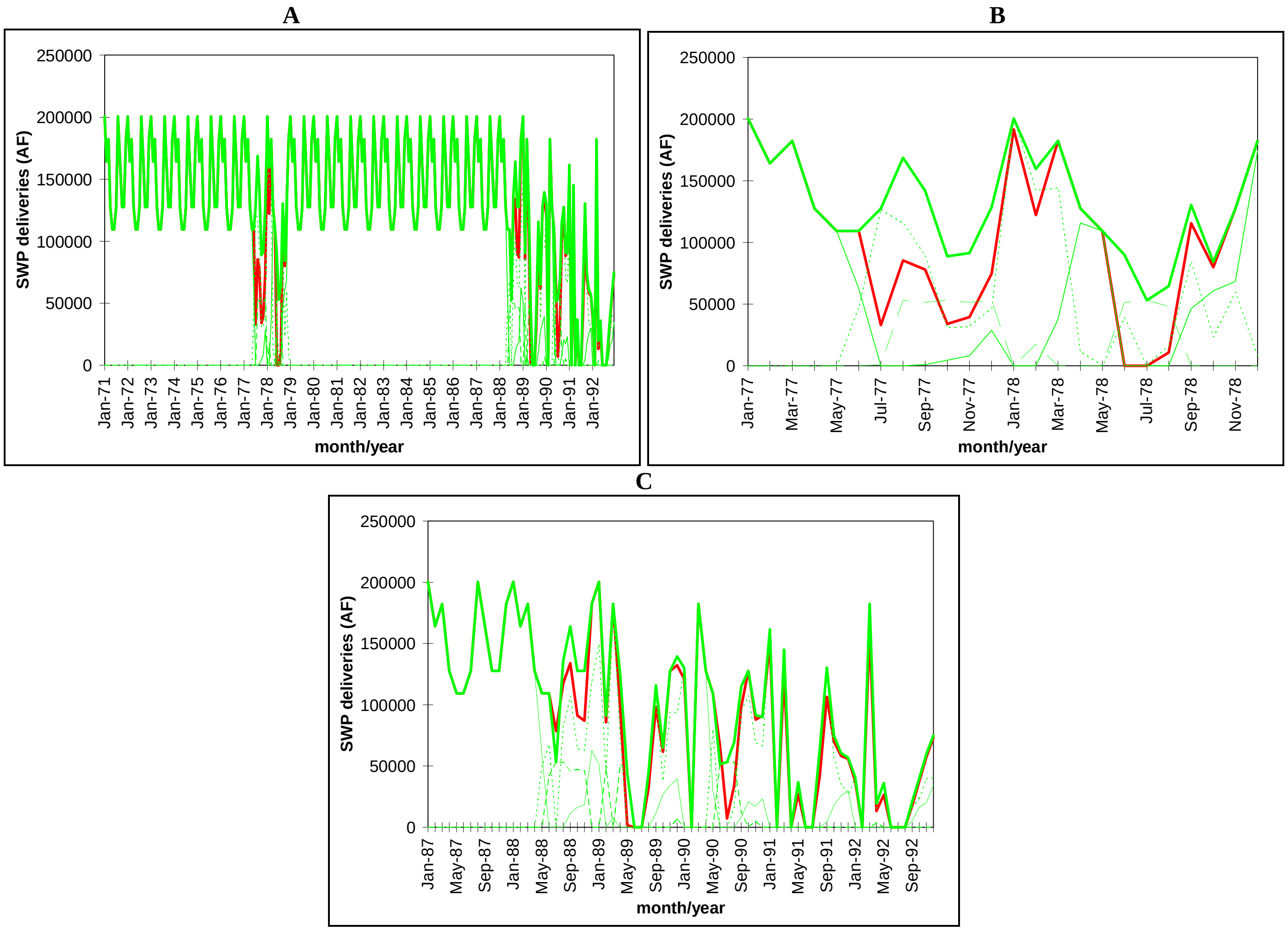


Figure 30: Deliveries to the CVP Demand Node for the Base Case (red) and Isolated Facility/1.2 MAF Conjunctive Use Alternative (green)
A: Over the Entire Simulated Time Horizon; B: During the 1977-1978 Drought; and C: During the 1987-1992 Drought
(heavy solid line: total deliveries; light solid line: Delta pumping; short dashed line: Isolated Facility; long dashed line: aquifer storage)

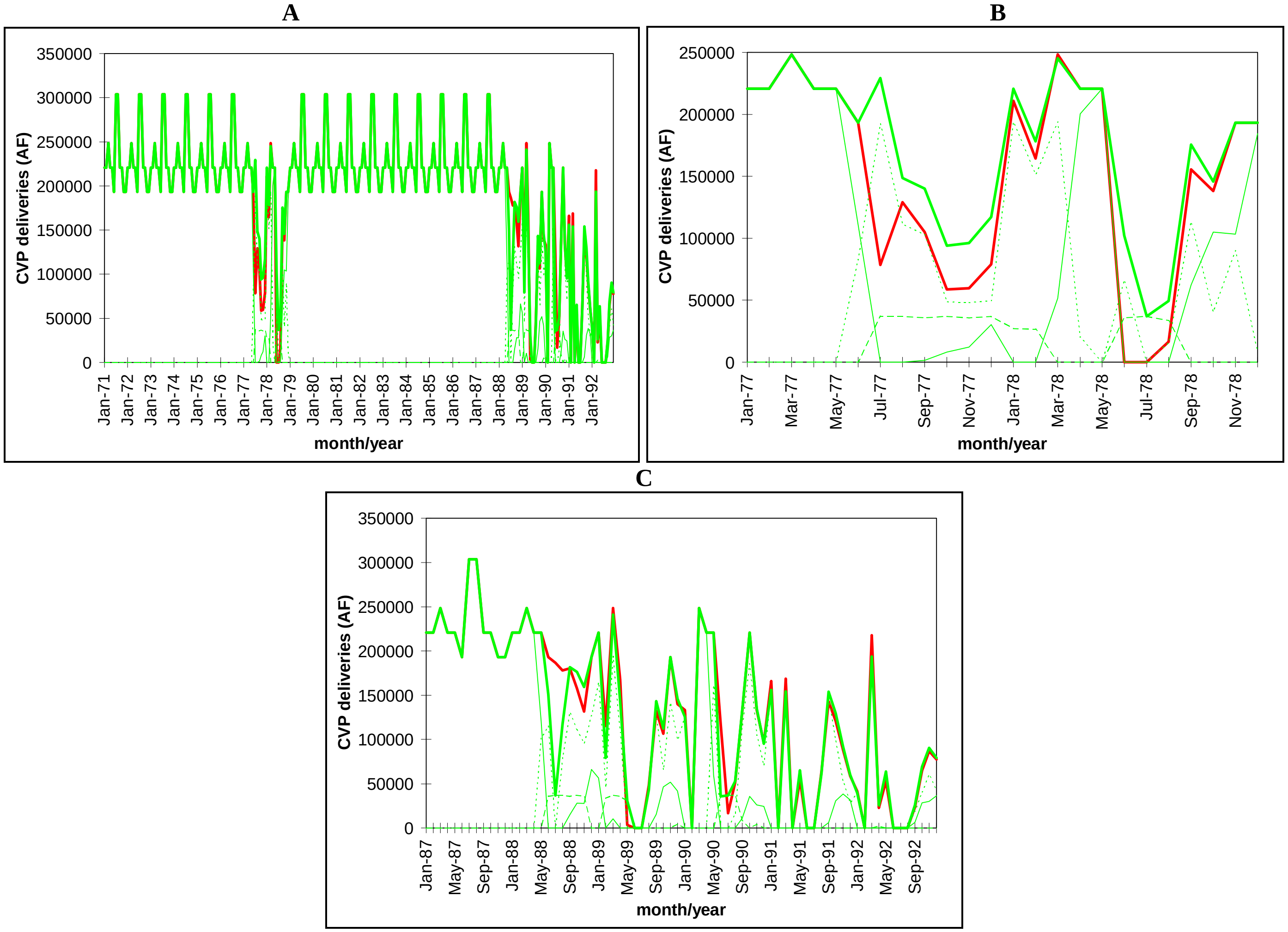
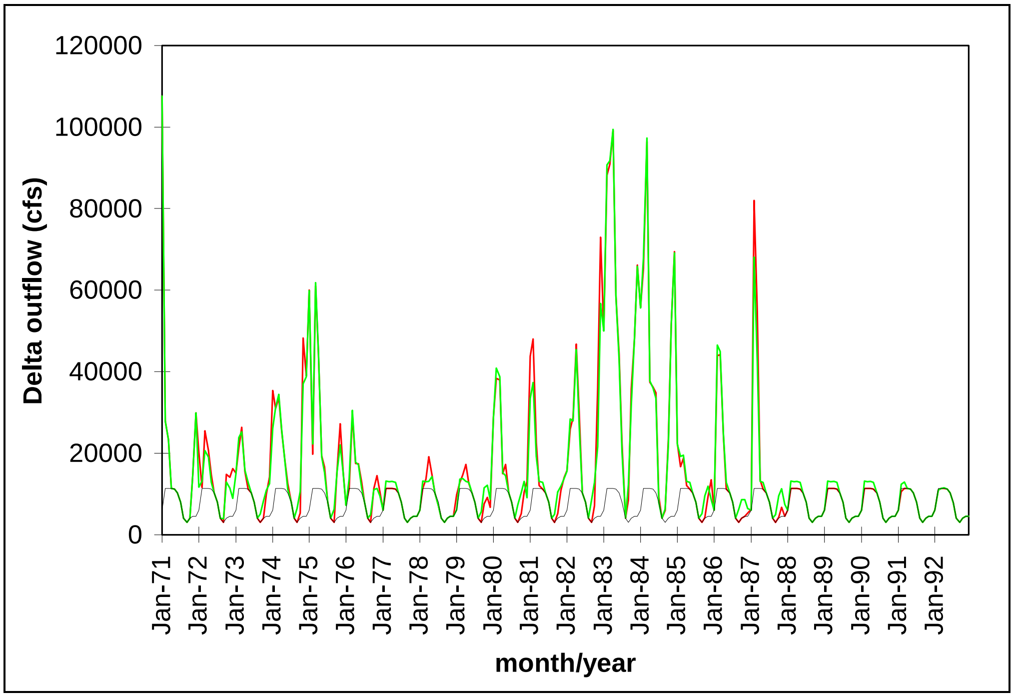
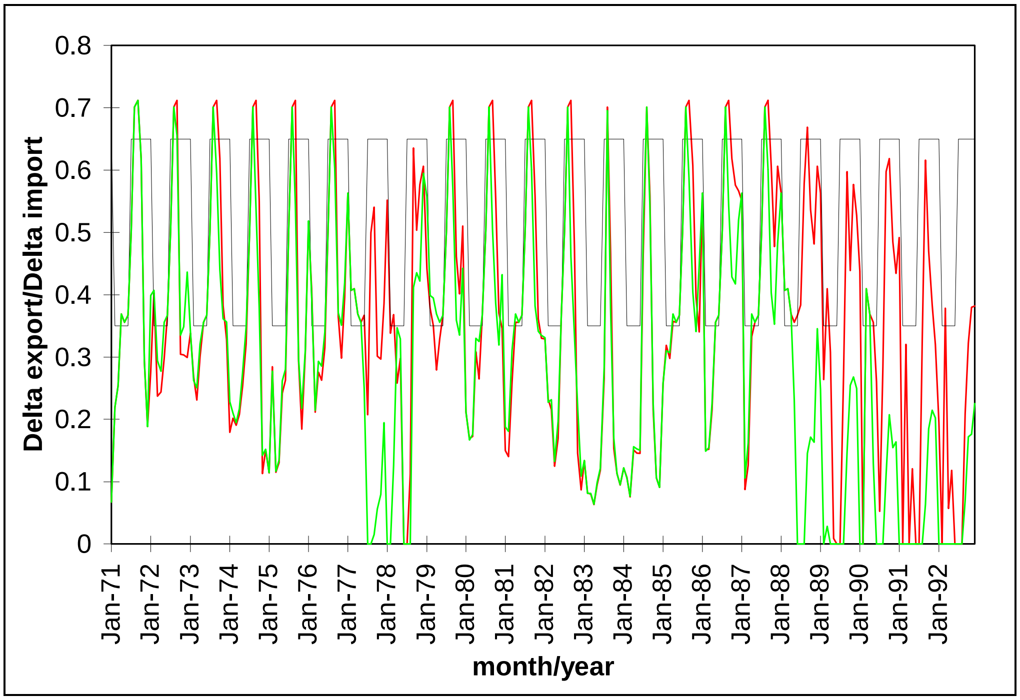


Figure 31: Simulated Delta Flow Regimes A: Delta Outflow and B: Export/Import Ratio for the Base Case (red) and the Isolated Facility/Conjunctive Use Alternative (green) as Compared to the Standard (black)

A



B



VII. Workplan Step 5: Economic Analysis

The economics of groundwater banking are often difficult to estimate and highly dependent on the specific characteristics of a given project. Recharge and extraction costs vary depending on aquifer characteristics and the nature of existing facilities. Greater uncertainties arise from the potential for unanticipated costs due to third party or environmental impacts. These can arise both in the source and recharge areas. Benefits are also variable. They range from the easily quantified savings associated with lower pumping lifts to the less easily quantified benefits associated with the insurance value of secure supplies. As with costs, many of these benefits depend on site characteristics.

VII.1 Direct Costs

Recharge and extraction costs in current projects range from a low roughly $20 to over $300 per acre-foot (Appendix V). Typical cost ranges for new projects estimated in the context of the CVPIA are $90-120/acre-foot at the source (USDOI, USBR et al. 1995). These costs do not, however, include any charges for the water being supplied. Districts in MWD's service area would, for example, need to pay its charges for replenishment water on top of their actual costs for recharge and extraction. Where in-lieu methods of recharge are possible using existing facilities, recharge costs can be extremely low. On the Conway ranch in Yolo County and in parts of Kern county they can be as little as $5/acre-foot.[36]

The direct costs indicated above and in Appendix V may, however, be misleading for conjunctive management activities in the future. As MWD notes in its recent IRP document: "A significant problem with groundwater conjunctive use storage is getting the water into the basin." (MWD 1996). This constraint is noted as a significant justification for their major Eastside Reservoir Project which could be used to temporarily store water during periods when existing recharge facilities are operating at capacity. The cost of this facility is estimated to be $1.9 billion.

VII.2 Benefits

Previous analyses of groundwater banking economics have focused primarily on the value of groundwater management activities within a limited agricultural area (e.g. Knapp and Olson 1995). Groundwater banking is modeled not as a way of creating "new" water supplies that would be available for any use, but more as a way of changing the cost structure of supplying a given amount of water to existing -- generally agricultural -- uses. As a result, the benefits are determined primarily by changes in the pumping costs versus management investments to supply that water. In contrast, this paper views the economics of groundwater banking from the perspective of storage creation. Groundwater banking use is a way of increasing the reliability of existing supplies and capturing new supplies that would otherwise be unavailable to the system as a whole through the creation of groundwater reservoir storage facilities. The economics of groundwater banking must therefore be analyzed in the same manner as surface storage reservoirs or other mechanisms for generating new or more reliable yield within an existing system.

While a full economic analysis of the benefits from groundwater banking is beyond the scope of this paper, it is important to note that the benefits associated with groundwater banking are not fully captured by analysis of new yield options on a least-cost of average annual supply basis. Three factors seem particularly important to note: (1) the stabilizing role of groundwater supplies; (2) the insurance value associated with ability to pre-deliver supplies; and (3) relative insensitivity of groundwater banking projects to changes in key economic assumptions.

In any situation where surface water supplies are variable, the presence of groundwater resources that can be tapped "as needed" for municipal, agricultural or other uses carries a stabilization value beyond that associated with increases in water supply alone. In an analysis of wheat cropping in the Negev desert,

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[36] DWR, 1994, SWP Conjunctive Use--Eastern Yolo County; Kern County CA. April 1995. 1995 KFE Property Recharge Program.

Tsur estimated the stabilization value of groundwater development as "more than twice the benefit due to the increase in water supply."(Tsur 1990). In Southern California where surface water supplies are less variable than the Negev, the stabilization value in agriculture is, in some cases, as much as 50% of the total value of groundwater (Tsur 1993). Crop yield responses are often dependent on the timing of water application as well as the volumes delivered. Since water stored in a groundwater banking site and dedicated for agricultural use will often be close to the point of end-use (e.g. on overlying lands), users will be far more able to fine tune extraction to meet their needs than they would be if they depended primarily on supplies stored in distant reservoirs. Groundwater banking operations will, thus, enhance the ability of groundwater resources to play a stabilization role. Furthermore, developing groundwater banking operations in areas currently dependent primarily on surface water would give those areas direct access to new "stabilization" benefits. In an analysis of groundwater banking in the South Platte system in Colorado, Bredehoeft and Young found that *installing sufficient groundwater pumping capacity to provide water to all areas irrigated by surface supplies made economic sense*. Doing this maximized expected net benefits and minimize annual income variation (Bredehoeft and Young 1983). As Tsur notes, ignoring the stabilization value of groundwater in economic comparisons with surface supplies, can seriously bias policy making based on cost-benefit considerations (Tsur 1993).

Municipal users also place a premium on supply stability. A recent contingent valuation survey found that: "on average California residents are willing to pay $12 to $17 more per month per household on their water bills to avoid the kinds of water shortages which they or their regional neighbors have incurred in recent memory. The statewide magnitude of such additional consumer payments would be well over $1 billion per year." (Barakat & Chamberlin 1994). The lower figure represents a 20% shortage every 30 years while the higher applies to a 50% shortage every 20 years. Residents are also willing to pay between $11.67/month and $12.14/month to avoid shortages of 10% occurring with a frequency of 10 and 3 years respectively.

Insurance values associated with groundwater banking are closely related to stabilization. The distinction between stabilizing natural fluctuations in water availability and insurance against major disruptions is important. Elements of California's surface water supply system are highly vulnerable to earthquakes. Other sudden events -- for example, major pollution spills -- could also disrupt water supplies over short to medium term periods. The economic costs of these disruptions could be major for any of the industrial, agricultural, municipal or environmental users. Groundwater banking operations, by pre-delivering water to locations nearer to points of end-use and storing it in underground reservoirs that are relatively invulnerable to sudden disruption, will provide major insurance benefits.

Another economic benefit of conjunctive use in comparison to most water supply projects is relative insensitivity to discount rate and other development cost assumptions. Unlike surface supply, most conjunctive use projects can be completed rapidly or brought on-line sequentially as components are completed. They often do not have the long gestation periods and high up-front capital costs associated, for example, with the construction of a new reservoir. Furthermore, the benefits associated with individual components, such as spreading basins, can be realized even if a system is only partially completed. They do not depend on completion of an entire system. As a result, the economic viability of conjunctive use does not depend to the same degree as large surface projects on accurate projections of economic and other parameters (such as population growth) into the future. This benefit will, of course, only be true to the extent that groundwater banking projects are not dependent on the construction of major new surface facilities.

The stabilization and insurance values of water stored underground and the relative insensitivity to economic assumptions of conjunctive use projects are not captured in least-cost comparisons of yield generated. Estimating these and incorporating them into the economic evaluation will be important to evaluate the true costs and benefits of conjunctive use.

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Appendix I: Limnological Context for Reservoir Stratification

In a barotropic water body, the fluid density remains invariant with depth. This is somewhat of a hypothetical state which would be difficult to establish and maintain in a natural system. Many factors leading to the establishment of vertical density gradients, so called baroclinic conditions, act upon lakes in nature. In the context of a maximal groundwater banking program, the most important is the input of solar radiation at the water surface. Workplan Step I describes how reservoir re-operation would increase yield in the Central Valley water system via the transfer of surface water to aquifer storage in advance of winter storms. In the event of a wet winter, the excess reservoir capacity would be used to retain runoff normally released as part of flood control operations. A dry winter, on the other hand, might leave the reservoirs drawn down to a point where the input of solar radiation might subsequently make it difficult to maintain downstream temperature regimes suitable for aquatic resources, primarily anadromous fish.

As solar radiation penetrates into a lake or reservoir, it is absorbed at an exponential rate. Figure AI.1 shows how far into a body of distilled water two different wavelengths of visible light penetrate.

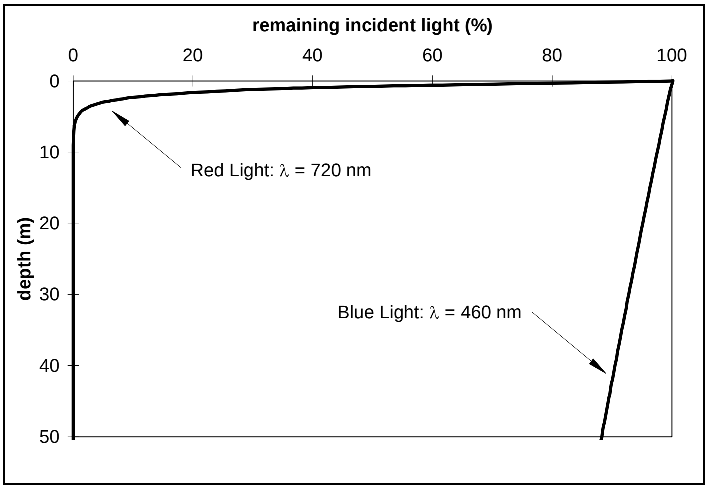

Figure AI.1: Light Penetration into Distilled Water for Red and Blue Regions of the Visible Light Spectrum
(source: Cole 1983)

According to these curves, by a depth of 5m, all but 1% percent of the incident red light (λ=720 nm) has is absorbed by the water and converted to thermal energy. A similar pattern exists for infrared radiation which lies just outside of the visible portion of the spectrum. Shorter wavelength blue light (λ=460 nm), on the other hand, remains relatively unabsorbed even at depth of 50 m. Since it is the red/infrared wavelengths which convert much of their energy to heat when absorbed, the most intense warming takes place in top several meters of the water column.

If the input of solar radiation occurred in an initially isothermal lake, the resulting temperature profile would resemble the red/infrared penetration profile (Figure AI.2A). Under these conditions additional inputs of radiation would generate downward heat flow driven by temperature gradients. In addition to this driving force, however, the lake is exposed to winds passing over its surface. This wind serves to mix the water near the surface of the lake distributing the heat more evenly within the zone of mixing (Figure AI.2B). The end result is a layer of warmer, less dense water which overlies colder heavier water below. Additional inputs of solar energy and further wind-driven mixing will continue to warm the surface layer making it increasing less dense relative to the cold layer below. The lake has become *stratified*, a common occurrence during the summer months in deep lakes located in temperate regions.

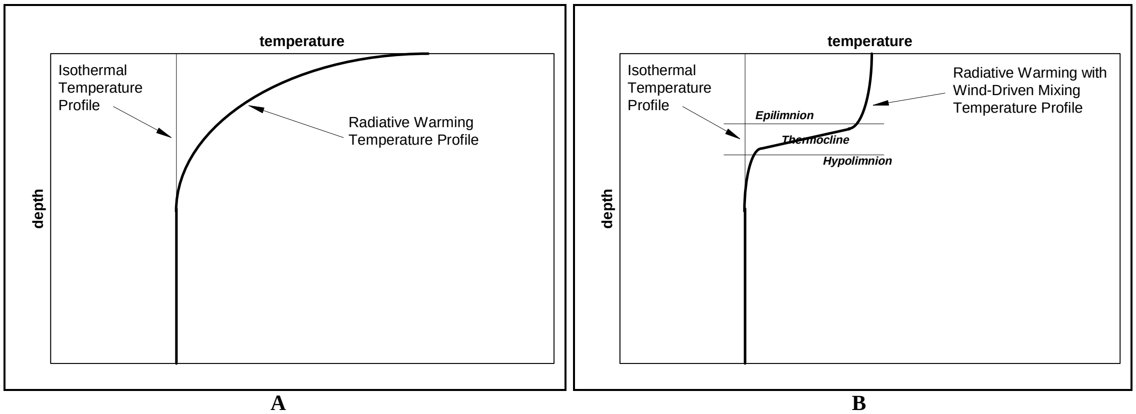

Figure AI.2: Hypothetical Vertical Temperature Profiles Assuming
A: Simple Radiative Warming; and B: Combined Radiative Warming and Wind-Driven Mixing
(source: Laska 1981)

The thickness of the upper layer, or the *epilimnion*, is a function of the physio-chemical properties of the water in the lake and the dynamic interaction between the temporal pattern of incoming solar radiation and the local wind regime. It should be pointed out that the same amount of thermal energy can lead to the conditions shown in Figures AI.2A and AI.2B. If so, the integral of temperature with depth must be the same for both profiles. As the uniformly cold regions of each curve, referred to as the *hypolimnion* of the lake, are identical, the only way to preserve this equality is for a region of rapid temperature drop, or a *thermocline*, to become established between the two layers. The sharp temperature, and hence density, contrast means that in a *stratified* lake the epilimnion and the hypolimnion essentially act as separate bodies of fluid until sufficient work can be done on the system to remix them.

Actual temperature profiles taken at Lake Shasta during the month of September, Figure AI.3, reveal that stratified conditions do develop in the reservoir. Stratification seems to be most pronounced in years where the lake stage was relatively low in the late summer, as in 1961, 1964, and 1968. Data also suggest that the thermocline deteriorates with the advancing autumn. Figures AI.4A and AI.4B depict the evolution of the 1968 temperature profile in Shasta and Whiskeytown Lakes between September and November. Presumably the acceleration of radiative cooling and the inflow of cooler water with the onset of winter storms are responsible for the general cooling down of these lakes late in the fall.

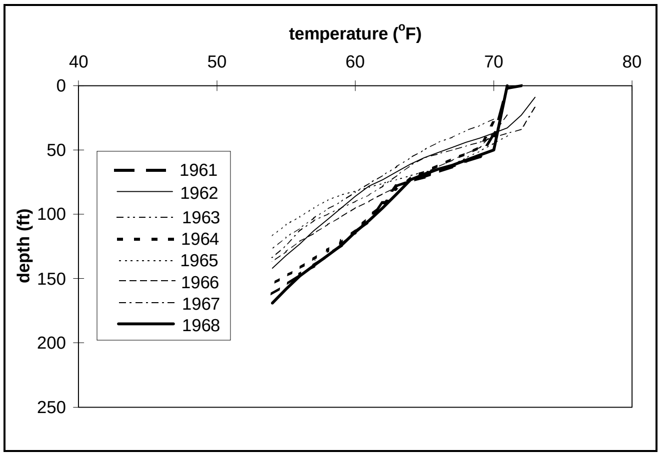

Figure AI.3: September Temperature Profiles in Lake Shasta
(bold curves represent years of low reservoir stage)
(source: Weidlein 1971)

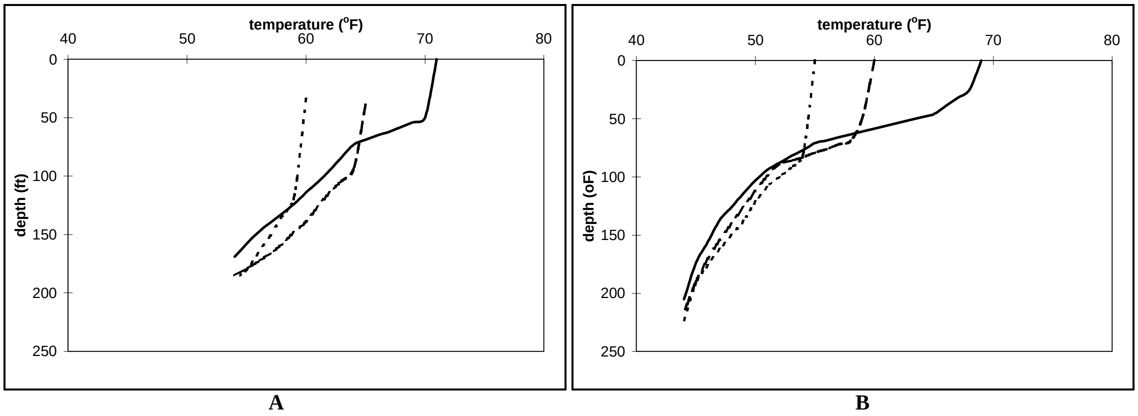

Figure AI.4: Evolution of Autumn, 1968 Water Temperature Profiles in A; Lake Shasta; and B: Wiskeytown Lake
(September: solid line; October: long dashed line; November: short dashed line)
(source: Weidlein 1971)

One conclusion which can be drawn from Figures AI.3 and AI.4 is that water temperatures in the epilimnion of these reservoirs are substantially higher than the 56°F recommended in the AFRP for the protection and restoration of anadromous fish in the Sacramento River, particularly in September. This has profound implication for the operation of reservoirs as part of the proposed groundwater banking program. To insure that only cold water from the hypolimnion will flow into the river downstream, reservoir releases must be made from depths below the thermocline. Unfortunately, under the worst case scenario of a critically dry winter following the ambitious pre-delivery of water to aquifer storage, the thermocline may be dangerously close to the level of the reservoir release works. In this case the flow hydraulics in the vicinity of the intake may lead to the release of warm water from the epilimnion. Of particular concern in this context are internal waves in the body of the reservoir, or *seiches*, which can cause the thermocline to oscillate and may, under drawn down conditions, result in periods of time when cold water is completely absent from the vicinity of the reservoir release works. The equations governing this phenomenon are presented in the following Appendix.

Appendix II: The Initiation and Magnitude of *Seiche* Oscillations

AII.1 Wind Driven Set-Up

As the wind passes over a reach of open water it imposes a shear stress proportional to the square of the wind speed and the density of the atmosphere. This relationship is defined as:

$$\tau_S = C\rho_a W^2 \qquad \text{(AII.1)}$$

where τ_S is the shear stress; ρ_a is the density of the atmosphere immediately above the lake surface; W is the wind speed and C is an empirical parameter known as the drag coefficient. The imposition of this shear stress acts to pile up the lake surface at the offshore end thereby generating a head gradient along a line parallel to the wind direction. Theory holds that at steady state this head gradient is balanced by the opposing shear stresses acting on the lake surface and along the lake bottom.

$$\tau_S - \tau_B = \rho g i H \qquad \text{(AII.2)}$$

where τ_B is the shear stress acting along the bottom of the lake; g is gravitational acceleration; i is the angle of denivelation of the lake surface; and H is the static depth of the lake. When lake currents are turbulent, the shear stress at the surface is generally considered to be significantly larger than those acting on the lake bottom so that the ϑ_B parameter can be ignored.

Making this assumption, one can equate equations AII.1 and AII.2 and solve for the angle of denivelation under a given wind regime:

$$i = C\frac{\rho_a}{\rho}\frac{W^2}{gH} \qquad \text{(AII.3)}$$

When combined with a parameter describing the length of the lake, equation AII.3 can be used to determine the magnitude of the wind driven set-up:

$$\zeta' = \frac{iL}{2} \qquad \text{(AII.4)}$$

where ζ' is the set-up, or lake surface displacement, at the off-shore end; and L is the length of the lake. During this investigation, to solve equation AII.4, the drag coefficient was set equal to $2.3\text{x}10^{-3}$ and the density of the atmosphere to $1.25\text{x}10^{-3}$ gm/cm^3.

AII.2 *Seiche* Oscillation

Stratified lakes are not static features in which a warm layer rest motionless upon a static pool of cold water. It has long been recognized that the interface between the two bodies of water in stratified lakes, the thermocline, oscillates (Wedderburn, 1909). This oscillation is often uninodal around some central point in the lake with the end effect being that when the thermocline is elevated relative to it static level at one end of the lake, it is depressed at the other.

When a dry rainy season follows pre-delivery to aquifer storage, there is an increased risk that these oscillations, or *seiches*, will periodically place warm water in close proximity to the reservoir release works thereby displacing the cold water which would have been present under static conditions. This displacement could compromise the ability to maintain suitable temperature regimes downstream. Obviously *seiches* are complex hydrodynamic features whose properties depend on multiple variables. Nonetheless, by making some simple assumptions about the system, it is possible to develop some rules of thumb about the amplitude of these oscillations which might guide the establishment of suitable reservoir carryover storage parameters for the Central Valley reservoirs.

Consider a lake of length L and width W, where L>>W. Assume the lake is stratified into an upper warm layer of thickness h' and density ρ' and a lower cold layer of thickness h and density ρ. Once oscillation is initiated, the divergence of the lake surface and the thermocline from their static levels are represented by ζ' (the wind driven set-up in equation AII.4) and ζ respectively. As the lake is much longer than it is wide, one can assume that the oscillation is largely confined to the long, or x axis, of the lake. Manipulation of the equations of continuity and momentum for this simplified system lead to the following definition of the amplitude of the internal oscillation:

$$\zeta = -\zeta' \, \frac{\rho}{\rho - \rho'} \left(1 + \frac{h'}{h}\right) \qquad \text{(AII.5)}$$

Equation AII.5 suggests the following interactions between the displacement of the water surface and the displacement of the thermocline at depth:

- For a given water surface displacement, ζ', and for a given set of static eplimnoin and hypolimnion thickness values, h' and h, the internal displacement of the thermocline is inversely proportional to the density contrast between the warm and cold water pools; and
- For a given water surface displacement, ζ', and for a given density contrast between the warm and cold water pools, the internal displacement of the thermocline is proportional to the relative thickness of the epilimnion.

The combined effect of these interactions is that in stratified lakes a set-up on the order of centimeters can generate *seiche* displacements on the order of meters.

AII.3 Juxtaposition of Warm Water and Reservoir Release Works

Using the data presented in the previous sections, it is possible to approximate the magnitude of the wind driven set-up in each of the major foothill reservoirs (equation A.II.4) and the maximum displacement of warm water in the epilimnion below the static thermocline elevation during seiche-like oscillations (equation A.II.5). Having estimated the potential magnitude of displacement, the difference between the minimum elevation of the warm water in the reservoir and the elevation of the intake to the reservoir release works can be established for a given reservoir storage condition according to:

$$HT = \left(E_{surf} - D_{thermo} - \zeta\right) - E_{releases} \qquad \text{(AII.6)}$$

where: HT is the minimum hypolimnion thickness lying above the release works; E_{surf} is the lake surface elevation associate with the assumed reservoir storage level; D_{thermo} is the observed depth of the thermocline below the lake surface; and $E_{release}$ is the elevation of the release works.

Appendix III: Survey of District Recharge Activities

District	Storage Potentially Available	Current annual operating potential	Average current recharge volume
Arcade WD[37]			17,960 AF
Yuba Co. WA[38]	1,710,000		
DWR - M&T Chico Ranch[39]			12,000 AF
Western Canal Water District[40]	4,000,000 AF - total groundwater basin storage		
DWR - American Basin[41]			
DWR - Eastern Yolo County[42]			19,000 AF[43]
Alameda County WD[44]	20-32,000 AF		28,900 AF
Alameda Co. Flood Control District #7[45]	250,000 AF		10,000 AF
East Bay MUD[46]	600,000-700,000 AF	200,000 AF[47]	feasibility stage
Santa Clara Valley WD[48]		400,000 AF[49]	150,000 - 210,000 AF max Average year 100,000
Stockton-East WD[50]			5,800 AF
Chowchilla WD[51]	75,000 AF		30,000 AF

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[37] CH2MHILL prepared for Arcade Water District. November 1993. Groundwater Recharge Project Feasibility Report. Arcade WD is in the process of implementing a combination injection and in-lieu recharge program. Figures were calculated using Arcade's recommended project which injects 9896 AF/yr and purchases 7.2 mgd of surface water from the City of Sacramento and delivered as in-lieu recharge. 7.2 mgd * 365 = 2,628 g/year. 2,628 g/year = 8,064 AF/yr in-lieu (1 AF = 325,900 g). 9,896 injection + 8,064 in-lieu = 17,960 AF/yr. This program, however, has not yet been implemented.

[38] Yuba County WA. September 1992. Ground Water Resources and Management in Yuba County. Figure is total storage capacity, it would not be feasible to include this amount of water in a conjunctive use program. Calaculated within the Yuba Co. groundwater study area which includes 49,800 acres in Yuba-North subarea and 88,700 acres in Yuba-South subarea to a depth of 200 feet.

[39] CH2MHILL. November 1994. DRAFT Conjunctive Use Working Paper Water Augmentation Program.

[40] Brown, G., Western Canal Water District. June 19,1995. Personal Communication.

[41] DWR, 1995, American Basin Conjunctive Use Project, Pre-Feasibility Report, California Department of Water Resources, Sacramento, pp 138.

[42] DWR, 1994, SWP Conjunctive Use--Eastern Yolo County, Draft Pre-Feasibility Report, California Department of Water Resources, Sacramento.

[43] In-delivery occurs during wet years, therefore, pre-feasibility report estimate indicates this amount of recharge would occur every other year.

[44] Halliwell, M., Alameda County WD. August 15, 1995. Personal Communication. 28,900 AF were recharged in 1993-94 water year due to an excess amount of water being discharged, forecasted recharge volume 1994-95 is 21,100 AF. Alameda County Water District. February 1995. Survey Report on Groundwater Conditions.

[45] Chahal, J., Alameda Co. FCD and WCD #7. July 17, 1995. Personal Communication.

[46] EDAW, Inc. December 1992. Draft EIS/EIR for the Updated Water Supply Management Program. Prepared for East Bay Municipal Utility District, Oakland, California.

[47] Potential annual withdrawal for conjunctive use if the program incorporated 100 wells with an average production capacity of 1200 gpm

[48] CH2MHILL draft report. estimate pending information from district.

[49] Personal Communication, William Molnar, Water Resource Development Division

[50] Thomas, J., Stockton-East WD. July 1995. Personal communication. District is currently searching for additional percolation sites to increase their annual recharge rate, and reduce overdraft.

[51] CH2M HILL. 1994. DRAFT Conjunctive Use Working Paper.

Rosedale RioBravo WD		209,950 AF[52]	89,385 AF[53]
Kern Delta WD		76,740 AF[54]	3,874 AF[55]
Buena Vista WSD		372,843 AF[56]	30,732 AF[57]
Tranquility WD[58]			At reconnaissance level which may evolve into a project (2-3 years) storage account 5,000 AF
Kern Water Bank[59]			Project on hold pending habitat conservation plan - previously recharging 100,000 AF annually
City of Fresno[60]			> 50,000 AF
Fresno ID[61]			60,000 AF
Laton CSD[62]			117 AF
Liberty WD[63]			15,000 AF
Westlands[64]			No formal recharge project, individual growers bank water
Arvin-Edison WSD		108,595 AF[65]	122,917 AF[66]
City of Bakersfield		180,992 AF[67]	7,881 AF[68]
Semitropic WSD, Groundwater Banking Project with MWD[69]	Roughly 1,000,000 acre-feet total available.	"put" max 315,000 AF/yr, "Take" max 224,000; guaranteed put of 91,000; guaranteed take of 90,000.	
Semitropic/MWDSC Water Storage and Exchange Program		31,500 - 170,000 AF[70]	

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[52] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency.

[53] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[54] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency.

[55] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[56] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency.

[57] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[58] Brian Ehlers of Provost and Pritchers. June 16, 1995. Personal Communication.

[59] Arvey Swanson, DWR. July 21, 1995. Personal Communication. CH2MHILL 1994. DRAFT Conjunctive Use Working Paper.

[60] Integrated Water Technologies, Inc. June 1995. Presented at ACWA Groundwater Mini-Conference.

[61] Bettner, T., Fresno ID. July 1995. Personal Communication.

[62] Buttle, R., Laton CSD. July 1995. Natural Heritage Institute survey results. Substantial annual variation, depending on hydrologic conditions in the Sierras, range is from 0 - 15,000 AF.

[63] Liberty WD. July 1995. Natural Heritage Institute survey results.

[64] Dave Sunding. August 15, 1995. Personal Communication.

[65] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency. Kern County Water Agency.

[66] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[67] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency. Kern County Water Agency.

[68] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[69] Semitropic Water Storage District and Metropolitan Water District of Southern California (1994) Semitropic Groundwater Banking Project, Final EIR, July 1994, p. 5-197.

[70] Metropolitan Water District of Southern California. July 1995. Regional Urban Water Management Plan for MWDSC, p. 109. Under the joint program, MWDSC will have the right to store up to 350,000 AF. Semitropic provides Metropolitan with access to existing and new facilities and provides other necessary services for storage and recovery of SWP or other water supplies. MWDSC pays Semitropic for water management services.

I.D. No. 4 (Kern County)		296,102 AF[71]	82,960 AF[72]
Wheeler Ridge-Maricopa WSD			6,882 AF[73]
North Kern WSD		340,264 AF[74]	107,060 AF[75]
Kern County WA		1,400,000 AF[76]	176,272 AF[77]
Antelope Valley - East Kern WA[78]			18,467 AF
Kern-Tulare WD and Rag Gulch WD[79]			26,000 - 27,000 AF
Joint Powers Authority – Terra Bella ID, Lower Tule River ID, Saucelito ID, Pixley ID, and Porterville ID[80]			300,000 AF
Golden Hills CSD[81]			200 AF
Tehachapi-Cummings			
City of Santa Barbara – Goleta[82]		500 AF	
City of Oxnard[83]			3800 AF in two years
City of Santa Barbara – Foothill basin[84]	3,000 AF	1200-1500 AF	
Calleguas (In conjunction with MWDSC)[85]			10,000 AF
United WCD			
Chino Basin Watermaster[86]	Several hundred thousand AF	25,000 - 30,000 AF + 50 - 60,000 in-lieu	20,000 AF
Chino Basin WCD[87]			17,000 AF
MWDSC and			4,800 AF

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[71] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency. Kern County Water Agency.

[72] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[73] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[74] Figure is calculated using the recharge rate (cfs) for facilities within the district, therefore it is the highest possible number using existing facilities and assuming water is available year round. Kern County Water Agency. Kern County Water Agency.

[75] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[76] Calculated from potential recharge facilities assuming 100% efficiency of recharge. Kern County Long Term Storage Supply Project Report.

[77] Kern County Water Agency. 1995. Water Supply Report. Figures are for 1993.

[78] Fuller, R., Antelope Valley - East Kern WA. July 18, 1995. Personal Communication. Through the district's in-lieu incentive program, where well owners received a discounted price for surface water. From 1976-1994, 332,409 AF of in-lieu water was provided, giving an annual average of 18,467 AF. More water is expected to be recharge due to their new incremental incentive program.

[79] Bowers, B., Kern-Tulare WD. July 1995. Personal Communication. Amount of water recharged since 1993.

[80] Robb, R., Lower Tule River ID. July 1995. Personal Communication. Estimated recharge in first year of Joint Powers Authority. Previously each of the five districts had conjunctive use programs, they are in the process of combining their projects and adopting a joint management groundwater plan.

[81] Golden Hills CSD. July 1995. Natural Heritage Institute survey results.

[82] Integrated Water Technologies, Inc. June 1995. Presented at ACWA Groundwater Mini-Conference. Program uses existing facilities, and recharging during only 4 months of the year (when water is available)

[83] Integrated Water Technologies, Inc. June 1995. Presented at ACWA Groundwater Mini-Conference.

[84] Integrated Water Technologies, Inc. June 1995. Presented at ACWA Groundwater Mini-Conference.

[85] Horne, W.June, 8, 1995. General Methods & Facilities to Expand Conjunctive Use. Presented at the ACWA 1995 Ground Water Mini-Conference Conjunctive Use

[86] Stewart, T., Chino Basin Watermaster. August 1995. Personal Communication.

[87] Gumina, Sal, Chino Basin WCD. July 1995 Natural Heritage Institute survey results.

Cucamonga CCWD[88]			
Mojave WA[89]			360,000 AF
San Fernando Basin – includes Los Angeles, Glendale, and Burbank's water rights[90]	3,200,000 AF is the size of the basin, however 200,000 AF safe storage capacity	100,000 AF	152,000 AF
Orange County WD[91]		115,000 AF more than current recharge due to new facilities	300,000 - 400,000 AF
Water Replenishment District of southern California[92]			155,000 AF + 20 - 30,000 AF from injection
Los Angeles County[93]			220,000 AF local storm 68,000 AF imported 50,000 AF reclaimed
Central and West Coast Basins[94]		450,000 AF	145,000 AF
Eastern MWD - San Jacinto Basin[95]		7,641 - 9,526	
Elsinore Valley MWD[96]			13,000 AF
Three Valleys MWD[97]		75,000 AF	
San Bernadino Valley MWD[98]	500,000 AF		
City of Oxnard[99]			2,000 AF, but with improvements will recharge 6,000 AF
Calleguas and MWD in North Las Posas Basin	300,000 AF[100]	100,000 AF[101]	
Main San Gabriel Basin[102]	8,000,000 AF total storage potential		

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[88] Metropolitan Water District of Southern California. July 1995. Regional Urban Management Plan for MWDSC.

[89] Rowe, L. July 26, 1995. Personal Communication.

[90] Blevins, M., San Fernando Basin Watermaster. June 1995. Outline of presentation at ACWA Groundwater Mini-Conference. Average annual groundwater pumping (1968 through 1993) is 86,300.

[91] Orange County Water District, 1994, Groundwater Management Plan.

[92] Water Replenishment District of Southern California. 1995. Water supply report. Garcia, Mario. July 1995. Personal Communication.

[93] Survey Response, Robert D. Pedigio, Hydraulic/Water Conservation Division, LAPWD. Figure includes amount recharged in LAPWD operated facilities for other organizations.

[94] John Norman, General Manager, WRD. Letter to Dirk Reed, MWDSC. 300,000 AF of operating storage capacity is currently being operated by WRD. Includes barrier injection, spreading of imported and reclaimed water, and in-lieur deliveries.

[95] Wang, C., B. Mortazavi., W. Liang, N. Sun, and W. Yeh. April 1995. Model Development for Conjunctive Use Study of the San Jacinto Basin, California. Water Resources Bulletin **31:** (2). p. Figure based on artificial recharge model for San Jacinto Basin.

[96] Elsinore Valley MWD. February 28, 1994. Ground Water Recharge Feasibility Study. Feasibility stage, not yet implemented.

[97] Stetson, T. June 1995. Case Studies on Implementing Conjunctive Use. Presented at ACWA Groundwater Mini-Conference on Conjunctive Use.

[98] Tincher, Bob, San Bernadino Valley MWD. August 3, 1995. Personal Communication.

[99] Arora, S., and S.Darabzand. 1990. Conjunctive Use of Surface and Groundwater Resources in the Central Valley of California, in Hydraulics/Hydrology of Arid Lands, Proceedings of the International Symposium, (ed. by R. H. French), ASCE, New York. p. 373-378.

[100] Atwater, R., The Use of Wholesale Water Rates to Encourage the Groundwater Conjunctive Use. 1990. in Hydraulics/Hydrology of Arid Lands, Proceedings of the International Symposium, (ed. by R. H. French), ASCE, New York. pp. 46-48.

[101] Horne, W.June, 8, 1995. General Methods & Facilities to Expand Conjunctive Use. Presented at the ACWA 1995 Ground Water Mini-Conference Conjunctive Use

[102] Stetson, T. June 9, 1995. Presentation at ACWA's 1995 Groundwater Mini-Conference.

Raymond Basin	100,000 AF[103]	23,600 - 31,300[104]	10,798.8 AF[105]
Sweetwater Authority[106]	120,000 - 240,000 AF		3,500 AF
San Diego River Groundwater Basin Task Force[107]			5,000 AF
City of San Diego and the San Pasqual Basin[108]			7,000 AF

Disclaimer: these figures cannot be added for a total volume of recharge because some districts are double counted, i.e. the districts report recharge, but recharge is done by another entity.

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[103] Man, D. June 8, 1995. Current Practices of Conjunctive Use in the State. Presented at ACWA 1995 Ground Water Mini-Conference Conjunctive Use.

[104] Palmer, R., Raymond Basin Management Board. July 1995. Personal Communication.

[105] Raymond Basin. 1995. Management Board Report, p. 18.

[106] Daniel Diehr, San Diego County Water Authority. July 25, 1995. Facsimile communication. Preliminary results of agency's investigation. Planned project expected to begin by 1997-98.

[107] Daniel Diehr, San Diego County Water Authority. July 25, 1995. Facsimile communication. Figure is an estimate, potential production is unknown at this time.

[108] Daniel Diehr, San Diego County Water Authority. July 25, 1995. Facsimile communication. Production figure is from an earlier study, potential production is unknown at this time.

Appendix IV: Environmental Risks

AVI.1 Risks in Changing Surface Operations

One approach to increasing system yield analyzed in this paper involves transferring water from surface storage to underground storage in advance of periods when precipitation can be anticipated. This mode of operation may lead to two kinds of negative impacts. First, since the surface reservoirs will, in general have greater empty space going into the winter, pulse flows that would normally pass through the reservoir will now be captured. This may have negative consequences downstream. Second, if reservoir levels are lowered before the winter the winter is dry, it may be more difficult to maintain instream flows and temperature control below the dam .

The environmental benefits of pulse flows is a high priority topic for additional work. Benefits may be derived from the effect of the water in transporting organisms downstream. Perhaps more important, occasional high flows are important for maintaining the natural morphology in downstream streambeds. Central Valley rivers are already highly regulated, though very high flow peaks still cannot be captured by storage. The use of groundwater storage to enhance yield would continue the historical reduction in pulse flows. The working hypothesis is that the benefits of enhanced environmental flows during critical seasons and dry years outweighs this negative effect, but more work is needed to determine whether this assumption is warranted.

