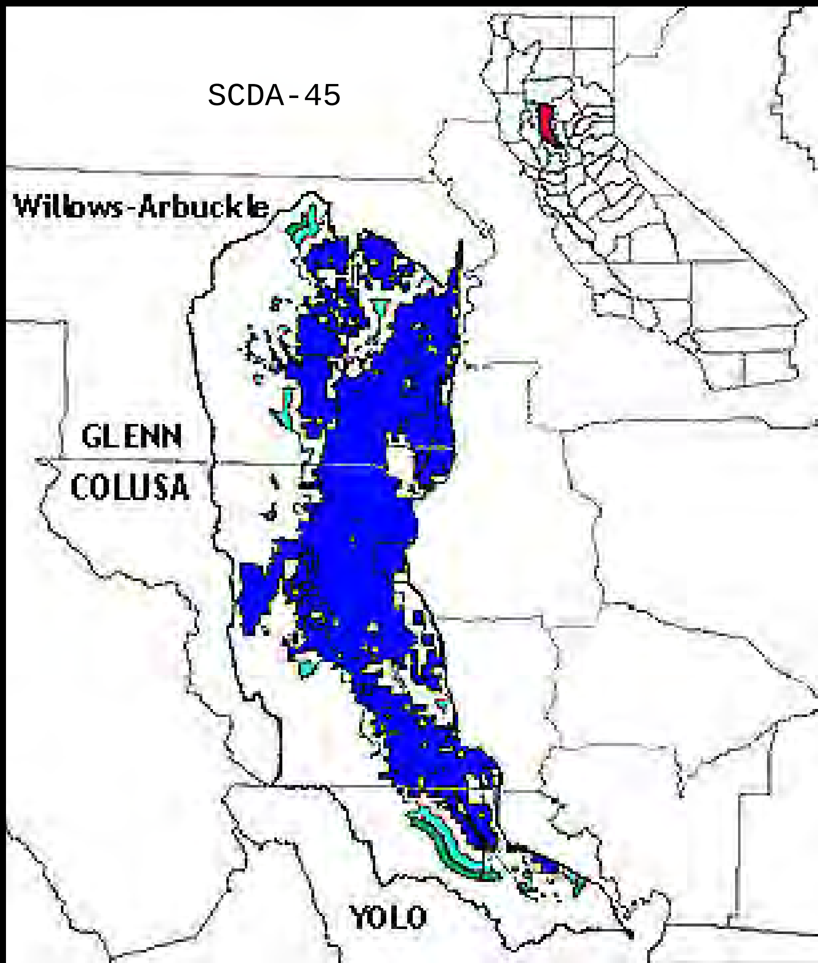
SYSTEM-WIDE CONJUNCTIVE WATER MANAGEMENT

ESTIMATING THE POTENTIAL FOR IN LIEU CONJUNCTIVE WATER MANAGEMENT IN THE CENTRAL VALLEY OF CALIFORNIA



THE NATURAL HERITAGE INSTITUTE

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This report and others from this project are available on-line from NHI's website at www.n-h-i.org or contact the Natural Heritage Institute at the address below.

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The Natural Heritage Institute is a non-profit natural resource conservation organization composed of technical and legal specialists and dedicated to the improvement of the laws and institutions that manage our natural heritage both domestically and internationally.

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1.0 Introduction

Over the course of the past several years conjunctive use has emerged as a key element of California water management strategy. This fact is most prominently embodied in the call for 500,000 to 1,000,000 acre-feet of additional groundwater storage made in the CALFED Record of Decision (RoD). In response to this call efforts are underway across the state to design and develop conjunctive use programs—efforts that are being supported financially by CALFED and by a number of other State and Federal agencies. In keeping with the current agency philosophy that groundwater management initiatives should grow out of local initiatives, the vast majority of these efforts focus on projects with a well-defined local geographic scope.

While these projects, when viewed as a whole, will surely produce important water management flexibility in the future, they represent a change in focus from historical surface water development efforts in California that often adopted a more statewide geographic perspective. The impact of this history is now manifest in the far-flung distribution of reservoirs, canals and water users that characterize the California water system. While this system has dramatically altered the natural hydrology of the Sacramento and San Joaquin Basins, it also offers remarkable opportunities for management integration and innovation, including the possibility of regional and system-wide conjunctive water management initiatives that may offer benefits that would be missed by adopting a purely local conjunctive use planning perspective.

In recent years, the Natural Heritage Institute (NHI) has been exploring the role that system-wide conjunctive use and groundwater banking focused on the reservoirs and aquifers in the Central Valley can play in balancing the water needs of California's agricultural, urban and environmental interests. The starting point of each element of this analysis is that the interests of groundwater users overlying individual groundwater basins in the Central Valley must be protected, or even enhanced, when evaluating any system-wide conjunctive use initiative. If system-wide integration of a groundwater basin causes harm to the historic users of the resource, no amount of cajoling can compel the basin's managers to pursue this option. The rules governing the use of groundwater in California simply do not accommodate this possibility. However, determining whether system-wide integration of a groundwater basin can generate a broad spectrum of benefits that accrue both locally and across the state requires analysis. The System-Wide Conjunctive Management Series published by NHI, which has been supported by the U.S. Bureau of Reclamation and a consortium of other public water management agencies, attempts to respond to this need.

