JUL 3 1 2013

Mr. Sam Harader
Program Manager II
Delta Stewardship Council – Delta Science Program
980 9th Street, Suite 1500
Sacramento, CA 95814

Dear Mr. Harader:

REQUEST FOR RECOMMENDATION OF METHOD TO DEVELOP FLOW CRITERIA FOR PRIORITY TRIBUTARIES TO THE SACRAMENTO-SAN JOAQUIN DELTA

The State Water Resources Control Board (State Water Board) seeks the assistance of the Delta Science Program in identifying one or more scientifically defensible methods to develop flow criteria for priority tributaries. The Delta Science Program's input will inform the development of flow criteria for a minimum of five priority tributaries in the Bay-Delta watershed by June 2018, and the remaining priority tributaries thereafter. The flow criteria will be applied to the bulk of each priority tributary's watershed to inform the development of flow objectives in Phase 4 of the State Water Board's Bay-Delta planning process.

The State Water Board is specifically requesting the Delta Science Program to provide a written recommendation that identifies a method or methods to determine instream flow criteria that are:

- scientifically defensible,
- cost-effective,
- applicable to the bulk of each tributary's watershed, and
- able to be implemented in a timely fashion.

The enclosed document includes a description of two methods to develop regional flow criteria. In California, site-specific habitat based studies have historically been used to provide a comprehensive assessment of flow needs for specific stream reaches. The application of traditional site specific studies however is constrained by resource needs, both in the amount of time such studies take and the amount of funding available to conduct the studies. The State Water Board would like to develop flow criteria that can be applied to the bulk of each priority tributary's watershed, and which address multiple species or life stages and fluvial processes. Traditional site-specific studies do not adequately meet this goal due to the stream reach and species and life stage specific nature of these studies.

To assist the State Water Board in identifying a flow methodology that is both timely and cost-effective, please conduct a review of methods which can be applied more broadly, such as on a watershed or regional scale. Two such methods are included in the enclosed document: the Instream Flow Incremental Methodology (IFIM) regional habitat based method; and the Ecological Limits of Hydrologic Alteration (ELOHA) method. State Water Board staff recognizes that there are other scientifically defensible methods not discussed in the enclosed document. If the Delta Science Program determines that a different method or combination of methods will achieve the goal more effectively, please provide those recommendations.

In addition to a recommendation for a method or methods to determine instream flow criteria, the State Water Board is interested in the following:

1. If the IFIM regional habitat based method is recommended, please provide specific comments on the tools that should be used to address the biological resource and fluvial process needs (e.g., salmonids, amphibians, macro-invertebrates, bedload transport, floodplain processes, and wetland/riparian communities) that are likely to occur in tributaries throughout the Bay-Delta watershed. For example, to address Chinook salmon passage issues a recommendation could be made to use the Critical Riffle Assessment Methodology, where applicable.

2. If an IFIM regional habitat based method is recommended, how can the information generated be used, or augmented with other methods, to inform the development of flow criteria for portions of the watershed outside of the study plan area?

3. If ELOHA is used, it is possible that local stakeholders or agencies may desire to perform site-specific studies to refine the regional flow criteria. For example, fish passage and spawning habitat are often localized issues that may benefit from site-specific refinements or calibrations of regional criteria. In such cases, and others (i.e., temperature, flushing flows, fluvial processes, etc.), it is anticipated that the same methods and tools used to address the biological resource and fluvial process needs recommended for the IFIM regional habitat method would be used to calibrate or refine regional flow criteria (i.e., those recommended under 1 above). Please provide specific comments on the tools that should be used to address these needs.

To discuss the timing of this request as well as to answer any questions, please contact me at (916) 323-9392 or at Daniel.Schultz@waterboards.ca.gov. Written correspondence should be addressed as follows:

State Water Resources Control Board
Division of Water Rights – Public Trust Unit
Attn: Daniel Schultz
P.O. Box 2000
Sacramento, CA 95812-2000

Sincerely,

Daniel Schultz
Public Trust Unit Chief
Division of Water Rights

Enclosure: Potential Methods to Develop Flow Criteria for Priority Tributaries to the Sacramento-San Joaquin Delta

POTENTIAL METHODS TO DEVELOP FLOW CRITERIA FOR PRIORITY TRIBUTARIES TO THE SACRAMENTO-SAN JOAQUIN DELTA

July 2013

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

1. Purpose and Need

The State Water Resources Control Board (State Water Board) seeks the assistance of the Delta Science Program in identifying one or more scientifically defensible methods to develop flow criteria for tributaries to the Sacramento-San Joaquin Delta (Bay-Delta). The State Water Board is specifically requesting the Delta Science Program to provide a written recommendation that identifies a method or methods to determine in-stream flow criteria that are:

- scientifically defensible,
- cost-effective,
- applicable to the bulk of each tributary's watershed, and
- able to be implemented in a timely fashion.

The purpose of this document is to provide information and background for the Delta Science Program to consider in responding to the State Water Board's request. Two specific methods are described in this document, however, the evaluation need not be limited to these methods if other scientifically defensible methods exist which would also meet the State Water Board's criteria for cost-effective and timely consideration of developing regional flow criteria.

The State Water Board plans to use the recommendation to inform a general approach for developing flow criteria and establishing flow objectives for a minimum of five priority tributaries in the Bay-Delta watershed by June 2018, and the remaining priority tributaries thereafter.

2. Introduction and Background

The State Water Board is in the process of updating the Bay-Delta Water Quality Control Plan (Bay-Delta Plan). In its final *Delta Plan*[1], the Delta Stewardship Council included the update and development of flow objectives for the Bay-Delta and high priority tributaries as key to the achievement of the State's coequal goals. The State Water Board's process for both updating and developing flow objectives for the Delta and its tributaries is consistent with the Delta Plan's ecosystem restoration key components. This work will be conducted in phases:

- Phase 1: Bay-Delta Plan review and update of the San Joaquin River flow and southern Delta salinity objectives and its program of implementation;
- Phase 2: Comprehensive review and update of other components of the Bay-Delta Plan and its program of implementation;
- Phase 3: Amendment of water rights and other measures to implement changes to the Bay-Delta Plan resulting from Phases 1 and 2; and
- Phase 4: Development and implementation of policies for water quality control, including the development of flow criteria and flow objectives for priority tributaries to the Bay-Delta, with a focus on the Sacramento River watershed.

Phases 1 and 2 of the State Water Board's current Bay-Delta effort will update the 2006 Bay-Delta Plan. In Phase 1, the State Water Board is considering amendments to the Bay-Delta Plan related to the flows of the San Joaquin River and its tributaries, and Southern Delta

[1] The final Delta Plan was adopted by the Delta Stewardship Council on May 16, 2013.

salinity. In Phase 2, the State Water Board is considering other potential changes to the Bay-Delta Plan, including changes to: 1) Delta inflow and outflow objectives; 2) export/inflow objectives; 3) Delta Cross Channel Gate closure objectives; 4) Suisun Marsh objectives; 5) new reverse flow objectives for Old and Middle Rivers; 6) new floodplain habitat flow objectives; 7) changes to the monitoring and special studies program; and 8) other changes to the program of implementation.

In Phase 3 of the State Water Board's Bay-Delta effort, the State Water Board will consider potential changes to water rights and other measures to implement the changes to the Bay-Delta Plan resulting from Phases 1 and 2.