As previously noted, many in-stream environmental uses depend on water temperature. Anadromous fish migration and spawning is affected by stream temperatures. Major streams such as the Sacramento and Mokelumne have temperature standards. Supplying water at these temperatures depends on maintaining thermal stratification in water supply reservoirs. Temperatures in upper levels increase during the summer but water at lower levels maintains stable temperatures and can be used to meet instream flow needs. If buffer storage levels are drawn down too far, water in the reservoirs will turn over and thermal stratification will be lost.

Risks of losing thermal stratification may increase with groundwater banking operations. Since conjunctive management necessitates partial evacuation of reservoirs in advance of precipitation, storage will inevitably be lower if the anticipated precipitation does not occur. As previously noted, California has historically faced drought periods extending for six or more years. The adequacy of groundwater banking to maintain sufficient surface storage will be most critical when this happens. Anadromous fish species have a migration cycle that spans a number of years. If spawning and other conditions are sub-optimal for individual years, overall population impacts may be minor. If sub-optimal conditions extend over consecutive years, net impacts will be substantially greater.

With groundwater banking, reservoir storage levels going into droughts will be lower than they would be under current operating procedures. Risks to in-stream flows and temperatures during this type of event depend critically on how rapidly the likelihood of a long-term deficit can be identified and how completely non-environmental users can be shifted to banked groundwater. If non-environmental demands on surface supplies can be reduced greatly before surface storage reaches critical levels, conjunctive management may increase the ability to maintain temperature stratification and surface supplies for in-stream uses. On the other hand, if operating mechanisms do not allow adequate shifts of high priority non-environmental demands from surface storage, if warning systems are insufficient to identify the probability of long-term deficits or if aggressive operating procedures result in inadequate surface reserves, temperature and in-stream flow impacts could be substantial. Current instream flow standards are often set just below dams. It is likely to be physically impossible (or at least economically impossible) to shift water from aquifer storage sites to these locations if buffer supplies prove inadequate. If buffer storage is too low, additional supplies could, potentially, be purchased from utility or district reservoirs upstream. How this might work, what it would cost and the availability of water for purchase during long-term droughts have yet to be investigated.

Beyond the environmental costs associated with conjunctive management, it is important to note that realizing many of the environmental benefits depends very heavily on operations procedures and hydraulic system configuration. The ability to shift non-environmental users onto groundwater during drought years depends on their location in relation to groundwater basins having appropriate storage characteristics. Banked water often cannot be directly applied to meet in-stream environmental needs. Aquifers are often located substantially downstream from critical environmental needs – such as spawning sites. In addition, groundwater is often warmer than water in surface streams. Since many habitat characteristics are temperature dependent, this can greatly affect the usability of banked groundwater for environmental purposes. As a result, generation of environmental benefits may depend critically on the degree to which banked water can be used to displace non-environmental demands on surface water supplies, particularly during intense drought periods. Similarly, the ability to create wetland habitat benefits depends on the match between the timing of water availability for recharge in relation to waterfowl wetland needs.[109] Overall, the environmental benefits of conjunctive management could be major – but the devil lies in specific details.

AIV.2 Recharge and Extraction Associated Risks

There is an array of potential environmental risks associated with the extraction and recharge component of any conjunctive management operation. In a broad sense these can be divided into two categories: (1) those associated with basin hydrology such as the potential for subsidence or interaction with surface stream flows; and (2) those related to water quality and pollution considerations. The first class of risks heavily depends on the degree to which the regional hydrology is accurately understood and the magnitude of flows related to storage and extraction in comparison to other flows. The second class may depend more on recharge and extraction mechanisms and agricultural chemical use patterns.

AIV.2.1 Hydrologic Uncertainty

The degree to which basin hydrologic characteristics are understood is a major factor influencing the risk of unanticipated environmental impacts. In addition, the accuracy with which the regional hydrology is understood greatly influences the degree of assurance the program has regarding ability to store and extract water in the amounts anticipated – and, thus, the overall benefits of conjunctive management.

Information on basin hydrology in the Sacramento-San Joaquin systems varies greatly depending on location. In general, the hydrology of the adjudicated basins in southern California has been quantified to a much greater degree than basins further north. This reflects the much longer history of water shortage and attempts to address it in the south compared to the north.

Characterization of the aquifer system underlying the Sacramento-San Joaquin has changed significantly over time. Early reports viewed the Sacramento basin essentially as a single unconfined aquifer and the San Joaquin essentially a two or multi-layered system in which confined and unconfined aquifers were separated by the dense and regionally extensive Corcoran Clay, or e-clay, member of the Tulare formation (Bertoldi, Johnston et al. 1991). More recently, the intensive Regional Aquifer System Analysis (RASA) study undertaken by the USGS has changed that image fundamentally. This detailed modeling effort characterized both the Sacramento and San Joaquin systems as essentially a single aquifer with multiple, discontinuous layers of low permeability clays creating semi-confined conditions in many locations (Bertoldi, Johnston et al. 1991). Study authors viewed flow within the system as linked throughout with substantial changes due to development. In some areas, vertical permeability of confining layers such as the Corcoran Clay has been reduced by 1.5 to 6 times (Bertoldi, Johnston et al. 1991, p. A26). Overall vertical flow has, however, increased by roughly an order of magnitude from conditions prior to development up to the 1970s. This was caused by leakage through wells with long perforated

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[109]. It would, for example, be important to evacuate reservoirs in the fall in advance of major precipitation periods in order to increase capture. Much of the recharge might, for this reason, need to be done in the late fall and early winter. Wetland habitat needs may, however, be particularly important in the spring and early summer.

sections (Bertoldi, Johnston et al. 1991). Most recently, work by the California DWR suggests that much of the Sacramento Valley might best be conceived as a two layer aquifer system in which extraction from or recharge to lower layers is essentially isolated from river flows.[110]

The above uncertainties have potentially great implications for conjunctive use activities. First, in parts of the Central Valley, the hydrologic system is not well enough understood at present to predict potential recharge and extraction effects on stream flows, wetlands and other associated environmental resources. This is particularly true in the Sacramento basin. Second, the same uncertainty limits the assurance a program could have regarding how much of the water it recharges will actually be available for extraction when needed and what liabilities the program might incur due to impacts on third parties. Vertical flow rates might be particularly important to this. In the Sacramento valley, for example, much would depend on whether or not recharge to deeper aquifer levels could be tapped during drought years without affecting levels in the upper unconfined aquifer or surface streams.

The above uncertainties are unlikely to represent as much of a concern in parts of the Central Valley (such as much of the San Joaquin and other groundwater basins in Southern California) where hydrological conditions are better known and where aquifers have been historically drawn down substantially or major pumping depressions currently exist. In these areas, surface-groundwater interactions are often minimal because streams are not in direct hydraulic connection with aquifers. Subsidence, while a concern, has often already occurred and, if fluctuations are kept within historical ranges, is unlikely to increase. Furthermore, because of overdraft, subsidence and other concerns, these areas have often been subject to extensive study. There is, therefore, a much larger body of information on aquifer characteristics and probable responses to the types of operations involved in a conjunctive management program. This substantially increases the degree of assurance a program would face with regard to environmental and third party impacts and the probability of stored water being available when needed.

AIV.2.2 Water Quality

A groundwater banking project of the type envisioned here should not encounter major water quality related problems in the short run. Longer term impacts are, however, much more difficult to predict. During the initial phases of a state-level conjunctive use program, water quality related problems are likely to be limited primarily to monitoring residues from agricultural operations (fertilizers and pesticides) and potential micro-element concerns in source water.[111] If direct percolation of water conveyed without intervening uses in dedicated recharge facilities is the primary recharge mechanism, source water quality should be high and problems relatively straightforward to monitor and control. Contamination is a point of concern primarily with spreading. It is also a concern if extraction causes major changes in hydraulic gradients and results in the mobilization of polluted or otherwise low quality water. This could emerge as a particular concern during long duration droughts when irrigators would be depending on groundwater as their primary source of supply over extended periods. There are two points it is important to make in this context:

1) Substantial contaminant loads including pesticides, fertilizers, salts and micro-elements such as selenium are currently isolated in the soil column. Increased flushing of the soil column due to intentional recharge (spreading) could mobilize large amounts of these contaminants. This would add to the contaminants picked up from current agricultural operations. Flushing from increased recharge could, on the other hand, have the opposite effect. Some suggest that the increased flow through aquifers resulting from conjunctive use operations could be used as a technique to reduce existing nitrate and other contamination.[112]

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[110]. Discussion with Glen Pearson, DWR on 8/17/95. In rice growing areas of the Sacramento Valley, shallow wells are observed to maintain steady water levels (lots of recharge) but deeper wells fluctuate substantially as pumping levels change. This suggests at least partial isolation of lower aquifers from upper levels.

[111]. Many conjunctive use projects envision recharge of reclaimed water. In this situation, treatment prior to injection is a major source of cost.

[112]. Personal communication, Walter Swain, U.S. Geological Survey

2) Changes in hydraulic gradients associated with extraction of stored groundwater is a major potential cause of contamination. In many locations, fresh water aquifers are in hydrologic contact with low quality water. Pumping fresh aquifers can cause intrusion of the low quality water essentially ruining them as a source or storage location. This is a common problem in coastal areas but is also of potentially great concern in many inland locations as well. On the western side of the Sacramento valley there are large areas of shallow saline groundwater that could be mobilized if hydraulic gradients change due to pumping associated with a conjunctive use program. Similar issues are present where high levels of Boron exist in groundwater making it unusable for many agricultural operations.[113]

Groundwater banking will inherently increase fluctuations in aquifer levels. This will increase both lateral and vertical flow within the groundwater system. This will, in turn, have a tendency to mobilize pollutants and naturally occurring contaminants. The net effects are, on a broad scale, difficult to predict. In some areas, increased flushing could cause net water quality improvements. In others, mobilization could have the opposite impact.

The degree to which water quality concerns are likely to emerge if conjunctive use operations are implemented is unknown. Clearly, care would be needed to avoid regions where quality problems already exist that could be exacerbated by program operations. Program exposure to potential quality problems is likely, however, to be greatest with spreading methods. These techniques are otherwise often the least costly. This suggests that direct recharge using percolation or injection techniques may, over the long term, prove less expensive because it is possible to avoid non-point sources of contamination to a much greater extent. Overall, monitoring of groundwater quality trends is particularly essential in any conjunctive management program using spreading for recharge or one that causes significant water table fluctuations to ensure that contamination from agricultural residues or other sources does not occur.

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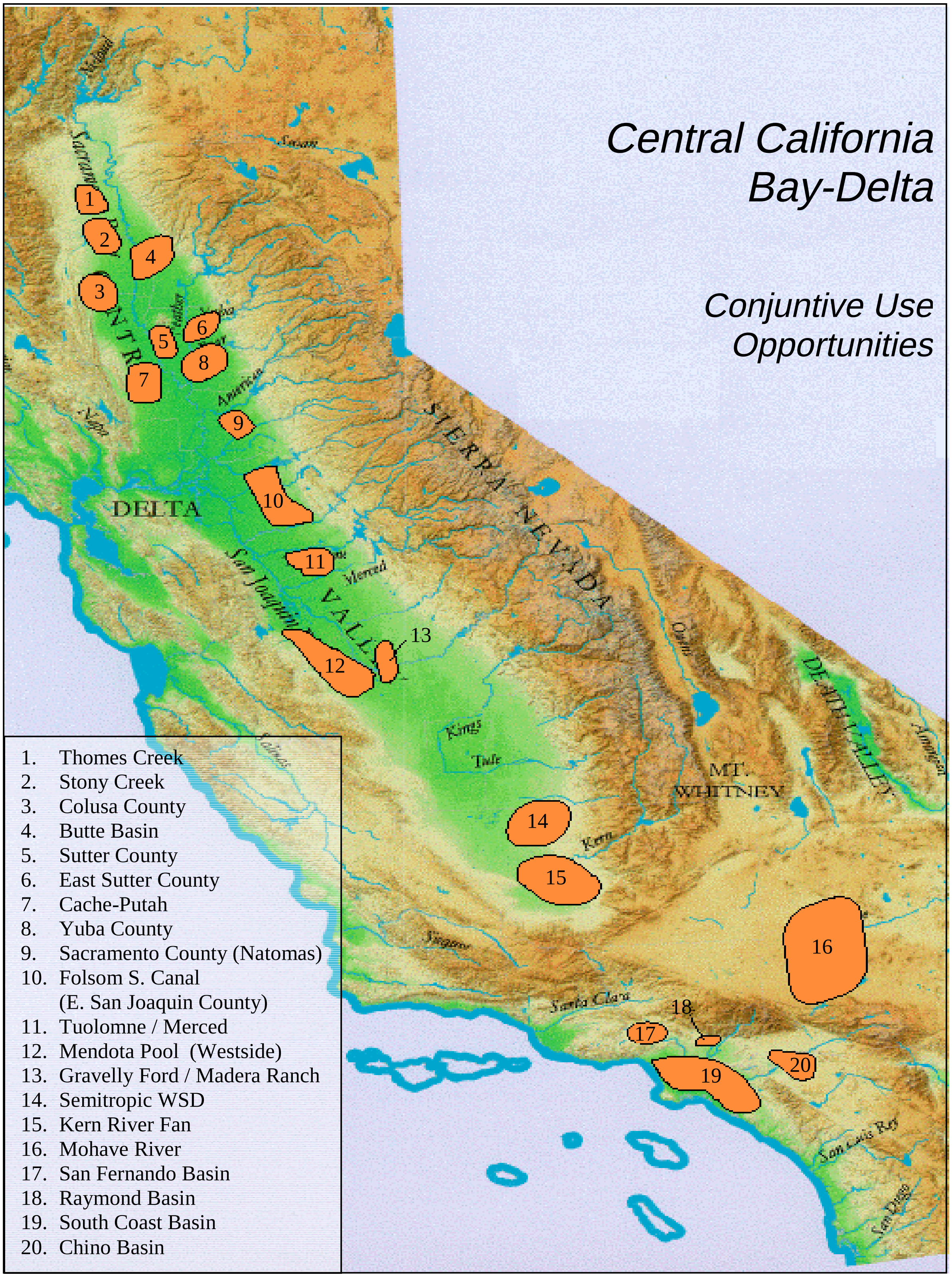
[113]. Personal Communication, Tocay Dudley, DWR, 8/21/95

Appendix V: Groundwater Banking Cost in California

Site	Cost per Acre-Foot (1994-95)	Method
Eastern Yolo County [1]	54	In lieu of irrigation
Natomas Central Mutual Water Company [2]	150	In lieu of irrigation
Pleasant Grove-Verona Mutual Water Company [2]	71	In lieu of irrigation
South Sutter Water District [2]	83	In lieu of irrigation
WID [3]	110-208	In-lieu and off season irrigation, price range depends on scale, small scale=low price. Most of difference related to additional wells and reconfiguring existing surface storage for recharge.
Antelope Valley-East Kern WA [4]	90	In lieu deliveries
Water Replenishment District of Southern California [5]	112	In lieu deliveries
Yuba County Water Agency [6]	30-35	In lieu deliveries
Leach Canyon in Riverside County [7]	141	Spreading Basins
McVicker Canyon in Riverside County [7]	176	Spreading Basins
Kern-Tulare WD and Rag Gulch WD [8]	30	Spreading Basins outside of district
Rosedale-Rio Bravo WSD [9]	10-12	Spreading Basins using excess river flow
Water Replenishment District of Southern California[10]	20	Spreading Basins using imported water. Cost/AF of imported water, depending on source can be $263, $480, or $501 11
Water Replenishment District of Southern California[10]	20	Spreading Basins using recycled water. Cost/AF of recycled water can be $15 or $380 11
Rosedale-Rio Bravo WSD [9]	50-62	Spreading Basins using SWP water
San Bernadino Valley MWD [12]	60-120	Spreading Basins
Mojave WA [13]	200	Spreading basins using SWP water
Kern County WA [14]	5-35	Spreading Basins, depending on source of water, cost for recharge alone.
Joint Management Board - Terra Bella ID, Lower Tule River ID, Saucelito ID, Pixley ID, and Porterville ID[15]	25	Spreading Basins
Average for various sites in Central Valley 16	90-120	Active percolation
Orange County WD [17]	20	Active percolation
WID & SJCID [3]	110-337	Active percolation combined with in-lieu and off-season irrigation. Price range depends on scale. Most of difference related to conveyance facilities for withdrawal.
Alameda Co. WD [18]	189	Active percolation in recharge pits and along creek bed
Raymond Basin Management Board[19]	10	Active percolation of natural run-off

Chino Basin Watermaster[20]	249	Active percolation with MWDSC SSP water
Chino Basin WCD[21]	102	Active percolation recharge
Dudley Ridge WD[22]	65-110	Active percolation recharge outside of district
Wetlands east of Lake Elsinore in Riverside County[7]	186	Injection
MWDSC with Calleguas WD in Las Posas Basin[23]	130	Injection and extraction
Raymond Basin Management Board[19]	50	Injection using discounted water from MWDSC
Arcade WD[24]	80	Combination of injection and in-lieu deliveries

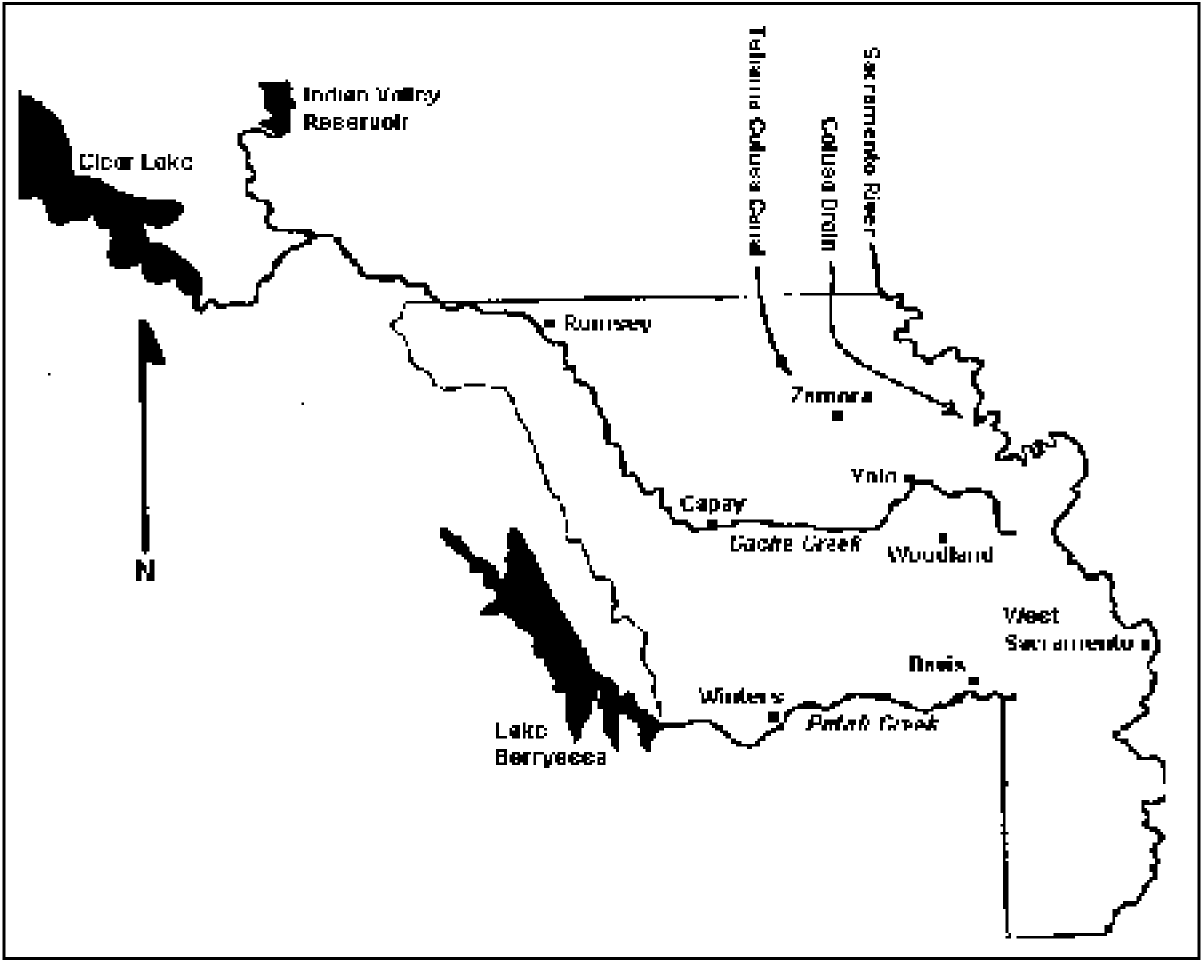
1 DWR, 1994, SWP Conjunctive Use--Eastern Yolo County
2 DWR, 1995, American Basin Conjunctive Use Project, Pre-Feasibility Report, P. 125
3 EDAW, Inc. December, 1992. Draft EIS/EIR for the Updated Water Supply ManagementProgram, Volume V, Technical Appendices D1-D3 and E1-E3. Prepared for East Bay Municipal Utility District, Oakland, California.
4 Fuller, R., Antelope Valley-East Kern WA. July 18, 1995. Personal Communication.
5 Water Replenishment District of Southern California. 1995. Annual Survey and Report on Groundwater Replenishment, p. 30. In-lieu reimbursement is $112, the District uses the same rate to determine expenditures for in-lieu replenishment.
6 Wilson, D., Yuba County WA. June 1995. Personal Communication.
7 Elsinore Valley Municipal Water District, 1994, Ground Water Recharge Feasibility Study Final Report, prepared by GEOSCIENCE Support Services Inc., p. 46
8 Bowers, B., Kern-Tulare and Rag Gulch WD. July 1995. Personal Communication. $30/AF is an average estimate
9 Crossley, H., Rosedale-Riobravo WSD. June 1995. Personal Communication. Cost includes variable costs only.
10 Garcia, M., Water Replenishment District of Southern California. August 18, 1995. Personal Communication. Cost of recharge is roughly estimated to be $20/AF. Currently, the Los Angeles Department of Public Works operates and funds recharge activities, and has not calculated the cost per AF for recharge.
11 Water Replenishment District of Southern California. 1995. Annual Survey and Report on Groundwater Replenishment., p. 5.
12 Tincher, Bob, San Bernadino Valley MWD. August 3, 1995. Personal Communication. Cost figures include amount paid for recharge facilities, does not include pumping costs. Price is subsidized
13 Mojave Water Agency. May 1993. Regional Water Management Plan. Prepared by Boyle Engineering Corporation
14 Kern County WA. April 1995. 1995 KFE Property Recharge Program.
15 Robb, R., Lower Tule River ID. July 1995. Personal Communication.
16 U.S. Bureau of Reclamation and Fish and Wildlife Service, July 1995, DRAFT Conjunctive Use Technical appendix #4 to the Least-Cost CVP Yield Increase Plan, p. 6-1
17 Van Haun, J., Orange County WD. June 1995. Personal Communication.
18 Alameda County WD. February 1995. Survey Report on Groundwater Conditions. p. 21.
19 Ron Palmer, Raymond Basin Management Board. July 1995. Personal Communication.
20 Stewart, T., Chino Basin Watermaster. August 1995. Personal Communication.
21 Gumina, S., Chino Basin WCD. July 1995. Survey results.
22 Melville, D., Dudley Ridge WD., July 1995. Survey results. Cost does not include cost of water which can be highly variable.
23 Horne, W.. June, 8, 1995. General Methods & Facilities to Expand Conjunctive Use. Presents at the ACWA 1995 Ground Water Mini-Conference Conjunctive Use
24 CH2M Hill,. November 1993. Groundwater Recharge Project Feasibility Report. Prepared for Arcade Water District. Cost/AF calculated using present worth of project (20-year project life, 4% annual inflation, and 8.25% discount rate) of $28.65 million / 17,960 AF/yr * 20 years (359,200 AF) = $80/AF

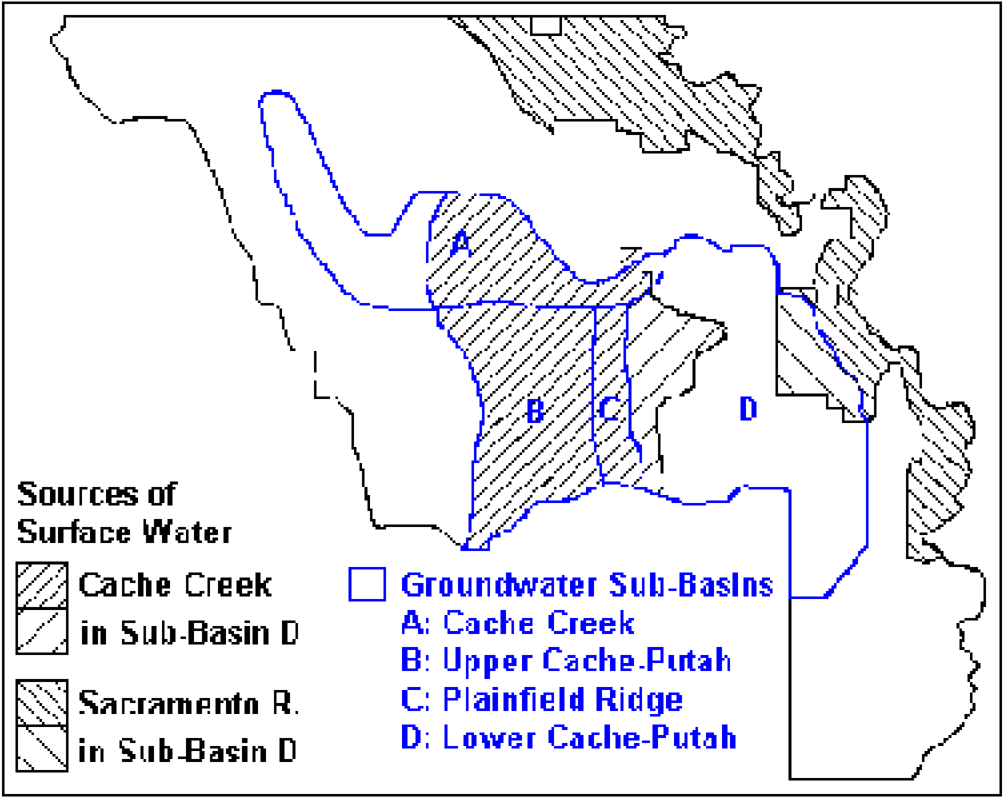


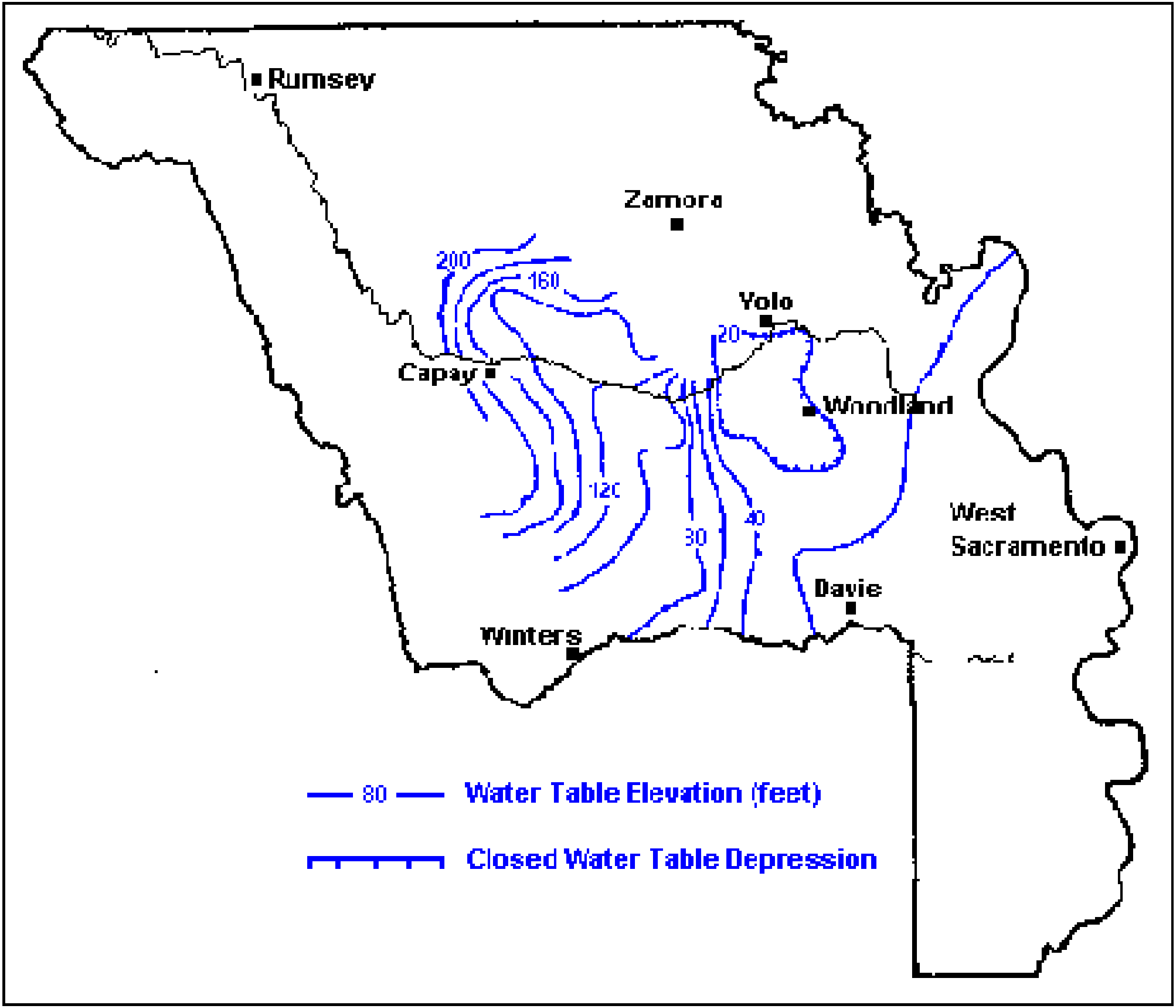
Central California Bay-Delta

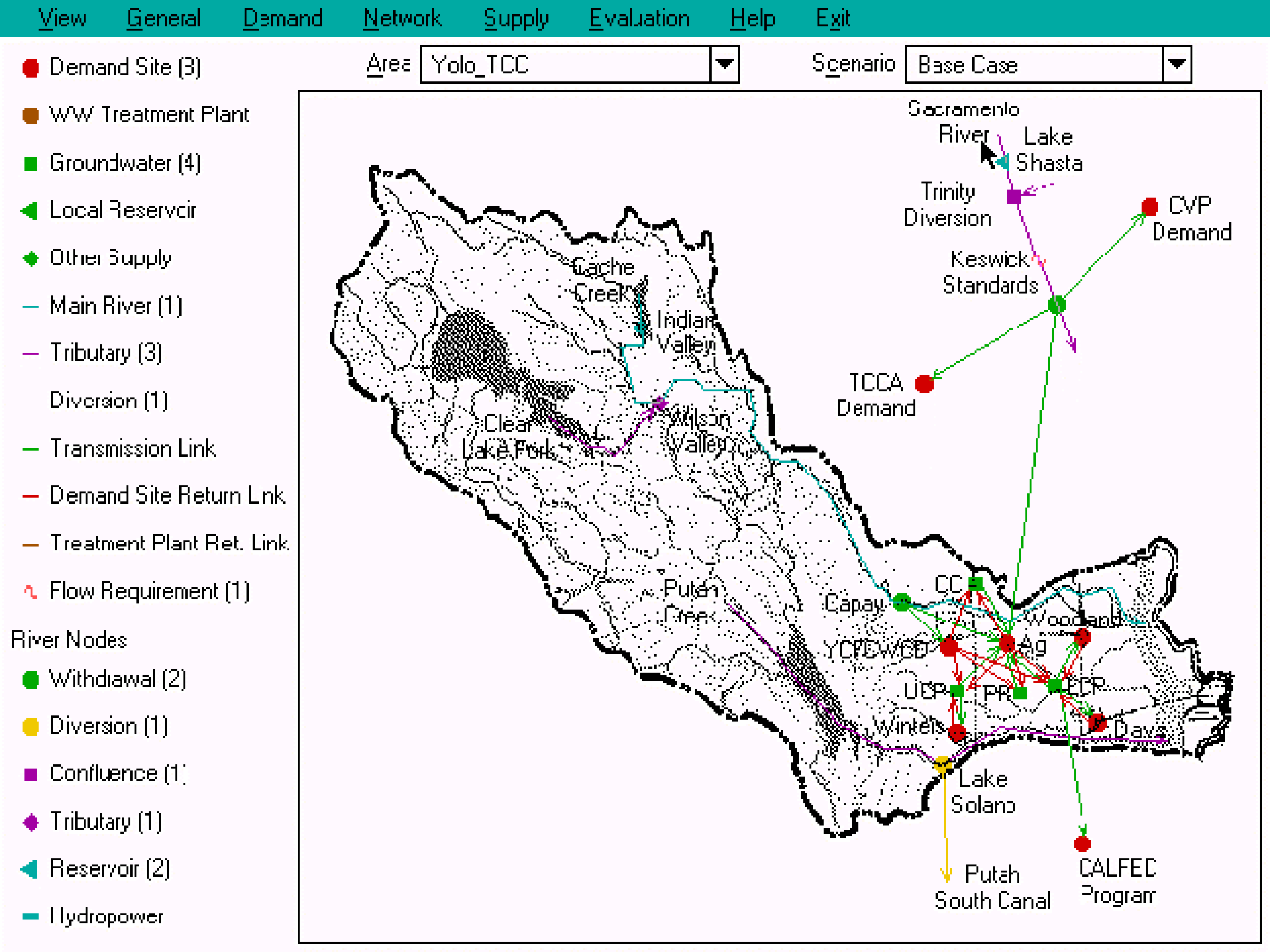
Conjuntive Use Opportunities

1. Thomes Creek
2. Stony Creek
3. Colusa County
4. Butte Basin
5. Sutter County
6. East Sutter County
7. Cache-Putah
8. Yuba County
9. Sacramento County (Natomas)
10. Folsom S. Canal (E. San Joaquin County)
11. Tuolomne / Merced
12. Mendota Pool (Westside)
13. Gravelly Ford / Madera Ranch
14. Semitropic WSD
15. Kern River Fan
16. Mohave River
17. San Fernando Basin
18. Raymond Basin
19. South Coast Basin
20. Chino Basin


Tehama Colusa Canal
Sacramento River
Colusa Drain
Indian Valley Reservoir
Clear Lake
Rumsey
Zamora
N
Yolo
Capay
Cache Creek
Woodland
West Sacramento
Davis
Winters
Putah Creek
Lake Berryessa

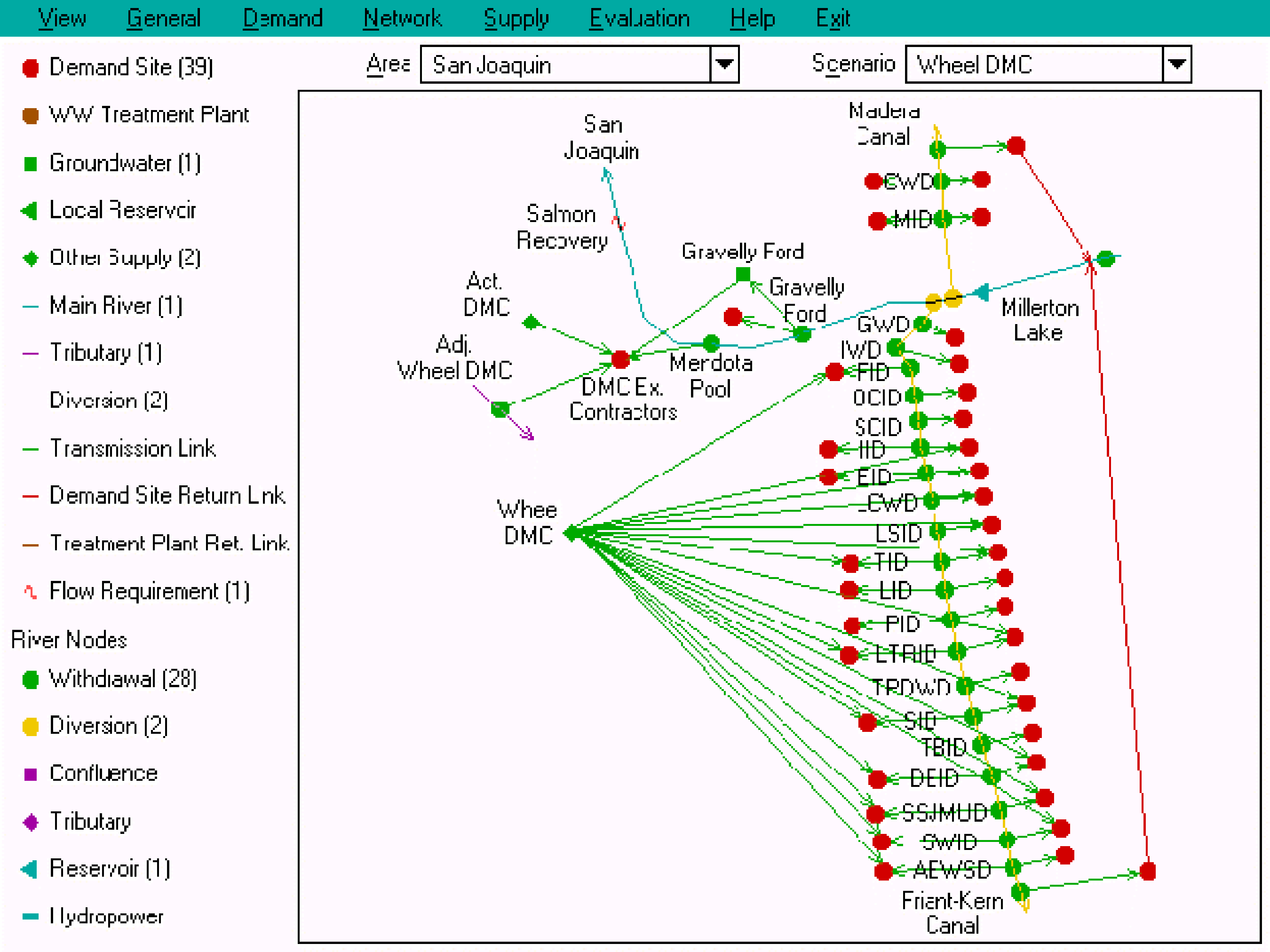

A
B
C
D
Sources of Surface Water
Cache Creek
in Sub-Basin D
Sacramento R.
in Sub-Basin D
Groundwater Sub-Basins
A: Cache Creek
B: Upper Cache-Putah
C: Plainfield Ridge
D: Lower Cache-Putah


Rumsey
Zamora
200
160
Yolo
20
Capay
Woodland
120
40
30
West
Sacramento
Davis
Winters
80 Water Table Elevation (feet)
Closed Water Table Depression



Area: Yolo_TCC

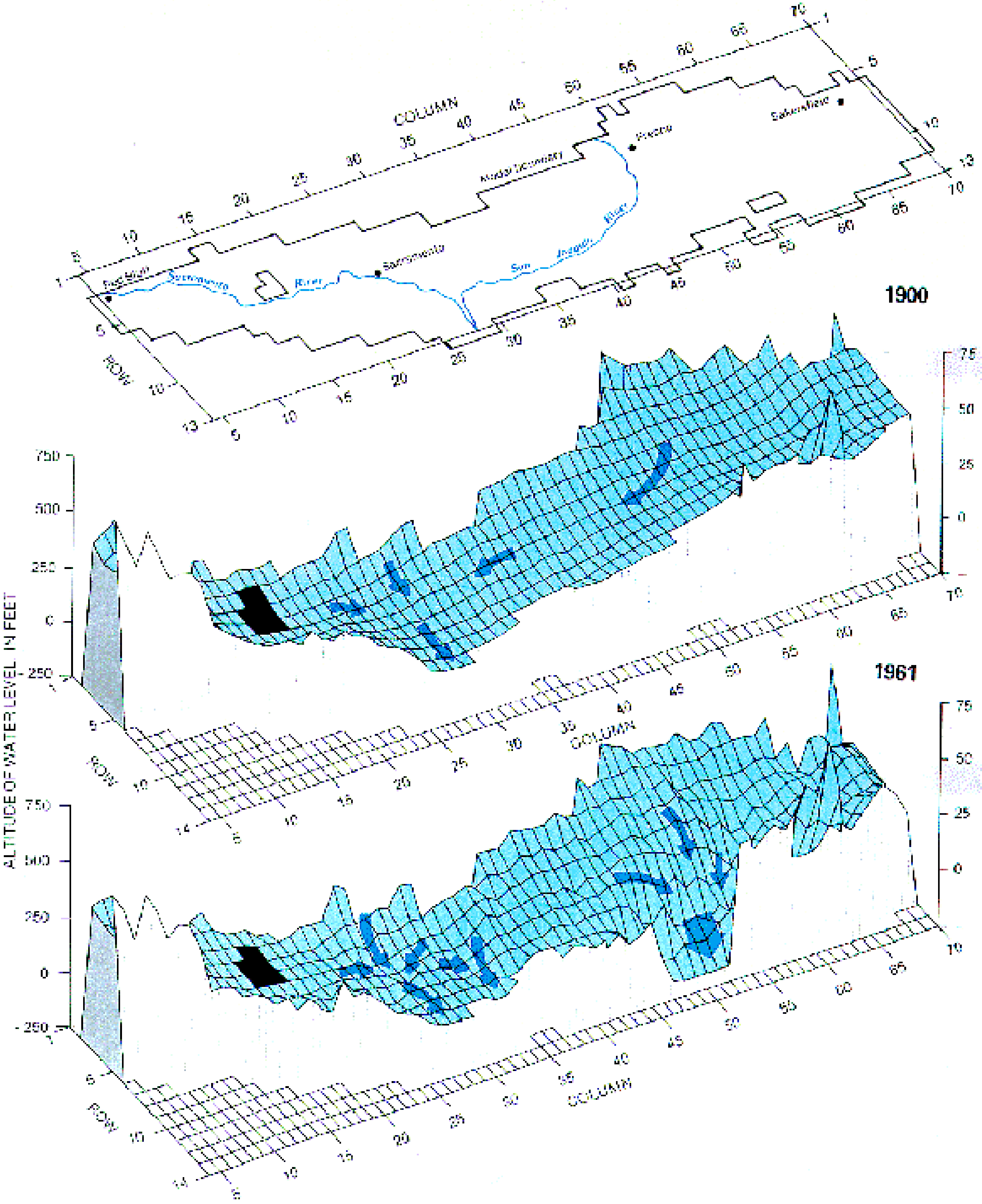
Scenario: Base Case

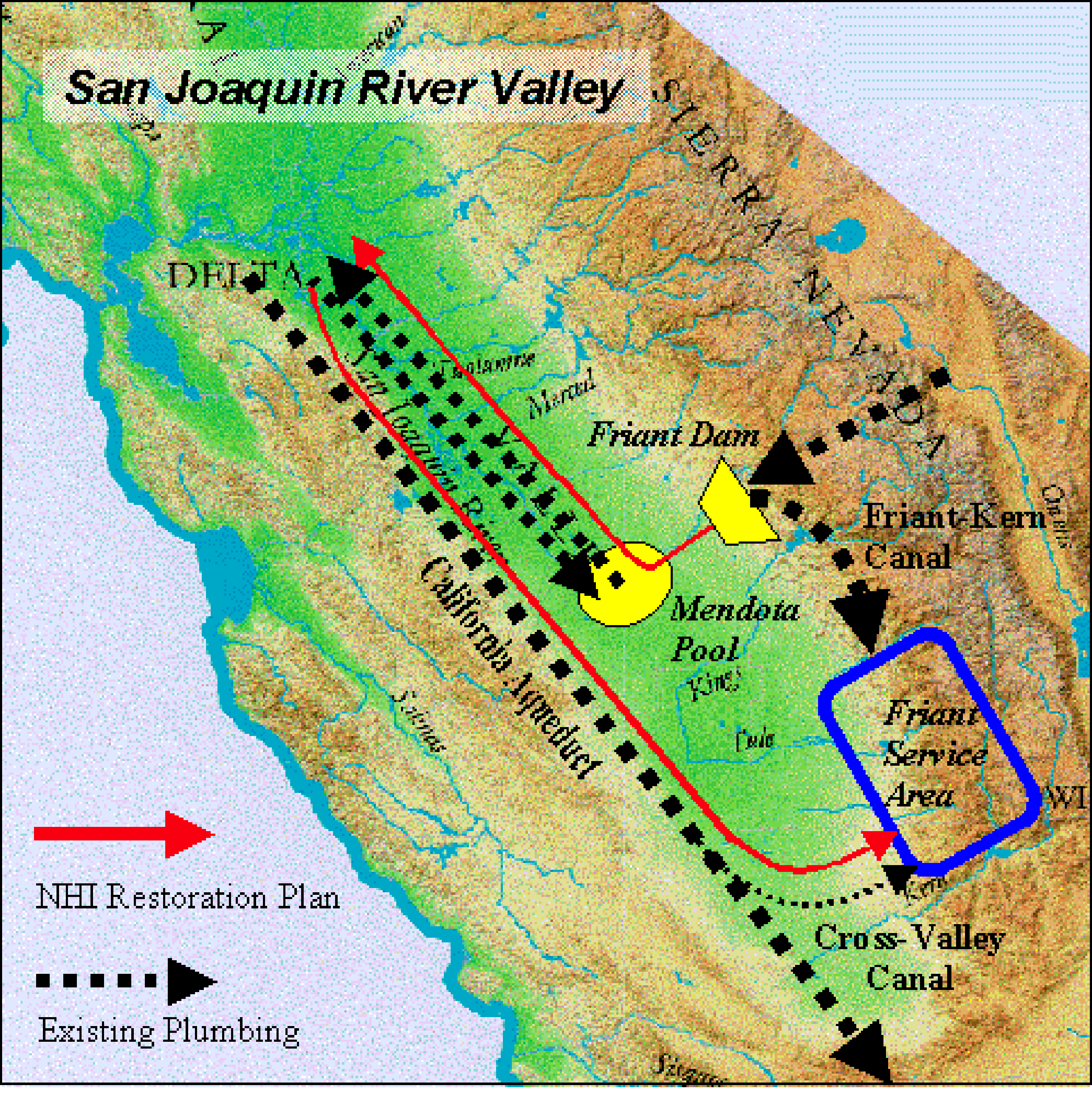


Area: San Joaquin

Scenario: Wheel DMC


Clifton Court
Madera Ranch/ Gravelly Ford
Madera Canal
San Luis Reservoir/ O'Neill Forebay
San Joaquin River
Friant Dam/ Millerton Lake
Dos Amigos PP
Medota Pool
Delta-Mendota Canal
Friant-Kern Canal
California Aqueduct
Buena Vista PP
Cross Valley Canal


COLUMN
ROW
Red Bluff
Sacramento River
Sacramento
San Joaquin River
Fresno
Bakersfield
Model boundary
1900
1961
ALTITUDE OF WATER LEVEL, IN FEET
750
500
250
0
-250
75
50
25
0


San Joaquin River Valley
SIERRA NEVADA
DELTA
Tuolumne
Merced
San Joaquin River
California Aqueduct
Friant Dam
Friant-Kern Canal
Mendota Pool
Kings
Tule
Friant Service Area
Kern
Cross-Valley Canal
Salinas
NHI Restoration Plan
Existing Plumbing

DRAFT Technical Memorandum

Operation Guidelines for Implementing Restoration Flows

SAN JOAQUIN RIVER
RESTORATION PROGRAM

April 2008

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List of Abbreviations and Acronyms

cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
FWUA	Friant Water Users Authority
NRDC	Natural Resources Defense Council
RA	Restoration Administrator
Reclamation	United States Department of the Interior, Bureau of Reclamation
RWA	Recovered Water Account
Settlement	San Joaquin River Settlement
SJRRP	San Joaquin River Restoration Program
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TM	Technical Memorandum

This Draft Technical Memorandum (TM) was prepared by the San Joaquin River Restoration Program (SJRRP) Team as a draft document in support of preparing a Program Environmental Impact Statement/Report (PEIS/R). The purpose for circulating this document at this time is to facilitate early coordination regarding initial concepts and approaches currently under consideration by the Program Team with the Settling Parties, the Third Parties, other stakeholders, and interested members of the public. As such, the content of this document may not necessarily be included in the PEIS/R.

This Draft TM does not present findings, decisions, or policy statements of any of the Implementing Agencies. Additionally, all information presented in this document is intended to be consistent with the Settlement. To the extent inconsistencies exist, the Settlement should be the controlling document and the information in this document will be revised prior to its inclusion in future documents. While the Program Team is not requesting formal comments on this document, all comments received will be considered in refining the concepts and approaches described herein to the extent possible. Responses to comments will not be provided and this document will not be finalized; however, refinements will likely be reflected in subsequent program documents.

1.0 Introduction

This Operation Guidelines for Implementing Restoration Flows Technical Memorandum (TM) was prepared in support of the San Joaquin River Restoration Program (SJRRP). This TM provides an interpretation of the Stipulation of Settlement (Settlement) that includes details on releasing Restoration Flows from Friant Dam in accordance with hydrographs attached to the Settlement as Exhibit B. It is intended that this TM be used to supplement the existing Friant Operations Guidelines, and also used to guide default operations during periods when specific recommendations have not been provided to the Secretary by the Restoration Administrator (RA), or during periods of conflict.