Previous reports that have been published in the Series include:

- *A Feasibility Study of Maximal Scale Program of Groundwater Banking in California* (NHI 1999), which dealt with the technical feasibility increasing the yield of the California water system through the re-operation of the State's major surface water reservoirs as part of a system-wide groundwater banking program, and included three case studies.

- *Designing Successful Groundwater Banking Programs in the Central Valley* (NHI 2001a), which described in detail the legal and institutional opportunities and constraints suggested by the successes and failures encountered during earlier attempts to implement ambitious groundwater management projects.
- *The Hydrogeologic Suitability of Potential Groundwater Banking Sites in the Central Valley of California* (NHI 2001b), which proposed an index to rank the hydrogeologic suitability of various groundwater basins in the Central Valley as targets for direct recharge groundwater banking based on geologic, groundwater quality, soils and hydrologic considerations.

Others will follow, subject to the availability of financial resources, on:

- Design specifications for local groundwater management institutions;
- The potential for integrating conjunctive use into reservoir re-operation strategies that are also intended to enhance downstream fluvial processes;
- The analysis of institutional, land use, infrastructure, and environmental and other factors bearing upon siting decisions for groundwater banks;
- The results of "gaming" analysis of a series of conjunctive use configurations in the Central Valley;
- Economic optimization analysis; and
- The final feasibility of and strategic plan for an appropriate system-wide conjunctive water management initiative.

The current report contains analysis on the potential role that *in lieu* conjunctive water management in the Central Valley could play in a system-wide conjunctive water management initiative. This conjunctive use strategy relies upon offsetting historical groundwater pumping with surface water deliveries from project participants during times of excess surface water supply. These extended deliveries of surface water could also be part of a reservoir re-operation strategy designed to enhance the overall yield of the major water supply reservoirs in the Central Valley (NHI 1999). Any foregone groundwater pumping that results from the delivery of surplus surface water or reservoir re-operation is, in turn, considered to be stored groundwater water that can be reclaimed by project participants during times of surface water shortfalls. This strategy, which obviously rests heavily on institutional and accounting arrangements, is an alternative to direct aquifer recharge of surface water either during years of surplus or as part of the reservoir re-operation that was the focus of previous analyses published in the System-Wide Conjunctive Management Series (NHI 2001b).

In theory, any historic user of groundwater, either municipal or agricultural, could receive surface water deliveries *in lieu* of groundwater pumping. An interesting example of urban *in lieu* conjunctive use is emerging in the Sacramento Region north of the American River, where several municipal water districts have formed a joint powers authority to coordinate the use of their individual American River surface water rights and pumping from their common underlying aquifer (Winkler 2002). In addition, the delivery of surface water to offset groundwater pumping does not necessarily require water delivery outside of the jurisdiction of the original surface water rights holder.

In many, perhaps most, water districts irrigators draw upon both surface water and groundwater to meet crop water requirements based on water availability, delivery timing and overall cost considerations. In this setting, however, realizing viable *in lieu* conjunctive water management opportunities is likely to occur as part of standard internal water district planning.

Outside of urban regions and water districts endowed with surface water supplies, there remains a substantial opportunity to carry out *in lieu* conjunctive use by delivering available surface water to irrigated lands lying outside of the boundaries of established surface water delivery districts. These are lands that rely completely on groundwater pumping as a source of irrigation water. While water districts are both common and extensive in the Central Valley, there remain vast tracts of land that fall into the land use category of "unincorporated irrigated agriculture". Evaluating the extent of delivering surface water to these lands as part of an *in lieu* conjunctive use program, either during years of surplus or as part of an overall reservoir re-operation strategy, is the focus of this report.

The report continues in Section 2.0 with a brief discussion of the evaluation criteria that can be used to evaluate where in the Central Valley an *in lieu* conjunctive water management program could be implemented. Subsequently, in Section 3.0, the analytical methodology used to examine these evaluation criteria is presented, including a discussion of the data collected and tools used. Section 4.0 presents the results of analysis of the evaluation criteria and an estimate of the scale of potential *in lieu* conjunctive water management in the Central Valley. The report closes with some thoughts on the implications of this work on the System-Wide Conjunctive Water Management Initiative.

2.0 Evaluation Criteria for Assessing *In Lieu* Conjunctive Use Opportunities

As mentioned in Section 1.0, this report explores the potential for implementing *in lieu* conjunctive water management projects on agricultural land in the Central Valley that has historically relied solely on groundwater pumping to supply irrigation water. One consideration in developing such a program is the availability of surface water for delivery to these lands. The possibility of generating new surface water was discussed in an earlier publication in the System-Wide Conjunctive Water Management Series (NHI 1999). Other hydrologic modeling exercises have also focused on enhancing the storage capacity available to manage surface water in the Central Valley. What has been missing, at least in the context of *in lieu* conjunctive water management, is an inventory of the magnitude of the opportunity for historic agricultural users of groundwater to accept any available surface water supplies.

While the willingness of historic groundwater users to participate in such a program will turn primarily on local considerations related to cost and assurances, there are some physical characteristics that can make a particular region attractive for *in lieu* conjunctive use. In pursuing this investigation, three evaluation criteria that will influence the viability of this water management strategy were identified.

- The relative contribution of surface water and groundwater to irrigated agriculture in an area of interest. Ideally *in lieu* groundwater banking will occur in areas where significant amounts of groundwater pumping for irrigation takes place in the same locale where significant amounts surface water are available to offset groundwater pumping.
- The physical proximity of lands irrigated solely with groundwater to water districts that own the surface water distribution network that would be extended to deliver surface water in lieu of groundwater pumping.
- The amount of available aquifer storage space to accommodate the "stored" groundwater that will be left behind by delivering surface water to land historically dependent on groundwater pumping.