In Phase 4, the State Water Board will develop and implement tributary specific policies for water quality control (policies) for priority tributaries to the Bay-Delta watershed, with a focus on the Sacramento River watershed. This effort includes: 1) development of non-binding flow criteria; 2) development of flow objectives and implementation plans; 3) development of policies that incorporate flow objectives, methods for adaptive management, and implementation plans; and 4) implementation of policies through conditioning of water rights and other measures as appropriate.

Flow criteria, as referred to in this document, provide the technical basis for the development of flow objectives, but do not have regulatory effect. Flow criteria do not consider the costs of providing this water or the competing uses for water. Flow criteria will identify the range of instream flows needed to ensure the viability of aquatic species and support fluvial processes. Flow criteria should consider the needs of each tributary's flow dependent aquatic organisms and emphasize the protection of threatened or endangered species, or species likely to become threatened or endangered in the foreseeable future.

2.A. Identification of Two Regional Flow Criteria Development Methods

To be responsive to the timeline requested by the Delta Stewardship Council and ensure the efficient use of resources, the State Water Board is evaluating methods and tools to develop flow criteria, under Phase 4, for priority Bay-Delta tributaries. In California, site-specific habitat based studies have historically been used to provide a comprehensive assessment of flow needs for specific stream reaches. The application of traditional site specific studies however is constrained by resource needs, both in the amount of time such studies take and the amount of funding available to conduct the studies. The State Water Board would like to develop flow criteria that apply to the bulk of each priority tributary's watershed, and which address multiple species or life stages and fluvial processes. Traditional site-specific studies do not adequately meet this goal due to the stream reach and species and life stage specific nature of these studies. Therefore, the State Water Board is evaluating regional methods that can build upon existing information to develop regional flow criteria. As part of the Phase 4 effort, existing flow information will be evaluated and augmented with additional studies and modeling, as needed, to support the establishment of flow criteria on a regional scale.

State Water Board staff has identified two potential regional methods that could be used to develop flow criteria, as outlined below:

1) an Instream Flow Incremental Methodology (IFIM) regional habitat based method, similar to the Pennsylvania-Maryland Method, which uses site-specific habitat tools such as critical riffle analyses, Physical Habitat Simulation (PHABSIM), and the wetted perimeter method, on representative and randomly selected stream segments within a

region to evaluate the effects of alternative water management scenarios on habitat at a regional scale; and

2) the Ecological Limits of Hydrologic Alteration (ELOHA) method, which uses statistical models to generate regional flow alteration-ecological response relationships to analyze ecological impacts caused by flow impairment.

Each of these methods is discussed in more detail in Section 3 of this document. The Delta Science Program may consider other methods not described in this document.

2.B. Summary of Current and Planned Instream Flow Studies and Associated Entities

Multiple State and federal agencies, nongovernmental organizations (NGOs), and watershed resource groups (groups) are conducting instream flow studies and/or collecting biological and habitat data relevant to instream flow studies. The State Water Board will coordinate with these entities to incorporate the applicable and defensible information they produce, through site-specific studies and other methods, into the development of flow criteria for Phase 4. This section provides an overview of relevant instream flow related processes that various groups are working on related to this Phase 4 effort.

California Department of Fish and Wildlife

The California Department of Fish and Wildlife (CDFW) is a trustee for California's fish and wildlife resources and under Public Resources Code 10000 is required to develop and provide stream flow recommendations to the State Water Board. The CDFW Instream Flow Program is working on, and/or planning to develop IFIM based flow recommendations for protection of fish and wildlife for several Bay-Delta tributaries including Butte Creek, Clear Creek, Deer Creek, and Mill Creek. The CDFW Bay-Delta tributary flow studies will address multiple salmonid lifestage flow needs, and the resulting flow recommendations will be transmitted to the State Water Board for use in its water rights decisions.

Studies conducted by CDFW often include the use of habitat-based tools to quantify the relationships between discharges and important habitat components. Currently, CDFW is partnering with the United States Fish and Wildlife Service (USFWS) on the lower Butte Creek flow study. It is anticipated that the final report for lower Butte Creek will be completed by October 2016. The flow work on lower Butte Creek includes examination of the relationship between flow and upstream passage of spring-run Chinook salmon in lower Butte Creek. In addition, CDFW is currently preparing contract scopes of work and/or study plans for Mill and Deer Creeks.

United States Fish and Wildlife Service

USFWS conducts many instream flow studies, often addressing salmon, steelhead, and sturgeon needs. The studies are typically PHABSIM/Riverine Habitat Simulation (RHABSIM), River2D, or temperature studies. USFWS is heavily involved in flow work on the Sacramento River (below Keswick Dam) and Clear Creek, because these locations are associated with the Central Valley Project Improvement Act. Additionally, USFWS is currently conducting an instream flow study on Cottonwood Creek and is providing technical assistance to CDFW for instream flow work on Butte Creek. USFWS is expected to remain actively involved in flow related work in the near future.

Federal Energy Regulatory Commission

Federal Energy Regulatory Commission (FERC) licenses hydropower projects. FERC hydropower licenses often contain flow requirements. In California, hydropower projects that were established and licensed 30 to 50 years ago are now undergoing relicensing. Many of the fisheries resource agencies are involved in the FERC licensing process through scoping, commenting, and sometimes mandatory conditioning of a FERC license. The State Water Board is directly involved in the FERC licensing process, and its water quality certifications typically include minimum instream flow requirements. Before FERC can issue a new license in California, it must provide the State Water Board (or authorized tribes) with the opportunity to issue a water quality certification pursuant to Section 401 of the Clean Water Act. The State Water Board's conditions of water quality certification become conditions of the FERC license.

The FERC licensing process is a data rich source of flow related information, as the licensing and post-licensing processes often produce studies associated with the aquatic environment, including flow and temperature studies. Available aquatic resource and flow data generated from the FERC licensing process will likely be used to inform the development of flow criteria.

National Marine Fisheries Service

The National Marine Fisheries Service (NMFS) often prepares instream flow recommendations pursuant to its Endangered Species Act (ESA) responsibilities. When NMFS ESA responsibilities are triggered as a result of dam or hydropower projects, NMFS often issues flow recommendations or requirements to protect endangered species within affected watersheds. NMFS does not usually conduct its own studies, but rather provides technical assistance to those performing the studies.

Other Groups Involved with Instream Flows

There are many other agencies and NGOs that develop water use plans or collect aquatic resource data. The American River Water Forum, the Lower Yuba River Management Team, Tehama County Resource Conservation District, and Stockton East Water District are examples of groups that have developed or are developing water use and instream flow information. The State Water Board could use flow information developed by these groups to inform the development of flow criteria or flow objectives.

Summary of Timelines for Flow Related Information

Table 1 displays approximate timelines associated with the development of flow related information for tributaries to the Bay-Delta. The table focuses on work to be done by agencies and does not represent all work being done or planned in all tributaries to the Bay-Delta. In addition to the flow related activities presented in Table 1, there is also a significant amount of information related to FERC projects. Table 2 summarizes recent and relevant FERC licensing activities in tributaries to the Bay-Delta.