1.1 Background

In 1988, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC), filed a lawsuit challenging the renewal of long-term water service contracts between the United States and the Central Valley Project (CVP) Friant Division contractors. After more than 18 years of litigation of this lawsuit, known as *NRDC et al. v. Kirk Rodgers et al.*, a Settlement was reached. On September 13, 2006, the “Settling Parties” agreed on the terms and conditions of the Settlement, which was subsequently approved by the Court on October 23, 2006. The “Settling Parties” include NRDC, Friant Water Users Authority (FWUA), and the United States Departments of the Interior and Commerce.

The Settlement identified two goals, the Restoration Goal and the Water Management Goal:

- Restoration Goal – Restore and maintain fish populations in "good condition" in the main stem of the San Joaquin River below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish.

- Water Management Goal – Reduce or avoid adverse water supply impacts to all of the Friant Division long-term contractors that may result from the Interim Flows and Restoration Flows.

The SJRRP will implement the San Joaquin River litigation Settlement by meeting these two identified goals. The "Implementing Agencies" responsible for management of the SJRRP include the United States Department of the Interior, through the Bureau of Reclamation (Reclamation) and the Fish and Wildlife Service; United States Department of Commerce through the National Marine Fisheries Service; and the State of California through the Department of Water Resources (DWR) and the Department of Fish and Game.

1.2 Related Settlement Language

This TM covers default operation guidelines for implementing Restoration Flows. The procedures for establishing a Recovered Water Account (RWA) required in the Settlement is a related topic that must be considered at the same time and is also discussed herein. Language in the Settlement related to the default operation guidelines and RWA is given below.

1.2.1 Restoration Flow Guidelines

Paragraph 13 of the Settlement describes implementing Restoration Flows. Some subsections are especially relevant to this TM, and are included in the following:

Line 24, Page 10

> 13. In addition to the channel and structural improvements identified in Paragraph 11, releases of water from Friant Dam to the confluence of the Merced River shall be made to achieve the Restoration Goal as follows:
>
> (a) All such additional releases from Friant Dam shall be in accordance with the hydrographs attached hereto collectively as Exhibit B (the "Base Flow"), plus releases of up to an additional ten percent (10 percent) of the applicable hydrograph flows (the "Buffer Flows") may be made by the Secretary [of the Interior] based upon the recommendation of the Restoration Administrator to the Secretary, as provided in Paragraph 18 and Exhibit B. The Base Flows, the Buffer Flows and any additional water acquired by the Secretary from willing

sellers to meet the Restoration Goal are collectively referred to as the "Restoration Flow." Additional water acquired by the Secretary may be carried over or stored provided that doing so shall not increase the water delivery reductions to any Friant Division long-term contractor beyond that caused by releases made in accordance with the hydrographs (Exhibit B) and the Buffer Flows.

(b) The Restoration Flows identified in Exhibit B include releases from Friant Dam for downstream riparian interests between Friant Dam and Gravelly Ford and assume the current level of downstream diversions and seepage losses downstream of Gravelly Ford.

Line 19, Page 13

(d) Notwithstanding Paragraphs 13(a), (b), and (c), the Parties acknowledge that flood control is a primary authorized purpose of Friant Dam, that flood flows may accomplish some or all of the Restoration Flow purposes to the extent consistent with the hydrographs in Exhibit B and the guidelines developed pursuant to Paragraph 13(j), and further acknowledge that there may be times when the flows called for in the hydrographs in Exhibit B may be exceeded as a result of operation of Friant Dam for flood control purposes. Nothing in this Settlement shall be construed to limit, affect, or interfere with the Secretary's ability to carry out such flood control operations.

(e) Notwithstanding Paragraphs 13(a), (b), and (c), the Secretary may temporarily increase, reduce, or discontinue the release of water called for in the hydrographs shown in Exhibit B for the purpose of investigating, inspecting, maintaining, repairing, or replacing any of the facilities, or parts of facilities, of the Friant Division of the Central Valley Project (the "CVP"), necessary for the release of such Restoration Flows; however, except in cases of emergency, prior to taking any such action, the Secretary shall consult with the Restoration Administrator regarding the timing and implementation of any such action to avoid adverse effects on fish to the extent possible. The Secretary shall use reasonable efforts to avoid any such increase, reduction, or discontinuance of release. Upon resumption of service after any such reduction or discontinuance, the Secretary, in consultation with the Restoration Administrator, shall release, to the extent reasonably practicable, the quantity of water which would have been released in the absence of such discontinuance or reduction when doing so will not increase the water delivery reductions to any Friant Division long-term contractors beyond what would have been caused by releases made in accordance with the hydrographs (Exhibit B) and Buffer Flows.

Line 25, Page 16

> (j) Prior to the commencement of the Restoration Flows as provided in this Paragraph 13, the Secretary, in consultation with the Plaintiffs and Friant Parties, shall develop guidelines, which shall include, but not be limited to: (i) procedures for determining water-year types and the timing of the Restoration Flows consistent with the hydrograph releases (Exhibit B); (ii) procedures for the measurement, monitoring and reporting of the daily releases of the Restoration Flows and the rate of flow at the locations listed in Paragraph 13(g) to assess compliance with the hydrographs (Exhibit B) and any other applicable releases (e.g., Buffer Flows); (iii) procedures for determining and accounting for reductions in water deliveries to Friant Division long-term contractors caused by the Interim Flows and Restoration Flows; (iv) developing a methodology to determine whether seepage losses and/or downstream surface or underground diversions increase beyond current levels assumed in Exhibit B; (v) procedures for making real-time changes to the actual releases from Friant Dam necessitated by unforeseen or extraordinary circumstances; and (vi) procedures for determining the extent to which flood releases meet the Restoration Flow hydrograph releases made in accordance with Exhibit B. Such guidelines shall also establish the procedures to be followed to make amendments or changes to the guidelines.

Line 5, Page 23

> 18. The selection and duties of the Restoration Administrator and the Technical Advisory Committee are set forth in this Settlement and Exhibit D. Consistent with Exhibit B, the Restoration Administrator shall make recommendations to the Secretary concerning the manner in which the hydrographs shall be implemented and when the Buffer Flows are needed to help in meeting the Restoration Goal. In making such recommendations, the Restoration Administrator shall consult with the Technical Advisory Committee, provided that members of the Technical Advisory Committee are timely available for such consultation. The Secretary shall consider and implement these recommendations to the extent consistent with applicable law, operational criteria (including flood control, safety of dams, and operations and maintenance), and the terms of this Settlement. Except as specifically provided in Exhibit B, the Restoration Administrator shall not recommend changes in specific release schedules within an applicable hydrograph that change the total amount of water otherwise required to be released pursuant to the applicable hydrograph (Exhibit B) or which increase the water delivery reductions to any Friant Division long-term contractors.

Exhibit B presents hydrographs that constitute the Base Flows referenced in Paragraph 13 of the Settlement. In addition, the exhibit contains specifics of the following subjects:

- Buffer Flows[1]
- Restoration year types for applying the six hydrographs
- Intent to transform the annual allocation methodology from Exhibit B's stair-step hydrograph approach to more continuous approach
- Flexibility in timing of releases in selected periods
- Flushing flows (a block of water averaging 4,000 (cubic feet per second (cfs)) from April 16 through 30 in normal-wet and wet years
- Riparian recruitment flows (a block of water averaging 2,000 cfs) from May 1 through June 30 in wet years[2]

1.2.2 Recovered Water Account

Page 20, Line 9

> 16. In order to achieve the Water Management Goal, immediately upon the Effective Date of this Settlement, the Secretary, in consultation with the Plaintiffs and Friant Parties, shall commence activities pursuant to applicable law and provisions of this Settlement to develop and implement the following:
>
> (b) A Recovered Water Account (the "Account") and program to make water available to all of the Friant Division long-term contractors who provide water to meet Interim Flows or Restoration Flows for the purpose of reducing or avoiding the impact of the Interim Flows and Restoration Flows on such contractors. In implementing this Account, the Secretary shall:
>
> (1) Monitor and record reductions in water deliveries to Friant Division long-term contractors occurring as a direct result of the Interim Flows and Restoration Flows that have not been replaced by recirculation, recapture, reuse, exchange or transfer of Interim Flows and Restoration Flows or replaced or offset by other water programs or projects undertaken or funded by the Secretary or other Federal Agency or agency of the State of California specifically to mitigate the water delivery impacts caused by the Interim Flows and Restoration Flows ("Reduction in Water Deliveries"). For purposes of this Account, water voluntarily sold to the Secretary either to mitigate Unexpected Seepage Looses or to augment Base Flows by any Friant Division long-term contractor shall not be considered a Reduction in Water Delivery caused by this Settlement. The Account shall establish

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[1] In Exhibit B, the term "Restoration Flows" was defined as Base Flows plus Buffer Flows.

[2] See Exhibit B, Table 1F, Proposed Restoration Flow Release Schedule and Accounting for Wet Year Type on the San Joaquin River, Footnote 9.

> a baseline condition as of the Effective Date of this Settlement with respect to water deliveries for the purpose of determining such reductions. The balance of any Friant Division long-term contractor in the Account shall be annually adjusted in accordance with the provisions of this Paragraph 16(b)(1) and of Paragraph 16(b)(2). Each Friant Division long-term contractor's account shall accrue one acre foot of water for each acre foot of Reduction in Water Deliveries. In those years when, pursuant to Paragraphs 13(a) and 19, the Secretary, in consultation with the Restoration Administrator, determines to increase releases to include some or all of the Buffer Flows, Friant Division long-term contractors shall accrue into their account one and one quarter acre foot for each acre foot of Reduction in Water Deliveries;
>
> (2) Make water available as herein provided to all of the Friant Division long-term contractors who experience a Reduction in Water Deliveries as a direct result of the release of Interim Flows and Restoration Flows as reflected in their Account maintained pursuant to Paragraph 16(b)(1). Water shall be made available only in wet hydrologic conditions when water is not needed for the Interim Flows and Restoration Flows as provided for in this Settlement, to meet obligations of the Secretary existing on the Effective Date of this Settlement, as determined by the Secretary;
>
> (3) Make water available to the Friant Division long-term contractors pursuant to Paragraph 17(b)(2) at the total cost of $10.00 per acre foot, which amounts shall be deposited into the Restoration Fund to be established by the legislation authorizing implementation of the Settlement;
>
> (4) Ensure that recovery of the cost of any new CVP facilities for storage or conveyance of CVP water is not determined according to the provisions of this Paragraph 16; and
>
> (5) Implement the Account and program developed pursuant to this Paragraph in accordance with all applicable laws, regulations and standards.

1.3 Purpose and Scope of this Technical Memorandum

As previously mentioned, this TM covers the default operation guidelines for implementing Restoration Flows under the Settlement. The RWA, an account to record associated water supply impacts from implementing the Restoration Flows, is a related subject and thus is discussed herein. This TM focuses on the following topics associated with Restoration Flows:

- Restoration year type classification and application [Paragraph 13(j)(i)]
- Interannual interpretation of hydrographs [Paragraphs13(a), 13(b) and Exhibit B]
- Default Friant Dam operation with obligation of releasing Restoration Flows [Paragraphs 13(j)(iii), 13(j)(v), and 13(j)(vi)]
- Procedures for making real-time changes to actual releases from Friant Dam necessitated by hydrologic uncertainties and other real-time operation considerations [Paragraphs 13(j)(v) and 18]
- Procedures for determining the extent to which flood releases meet Restoration Flow hydrograph releases made in accordance with Exhibit B [Paragraphs 13(d) and 13(j)(vi)]
- Procedures for RWA accounting [Paragraph 16(b)]

The guidelines described in this TM may ultimately be incorporated into a definitive policy document separate from or amended to the Operational Guidelines for Water Service – Friant Division Central Valley Project, which is currently used for Friant Division operation (Reclamation, 2005).

1.4 Related Topics Covered by Future Refinements and/or Other Technical Memoranda

The following topics included in Paragraph 13 and Exhibit B of the Settlement will not be addressed in this TM, but in future refinement or other TMs:

- Procedures and protocols for implementing Buffer flows and hydrograph flexibility that may be recommended by the RA and/or other advisory parties are considered part of real-time operations [Exhibit B]
- Intermonthly hydrograph smoothing based on flushing flows for fishery and riparian vegetation, or riparian recruitment flows [Exhibit B]
- Measurement procedures and monitoring requirements [Paragraph 13(j)(ii)]
- Development of methodology and procedures for seepage evaluation [Paragraph 13(j)(iv)]
- Framework for developing a plan to achieve the Water Management Goal and details of plan components [Paragraph 16]

Some of the topics above would also be incorporated in the above-mentioned policy document separate from or amended to the Operational Guidelines for Water Service – Friant Division Central Valley Project (Reclamation, 2005).

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2.0 Restoration Flow Year Types

This section provides the derivation of the Restoration year type classification and its application in real-life operations with use of forecast hydrological information.

2.1 Settlement Specification and Required Refinements

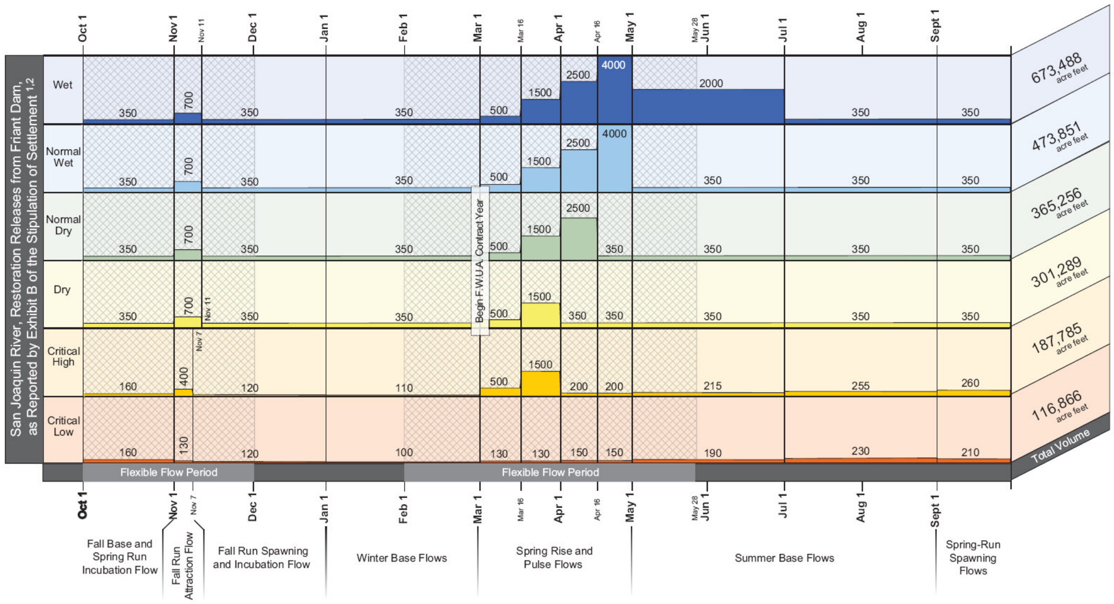
Exhibit B of the Settlement identifies a set of six hydrographs (see Figure 2-1) that vary in shape and volume according to the annual unimpaired runoff of the San Joaquin River at Friant Dam for a water year (October 1 through September 30). The six year types (referred to as Restoration Flow year types in this TM) are “critical-low,” “critical-high,” “dry,” “normal-dry,” “normal-wet,” and “wet.”

Based on the historical record of unimpaired flow for water years 1922 through 2004, Exhibit B includes a Restoration year type classification system based on percentage of occurrence in this 83-year period. The wettest 20 percent of these years are classified as “wet.” In order of descending wetness, the next 30 percent of the years are classified as “normal-wet,” the next 30 percent of the years are classified as “normal-dry,” and the next 15 percent of the years are classified as “dry.” The remaining 5 percent of the years are classified as “critical.” A subset of the critical years, with less than 400,000 acre-feet of unimpaired runoff (i.e., water years 1924 and 1977), are classified as “critical-low”; the remaining critical years are classified as “critical-high.”

The Settlement defines year types based on their occurrence in an 83-year period, from 1922 through 2004, without using a conventional threshold approach. While the associated year type for each year within the 83-year period is clear, the extrapolation of such a Restoration year type definition for years outside this period is not. The refinements of Restoration year type classification for the SJRRP are discussion below in three parts:

- Classification thresholds
- Beginning date for year type application and corresponding Restoration Flows schedule
- Incorporation of hydrologic forecast uncertainties

The first two items are discussed in this section, and hydrologic forecast uncertainties are discussed in detail in Section 4.



San Joaquin River, Restoration Releases from Friant Dam, as Reported by Exhibit B of the Stipulation of Settlement[1,2]

1 - NRDC v Rodgers, Stipulation of Settlement, CIV NO. S-88-1658 - LKK/GGH, Exhibit B. September 13, 2006
2 - Hydrographs reflect assumptions about seepage losses and tributary inflows which are specified in the settlement

Figure 2-1.
Restoration Flow Hydrographs, by Restoration Year Type:
Presentation Depicts the Stair-Step Hydrograph Allocation Method, as in Exhibit B

2.2 Classification Thresholds

The Settlement defines Restoration year types using annual unimpaired inflow below Friant Dam, for water years 1922 through 2004. Table 2-1 compares the Restoration year type classification with the San Joaquin Valley Water Year Types,[3] which is referenced in other management activities throughout the San Joaquin River basin. Table 2-2 shows the Restoration year type classification of the referenced period, sorted by annual unimpaired inflow below Friant Dam.

As previously mentioned, the Restoration year type classification was not based on a set of statistical thresholds, but instead by using the percentage of occurrences for annual inflows over the 83-year period of record; this is equivalent to the *n*-plotting position method without any hypothesis for the underlying statistical distribution. For Restoration year type classification purposes, the question is: at what point within the difference between these two volumes does the Restoration year type classification change?

---

[3] State Water Resources Control Board (SWRCB), Water Right Decision 1641.

Table 2-1.
Restoration Year Type Classification Compared with San Joaquin Valley Water Year Types

Water Year	October-through-September San Joaquin River Unimpaired Flow at Friant Dam (TAF)	Restoration Year Type*	San Joaquin Valley Water Year Types*
1922	2,355.1	Normal-Wet	Wet
1923	1,654.3	Normal-Wet	Above Normal
1924	444.1	Critical High	Critical
1925	1,438.7	Normal-Dry	Below Normal
1926	1,161.4	Normal-Dry	Dry
1927	2,001.3	Normal-Wet	Above Normal
1928	1,153.7	Normal-Dry	Below Normal
1929	862.4	Dry	Critical
1930	859.1	Dry	Critical
1931	480.2	Critical High	Critical
1932	2,047.4	Normal-Wet	Above Normal
1933	1,111.4	Normal-Dry	Dry
1934	691.5	Dry	Critical
1935	1,923.2	Normal-Wet	Above Normal
1936	1,853.3	Normal-Wet	Above Normal
1937	2,208.0	Normal-Wet	Wet
1938	3,688.4	Wet	Wet
1939	920.8	Dry	Dry
1940	1,880.6	Normal-Wet	Above Normal
1941	2,652.5	Wet	Wet
1942	2,254.0	Normal-Wet	Wet
1943	2,053.7	Normal-Wet	Wet
1944	1,265.4	Normal-Dry	Below Normal
1945	2,138.1	Normal-Wet	Above Normal
1946	1,729.6	Normal-Wet	Above Normal
1947	1,125.5	Normal-Dry	Dry
1948	1,214.8	Normal-Dry	Below Normal
1949	1,164.1	Normal-Dry	Below Normal
1950	1,310.5	Normal-Dry	Below Normal
1951	1,859.0	Normal-Wet	Above Normal
1952	2,840.1	Wet	Wet
1953	1,226.7	Normal-Dry	Below Normal
1954	1,313.8	Normal-Dry	Below Normal
1955	1,161.0	Normal-Dry	Dry
1956	2,960.1	Wet	Wet
1957	1,326.6	Normal-Dry	Below Normal
1958	2,631.0	Wet	Wet
1959	949.3	Normal-Dry	Dry
1960	828.6	Dry	Critical
1961	646.9	Critical High	Critical
1962	1,923.6	Normal-Wet	Below Normal
1963	1,944.9	Normal-Wet	Above Normal
1964	922.2	Dry	Dry
1965	2,272.2	Normal-Wet	Wet
1966	1,298.6	Normal-Dry	Below Normal
1967	3,232.2	Wet	Wet
1968	862.1	Dry	Dry
1969	4,040.3	Wet	Wet
1970	1,445.6	Normal-Dry	Above Normal
1971	1,417.5	Normal-Dry	Below Normal
1972	1,039.0	Normal-Dry	Dry
1973	2,047.0	Normal-Wet	Above Normal
1974	2,190.5	Normal-Wet	Wet
1975	1,795.7	Normal-Wet	Wet
1976	629.2	Critical High	Critical
1977	361.6	Critical Low	Critical
1978	3,401.9	Wet	Wet
1979	1,830.3	Normal-Wet	Above Normal
1980	2,972.7	Wet	Wet
1981	1,068.0	Normal-Dry	Dry
1982	3,316.1	Wet	Wet
1983	4,641.9	Wet	Wet
1984	2,048.9	Normal-Wet	Above Normal
1985	1,129.0	Normal-Dry	Dry
1986	3,031.4	Wet	Wet
1987	757.6	Dry	Critical
1988	862.1	Dry	Critical
1989	939.2	Normal-Dry	Critical
1990	742.5	Dry	Critical
1991	1,034.1	Normal-Dry	Critical
1992	808.5	Dry	Critical
1993	2,672.9	Wet	Wet
1994	826.4	Dry	Critical
1995	3,877.7	Wet	Wet
1996	2,202.8	Normal-Wet	Wet
1997	2,781.5	Wet	Wet
1998	3,159.8	Wet	Wet
1999	1,527.1	Normal-Wet	Above Normal
2000	1,741.9	Normal-Wet	Above Normal
2001	1,065.1	Normal-Dry	Dry
2002	1,170.9	Normal-Dry	Dry
2003	1,449.9	Normal-Wet	Below Normal
2004	1,130.7	Normal-Dry	Dry

*Based on D-1641

Key: TAF = thousand acre-feet

San Joaquin River Settlement Restoration Year Type	San Joaquin Valley Water Year Types				
	Wet	Above Normal	Below Normal	Dry	Critical
Wet	16				
Normal-Wet	8	15	2		
Normal-Dry		1	11	11	2
Dry				3	9
Critical High					4
Critical Low					1

San Joaquin River Restoration Year Types:

The total annual unimpaired runoff at Friant Dam for the water year (October through September) is the index by which the water year type is determined.

In order of descending wetness, the wettest 20 percent of the years are classified as Wet, the next 30 percent of the year are classified as Normal-Wet, the next 30 percent of the year are classified as Normal-Dry, the next 15 percent of the years are classified as Dry, and the remaining 5 percent of the year are classified as Critical. A subset of the Critial years, those with less than 400 TAF of unimparied runoff, are identified as Critical Low.

San Joaquin Valley Water Year Types:

The San Joaquin Valley Water Year Type is determined through the use of an index. The index is based upon Stanislaus River inflows to New Melones Lake, Tuolumne River inflows to New Don Pedro Reservoir, Merced River inflows to Lake McClure, and San Joaquin River inflows to Millerton Lake, in million acre-feet (MAF).

San Joaquin Valley Water Year Index
= 0.6 * Current Apr-Jul Runoff Forecast (MAF)
+ 0.2 * Current Oct-Mar Runoff in (MAF)
+ 0.2 * Previous Water Year's Index (if the Previous Water Year's Index exceeds 4.5, then 4.5 is used).

Wet Equal to or greater than 3.8 MAF;
Above-Normal Greater than 3.1, and less than 3.8;
Below-Normal Greater than 2.5, and equal to or less than 3.1;
Dry Greater than 2.1, and equal to or less than 2.5; and
Critical Equal to or less than 2.1

This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the San Joaquin Valley water year type as implemented in SWRCB D-1641. Water year types are set by first of month forecasts beginning in February. Final determination for San Joaquin River flow objectives is based on the May 1st 75% exceedence forecast.

Table 2-2.
Restoration Year Type Classification, Sorted by Annual Unimpaired Inflow Below Friant Dam

Water Year	October-through-September San Joaquin River Unimpaired Flow at Friant Dam (TAF)	Restoration Year Type
1,983.0	4,641.9	Wet
1969	4,040.3	Wet
1995	3,877.7	Wet
1938	3,688.4	Wet
1978	3,401.9	Wet
1982	3,316.1	Wet
1967	3,232.2	Wet
1998	3,159.8	Wet
1986	3,031.4	Wet
1980	2,972.7	Wet
1956	2,960.1	Wet
1952	2,840.1	Wet
1997	2,781.5	Wet
1993	2,672.9	Wet
1941	2,652.5	Wet
1958	2,631.0	Wet
1922	2,355.1	Normal-Wet
1965	2,272.2	Normal-Wet
1942	2,254.0	Normal-Wet
1937	2,208.0	Normal-Wet
1996	2,202.8	Normal-Wet
1974	2,190.5	Normal-Wet
1945	2,138.1	Normal-Wet
1943	2,053.7	Normal-Wet
1984	2,048.9	Normal-Wet
1932	2,047.4	Normal-Wet
1973	2,047.0	Normal-Wet
1927	2,001.3	Normal-Wet
1963	1,944.9	Normal-Wet
1962	1,923.6	Normal-Wet
1935	1,923.2	Normal-Wet
1940	1,880.6	Normal-Wet
1951	1,859.0	Normal-Wet
1936	1,853.3	Normal-Wet
1979	1,830.3	Normal-Wet
1975	1,795.7	Normal-Wet
2000	1,741.9	Normal-Wet
1946	1,729.6	Normal-Wet
1923	1,654.3	Normal-Wet
1999	1,527.1	Normal-Wet
2003	1,449.9	Normal-Wet
1970	1,445.6	Normal-Dry
1925	1,438.7	Normal-Dry
1971	1,417.5	Normal-Dry
1957	1,326.6	Normal-Dry
1954	1,313.8	Normal-Dry
1950	1,310.5	Normal-Dry
1966	1,298.6	Normal-Dry
1944	1,265.4	Normal-Dry
1953	1,226.7	Normal-Dry
1948	1,214.8	Normal-Dry
2002	1,170.9	Normal-Dry
1949	1,164.1	Normal-Dry
1926	1,161.4	Normal-Dry
1955	1,161.0	Normal-Dry
1928	1,153.7	Normal-Dry
2004	1,130.7	Normal-Dry
1985	1,129.0	Normal-Dry
1947	1,125.5	Normal-Dry
1933	1,111.4	Normal-Dry
1981	1,068.0	Normal-Dry
2001	1,065.1	Normal-Dry
1972	1,039.0	Normal-Dry
1991	1,034.1	Normal-Dry
1959	949.3	Normal-Dry
1989	939.2	Normal-Dry
1964	922.2	Dry
1939	920.8	Dry
1929	862.4	Dry
1988	862.1	Dry
1968	862.1	Dry
1930	859.1	Dry
1960	828.6	Dry
1994	826.4	Dry
1992	808.5	Dry
1987	757.6	Dry
1990	742.5	Dry
1934	691.5	Dry
1961	646.9	Critical High
1976	629.2	Critical High
1931	480.2	Critical High
1924	444.1	Critical High
1977	361.6	Critical Low

Key: TAF = thousand acre-feet

For example, the Restoration year type classification changes from a normal-wet year type to a wet year type between the historical runoff volumes associated with 1922 (2,355,000 acre-feet and 1958 (2,631,000 acre-feet). Because hydrological conditions in the years after 2004 are not likely to repeat those in the 1922 through 2004 period, it is necessary to define a set of thresholds for Restoration year type classification that is consistent with the Restoration year type classification.

To be consistent with Exhibit B, a threshold was defined using a practical point near the average of the unimpaired runoff amounts of 2 years that bracket the transition. Therefore, the following classification of Restoration year types is recommended (based on annual October-through-September unimpaired flow below Friant Dam):

• Wet	equal to or greater than 2,500,000 acre-feet
• Normal-wet	equal to or greater than 1,450,000 acre-feet
• Normal-dry	equal to or greater than 930,000 acre-feet
• Dry	equal to or greater than 670,000 acre-feet
• Critical-high	equal to or greater than 400,000 acre-feet
• Critical-low	less than 400,000 acre-feet

Based on the Settlement, the designation of year type is for the period of October through September that is consistent with the water year definition. For water years 2005, 2006, and 2007, the annual unimpaired flows of the San Joaquin River below Friant Dam are 2,830, 3,181, and 684 thousand acre-feet (TAF), respectively (DWR, 2007). Therefore, based on this set of thresholds for Restoration year type classification, water years 2005, 2006, and 2007 would be classified as wet, wet, and dry years, respectively.

2.3 Beginning Date for Hydrograph Application

While the above Restoration year type classification is applicable for a water year from October through September, October 1 may not be a good beginning date for applying a corresponding hydrograph because of the following hydrologic and biological considerations, and existing contract allocation practices.

2.3.1 Availability and Quality of Hydrologic Forecasts

Forecasts of annual unimpaired flow below Friant Dam, while imperfect, will be a necessary tool for Restoration year type designations. Making the current year's Restoration flow hydrograph representative of the current year's runoff requires a forecast of a portion of the entire year's runoff. These forecasts combine estimates of snow accumulation, antecedent precipitation, and a statistical range of precipitation predictions. More than one forecast of runoff is made for the San Joaquin River basin, including forecasts from Southern California Edison Company, Reclamation, and DWR.

For establishing Restoration year types, it is recommended that the California Cooperative Snow Survey forecast, prepared by DWR (provided periodically in Bulletin

120 – Water Conditions in California) be used to forecast unimpaired flow of the San Joaquin River below Friant. Reclamation currently operates Friant Dam using Bulletin 120 forecast information. In addition, Reclamation and DWR rely on the Bulletin 120 forecasts to make water allocations for the CVP and State Water Project (SWP). Therefore, using Bulletin 120 forecast information for the SJRRP would be consistent with statewide water management practices.

DWR publishes Bulletin 120 four times a year, generally during the second week of February, March, April, and May. Bulletin 120 contains forecasts of the volume of seasonal runoff from the State's major watersheds (including unimpaired flow of the San Joaquin River below Friant Dam), including values for different forecast confidence intervals. The earliest available forecast information is in February.

Additional information contained in Bulletin 120 includes summaries of precipitation, snowpack, reservoir storage, and runoff in various regions of the State (see http://cdec.water.ca.gov/snow/bulletin120/). Supplementing the published report are periodic updates to the forecasts during the primary runoff season.

As with all forecasts, the accuracy of projections increases as the year progresses, with more and more of the predictive element of the forecast being eliminated with the passage of time. As a result, allocations to Restoration flow hydrograph will need to consider the potential inaccuracy of runoff forecasts to prevent overcommitting water supplies before their availability, or undercommitting water and thus frustrating either goal in the Settlement. Section 4 contains more discussion on balancing forecast uncertainties and practical operation of Friant Dam.

2.3.2 Consideration of Chinook

SJRRP is considering both spring-run and fall-run Chinook salmon in the current planning process; other fishery species may also be considered. However, the discussion on Chinook herein as a surrogate for biological considerations used to determine the beginning date for Restoration flow hydrograph application.

Spring-Run Life Cycle Timing

In the Sacramento River watershed (the closest population of spring-run Chinook salmon to the San Joaquin River), adult spring-run Chinook salmon historically returned to fresh water between late March and early July (DFG 1998). After they arrive in their natal streams in the spring, they hold in deep pools through the summer, conserving energy until the fall when their gonads ripen and they spawn, between August and October (DFG 1998, McReynolds et al. 2005). In the Sacramento River, the egg incubation period for spring-run Chinook salmon extends from August to March (Fisher 1994, Ward and McReynolds 2001).

After hatching, fry may move downstream to the estuary and rear, or may take up residence in the stream for a period of time from weeks to a year (Healey 1991). The Butte Creek fry primarily disperse downstream from mid-December through February whereas the subyearling smolts primarily migrate between late-March and mid-June.

Spring-run yearlings in Butte Creek migrate from September through March (Hill and Webber 1999, Ward and McReynolds 2001, Ward et al. 2002).

Fall-Run Life Cycle Timing

Adult fall-run Chinook salmon in the San Joaquin River basin typically migrate into the upper rivers between late September and mid-November (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007). Spawning in the San Joaquin River takes place between October and December (DFG 2001-2005), and the incubation period extends from late October through February. Fall-run juveniles will rear and migrate between January and June (Fishbio Environmental, LLC. Unpublished Data)

In noncritical years, Restoration flow hydrographs (see Figure 2-1) schedule the same flow rates between the months of August and February, with only minor differences in fall-run attraction flows in the first week of November. The scale of flow change during August through February across the various Restoration year types is significantly less than that of the period from March through July. In other words, Restoration year type classification is a more meaningful consideration for Restoration flow hydrograph implementation after February.

The period exhibiting the most significant differences, among the Restoration flow hydrographs is during the months of March and April. Restoration years classified as Wet are additionally unique in scheduling additional flow for the months of May and June. However, the Settlement allows for flexibility in the release of Restoration flow hydrographs within some periods. Specifically,[4]

> … releases allocated during the period from March 1 through May 1 ("Spring Period") in any year may be shifted up to four weeks earlier and later than what is depicted in the hydrograph for that year, and managed flexibly within that range (i.e. February 1 through May 28), so long as the total volume … allocated for the Spring Period is not changed.

Accommodating this intended flexibility suggests that the Restoration year type classification could recognize year-specific differences in Restoration flow hydrograph shaping as early as February if necessary.

2.3.3 Existing Contract Allocation Practice

Friant Division long-term contractors are currently given initial allocations in mid-February of each year, after the first forecast of unimpaired inflow to Millerton Lake becomes available (i.e., in February).

This declaration of allocation to long-term contractors and temporary contractors is periodically revised as changing water supply conditions evolve; typically, the revision continues through June. As confidence in the forecast hydrology increases over time, the revision is generally for increased allocation as opposed to retracting a previously

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[4] Refer to the Settlement, Exhibit B, Paragraph 4(b)

declared water allocation. More details on hydrologic forecast uncertainties are contained in Section 4.

2.3.4 March 1 as Beginning Date for Restoration Flow Hydrographs

March 1 is recommended as the beginning date for Restoration year type classification and, more importantly, the beginning date for the resulting Restoration flow hydrograph application. This recommendation was based on the above discussion, summarized herein.

- From a practical viewpoint, the first determination of Restoration year type and flow hydrographs could be in mid-February, when Bulletin 120 forecast information becomes available. Before the February forecast, there is insufficient information for a determination.

- Based on the review of historical forecast, February forecast is subject to a much greater margin of error, resulting in a greater risk of misclassification of year type. From fisheries management viewpoint, it is common to maintain established flow in the river to March for avoiding risk of dewatering redds. Reviewing the Restoration flow hydrographs in Figure 2-1, March Restoration flow of all year types (except for critical-low years) are higher than 350 cfs, the maximum of February Restoration flows for all year types. Therefore, the risk of dewatering the redds due to misclassification of year type using early forecast information can be avoided completely by delaying the beginning point of the new year until March.

- While the flexibility of shifting Restoration flow hydrograph to start as early as February 1 is provided in the Settlement, due to the risk of redd dewatering, such flexibility would be better provided through real-time adjustments based on monitoring information.

It is anticipated that the Restoration year type classification would be revised, if necessary, as subsequent Bulletin 120 forecasts become available in April and May. There are years that an additional forecast in June is available (although not necessarily published officially in Bulletin 120 format); in these years, additional revisions of Restoration year type classification may be made. It would not be meaningful to modify the designation after June because the associated flow hydrographs return to a more uniform schedule for all year types.

The Restoration flow hydrograph for months before the March 1 date would follow the Restoration year type designation of the prior year. This practice is commonly applied to river management in California watersheds.

Additional considerations and recommendations for Restoration flow hydrograph implementation with consideration of forecast uncertainties are discussed in Section 4.

3.0 Developing Continuous Hydrographs

This section presents the process recommended for developing continuous hydrographs per the requirements in the Settlement.

3.1 Need for Continuous Hydrographs

Exhibit B of the Settlement identifies a set of six Restoration flow hydrographs, which present a schedule for flow rates throughout the year. These flow hydrographs vary in shape and annual cumulative volume according to wetness in the San Joaquin River basin. The method producing a single flow hydrograph for each Restoration year type is referred to as the “stair-step hydrographs” within the Settlement. The Settlement indicates that transforming the stair-step hydrograph method into a continuously increasing hydrograph method is desired:

> The Parties agree to transform the stair step hydrographs to more continuous hydrographs prior to December 31, 2008 to ensure completion before the initiation of Restoration Flows, provided that the Parties shall mutually-agree that transforming the hydrographs will not materially impact the Restoration or Water Management Goal.

The stair-step hydrograph method, as summarized in Table 3-1, is relatively easy to apply, and the ranges of wetness indices associated with a year type provide some level of buffer against hydrologic uncertainties. However, challenges could regularly arise when a year’s projected wetness is borderline between two Restoration year type classifications, especially when hydrologic forecast uncertainties are considered. The resulting differences in annual allocations between the two borderline year type classifications could be subject to disagreement; the disagreement could become even greater as availability and quality of hydrologic forecasts are also considered.

Table 3-1.
Stair-Step Restoration Flow Hydrographs as in Settlement Exhibit B (TAF)

Year Type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Wet	21.5	27.8	21.5	21.5	19.4	62.5	193.4	123.0	119.0	21.5	21.5	20.8	673.5
Normal-Wet	21.5	27.8	21.5	21.5	19.4	62.5	193.4	21.5	20.8	21.5	21.5	20.8	473.9
Normal-Dry	21.5	27.8	21.5	21.5	19.4	62.5	84.8	21.5	20.8	21.5	21.5	20.8	365.3
Dry	21.5	27.8	21.5	21.5	19.4	62.5	20.8	21.5	20.8	21.5	21.5	20.8	301.3
Critical-High	9.8	9.9	7.4	6.8	6.1	62.5	11.9	13.2	12.8	15.7	15.7	15.5	187.2
Critical-Low	9.8	7.2	7.4	6.1	5.6	8.0	8.9	11.7	11.3	14.1	14.1	12.5	116.8

Key: TAF = thousand acre-feet

Figure 3-1 shows the classification system developed in Section 2, the associated annual flow volume, as defined in Exhibit B stair-step hydrographs, and corresponding historical records for the 1922 through 2004 period. The potential for disagreement on Restoration year type classification and associated hydrograph volume is evident in borderline years using forecast hydrology. For example, for a year with approximately 1,400,000 acre-feet of unimpaired runoff, an additional 1 acre-foot of runoff would lead to the year type being changed in the classification from normal-dry to normal-wet, and require more than 100,000 acre-feet of additional release for Restoration Flows. This could create unexpected challenges in real-time water management and fishery management.

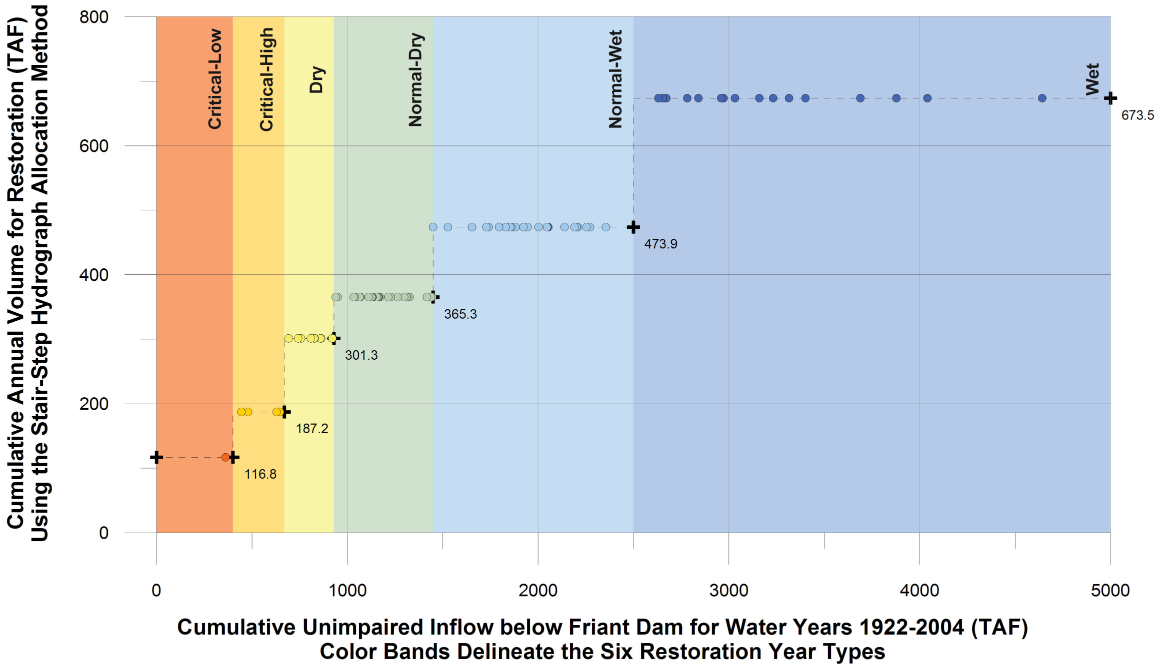

Figure 3-1.
Annual Restoration Flow Volume (TAF) for the 1922-2004 Period of Record Resulting from the Settlement's Stair-Step Hydrographs

Developing a continuous function to determine annual Restoration hydrograph allocations reduces such potential challenges. The continuous function responds to the need for a systematic methodology to distribute the resulting Restoration hydrograph allocation into a Restoration flow hydrograph.

3.2 Determining Continuous Restoration Flow Hydrographs

As described in Exhibit B, the six Restoration flow hydrographs were developed for fishery management purposes and, in wet years only, additional specific considerations for vegetation recruitment purposes. The annual cumulative volumes were estimated to have a certain impact on CVP Friant Division long-term contractors' water supply. Therefore, the transformation from stair-step hydrographs to a continuous hydrograph method needs to be consistent with these premises in the Settlement.

3.2.1 Annual Restoration Flow Volume

The major concern over stair-step approach is the potential for abrupt changes in allocated Restoration flow hydrograph volumes with small changes in unimpaired flow conditions.

A straightforward approach is recommended to form a continuous function where the six stair-step hydrographs from Exhibit B occur at the midpoint of the Restoration year type's range of indexed inflows.

- The approach is simple and easy to implement.
- The approach could automatically preserve the long-term average (by Restoration year type) for both the Restoration Flow volume, and the associated water supply impacts. Maintaining these averages provides consistency with the Settlement.

The following are details for developing a piece-wise linear function for annual Restoration flow hydrograph volume:

1. The Restoration Flow volume for critical-low years is the existing release from Friant Dam for downstream riparian water right diversions; and can be used as the starting point for developing the piece-wise linear function for annual volume.
2. The critical-low year type was classified to be any year when unimpaired San Joaquin River flow below Friant Dam is less than 400,000 acre-feet (see Section 2). A critical-high year was classified to be any year when unimpaired San Joaquin River flow below Friant Dam is between 400,000 acre-feet and 670,000 acre-feet, with a midpoint unimpaired inflow of 535,000 acre-feet. Considering that the midpoint unimpaired inflow of 535,000 acre-feet is the representative condition for critical-high years, it is assumed that the corresponding volume of Restoration Flows would be the volume of 187,000 acre-feet, as prescribed by the stair-step hydrograph for the critical-high years.

3. A line can be drawn through the following two points:

    - The point corresponding to the critical-high midpoint unimpaired inflow (535,000 acre-feet) and Restoration Flow volume of 187,000 acre-feet
    - The boundary condition for critical-low years with unimpaired flow of 400,000 acre-feet and Restoration Flow requirements of 117,000 acre-feet

The linear function for determining Restoration Flow volume by unimpaired San Joaquin River flow below Friant Dam can be completed by extending the line to the maximum of unimpaired inflow volume for critical-high years (670,000 acre-feet). The resulting Restoration Flow requirement is 257,000 acre-feet.

1. This mathematical procedure continues for the dry, normal-dry, and normal-wet year type ranges.
2. For wet years, no median reference point exists for the above linear process. Therefore, it is recommended that the original stair-step hydrograph volume of 673,000 acre-feet be used whenever unimpaired inflow is estimated to equal or exceed 2,500 TAF. This would result in an abrupt change in hydrograph volume, at a much reduced scale, when the annual unimpaired flow forecast suggests a change from a normal-wet to a wet Restoration year type. However, the associated concerns over the abrupt change in Restoration Flow volume for water supply and fishery management are less in years of high runoff.

Figure 3-2 illustrates the piece-wise linear function of the recommended approach. Figure 3-3 shows the application of this concept to the period from 1922 through 2004, which was referenced in the Settlement for Restoration year type definition. The piece-wise linear function for annual Restoration Flow volume runs through the midpoint of each Restoration year type's range of indexed flows, with the continuous flow requirement being less than the explicit Restoration Flow volume for the lower half of the range, and higher than the explicit Restoration Flow volume for the higher half of the range.

Using the midpoint-driven volumes as connecting points between Restoration year types closely approximates the average Restoration Flow volume and potential water supply impacts within each classification, thereby maintaining consistency with the Settlement. The transformation should alleviate the concerns over abrupt changes in the volume requirement for Restoration Flows, and enhance the correspondence between volumes of Restoration Flows and annual unimpaired flow.

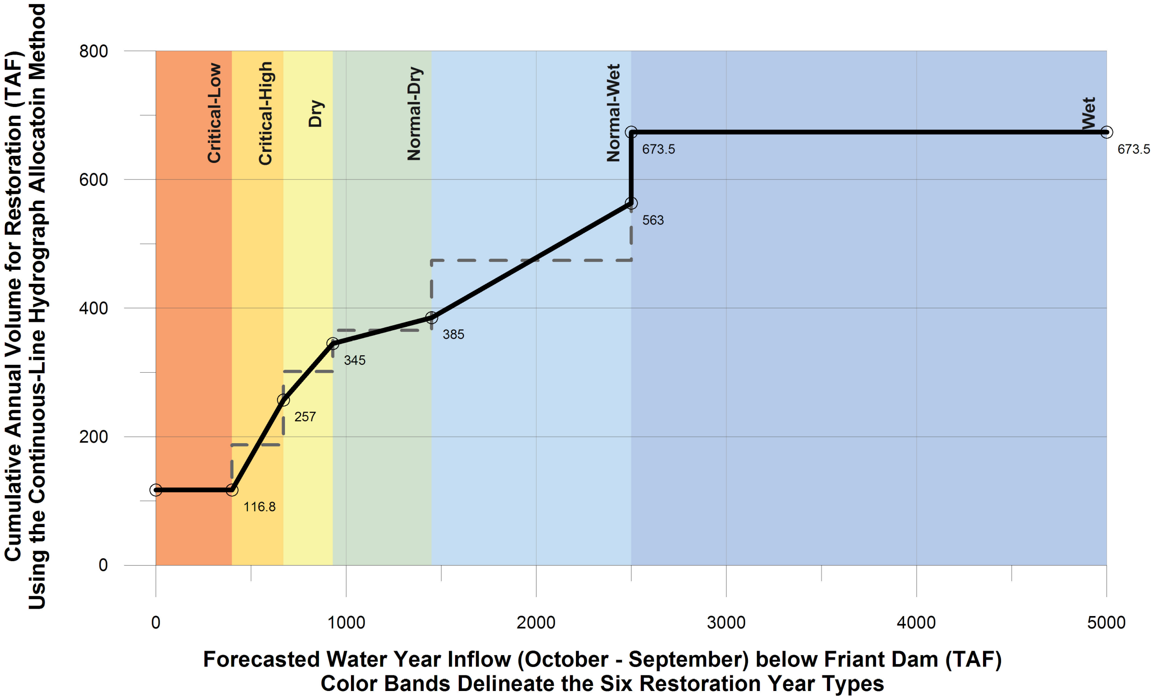

Figure 3-2.
Proposed Concept of a Continuous Hydrograph Method for Determining Annual Restoration Flow Volume (TAF)

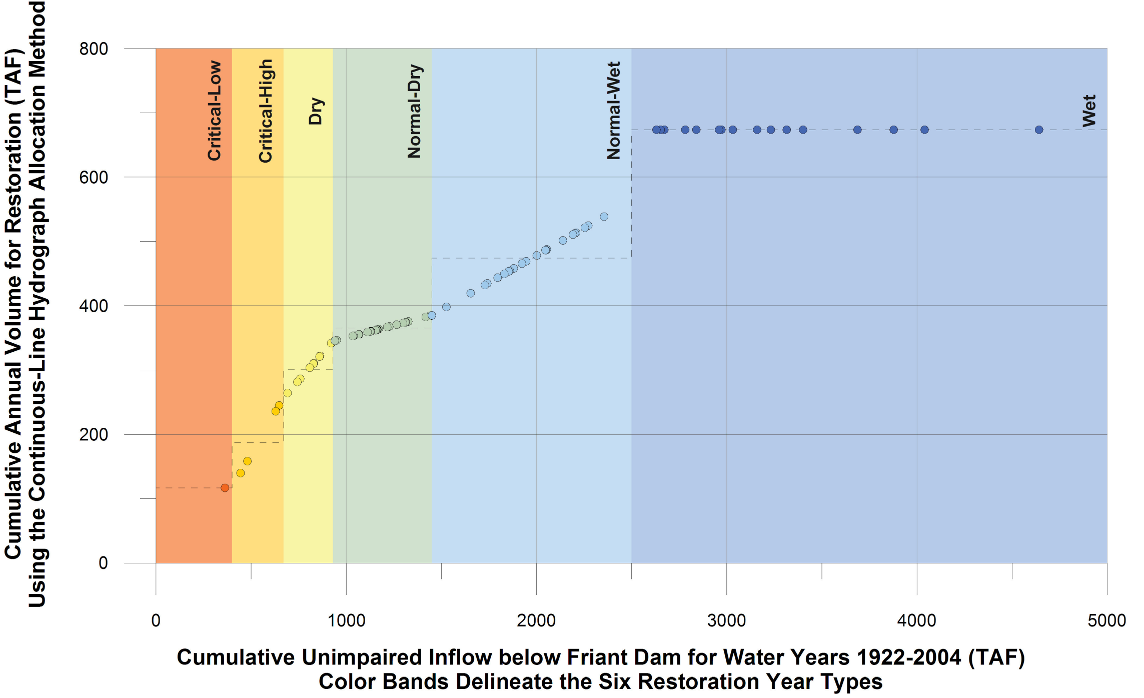

Figure 3-3.
Annual Restoration Flow Volume (TAF) for the 1922-2004 Period of Record Resulting from the Continuous Hydrograph Method

3.2.2 Monthly Pattern

Table 3-1 illustrates the monthly release requirement by year type, as presented by the Settlement's six stair-step Restoration flow hydrographs. The above development of a continuous function for the annual flow requirement necessitates development of a method to distribute monthly the resulting annual flow volume that is not described by one of the six stair-step Restoration flow hydrographs.