The analytical methodology used to evaluate each of these parameters is found in the following section.

3.0 Analytical Methodology

Having selected three criteria for evaluating the potential for *in lieu* groundwater banking in the Central Valley, we developed an analytical methodology that would allow for comparisons among different parts of the region. These are discussed below.

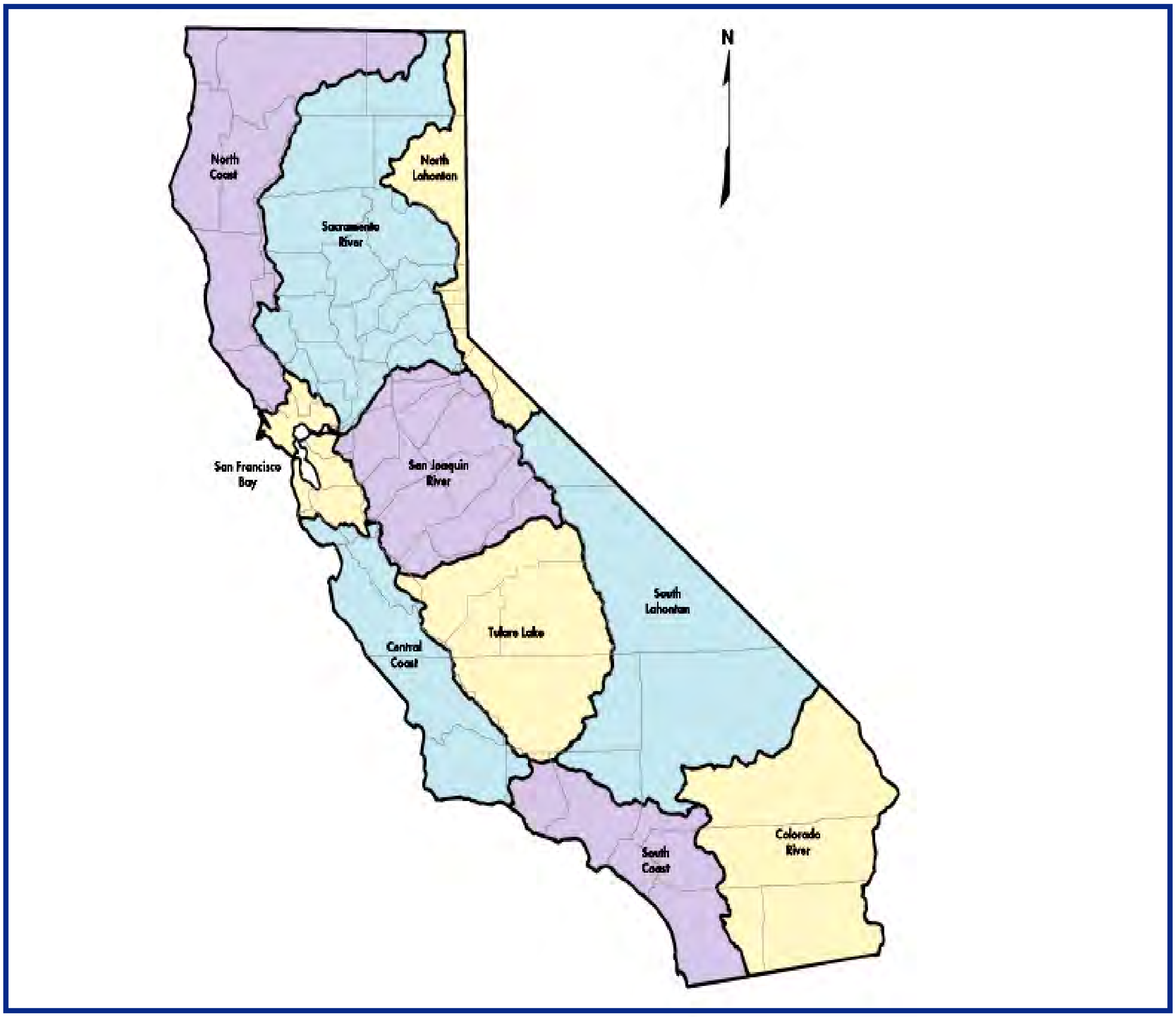
3.1 Relative Contribution of Surface Water and Groundwater

This evaluation criterion relates to local balance between the use of surface water and groundwater to meet crop water requirements on irrigated lands. If all of the land in a particular area has access to adequate surface water, then there is little possibility to increase groundwater storage by offsetting groundwater pumping. Conversely, in an area characterized uniquely by groundwater pumping there is no surface water to more widely distribute, either in times of excess supply or as part of reservoir re-operation. This suggests that *in lieu* conjunctive water management is a strategy best suited for areas where both groundwater and surface water contribute to the overall agricultural water supply.

The question becomes, however, how to define the boundaries of an area for analysis. An area such as the Central Valley certainly relies upon a mix of surface water and groundwater to meet crop water requirements. According to the most recent State Water Plan Update (DWR 1998), 28.3 MAF of surface water and 9.2 MAF of groundwater are used during average water years in the Central Valley. At this scale it is possible to imagine that surface water supplies might be available to offset groundwater pumping as part of *in lieu* conjunctive water management. This conclusion, however, does little to help in identifying where the most promising opportunities for this arrangement lie. To achieve this objective some more refined characterization of the mix of available surface water and groundwater for irrigation is required.