Table 1. Approximate timelines for instream flow studies and flow criteria development in priority tributaries to the Bay-Delta – This table includes those agencies most involved with establishing flow criteria. This table does not display flow criteria development that is occurring through the FERC process.

Water Body	Agency/ Process	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
American River (Lower)	WF/ NMFS													
Antelope Creek	TCRCD													
Battle Creek														
Bear River														
Big Chico Creek														
Butte Creek (Lower)	USFWS/ CDFW													
Calaveras River (Lower)	SEWD/ NMFS													
Clear Creek (Lower)	NMFS/ USFWS/ CDFG													
Cosumnes River														
Cottonwood Creek	USFWS													
Cow Creek														
Deer Creek	CDFW													
Dry Creek														
Feather River (Lower)														
McClure Creek														
Mill Creek	CDFW													
Mokelumne River (Lower)														
Paynes Creek														
Putah Creek														
Sacramento River (below Keswick)	NMFS													
Stony Creek (Lower)														
Thomes Creek														
Yuba River (Lower)														

Recently Completed Processes	Underway Processes	Expected Near Term Processes

Abbreviations: California Department of Fish and Wildlife (CDFW), United States Fish and Wildlife Service (USFWS), American River Water Forum (WF), Stockton East Water District (SEWD), and Tehama County Resource Conservation District (TCRCD).

Table 2. FERC Projects with Flow Information Relevant to Phase 4

Major Water Body	Project Name (FERC Project Number)	Date of Recent FERC Licenses Issued	FERC Relicensing Projects Underway – License Expiration Date	Upcoming FERC Relicensing Projects – License Expiration Date
American River Middle Fork	Middle Fork American River (2079)		2/28/2013	
American River South Fork	El Dorado (184)	10/18/2006		
	Chili Bar (2155)		7/31/2007	
	Upper American River (2101)		7/31/2007	
Battle Creek	Battle Creek 1121		7/31/2026	
Bear River	Camp Far West (2997)			6/30/2021
Butte Creek/West Fork Feather River	DeSabla-Centerville (803)		10/11/2009	
Cow Creek	Kilarc - Cow Creek (606)		3/27/2007	
Feather River	Oroville (2100)		1/31/2007	
Feather River North Fork	Bucks Creek (619)			12/31/2018
	Poe (2107)		9/30/2003	
	UNF Feather River (2105)		10/31/2004	
Feather River South Fork	South Feather Power (2088)		3/31/2009	
Hat Creek	Hat Creek 1 & 2 (2661)	11/4/2002		
Kern River	Kern Canyon (178)	2/25/2009		
McCloud River	McCloud- Pit (2106)		7/31/2011	
Merced	Merced Falls (2467)		2/28/2014	
	Merced River (2179)		2/28/2014	
Pit River	Pit 1 (2687)	3/19/2003		
	Pit 3, 4, & 5 (233)	7/2/2007		
San Joaquin	Vermillion Valley (2086)		8/31/2003	
	Portal (2174)		3/31/2005	
	Mammoth Pool (2085)		11/30/2007	
	Big Creek Nos. 2A, 8 and Eastwood (67)		2/28/2009	
	Big Creek No. 3 (120)		2/28/2009	
	Big Creek No. 1 & No. 2 (2175)		2/28/2009	
	Big Creek No. 4 (2017)	12/4/2003		
	Kerckhoff (96)			11/30/2022
Stanislaus River	Upper Utica (11563)	9/3/2003		
Stanislaus River Middle Fork	Beardsley/Donnells (2005)	1/30/2006		
Stanislaus River Middle/South Fork	Spring Gap-Stanislaus (2130)	4/24/2009		
Stanislaus River South Fork	Phoenix (1061)			8/31/2022
Tule River	Lower Tule River (372)	9/3/2004		
Tuolumne	Don Pedro (2299)		4/30/2016	
Yuba River	Yuba River (2246)		3/31/2016	
	Narrows (1403)			1/31/2023
Yuba River South Fork	Drum-Spaulding (2310)		4/30/2013	
	Yuba-Bear (2266)		4/30/2013	

3. Methods under Consideration for Development of Regional Flow Criteria

In this document, two regional methods for developing flow criteria are considered. The two methods are:

1) A Regional IFIM Habitat Based Method (Pennsylvania-Maryland Method); and
2) The ELOHA Regional Method.

The paragraphs below provide brief summaries of the IFIM and ELOHA frameworks. The two proposed methods which use these frameworks are discussed in more detail following these brief summaries. The State Water Board anticipates that available site-specific flow criteria will be used in lieu of regional flow criteria, when available.

Instream Flow Incremental Methodology
IFIM is a decision-support framework designed to help natural resource managers and their constituencies determine the benefits or consequences of different water management alternatives by quantifying the relative amounts of total available habitat in a network of stream segments for selected aquatic species under proposed alternative flow regimes (Annear et al. 2004). IFIM is the framework most commonly used for instream flow assessment throughout the United States (Moyle et al. 2011) and in California. IFIM is often thought to be a collection of computer models; however, IFIM should be primarily considered a process for solving water resource allocation problems that include concerns for riverine habitat resources.

IFIM was developed under USFWS leadership by an interdisciplinary team of scientists drawn from federal and state resource agencies and academia (Trihey and Stanaker 1985; and Stalnaker 1993 as cited in Bovee et al. 1998). IFIM is meant to be implemented in the following five sequential phases: 1) problem identification; 2) study planning; 3) study implementation; 4) alternatives analysis; and 5) problem resolution (USGS 2013, http://www.fort.usgs.gov/Products/Software/ifim/5phases.asp). This methodology can address hydrology, biology, sediment transport, and water quality (Stanlnaker et al. 1995; and Bovee et al. 1998).

The IFIM framework is frequently confused with the PHABSIM model. IFIM is a general problem solving framework that typically uses site-specific habitat based tools to make water management decisions. Site-specific habitat based tools are studies and investigations that are used in step 3 of the IFIM process to provide information to support the development of flow criteria. PHABSIM is an example of a tool that is designed to calculate and model the amount of microhabitat available for specific life stages of a species (e.g., juvenile rearing of Central Valley steelhead) at different flow levels (Annear et al. 2004). The IFIM process is capable of incorporating a variety of tools including the examples provided in the IFIM section of this document.

CDFW staff use IFIM to determine instream flows and has recommended it to the State Water Board as a framework to develop flow criteria. If the IFIM framework is selected, it is anticipated that flow criteria would be developed through a coordinated effort between the State Water Board and CDFW.

Ecological Limits of Hydrologic Alteration

ELOHA is a scientifically robust and flexible framework for assessing and managing instream flows across large regions, when lack of time and resources preclude evaluating individual rivers. ELOHA is a regional method, developed by The Nature Conservancy (TNC), which synthesizes existing hydrologic and ecological databases from many rivers within a region to generate flow alteration-ecological response relationships. These relationships correlate measures of ecological condition to streamflow conditions. The ELOHA framework is comprised of a scientific process and a social process interconnected through monitoring and adaptive adjustments (Poff et al. 2010).

The ELOHA scientific process can be broken into the following four main steps:

1) Hydrologic Foundation – development of baseline hydrographs, unimpaired hydrographs, and hydrologic models;
2) River Classification – characterization and grouping of river segments according to their flow regimes and geomorphic features;
3) Hydrologic Alteration – calculation of the degree of change between present and historic flow conditions, based on hydrologic variables of interest; and
4) Flow Alteration Ecological Response Relationships – quantification of biological response to varying degrees of flow alteration for each river segment classification group (Poff et al. 2010).