The stair-step hydrographs shown in Figure 2-1 also display the progression in monthly patterns for six hydrographs: as the annual volume of Restoration Flows increases, the monthly volume increases - ultimately the period of high flow in spring is extended for wet years. In other words, the monthly hydrograph release rates for wetter year types are always equal to or higher than those of any drier year type; the increase in release occurs only in selected months in November and in the spring months. To be consistent with the Settlement, the method for distributing the above-determined annual amount (see Section 3.2.1) should be consistent with the progressive characteristics in the original stair-step hydrographs.

The continuous hydrograph approach outlined in Section 3.2.1 produces a series of key reference hydrographs that can be used for defining monthly patterns for all Restoration Flow volumes. Table 3-2 shows these key reference hydrographs. The referenced unimpaired inflow amounts are either boundaries (for critical-low, normal-wet (max), and wet years), or midpoints (for critical-high, dry, normal-dry, and normal-wet years). The monthly distribution pattern for each referenced unimpaired inflow amount is consistent with that of the stair-step hydrograph method in the Settlement. These key reference hydrograph monthly patterns can be used with interpolation, for any given annual unimpaired inflow below Millerton Lake, to produce a corresponding hydrograph.

For instance, for a year that requires 500,000 acre-feet of Restoration Flow volume, 473,900 acre-feet would be distributed according to the normal-wet reference hydrograph and the remaining 26,100 acre-feet would be proportionately distributed in May and June (the 2 months that show an increase in flow when adjusting from the normal-wet Restoration flow hydrograph to the normal-wet (max) reference hydrograph).

Although they are not discussed by this TM, the specifications for daily flow operations (e.g., ramping rate restrictions for ecological purposes and recommendations to the Secretary) will further refine the default release patterns presented in this section.

Table 3-2.
Reference Hydrographs for Transformation to Continuous Hydrograph

Year Type		**Critical-Low**	**Critical-High**	**Dry**	**Normal-Dry**	**Normal-Wet**	**Normal-Wet (max)**	**Wet**
Forecasted Inflow (TAF)*		400	537	801	1,193	1,974	2,500	2,500
Allocation Volume (TAF)*		117	188	301	365	474	563	673
Month	Day	**Hydrograph (cfs)**	**Hydrograph (cfs)**	**Hydrograph (cfs)**	**Hydrograph (cfs)**	**Hydrograph (cfs)**	**Hydrograph (cfs)**	**Hydrograph (cfs)**
10	1	160	160	350	350	350	350	350
10	16	160	160	350	350	350	350	350
11	1	124	232	583	583	583	583	583
11	16	120	120	350	350	350	350	350
12	1	120	120	350	350	350	350	350
12	16	120	120	350	350	350	350	350
1	1	100	110	350	350	350	350	350
1	16	100	110	350	350	350	350	350
2	1	100	110	350	350	350	350	350
2	16	100	110	350	350	350	350	350
3	1	130	500	500	500	500	500	500
3	16	130	1,500	1,500	1,500	1,500	1,500	1,500
4	1	150	200	350	2,500	2,500	2,500	2,500
4	16	150	200	350	350	4,000	4,000	4,000
5	1	190	215	350	350	350	1,087	2,000
5	16	190	215	350	350	350	1,087	2,000
6	1	190	215	350	350	350	1,087	2,000
6	16	190	215	350	350	350	1,087	2,000
7	1	230	255	350	350	350	350	350
7	16	230	255	350	350	350	350	350
8	1	230	255	350	350	350	350	350
8	16	230	255	350	350	350	350	350
9	1	210	260	350	350	350	350	350
9	16	210	260	350	350	350	350	350

* Forecasted inflow and allocation volume are defined in Section 3.2.1 as boundary conditions (critical-low, normal-wet(max) and wet), or midpoint conditions (critical-high, dry, normal-dry and normal-wet)

Key: cfs = cubic feet per second TAF = thousand acre-feet

3.2.3 Validation for Settlement Consistency

The period from 1922 through 2004 was used in negotiating the Settlement; therefore, the same period was used in the validation process to verify that the resulting Restoration Flow releases and canal deliveries are consistent with the Settlement. Overall, consistency with the Settlement was confirmed through the validation process.

Figure 3-3 shows the annual Restoration Flow volumes for water years 1922 through 2004 using the above-mentioned continuous hydrograph concept. The monthly pattern proposed in Section 3.2.2 was used to further delineate the annual amount into a corresponding monthly distribution. The Settlement spreadsheet model was used to also eliminate potential differences, if any, that may be created by using different analytical tools.

Tables 3-3 and 3-4 summarize the simulated average annual releases from Friant Dam and average annual canal deliveries to Friant Division long-term contractors using the continuous hydrograph, the Settlement compared to stair-step hydrographs, and existing conditions without Settlement releases.

The average annual release requirements of two Restoration hydrograph scenarios are essentially the same, consistent with the intent of the proposed approach to derive the continuous hydrograph. There is a slightly higher average release requirement under the continuous hydrograph scenario in dry and critical-high years, resulting in a slightly conservative, but not significant practice. Similarly, the difference in canal deliveries derived from stair-step hydrographs and continuous hydrographs is not significant. Appendix C shows detailed results for canal deliveries. The largest difference, in critical-low years (approximately 25,000 acre-feet), shows 1977 to be the only year in the average, and the effect is due to the carryover operation from 1976.

Table 3-3.
Simulated Average Restoration Flow Volumes by Restoration Year Type for Contract Years 1922 Through 2003

Restoration Year Type	**Average Annual Release from Friant Dam (TAF)**			
	Without Restoration (Existing Condition)	**With Restoration Releases**		
		Continuous Hydrograph Method	**Stair-Step Hydrograph Method**	**Difference Between Methods**
Wet	117	674	673	0
Normal-Wet	117	471	474	-3
Normal-Dry	117	365	365	0
Dry	117	311	301	10
Critical-High	117	195	187	8
Critical-Low	117	117	117	0
All Years	117	438	437	1

Key: TAF = thousand acre-feet

Table 3-4.
Simulated Average Canal Delivery Volumes by Restoration Year Type for Contract Years 1922 Through 2003

Restoration Year Type (Mar - Feb)	**Average Canal Delivery to Friant Division Long-Term Contractors (TAF)**			
	Without Restoration (Existing Condition)	**With Restoration Releases**		
		Continuous Hydrograph Method	**Stair-Step Hydrograph Method**	**Difference Between Methods**
Wet	1,967	1,802	1,802	0
Normal-Wet	1,627	1,343	1,339	3
Normal-Dry	1,095	892	892	1
Dry	778	615	627	-13
Critical-High	525	401	389	12
Critical-Low	322	289	320	-31
All Years	1,344	1,135	1,136	0

Key: TAF = thousand acre-feet

Tables 3-5 and 3-6 show the annual amounts for Tables 3-3 and 3-4, respectively. Within each year type's range of forecasted inflow, the continuous method reduces canal diversions on wetter end of the range, and increases them on the drier end of each range, relative to the stair-step hydrographs. This corresponds with increases and decreases to the Restoration Flow requirement on the high and low end of each range, respectively.

Table 3-5.
Simulated Restoration Flow Releases for Contract Years 1922 Through 2004

Total River Release Requirement (TAF)												
Chronological Listing						Descending Order of Wetness						
Year	Without Restoration (Existing Condition)	Continuous Hydrograph Method	Stair-Step Hydrograph Method	Difference Between Methods	Difference Continuous Function and Existing Conditions	Year		Without Restoration (Existing Condition)	Continuous Hydrograph Method	Stair-Step Hydrograph Method	Difference Between Methods	Difference Continuous Function and Existing Conditions
1922	117	538	474	65	421	1983	Wet	117	674	673	1	557
1923	117	420	474	-54	303	1969		117	673	673	0	556
1924	117	140	187	-47	23	1995		117	674	673	1	557
1925	117	384	365	19	267	1938		117	673	673	0	556
1926	117	363	365	-2	246	1978		117	673	673	0	556
1927	117	479	474	5	362	1982		117	673	673	0	556
1928	117	362	365	-3	245	1967		117	674	673	1	557
1929	117	322	301	21	205	1998		117	673	673	0	556
1930	117	321	301	20	204	1986		117	673	673	0	556
1931	117	159	187	-29	42	1980		117	673	673	0	556
1932	117	486	474	12	369	1956		117	673	673	0	556
1933	117	359	365	-6	242	1952		117	673	673	0	556
1934	117	264	301	-37	147	1997		117	673	673	0	556
1935	117	466	474	-8	349	1993		117	673	673	0	556
1936	117	453	474	-20	336	1941		117	673	673	0	556
1937	117	513	474	40	396	1958		117	673	673	0	556
1938	117	673	673	0	556	1922	Normal-wet	117	538	474	65	421
1939	117	343	301	41	226	1965		117	524	474	51	407
1940	117	458	474	-16	341	1942		117	521	474	47	404
1941	117	673	673	0	556	1937		117	513	474	40	396
1942	117	521	474	47	404	1996		117	513	474	39	396
1943	117	488	474	14	371	1974		117	511	474	37	394
1944	117	371	365	6	254	1945		117	502	474	28	385
1945	117	502	474	28	385	1943		117	488	474	14	371
1946	117	432	474	-41	315	1984		117	487	474	13	370
1947	117	361	365	-5	244	1932		117	486	474	12	369
1948	117	367	365	2	250	1973		117	486	474	12	369
1949	117	363	365	-2	246	1927		117	479	474	5	362
1950	117	374	365	9	257	1963		117	470	474	-4	353
1951	117	455	474	-19	338	1962		117	465	474	-9	348
1952	117	673	673	0	556	1935		117	466	474	-8	349
1953	117	368	365	3	251	1940		117	458	474	-16	341
1954	117	375	365	9	258	1951		117	455	474	-19	338
1955	117	363	365	-2	246	1936		117	453	474	-20	336
1956	117	673	673	0	556	1979		117	450	474	-24	333
1957	117	376	365	10	259	1975		117	444	474	-30	327
1958	117	673	673	0	556	2000		117	434	474	-39	317
1959	117	347	365	-18	230	1946		117	432	474	-41	315
1960	117	311	301	9	194	1923		117	420	474	-54	303
1961	117	245	187	58	128	1999		117	399	474	-75	282
1962	117	465	474	-9	348	2003		117	386	474	-88	269
1963	117	470	474	-4	353	1970		117	385	365	19	268
1964	117	342	301	41	225	1925		117	384	365	19	267
1965	117	524	474	51	407	1971		117	383	365	18	266
1966	117	373	365	8	256	1957		117	376	365	10	259
1967	117	674	673	1	557	1954		117	375	365	9	258
1968	117	322	301	21	205	1950		117	374	365	9	257
1969	117	673	673	0	556	1966		117	373	365	8	256
1970	117	385	365	19	268	1944		117	371	365	6	254
1971	117	383	365	18	266	1953		117	368	365	3	251
1972	117	353	365	-12	236	1948		117	367	365	2	250
1973	117	486	474	12	369	2002		117	364	365	-2	247
1974	117	511	474	37	394	1949		117	363	365	-2	246
1975	117	444	474	-30	327	1926		117	363	365	-2	246
1976	117	236	187	49	119	1955		117	363	365	-2	246
1977	117	117	117	0	0	1928		117	362	365	-3	245
1978	117	673	673	0	556	2004		Partial Year				
1979	117	450	474	-24	333	1985		117	360	365	-5	243
1980	117	673	673	0	556	1947		117	361	365	-5	244
1981	117	356	365	-10	239	1933		117	359	365	-6	242
1982	117	673	673	0	556	1981		117	356	365	-10	239
1983	117	674	673	1	557	2001		117	355	365	-10	238
1984	117	487	474	13	370	1972		117	353	365	-12	236
1985	117	360	365	-5	243	1991		117	354	365	-12	237
1986	117	673	673	0	556	1959		117	347	365	-18	230
1987	117	287	301	-14	170	1989		117	346	365	-20	229
1988	117	322	301	21	205	1964	Dry	117	342	301	41	225
1989	117	346	365	-20	229	1939		117	343	301	41	226
1990	117	282	301	-20	165	1929		117	322	301	21	205
1991	117	354	365	-12	237	1988		117	322	301	21	205
1992	117	304	301	3	187	1968		117	322	301	21	205
1993	117	673	673	0	556	1930		117	321	301	20	204
1994	117	310	301	9	193	1960		117	311	301	9	194
1995	117	674	673	1	557	1994		117	310	301	9	193
1996	117	513	474	39	396	1992		117	304	301	3	187
1997	117	673	673	0	556	1987		117	287	301	-14	170
1998	117	673	673	0	556	1990		117	282	301	-20	165
1999	117	399	474	-75	282	1934		117	264	301	-37	147
2000	117	434	474	-39	317	1961	CH	117	245	187	58	128
2001	117	355	365	-10	238	1976		117	236	187	49	119
2002	117	364	365	-2	247	1931		117	159	187	-29	42
2003	117	386	474	-88	269	1924		117	140	187	-47	23
2004	Partial Year					1977	CL	117	117	117	0	0
Avg	117	438	437	1	321	Wet Avg		117	674	673	0	557
Max	117	674	673			Normal-Wet Avg		117	471	474	-3	354
Min	117	117	117			Normal-Dry Avg		117	365	365	0	248
						Dry Avg		117	311	301	10	194
Driest 20% of Water Years on Record						Critical-High Avg		117	195	187	8	78
Driest Avg	117	272	264	9	155	Critical-Low Avg		117	117	117	0	0

Note: Values are summed over Contract Years (March-February)

Note: Wetness based on water year unimpaired inflow below Friant Dam

Key: TAF = thousand acre-feet

Table 3-6.
Simulated Annual Canal Delivery to Friant Division Long-Term Contractors for Contract Years 1922 Through 2004

Total Canal Diversions (TAF)												
Chronological Listing						Descending Order of Wetness						
Year	Without Restoration (Existing Condition)	Continuous Hydrograph Method	Stair-Step Hydrograph Method	Difference Between Methods	Difference Continuous Function and Existing Conditions	Year		Without Restoration (Existing Condition)	Continuous Hydrograph Method	Stair-Step Hydrograph Method	Difference Between Methods	Difference Continuous Function and Existing Conditions
1922	1,962	1,713	1,799	-86	-248	1983	Wet	2,010	1,972	1,973	-1	-38
1923	1,373	1,247	1,152	96	-126	1969		1,843	1,822	1,822	0	-21
1924	506	408	365	43	-97	1995		2,236	2,138	2,138	-1	-98
1925	1,130	938	955	-17	-192	1938		1,952	1,880	1,878	2	-72
1926	1,144	847	845	3	-297	1978		2,056	1,981	1,981	0	-76
1927	1,701	1,363	1,368	-5	-338	1982		2,088	2,005	2,005	0	-83
1928	1,202	988	985	3	-214	1967		2,067	1,942	1,942	0	-125
1929	707	536	557	-21	-172	1998		1,853	1,768	1,768	0	-85
1930	727	525	544	-19	-201	1986		1,938	1,797	1,797	0	-142
1931	394	278	250	28	-116	1980		2,063	1,720	1,720	0	-343
1932	1,651	1,373	1,385	-12	-278	1956		2,027	1,581	1,581	0	-446
1933	1,104	860	854	6	-243	1952		1,833	1,742	1,742	0	-91
1934	649	480	466	14	-169	1997		1,597	1,329	1,329	0	-268
1935	1,573	1,234	1,202	32	-340	1993		2,066	1,736	1,736	0	-331
1936	1,578	1,316	1,305	10	-263	1941		2,022	1,763	1,763	0	-258
1937	1,675	1,501	1,519	-18	-174	1958		1,818	1,654	1,654	0	-164
1938	1,952	1,880	1,878	2	-72	1922	Normal-wet	1,962	1,713	1,799	-86	-248
1939	848	646	687	-41	-202	1965		1,777	1,392	1,442	-50	-385
1940	1,538	1,267	1,252	15	-272	1942		1,983	1,595	1,635	-40	-388
1941	2,022	1,763	1,763	0	-258	1937		1,675	1,501	1,519	-18	-174
1942	1,983	1,595	1,635	-40	-388	1996		1,786	1,592	1,631	-39	-193
1943	1,545	1,298	1,306	-9	-247	1974		1,818	1,493	1,570	-77	-325
1944	1,102	990	1,000	-11	-112	1945		1,873	1,548	1,575	-27	-325
1945	1,873	1,548	1,575	-27	-325	1943		1,545	1,298	1,306	-9	-247
1946	1,475	1,208	1,167	41	-268	1984		1,539	1,225	1,238	-13	-313
1947	1,073	885	880	5	-188	1932		1,651	1,373	1,385	-12	-278
1948	920	694	696	-2	-226	1973		1,733	1,416	1,416	0	-317
1949	1,048	804	802	2	-244	1927		1,701	1,363	1,368	-5	-338
1950	1,383	1,127	1,136	-9	-256	1963		1,707	1,408	1,403	5	-299
1951	1,265	978	959	19	-288	1962		1,649	1,326	1,354	-27	-323
1952	1,833	1,742	1,742	0	-91	1935		1,573	1,234	1,202	32	-340
1953	1,066	877	879	-3	-190	1940		1,538	1,267	1,252	15	-272
1954	1,130	866	875	-9	-264	1951		1,265	978	959	19	-288
1955	1,125	1,062	1,059	3	-63	1936		1,578	1,316	1,305	10	-263
1956	2,027	1,581	1,581	0	-446	1979		1,653	1,327	1,315	12	-327
1957	1,226	1,084	1,094	-10	-143	1975		1,606	1,343	1,294	49	-262
1958	1,818	1,654	1,654	0	-164	2000		1,615	1,255	1,218	37	-360
1959	855	822	804	19	-33	1946		1,475	1,208	1,167	41	-268
1960	704	510	520	-10	-194	1923		1,373	1,247	1,152	96	-126
1961	518	357	379	-21	-161	1999		1,321	1,134	1,058	76	-187
1962	1,649	1,326	1,354	-27	-323	2003		1,274	1,012	923	89	-263
1963	1,707	1,408	1,403	5	-299	1970	Normal-dry	1,306	1,038	1,058	-20	-268
1964	1,101	906	947	-42	-195	1925		1,130	938	955	-17	-192
1965	1,777	1,392	1,442	-50	-385	1971		1,208	980	997	-17	-228
1966	1,346	1,108	1,116	-8	-238	1957		1,226	1,084	1,094	-10	-143
1967	2,067	1,942	1,942	0	-125	1954		1,130	866	875	-9	-264
1968	988	842	863	-21	-146	1950		1,383	1,127	1,136	-9	-256
1969	1,843	1,822	1,822	0	-21	1966		1,346	1,108	1,116	-8	-238
1970	1,306	1,038	1,058	-20	-268	1944		1,102	990	1,000	-11	-112
1971	1,208	980	997	-17	-228	1953		1,066	877	879	-3	-190
1972	1,056	789	777	11	-267	1948		920	694	696	-2	-226
1973	1,733	1,416	1,416	0	-317	2002		1,030	785	784	2	-245
1974	1,818	1,493	1,570	-77	-325	1949		1,048	804	802	2	-244
1975	1,606	1,343	1,294	49	-262	1926		1,144	847	845	3	-297
1976	684	562	563	-2	-122	1955		1,125	1,062	1,059	3	-63
1977	322	289	320	-31	-33	1928		1,202	988	985	3	-214
1978	2,056	1,981	1,981	0	-76	2004				Partial Year		
1979	1,653	1,327	1,315	12	-327	1985		1,127	893	888	5	-233
1980	2,063	1,720	1,720	0	-343	1947		1,073	885	880	5	-188
1981	1,114	1,039	1,029	10	-75	1933		1,104	860	854	6	-243
1982	2,088	2,005	2,005	0	-83	1981		1,114	1,039	1,029	10	-75
1983	2,010	1,972	1,973	-1	-38	2001		955	748	738	10	-208
1984	1,539	1,225	1,238	-13	-313	1972		1,056	789	777	11	-267
1985	1,127	893	888	5	-233	1991		845	624	600	24	-221
1986	1,938	1,797	1,797	0	-142	1959		855	822	804	19	-33
1987	589	586	580	5	-3	1989		797	570	551	20	-227
1988	732	536	548	-12	-196	1964	Dry	1,101	906	947	-42	-195
1989	797	570	551	20	-227	1939		848	646	687	-41	-202
1990	620	445	438	7	-175	1929		707	536	557	-21	-172
1991	845	624	600	24	-221	1988		732	536	548	-12	-196
1992	794	553	557	-4	-241	1968		988	842	863	-21	-146
1993	2,066	1,736	1,736	0	-331	1930		727	525	544	-19	-201
1994	878	812	820	-9	-67	1960		704	510	520	-10	-194
1995	2,236	2,138	2,138	-1	-98	1994		878	812	820	-9	-67
1996	1,786	1,592	1,631	-39	-193	1992		794	553	557	-4	-241
1997	1,597	1,329	1,329	0	-268	1987		589	586	580	5	-3
1998	1,853	1,768	1,768	0	-85	1990		620	445	438	7	-175
1999	1,321	1,134	1,058	76	-187	1934		649	480	466	14	-169
2000	1,615	1,255	1,218	37	-360	1961	CH	518	357	379	-21	-161
2001	955	748	738	10	-208	1976		684	562	563	-2	-122
2002	1,030	785	784	2	-245	1931		394	278	250	28	-116
2003	1,274	1,012	923	89	-263	1924		506	408	365	43	-97
2004			Partial Year			1977	CL	322	289	320	-31	-33
Avg	1,344	1,135	1,136	0	-209	Wet Avg		1,967	1,802	1,802	0	-165
Max	2,236	2,138	2,138			Normal-Wet Avg		1,627	1,343	1,339	3	-284
Min	322	278	250			Normal-Dry Avg		1,095	892	892	1	-203
						Dry Avg		778	615	627	-13	-163
Driest 20% of Water Years on Record						Critical-High Avg		525	401	389	12	-124
Driest Avg	692	545	553	-8	-147	Critical-Low Avg		322	289	320	-31	-33

Note: Values are summed over Contract Years (March-February)

Note: Wetness based on water year unimpaired inflow below Friant Dam

Key: TAF = thousand acre-fee

4.0 Incorporation of Hydrologic Forecast Uncertainties

The major challenge in using a hydrologic forecast in water operations is the uncertainties associated with the forecast (i.e., the risks of not meeting anticipated operational objectives). For the SJRRP, these uncertainties could raise concerns over equity in operation guidelines for fishery protection and water supply reliability. This section discusses hydrologic uncertainties, and a proposal for incorporating this consideration into water operations.

4.1 Quality of Bulletin 120 Hydrologic Forecast

DWR uses a composite approach to produce 10-, 50- and 90-percent forecasts. The 50-percent forecast is produced from snow survey data, using correlations between historic flows and snow survey data. However, the 90- and 10-percent forecasts are produced by imposing an envelope of likely inflows around the 50-percent forecast.

The envelope is defined with data from the previous 50 years, and reflects the 10- and 90-percent deviations from the 50-percent forecast which have occurred during the remaining portions of the year. The timing and volumes of the 90th and 10th percentile forecasts are distributed across the months of forecast based on historical patterns and professional judgment. Thus, the 50-percent forecasts are based directly upon snow survey data (i.e., antecedent conditions), whereas the 10- and 90-percent exceedences are based upon the spread of inflows over the previous 50 years about the 50-percent forecast, and professional judgment. (Rizzardo, 2007) [5]

Figures 4-1 through 4-4 compare the historical annual unimpaired flow of 1966 through 2007[6] with corresponding February, March, April, and May forecasts. Comparison plots for both 50-percent and 90-percent forecasts are shown. Several observations on forecast quality are summarized as follows:

- In general, the forecast quality is not ideal, and has a significant variation of error.
- The quality of the February forecast is low for both 50-percent and 90-percent exceedence forecasts; more forecast errors in quantity occur in wetter years.
- The quality of the forecast improves significantly for May; however, the forecast for wetter years has greater error.
- By definition, the 90-percent exceedence forecast would be more likely to underestimate the annual unimpaired flow than the 50-percent exceedence

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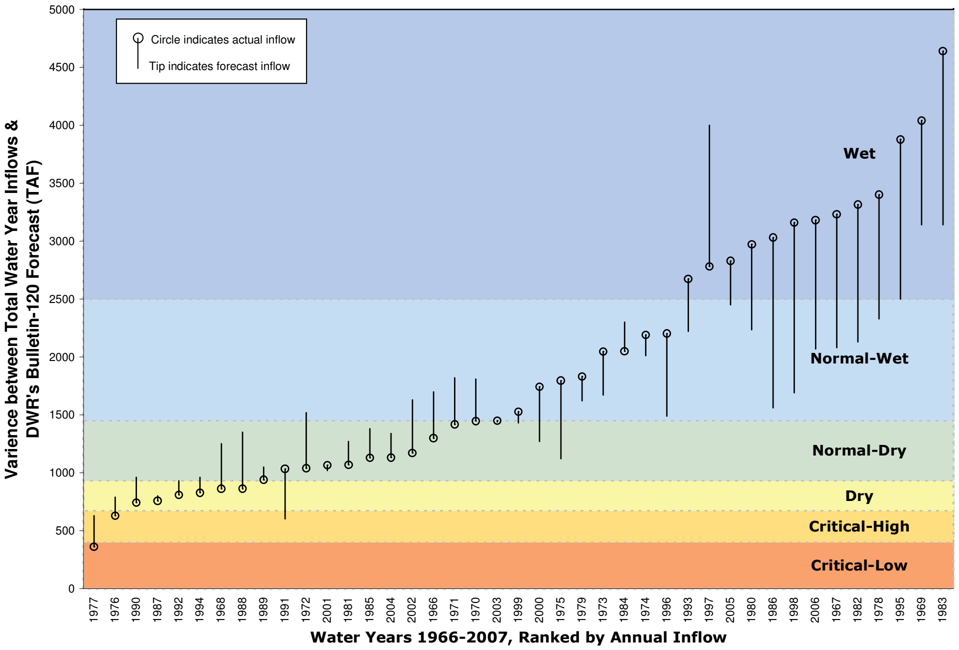
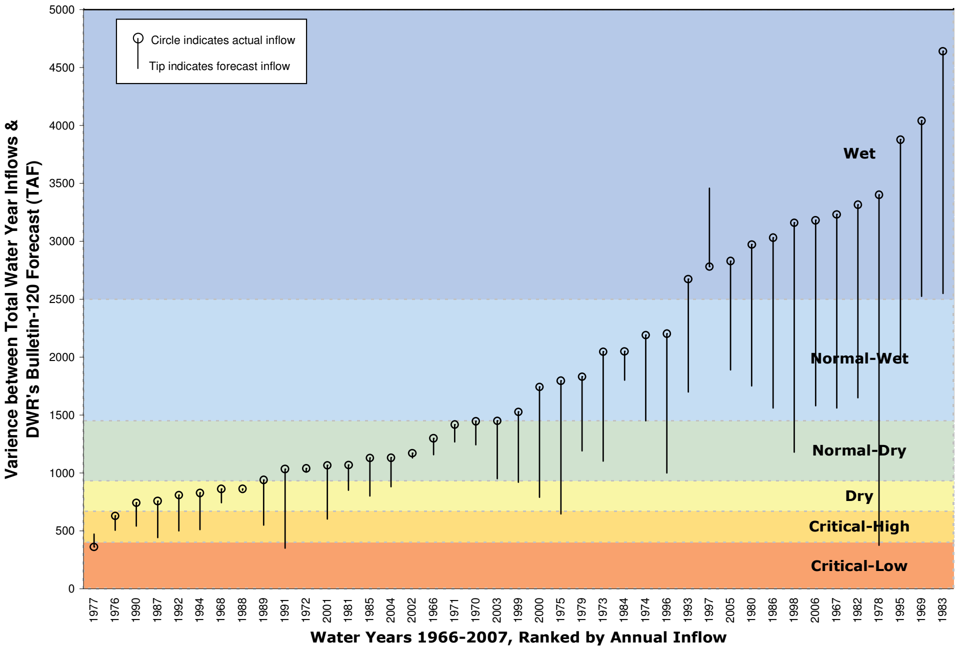
[5] Details of Bulletin 120 forecast methodology are beyond the scope of this TM. While relevant, the more important consideration herein is the adequate application of such forecast data.

[6] The common period for available 50-percent and 90-percent forecast data by DWR.

forecast; however, the actual quantity difference between these two forecasts gradually diminishes in later months.

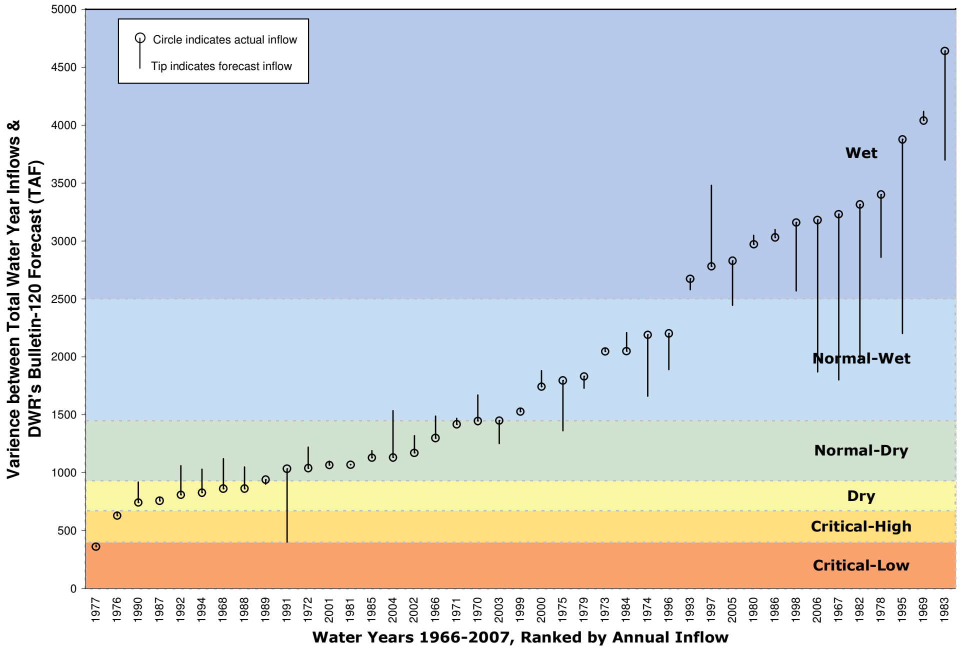


(a) 50-Percent Exceedence Forecast

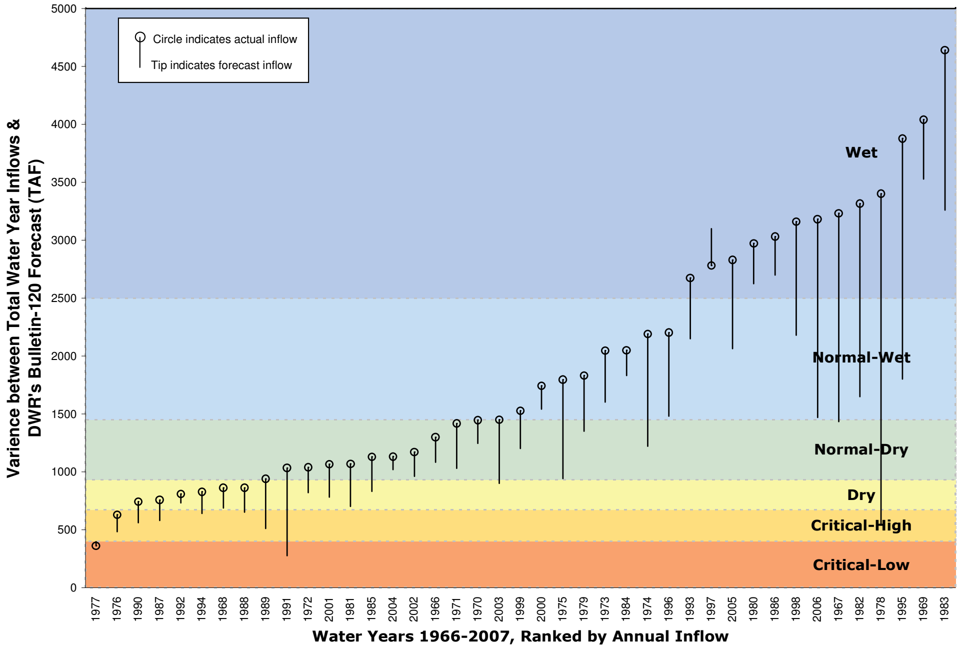


(b) 90-Percent Exceedence Forecast

Figure 4-1.
Comparison of Actual Annual Unimpaired Flow and February Forecast from Bulletin 120, for Water Years 1966-2007

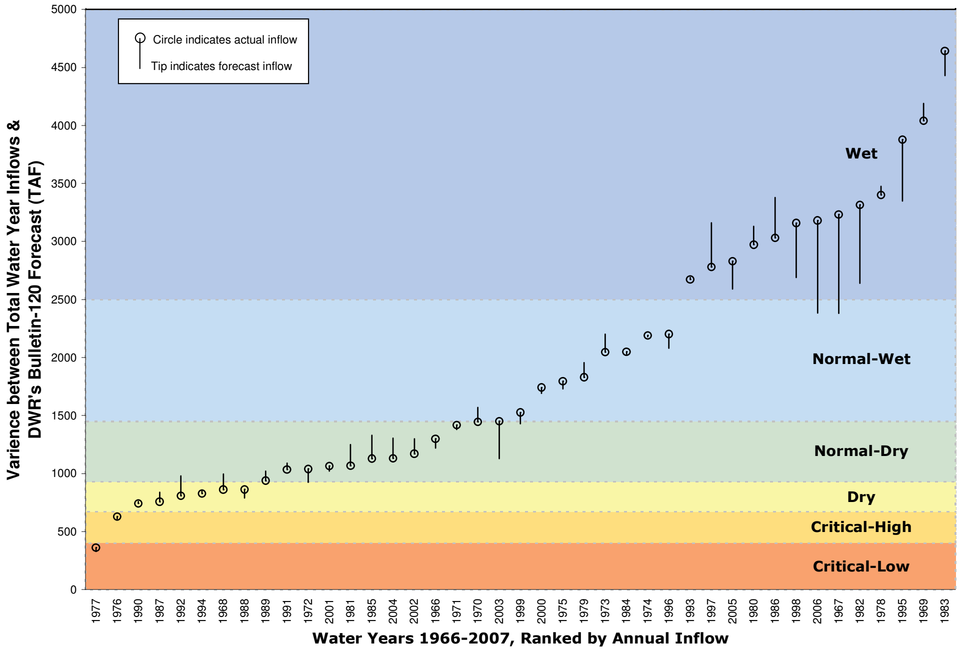


(a) 50-Percent Exceedence Forecast

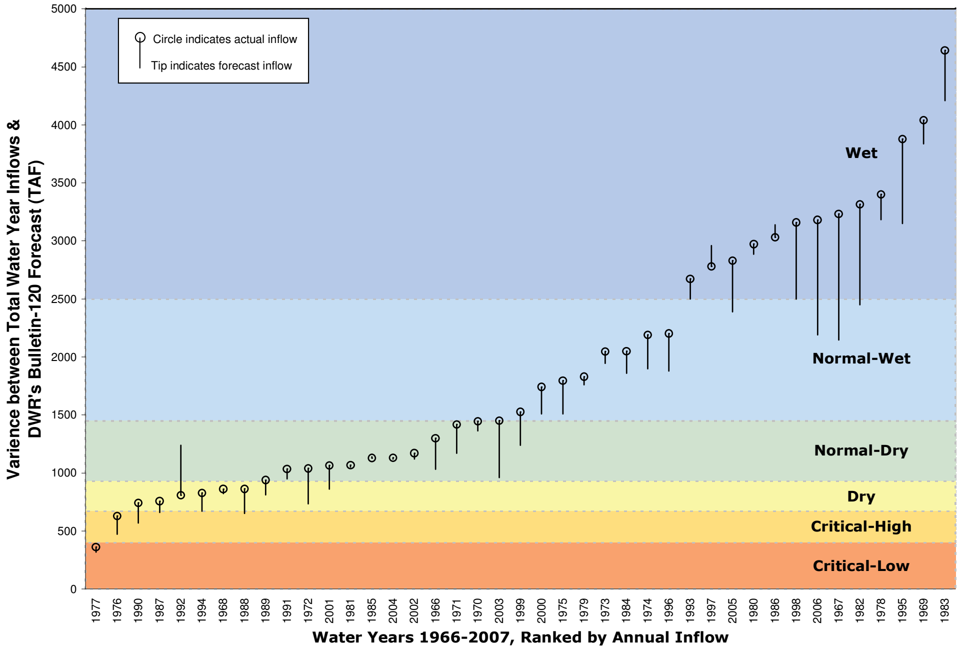


(b) 90-Percent Exceedence Forecast

Figure 4-2.
Comparison of Actual Annual Unimpaired Flow and March Forecast from Bulletin 120, for Water Years 1966-2007

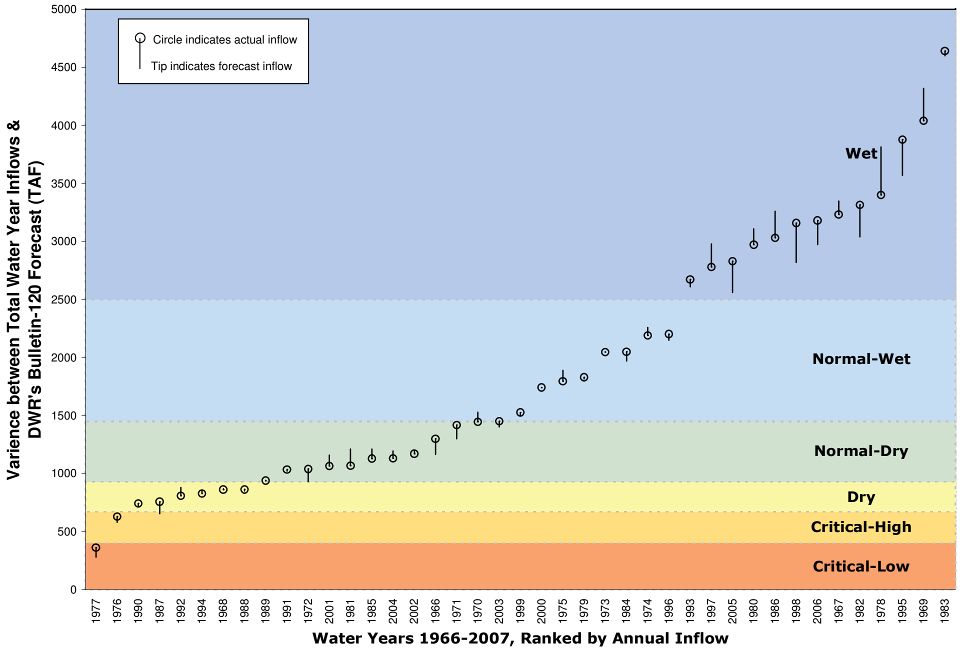


(a) 50-Percent Exceedence Forecast

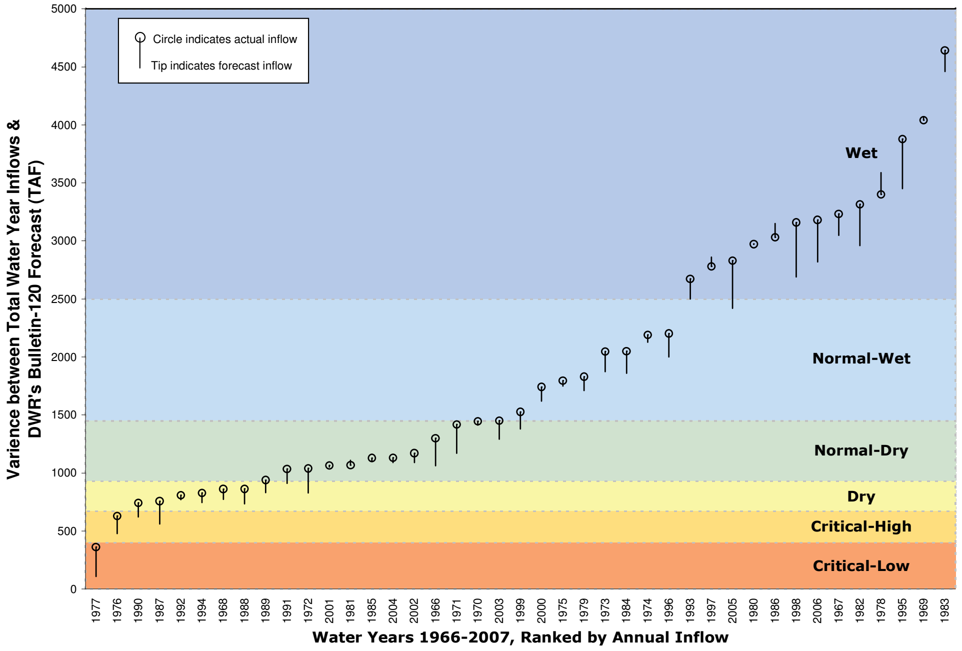


(b) 90-Percent Exceedence Forecast

Figure 4-3.
Comparison of Actual Annual Unimpaired Flow and April Forecast from Bulletin 120, for Water Years 1966-2007



(a) 50-Percent Exceedence Forecast



(b) 90-Percent Exceedence Forecast

Figure 4-4.
Comparison of Actual Annual Unimpaired Flow and May Forecast from Bulletin 120, for Water Years 1966-2007

Table 4-1 shows another Bulletin 120 forecast summary for assessing associated forecast quality. Because the unimpaired flow largely originates from snowmelt, the period forecast (i.e., April through July) may be more reliable than the forecasts for individual months. However, 2006 is a good example of a forecast that cannot capture the associated year type until much later in spring because of the late storms that occurred in that year. The volatility associated with a hydrologic forecast is a great challenge for real-time operations and a water year definition and associated operations hinged upon the total annual unimpaired flow amount, as required in the Settlement.

Table 4-1.
Summary of Bulletin 120 Forecast for San Joaquin River Unimpaired Inflow to Millerton Lake from 2001 Through 2006 (in TAF)

Year	Forecast Month	Forecast Period															
		Apr-Jul	**% Error**	**Feb**	**% Error**	**Mar**	**% Error**	**Apr**	**% Error**	**May**	**% Error**	**Jun**	**% Error**	**Jul**	**% Error**	**Aug-Sept**	**% Error**
2001	Feb	730	-8%	65	55%	105	-17%	190	1%	300	-33%	180	57%	60	28%	40	74%
	Mar	830	4%			110	-13%	200	6%	350	-21%	220	91%	60	28%	40	74%
	Apr	740	-7%							310	-30%	180	57%	60	28%	35	52%
	May	870	9%							370	-17%	230	100%	80	70%	45	96%
	Actual	**795**		**42**		**126**		**188**		**445**		**115**		**47**		**23**	
2002	Feb	1,190	41%	100	75%	140	49%	240	-3%	450	39%	380	70%	120	126%	45	114%
	Mar	960	13%			105	12%	200	-19%	380	18%	280	26%	100	89%	45	114%
	Apr	950	12%					210	-15%	380	18%	270	21%	90	70%	45	114%
	May	860	2%							355	10%	200	-10%	60	13%	35	67%
	Actual	**846**		**57**		**94**		**247**		**323**		**223**		**53**		**21**	
2003	Feb	1,030	-3%	70	17%	130	19%	250	58%	400	-8%	290	-23%	90	1%	35	-24%
	Mar	880	-17%			110	1%	240	52%	340	-22%	240	-36%	60	-33%	25	-46%
	Apr	760	-28%					240	52%	290	-33%	180	-52%	50	-44%	25	-46%
	May	1,020	-4%							420	-4%	330	-12%	110	24%	35	-24%
	Actual	**1,058**		**60**		**109**		**158**		**436**		**375**		**89**		**46**	
2004	Feb	1,050	43%	45	-35%	85	-56%	200	-10%	420	48%	310	79%	120	118%	45	125%
	Mar	1,170	59%			130	-32%	240	8%	480	69%	350	102%	100	82%	50	150%
	Apr	880	20%					210	-6%	350	23%	240	39%	80	45%	50	150%
	May	780	6%							295	4%	200	16%	60	9%	40	100%
	Actual	**735**		**69**		**192**		**223**		**284**		**173**		**55**		**20**	
2005	Feb	1,730	-17%	150	13%	180	-20%	325	26%	590	-28%	565	-15%	250	-27%	90	0%
	Mar	1,720	-17%			200	-12%	310	21%	610	-25%	565	-15%	235	-31%	90	0%
	Apr	1,840	-12%					370	44%	650	-21%	585	-12%	235	-31%	90	0%
	May	1,810	-13%							685	-16%	620	-6%	250	-27%	90	0%
	Actual	**2,080**		**133**		**226**		**257**		**818**		**662**		**343**		**90**	
2006	Feb	1,460	-41%	95	-16%	140	-29%	270	-46%	525	-41%	470	-38%	195	-40%	60	-31%
	Mar	1,270	-49%			115	-42%	230	-54%	460	-48%	410	-46%	170	-48%	60	-31%
	Apr	1,700	-31%					300	-40%	550	-38%	580	-24%	270	-17%	60	-31%
	May	2,180	-12%							680	-23%	660	-13%	345	6%	170	95%
	Actual	**2,471**		**113**		**198**		**498**		**884**		**763**		**326**		**87**	

4.2 Existing Operation Guidelines Associated with Hydrologic Uncertainties

The Friant Division uses a contract year of March through February to be consistent with allocation practices. The existing contract allocation practices for the Friant Division allow Reclamation to exercise its discretion in using a forecast within the range of 50 to 90 percent of exceedence (Reclamation, 2005). Contract allocations are based on the review of several forecasts, which combine estimates of snow accumulation, antecedent conditions, and a statistical range of precipitation predictions.

Using discretion, Reclamation tends to establish initial allocations in February by using higher probability forecasts (i.e., an expectancy that forecasted runoff would have a 90 percent of exceedence) early in the year and when dry conditions have prevailed. In years with wet conditions, with surplus water or possible flood control releases, an initial forecast might favor a lower percent of exceedence because the negative consequences of overestimating runoff and allocations are potentially great.

As additional forecast information becomes available in subsequent months, water contract allocations are amended to reflect the increasing confidence in hydrologic forecasts. Allocations may also increase during this period if inflows are projected to be greater than previously forecasted.

The majority of snow in the Sierra typically melts by the end of June, causing the forecast of unimpaired runoff for the remainder of the year to become more certain. After June, inflow to Millerton Lake depends highly on releases from upstream storage. At this point, allocations are set mostly by the projected operation of upstream projects and end-of-year carryover targets. Allocations are generally held constant from July through the following February (i.e., the end of the contract year).

4.3 Incorporating Hydrologic Forecast Uncertainties in Restoration Flow Accounting

While Reclamation may, at its discretion, use any exceedence forecast between 50 and 90 percent for contract allocations, it is recognized that additional resolutions are necessary for managing Restoration Flow releases because of potential differences in hydrographs in the spring period. The continuous hydrograph in Section 3 would help alleviate concern over forecast uncertainties; however, forecast uncertainties remain a very critical issue for real-time water operations.

4.3.1 Considerations in Using Exceedence Forecast

Concern over hydrologic forecast uncertainties in Settlement implementation is due to the resulting water-year classification, and potential undefined risks associated with overestimated or underestimated Restoration Flow requirements. The actual impacts of misclassification of year type and associated flow requirements are significantly reduced when hydrographs are transformed into a continuous format, as recommended in Section 3, to alleviate abrupt changes in flow requirements.

Within a Restoration Flow year, from March through February, Restoration Flow releases would be accounted for and compared with the volumes determined by procedures outlined in Section 3. Because of a changing annual allocation of flow due to revised forecasts (through June) of unimpaired runoff, diligent management and planning of the release of Restoration Flows is necessary.

In principle, when an allocation is revised as a result of a changed forecast, the total volume of Restoration Flows for the entire Restoration Flow year (March through February) would be reevaluated and modifications to the remaining portion of the Restoration flow hydrographs would be implemented. When the revised forecast of unimpaired inflow below Millerton Lake becomes available each month, a balance of flow to-date would be calculated as the difference between annual Restoration Flow allocations under the previous determination and the current determination. The balance would then add to or subtract from the releases in the remaining year in a manner proportional to the Restoration flow hydrographs.