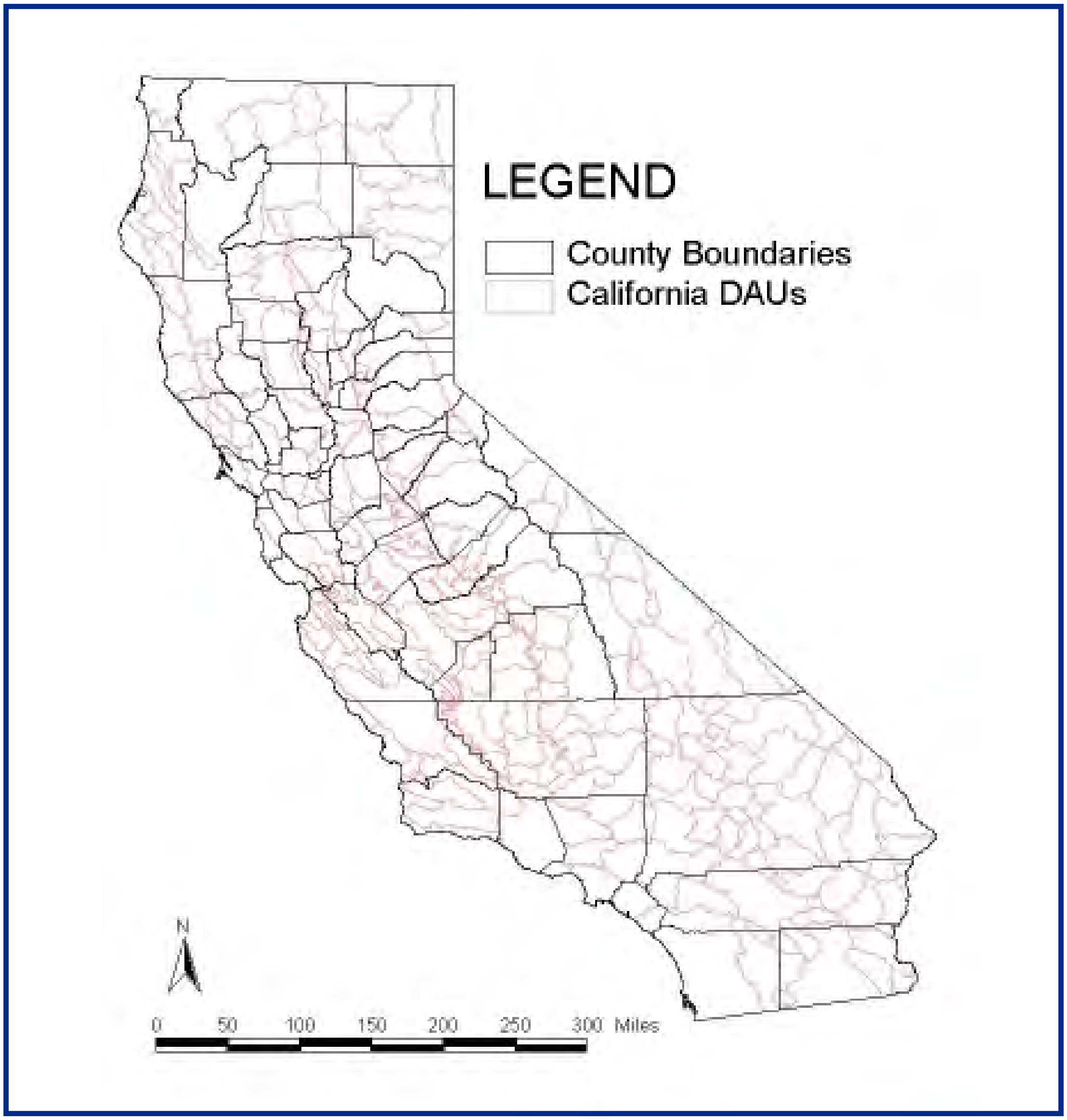
The State Water Plan Update (Bulletin 160), published once every five years by the Department of Water Resources (DWR), was identified as the logical source of information for developing this more refined characterization. Bulletin 160 reports on the composition of water supplies and demands at the level of 10 Hydrologic Regions in the State (Figure 3.1) and uses this data to anticipate the evolution of the statewide balance of water supply and demand over a planning horizon of several decades.

Figure 3.1: Hydrologic Regions Defined by California Department of Water Resources for the Purpose of Statewide Water Planning (DWR 1998)



In actuality, however, the data published in Bulletin 160 are aggregated up from water balance calculations performed at the level of 280 Detailed Analysis Units (DAU) defined by DWR (Figure 3.2). These range in area from roughly 11 mi^2 up to over 3600 mi^2. While the actual logic used to delineate these DAUs is not included in Bulletin 160, they appear to be based largely on the location of local important physical (mountains, rivers, distribution canals) and political (local government and water district boundaries) features.

Figure 3.2: Detailed Analysis Units Defined by California Department of Water Resources for the Purpose of Conducting Water Balance Calculations



Given their foundational role as the level at which water supply and demand data are actually assembled and analyzed, the DAUs were deemed the most appropriate unit for evaluating the local mix of surface water and groundwater used by irrigated agriculture. As the scope of the current investigation was limited to *in lieu* conjunctive water management opportunities in the Central Valley, a set of 56 DAUs was identified for further analysis (Figure 3.3). The logic used for selecting these DAUs was that the most significant portion of the DAU lies within the relatively flat, heavily agricultural region lying between the Coast Range Mountains and the Sierra Nevada Foothills. This logic also appears to have driven the original definitions of the DAUs, as those selected generally lie entirely within this zone. Details regarding the identifying code number, name, Hydrologic Region and surface area of the 56 selected DAUs are presented by identifying code number in Table 3.1.