The ELOHA social process is designed to incorporate stakeholders' values at each stage of the scientific process. The flow-ecology relationships developed through step four of the scientific process directly connect the social process of ELOHA to the scientific process by joining the policy goal of acceptable ecological condition to hydrologic alteration (Konrad 2009). USFWS staff recommends the State Water Board use ELOHA to develop flow criteria. If the ELOHA method is selected, it is anticipated that the State Water Board would coordinate with CDFW to address fish passage issues and to maximize the collection and use of data.

3.A. Method 1: Regional IFIM Habitat Based Method (Pennsylvania-Maryland Method)

Introduction

The Pennsylvania-Maryland Method (PMM) is a regional IFIM that requires less time and resources than a traditional site-specific IFIM (Annear et al. 2004, pp. 153-155). This method was created and used in Pennsylvania and Maryland (Denslinger et al. 1998) as a regional IFIM using habitat based tools. This method begins by grouping stream segments with similar physical characteristics, identifying, important biological resources and fluvial processes in the stream segment groups through an IFIM framework, and then performing site-specific habitat based (site-specific) studies on a few representative stream segments identified within each group. For example, if spawning habitat for steelhead is identified as a resource of concern, a site-specific tool would be used to study the flow needs for steelhead spawning in selected sections of stream segment groups. Multiple tools could be used to develop flow criteria to identify and balance multiple resource needs. The results of the site-specific studies are then applied to the entire stream segment group for which they represent. By grouping similar stream segments together within a watershed, the PMM is able to limit the overall number of site-specific studies required in a hydraulic region.

Background of Pennsylvania-Maryland Method

From 1995 to 1998 the Pennsylvania Department of Environmental Protection, the Susquehanna River Basin Commission, Pennsylvania Fish and Boat Commission (PFBC), United States Army Corps of Engineers (USACOE), Maryland Department of the Environment, and the Biological Resources Division of the USGS cooperatively conducted an instream flow study (Denslinger et al. 1998). The incentive for the study was an attempt to resolve discrepancies in the way instream flow protection was being addressed. The study addressed streams with reproducing trout populations and drainage areas less than 100 square miles. The specific goal of the study was to develop a procedure for determining instream flow protection levels that: 1) were based on fishery resource protection; 2) were clearly applicable to Pennsylvania streams; 3) do not require expensive site-specific studies; and 4) could be easily applied during the administrative review of applications for surface water allocations. To develop the PMM, a total of 109 stream segments distributed among 83 streams in four designated regions were evaluated using PHABSIM. The primary users of PMM (PFBC, Pennsylvania Department of Environmental Protection, and the Susquehanna River Basin Commission) found that microhabitat is readily accepted as an appropriate decision variable in many instances (Leroy Young, PFBC, personal communication as cited in Annear et al. 2004).

The final product developed for the PMM was a computer program that estimates the effects of withdrawals and bypass flows on physical microhabitat for trout streams with drainage areas less than 100 square miles in Pennsylvania and Maryland. This has allowed water users and managers to quickly evaluate the effects of alternative water management scenarios on physical habitat available to trout. The computer program which models flow versus habitat in the project areas can be found at the Pennsylvania Department of Environmental Protection's website at: http://www.portal.state.pa.us/portal/server.pt/community/instream_flow/10633. Water use scenarios can be analyzed by either running the computer model or by examining figures that are available in the study report, which were generated from numerous iterations of running the model for representative stream gages throughout Pennsylvania and Maryland.

More recently (2010), the Susquehanna River Basin Commission and the USACOE commissioned TNC to develop flow recommendations for other parts of the Susquehanna River Basin in Pennsylvania and Maryland that were not included in the PMM study. For these flow recommendations TNC used an ELOHA framework.

PMM Timeline

The PMM took approximately three years to develop including field data collection and model development. This was a joint effort between multiple agencies and cost approximately $1 million, not including in-kind services (personal communication March 2013, Mark Hartle, Aquatic Resources Section Chief, PFBC).

Examples of Habitat Based Tools Used in an IFIM Framework

Although the PMM is a regional method, it requires the use of site-specific tools. In a summary of instream flow decision making, Annear et al. (2004, pp.129) states: "there is no universally accepted method or combination of methods that is appropriate for establishing instream flow regimes on all rivers or streams. Rather, the combination or adaptation of methods should be determined on a case-by-case basis; that is, choosing the method that is best suited to the particular water body and potential modification under consideration." The IFIM framework follows this process by identifying problems and underlying circumstances for each individual watershed or region, and selecting the tools most appropriate to solve the problems. It is expected that salmonids, amphibians, macro-invertebrates, bedload transport, floodplain processes, and wetland/riparian communities will be re-occurring concerns in each of the priority tributaries. The consistent use of site-specific tools to address similar resource concerns and questions would improve data comparability and efficiency as the State of California moves forward in managing its water resources. The tools discussed below are examples of tools that are likely to be used in a regional IFIM method. However, additional or alternative tools could be used. Using a decision support system like IFIM and involving multidisciplinary expertise would increase the likelihood of success of a regional habitat based method.

Example: Habitat Based Hydraulic Models

PHABSIM and RHABSIM (Bovee 1997; Bovee et al. 1998; and Milhous et al. 1984) are common habitat based hydraulic models used to address aquatic resource needs throughout the United States. In this section, habitat based hydraulic models specifically refer to PHABSIM and RHABSIM. These models are commonly used by CDFW, USGS, USFWS, and in the FERC process.

Habitat based hydraulic models are designed to calculate the amount of microhabitat available for a selected species, at a defined life stage, as a result of different discharges. Habitat based hydraulic models have two analytical components: 1) stream hydraulics; and 2) life stage-specific habitat suitability requirements. The model output is the functional relationship between the amount of habitat and discharge for a specified stream reach; the output is typically presented as a graph of weighted usable area (i.e., microhabitat) versus discharge (Annear et al. 2004).

Habitat based hydraulic models use data collected at calibration flows to compute water depth and velocity profiles across a range of discharges. These computed velocity profiles can be combined with collected habitat data such as substrate size and cover. This creates a composite habitat description of depth, velocity, substrate, and sometimes distance to cover (with respect to juvenile rearing). Water surface elevations are also collected and are used to calibrate the hydraulic models. The hydraulic models are used to calculate water surface elevations and simulate velocities at specified flows. The habitat suitability component is developed using direct observations (i.e., snorkeling), or by expert opinion (Annear et al. 2004).

The most valuable use of a habitat based hydraulic model is to identify and quantify areas within the wetted stream environment that are suitable for specific life stages of aquatic species under various discharges. When coupled with hydrologic time series, the timing, amount, and duration of suitable areas can help identify potential habitat bottlenecks induced by natural or managed flow events, or the relative strengths of one prescribed flow regime versus another. Habitat based hydraulic models generally require intensive fieldwork (i.e., multiple site-specific measurements within river reaches and mesohabitats) and calibration/verification of both hydraulic and suitability sub-models. This is a relatively time and resource intensive method that produces some of the most accepted instream flow determinations (Annear et al. 2004). Habitat based hydraulic studies generally take between three and four years to collect data, model results, and finalize peer-reviewed flow recommendations for targeted stream reaches, biological species, and life stages.