Note that many options of this adjustment protocol are based on fishery management preferences and risk management, the use of other provisions in the Settlement on Buffer Flows and Flexible Flows described in Exhibit B, and the management structure that would be established for SJRRP implementation. Therefore, further coordination and development of a final protocol is necessary in continued SJRRP development.

4.3.2 Consideration of Flood Releases

The adjustment mentioned above accounts for forecast uncertainties; further adjustment is required for incorporating consideration of flood releases.

The Settlement allows using flood releases to meet Restoration Flow requirements. Therefore, the obligation to release water from Millerton Lake for restoration purposes will be met when required flood control releases at Friant Dam are above Restoration flow hydrographs under the default, or subsequently modified Restoration Flow requirements. Releases in excess of Restoration Flow requirements are considered flood releases in Restoration Flow accounting.

For illustrative purposes, consider the following scenario:

- an April 1st forecast which establishes a Normal-Dry restoration year type.
- an intense rain event causes uncontrolled releases from Friant Dam of
    - 2,800 cfs from April 1st through 15th, and
    - 3,000 cfs from April 16th through April 30th.

Table 4-2 depicts an example where the following May 1st forecast establishes the year type as Dry, which retroactively decreases the Restoration Flow volume provided for April. In this example, regulations throughout the entire month of April are being determined by flood control (uncontrolled releases) and all scheduled releases are below the actual uncontrolled releases. So long as the scheduled releases are below actual uncontrolled release rates, and so long as the releases were made as part of uncontrolled operations, the revised scheduled release will be charged against Restoration flow allocations. This approach is not expected to incur a water supply impact above the quantities assessed for the Settlement.

Table 4-2.
Example of Charges to Restoration Flows Resulting from Decreasing Forecasts During Periods of Uncontrolled Release

Period of Release	Scheduled Release using April Forecast (cfs)	Actual Uncontrolled Releases (cfs)	Revised Scheduled Release using May Forecast (cfs)	Charges against Restoration Flow Allocations (TAF)
April 1-15	2,500	2,800	350	**10.4**
April 16- 30	350	3,000	350	**10.4**

Table 4-3 depicts an example where the following May 1st forecast establishes the year type as Normal-Wet, which retroactively increases the Restoration Flow volume provided for April. However, releases have been made for April when May forecast becomes available. Therefore, the lesser of scheduled release based on April forecast and actual release is charged to Restoration flow account.

In this example, regulations throughout the entire month of April are being determined by flood control (uncontrolled releases). For the first period, the Restoration flow volume is unchanged by the revised schedule: the charge for this period equal to 2,500 cfs held over the full 15 days, even though the uncontrolled releases were in addition to this quantity. This is an example where the uncontrolled releases are used toward Restoration flow, as prescribed in the Settlement.

Table 4-3.
Example of Charges to Restoration Flows Resulting from Increasing Forecast During Periods of Uncontrolled Release

Period of Release	Scheduled Release using April Forecast (cfs)	Actual Uncontrolled Releases (cfs)	Revised Scheduled Release using May Forecast (cfs)	Charges against Restoration Flow Allocations (TAF)
April 1-15	2,500	2,800	2,500	**74.4**
April 16- 30	350	3,000	4,000	**89.3**

However, the revised schedule for releases exceeds the uncontrolled releases made during the April 16-30 period. Thus, the change in forecast calls for more water than was provided by either the previous scheduled amount or the uncontrolled release. Therefore, the full uncontrolled release will be charged against the Restoration flow allocation. However, the Restoration flow allocation was not fully met for this period: the shortfall equals 1000 cfs for 15 days. This difference is available to subsequent Restoration flow releases within the current Restoration year.

4.3.3 Recommendation for Forecast Use

It is necessary to use a higher percent exceedence forecast in early months to avoid overcommitment of Restoration Flow designations and also water supply allocation. This will result in additional adjustment problems for river and water management, and in a greater level of risk of depleting Millerton Lake without an additional remedy for water supply and river management in place. As the accuracy of forecast improves in later months, a lower percent exceedence forecast should be used. However, as previously mentioned, the difference between 50- and 90-percent exceedence forecasts is gradually diminishing as time progresses. Therefore, the use of 50- or 90-percent exceedence forecasts may not result in significant differences:

Based on the review of forecast quality and the above-mentioned considerations, the following schedule is proposed for use as a reference in allocating both Restoration Flows and contract deliveries.

- March 90-percent exceedence forecast
- April 75-percent exceedence forecast
- May 75-percent exceedence forecast
- June 50-percent exceedence forecast

The above sequence of exceedence percentages for estimating Restoration Flows and contract allocations is intended for default operations, which are further subject to real-time adjustments recommended by advisory parties. Bulletin-120 forecasts are generally available within the first ten days of each month. Because they may not be available on the 1st of each month, real-time adjustments may be required in advance of available forecast information. (See Section 5 for additional discussion on real-time considerations.)

4.3.4 Validation of Recommended Forecast Use

Forecast-based operation is a true real-time operation challenge. Therefore, the validation presented herein provides additional information to support the above-recommended forecast exceedence sequence in the beginning months of a Restoration Flow year. More importantly, this validation establishes the reasonableness of such a recommendation, rather than presenting a definite procedure or process for real-time adjustments and management.

Major concerns over the sequence of choice for forecast exceedence are the balance between aggressive operation to realize potential restoration benefits (and water deliveries) in early months, and subsequent risk in fishery management and water supply if the hydrology is drier than predicted. The risks of managing Restoration Flows and concurrent water contract allocations are critical to Settlement implementation. While expectations were established in the Settlement, the details of balancing these risks were the focus herein.

Scenarios were used to demonstrate that (1) the recommended forecast exceedence sequence is acceptable and (2) there are no apparent benefits in using other sequences if the equity of Restoration Flows could be accomplished. Table 4-4 shows four scenarios of exceedence sequence for the February-through-June forecast. The period of analysis is from 1966 through 2004 to better facilitate comparison and discussion because (1) historical 50-percent and 90-percent forecast data in the February-through-May period are available after 1966, and (2) the Settlement model and analysis were for the period of 1922 through 2004.

A set of procedures was used in these scenarios to demonstrate the possibility of using a continuous forecast-and-adjustment method to maintain the equity of Restoration Flow accounting. These procedures are for illustrative purposes. There is no further assumption in adopting these procedures for implementation; however, it is a viable approach. It is important that the equity of Restoration Flow accounting can be demonstrated to allow for later proposed procedures for RWA accounting (see Section 4.4). In other words, the strategy herein is to decouple the equity issues associated with the accountings for Restoration Flows and for water allocation.

Table 4-4.
Scenarios of Forecast Exceedence Sequence

Scenario	Forecast Exceedence Level			
	March	April	May	June**
1	90	90	90	50
2	90	75*	75*	50
3	75*	75*	75*	50
4	50	50	50	50

* Historical 75% forecast is not available; for illustrative purposes, an average between 90% and 50% forecast was used.

** Historical June forecast is not available; for illustrative purposes, the 50% May forecast was used.

The adjustment for changing the forecast used in the analysis is outlined below:

1. Based on the new forecast, a new annual Restoration Flow requirement is established per the procedure in Section 3.2.1.
2. The resulting Restoration Flow requirement from Step 1 is distributed among months per the procedure in Section 3.2.2. The verification in Section 3 suggests that no additional inconsistency would be introduced in these two steps.
3. The to-date balance calculated from the to-date releases, established by using the previous month's forecast, and the new hydrograph, established by using the current forecast, are added to the Restoration Flow requirement volume in Step 1.
4. The adjusted Restoration Flow requirement volume from Step 3 is distributed into a Restoration flow hydrograph, per the procedure in Section 3.2.2. If uncontrolled releases are made, charges are assessed against the Restoration flow allocation, as described in section 4.3.2.[7]
5. At the end of October, if the to-date balance is positive, the balance is allocated to November flow to augment fall pulse flows, with a cap of 700 cfs, described as the highest fall pulse flow rate. If the to-date balance is negative, no adjustments are made.
6. No further adjustments are made for the remaining balance.

The above approach was not designed to provide detailed accounting of Restoration Flow releases to resolve all equity issues. However, it is considered adequate for illustrative purposes that equity issues could be resolved through adjusting flood release credits, augmenting fall pulse flow implementation, and current unspecified real-time adjustments being made by the Secretary in consultation with advising parties.

Figures 4-5 and 4-6 show, for four scenarios, the end-of-June Restoration Flow account balance, and the end-of-January account balance, based on the procedure prescribed above.

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[7] Flood release credits herein do not refer to the conversion of flood releases under existing operations to Restoration Flow releases under the Settlement (see discussion in Section 4.4.2). The credits refer to flood releases under the Settlement that can be used to offset the difference in hydrograph releases created by changes in forecast.

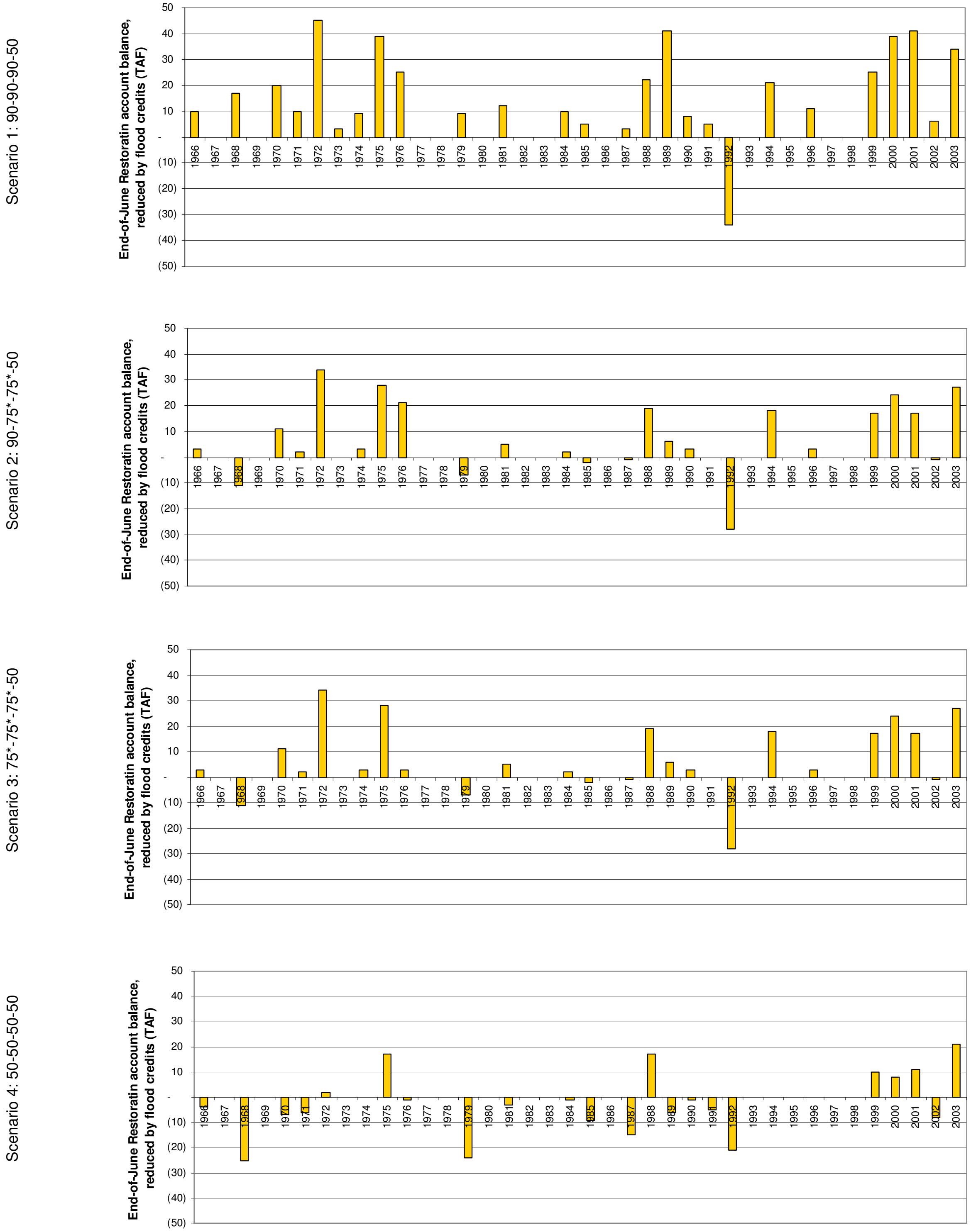

Figure 4-5.
End-of-June Restoration Flow Account Balance by Scenario Adjusted for Flood Release Credits

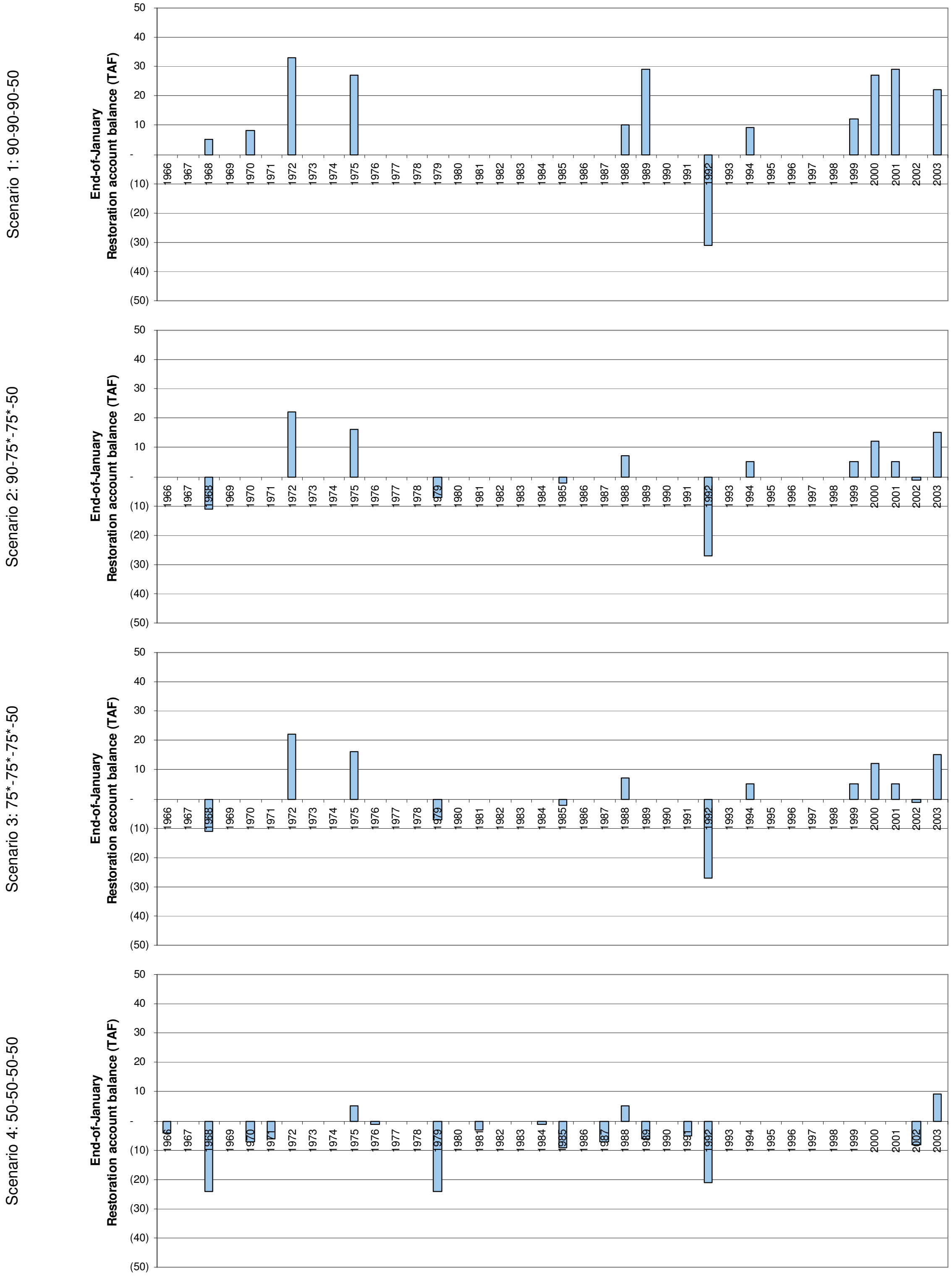

Figure 4-6.
End-of-February Restoration Flow Account Balance by Scenario Adjusted for Flood Release Credits and Fall Augmentation Flows

The results of this analysis suggest the following:

- A two-part answer is required to answer the question outlined in Settlement Paragraph 13(j)(v) in evaluating flood releases for Restoration Flow purposes:
    1. Under Settlement operations, the flood releases that occurred in existing operations could be transformed into Restoration Flow releases, as shown in Figure 4-7.
    2. Additional flood release credits may offset the Restoration Flow account balance created by forecast uncertainties; however, this occurrence is infrequent and its effects are not significant. This observation is consistent with all scenarios of exceedence sequences. This suggests that the corrective measure used in the analysis to reconcile the Restoration Flow account through changes in forecast is functioning reasonably well.
- More aggressive operation using lower exceedences in early months would increase the chance of a negative Restoration Flow balance at the end of June. Considering equity for Restoration Flow releases and water supply, subject to further discussion, the negative Restoration Flow balance could potentially impact implementation of fall pulse flows under the equity consideration. Similar risks would be reflected in water contract delivery reliability.
- The positive end-of-June Restoration Flow balance could be used to augment fall pulse flows and resolve much of the balance.
- The balance at the end of February (being, the end of the Restoration flow year) is generally relatively small, and likely to be resolved with additional real-time adjustments that the Secretary may implement in consultation with advising parties.
- The use of a different forecast exceedence level in early months such as March would not result in major differences in the Restoration Flow account balance. Therefore, from the risk management viewpoint, it is reasonable to maintain a high exceedence level use in early months because this would not impact Restoration Flow implementation, but would provide conservative allocations for water supply, as then currently being implemented. The limited differences in flow schedule in March across the six stair-step Restoration flow hydrographs would also alleviate concerns over using the forecast of a higher exceedence level.

Overall, the analysis above confirms the reasonableness of using the proposed 90-90-75-75-50 sequence of forecast exceedence for Restoration Flow implementation. Equity issues associated with the Restoration Flow account can be largely resolved by in-year adjustments, as demonstrated as an example in the above analysis. The remaining end-of-January balance is small and could be further resolved through real-time adjustments by the Secretary in consultation with advising parties.

The above validation demonstrates that the equity associated Restoration Flow accounting could be achieved; thus, RWA accounting can be decoupled.

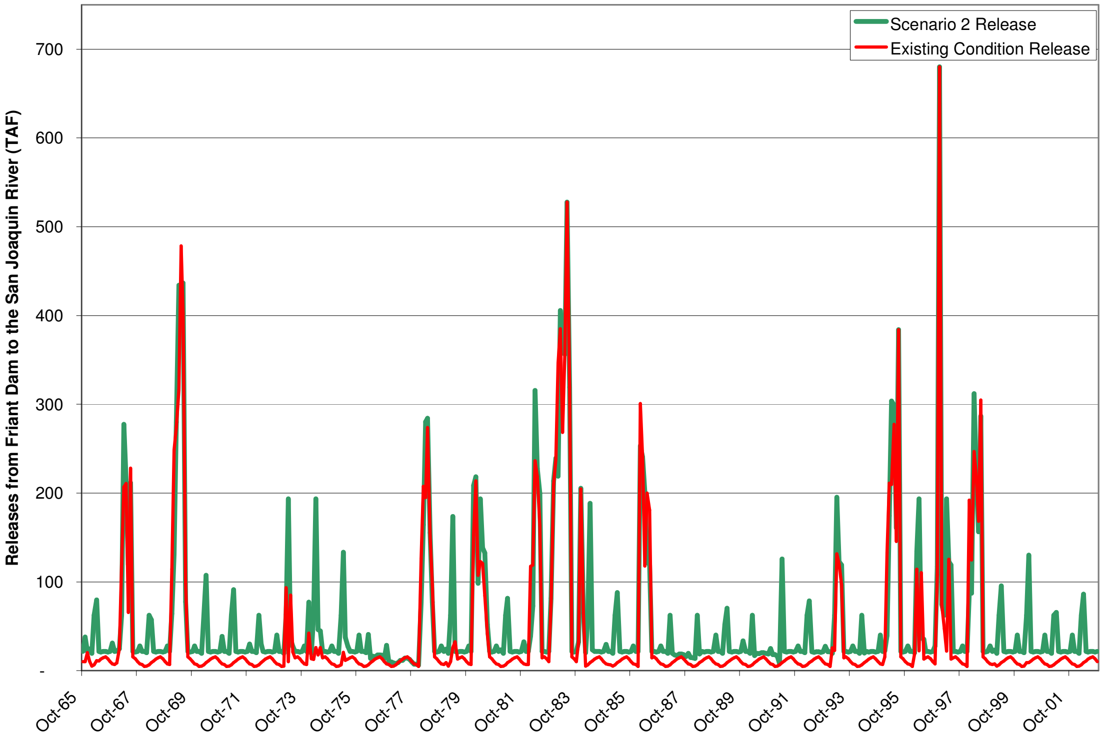

Figure 4-7.
Comparison of Flood Releases Under the Existing Operation with Releases Under Scenario 2.

5.0 Real-Time Operational Considerations

Additional real-time operational considerations may be considered as part of Friant Division operations. While some of the considerations are not stipulated in the Settlement, they could still relate to Restoration Flow management as part of overall water management practices of the Friant Division. Following is a list of additional real-time operational considerations that would be addressed at the appropriate level in the SJRRP Program Environmental Impact Statement/Report.

- Formal protocol for real-time adjustments that the Secretary may use for equity issues, in consultation with advising parties. The organization of advising parties and associated responsibilities is expected to be formalized through a policy document and through continued discussion with the RA, Settling Parties, and potential advising parties.
- Ramping rates that consider operational constraints at Friant Dam and downstream channels and levees, and constraints in fishery management for the Restoration Goal.
- Implementation of the flexible flow periods in spring and fall.
- Regular maintenance of facilities, which may require rescheduling Restoration Flow releases.
- Power operations as part of the release mechanism for providing Restoration Flows.

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Estimating Ecologically Based Flow Targets for the Sacramento and Feather Rivers

THE NATURAL HERITAGE INSTITUTE

John Cain

Carrie Monohan

April 2008

PREFACE

This report was prepared as part of a collaborative investigation by the Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) to explore opportunities to expand water supplies in the Sacramento Valley through conjunctive management of surface water and groundwater supplies. These expanded supplies could contribute toward achieving three primary objectives: (1) improve local in-basin water supply reliability for farms, cities, and the environment; (2) contribute to improvement of statewide water supply reliability; and (3) enhance ecosystems in the rivers in the Sacramento Valley. The investigation was funded by the California Department of Water Resources and Bureau of Reclamation.

The Scope of Work of the federal and state grants includes a task to define a range of environmental flows to restore in stream and riparian ecosystem processes to the maximum extent compatible with the protection of the interests of the riparian landowners in the floodplain improvements. Flows shall be defined for both the Sacramento River below Shasta and Keswick dams, and the Feather River below Oroville and Thermalito dams, in terms of magnitude, duration, frequency, seasonality and reach. This will be defined in a manner to avoid any uncompensated risks to affected landowners. The range may include various assumptions about levee setbacks in the floodplains. Flood-routing models will be used to estimate the potentially inundated area and system capacity to carry environmental flows.

This report was prepared by the NHI in partial fulfillment of the above-defined task. It postulates hypothetical environmental flow regimes for the Sacramento and Feather Rivers that are significantly different from those that presently exist. It is not yet known to what extent the flows can be achieved through conjunctive water management or, potentially, by other means that are outside the scope of this investigation, while other existing and future water demands are satisfied. Also, the risks that the recommended flows may pose to affected landowners are not addressed in the report, but will be addressed in subsequent work. NHI has prepared this report for the purposes of this planning investigation only. To the extent this report is used or referenced for other purposes, it will be subject to review, modification, and acceptance by the larger number of entities and stakeholders necessarily involved in crafting water management policies, projects and practices in the Sacramento Valley and downstream affected areas.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

This study identifies an environmental flow regime for the Sacramento and the Feather Rivers in order to:

- Test the feasibility of reoperating terminal reservoirs in the Sacramento River Basin without diverting additional water away from agriculture,
- Develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River, and
- Use the environmental flow targets to inform and guide conjunctive use scenarios.

The development of environmental flow regimes is as much an art as a science, but we attempted, to the extent possible, to use established methods to develop a transparent and replicable approach for identifying and environmental flow regime. We conducted a detailed literature review of various methods and approaches previously utilized to develop environmental flow recommendations, and employ a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento and Feather Rivers. This approach relies heavily on hydrological evaluations, previous studies and modeling efforts analysis of historical hydrology, and expert opinion to estimate environmental flow requirements.

Our approach consists of five basic steps:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support achieve environmental objectives.
3. Compare and analyze existing and historical hydrology to understand natural hydrologic patterns and how they have been altered.
4. Identify obvious gaps between flows necessary to achieve objectives and existing flows.
5. Modify the existing hydrograph into an environmental flow hydrograph based on an understanding of natural hydrology and the flows necessary to achieve key objectives.

These five steps will ultimately need to be followed by an adaptive management research program to test and refine an improved environmental flow regime over time.

We designed the environmental hydrograph to achieve the following three types of objectives

- Geomorphic Functionality: Bed mobility, channel migration, and floodplain inundation.

- Riparian Habitat Sustainability: Recruitment and maintenance of Fremont Cottonwood.
- Chinook Salmon: Improved habitat, particularly rearing habitat, for all runs.

We relied on field data, modeling results, and studies , particularly the recent Nature Conservancy Study of the Sacramento River, to identify the minimum flows and critical thresholds to achieve each of our objectives. We then analyzed historical and existing hydrology to understand how the objectives may have been achieved under pre-dam conditions and to evaluate how existing hydrology may fall short of meeting those objectives.

A sharp reduction in the magnitude and duration of the late winter and early spring hydrograph and a corresponding reduction of inundated floodplain habitat is the most obvious and significant change in the hydrograph on both the Sacramento and Feather Rivers. The reduction in late winter and spring flows reduces the frequency of geomorphic and riparian flows and substantially reduces the extent and frequency of occurrence of inundated floodplain rearing habitat for salmonids. Restoring spring flows alone, however, will not be sufficient to dramatically increase the amount of floodplain habitat. Modifications of the levees and bypass system will also be necessary to enable high flows to inundate historical floodplains. We evaluate the amount of flow necessary to inundate the Yolo and Sutter Bypasses assuming modification of the weirs controlling flows into those bypasses in the interest of identifying water efficient strategies for creating large areas of inundated floodplain habitat.

The last chapter identifies an environmental flow regime for the Sacramento and Feather Rivers. An increase in late winter and early spring flow is the primary component of the environmental flow regime, but a corresponding reduction in summer base flows is also recommended. Reduced summer flows are primarily needed to free-up water needed to restore the spring hydrograph but may also provide ecological benefits by better approximating the natural hydrograph. Reducing summer base flows could, however, increase summer temperatures and harm salmonids including the endangered winter-run Chinook salmon. On the other hand, cool water temperatures in the upper Sacramento River are largely controlled by the volume of cold water storage behind Shasta Dam and the environmental flow regime identified here does not involve modifying coldwater pool management.

The summer temperature issue is one of several key uncertainties that must be addressed before any significant modifications to the flow regime can be refined and implemented for environmental purposes. Articulating a hypothetical environmental flow regime is the first step in identifying and addressing constraints and uncertainties associated with improving environmental flow regimes on regulated rivers. To that end, NHI welcomes comments and criticisms so that we can improve upon this report as we learn more about the rivers and the people who depend upon them for their livelihood.

2. INTRODUCTION

This study identifies environmental flow targets for the Sacramento River and the Feather River. The purpose of developing environmental flow targets is to:

- Test the feasibility of reoperating terminal reservoirs in the Sacramento River Basin without diverting additional water away from agriculture,
- Develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River, and
- Use the environmental flow targets to inform and guide conjunctive use scenarios.

Our thesis is that reservoirs operated today for a limited set of water supply and flood control objectives could be reoperated to achieve newly defined ecological objectives without compromising existing objectives. This opportunity was recognized by the authors of CALFED's Strategic Plan for Ecosystem Restoration:

> "There is underutilized potential to modify reservoir operations rules to create more dynamic, natural high-flow regimes in regulated rivers without seriously impinging the water storage purposes for which the reservoir was constructed. Water release operating rules could be changed to ensure greater variability of flow, provide adequate spring flows for riparian vegetation establishment, simulate effects of natural floods in scouring riverbeds and creating point bars, and increase the frequency and duration of overflow onto adjacent floodplains."

Clearly defining this new set of ecological objectives and estimating the flows necessary to achieve them is the first step toward evaluating the feasibility of restoring these flows. The biological and physical processes that support natural riverine functions are complex and the task of defining environmental flow regimes is enormously difficult. For the purpose of defining an environmental flow regime and assessing the feasibility of attaining it, we have identified a simplified but broad set of water intensive ecological objectives that best capture the full range and magnitude of environmental flow requirements in the Sacramento Basin. These objectives include:

- Geomorphic Processes: sediment transport, channel geomorphology, floodplain inundation.
- Riparian vegetation: cottonwood recruitment and maintenance flows
- Chinook and Steelhead: stream temperatures and adequate flow for various life stages.

This study focuses on the magnitude and timing of flows necessary to replicate key ecological and geomorphic processes, and considers the flows necessary to provide suitable conditions for various life stages of Chinook salmon and steelhead. This study does not identify specific population targets for salmonid restoration, nor does it address important non-flow objectives such as habitat area required for restoration of target species or augmentation of coarse sediment supplies necessary to restore full geomorphic structure and function. Rather this study focuses on magnitude, pattern, and quantity of water necessary to restore ecological functions assuming that adequate physical habitat exists or will be created to complement a suitable environmental flow regime. The rationale of this focus is to identify a hypothetical environmental flow regime for the purpose of evaluating whether it is possible to reestablish ecological and geomorphic flows on the rivers of the Sacramento Basin without reducing water supply deliveries to existing water users.

This report would not have been possible without the foundational analysis conducted by the Nature Conservancy and their consulting team, but it differs substantially from the Sacramento River Ecological Flows Study (SREFS) developed by the Nature Conservancy with funding from the CALFED Bay-Delta Program. The SREFS compiled information on the state of the Sacramento River ecosystem and developed a decision support tool to predict how changes in the flow regime of the Sacramento River might affect key attributes and species of the riverine ecosystem. The SREFS did not, however, attempt to develop an environmental flow prescription for the river and did not address ecological conditions or flow requirements for the Feather River. The SREFS decision support tool could be used to test and refine the flow regime developed for this report, but the SREFS did not and will not propose an environmental flow regime. We relied heavily on the information developed for the SREFS to generate the environmental flow regime described in this report.

Our study relies heavily on analysis of historical hydrology and the habitat it created to provide a reference point for identifying ecosystem restoration goals, but we recognize that it is not possible to restore historic conditions in highly altered systems such as the Sacramento River. Historical hydrologic analysis is useful for identifying patterns in the timing, magnitude, duration, and frequency of flows that may be important for maintaining native species, but it is less useful in developing specific flow prescriptions, because physical habitat has been so profoundly changed by dams and levees. We recognize that it is not possible to fully restore historical hydrology or habitat conditions in the Sacramento Valley, but ecosystem restoration will require reestablishment of a minimum threshold of both hydrologic and physical habitat conditions.

Although this study identifies hypothetical restoration flow regimes for the Sacramento and Feather Rivers, we recognize that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The hypothetical flow regime serves as a reasonable starting point for evaluating the economic feasibility of reoperating reservoirs and a long-term adaptive management program. The assumptions and uncertainties associated with the hypothetical flow regime are important to acknowledge and understand. To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of modeling, pilot flow studies, model calibration, and long-term implementation.

3. METHOD FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS FOR THE SACRAMENTO AND FEATHER RIVERS

We conducted a detailed literature review of various methods and approaches previously utilized to develop environmental flow recommendations, which is described in further detail in Appendix A. We have employed a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento River. This approach relies heavily on hydrological evaluations, previous studies, and expert opinion to estimate environmental flow requirements and develop a long-term adaptive management plan for implementing and refining an environmental flow regime over time. The results of the holistic approach provide a framework for increasing knowledge regarding the relationship between flow and environmental objectives and refining water management practices over time. The output of the holistic method envisioned here provides not only an estimate of environmental flow requirements, but more importantly, an explicit identification of key assumptions and uncertainties that need to be tested overtime to more accurately describe the flow requirements necessary to achieve environmental objectives.

We made two important assumptions in generally applying this method to the Sacramento River.

- Similarities in both the restoration objectives and the hydrologic, geomorphic, and ecological conditions on the Sacramento River will result in relatively similar prescriptions for environmental management flows. We believe this assumption is well supported by the environmental conditions and historical alteration of this river.

- The flow necessary to achieve restoration objectives may vary greatly depending on non-flow restoration actions such as improving spawning habitat, reconstructing degraded channel, removing levees to restore floodplain habitat, modifying and screening water diversions, reducing polluted run-off, managing ocean harvest, and other factors. In general, non-flow restoration actions will reduce the amount of water necessary to achieve restoration objectives.

The holistic approach applied in this study consists of the following 6-step process to identify an environmental flow regime:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.
3. Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.
4. Identify obvious gaps between objective flow requirements and existing flows.

5. Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.
6. Design an adaptive management program to further test and refine environmental flows.

1) Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).

Well-articulated target ecological conditions and desired species and communities are necessary for establishing environmental flows. Despite the correctly vogue concept of restoring ecosystem processes and avoiding species specific approaches, there is no getting around the fact that key species need specific hydrologic conditions at specific times. This analysis will include both aquatic and riparian communities and the flow parameters necessary to sustain these communities such as floodplain inundation, appropriate water temperature, or creation of structural habitat through geomorphic processes. These specific environmental objectives may vary by region, sub-basin, and reach of the river.

2) Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.

An environmental flow regime encompasses the adequate timing, magnitude, duration, and frequency of flows necessary to support target species and facilitate specific ecological processes encompassed in the stated environmental objectives. Where we understand the life cycle timing of various target species, it is relatively easy to identify the approximate timing and duration of flows necessary to support different life stages of target species. Estimating the required flow magnitude is far more difficult but can be informed by field data, results of numerical models, and general relationships described in the literature. Most short lived target species require adequate flows each year to reproduce, while longer lived species can sustain their populations with a lower frequency of flow conditions conducive to reproduction. For example, riparian forest species may only require recruitment flows every five to ten years to establish new seedlings.

Estimating the magnitude of flows necessary to support or optimize conditions for target species and processes is by far the most difficult element of the environmental hydrograph to approximate. Environmental engineers and biologists have developed relatively elaborate methods for determining ideal flow regimes such as physical habitat simulation (PHABSIM) and Instream Incremental Flow Methodology (IFIM) to identify optimum flow magnitudes based on known habitat preferences of target species, measured habitat conditions (velocity and depth) at various flows, and numerical models that predict habitat conditions at a range of flows. Numerical models that describe the width, depth, and velocity of the rivers at various discharges are useful for predicting river stage and temperature at various locations, factors that are important considerations for habitat or facilitating geomorphic and hydrologic processes. As discussed above, these models tend to focus on the needs of specific species and can sometimes produce results that are inconsistent with both holistic ecological process restoration and common sense. Furthermore, these models are often not calibrated, particularly at higher flows relevant to riparian recruitment, geomorphic processes, and spring outmigration temperatures. Nevertheless, we utilized the results of these models as a guide combined with other information to develop our environmental flow management hypothesis.

Where possible, we relied on actual data and measurements to estimate the flows necessary to achieve suitable conditions to support biological, riparian, and geomorphic objectives for temperature, floodplain inundation, and bed mobilization. In particular, we relied on USGS temperature gauges to characterize the relationship between temperature and flow. Similarly, we relied on previous studies of the rivers to characterize flows necessary to mobilize bed material and inundate the floodplain.

3) Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.

Analyses of historical hydrologic data is useful for describing natural patterns and identifying potential links between hydrology and the requirements necessary to maintain species and precipitate key processes. An analysis of historical patterns can provide clues about the timing, magnitude, duration, and frequency of flows under which target species have evolved. Identification of major changes between historical and hydrologic patterns combined with the life history requirements of various species can help generate hypotheses about how flow regulation may be limiting target species. We will use the an analysis similar to the Index of Hydrologic Alteration approach (Richter et al. 1996) and the Hydrograph Component Analysis (HCA) (Trush et al. 2000) to evaluate changes in flow patterns. The analysis similar to the IHA provides a quick statistical overview of how several important hydrologic attributes have changed. The analysis similar to the Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. While valid and useful, the statistical analysis in the IHA method is not substitute for visually comparing and evaluating key components of the pre- and post-dam hydrographs. Similarly, visual comparisons of pre- and post-alteration hydrographs don’t always reveal important changes identified by the IHA method.

4) Identify obvious gaps between objective flow requirements and existing flows.

An analysis of historical flow patterns combined with an approximation of the TMDF of flows necessary to achieve objectives compared with the regulated flow regime can help illustrate obvious gaps between regulated flows and flows that may be necessary to achieve environmental objectives. We will plot TMDF flow requirements developed in Step 2 as an annual hydrograph and compare it with average regulated and historical conditions.

5) Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.

This project identifies hypothetical restoration flow regimes but recognizes that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The purpose of developing the hypothetical flow regime is to develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River. However, the assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself.

6) Design an adaptive management program to further test and refine environmental flows.

To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of numerical modeling, pilot flow studies, model calibration, and long-term restoration implementation.

4. IDENTIFY ENVIRONMENTAL OBJECTIVES AND UNDERLYING CONCEPTUAL MODELS

4.1. Environmental Objectives

The geomorphic, riparian, and salmonid objectives considered in this report are summarized below. A more detailed description of the objectives, background information, and the underlying conceptual models is included in Appendix B.

Geomorphic Objectives

- Sediment Transport: bed mobilization and bed scour
- Channel Migration
- Floodplain Processes: inundation and fine sediment deposition

Riparian Objectives

- Fremont cottonwood seedbed preparation
- Fremont cottonwood seed germination
- Fremont cottonwood seedling growth
- Periodic large-scale disturbance of the riparian zone
- Riparian stand structure and diversity

Chinook Objectives

- Chinnook salmon: suitable flow conditions and temperatures for all life stages.
- Provide inundated floodplain habitat for rearing juveniles during the later winter and early spring.
- Maintain and recruit spawning habitat, but avoid scouring gravels while eggs or alevon are present

We purposely did not identify population targets for salmonids. The extent and magnitude of restoration actions depends on the size of the population fish managers are attempting to restore. More fish require presumably require more habitat particularly for spawning and rearing. Creating more habitat may require both physical changes in channel conditions and increased flows. .

Appendix B describes the underlying assumptions and rationale (conceptual model) for environmental flow requirements. It describes the science of how and why river flows are necessary to achieve the objectives listed above, and identifies some of the challenges associated with developing environmental flow prescriptions.

5. ENVIRONMENTAL FLOW THRESHOLDS AND REQUIREMENTS

5.1 Geomorphic Thresholds

Flow requirements broadly fall into two categories: threshold and targets. Thresholds are flow prescriptions that only achieve their objective if the threshold is reached or exceeded. For example, bed mobility flows must be high enough to mobilize the bed. If they are below the threshold, the bed does not mobilize and no progress toward the objective occurs. In actuality, however, bed mobilization may occur at different flows in different reaches making it difficult if not impossible to name a single threshold number. Targets are flow requirements that are desirable but not essential to achieve. Benefits still accrue when there is progress toward the target even though the target is not actually reached. For example, a flow release to meet a target of 5,000 cfs to achieve an optimal water temperature for twenty four hours a day will still provide temperature benefits even if the release only achieves 4,000 cfs and optimal water temperatures eighteen hours per day. At some point, however, there is a minimum threshold or minimum flow below which temperatures are lethal or flows are insufficient to support fish.

This paper focuses on thresholds for key ecological and geomorphic objectives that generally require high flow thresholds, but also identifies flow targets to sustain salmon. We have not attempted to define minimum flow thresholds for salmon, but rather have identified more generous targets based on historical base flow conditions. We identify the basis for these thresholds and targets in this section and compile them into a environmental hydrograph in the final chapter of this report.

For each threshold, we have estimated the magnitude, duration, frequency, and timing of flows necessary to achieve a desired outcome and have organized table X and the following text accordingly.

5.1.1. Bed Mobilization:

Magnitude: There is limited information regarding the magnitude of flows required to initiate bed mobilization on the Sacramento River, but less information regarding flows necessary to precipitate full-scale bed mobilization. Under natural conditions the gravel bedded reaches of the Sacramento River were theoretically mobilized by peak flows exceeding the 1.5 to 2 year recurrence interval of the annual instantaneous peak (Leopold et al 1964), which is approximately 80,000 cfs to 120,000 cfs. For comparison, the post dam Q1.5 and 2.0 recurrence interval flow is approximately 65,000 and 80,000 cfs respectively. The Department of Water Resources estimated that the threshold for spawning gravel mobilization immediately below Keswick Dam was 50,000 cfs (CDWR 1981), but this is considered to be a minimum because it was based on observations of gravel that was artificially deposited below the dam *(Stillwater,* *2006).*[1] DWR added 13,300 yd^3 of gravel below Keswick Dam in 1978 and 1979, and estimated that 85% of it was eroded by high flows of 36,000 and 50,000 cfs during the winter of 1980 (CDWR 1981). Latter, Koll Buer of the USBR measured mobility and transport downstream of Keswick with "flower box" samplers – boxes placed into the channel bed before a high flow event. Buer's measurements indicate that gravel transport begins at 24,000 cfs but did not provide information about when larger gravels and the entire bed begin to mobilize. The coarser riffles downstream of Keswick (small boulders and large cobbles) are probably armored due to years of erosion from sediment free water released from Shasta Dam. These armored riffles appear not to change and thus probably remain immobile even at flows exceeding 100,000 cfs (K. Buer, personal communication in Kondolf, 2000).

There are not empirical studies or observations regarding bed mobility on the Feather River. Historical flow data is the only information available to estimate the discharge necessary to mobilize the bed on the Feather River. The 1.5 to 2 year recurrence interval of the annual instantaneous peak prior to the construction of Oroville Dam was 33,000 to 50,000 cfs respectively.

Frequency: Relatively frequent bed mobilization is necessary to prevent vegetation establishment and encroachment on gravel bars. Willows can become well established and resistant to scour in three to four years (cite). Therefore, bed mobilization flows are necessary at a greater frequency then every three to four years to prevent vegetation establishment.

Duration: The duration of peak flows may vary depending on the objective. A short duration may be enough to clean gravels on a spawning riffle while a longer duration flow may be necessary to maintain overall transport of gravels. Because coarse sediment inputs are limited by the upstream dam and riffles already show signs of armoring, long duration peak flows may actually degrade riffles. For this reason and to both reduce flood hazards and economize water, a short duration bed mobilization flow of approximately 12 hours at the recommended peak flow and then ramping down thereafter consistent with historical patterns may be optimal.

Timing: Ideally, bed mobility flows should occur after fall run fry have emerged from the gravel and before swallows begin nesting on stream banks in late march. We therefore recommend a 30 day target window between February 20 and March 20.

5.1.2 Bed Scour

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[1] These gravels may have mobilized at lower flows because of their unnatural position relative to the high flows or because they were not integrated into the gravel/cobble matrix of the natural bed

Less is known about the bed scour process, flows exceeding the natural 5–10 year recurrence interval are probably necessary to precipitate bed scour (Trush et al. 2000). The pre-dam Q5 and Q10 recurrence interval on the Sacramento are 150,000 and 200,000 cfs respectively. During the post dam era, flows of 150,000 cfs or more occurred roughly once every 10 years. On the Feather River, the pre-dam Q5 and Q10 were 104,000 and 144,000 respectively. Flows of this magnitude have only occurred twice in the forty years since Oroville Dam was constructed. Because of the lack of information regarding bed scour and the probable flooding impacts of these flows, it is exceptionally difficult to develop and achieve a bed scour flow recommendation.

5.1.3 Bank Erosion and Channel Migration

Magnitude

Stillwater reports that there is general disagreement on the exact magnitude of flow to initiate substantial bank erosion, but claims there is growing evidence that flows between 20,000 and 25,000 cfs will erode some banks while flows above 50,000 to 60,000 cfs are likely to cause widespread bank erosion (Stillwater, 2007). Meander migration modeling analysis for the Sacramento River assumed that 15,000 cfs was the lower threshold for meander migration (Larsen, 2007). Total bank erosion and channel migration, however, is dependent on both the duration and magnitude of flows, which together produce a cumulative streampower in any given year. Analysis of cross section surveys (Buer, 1994a) over more than ten years shows that rates of bank erosion are closely correlated with cumulative annual stream power (Larsen, et al., unpublished in Stillwater, 2006). Bank erosion.

On the Feather River, there is very little information regarding flows necessary to initiate bank erosion and channel migration. The pre-dam Q1.5 on the Feather River (35,000 cfs) is approximately forty four percent of the pre-dam Q 1.5 on the Sacramento River (80,000) cfs. If channel migration flows on the Feather were similarly proportioned channel migration flows on the Sacramento (50,000 – 60,000 cfs), then one could expect significant and wide spread bank erosion on the Feather River at flows between 20,000 and 25,000 cfs. Instantaneous peak flows of this magnitude reoccur every 2.5 years on average, and large areas of channel revetment along the Feather River indicate that the unprotected bank is subject to erosion under the current flow regime.

Duration

The stream power relationship between magnitude and duration make it difficult to identify a specific threshold. Without modeling analysis, it is difficult to assess whether two weeks at 30,000 cfs could result in as much bank erosion as two days at 60,000 cfs.

Frequency

Bank erosion and channel migration are important for maintaining general riparian habitat, nesting habitat for bank swallows, and turbidity for juvenile fish cover. We are uncertain how often migration and erosion should occur but suspect that some bank erosion every year is a reasonable target. Slight but annual bank erosion may be beneficial for maintaining optimal bank swallow habitat. More significant and annual erosion events may be necessary for producing turbid water conditions. Moderate but less frequent bank erosion, every (2-4) years, may be adequate for generating new riparian habitat.

Timing
Erosive flows during the bank swallow nesting period, which generally begins in late March, can actually disrupt bank swallows. Therefore, it may be most beneficial to bank swallows to achieve bank erosion objectives prior to late march.

5.1.4 Floodplain Inundation and Rearing Habitat Flows

The occurrence of inundated floodplain habitat has been substantially altered by both levees and dams. Dams have reduced the frequency of high flows sufficient to inundate floodplains, while levees have prevented high flows, even very high flows, from inundating floodplains particularly in the lower reaches of the river below Colusa. It is not reasonable to reestablish inundated floodplains by overtopping levees, because it would require extremely, even unnaturally, high flows and would cause widespread flood damage.

Adequate duration of flooding in the designated flood bypasses generally occurs in the wet years and sometimes in normal wet years creating excellent conditions for salmon and splittail. But overtopping the weirs and flooding the bypasses in normal dry and dry years would require prohibitive amounts of water to achieve in normal dry and dry years. For efficiency sake, it is probably only realistic to achieve prolonged (30-60 days) floodplain inundation in normal dry and dry years by notching (or removing) the upstream weirs to allow a small amount of water to pass (3,000-5,000 cfs) and installing inflatable weirs in the low flow channels of the bypasses to back-up water.

Strategically breaching levees and flood control weirs to inundate flood bypasses and other undeveloped land is a much more prudent and achievable approach for creating inundated habitat. Although there may be many places to create inundated flood plain habitat with strategic levee modifications, we have focused on identifying flows that would create inundated habitat in the Yolo and Sutter Bypasses if modifications are made to the weirs that control flow onto the bypass. The area of inundation under a given flow is determined by topography and drainage. We assume changes in the topography and drainage of the bypasses (i.e. berms or inflatable wiers) to maximize the area of inundation at lower flows and minimize the potential for stranding. While it might be possible to create large areas of habitat at low flows, more flows may be necessary to optimize temperatures on the flood plain and conveyance of nutrients from the floodplain to the Delta.

Magnitude
We evaluated two questions associated with magnitude: the magnitude of flow necessary in the Sacramento or Feather Rivers necessary to inundate the bypasses and the magnitude of flow in the bypasses necessary to create large areas of suitable floodplain habitat. It may be possible to inundate large areas of the bypass with relatively little flow by installing flow barriers in the bypass to back-up water onto the floodplain. While this

may be suitable for creating large areas of inundation, it might not create the right residence time and temperature for optimal habitat. Habitat characteristics such as velocity, depth, temperature, residence time, primary productivity are negatively correlated with flow, while Diptera, an important food resource, was positively correlated with flow (Sommer et al, 2004).

According to DWR modeling analysis, large areas of the bypass become inundated with as little as 5,000 cfs flowing through the bypass (figure 5.1) (Harrell, B., 2008). Flows in excess of 25,000 cfs in the Sacramento River, however, may be necessary before it is possible to get 5,000 cfs down the bypass.