Figure 3.3: Detailed Analysis Units in the Central Valley Selected for Analysis of the Potential for *In Lieu* Conjunctive Water Management

DWR's regional offices maintain databases for the various DAUs around the state. 1995 and 1996 data for the Central Valley DAUs shown in Figure 3.3, which presumably were used to develop the 1998 edition of Bulletin 160, were obtained directly from DWR personnel in the Redding, Sacramento and Fresno offices. A number of different data sets were extracted from these Excel spreadsheets, some of which were used to perform calculations designed to evaluate the relative contribution of surface water and groundwater to the irrigation water supply in the DAU.

Table 3.1: Relevant Details Pertaining to the 56 Central Valley DAUs Selected for Analysis of the Potential for *In Lieu* Conjunctive Water Management

ID No.	Name	Hydrologic Region	Area (mi^2)	ID No.	Name	Hydrologic Region	Area (mi^2)
141	Redding West	Sacramento River	416.1	211	Merced Stream Group	San Joaquin River	241.0
142	Red Bluff-Orland	Sacramento River	868.5	212	El Nido-Stevinson	San Joaquin River	339.6
143	Redding East	Sacramento River	240.9	213	Madera-Chowchilla	San Joaquin River	283.1
144	Los Molinos	Sacramento River	317.3	214	Adobe - Valley Eastside	San Joaquin River	286.2
162	Lower Cache Creek	Sacramento River	550.0	215	Gravelly Ford	San Joaquin River	248.2
163	Willows-Arbuckle	Sacramento River	1426.1	216	West Side	San Joaquin River	1104.0
164	Glenn-Knights Landing	Sacramento River	239.8	233	Fresno	Tulare Lake	411.2
165	Meridian-Robbins	Sacramento River	159.4	234	Academy	Tulare Lake	73.1
166	Durham-Sutter	Sacramento River	418.0	235	Raisin	Tulare Lake	291.1
167	Butte City	Sacramento River	148.1	236	Consolidated	Tulare Lake	274.2
168	Yuba City-Gridley	Sacramento River	400.9	237	Lower Kings River	Tulare Lake	277.8
170	Honcut Valley	Sacramento River	66.0	238	Hanford-Lemoore	Tulare Lake	266.3
171	Yuba	Sacramento River	259.0	239	Alta	Tulare Lake	208.8
172	Placer	Sacramento River	592.8	240	Orange Cove	Tulare Lake	84.0
173	Sacramento	Sacramento River	221.8	241	Tulare Lake	Tulare Lake	403.1
180	Elk Grove	San Joaquin River	311.4	242	Kaweah Delta	Tulare Lake	695.9
181	Ione-Jenny Lind	San Joaquin River	303.0	243	Tule Delta	Tulare Lake	660.3
182	Lodi	San Joaquin River	618.8	244	Westlands	Tulare Lake	1016.9
184	Bachelor Valley	San Joaquin River	109.1	245	Kettleman Plain	Tulare Lake	264.0
185	San Joaquin Delta	San Joaquin River	625.3	246	South Tulare Lake	Tulare Lake	146.8
186	Sacramento Delta	Sacramento River	437.7	254	Kern Delta	Tulare Lake	531.3
191	Vacaville	Sacramento River	406.6	255	Semitropic	Tulare Lake	426.1
205	South San Joaquin ID	San Joaquin River	153.5	256	North Kern	Tulare Lake	365.3
206	Modesto-Oakdale	San Joaquin River	286.9	257	Northeastern Kern	Tulare Lake	341.5
207	Modesto Reservoir	San Joaquin River	171.5	258	Arvin-Edison	Tulare Lake	333.7
208	Turlock	San Joaquin River	319.2	259	Antelope Plain	Tulare Lake	644.1
209	Turlock Lake	San Joaquin River	224.4	260	Buena Vista Valley	Tulare Lake	187.5
210	Merced	San Joaquin River	244.0	261	Wheeler Ridge-Maricopa	Tulare Lake	271.3

The extracted data sets included:

- Reported applied water to agriculture (AGAW)
- Reported evaporation of applied water (ETAW)
- Reported applied surface water to agriculture (ASW)
- Reported applied groundwater to agriculture (AGW)

These values are considered to be reported because it was generally not clear from the spreadsheets how the numbers were developed and in several cases it was evident that the numbers were calculated from other variables (see the text box on the following page). As they represented the best available data, however, these values were used to calculate the following variables:

- Irrigation Efficiency (E) = ETAW/AGAW
- Agricultural Surface Water Contribution (%SW) = ASW/AGAW
- Agricultural Groundwater Contribution (%GW) = 1 - %SW

The values of ETAW, ASW, AGW, %SW and %GW were then tabulated and graphed in order to identify DAUs with the proper mix of surface water and groundwater use to make them attractive candidates for *in lieu* conjunctive water management. The results of this analysis are presented in Section 4.0. The estimated irrigation efficiency was used to examine where improvements in irrigation water management might allow for a wider distribution of available surface water. This opportunity is also discussed in greater detail in the Results section below.