The use of habitat based hydraulic models relies on the assumption that there is a relationship between physical aquatic habitat and population abundance/biomass (Annear et al. 2004). Critics of habitat based hydraulic models suggest that there may not be a relationship between habitat and abundance/biomass, or that habitat is not the most important factor to abundance/biomass (Moyle et al. 2011).

Strengths of Habitat Based Hydraulic Models

- Widely used and accepted throughout the United States
- Usually site, species, and life stage specific
- Quantify suitable habitat at different flows
- Self-contained and do not require large amounts of background data to develop relationships between flow and other variables (i.e., ecology, economics)
- Quantify physical habitat, which is directly measureable compared to methods that quantify/score the integrity of biological communities to build ecological response relationships

Limitations and Constraints of Habitat Based Hydraulic Models

- Habitat preference of fish may change with environmental conditions (Gowan et al. 1994), and this is not always accounted for in the development of habitat suitability criteria
- Users assume that increasing suitable habitat will benefit target populations
- Site, species, and life stage specific, which limits application outside of the study area and to species not included in the study

Example: Critical Riffle Assessment

In February 2013, CDFW released a standard operating procedure (SOP) for critical riffle analysis (CRA) for use by CDFW and others in California (CDFG 2013). The CRA methodology is used to identify the minimum stream flow rates (also known as passage flows) necessary for the passage of salmon and trout through critical riffles, producing a habitat connectivity versus flow relationship. Critical riffles are shallow riffles which are particularly sensitive to changes in stream flow due to diminished water depth. Changes in stream flow and associated water depth may limit the hydrologic connectivity of river habitats and impede critical life history tactics of salmonids. In such cases, the critical riffle may become a potential barrier to upstream and downstream passage for salmon and trout, which in turn may prevent adults from moving to and from spawning areas, prevent smolts from migrating downstream towards the ocean, as well as prevent rearing juvenile salmonids from being able to move between adequate freshwater rearing habitats. The CRA methodology applies only to wadeable streams having low gradient riffles with less than four percent (4%) gradient and substrates dominated by gravel and cobble (CDFG 2013).

Adequate salmonid passage flows are determined by locating critical riffles, identifying a single transect along the riffle's shallowest course from bank to bank, and measuring water depth at multiple locations across the transect. Measured field data are then compared to specific species and lifestage water depth criteria to determine if measured depths meet the criteria for percent total and percent contiguous proportion of the critical riffle width available, for fish passage. Water depth measurements are taken along a single critical riffle transect, over a range of at least three to six significantly different discharges. Measurements of stream discharge and water depth can then be plotted to determine the necessary flow rates for passable depths. Adequate water depths of sufficient width are necessary to identify passage flows and promote passage of adult and juvenile salmonids at critical riffle sites. Both criteria (percent total and the percent contiguous) must be met for the minimum depth requirements of the targeted species and lifestage. The higher flow rate among the two criteria is used to identify the passage flow requirement at the critical riffle site (CDFG 2013).

Strengths of Critical Riffle Assessment

- Identifies the minimum stream flow necessary for fish passage through critical riffles

Limitations and Constraints of Critical Riffle Assessment

- Applies only to fish passage in wadeable streams having low gradient riffles with less than four percent (4%) gradient and substrates dominated by gravel and cobble

Example: Wetted Perimeter

The wetted perimeter method (Stalnaker et al. 1995; and Annear et al. 2004) can be used to identify flows needed to protect and promote productive invertebrate populations in stream riffle habitats. It uses a graphical representation of the wetted stream width (wetted perimeter) versus discharge as a surrogate for physical habitat. The wetted perimeter is determined by locating riffles and measuring the distance along the bottom and sides of a channel cross-section from one wetted edge to the other wetted edge. The method is used to relate wetted perimeter measurements to corresponding flow measurements in order to evaluate tradeoffs between flow and wetted stream habitat. After the wetted perimeters are measured at various flows, the wetted perimeter and flow data are plotted against each other to identify upper and lower break or “inflection” points (CDFG 2012).

Strengths of Wetted Perimeter Method

- Provides a quick relationship between wetted habitat and discharge

Limitations and Constraints of Critical Riffle Assessment

- Does not actually measure suitable riffle habitat, but instead relies on wetted perimeter measurements to approximate suitable riffle habitat
- Addresses only low flows and does not address intra- or inter-annual variability
- Does not address channel geomorphology, water quality, or connectivity and should be restricted to streams with well-defined riffle and pool sequences (Annear et al., 2004)

Example: Stream Network Temperature Model

The Stream Network Temperature Model (SNTEMP and SSTEMP models) predict the daily mean and maximum water temperature as a function of discharge, stream distance, and environmental heat flux. These models include: 1) a solar model to predict the solar radiation penetrating the water as a function of latitude and time of year; 2) a shade model that quantifies riparian and topographic shading; 3) algorithms that correct air temperature, relative humidity, and atmospheric pressure for changes in elevation within the watershed; and 4) regression algorithms that smooth and/or fill missing observed water temperature measurements.

SSTEMP is a simplified version of SNTEMP. Annear et al. (2004) suggested that SSTEMP is so easy to use that it should be used routinely to check recommended flow regimes for unanticipated water temperature problems. When water temperature issues are evident, SNTEMP or other water temperature models are appropriate for temperature-based flow prescriptions.

Strengths of SNTEMP/SSTEMP

- SSTEMP is a reconnaissance level model and SNTEMP is appropriate for prescribing flows

Limitations and Constraints of SNTEMP/SSTEMP

- Neither model predicts maximum temperatures very well without calibration
- Long-term weather records are usually not representative of the study area

Example: Bedload Assessment in Gravel-bedded Streams Software
Bedload Assessment in Gravel-bedded Streams (BAGS) software was written to facilitate computation of sediment transport rates in gravel-bed rivers (Wilcock et al. 2009). BAGS is a spreadsheet-based program that predicts bedload transport using six well-known bedload transport equations developed specifically for gravel-bed rivers. Sediment transport estimates are calculated on the basis of field measurements of channel geometry, reach-average slope, and bed material grain size. Field data and other relevant input parameters are entered into the program sequentially through a series of prompts to the user. Calculations are carried out using Visual Basic for Applications and the output is stored on individual spreadsheets (http://www.stream.fs.fed.us/publications/bags.html). BAGS software provides a choice of different formulas and supports a range of different input information. It offers the option of using measured transport rates to calibrate a transport estimate. BAGS can calculate a transport rate for a single discharge or for a range of discharges (Wilcock et al. 2009). Modeling sediment transport helps identify flows that trigger important fluvial processes, such as flushing flows and channel maintenance flows. Use of sediment transport software like BAGS is something that could be accomplished alongside other hydraulic models with relatively little additional field work.