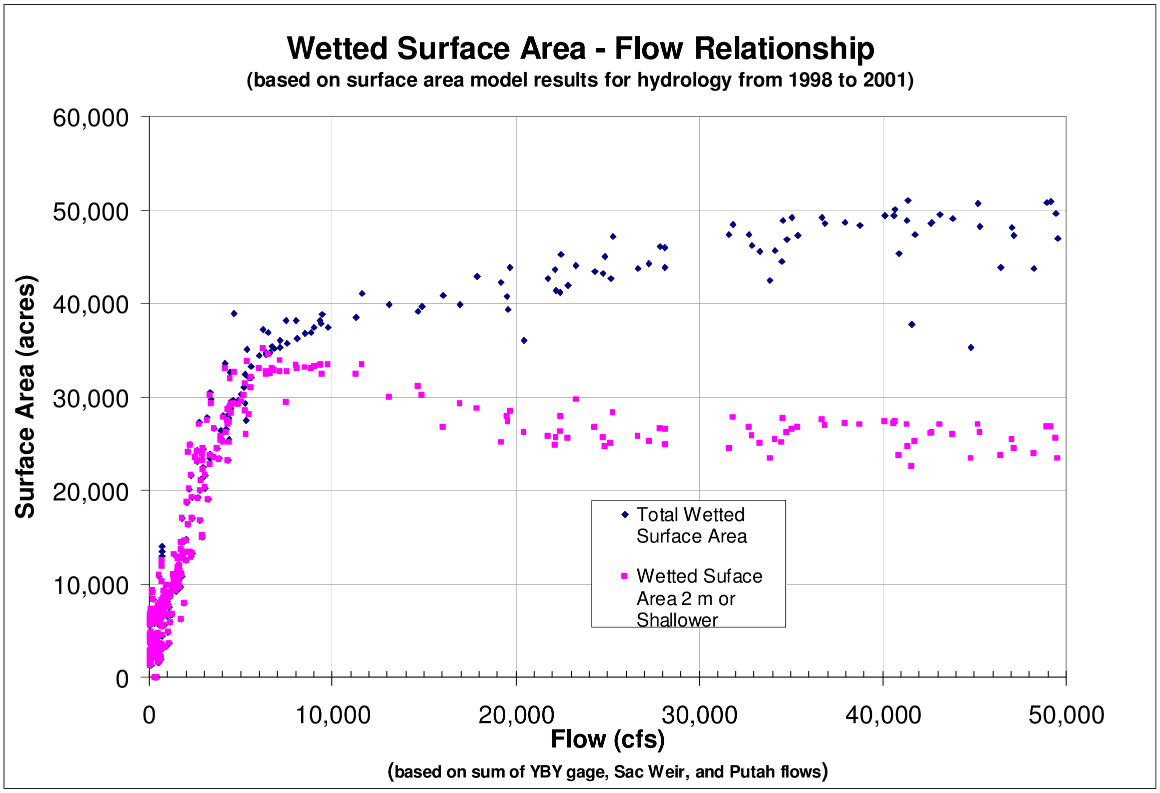

Figure 5.1: Wetter surface area-flow relationship for flows in the Yolo bypass (cite)

To estimate the amount of flow necessary to inundate the Sutter and Yolo Bypasses, we referred to USGS topographic maps to determine ground elevations at Tisdale and Freemont weirs which currently control flows onto the bypass, and then used stage discharge relationships for nearby gauges to estimate the amount of flow necessary to achieve a stage equal to the ground elevation at the weir – an overbank flow assuming the weir did not exist or was operable (table 5.1). The overbank flow, however, is not enough to push substantial amount of water down the bypasses. We therefore assumed that a minimum of 5,000 to 10,000 cfs above the overbank flow was necessary to create substantial inundated floodplain in the bypass.

Table 5.2 identifies flow recommendations for various year types at four key sites: Tisdale Weir, Freemont Weir, and Verona Gauge on the Sacramento River and Nicolaus

Gauge on the Feather River. Tisdale Weir spills into the Sutter Bypass and then flows back into the Sacramento River near Freemont Weir. The sum of Freemont and Nicolaus should equal Verona. Note, however, that table 5.1 flows at Verona are lower then the sum of Freemont and Nicolaus. This is because large amounts of the Sutter Bypass (ground elevation of 25 feet) will flood with backwater from the Sacramento at flows above 27,000 cfs at Freemont Weir. In other words, if Freemont or Verona is greater then 30,000 cfs, then large amounts of the Sutter Bypass are flooded irregardless of flows in the Feather River or at Tisdale Weir.

Table 5.1: Overbank flows in the Yolo or Sutter Bypass assuming levees or weirs along the Sacramento and Feather Rivers are breached or removed

Gauge or Weir	Ground Elevation	Overbank Flow	Notes
Nicolaus Gauge (Feather)	30	10,500	
Freemont Weir	25	27,000	Approximate based on Verona Gauge
Freemont with Excavation	13	15,000	Invert of the Toe Drain
Tisdale Weir	40	25,000	Approximate
Sacramento Wier (I Street Bridge)	15	49,000	
Sac Weir with Excavation	10	31,000	Sac Weir with excavation
Right Bank at Verona	25	42,000	Remove right bank levee

Table 5.2: Recommended flows to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types.

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Duration and Timing

Provide floodplain inundation flows for 30 – 60 days between February 15 and April 30 into Sutter and Yolo Bypasses to provide rearing habitat for salmon and splittail and spawning habitat for splittail. Where possible, time releases to coincide with and extend duration of high releases on the Yuba and Sacramento.

Frequency

Ideally, it would be possible to inundate the bypass in every year to enhance foodweb productivity and improve rearing habitat for every year class of salmon. It may be possible to do this while economizing on water by inundating relatively small areas in dry years and very large areas in wet years with no inundation in critical dry years.

5.2 Riparian Flow Requirements

A sequence of hydrologic, geomorphic, and biologic phenomena is necessary to recruit cottonwood seedlings to the riparian forest. Under natural flow regimes, moderate 5- to 10-year flood events precipitate channel migration and the creation of point bars suitable for cottonwood seedling establishment (McBain and Trush 2000, Trush et al. 2000). Analysis of hydrologic data, dendrochronologic data, historic channel mapping, and aerial photography riparian recruitment appears to occur approximately once per decade in the post-regulation period (Roberts, 2003). But recruitment may now be limited to larger, less frequent events due to greater hydrologic modification in recent years. Recruitment did result from the recent large flood events of 1983-1986, and 1995-1997, (Roberts, 2003) but willows dominate while cottonwood recruitment is spatially limited.

In order to maintain or re-establish woody riparian vegetation using a process-based restoration approach, managed flows need to mimic natural hydrographs in the following key ways (Stillwater, 2007):

- High flow peaks, which should mimic to some degree the characteristics of peak flows associated with winter peak rain events in the unimpaired hydrograph are necessary to control vegetation encroachment by herbaceous and weedy species and prepare seedbeds prior to seedling recruitment flows in wet years (scouring or encroachment prevention flows) and seedbed preparation flows.
- High spring snow-melt peak flows with relatively gradual recession rates during wet years to moisten the seedbeds and induce seed germination on geomorphic surfaces suitable for long-term establishment (recruitment flows for seedling initiation).
- Summer and fall base flows are needed to ensure that new seedling cohorts and older cohorts of saplings and mature trees have adequate soil moisture for summer growth and survival during the annual dry season (seedling establishment and maintenance flows).

In regulated rivers it may also be necessary to limit unnaturally high summer flows. Summer base flows higher than spring flows may give a competitive advantage to non-native species that reproduce by seed during the summer months. Establishment of non-natives could impede later recruitment of natives such as cottonwood (cite).

5.2.4 Site Preparation

Large flows scour away herbaceous plants and/or deposit fine sediments on floodplains, preparing new seed beds for pioneer riparian species (Mahoney and Rood 1998). The magnitude of flows necessary to scour or deposit seed beds is presumably much larger then the amount of water necessary to inundate these sites. For this analysis, we assume that flows sufficient to mobilize the bed (80-100k cfs on the Sacramento and 35,000-50,000 on the Feather) are sufficient and that seedling establishment flows will only occur in wetter years after bed mobilization generally occurs.

5.2.5 Seedling establishment:

In order to assure long-term survival, seedlings must become established in a zone that is high enough on the bars and banks to avoid scour from peak flows, but low enough to avoid desiccation during low flows in summer and fall. Rood and Mahoney (2000) developed a recruitment box model that placed this zone at 2.5 to 4 feet above mean low (MLW) water for the St. Mary River in Alberta Canada. Roberts (2003) calibrated the recruitment box model on the Sacramento placing the recruitment zone at 3-6 feet above MLW and developed a stage discharge relationship at three representative sites to determine that recruitment zone is inundated at flows between 23,000 and 30,000 cfs. Roberts recruitment zone, however, is based on the artificially high summer flows in the Sacramento River. Under natural summer flow conditions the recruitment zone, and flows necessary to inundate it, may be somewhat lower.

Little to no information exists regarding seedling establishment elevation for the Feather River. Furthermore, it is difficult to identify a suitable recruitment zone at some distance from the mean low water, because mean low water levels in the summer are two to three times higher then pre-dam, natural levels. The stage discharge relationship for the Feather River at Nicolaus combined with topographic maps indicate that the Feather River overflows its banks at Nicolaus at approximately 12,500 cfs. The banks further upstream are higher and can convey more flow before overtopping. Since cottonwoods generally become established on the banks and gravel bars of alluvial rivers, it is reasonable to assume that the recruitment zone is below the stage of the bankfull discharge. The seedling establishment flow on the Sacramento (23,000 – 30,000 cfs) is twenty seven to thirty seven percent of the bankfull discharge (Q1.5 to Q2) on the Sacramento. Assuming a similar proportional relationship on the Feather River, flows in the range of 9,500 to 18,000 would be suitable for seedling establishment. Analysis of historical flow data (section seven of this report) indicate that flows in this range were common during April and May when germination is most likely to occur.

Post-germination decline of river stage, which is presumed to control adjacent groundwater levels, should not exceed approximately one inch per day (Mahoney and Rood 1998, Busch et al. 1992). This is the rate at which seedling root growth (0.16–0.47 inches/day; Reichenbacher 1984, Horton et al. 1960) can maintain contact with the capillary fringe of a receding water table in a sandy substrate. Cottonwood root growth and seedling establishment rates are higher in these soils than in coarser textured soils, which are more porous (Kocsis et al. 1991). In reaches with gravelly substrates, slower draw-down rates are necessary to support seedling establishment.

Information necessary to design a gentle recession limb is limited. Stage discharge data from gauging stations may not be representative of Cotonwood recruitment sites, because they are generally sited at geomorphically stable and simple sites while cottonwood recruitment often occurs on complex and dynamic sites. Kondolf and Stillwater (Kondolf, 2007) measured stage discharge relationships at several representative gravel bars along the Sacramento River and determined that stage drops 0.1 meter (.34 feet) per

1000 cfs at flows ranging from 7,000 to 15,000 cfs, but cautioned against extrapolating this relationship to flows outside the observed range. Within this range, however, a discharge decline of 250 cfs per day would yield a stage decline of one inch per day.

To estimate a suitable recession rate flow schedule, we assumed that cottonwood seedlings would become established six feet above the mean low water and then calculated that it would take 72 days to drop river stage six feet at a rate of one inch per day. On this basis, we recommend a 72 day recession period from the establishment flow to the summer base flow. The actual recession flow required may vary substantially depending where seedlings become established relative to the mean summer flows.

5.2.6 Recruitment stage:

After the second year, growth rates level. Despite extensive root development during this stage, cottonwoods are still somewhat susceptible to drought stress. Yearly flows must be sufficient to maintain groundwater levels within 10 to 20 feet of ground surface elevations (JSA and MEI 2002). Groundwater extraction and reduced flows can reduce groundwater levels and induce drought stress in cottonwood saplings (Jones & Stokes 1998. Acute draw down and corresponding drought stress is primarily a problem in arid river ecosystems and will probably not be a problem on the Sacramento River where summer flows are artificially high.

5.3 Chinook Flow Requirements

Adult Upstream Migration

If salmon migration is motivated by major storms, early freshets or pulses after the first rain, and most of the large flows from storm events are trapped behind dams, reservoir operators can simulate pulse events by releasing water from the reservoir. However, “There is [a] concern that pulse flow releases in mid October to attract salmon may cause the fish to enter the rivers earlier than normal, which may expose them to high water temperatures when the pulse flows cease.” (CMARP). Therefore, if flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for migrating adults and subsequent spawning.

Spawning

In order to provide quality areas of spawning habitat, adequate flows need to be released from dams into the tributaries during the spawning period. Due to channel alteration from gravel mining, artificial gravel habitat construction and enhancement may be necessary. Over the long run, periodic high flows are necessary to mobilize gravels and flush-out fine sediments. However, large peak flow events that occur in channels that have been excessively incised and leveed cause excessive gravel mobilization, which can disrupt spawning and cause egg mortality (CMARP). Therefore, these flows should be released after mid-February so they reduce mortality to incubating salmon eggs (McBain and Trush, 2000). Increased flows may also be needed to decrease water temperatures in late October and early November to prompt earlier spawning, expand the area with suitable temperatures for spawning and incubation, to increase egg viability, and to reduce the probability of superimposition of redds. If flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for spawning and to prevent dewatering of redds.

Egg Development and Emergence

Dewatering of redds is a known mortality factor effecting development of alevins. (Becker et al., 1982, 1983 in Healey, 1991). Dewatering of redds can be minimized below dams by careful flow regulation.

Adequate base flows during the incubation and emergence period combined with periodic flushing flows outside the period should reduce the mortality factor of eggs and alevins. Instream flows, at or above spawning flows, should be maintained throughout the incubation and emergence period to avoid dewatering redds. Siltation and capping from fine sediments could be minimized with small reservoir releases timed to coincide with rainfall induced local run-off. These releases would help convey fine sediments out of the spawning reach.

Rearing and Outmigration

We hypothesize that increasing rearing habitat will improve growth rates and successful smolt outmgration and may also reduce mortality from diversions and predation, because larger fish are less vulnerable to these sources of mortality. Based on robust results from research in the Yolo Bypass, it appears providing seasonally inundated floodplain habitat is perhaps the best way to ensure adequate growth before outmigration to the Delta and Ocean. If nothing else, providing seasonally inundated floodplain habitat will provide better habitat for the young that migrate or are washed out of the gravel bedded reaches early. We describe the flow regimes necessary to create inundated floodplain in section 6.3 above.

In addition to inundated floodplain habitat, seasonally inundated off-channel habitats may also provide valuable rearing habitats for juvenile salmon. Kondolf and Stillwater (Kondolf, 2007) determined that secondary scour channels on gravel bars along the upper Sacramento River become inundated and connected to the mainstem at flows above 12,500 cfs. They also determined that these same secondary channels become disconnected and desiccated at flows below 8,500 cfs. To assist juvenile rearing, it may therefore be advantageous to maintain flows between 8,500 and 12,500 cfs or greater during winter and spring when fish are rearing. To prevent establishment of non-native, resident predator fish populations that thrive in shallow or warm water habitats, however, it may be beneficial to maintain flows below 8,500 cfs during the summer months. Preventing inundation and connectivity of the off-channel habitats during summer months could also reduce temperatures by significantly reducing wetted perimeter and surface area. Lower temperatures should favor native fish over exotic fish populations.

6. EVALUATION OF EXISTING AND HISTORIC FLOW REGIMES

To identify specific hydrograph component alterations between historical and current conditions which may limit the attainment of environmental objectives an analysis of existing and historical hydrologic patterns was conducted using daily flow data from USGS gages at multiple locations on the Sacramento and Feather Rivers. We used two approaches to compare existing and historical hydrologic patterns, a statistical approach similar to IHA whereby specific hydrograph components were graphed using box plots for different year types and a visual approach similar to HCA whereby median hydrographs for historical and current conditions were compared.

We evaluated pre- and post-project hydrology using statistical methods similar to IHA and HCA methods to generate hypotheses regarding the causal links between historical hydrograph components and ecological conditions relevant to our restoration objectives. The Index of Hydrologic Alteration (IHA) method (Richter et al. 1996) provides a statistical overview of how several important hydrologic attributes change between historical and regulated conditions. The Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. Instead of using a formal IHA and HCA analysis the fundamental principals of these methods were used to conduct an analysis based on first principles.

To conduct this analysis USGS daily discharge data was organized into water year types based on the Sacramento Four Rivers Index. The water year data was divided into pre project or post project data sets. The project id defined by the construction of a dam in the headwaters of the river under consideration. For the Sacramento River the project is Shasta Dam which was constructed in 1945. For the Feather River the project is defined by Oroville Reservoir which was constructed in 1968. Hydrograph components for each water year were compared for pre and post project periods using box plots. This statistical approach was coupled with a visual comparison of the pre and post project median flows hydrographs. The pre project period was further defined by the 25th and 75th percentile hydrographs. The 25th and 75th percentile captured the natural range of variability around the median hydrograph during the pre project period for each year type. When the current hydrograph was outside of this acceptable range of variability then a significant discrepancy between the historic and current flow regimes could be identified.

The hydrograph components that were considered for the statistical analysis were: 1) summer baseflow, 2) winter peaks, 3) winter baseflows and 4) spring peaks(Figure 5). A useful way to describe streamflow hydrology and relate it to geomorphic, riparian, and biological ecosystem components is by quantifying these hydrograph components. Kondolf et. al. 2000 described these four primary components of the annual hydrograph in the following way:

(1) Summer base flows extending from July through Spetember/October

(2) Large magnitude, short duration winter floods during December through April

(3) Sustained high winter base flows intermittent between high flow events

(4) Spring snowmelt flood and recession limb of long duration, but typically moderate magnitude

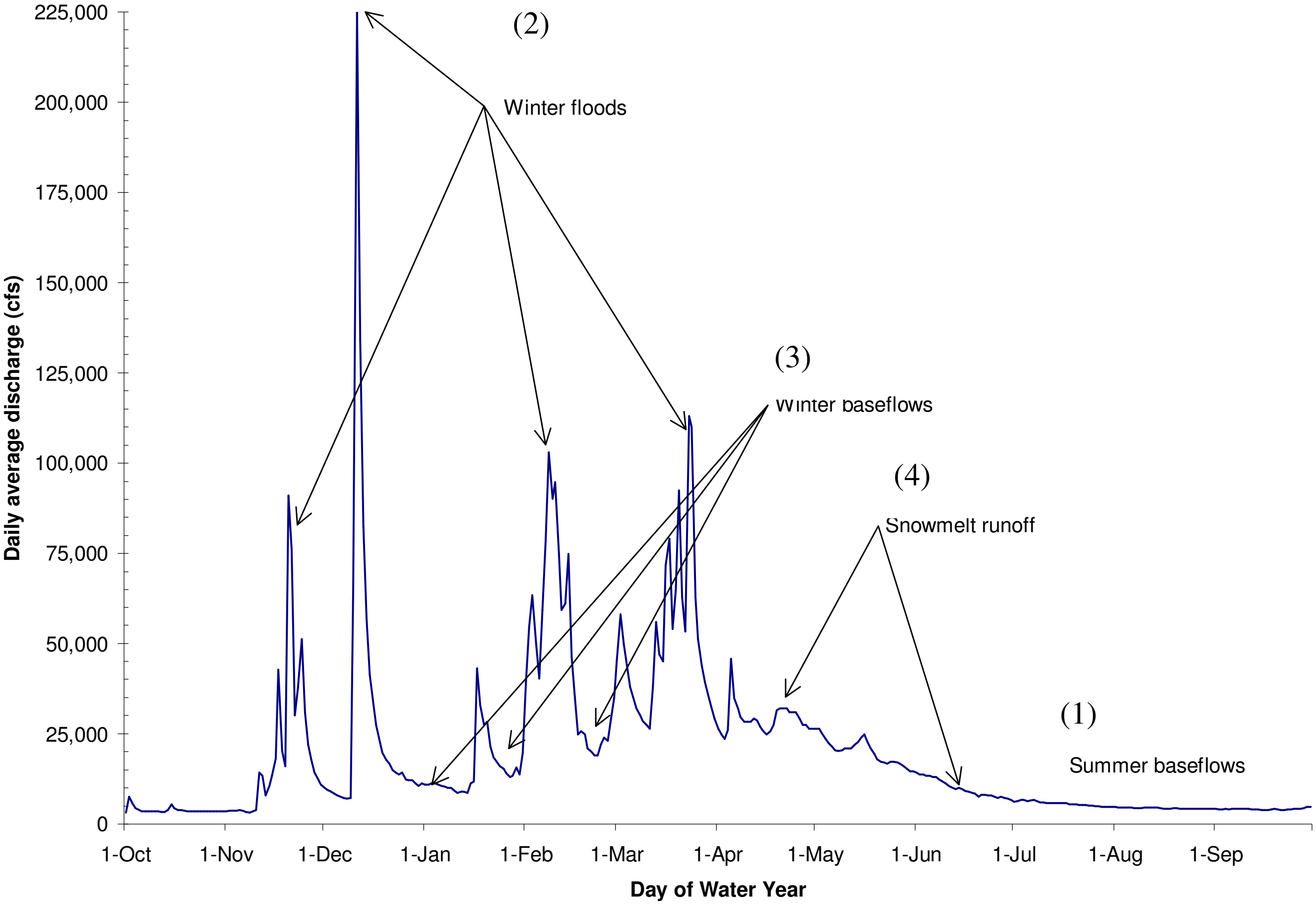

Figure 6.1: Sacramento River hydrograph components illustrated in the 1938 hydrograph for the Sacramento River above Bend Bridge, near Red Bluff gauging station. Modified from Kondolf et al. 2000.

a. Methods

Data Source

We analyzed hydrologic data for periods before and after dams were constructed on the Sacramento and Feather Rivers. Table 4 shows the gauges analyzed their period of record, and the pre and post-dam analysis periods. We divided data into five year types based on the Sacramento Basin Index: wet, above normal, below normal, dry, and critical.

Period of Analysis	River	Description	USGS Gage Number	Period of Record
Pre Shasta	Sacramento River	Bend Bridge	11377100	1906-1944
Post Shasta	Sacramento River	Bend Bridge	11377100	1945-2006
Pre Shasta	Sacramento River	Verona	11425500	1929-1944
Post Shasta	Sacramento River	Verona	11425500	1945-2006
Pre New Bullards Bar	Yuba River	Marysville	11421000	1944-1969
Post New Bullards Bar	Yuba River	Marysville	11421000	1970-2006
Pre Oroville	Feather River	Oroville	11407000	1906-1967
Post Oroville	Feather River	Oroville	11407000	1968-2006
Post Oroville	Feather River	Thermalito AfterBay	11406920	1968-2006

Table 6.1: USGS gauges used for hydrologic analysis, the period of analysis, location, description and the period of record.

Hydrographs

For each year type we compared post-dam median flows to pre-dam median flows. Median flows bounded by the 25th and 75th percentiles represent the natural range of variability during the pre-dam period for each water year type. Hydrographs provide a visual tool to identify portions of the current hydrograph that are outside of the historic range of variability. When the current hydrograph is outside of the natural range of variability we would expect the greatest potential loss of environmental flow benefits.

Box Plots

Box plots were used to statistically compare hydrograph components including summer baseflows, winter floods, winter baseflows, and spring peak flows. The lower edge of the boxes represent the 25th percentile and the upper end represents the 75th percentile, with the whiskers at the maximum and minimum values. The various components of the hydrograph were computed as follows.

- **Summer baseflows** were computed as average August discharge. Summer baseflows begin following the spring snowmelt recession in July and August and last through autumn when the first rainfall events occur.
- **Winter floods** were computed as the maximum daily average discharge over the course of the entire water year.
- **Winter baseflows** were computed as the median flow for February and March.
- **Spring peak flows** were computed as peak flows in April and June.

Flood Frequency Analysis

We conducted the food frequency analysis for a range of reoccurrence intervals for pre and post project periods using the peak instantaneous flow records at USGS. The flood frequency analysis enables further quantification of storm events and their geomorphic potential.

b. Results

The analysis utilized 100 years of daily flow data from the Bend Bridge gage near Red Bluff on the Sacramento River (11377100). This gage was selected for the analysis because it has a long period of record 1906-2006, and best characterizes flow conditions where salmon concentrate. The Bend Bridge gage is at the upstream end of what is considered the most valuable habitat in the Sacramento River. However, flows at Bend Bridge are not fully representative of downstream conditions, particularly in the irrigation season because irrigation diversions operate downstream. Four major diversions are listed below:

- The Glenn-Colusa Irrigation District (GCID) diversion, located just upstream of Hamilton City at RM 206, began diverting summer flows for irrigation around the turn of the century, and has a diversion capacity of about 3,000 cfs.
- The Anderson-Cottonwood Irrigation District (ACID) diversion, located on the north side of the City of Redding downstream of Shasta Dam, began diverting for irrigation during the summer months, around 1917.
- The Red Bluff diversion and Tehama-Colusa Canal at Red Bluff was built in 1964, and diverts during the summer months for irrigation.
- The Trinity River Division of the Central Valley Project was completed in 1963, and typically diverted over 1,000,000 acre-ft/yr of Trinity River flows into the Sacramento River basin just below Shasta Dam between 1963 and 2000. Due to new flow requirements for the Trinity River, substantially less flow is now diverted into the Sacramento River.

The hydrograph at Bend Bridge reflects operations at Shasta Reservoir in timing and magnitude, but it is only by looking at the hydrograph from a downstream gage that we can evaluate the impacts of diversions operations and the degree of hydrograph recovery from tributary inputs. It is for this reason that we used the eighty year record, from 1926-2006) daily discharge data at the USGS gage at Verona (11425500). Major tributary inputs to the Sacramento below Bend Bridge include Mill Creek, Deer Creek and the Feather River. The Feather River flow regime exhibits similar characteristics to the Sacarmento below Red Buff because of the operation of Oroville Dam. The major tributary to the Feather is the Yuba River which also displays similar characteristics due to the operation of Bullards Bar. For this reason a hydrograph comparison for the Feather (11407000, 11406920) and Yuba River (11421000) was also conducted.

5.2.1 Sacramento River at Bend Bridge

Hydrologic Changes
The hydrographs and box plots for pre and post Shasta at Bend Bridge (Figures 6 and 7) illustrate significant differences in all hydrograph components.

- Summer base flows are significantly higher post Shasta for all water year types. The average summer base flow pre-Shasta was 3,000-4,000 cfs which is significantly less than the current average of 10,000-12,000 cfs. These artificially high summer flows are driven by summer water supply demands for agriculture and power.

- Spring peak flow events are significantly reduced in the post Shasta era for below normal, above normal and wet year types and there is a truncated spring and early summer recession limb, particularly in wet years. The reduction in spring peak flows hampers cottonwood recruitment, seed establishment and germination.

- Winter peak flows are significantly reduced in the post Shasta era. The magnitude and duration of winter peak flows are responsible for channel forming flows. Channel forming flows effect cottonwood recruitment and off channel habitat formation critical to Chinook Salmon rearing and survival.

- In addition to significantly altered hydrograph components there is also a general decline in hydrologic variability in the post Shasta era.

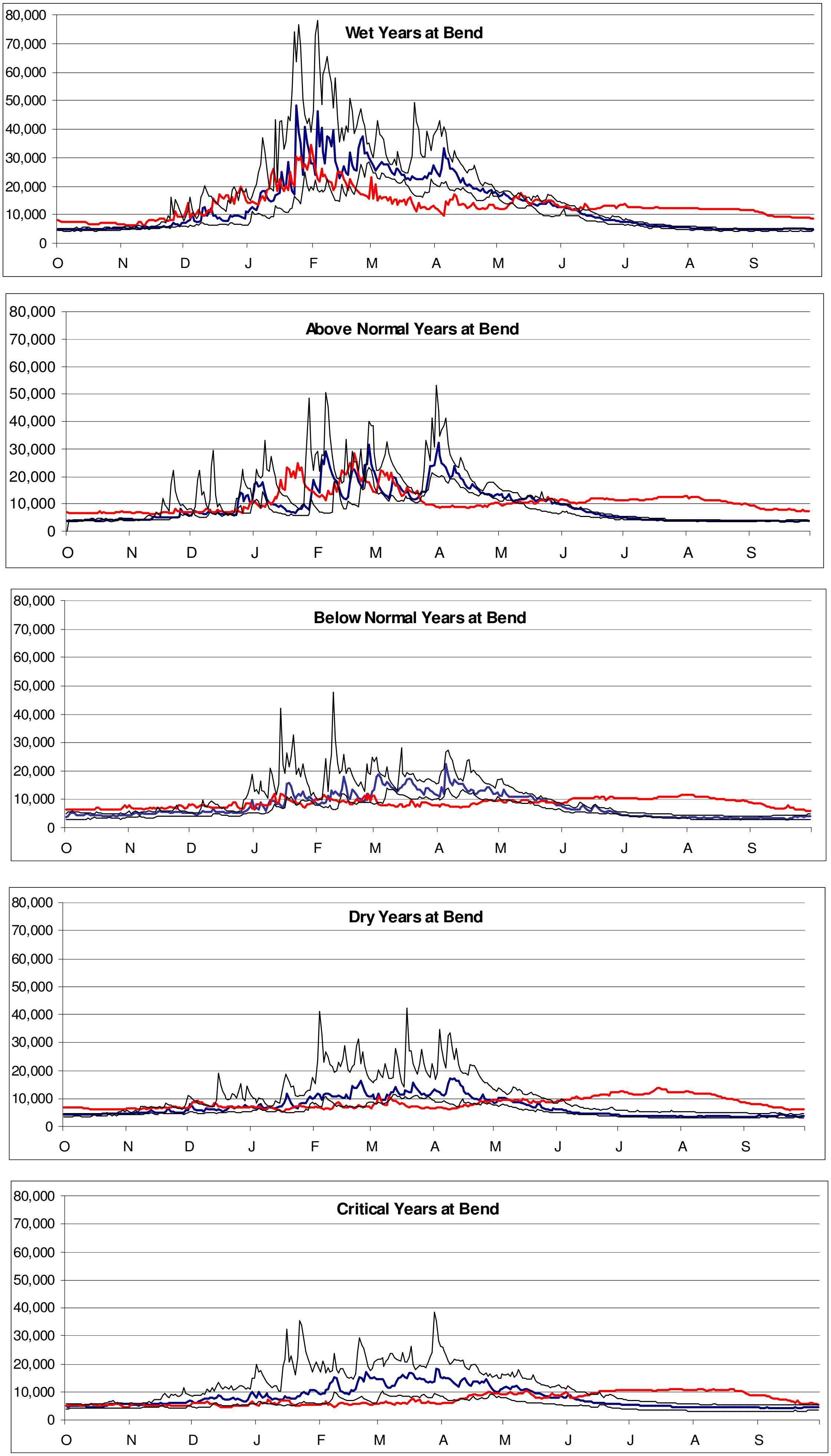

Figure 6.2: Bend Bridge median hydrographs : Historical data was used to construct hydrographs for five water year types at Bend Bridge (USGS Gage 11377100). The median hydrographs pre and post Shasta represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) See the table of the number of water year types below.

Water Year Type	Pre Shasta (1906-1944)	Post Shasta (1945-2006)
W	13	22
AN	5	10
BN	7	11
D	8	12
C	6	7
Total	**39**	**62**

Figure 6.3: Sacramento River Box Plots at Bend Bridge. Box plots display the median and the range of variability for each hydrograph component. Summer baseflows are represented by the average August discharge for each water year type. Winter floods are represented by the maximum daily average discharge for each water year type. Winter base flows are represented by the median discharge in February and March for each water year type. Spring peak flows are represented by peak average daily discharge value in April-June for each water year type. The top of the box plot is the 75th percentile and the bottom of the box is the 25th percentile. The 25th percentile means that 75% of the data is above this point. The wiskers represent the maximum and minimum values. The dark line inside the box is the median value, or 50th percentile. When the boxes do not over lap then there is a very highly significant difference between the data sets.

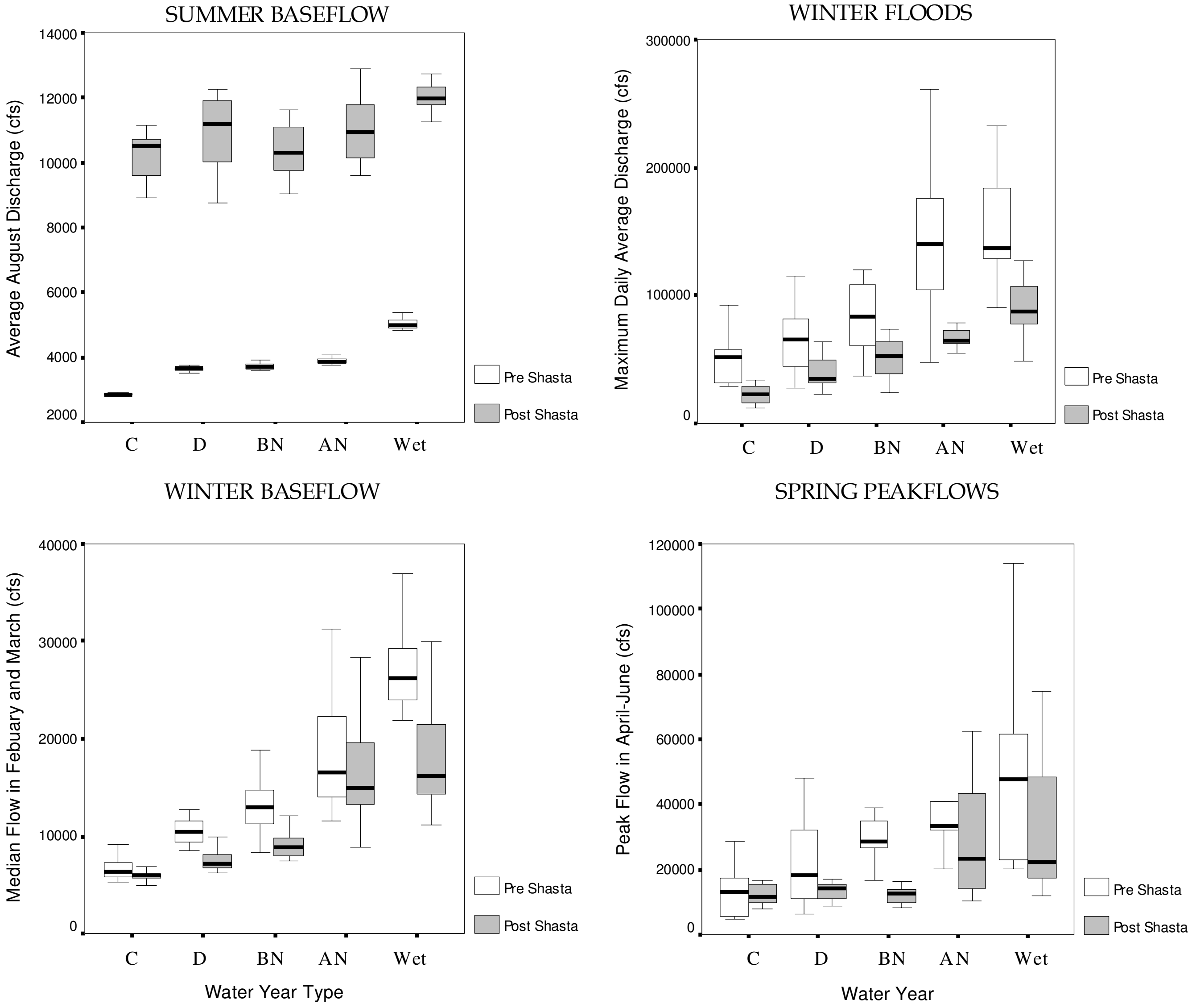

Figure 6.4: Flood frequency analysis at Bend Bridge Pre and Post-Shasta. The flood frequency analysis displays the magnitude of flows expected to occur in a 1.5, 2, 2.5, 5, 10, 20….year flood. The two year flood event in the pre Shasta era is ~100,000 cfs. Bed mobility is expected at the 1.5 year flood (Q1.5) or 82,795cfs.

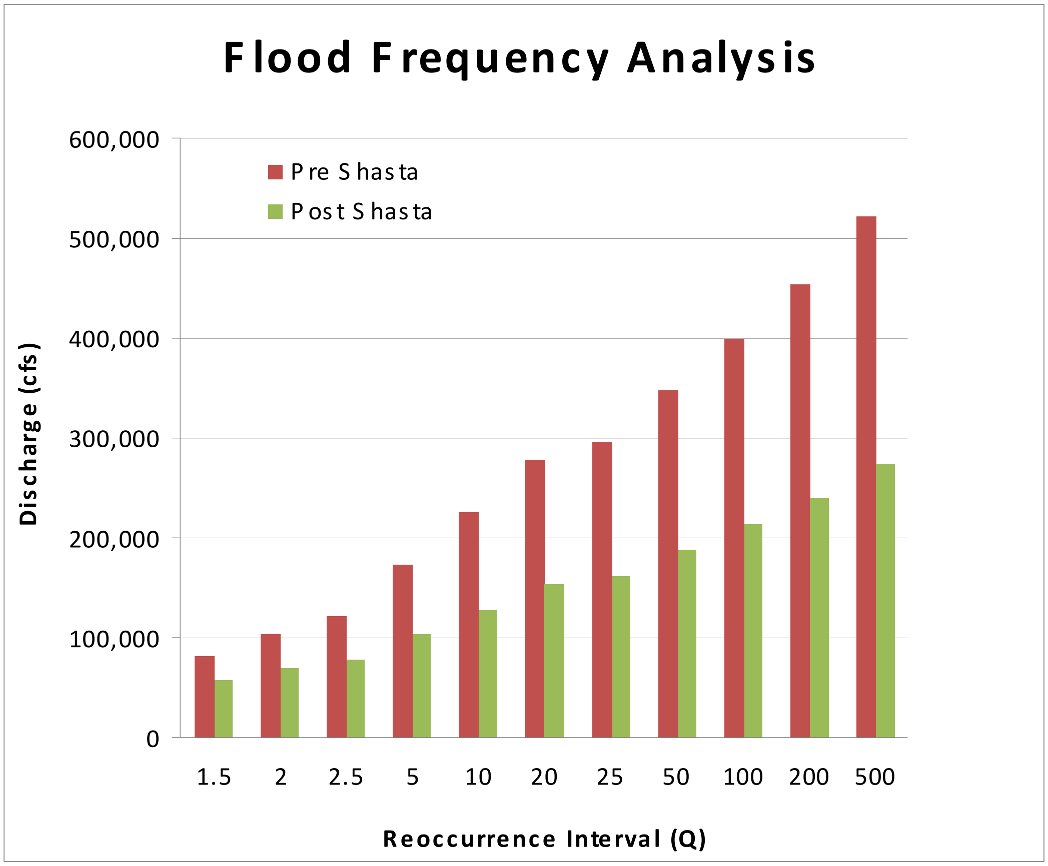

Table 6.2: Sacramento River Flood Frequency

Recurrence Interval (years)	Post 1939 (cfs)	Pre 1939 (cfs)
1.5	65,000	87,000
2	78,000	105,000
2.5	87,000	120,000
5	120,000	160,000
10	153,000	225,000
20	160,000	285,000
50	190,000	350,000
100	210,000	400,000

Table 6.3: Summary of Geomorphic Flow Thresholds

Sacramento River	**Pre-Dam $(Q_{1.5})$**	**Bed Mobility $(Q_{1.5})$**	**Channel Scour and Migration (Q_{10})**	**Floodplain Inundation (Q_{1})**
Flows at Bend	82,795	82,795	226,476	52,087

6.2.1 Feather and Yuba Rivers

Introduction

Oroville Dam and Reservoir on the Feather River were completed in 1968 and have a storage capacity of 3.5 million acre feet (maf). It is managed for water supply, hydropower, and flood control. The average annual yield of the upstream Feather River basin at Oroville is about 4.2 maf. Due to several diversions in the upper watershed, average annual inflow into Oroville Reservoir is approximately 4.0 maf, but varies annually depending on precipitation. From 1979 to 1999, annual inflows ranged from a minimum of 1.7 maf to as high as 10 maf . Most of the water released from the dam, except during flood spills, is routed through the Thermalito diversion pool and afterbay and therefore bypass a 7 mile stretch below the dam known as the low flow channel. A minimum flow of 700-800 cfs is released into the low flow channel to maintain habitat for salmonids.

We evaluated change in hydrology that resulted from construction and operation of Oroville Dam. We compared pre and post dam hydrology at the USGS gauge below Oroville. In order to account for the water in the post-dam period that is discharged into the Thermalito diversion pool and bypasses the Oroville gauge, we summed daily values from the Thermalito (11406920) and Oroville (11407000) gauges to calculate the average daily flow for the river below the low flow channel.

Minimum instream flows below Thermalito Afterbay range from 1,000 cfs in the late spring and summer to 1,200 -1,700 cfs during the fall winter months. Minimum flows for the low flow channel are between 700 and 800 cfs all year. Minimum flows are slightly higher during the fall and winter to provide flow for spawning and incubating salmonids. Minimum flows in the summer are necessary to maintain cool temperatures for over summering juveniles and adult salmonids.

Most irrigation releases are made directly into irrigation canals, so relatively little water is conveyed to irrigators via the Feather River channel. Most irrigation water is released from Oroville Reservoir into Thermolito Diversion Pool, Forebay, and Afterbay where it is subsequently diverted into irrigation canals. Thus, it is possible to substantially meet summer irrigation demands without conveying water through the Feather River Channel.

The Feather River is joined downstream by a major tributary, the Yuba River. The hydrology of the Yuba River was modified early in the 19th century, but the first big storage reservoir, Bullards Bar, was not constructed until 1968. As a result, the hydrology of both the Yuba and Feather River were substantially altered at the same time by large reservoirs constructed in the late 1960s.

Hydrologic Changes

The construction and operation of Oroville dam and reservoir have significantly altered the hydrograph of the Feather River downstream of Oroville. Figures 10 and 11 depict the hydrologic patterns during different year types before and after 1968 when Oroville

Dam was completed. Figure 12 and Table 6 show changes in peak flow magnitude and duration. The most significant changes to the hydrograph are:

- Very significant reductions in spring flows during all year types, particularly during April and May. Storage of spring run-off and snow melt behind Oroville Dam has virtually eliminated any spring flows above a base flow of approximately 2,000 cfs.
- Increases in summer flows by 150-200% in all year types during July, August, and September.
- Reduction in the frequency and magnitude of peak flows, such as Q1.5[2] or channel forming flow by an order of magnitude. Substantially less reduction in the magnitude of the 5 year recurrence interval event (Table 6)
- Reduction in the frequency of short duration fall and winter flow pulses.

These hydrograph modifications are a result of Oroville Reservoir's water supply, flood management, and hydropower operations. Oroville Reservoir captures high flows in the winter and spring for use during the summer months. Stored water is released to meet minimum instream flows, irrigation demand in the Feather River region between April 1 and October 31, generate hydropower primarily in the summer, and meet water quality and export water demands in the Delta. Large volumes of stored water are periodically released during the winter months to create reservoir space for flood management purposes.

Most of the increases in summer flow in the Feather River channel are the result of Oroville releases to meet water quality and export demands in the Delta. As a unit of the State Water Project, Oroville is specifically operated to meet water quality and export demands in the Delta. An analysis of pre-1995 and post 1995 hydrology shows that Feather River flows changed significantly after the 1995 Water Quality Control Plan tightened restrictions on the timing of Delta diversions. After implementation of the plan, spring flow in the Feather River has been further diminished while summer flow has been further increased.

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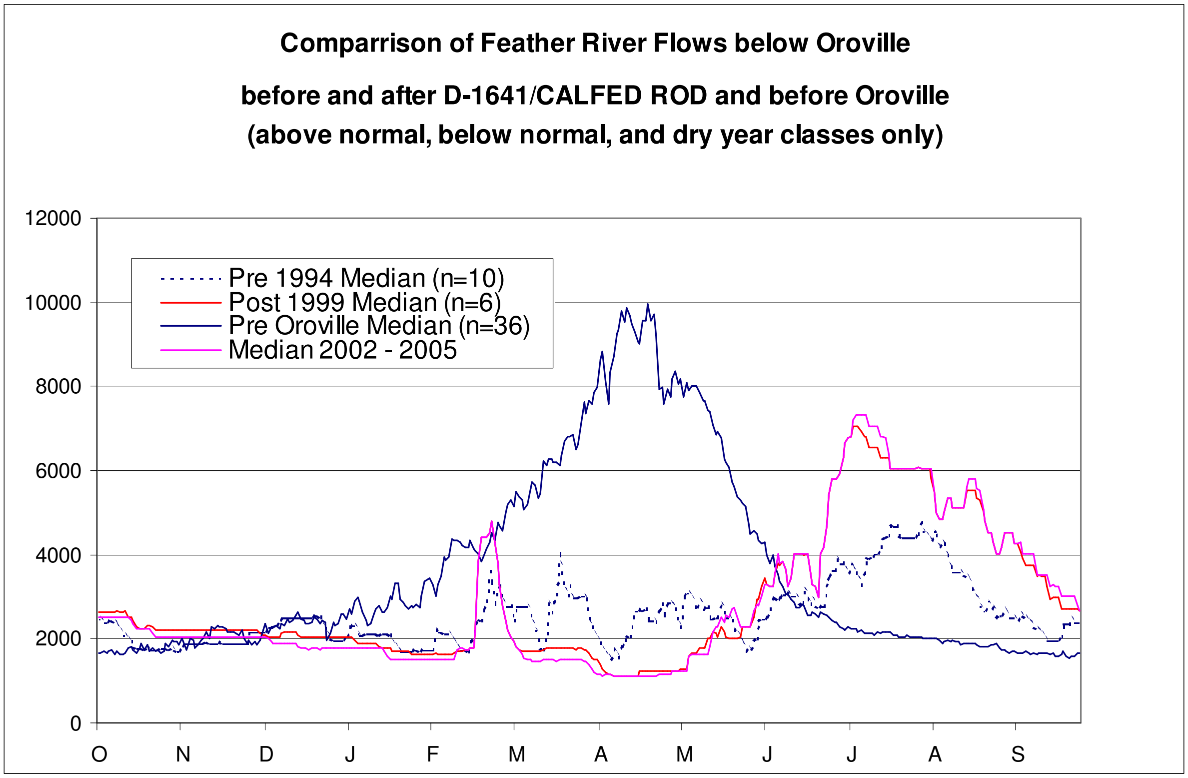
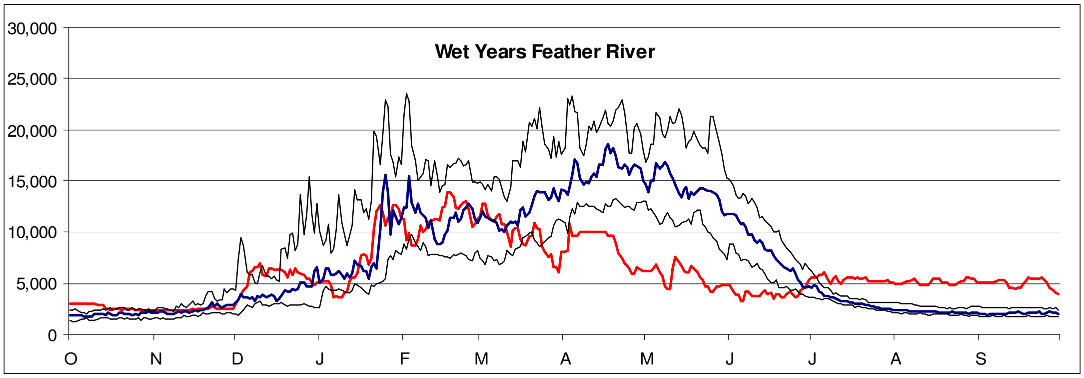
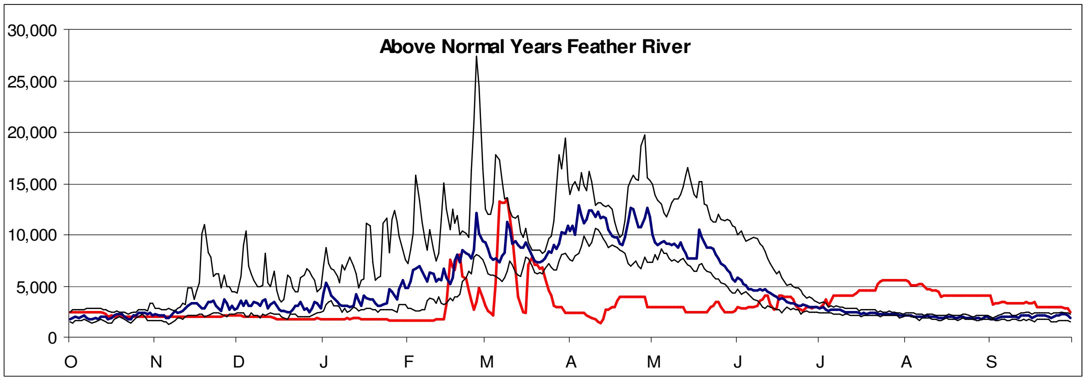
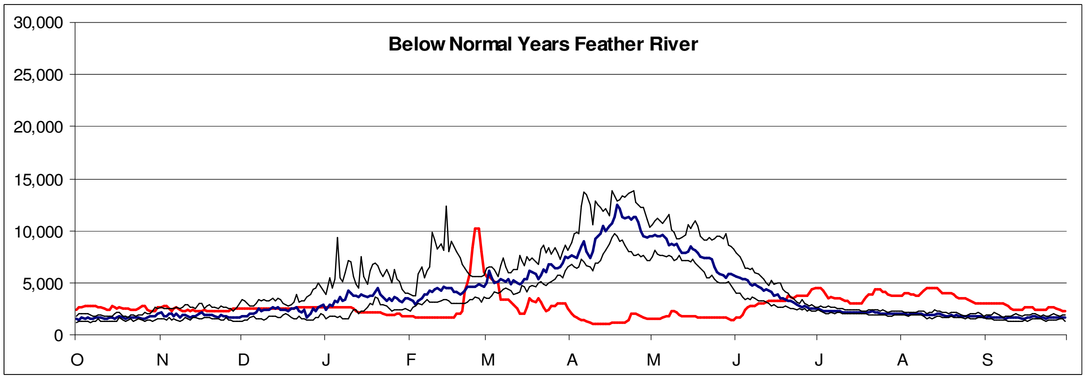
[2] The instantaneous peak annual flow with a recurrence interval of 1.5 years.