3.2 Physical Proximity of Lands Irrigated Solely with Groundwater

In addition to having an appropriate mix of surface water and groundwater use for irrigation, in order to implement an *in lieu* conjunctive use program it is desirable if much of the land irrigated solely with groundwater lies in close proximity to water districts. These are the entities endowed with the surface water delivery networks that would presumably be expanded to deliver surface water to these lands *in lieu* of groundwater pumping. This criterion was evaluated by carrying out spatial analysis on databases describing the location of water districts and the distribution of agricultural lands within the 56 Central Valley DAUs.

The U.S. Bureau of Reclamation's (USBR) Mid-Pacific Region originally developed the water district databases used in this exercise. The database differentiated water districts into three categories: Federal districts that contract with the USBR for water, State districts that contract with the State Water Project for water, and private districts that own and operate their own surface water supply systems. Districts lying at least partially within the Central Valley DAUs that are the basis of the current analysis are shown in Figure 3.4.

Observations on the DAU Databases

Given their foundational role in developing the aggregate Hydrologic Region water supply and demand numbers reported in Bulletin 160, it was surprising to discover that the DAU databases are neither easy to acquire nor uniform in format. The following observations regarding the DAU databases are offered in the hope that they may assist in expanding the utility and integrity of this important dataset.

1. DAU databases for the entire State should be available from a single source, preferably on-line.

2. DAU databases should follow a single transparent format so that interested parties outside of DWR can easily use them.

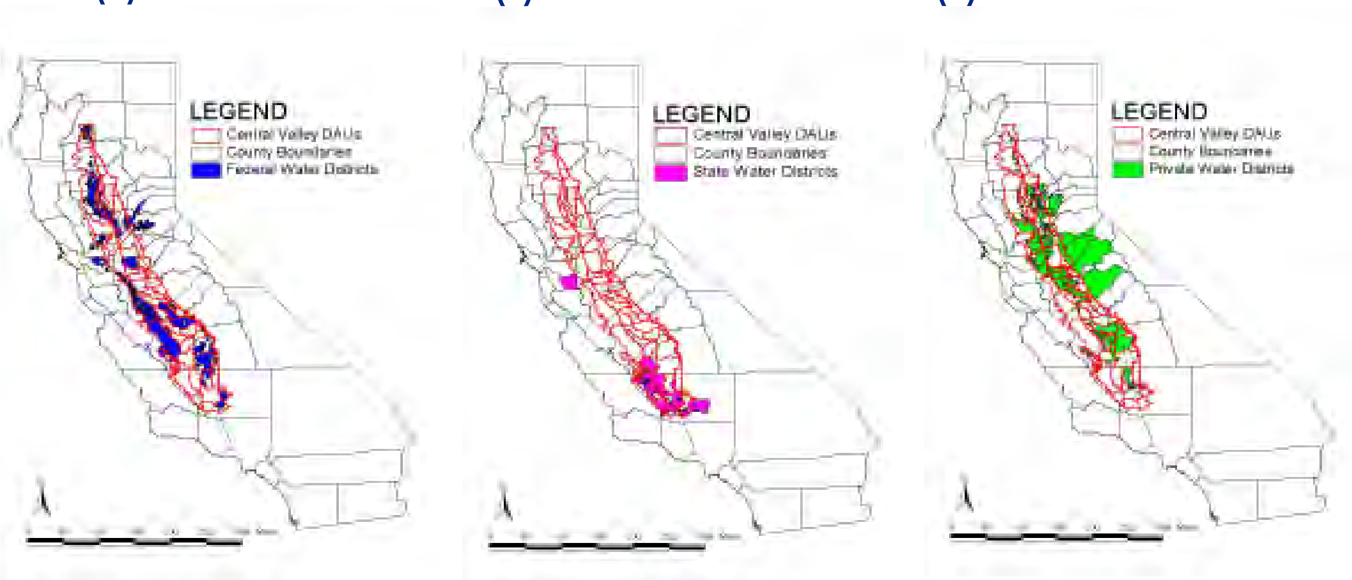
3. Detailed meta-data descriptions of the numbers included in the DAU databases should be developed. This meta-data should draw a clear distinction between what has been measured and what has been estimated. For estimated data, the methodology used to arrive at the estimate should be included.

4. For DAUs in the San Joaquin River and Tulare Lake Hydrologic Regions, a groundwater use is estimated to be a closure term in a mass balance that relies upon several coarse assumptions. Given the importance of groundwater in California, a better method of estimating groundwater use must be developed.

5. Bulletin 160 should include an appendix that clearly lays out how the uncertainty in the DAU water budget calculations can aggregate up into the reported Hydrologic Region supply and demand numbers.