Strengths of BAGS Software

- Takes very little additional data beyond that required by a habitat based hydraulic model

Limitations and Constraints of BAGS Software

- Sediment transport models can produce highly variable results among different models (Annear et al. 2004; and Wilcock et al. 2009)
- Site-specific validation is needed before flow determinations and recommendations are adopted based on bed-load modeling (Annear et al. 2004; and Wilcock et al. 2009)

Summary and Discussion of the PMM to Develop Flow Criteria
The PMM would identify similar stream segments in a watershed or region and group them into stream classes based on geomorphic and flow characteristics. A more detailed description of the stream classification process is discussed later in this document in the stream classification section of ELOHA. After stream segment groups are established, a scientifically defensible study plan would be developed to sample a representative number of segments within each group. Habitat based tools (e.g., PHABSIM, wetted perimeter, etc.) would be used to develop models that create habitat versus discharge relationships for each stream classification group. The habitat based information produced by other agencies and groups would also be incorporated into the study design, as applicable. Once habitat versus discharge relationships are developed for each stream classification group, the models could be used to evaluate the impacts of water management decisions on physical habitat for all stream segments within each group.

The State Water Board recognizes that new information pertaining to flow criteria in Bay-Delta tributaries will be developed. An adaptive management program would be designed to incorporate the ongoing scientifically defensible site-specific studies that are subsequently completed by other entities, so they may potentially be used to refine the flow objectives developed through the PMM.

Strengths, Limitations, Assumptions and Uncertainties of the PMM
IFIM is the framework most commonly used for instream flow assessment throughout the United States (Moyle et al. 2011) and in California, and has been widely accepted for decades. As discussed in this document, there are many site-specific IFIM studies being conducted in Bay-Delta tributary watersheds by various groups. The information is generally being produced for anadromous habitats and in FERC project areas. The State Water Board could develop new information and incorporate the site-specific information developed by other agencies and groups into a Pennsylvania-Maryland type method. If PMM is chosen, it is anticipated that the State Water Board and CDFW would work closely and coordinate efforts to develop regional flow criteria.

The main limitations of PMM are that it is less accurate than non-regionalized site-specific methods, and like other habitat based methods, it relies on the assumption that optimizing habitat will benefit fish and wildlife.

3.B. Method 2: Ecological Limits of Hydrologic Alteration Regional Method

Introduction
ELOHA is a regional method that has been successfully applied to multiple river basins in several states (e.g., Michigan's Water Withdrawal Assessment Process, Connecticut River Basin Ecosystem Flow Restoration, and Middle Potomac River Basin Environmentally Sustainable Flows). ELOHA is a flexible framework which can broadly assess environmental flow requirements when site-specific assessments cannot be performed on all streams within a hydrologic region. ELOHA builds upon the assumption that an independent variable, such as flow, can exert a significant effect on a biological community or habitat condition and that the relationship can be described through the development of statistical models. Once the statistical relationship between an independent variable (such as flow) and a biological response is identified, the independent variable can be tested within the model and used to predict a biological response to flow alteration within the hydraulic region for which the relationship was identified (Annear et al. 2004).

ELOHA was developed to be conducted in a stepwise fashion, which includes feedback loops and iterations. The main steps of the ELOHA process include: 1) building a hydrologic foundation (Hydrologic Foundation); 2) characterizing river types according to their flow regimes and geomorphic features (River Classification); 3) computing present-day degrees of flow alterations (Hydrologic Alteration); 4) defining flow alteration-ecological response relationships (Flow Alteration Ecological Response Relationships); and 5) using flow alteration-ecological response relationships to manage environmental flows through an informed social process (Flow Management) (Kendy et al. 2010). The following overview describes each step's general process, and highlights the expected result from each stage of analysis.

1. Hydrologic Foundation
The hydrologic foundation is a geographically-indexed database of daily or monthly streamflow hydrographs representing both baseline (pre-development) and current conditions over a common time period. This data are used to assess flow characteristics, classify stream types, quantify flow alteration, and relate ecological responses to flow alteration. Flow data must contain enough spatial detail to resolve reaches with different streamflow characteristics as well as include small streams which can provide significant habitat to aquatic organisms. To provide

an adequate foundation for ELOHA, hydrologic information needs to: be spatially comprehensive and capture regional scale hydrologic variability; represent baseline (historic), current, and future streamflow conditions; characterize a range of ecologically relevant flow characteristics; address groundwater and estuarine flows, if applicable; and be able to simulate new and improved water use and reservoir operations *(*Kendy, Apse, and Blann 2012; and TNC 2012).

A variety of methods have been used to develop hydrologic information for hydroecological analysis (see Konrad 2009). Hydrologic modeling is one method which can be used to obtain all of the required components of ELOHA's hydrologic foundation through the extension of available streamflow records or synthesis of data for ungauged stream segments. Hydrologic simulation is used to estimate flow conditions through either regression modeling or process modeling. Regression modeling has historically been the faster and simpler method; however, process modeling enables evaluation of land use and climate change scenarios (TNC 2012).

2. Stream Classification

ELOHA extends the use of limited ecological data by assuming that ecosystems with comparable streamflow and geomorphic characteristics respond similarly to flow alteration. River and stream segments within a large watershed are identified and grouped into stream classes based on geomorphic and flow characteristics. Stream classification within the region primarily focuses on the hydrologic regime, as it is assumed that hydrology is the main ecological driver in the watershed (Poff et al. 2010). Poff (1996) recommends classifying streams within a region using flow statistics, which are computed from the baseline hydrographs developed in the Hydrologic Foundation.

Three criteria should be considered when selecting flow statistics for developing stream classifications (Poff et al. 2010):

a. Flow data should collectively describe the full range of natural hydrologic variability, including the magnitude, frequency, duration, timing, and rate of change for flow events;
b. Data needs to be "ecologically relevant," or known to have some measureable ecological influence. This is important when assessing ecological responses to hydrologic alteration; and
c. Data should be amendable to management, so that the water managers can develop environmental flow standards using these same hydrologic metrics and evaluate the effects of other water uses in the catchment on these metrics.

Once general stream groupings have been identified based on varying hydrologic regime, they can be further delineated by individual geomorphic features (e.g., geology, channel confinement, channel slope). This allows for larger stream classification groups to be divided into small, geomorphically similar groups (Seelbach et al. 1997; and Higgins et al. 2005). The stream classification sub-groups may be further differentiated based on varying physical characteristics (e.g., constrained channels compared to alluvial channels, or channels with sand beds compared to cobble-bedded reaches). It is necessary to create these smaller stream classification sub-groups within the larger stream classification categories because a volume of streamflow in one geomorphic setting may differ from that in another geomorphic setting and consequently where a flow may translate into an important ecological event in one stream channel, it may not in another (Poff et al. 2006). Grouping stream segments into stream classes allows the flow alteration-ecological response relationships to be applied to all streams in a stream class, even if individual segments lack ecological data. Flow alteration-ecological response relationships better reflect the direct and indirect influences of hydrologic alteration on both ecological responses and ecosystem structure and function, with greater hydraulic and geomorphic input (Poff et al. 2010).