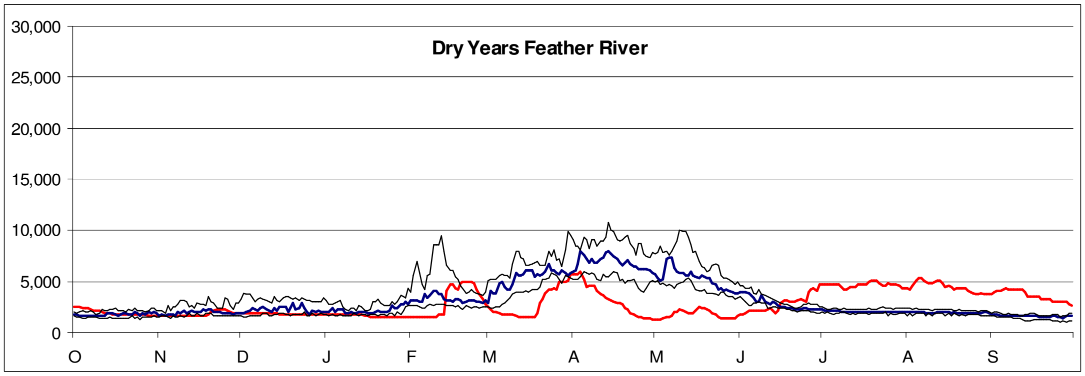
Figure 6.5: Influence of Sacramento-San Joaquin Delta Regulations on Feather River Hydrograph. The blue line of pre Oroville median flows represents the most natural hydrograph. In 1995 the Water Quality Control Plan tightened restrictions on the timing of Delta diversions. The pre 1994 hydrograph compared to the post 1999 illustrates how the hydrograph shifted spring flows to summer releases to meet Delta requirements.











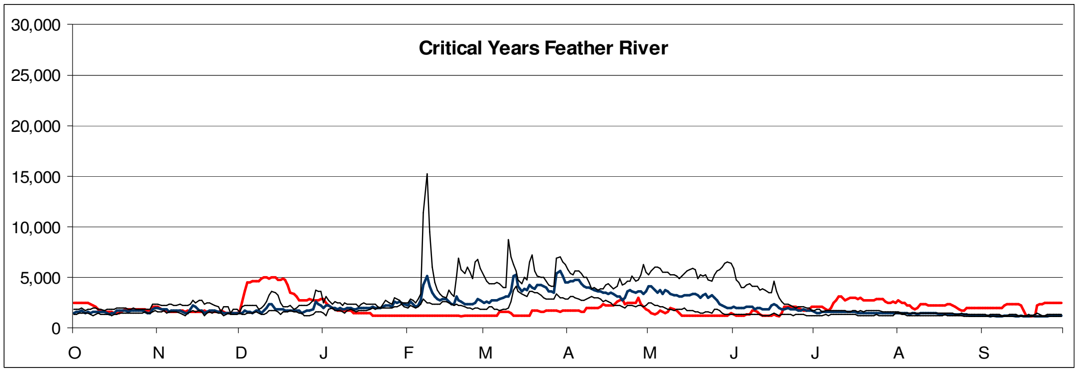


Figure 6.6: Feather River median hydrographs : Historical data was used to construct hydrographs for five water year types on the Feather River (USGS Gage11407000 and 11406920). The median hydrographs pre and post Oroville represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) The hydrographs post Oroville (1968-2006) are the sum of the Oroville (11407000) and Thermolito Afterbay gages (11406920). See the table of the number of water year types below.

Water Year Type	Pre Oroville (1906-1967)	Post Oroville (1968-2006)
W	20	15
AN	8	7
BN	14	4
D	14	6
C	6	7
Total	**62**	**39**

Figure 6.7: Feather River box plots for Oroville gauge. Box plots display the median and the range of variability for each hydrograph component. Summer baseflows are represented by the average August discharge for each water year type. Winter floods are represented by the maximum daily average discharge for each water year type. Winter base flows are represented by the median discharge in February and March for each water year type. Spring peak flows are represented by peak average daily discharge value in April-June for each water year type. The top of the box plot is the 75th percentile and the bottom of the box is the 25th percentile. The 25th percentile means that 75% of the data is above this point. The wiskers represent the maximum and minimum values. The dark line inside the box is the median value, or 50th percentile. When the boxes do not over lap then there is a very highly significant difference between the data sets.

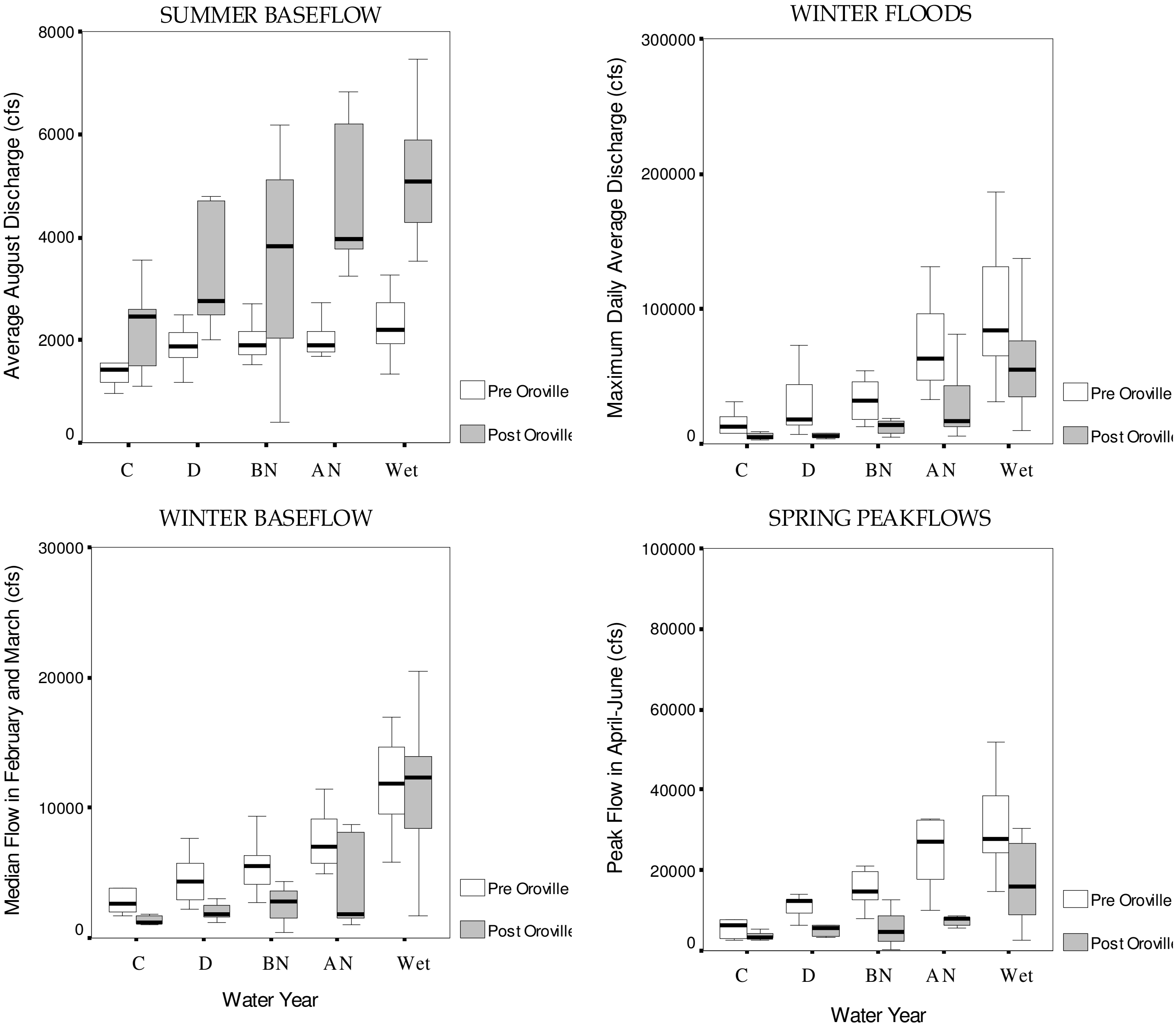


Figure 6.8: Flood Frequency Analysis for Feather River Flood frequency analysis at Bend Bridge Pre and Post-Shasta. The flood frequency analysis displays the magnitude of flows expected to occur in a 1.5, 2, 2.5, 5, 10, 20….year flood. The two year flood event in the pre Shasta era is ~50,000 cfs. Bed mobility is expected at the 1.5 year flood (Q1.5) or 33,224cfs.

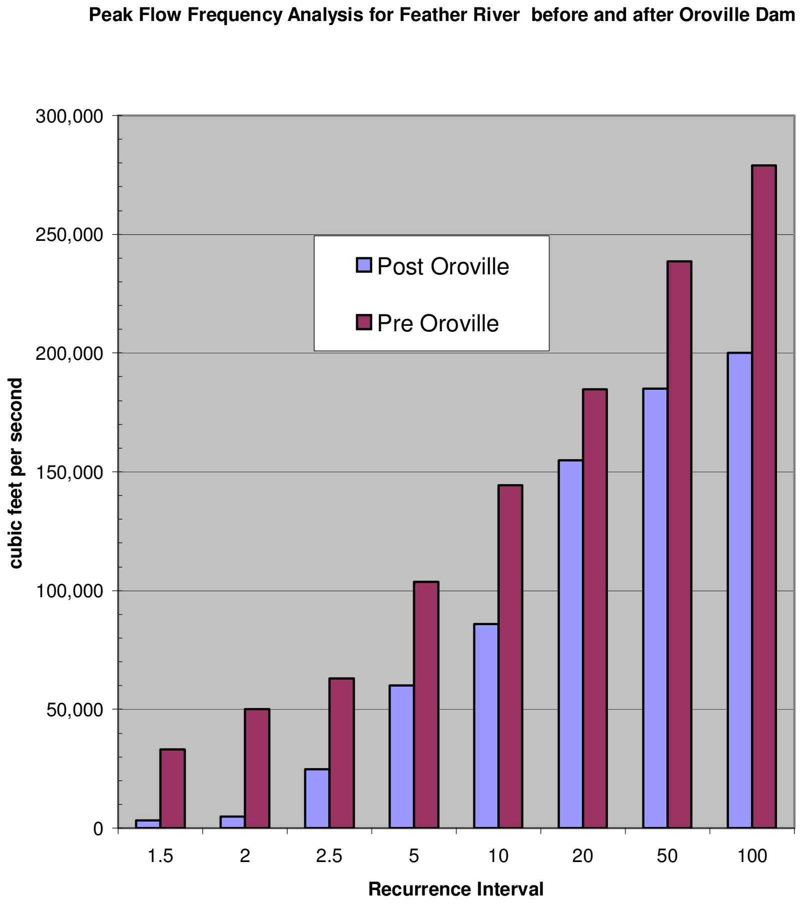


Table 6.4: Feather River Flood Frequency

Recurrence Interval (years)	Post 1968 (cfs)	Pre 1968 (cfs)
1.5	3,170	33,224
2	5,000	50,065
2.5	25,000	63,128
5	60,000	103,704
10	86,000	144,281
20	155,000	184,858
50	185,000	238,498
100	200,000	279,075

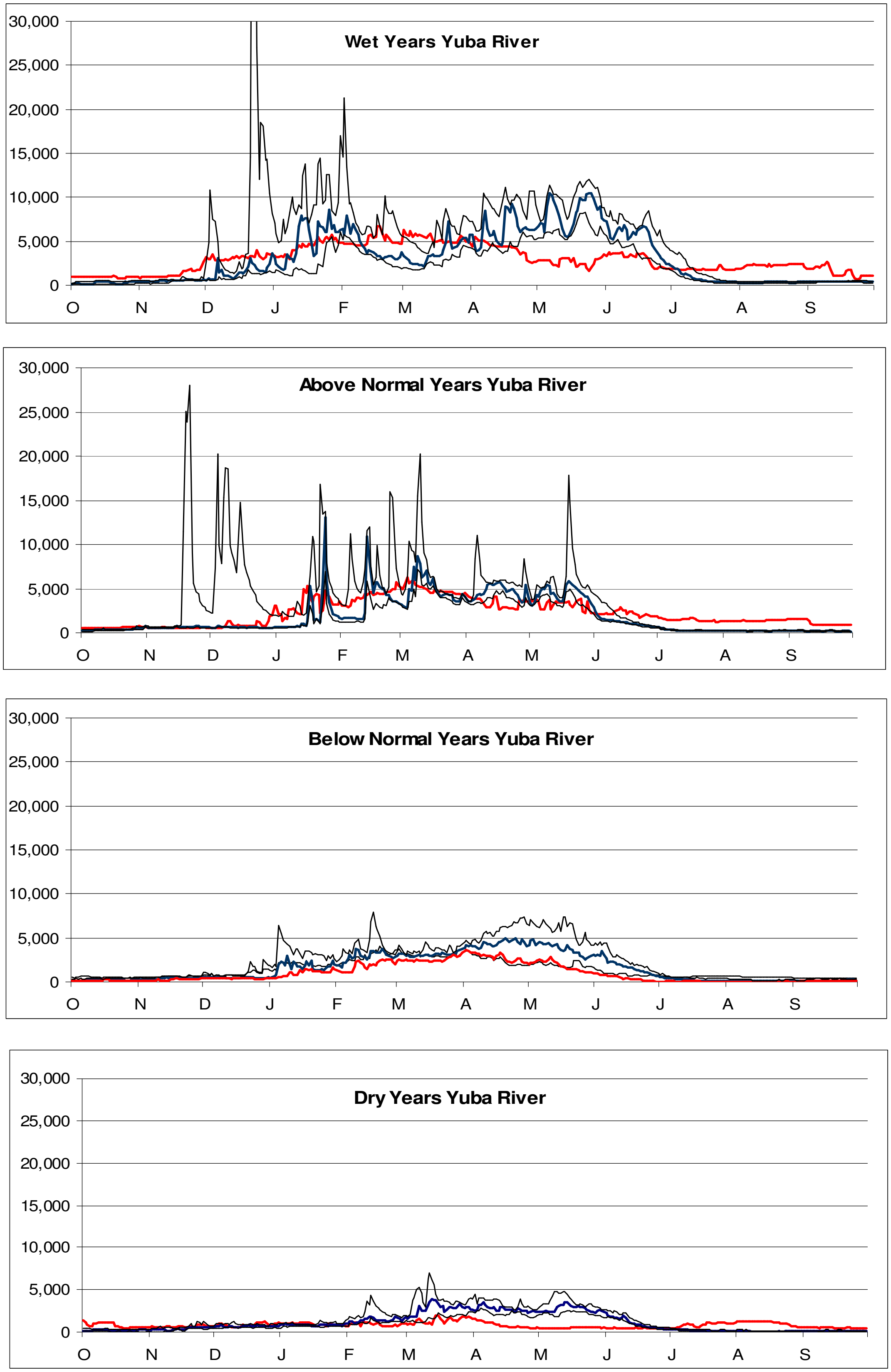


Figure 6.9: Yuba median hydrographs : Historical data was used to construct hydrographs for different water year types for the Yuba (USGS Gage 11421000). The median hydrographs pre and post New Bullards Bar represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.)There is no median hydrograph for the Critical Year type because there were no critical years between 1944 and 1969. See the table of the number of water year types below.

Water Year Type	Pre New Bullards Bar (1944-1969)	Post New Bullards Bar (1970-2006)
W	7	13
AN	3	7
BN	8	3
D	7	6
C	0	7
Total	**25**	**36**

6.3 Sacramento River at Verona

Analysis of the Sacramento and Feather Rivers at gauges near the large dams only tells part of the story. The Verona gauge is downstream of the confluence of the Sacramento and Feather River, and measures run-off from numerous large tributaries not measured by the gauges at Oroville and Bend Bridge. Several of these tributaries do not have large storage reservoirs and thus continue to exhibit relatively natural hydrographs. Figure 14 shows the hydrographs from Mill and Deer Creek which are characterized by large, gently receding spring flows. As a group, these less regulated tributaries tend to dampen the effect of Shasta, Oroville, and New Bullards Bar, but only to a limited extent.

Figures 16 shows hydrologic patterns for four periods: before Shasta, after Shasta but before Oroville Dam, after Oroville Dam, and after the implementation of the 1995 water quality control plan that established stringent limits on the timing of water exports from the Delta. The hydrology from all four periods shows a clear and consistent trend: progressively less spring flow and continuously increasing summer time flows. The decrease in spring flows and increase in summer flows is particularly striking after 2000 when the water quality control plan was in full effect in the Delta. Due to stringent export restrictions in the spring, the state water project, which operates Oroville Reservoir and controls the Harvey O'Banks pumping plant in the Delta, has apparently shifted operations to minimize spring time releases from Shasta and favor summer time releases so that it can deliver water to the Delta when pumping restrictions are less severe.

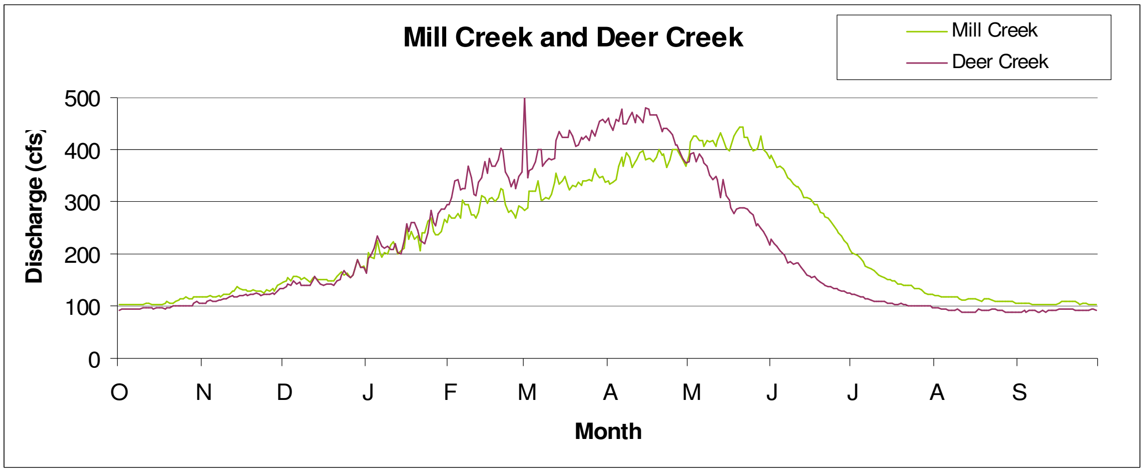
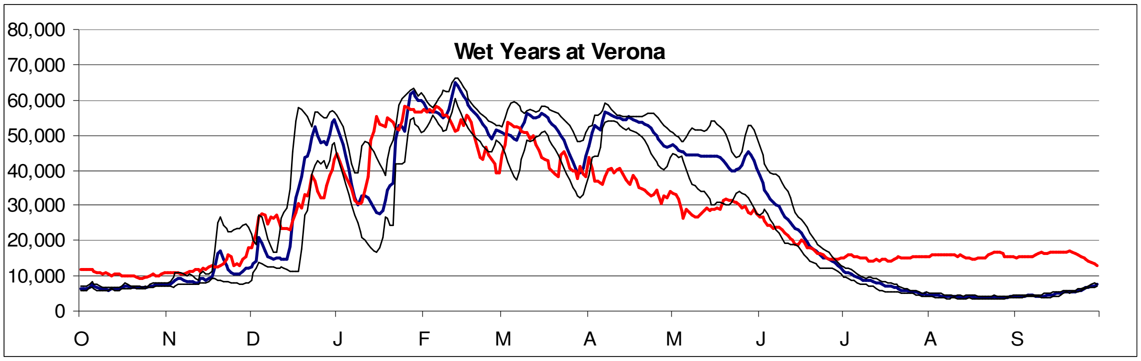
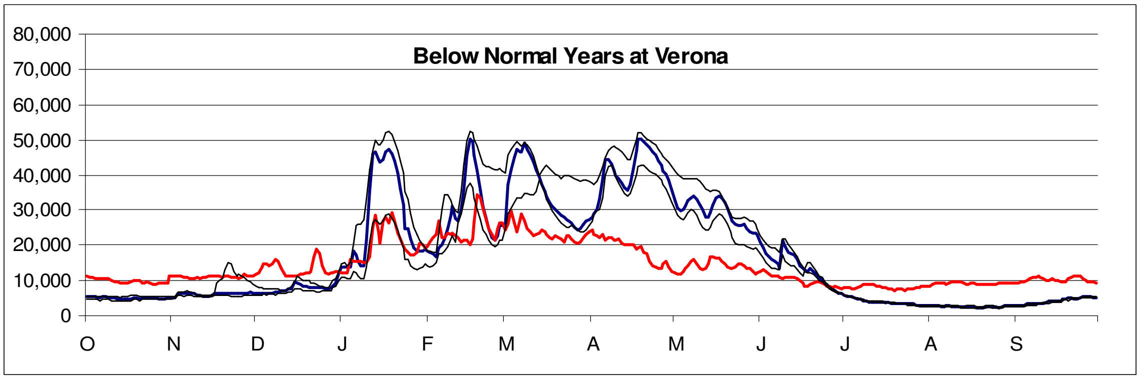
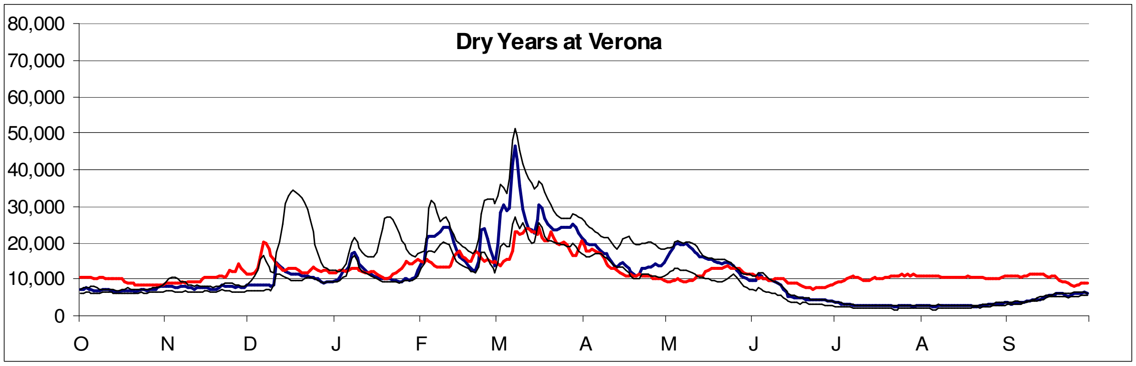


Figure 6.10: Median hydrographs for Mill and Deer Creek.







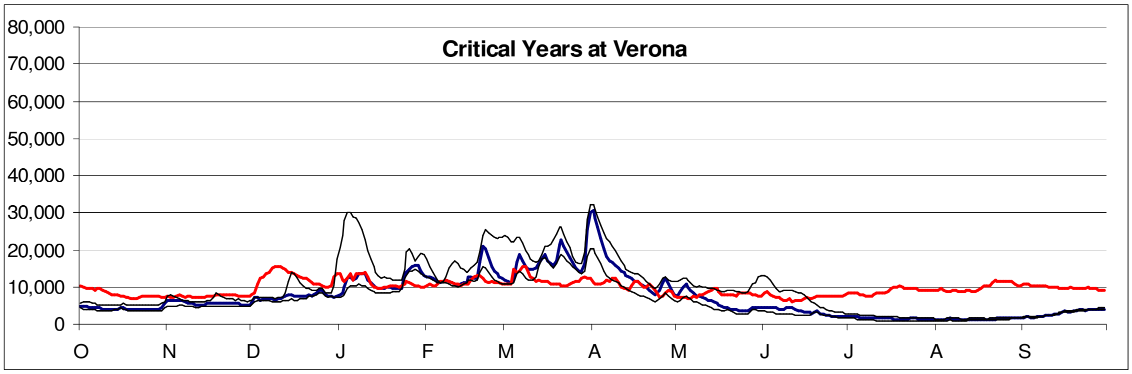


Figure 6.11: Verona median hydrographs : Historical data was used to construct hydrographs for different water year types at Verona (USGS Gage 11425500). The median hydrographs pre and post Shasta represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) There is no median hydrograph for an Above Normal Year type because there was only one year of this type between 1929 and 1944. See the table of the number of water year types below.

Water Year Type	Pre Shasta (1929-1944)	Post Shasta (1945-2006)
W	4	22
AN	1	10
BN	3	11
D	4	12
C	3	7
Total	**15**	**62**

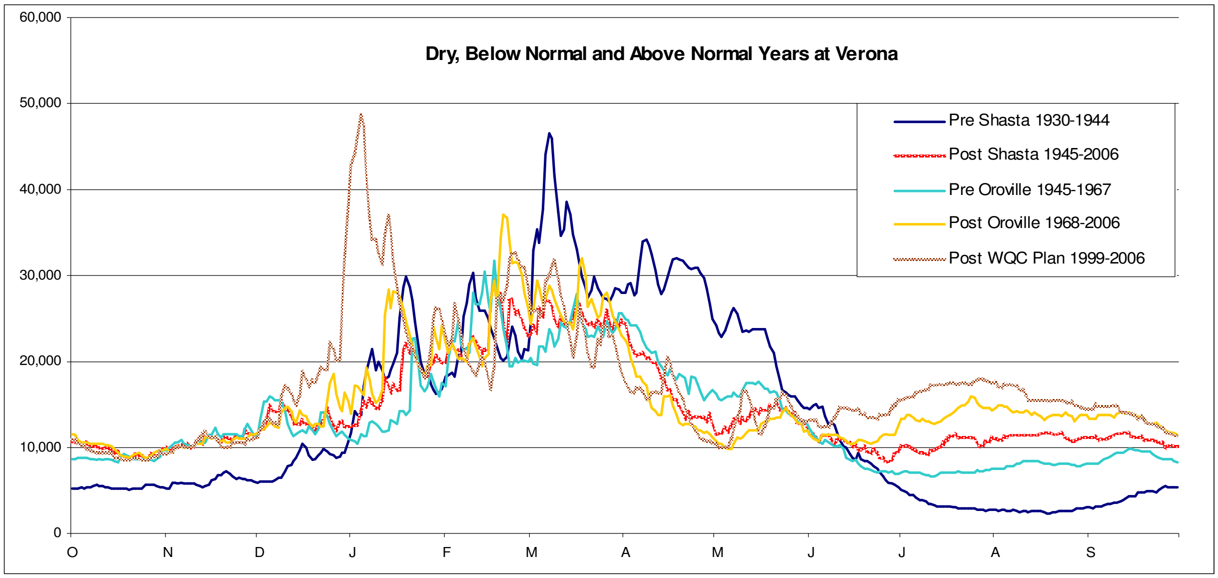


Figure 6.12: Median hydrographs for different time periods indicate a progression towards increased summer flows and decreased spring peaks. The increased regulation of the Sacramento and Feather Rivers with Shasta in 1945, Oroville in 1968 and the implementation of the Water Quality Control Plan in 1999 all had the effect of releasing increased flows during the summer when demands are high and as a consequence eliminated spring peak flows.

Summary of Results

From the hydrograph comparisons of current hydrographs to pre project, or natural hydrographs, a consistent trend immerges for all sites. This trend is the result of reservoir operations where by water is stored until periods of peak demand arise. In the Sacramento River basin peak demands occur in the summer months which means that reservoirs hold water through the spring, eliminating peak spring flows and augmenting summer base flows well above pre project levels. In this way reservoirs alter the timing and magnitude of the spring and summer hydrographs. In addition the presence large reservoirs in the headwaters dampen winter floods in all but the wettest of years. Loss of these geomorphic and riparian flows impacts riparian vegetation and Chinook Salmon habitat.

7.0 IDENTIFY OBVIOUS GAPS BETWEEN OBJECTIVES FLOW REQUIREMENTS AND EXISTING FLOWS

7.1 Gaps in Riparian Vegetation Objectives

Bed Mobilization

The frequency and size of large flows capable of mobilizing the bed have been reduced, but large flows occur in more than half of the years on the Sacramento River. The size of the Q1.5 has been reduced by twenty fiver percent. The pre-dam Q1.5 of 87,000 cfs now has a recurrence interval of every 2.5 years instead of every 1.5 years. While this is a significant reduction, it is a relatively small reduction in comparison to hydrologic alteration on other rivers such as the Feather or San Joaquin Rivers. The abundance of active riffles in the Sacramento River meander belt suggests that the river still periodically mobilizes its bed. Lack of bed mobility in the upper reach below Keswick Dam may be more a result of armoring due to coarse sediment trapping upstream then it is a result of reduced flows.

On the Feather River, the frequency and magnitude of peak flows has been reduced more substantially. The historical instantaneous Q1.5 – 2 has of 33,000 – 50,000 has been reduced by an order of magnitude to 3,000 – 5,000 cfs. The Q2.5, however, is 25,000 cfs. Under the post dam regime, several 4-5 years can pass without exceeding a bed mobilizing flow. This enable riparian vegetation to become established on gravel bars leading to long term stabilization and degradation of the channel.

Bed Scour

The frequency of very large, bed scouring events has been reduced substantially. The pre-dam Q5 of 160,000 cfs now has a twenty-year recurrence interval rather then a five-year recurrence interval. Similarly, the pre-dam ten-year flow now has a one hundred year recurrence interval. The physical processes and ecological function of these large events is not well understood. It is possible that smaller flows substantially scour the bed, rearrange the channel, and form new channel habitat. If so, the reduction in very large flows may not be as important. On the other hand, these very large events may be very important for creating and maintaining important habitats such as oxbow lakes and other off-channel habitats.

Bank Erosion and Channel Migration

We did not conduct an assessment of changes in stream power, but figure 5.2 illustrates that the occurrence of flows exceeding 15,000 or 20,000 cfs in dry, critical dry, and below normal years has been reduce substantially. Larson (2007) identified 15,000 cfs as the lower threshold for bank migration. Median flows frequently reached 15,000 cfs in these drier year types during the pre-dam period, but in the post-dam period median flows seldom rise above 10,000 cfs. During the wettest forty percent of years, wet and normal wet years, median flows frequently exceed 20,000 cfs and thus maintain some level of bank erosion and channel migration processes. Reduction in the frequency and duration of erosive events may have substantial impacts on the colonization and succession of riparian habitat over time. It definitely has habitat implications for bank swallow, a listed species that nests on recently eroded stream banks. Reduced bank erosion almost certainly lowers the suspended sediment levels and could therefore have significant impacts on instream fish habitat for juvenile salmon or Delta smelt that appear to prefer or concentrate in turbid waters (citation?). Although the reduction in the frequency or duration of bank erosion events may have significantly ecological impacts, it may be less important then the widespread presence of bank revetments along the Sacramento Rivers (Larson, 2007).

Inundated Floodplain and off-channel habitat during late winter and spring

The lack of prolonged flows of sufficient magnitude to inundate floodplain and off-channel habitats during the late winter and early spring months is perhaps the most significant ecological change to the Sacramento and Feather Rivers. Large, prolonged flows still occur in wet and normal wet years, but they are largely disconnected from the floodplains due to levees that prevent inundation of the vast historic floodplain of the lower Sacramento River. Large areas of the Sutter and Yolo Bypass become inundated in wet and normal wet years, but little or no floodplains become inundated for any length of time in the drier sixty percent of the years. This is a result of both levees and flow alteration, but flow alteration alone is sufficient to preclude floodplain inundation in the drier years.

Loss of shallow water habitats in secondary channels and floodplains not only reduces the amount of rearing habitat, it also may reduce foodweb productivity in the spring months when juvenile fish are rearing and moving downstream to the Delta. Increase connectivity between shallow water habitats and open water can substantially increase aquatic productivity in estuaries (Cloern, 2008).

Inundated off-channel habitat such as high flow channels can also provide rearing habitat for salmon (Peterson and Reid, 1984), but regulated spring flows are generally insufficient to inundate these habitats for prolonged periods (30-60) days. A recent study of these habitats in the Sacramento River determined that a large proportion of secondary channels between Red Bluff and Colusa become fully connected to the river at flows above 12,000 cfs (Kondolf, 2007). Regulated flows seldom exceed 10,000 cfs in the drier year types (dry and below normal) during late winter and spring when salmon are most likely to require spawning habitat. Even in normal wet years, median April flows are generally below 10,000 cfs.

7.2 Gaps in Riparian Vegetation Objectives

Peak spring flows are conspicuously absent under current conditions. On both the Sacramento and Feather River, median summer flows are significantly greater then median spring flows in all but wet years. As a result, any seeds that might germinate during the cottonwood seed release period in April and May are at risk of mortality from prolonged inundation throughout the summer months. If seeds to become established, they are less likely to grow deep roots during their first growing season due to high groundwater levels and therefore may be more vulnerable to desiccation mortality when water levels do drop.

In addition to the overall decapitation of the spring hydrograph, rapid flow declines during the spring months create a hostile environment for establishment of Fremont cottonwoods. Changes in the rate of the spring snowmelt recession are not obvious from the composite hydrographs depicted in figure 6 because they are of average spring flows over several years. The recession rate is more directly controlled by reservoir release operations in specific wet and above normal years. Our evaluation of hydrographs for individual years indicates that the recession rates are often characterized by abrupt changes in flow during the seed germination period on both the Sacramento and Feather rivers as illustrated in figures 6.1 and 6.2. Abrupt changes in reservoir releases during germination and initial seedling establishment period can limit recruitment by abruptly desiccating recently germinated seedlings before their roots reach the water table or by scouring and inundating newly established seedlings with high summer flows shortly after germination.

Even in wet years, median flows do not reach the documented threshold of 23,000 cfs on the Sacramento necessary to recruit riparian vegetation in a zone that is not vulnerable to subsequent channel scour. Similarly, the Feather River only reaches the assumed threshold of 8,000 -10,000 in median wet years. While it is true that the median numbers depicted in figure 6 obscure the variability that actually occurs in various years, figure 6 clearly illustrates how dramatically the critical spring and summer hydrograph has been altered in non-wet years. Even in wet years, the hydrographs are often not suitable due to the rapid fluctuation in flows (figures 6.1 and 6.2).

Figure 7.1: Annual hydrograph for Sacramento River at Bend Bridge illustrating abrupt flow decline in mid April during cottonwood germination period.

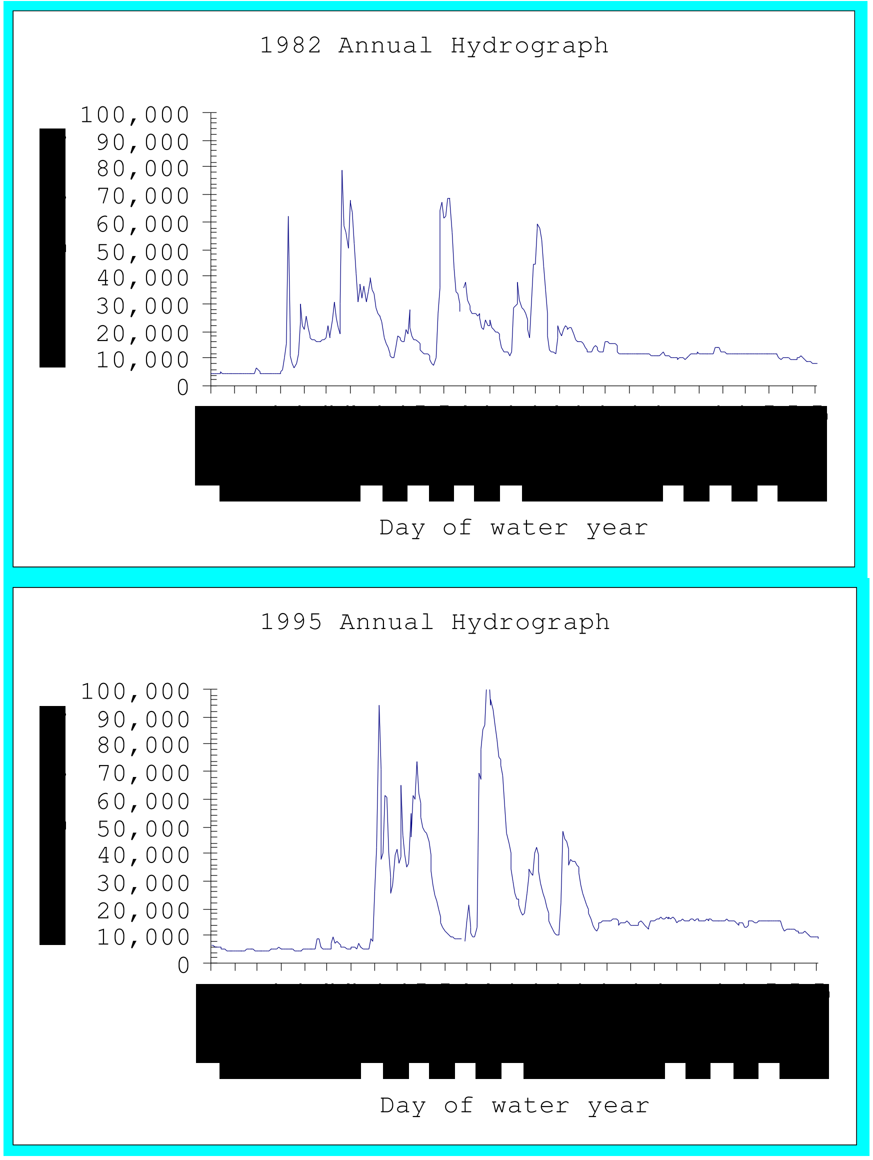
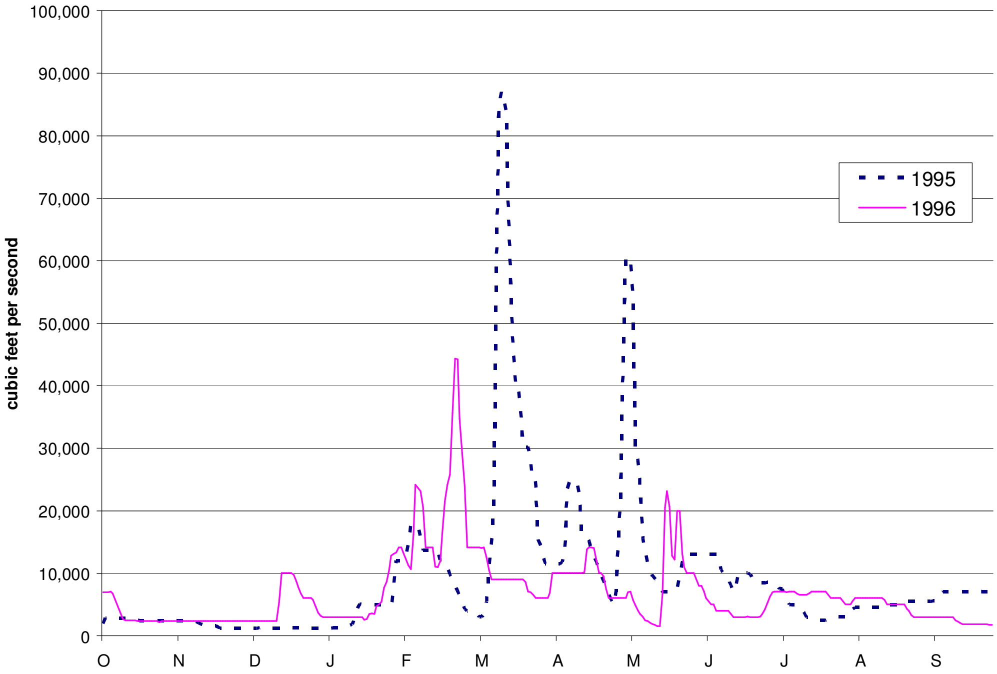


Figure 7.2: Annual hydrograph for Feather River at (sum of Oroville and Thermolito gauges) illustrating abrupt flow decline in mid April during cottonwood germination period.



7.3 Gaps in Chinook Salmon Objectives

Spring Pulse

Elimination of high winter and spring flows has substantially reduced the amount of rearing habitat on inundated floodplains and in off-channel habitats. A close examination of flow patterns indicate that later winter and early spring flows are increasingly the lowest flows of the entire year on both the upper Sacramento and Feather River. Under natural conditions, the highest prolonged flows of the year consistently occurred in the late winter and spring. This "spring rise" in flows inundated gravel bars, secondary channels and associated backwaters, and floodplains during the larger events.

Late winter and early spring flows at Bend Bridge on the Sacramento are about fifty to sixty five percent of what they were historically. A recent study of off-channel habitats on the upper Sacramento River (Kondolf and Stillwater, 2007) identified 12,500 cfs as an important threshold for inundating side channel habitats. On the Sacramento River, median spring flows at Bend Bridge seldom fell below 12,000 cfs between February and April prior to Shasta Dam. In the post dam era, median flows are consistently below 10,000 cfs in all but the wettest years. Meanwhile, summer flows which were historically below 5,000 cfs are now consistently above 10,000 cfs. The shift from spring to summer has become even more pronounced in recent years as dam operators have shifted operations to meet water quality and water supply demands for the Sacramento-San Joaquin Delta.

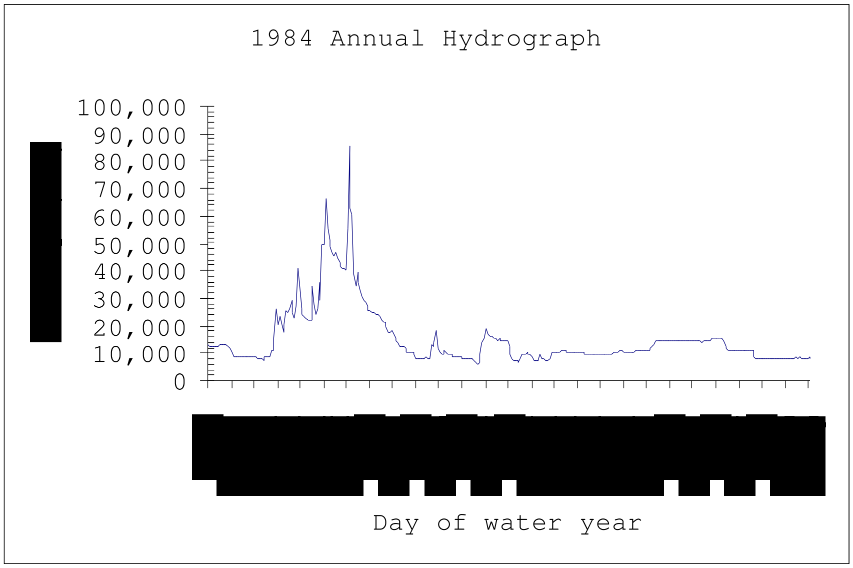
The pattern of reduced spring flows is even more pronounced on the Feather River where median spring flows are fifteen to thirty percent of what they were historically in most year types. The only exception is wet years when they are approximately fifty percent of the historical median. But even in these wetter years, the spring flows are characterized by abruptly fluctuating flood flows as illustrated in figure 6.2, rather then the prolonged spring pulse that characterized historic flows.

Fluctuating Flow Events

The median flow analysis presented in the previous chapter is not well suited for evaluating the frequency of abrupt flow changes, because the composite hydrographs depicted in figure 6 do not reveal individual flow events, which may harm salmon populations. The recent Nature Conservancy study of the Sacramento River (Stillwater, 2007, 2008 appendix F) hypothesized that abrupt increases or decreases in flows in the Sacramento may impact salmon and other species by scouring or dewatering reds, stranding fish, or eroding bank swallow nesting sites. Our cursory analysis of annual hydrographs, illustrated in figures x and xx, indicate that abrupt fluctuations in flow do occur in some years. The timing of these fluctuations may be a significant problem for fish in individual years. Large, rapid fluctuations in the winter or spring could strand juvenile salmon on floodplains or was juveniles downstream to poor habitat. Large reservoir releases in the fall, followed by declines to a significantly lower stage during the remainder of the winter, as illustrated in figure 6.3, could result in dewatering and stranding of redds. Large fall releases are usually limited to periods following very wet years when reservoir levels are high and need to be reduced prior to the rainy season for flood control purposes.

It is clear that large fluctuations in flow occurred under natural conditions on both the Feather and Sacramento Rivers. It is unclear how and whether individuals and populations of these salmon survived these events. Did very high flows that scoured the bed result in reproductive failure? How often did this occur? It is likely that today’s regulated flow regime fluctuates in the present day riverine conditions is more likely to harm salmon then fluctuating flows under historical conditions. Under historical flow conditions, high peak flows are often followed by subsequent peaks that might enable stranded fish to reenter the river. More habitat complexity under historical conditions increased the probability that salmon could spawn or take refuge in areas safe from the potential negative effects of high flows. In today’s environment, large peaks are often abruptly ended only to be followed by weeks of low flows. Levees and channelization have cut-off important refuge and foraging habitat that fish might have otherwise used during high flows.

Figure 7.3: 1984 annual hydrograph from the Sacramento illustrating high flow falls that could result in salmon redd stranding and reproductive failure.



Base Flows

Base flows in the Sacramento and Feather Rivers have been increased in most months except the spring, as previously discussed. Increased base flows during the summer and fall probably lower water temperatures and improve fish passage conditions. It is unclear whether unnaturally high base flows in the summer and fall have any deleterious impacts on fish such as harboring exotic species.

8 ENVIRONMENTAL FLOW REGIME RECOMENDATION

This chapter identifies flow recommendations for the Sacramento River based on the objectives and flow thresholds identified in chapters three and four, and the analyses of natural and regulated hydrology presented in chapters five and six.

Although this study identifies hypothetical restoration flow regimes for the Sacramento and Feather Rivers, we recognize that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program. The hypothetical flow regime that we have developed and identified is imperfect, but it serves as a reasonable starting point for evaluating the feasibility of reoperating reservoirs without impacts on existing reservoir functions.

The assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself. To cost effectively achieve restoration, managers will ultimately need to test these assumptions and address the uncertainties through a program of modeling, pilot flow studies, model calibration, and long-term restoration implementation. In the text below, we have explicitly identified some of these uncertainties so that they can be further evaluated.

8.1 Summary Recommendation

The key component of the environmental flow proposal for both the Sacramento and Feather Rivers is to restore higher flows during the late winter and spring. This period was once characterized by sustained, high flows. Under regulated conditions, however, spring flows are nearly half their historic volume and substantially below summer flows. We recommend restoring a stable spring base flow that is sufficient to inundate secondary channels, as well as, a spring pulse flow to inundated floodplains, particularly the Yolo and Sutter Bypasses.

A second key objective of the flow regime is to ensure adequate flows for the geomorphic and riparian processes that are necessary to sustain riverine and riparian habitat. We recommend short duration, high magnitude flows during the late winter to increase the frequency of hydrologic events that will mobilize the river bed or erode river banks. During late winter and early spring, we recommend prolonged duration moderately high flows to create inundated floodplain habitat for salmon. During the spring of wet and normal years, we recommend moderate duration, high flow evernts in wet and normal wet years to facilitate recruitment of Fremont cottonwoods and other riparian vegetation.

Restoring higher flows in the spring will necessarily reduce flows during other times of the year We propose reducing summer base flows to enhance spring flow, but realize that this could reduce suitable habitat for winter-run salmon during the summer months. We are not proposing any changes in the cold water pool management regime, which currently assures cold water releases from Shasta Reservoir. We recommend against diverting additional water away from the winter months, because we believe that existing winter flood events are necessary to create and maintain riverine and riparian habitat.

8.2 Sacramento River

Summary recommendations for Sacramento River base flows, key ecological flows, and a flow schedule are presented in tables 7.1 – 7.3. Illustrative flow recommendation hydrographs for each year type are presented in figure 7.2.

Table 8.1: Sacramento Environmental Flow Targets for Bend Bridge and Verona

	Critical	Dry	Below Normal	Above Normal	Wet	Location
Bed Mobilization		35,000	65,000	85,000	105,000	Bend
Floodplain Inundation			25,000	35,000	45,000	Verona
Riparian Establishment Flow				23,000	37,000	Bend
Bed Scour	No Recommendation					
Channel Migration						

Table 8.2: Sacramento River Base Flow Target Summary for Bend Bridge

	Critical	Dry	Normal Dry	Normal Wet	Wet
Fall base flow	5,250	5,250	5,250	5,250	5,250
Winter base flow	4,500	6,000	6,500	7,000	8,000
Spring base flow	10,000	12,000	12,500	14,000	14,000
Summer Base	8,000	8,000	8,000	8,000	8,000
Summer Base at Colusa	4,000	4,000	4,000	4,000	4,000

Table 8.3: General Timing and Duration of Sacramento Environmental Flow Targets

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Geomorphic				▨	🟨 2/15 -3/15	🟨	▨					
Floodplain Inundation					🟨 Only 45 Days	🟨	🟨					
Riparian Establishment Flow							🟨					
Riparian Recession Limb								🟨	🟨			
Spring Rise						🟨	🟨					
Fall Base Flow	🟨	🟨										🟨
Winter Base Flow			🟨	🟨	🟨							
Spring Base Flow						🟨	🟨	🟨				
Summer Base Flow									🟨	🟨	🟨	

8.2.1 Fall Base Flows

We propose stepping flows down from a stable summer base flow (see below) in late September in the upper river (between Keswick and Red Bluff). Under both natural and regulated conditions, flows in early fall are the lowest flows of the year. The primary purpose of lowering fall base flows closer to their historic levels is to economize on water and shift the saved water to the spring months when it is more important. The secondary purpose is to provide stable base flows for spring and fall-run spawning salmon and suitable rearing conditions for winter-run 5,500 cfs release from Keswick is about 1,000 – 1,500 cfs below existing fall base flows, but should be adequate for spawning habitat. The fall base flows must be stable to avoid dewatering or redds that may occur when flows are substantially dropped from the norm. Lower base flows in October could also potentially improve rearing habitat for winter run by creating slightly warmer fall water temperatures and thus an increased food supply.