Figure 3.4: Location of Federal (A), State (B) and Private (C) Water Districts Located at Least Partially within the 56 Selected Central Valley DAUs

(A) (B) (C)

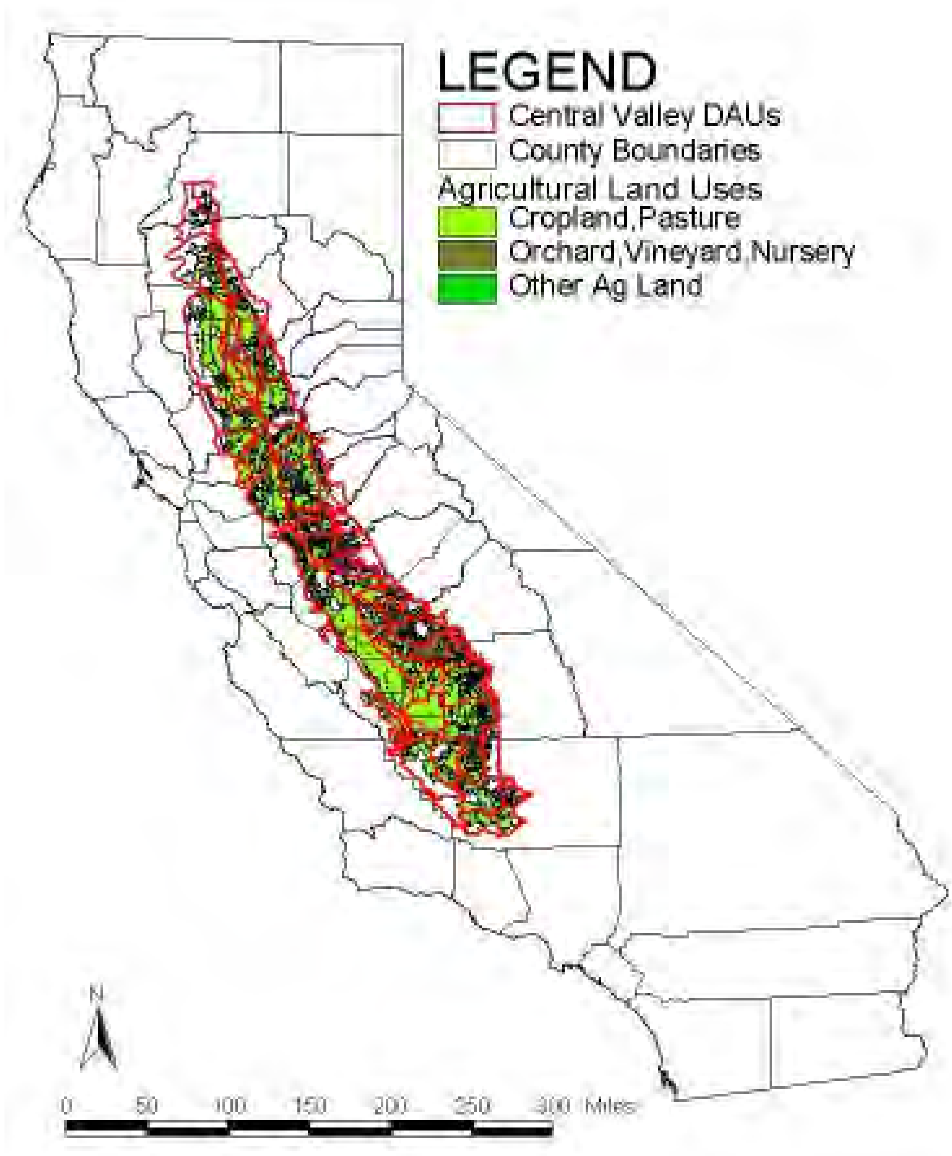


In order to estimate the amount of irrigated land historically irrigated solely with surface water that lies in close proximity to these districts, a land use/land cover database developed by the U.S. Geological Survey (USGS) at a scale of 1:250,000 was obtained. This database was edited so that it contained only land that would be under irrigation by removing all urban, industrial, non-irrigated agriculture and natural land use areas. The resulting database is found in Figure 3.5.

ArcView 3.2 buffers of 1, 2 and 3 miles were drawn around the portion of the Federal, State and private districts found within each of the 56 Central Valley DAUs. This buffering was performed separately for each of the three categories of water districts. Any land within the buffers of a particular water district category but inside the boundaries of another category of water district was eliminated from consideration. The remaining buffers were subsequently clipped to find those areas that contained irrigated agricultural land use types where groundwater pumping would presumably occur. The area of the remaining land was then calculated to evaluate the physical proximity of lands irrigated solely with groundwater to established water districts.

By treating the different categories of water districts separately, some of the irrigated lands located outside of the boundaries of incorporated water districts could be included in more than one set of buffers. As such the total amount of land irrigated by groundwater in a DAU within a given distance of any water district cannot be calculated by summing the area of buffers around the different categories of water districts. The analysis was carried out in this manner because the Federal, State and private districts are managed by different entities that generally make their own planning decisions.

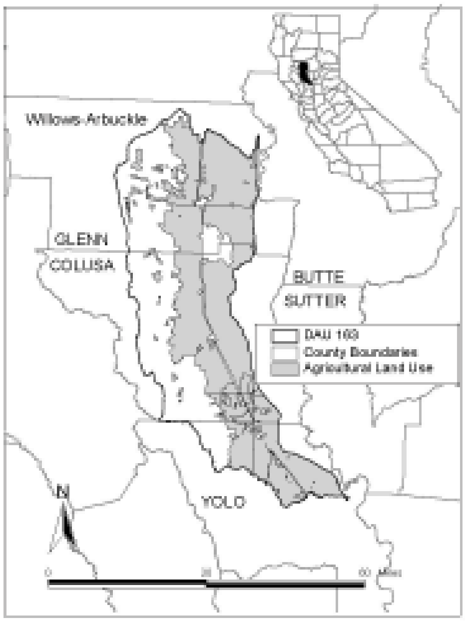
Figure 3.5: Irrigated Agricultural Land Use Type Located within the 56 Selected Central Valley DAUs