3. Hydrologic Alteration

ELOHA is based on the premise that increasing degrees of flow alteration from baseline conditions (i.e., the level of change that has occurred in a stream channel and flow regime over time due to human induced impacts), results in increasing levels of ecological change (Poff et al. 2010). To assess the degree of flow alteration, baseline (historic) hydrology is compared with current hydrology. This standardizes hydrologic impacts and allows for the creation of a degree of alteration data set. Previous study regions have achieved this through the use of rainfall-runoff models which use climate and landscape data and account for human alterations (e.g., Water Evaluation and Planning [WEAP] System), or through the coupling of runoff modes created for pervious and impervious areas with estimates of annual water extraction, discharges and reservoir storage (e.g., Kennen et al. 2008; and Poff et al. 2010). The hydrologic alteration for each river segment is typically expressed as the percent deviation of current flows from baseline flows. Hydrologic alteration is computed by analyzing flow statistics that are strongly linked to ecological conditions. The data set describing the degree of alteration can be used in conjunction with ecological data from multiple rivers in the same stream class. This enables data from individual rivers to be combined and used to help develop flow alteration-ecological response relationships for multiple rivers within a single classification group. In addition, development of the degree of alteration data set helps stakeholders to understand the extent to which a stream has already been altered within a region (Kendy et al. 2010).

4. Flow Alteration-Ecological Response Relationships

A key element of the ELOHA framework is the characterization of the relationships between altered flow and ecology. The relationship between flow alteration and ecological response are grounded in the biological condition gradient, which recognizes that increasing degrees of anthropogenic stress lead to decreasing ecological conditions (Davies and Jackson 2006). ELOHA relies on the development of flow ecology-relationships and the testing of these relationships with collected and observed data (Arthington et al. 2006). In places with limited data, scientists can use expert judgment, statistical analysis, and modeling to continue the ELOHA process.

The majority of available aquatic ecology literature is comprised of comparative and experimental studies that relate ecological processes to existing hydrologic conditions (e.g., PHABSIM). The ELOHA framework aims to not only qualitatively assess these relationships, but to directly link changes within an ecological community to changes in the flow regime. However, empirical models that directly predict the relationship between flow alteration and ecological response are not readily available. Therefore, ELOHA requires a series of testable hypotheses to be developed based on expert knowledge and existing published studies, to describe these flow alteration ecological response relationships. Flow-ecology relationships are hypothesized to vary among the major stream classes. It is anticipated that varying ecological responses will occur to the same type of flow alteration, as a result of varying baseline (pre-development) flow regimes and geomorphic conditions (Poff et al. 2010).

Defining relationships that link flow alteration to ecological response provides valuable information for the development of regional flow criteria. ELOHA recommends using process-based ecological response variables as well as some composite ecological indices, as they correlate with human induced changes in stream flow, for development of accurate relationships. Ecological data used to develop flow-ecology relationships for example, can consist of aquatic invertebrate species richness, riparian vegetation recruitment, or larval fish abundance. These examples are both sensitive to existing or proposed flow alteration, and can be validated with monitoring data (Poff et al. 2010). Where biological data and scientific resources are scarce, habitat assessments are able to provide a critical scientific basis for environmental flow recommendations (Poff and Zimmerman 2010; and Poff et al. 2010).

Many approaches exist for describing and measuring ecological responses to flow alteration. Based on current hydroecological understanding, it is expected that flow alteration-ecological response relationships will vary depending on the selected variable(s), the specific flow data, and the degree of alteration for a given river classification group. ELOHA suggests that when selecting an appropriate suite of ecological indicators, consideration be given to the different timeframes for which ecological responses occur relative to particular kinds of flow alterations. ELOHA emphasizes the use of ecological response variables which meet the following criteria:

a. Variables should be sensitive to existing or proposed flow alterations;
b. Variables should be amenable to validation with monitoring data; and
c. Variables should be valued by society.

5. Flow Management

In the ELOHA framework, environmental flow standards are determined by combining the scientific understanding of flow-ecology relationships with a defined goal of environmental health, and a socially acceptable level of risk of ecosystem degradation (Poff et al. 2010). After scientific analysis has developed the flow-ecology relationships, the results are expressed as flow ecology response curves. These relationships allow water managers to evaluate what level of ecological degradation is allowable in a given stream class (Kendy et al. 2012).

ELOHA Regional Method Timeline

The ELOHA framework enhances the sustainable management of rivers, considering both social and ecological benefits, in a timely manner and across a large spatial scale. At this time, the State Water Board is unable to develop a specific timeline for the development of ELOHA-based flow criteria due to a variety of uncertainties. In practice, ELOHA has taken many forms to account for the unique needs and constraints of different watersheds. The amount of time required to complete the ELOHA framework varies and is dependent on a variety of factors: the project budget; the amount of readily-available flow data; the method used to develop the hydrologic foundation (e.g., observed information or modeled); the chosen level of detail for determining stream classifications; and whether adequate ecological data exists to develop meaningful flow ecology relationships. A lack of available data may prompt the need to develop and validate models, which would extend the ELOHA timeline. The general time requirements for developing ELOHA-based flow criteria for case-studies (Middle Potomac River basin, Massachusetts, and Connecticut River basin) are based on the individual methods of ELOHA application. Each case-study is discussed briefly below:

1) The Middle Potomac River basin project began in May 2009 and is currently in final review. The Middle Potomac River basin project evaluates environmental flow requirements for rivers that are considered to be more impaired by land use change than by withdrawals or impoundments. The project relies on the engagement of water resource agencies and stakeholders and is using a structured iterative method for selecting flow-ecology metrics to strengthen flow-ecology relationships. The total project was estimated to take three years with $1 million designated for ELOHA (Kendy et al. 2012).

The Middle Potomac River basin project budget includes the refinement of a pre-existing hydrologic model and the timeline does not include a formal social process of developing flow recommendations as described by the ELOHA framework; both of which decrease the projects overall cost and time requirements.

2) The Massachusetts Sustainable Water Management Initiative (SWMI) began using an ELOHA framework in 2009. SWMI's ELOHA method focuses on a duration curve regression method to build a hydrologic foundation, bioperiods as temporal basis for setting flow criteria, quantitative flow-ecology response curves, and a management framework that assesses implementation actions with differing ecological condition goals. The Executive Office of Energy and Environmental Affairs released the SWMI Framework in November 2012 (Kendy et al. 2012; and Mass. Energy and Environmental Affairs 2013).

3) The Connecticut River Basin Program adopted principles from ELOHA without systematically following the framework. The objective of the ecosystem flow restoration component of the Connecticut River Basin Program was to restore important river processes thereby improving habitats and aquatic organism populations along the river and its tributaries by modifying management of dams and water supply systems (Kendy et al. 2012). The Connecticut River Basin Program ecosystem flow component had a study budget of $3 million with TNC raising an additional $1.5 million through private donation. The ELOHA process was initiated in 2008 with a workshop as well as site visits spanning into 2011. Workshops were used as an integral part of flow target development and they continue through the implementation process. At least one experimental flow release from an USACOE dam is anticipated in 2013. Monitoring at this site will document ecological conditions before and after flow implementation supporting flow-ecology relationships (Kendy et al. 2012).

Although the actual time required to complete the ELOHA process depends largely on the amount of data available and level of detail required for meeting project goals and objectives, the example ELOHA projects of the Middle Potomac River basin, Massachusetts SWMI, and Connecticut River basin indicate a time frame of between three and four years for completion of the hydrologic foundation and development of flow-ecology relationships.