Below Keswick	5,500
Below Red Bluff Diversion	5,250
Below GCID Diversion	5,000
Below Colusa	4,750

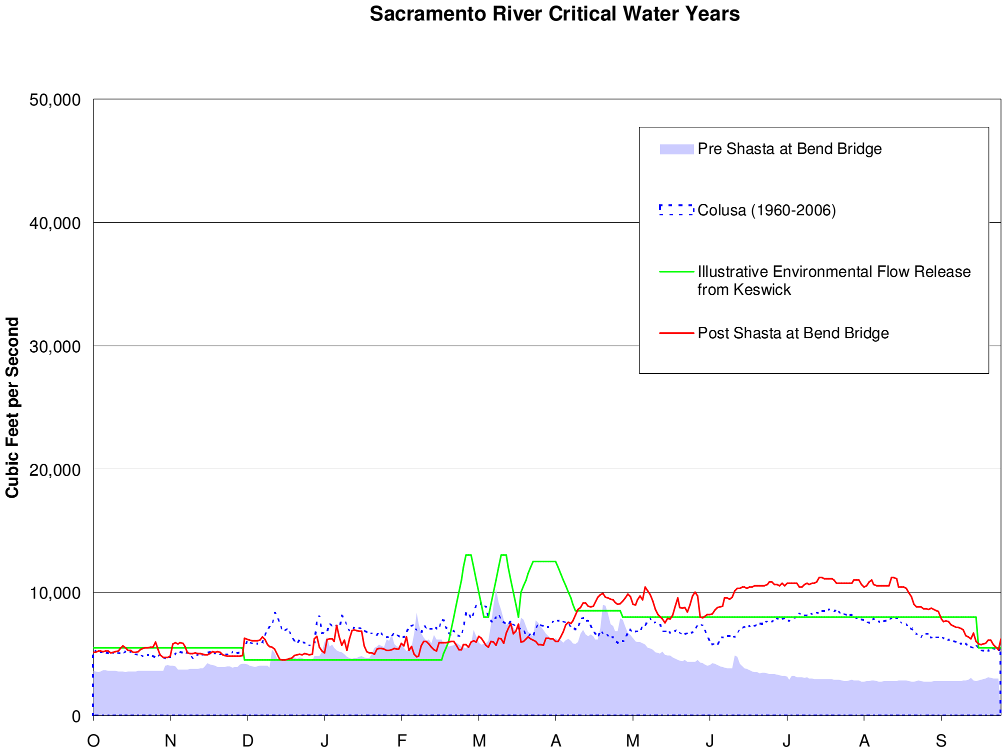
Key Uncertainties

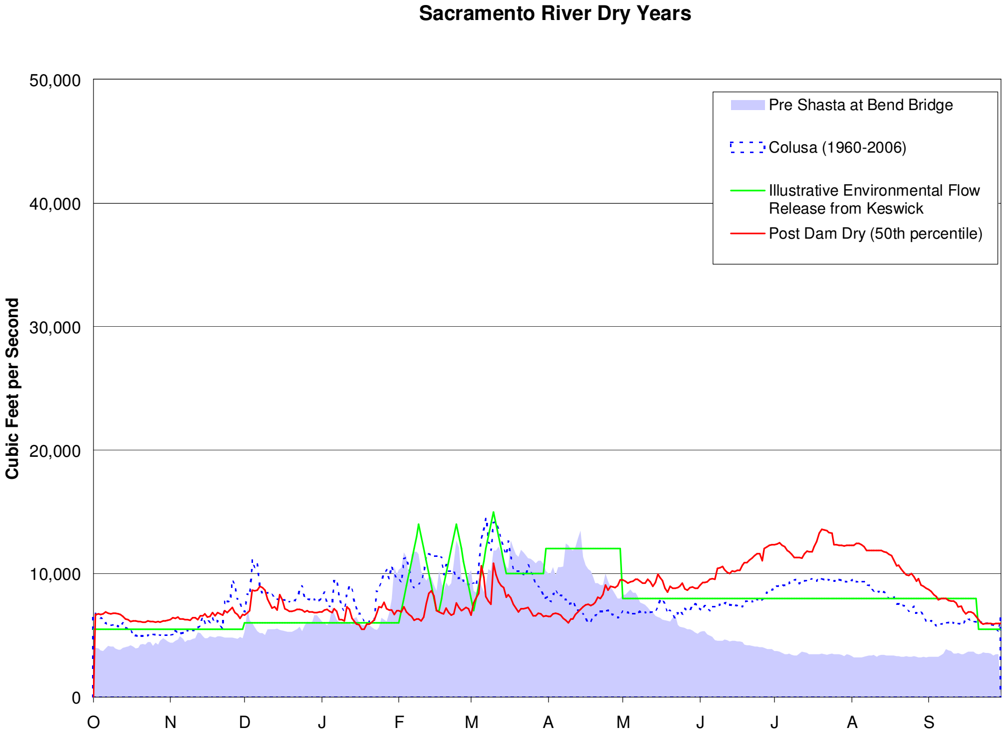
- Are proposed fall base flows sufficient for area of spawning habitat?
- Will lowering fall base flows provide warmer, slower velocity habitat for rearing winter run juveniles, and will this improve their growth and survival?
- Will reduce fall base flows cause adverse impacts in the Delta ecosystem?

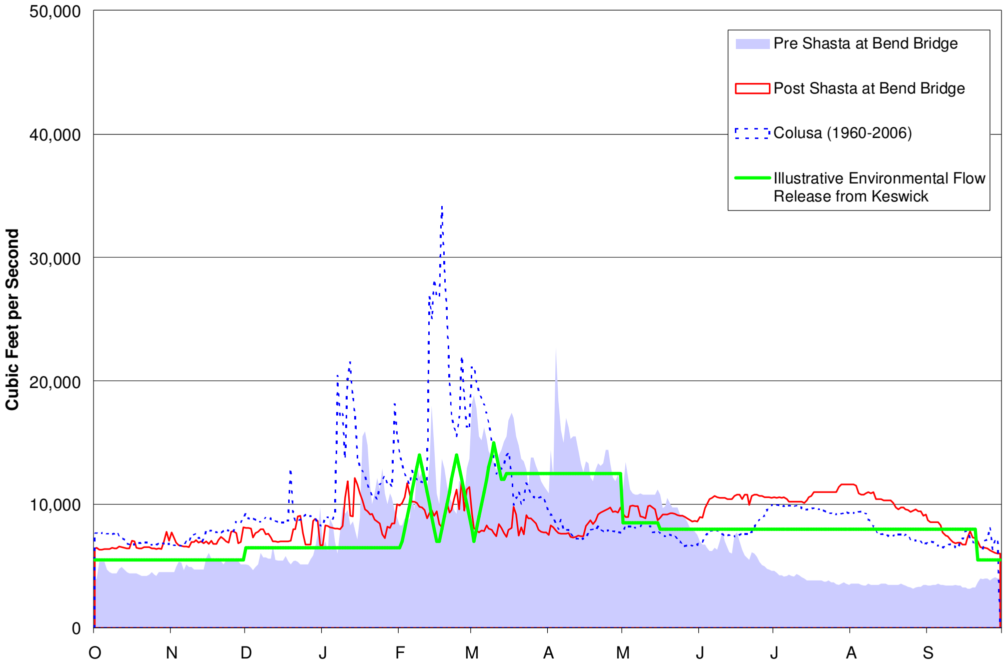
8.2.2 Fall Pulse Flow

We considered a pulse flow to improve rearing conditions for juvenile salmon in the fall but did not include it in figure 7.2. The purpose of the fall pulse flow would be to improve food supply and rearing conditions for the winter run salmon and is loosely

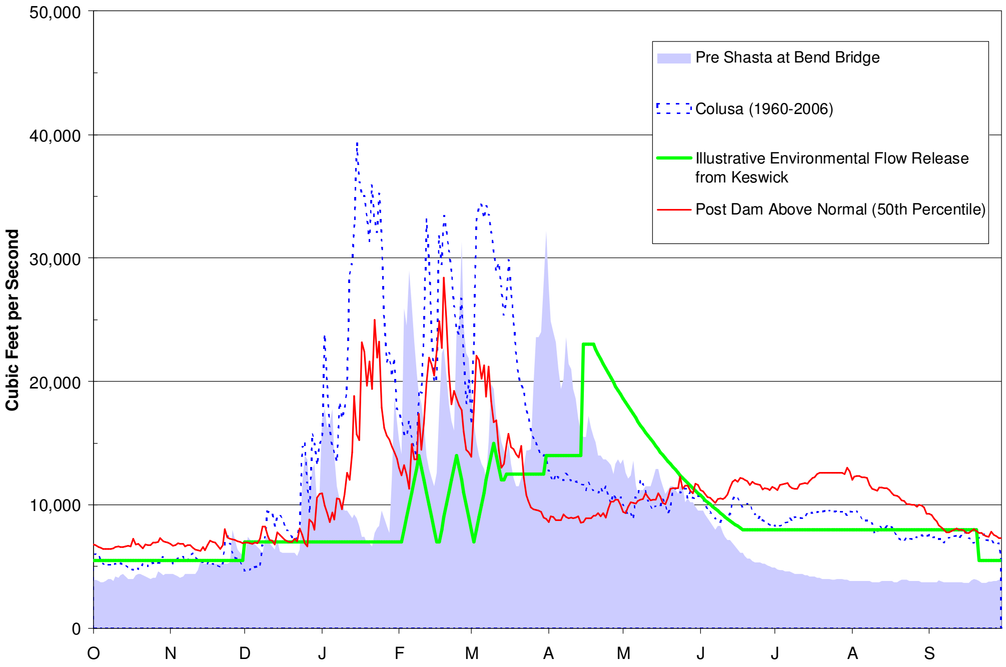
Figure 8.2: Illustrative environmental hydrographs for five year types on the Sacramento River relative to existing regulated hydrograph and pre-Shasta hydrograph.



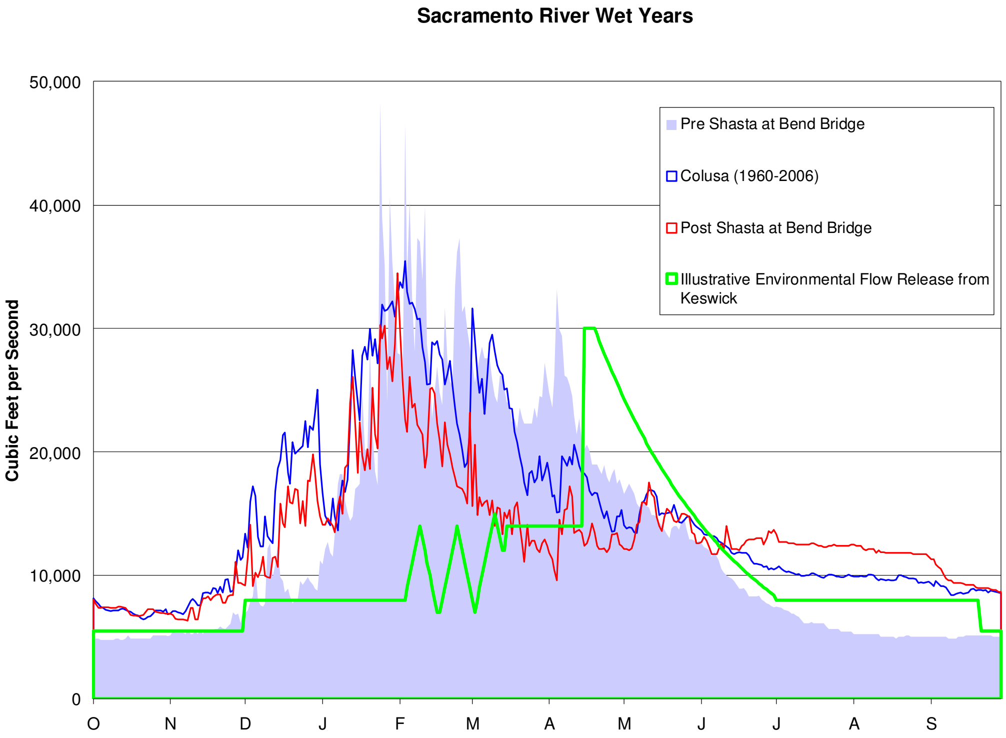




Sacramento River Below Normal Years



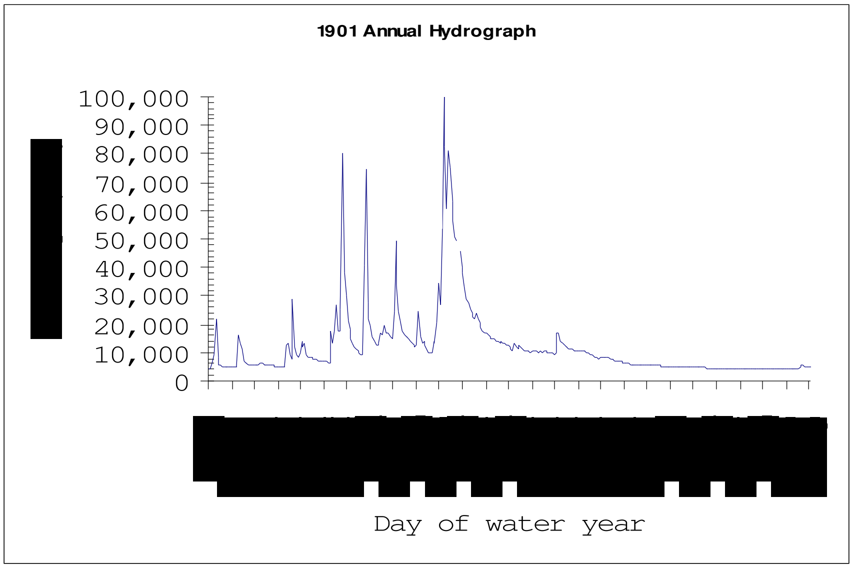
Sacramento River Above Normal Years


Sacramento River Wet Years
Cubic Feet per Second
50,000
40,000
30,000
20,000
10,000
0
O
N
D
J
F
M
A
M
J
J
A
S
Pre Shasta at Bend Bridge
Colusa (1960-2006)
Post Shasta at Bend Bridge
Illustrative Environmental Flow Release from Keswick

based on recommendations of the recently published Sacramento River Environmental Flows Report (Stillwater, 2007; ESSA Technologies, 2008). Rather then releasing a long duration rearing flow as proposed by Stillwater, it may be more economical to release two or three short duration pulses (3-5 days) of 12,000 cfs in late September and early October to inundate secondary channels and channel margins. The initial pulses would inundate the side channels and then be lowered to allow high residence times in the side channels. Each pulse would be followed by a subsequent pulse to flush food resources into the main channel and prevent fish stranding.

The main potential problem with a fall pulse flow would be to enable salmon, particularly spring run, to spawn on areas that would subsequently be dewatered. If the pulses are short enough, this problem may be limited. But the shorter the pulses will provide less potential for rearing habitat and food supply. Early fall pulse flows were rare under natural conditions, but they did occur occasionally as illustrated by the 1901 hydrograph (figure 7.1). Under regulated conditions, the winter run are confined to the mainstem river. The fall pulse, although largely unnatural, is designed to improve rearing conditions for them before cool winter months when food resources will presumably be less abundant.

Figure 8.1: 1901 hydrograph at Bend Bridge illustrating the rare, but natural occurrence of early fall pulse flows.



Key Uncertainties

- Will fall pulse flows for a few days result in dewatered reds once the pulse subsides?
- How long do secondary channel habitats need to be inundated in order to provide prolonged and substantial food supply benefits in the main channel?

8.2.3 Winter Base Flows

The purpose of the winter base flows is to provide stable conditions for incubating salmonids and reduce flashy regulated hydrology that can result when run-off from unregulated tributaries, primarily on the west side, is not modulated by less flashy natural hydrology from the larger, regulated watersheds. We recommend base flows of between 4,500 cfs in critical dry years and 8,000 cfs in wet years (table 7.4), which is similar to both existing regulated conditions and pre-dam historical conditions.

The winter base flows are a minimum base flow and are designed to occur in combination with unregulated run-off and flood control releases. Figure 7.2 shows the winter base flows as a straight line, but it is just a base flow that supports larger, unregulated peak flows. As a result, actual flows at Bend Bridge will be far more variable then depicted in figure 7.2.

Table 8.4: Winter base flow release from Keswick

	Critical	Dry	Normal Dry	Normal Wet	Wet
Winter base flow	4,500	6,000	6,500	7,000	8,000

Fairly substantial winter base flows combined with run-off events from less regulated tributaries will increase the frequency of inundation of channel margins and secondary channels that may serve as important rearing habitat.

8.2.4 Winter and Spring Peak Flows

The geomorphic flow targets discussed below may require additional releases from Shasta but are not explicitly included in figure 7.2 because they are short duration flow events that would be constructed upon unregulated run-off peaks. Smaller magnitude winter and spring peaks for fish rearing discussed below should be sufficient, particularly if reshaped, to achieve geomorphic targets below Red Bluff when combined with unregulated run-off.

Bed Mobilization

We recommend increasing the frequency of channel migration and bed mobilization flows during dry and below normal years for the reasons discussed in Appendix B. On the basis of thresholds discussed in chapter six, we recommend measures to achieve bed mobilization flows in most years (table 7.5). Based on the analysis of flow thresholds presented in chapter five, 35,000 cfs in dry years should be enough to initiate bed mobilization, at least locally, but it is probably not enough to precipitate widespread bed mobilization. The recommended peak flows in wetter years should be sufficient to precipitate significant bed mobilization in below normal, above normal, and wet years.

Table 8.5: Bed mobilization flow targets for Sacramento River between Keswick and Bend Bridge during different year types.

	Critical	Dry	Below Normal	Above Normal	Wet
Bed Mobilization		35,000	65,000	85,000	105,000

Some fish biologists have expressed concerns that high flow, even relative modest high flowss, could scour redds and thereby harm salmonid reproduction (ESSA, 2008; Stillwater, 2007). Based on our flow threshold analysis (chapter 5), we doubt that flows below 25,000 cfs will substantially mobilize the bed or scour redds. Much higher flows will significantly mobilize the bed, but the biological impact is not well documented and dependent on timing.

The ideal timing for bed mobilization is in early March after most salmon fry have emerged from the gravel and before bank swallow initiate nesting on cut banks. We expect that most mobilization events will result largely from unregulated run-off that humans are unable to control. While it seem logical that scouring flows would impair salmon reproduction, the natural hydrograph was characterized by multiple bed mobilization events in most years, raising the question of whether high, scouring flows actually limit salmonid reproduction. Under natural conditions, however, young fish would have had abundant floodplain and backwater habitat that is now scarce due to levees and reduced channel complexity.

Bed Scour

Information regarding the bed scour process and the magnitude of flow necessary to scour the bed is limited. While we recognize the potential importance of bed scour processes, we have not recommended any measures to precipitate bed scour due to the high level of uncertainty and the sheer magnitude of flow that may be necessary. We do, however, expect some bed scour to occur during the larges flow events once every ten years or more.

Channel Migration

Bank erosion and channel migration is a natural process that shapes the river ecosystem and provides habitats for riverine species. Bank swallows nest in recently eroded cut banks. Coarse and fine materials eroded from cut banks create substrates for growth of riparian vegetation and spawning salmon respectively. Turbid water resulting from bank erosion can provide important cover habitat for juvenile fish that would otherwise be very vulnerable to predation.

Some degree of bank erosion and channel migration will occur at the bed mobilization flows identified above and the spring pulse flows described below. Flows sufficient to erode unprotected banks already occurs and will continue to occur in wet and above normal years due to unregulated flows irregardless of a flow prescription. Furthermore, removal of bank revetment may be a more cost water efficient measure to facilitate natural channel migration then intentional flow releases. For all of these reasons, we have not developed a specific flow recommendation for bank erosion and channel migration at this time.

Key Uncertainties:

- How much does the bed need to be mobilized? Is it sufficient to barely move the gravel and cobble substrate on the surface of the bed, or is it necessary to achieve full scale mobilization.
- What duration of peak flow is necessary to adequately mobilize the bed?
- How much does or could natural rates of bank erosion contribute to the overall turbidity and sediment load of the Sacramento River.

8.2.5 Spring Base Flow

The purpose of the spring base flow is to substantially increase rearing habitat along channel margins and within high flow channels for 45 to 120 days. Under natural conditions, spring flows (March and April) were consistently the highest, prolonged flow of the water year and resulted in widespread inundation of flood plain habitats. Under existing conditions, spring flows are substantially reduced, and a system of levees prevents widespread floodplain inundations.

We propose base flows to inundate secondary channels for rearing habitat during the spring months (table x). According to a recent study, a large number of secondary channels become fully connected to the channel at flows above 12,000 cfs (Kondolf, 2007). In critical dry years, flows would average 10,000 for thirty days after March 15, but small pulses greater then 12,000 cfs would increase connectivity with rearing habitat. In wetter years, larger flows would presumably create more rearing habitat and connectivity for longer periods of time.

Figure 8.6: Spring Pulse Flows at Bend Bridge

	3/15 - 3/31	4/1 - 4/14	4/15 - 4/30	4/30 - 5/14	5/1 - 5/14	5/15 - 5/31	6/15 - 6/30
Critical	10,000	10,000	8,500				
Dry	10,000	12,000	12,000	8,500			
Below Normal	12,500	12,500	12,500	8,500			
Above Normal	12,500	14,000	14,000	14,000	8,500		
Wet	14,000	14,000	14,000	14,000	14,000	8,500	

Key Uncertainties:

- Do flows in excess of what is necessary to inundate high flow channels create better rearing habitat and more food then flows barely sufficient to inundate these habitats?

- What is the optimal flow and residence time to create ideal rearing habitat conditions (food supply, temperature, and depth) in the secondary channels.
- Is the secondary channel habitat significant enough to substantially improve rearing conditions relative to the rearing habitat in the channel.

8.2.6 Floodplain Inundation Flows

The purpose of the floodplain inundation flows is to inundate floodplains in the Sutter and Yolo flood bypasses for rearing habitat and food web productivity. The flow objective is to create substantial inundated floodplain habitat for 30-60 days between February 15 and April 15 in most year types. To economize on the amount of water necessary to inundate these bypasses, we propose modifying the Tisdale and Fremont weirs to created inundated flood plain habitat more frequently and for a longer duration. Based on the floodplain process analysis in chapter 5, we developed a schedule of flood flow targets for various year types to create good conditions for floodplain rearing and foodweb productivity in nearly all year types (table 7.7).

The floodplain inundation flows are not explicitly included in figure 7.2. The winter and spring pulse flows described above combined with unregulated run-off at Colusa and environmental flows from the Feather and Yuba should be sufficient to achieve the table 7.7 targets.

Table 8.7: Recommended average monthly flows at Verona and Nicolaus on the Feather to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types (30-60 days).

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Key Uncertainties:

- What magnitude of flow is necessary in the Sacramento and Feather Rivers to move water across the bypasses assuming a modified weir structure?
- What is the optimal timing and flow to create optimal habitat conditions on the bypasses (depth, velocity, temperature, residence time) and food web productivity for the estuary?

8.2.7 Spring Snowmelt Recession Limb

The purpose of the spring, snowmelt recession is to periodically provide conditions for recruitment of Fremont cottonwoods, a keystone species in the riparian ecosystem. As discussed in appendix A and chapter 5, recruitment of cottonwoods requires a high spring flow followed by a gradual decline in order to enable cottonwoods set roots into the groundwater on higher surfaces that are relatively immune from scour during subsequent winter floods. An earlier analyses (TNC, 2003) determined that a range of 23,000 cfs to 37,000 cfs inundates the appropriate seedbed for establishment of cottonwood. Cottonwood trees need not be recruited in all years to ensure a sustained riparian forest ecosystem.

We recommend recruitment flows of 23,000 in above normal years and 37,000 cfs (or somewhere in that general range) in wet years for 4-7 days between mid April and mid May followed by a gradual recession for 8-10 weeks. This flow regime should enable seeds released in mid spring to germinate on relatively high surfaces and then gradually extend roots to the permanent water table before the subsequent growing season.

8.2.8 Summer Base Flow June 15 to September 15

We have designed summer base flows between Keswick and Red Bluff to economically provide suitable conditions for winter run, spring run, and steelhead that spend a temperature sensitive portion of their life cycle between Keswick Dam and Red Bluff diversion Dam (table 7.8). Under natural conditions, these fish would have migrated upstream of Keswick and Shasta, but there mainstem habitat is now limited to the cold tail water provided by reservoir releases. Current base flows are artificially high to deliver water to Sacramento Valley irrigation districts and the Delta. Ideally, these unnaturally high flows could be shifted to the early spring to restore a prolonged spring pulse flow for rearing habitat and aquatic productivity, but providing a more natural flow regime (3,000 to 5,000 cfs) could result in lethal water temperatures for incubating winter run-eggs. Furthermore, flows of only 3,000-5,000 cfs would not provide sufficient water for both diversion into the north valley canals and base flows all the way downstream to the Delta. Therefore, we have proposed an intermediate level summer base that falls at the mid-range between historic base flows and existing base flows between Keswick and Red Bluff.

Table 8.8: Summer base recommendation at various points on the Sacramento River for all year types.

Below Keswick	8,000
Below Red Bluff Diversion	6,000
Below GCID Diversion	4,500
Below Colusa	4,000

Below Red Bluff and the GCID diversions, we have proposed substantially reduced summer base flows in order to shift more flow to the early spring months without disrupting the cold water pool management regime. The primary purpose is to provide better habitat conditions in the spring, but restoring a more natural summer base flow may have environmental benefits in its own right. Summer base flows substantially below the 8,000 cfs needed to inundate off-channel backwaters will create more natural summer conditions and thus may discourage invasive plant and animal species that may out compete natives under the existing artificial summer base flow regime. Seasonally desiccated off-channel habitats may be more productive then perennially inundated wetlands and less likely to harbor exotics predators such as bull frogs and bass. Lower summer water levels may be less beneficial to late germinating invasive vegetation such as tamarisk that can out compete native cottonwoods.

Key Uncertainties:

1. Assuming no changes to the cold water pool management, what flow is necessary to maintain sufficient water temperatures for over summering life stages of winter-run, spring-run, late fall-run and steelhead?
2. Will low flows and corresponding higher temperatures increase populations of non-native warm water fish that prey upon or compete with native species?
3. Will summer base flows be sufficient between Red Bluff and GCID to maintain water temperature conditions suitable for juvenile salmonids or adult migrating salmonids?
4. Will more “natural” conditions provide better habitat and feeding conditions for native species?

8.3 Feather River

Summary recommendations for Sacramento River base flows, key ecological flows, and a flow schedule are presented in tables 7.1 – 7.3. Illustrative flow recommendation hydrographs for each year type are presented in figure 7.2.

Table 8.9: Feather River Environmental Flow Targets for Bend Bridge and Verona

	Critical	Dry	Below Normal	Above Normal	Wet	Location
Bed Mobilization		10,000	20,000	55,000	50,000	Bend
Floodplain Inundation		6,000	8,000	10,000	12,000	Verona
Riparian Establishment Flow				10,000	12,000	Bend
Bed Scour	No Recommendation					
Channel Migration						

[redacted]

[redacted]

8.3.1 Fall Base Flows

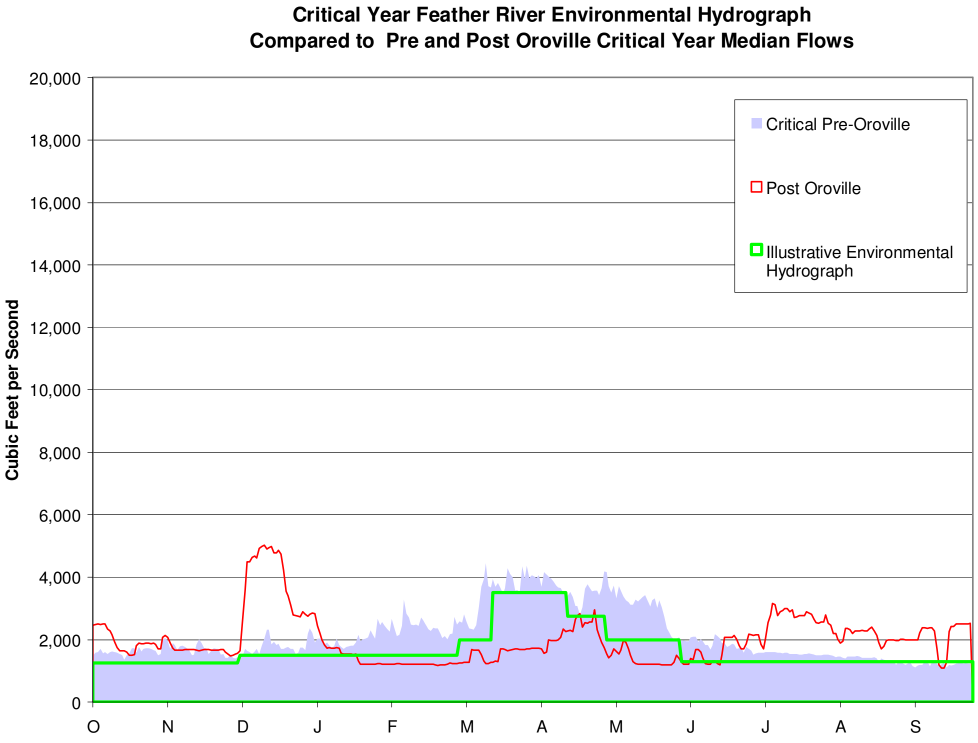
We propose stepping flows down from a stable summer base flow (see below) in late September (table 7.10) to fall spawning flows specified by the recent Oroville relicensing proceeding. The new minimum instream flows below Thermalito Afterbay range from 1,000 cfs in the late spring and summer to 1,200 -1,700 cfs during the fall winter months. Under both natural and regulated conditions, flows in early fall are the lowest flows of the year. The primary purpose of lowering base flows in the fall closer to their historic and regulatory minimum levels is to economize on water and shift the saved water to the spring months when it is more important. The secondary purpose is to provide stable base flows for spring and fall-run spawning and potentially to trigger spring-run spawning. The fall base flows must be stable to avoid dewatering or redds that may occur when flows are substantially dropped from the norm.

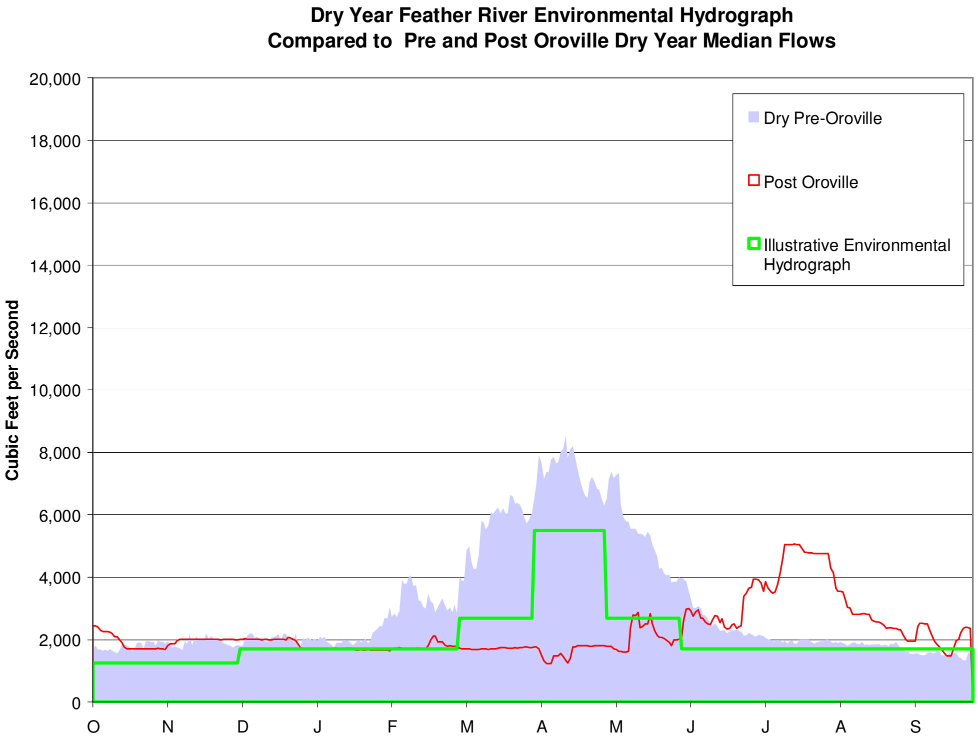
Key Uncertainties

- Are proposed fall base flows sufficient for area of spawning habitat?

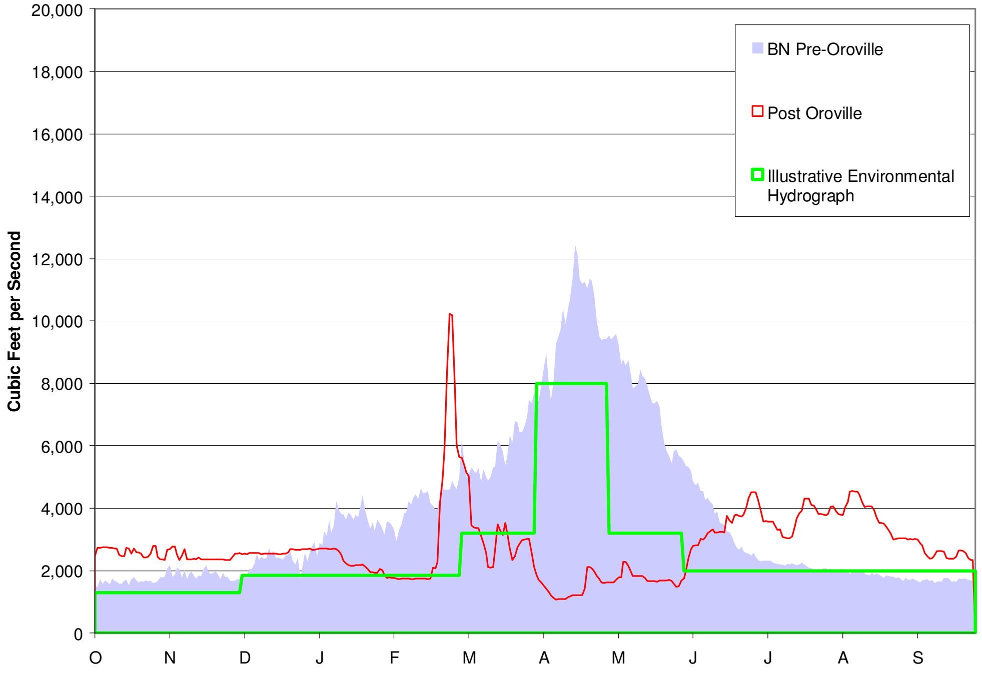
Will reduce fall base flows cause adverse impacts in the Delta ecosystem?

Figure 8.3: Illustrative environmental hydrographs for five year types on the Feather River relative to pre and post Oroville hydrographs.

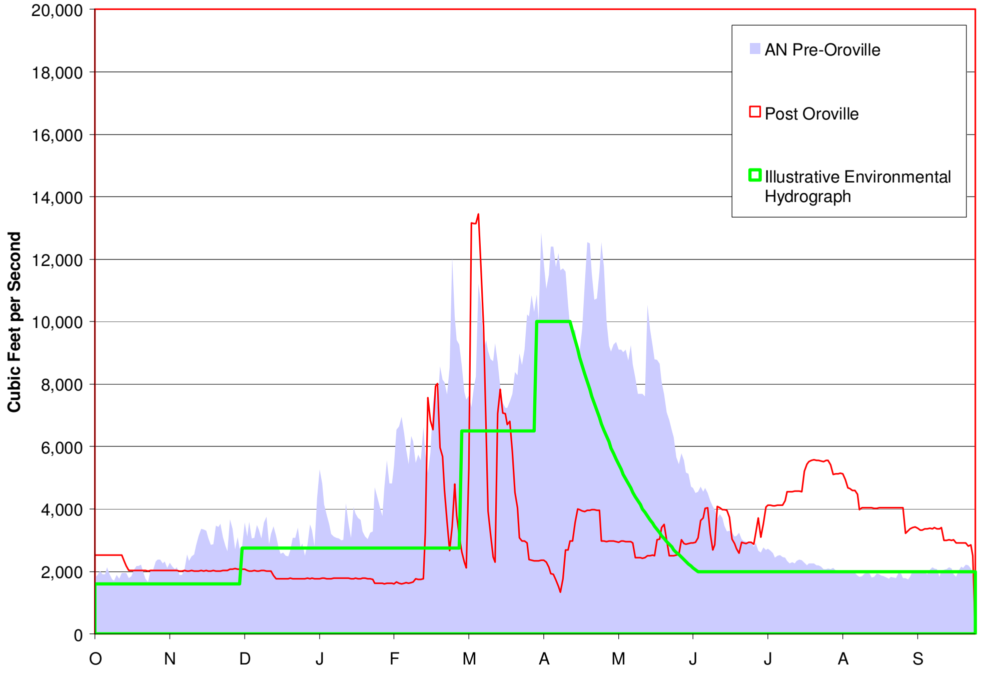


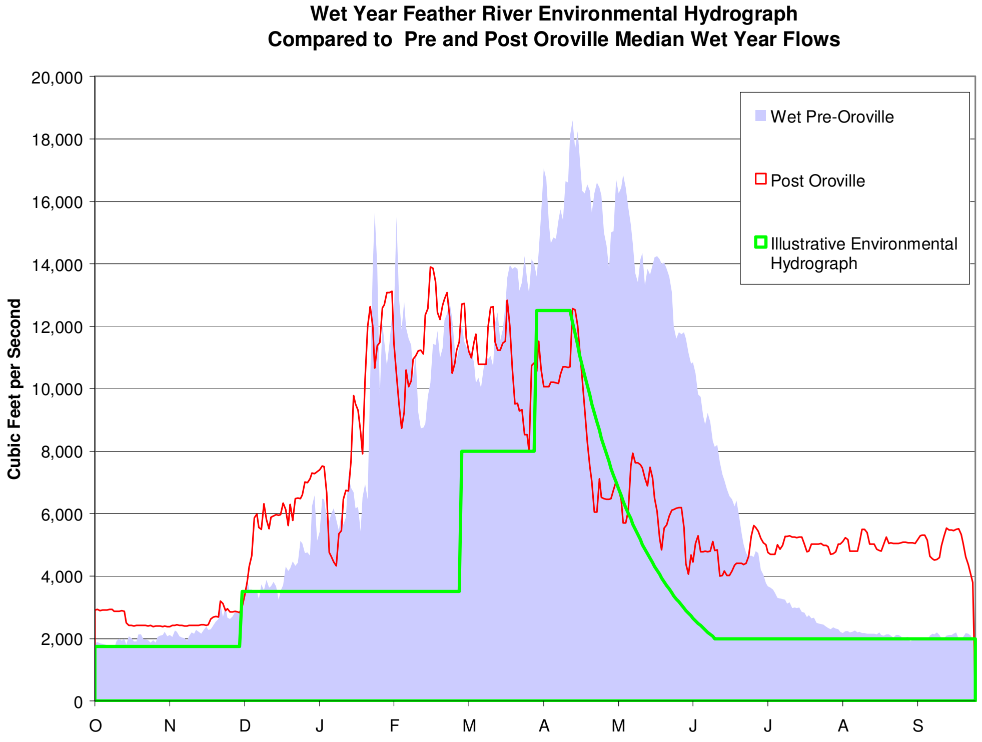


Below Normal Year Feather River Environmental Hydrograph
Compared to Pre and Post Below Normal Oroville Median Flows



Above Normal Year Feather River Environmental Hydrograph
Compared to Pre and Post Oroville Above Normal Median Flows





8.3.2 Winter Base Flows

The purpose of the winter base flows is to provide stable conditions for incubating salmonids and reduce flashy regulated hydrology that can result when run-off from unregulated tributaries, particularly the South Fork Yuba, is not modulated by less flashy natural hydrology from the larger, regulated watersheds. We recommend base flows of between 1,500 cfs in critical dry years and 3,500 cfs in wet years (table 7.10), which is similar to both existing regulated conditions and pre-dam historical conditions.

The winter base flows are a minimum base flow and are designed to occur in combination with unregulated run-off and flood control releases. Figure 7.3 shows the winter base flows as a straight line, but it is just a base flow that supports larger, unregulated peak flows. As a result, actual flows below the confluence with the Yuba will be far more variable then depicted in figure 7.3.
Fairly substantial winter base flows combined with run-off events from less regulated tributaries will increase the frequency of inundation of channel margins and secondary channels that may serve as important rearing habitat.

8.3.4 Winter and Spring Peak Flows

The geomorphic flow targets discussed below may require additional releases from Shasta but are not explicitly included in figure 7.3 because they are short duration flow events that would be constructed upon the spring rise or ordinary flood control releases. Smaller magnitude spring pulse flows for fish rearing discussed below should be sufficient, particularly if reshaped, to achieve geomorphic targets.

Bed Mobilization
We recommend increasing the frequency of channel migration and bed mobilization flows during dry and below normal years for the reasons discussed in Appendix B. On the basis of thresholds discussed in chapter six, we recommend measures to achieve bed mobilization flows in most years (table 7.5). Based on the analysis of flow thresholds presented in chapter five, 35,000 cfs in dry years should be enough to initiate bed mobilization, at least locally, but it is probably not enough to precipitate widespread bed mobilization. The recommended peak flows in wetter years should be sufficient to precipitate significant bed mobilization in below normal, above normal, and wet years.

Table 8.12: Bed mobilization flow targets for Feather River below Oroville

	Critical	Dry	Below Normal	Above Normal	Wet
Bed Mobilization		10,000	25,000	35,000	50,000

Some fish biologists have expressed concerns that high flow, even relative modest high flowss, could scour redds and thereby harm salmonid reproduction on the Sacramento River (ESSA, 2008; Stillwater, 2007). Because are bed mobilization flows for the Feather River are based on statistical estimates rather then empirical evidence of bed mobility, the potential for red scour is a big uncertainty, but we doubt it will occur at 25,000 cfs or less and the greater magnitude flows prescribed for above normal and wet are likely to happen from flood control releases regardless of our flow recommendations.

The ideal timing for bed mobilization after late February when most salmon fry have emerged from the gravel. We expect that most mobilization events will result largely from unregulated run-off that humans are unable to control. While it seem logical that scouring flows would impair salmon reproduction, the natural hydrograph was characterized by multiple bed mobilization events in most years, raising the question of whether high, scouring flows actually limit salmonid reproduction. Under natural conditions, however, young fish would have had abundant floodplain and backwater habitat that is now scarce due to levees and reduced channel complexity.

Bed Scour
Information regarding the bed scour process and the magnitude of flow necessary to scour the bed is limited. While we recognize the potential importance of bed scour processes, we have not recommended any measures to precipitate bed scour due to the high level of uncertainty and the sheer magnitude of flow that may be necessary. We do, however, expect some bed scour to occur during the larges flow events once every ten years or more.

Channel Migration
Bank erosion and channel migration is a natural process that shapes the river ecosystem and provides habitats for riverine species. Bank swallows nest in recently eroded cut banks. Coarse and fine materials eroded from cut banks create substrates for growth of riparian vegetation and spawning salmon respectively. Turbid water resulting from bank erosion can provide important cover habitat for juvenile fish that would otherwise be very vulnerable to predation.

Some degree of bank erosion and channel migration will occur at the bed mobilization flows identified above and the spring pulse flows described below. Flows sufficient to erode unprotected banks already occurs and will continue to occur in wet and above normal years due to unregulated flows irregardless of a flow prescription. Furthermore, removal of bank revetment may be a more cost water efficient measure to facilitate natural channel migration then intentional flow releases. For all of these reasons, we have not developed a specific flow recommendation for bank erosion and channel migration at this time.

Key Uncertainties:

- How much does the bed need to be mobilized? Is it sufficient to barely move the gravel and cobble substrate on the surface of the bed, or is it necessary to achieve full scale mobilization.
- What duration of peak flow is necessary to adequately mobilize the bed?
- How much does or could natural rates of bank erosion contribute to the overall turbidity and sediment load of the Sacramento River.

8.3.5 Spring Base Flow

The purpose of the spring base flow is to substantially increase rearing habitat along channel margins and within high flow channels for 45 to 120 days. Under natural conditions, spring flows (March and April) were consistently the highest, prolonged flow of the water year and resulted in widespread inundation of flood plain habitats. Under existing conditions, spring flows are substantially reduced, and a system of levees prevents widespread floodplain inundations.

On the Feather River, we do not have good information regarding the flows necessary to inundate back-water channels. As a result we developed spring flow targets based on historical hydrology and an assessment of the flows necessary to inundate the Sutter Bypass (table 7.13). Wetter year spring flow pulses begin later in the spring and last longer, while dryer year targets economize on water early to get salmon out of the river before temperatures could become a problem in the lower Sacramento.

Figure 8.13: Spring Pulse Flows below Oroville

	3/1-3/14	**3/14-3/30**	**4/1-4/14**	**4//14 - 4/30**	**5/1 - 5/14**	**5/15 – 5/31**
Critical	2,000	3,500	3,500	2,000		
Dry	2,700	2,700	5,500	5,500	2,700	
Below Normal	3,200	3,200	8,000	8,000	3,200	
Above Normal	6,500	6,500	10,000	10,000	5,000	3,000
Wet	8,000	12,500	12,500	11,000	6,000	4,000

Key Uncertainties:

- Do flows in excess of what is necessary to inundate high flow channels create better rearing habitat and more food then flows barely sufficient to inundate these habitats?
- What is the optimal flow and residence time to create ideal rearing habitat conditions (food supply, temperature, and depth) in the secondary channels.
- Is the secondary channel habitat significant enough to substantially improve rearing conditions relative to the rearing habitat in the channel.

8.3.6 Floodplain Inundation Flows

The purpose of the floodplain inundation flows is to inundate floodplains in the Sutter and Yolo flood bypasses for rearing habitat and food web productivity. The flow objective is to create substantial inundated floodplain habitat for 30-60 days between February 15 and April 15 in most year types. To economize on the amount of water necessary to inundate these bypasses, we propose modifying the Tisdale and Fremont weirs to created inundated flood plain habitat more frequently and for a longer duration. Based on the floodplain process analysis in chapter 5, we developed a schedule of flood flow targets for various year types to create good conditions for floodplain rearing and foodweb productivity in nearly all year types (table 7.7).

The floodplain inundation flows are not explicitly included in figure 7.3. The spring pulse flows described above combined with unregulated run-off from the Sacramento and Yuba Rivers will be sufficient to achieve the table 7.7 targets.

Table 8.14: Recommended average monthly flows at Verona and Nicolaus on the Feather to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types (30-60 days).

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Key Uncertainties:

- What magnitude of flow is necessary in the Sacramento and Feather Rivers to move water across the bypasses assuming a modified weir structure?
- What is the optimal timing and flow to create optimal habitat conditions on the bypasses (depth, velocity, temperature, residence time) and food web productivity for the estuary?

8.3.7 Spring Snowmelt Recession Limb

The purpose of the spring, snowmelt recession is to periodically provide conditions for recruitment of Fremont cottonwoods, a keystone species in the riparian ecosystem. As discussed in appendix A and chapter 5, recruitment of cottonwoods requires a high spring flow followed by a gradual decline in order to enable cottonwoods set roots into the groundwater on higher surfaces that are relatively immune from scour during subsequent winter floods. Since we did not have estimates of flows suitable for riparian recruitment on the Feather River, we estimated a seedling establishment flow target based on the Sacramento riparian recruitment target. We simply scaled down the Sacramento target based on the ratio of the seedling establishment flow to the Q1.5. The seedling establishment flow on the Sacramento (23,000 – 30,000 cfs) is twenty seven to thirty seven percent of the bankfull discharge (Q1.5 to Q2) on the Sacramento. Assuming a similar proportional relationship on the Feather River, flows in the range of 9,500 to 18,000 would be suitable for seedling establishment.

We recommend seedling establishment flows of 10,000 in above normal years and 12,500 cfsin wet years for 4-7 days between mid April and mid May followed by a gradual recession for 8-10 weeks. This flow regime should enable seeds released in mid spring to germinate on relatively high surfaces and then gradually extend roots to the permanent water table before the subsequent growing season.

8.3.8 Summer Base Flow June 15 to September 15

The purpose of the summer base flow is to provide suitable temperature and rearing conditions for over summering salmonids, both juvenile and adult spring-run and steelhead. We propose base flow targets ranging from 1,300 in critical dry years to 2,000 cfs in above normal and wet years. These flows are very similar to natural summer base flows and are higher then the minimum existing minimum flows established during the recent relicensing proceedings. Existing minimum regulatory flows are 1,000 cfs in the summer. Existing actual flows are far higher then are recommendation.

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