Summary and Discussion of the ELOHA Method to Develop Flow Criteria

The State Water Board would apply the ELOHA framework to the entire Bay-Delta watershed, if possible. The hydrologic foundation would be developed by amassing all available daily or monthly flow data from current gauges, and all available historic (pre-development) data. Once all available flow data are collected and quality assured, hydrographs of pre- and post-stream alteration would be generated. It is assumed that an adequate amount of both current and historic flow data will be available from tributaries of the Bay-Delta watershed to create a robust depiction of the varied flow characteristics within the region. In areas where insufficient flow data exists, it is anticipated that the State Water Board will develop a model to extend the period of record, to fill any data gaps, and to synthesize data for ungauged regions. Biological data would also be compiled and ideally paired to corresponding hydrologic data. The paired biological and flow data would be used to develop flow alteration-ecological response relationships.

Classification of all stream segments within the Bay-Delta watershed would be completed concurrent with creating the hydrologic foundation. Data pertaining to geomorphology, habitat, and biology would be collected and incorporated during the stream classification process. To establish smaller groups of river segments with similar comparable attributes, each tributary within the Bay-Delta watershed would be broken into segments based on important hydrologic variables such as: geology type; hydrograph fluctuation; water origin (i.e., snowpack, groundwater, or surface runoff); reach gradient; and thermal regime. Both current and historical hydrographs would be created as part of the hydrologic foundation, and could be used to help determine stream segment classifications.

Measures of hydrologic alteration, such as extreme low flow duration and magnitude, high flow pulse frequency, and flood frequency, would be determined based on specific characteristics of each stream class. Each segment's current hydrology would then be compared to its baseline (pre-development) hydrology to get a degree of alteration. By standardizing hydrologic impacts and creating a degree-of-alteration data set, data from the individual river segments can be combined within each of the stream classification groups. These relationships can then be used to correlate measures of ecological condition to streamflow attributes, as well as for generation of flow alteration-ecological response relationships for each of the different stream classes.

Within the Bay-Delta watershed, it is anticipated that there will be varying degrees of flow alteration. In order to evaluate the level of alteration and corresponding ecological response, hypotheses of flow-ecology relationships must first be developed. By testing hypothesis, staff can ensure that flow-ecology relationships identified are mechanistic and not simply empirical. Testing hypotheses also ensures that data compilation is systematic and therefore not biased. Ecological data would then be collected from each stream class to quantify any relationships identified. It is assumed that in some stream classification groups, ample ecological data will be available; however, modeling techniques and statistical analyses will likely need to be employed where data are limited. Where biota may be responding to factors other than hydrology, quantile regression would be used to identify the level of stream flow which acts as a limiting factor to that ecological indicator.

Flow-ecology relationships link social processes to the scientific process of ELOHA by relating ecological condition to hydrologic alteration; where the acceptable or desirable ecological condition for a stream classification group is the policy goal and the amount of hydrologic alteration is the management tool for achieving the goal (TNC 2012). Review of all flow-alteration response curves will help to determine what proportion of historical flow alteration is acceptable for maintaining an optimal ecological condition for each indicator species. Once the flow management process of determining the optimal level of flow for maintenance of ecological conditions has been completed, the optimal level of flow will represent the flow criteria for each stream classification group. It is anticipated that once flow criteria have been established through the ELOHA framework that any site-specific studies completed on selected representative stream segments may be used to calibrate the flow-ecology curves and ensure flows established through ELOHA achieve the desired instream flow targets. A site-specific passage study will be performed in tributaries where fish passage is a concern to ensure that the flow criteria developed through ELOHA will meet minimal fish passage requirements. Currently, CDFW, USFWS, and TCRCD are working on developing fish passage criteria in the valley floor reaches of Butte, Mill, Deer, and Antelope Creeks. The State Water Board will coordinate with these groups and others to ensure that fish passage is addressed in the development of the flow criteria.

The outcome of ELOHA is intended to be a decision support system that helps water managers minimize ecological impacts caused by new and continued water demands. The State Water Board anticipates that flow recommendations developed through scientifically defensible site-specific methods will be brought to the State Water Board during the development of ELOHA. These recommendations would be incorporated into the overall analysis to validate ELOHA derived flows, and would be used as the flow criteria for the stream reach they represent. State Water Board staff also recognizes that other entities may conduct new scientifically defensible, site-specific studies in the future that will produce flow recommendations that may be more representative of the study area than the ELOHA generated flow objectives. An adaptive management program would be designed to incorporate these studies and allow for refinement of the flow objectives developed through the ELOHA process, if necessary.

Strengths, Limitations, Assumptions and Uncertainties of ELOHA Regional Method
The ELOHA hydrologic foundation is based on hydrologic simulation completed by either regression modeling or process modeling of monthly streamflow data, which both introduce numerous assumptions and uncertainties into the analysis. The gauged data used to develop the monthly stream flows will be checked to ensure that it is adequate and representative of the flows throughout the project area. Additionally, it is assumed that the State Water Board's water right data can be refined to accurately represent the amount of water diverted and augmented within a watershed, to provide an accurate depiction of the watershed's water-balance. The representation of groundwater influences is also dependent on the type of hydraulic model used to generate the hydrologic foundation. The method used to account for surface water-groundwater interactions may introduce uncertainties into the analysis. If using a water balance method, groundwater may be accounted for under the assumption of direct and immediate impacts caused to water supply as a result of groundwater pumping. Alternatively, a groundwater-surface water interaction model may calculate the time, place, and amount of depletion.

The ELOHA framework is based on the assumption that although every stream is unique, many streams exhibit similar ecological responses to flow alteration. Moreover, the framework assumes that within every stream class, or group of ecologically similar rivers, there exist individual streams under various degrees of hydrologic, and resulting ecological, alteration. The ELOHA framework assumes that the relationships observed by assessing flow alteration impacts to ecological condition in a stream sample are representative of all other streams within the same stream classification group.

The quality and quantity of ecological data available may be a limiting factor in determining strong, defensible correlations between flow and ecological condition. Requirements for comparable data would likely include: multiple sample points collected during the same season and across multiple water year types (such as spring samples from dry and wet years); consistent deployment of the sampling technique (i.e., macroinvertebrate data only collected through kick-samples or fish community samples only collected by electrofishing survey, etc.); and samples representative of varying habitat and conditions.

The main strength of ELOHA is that flow criteria are linked to the entire condition or health of an aquatic system and therefore are not limited to a specific species or site. This potentially creates flow criteria inclusive of multiple species at varying life-stages as opposed to flow criteria developed for one particular species or life stage (e.g., spring-run Chinook salmon spawning). Flow criteria are also developed for entire watersheds, not specific sites. This ensures that adequate flows occur throughout an entire tributary watershed with optimal flows at specific stream reaches defined through the analysis of stream classification groups. The use and analysis of stream classification groups by the ELOHA framework also means that once flow-ecology relationships have been established for a stream class, flow criteria can be developed for that same class. This allows for multiple rivers within the Bay-Delta watershed to have flow criteria established simultaneously.

The strength of the relationship between flow alteration and ecological condition is likely to be subject to various interpretations. If water reallocation could result from flow objectives, there must be a strong correlation between flow and the ecological indicator to make a defensible case. It is therefore assumed that the strength of these relationships will support management and policy actions. Ultimately, it is anticipated that the ELOHA framework would be used to set initial flow objectives for the Bay-Delta watershed, within the required timeline, and which could be updated through an adaptive management process as more information is developed.

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