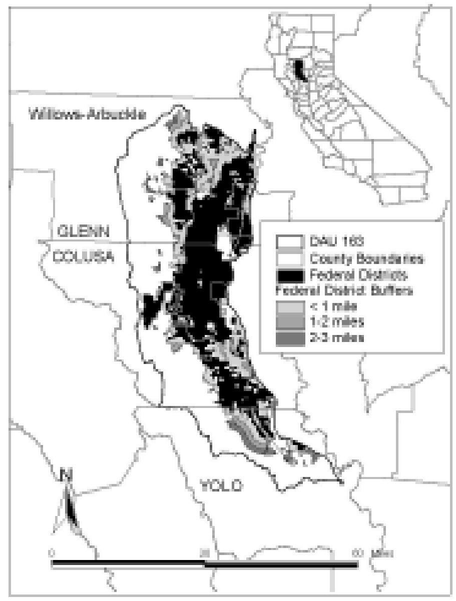
The basic framework for the spatial analysis used to evaluate this criterion is shown in Figure 3.6 for DAU 163, Willows-Arbuckle, which includes Federal and private water districts as well as substantial areas of irrigated land lying outside of district boundaries.

Figure 3.6: Spatial Analysis Framework for DAU 163, Willows-Arbuckle, with Area of Irrigated Agriculture (A), Federal Districts with 1-, 2- and 3-Mile Buffers (B), Private Districts with 1-, 2- and 3-Mile Buffers (C), and Tabulated Results (D)

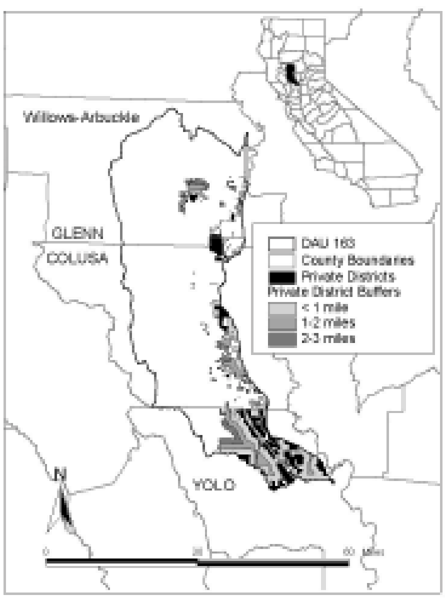
(A)



(B)



(C)



(D)

Buffer Distance (miles)	Area Relative to Federal Districts (miles)	Area Relative to Private Districts (miles)
< 1	180.3	92.1
1-2	30.1	40.8
2-3	21.3	21.1

Maps similar to those shown in Figure 3.6 are shown for all of the Central Valley DAUs in Appendix A. The results of the spatial analysis of this criterion are discussed in Section 4.0.

3.3 Amount of Available Aquifer Storage Space

When groundwater pumping is foregone as a result of *in lieu* surface water deliveries, the result is that more water is left in aquifer storage than otherwise would have been present. Given ample substitution of surface water, the increase in aquifer storage will translate to higher water levels in the unused wells. If the well is tapping an unconfined aquifer where the water table already lies close to the ground surface, then the additional groundwater storage may be problematic. High water tables can create drainage problems for agricultural crops and cause damage to structures with deep foundations. In addition, high water tables can result in increased seepage to streams and rivers meaning that some portion of the water stored in the aquifer as a result of *in lieu* surface water deliveries may be lost. Wells tapping deeper, confined aquifers are less prone to the problems associated with high water tables although increases in the piezometric surface in these wells may reduce seepage from overlying unconfined aquifers, leading indirectly to a rising water table.

Both types of aquifers are tapped by agricultural wells in the Central Valley. In the San Joaquin and Tulare Lake Basins in particular, much of the groundwater used for irrigation is pumped from the confined aquifer below the Corcoran Clay. In either case, *in lieu* conjunctive use becomes less attractive if either the water table or the piezometric surface is already close to the ground surface prior to the delivery of surface water to historic groundwater users. Identifying regions with ample available aquifer storage space was carried out using data available in the Fall 1999 DWR water level survey of wells in the Central Valley (the latest complete data set available on-line). Figure 3.7 depicts the wells included in the survey that lie within the 56 Central Valley DAUs selected for analysis.

While DWR includes some agricultural wells in its semi-annual water level survey, the vast majority of wells in the survey are used for irrigation. In order to further focus on these irrigation wells, only the wells located within the irrigated agricultural land-use types of each of the Central Valley DAUs were selected for analysis (see Figure 3.5). For example, Figure 3.8 shows the wells located within areas defined by an irrigated agricultural land-use type in DAU 163, Willows-Arbuckle. No attempt was made to differentiate between wells that were tapped in the surface unconfined aquifer and were recording the depth to water table and those recording the piezometric surface in a deeper confined aquifer. The fact that either surface lies close to the ground surface would detract from the attractiveness of this DAU, or any other DAU, for *in lieu* conjunctive use. Using the ArcView 3.2 Statistics tool, the average depth to water (DTW) reported in the Fall 1999 water level survey was found to be 35 feet in DAU 163. A similar calculation was carried out for each of the 56 Central Valley DAUs. While it may have been more accurate to contour the water level data in order to estimate the average depth to water, trial calculations on a few DAUs revealed that the results were not significantly different to merit the substantial increase in effort required for contouring. The results of this analysis for the entire Central Valley is presented in Section 4.0.

Figure 3.7: Location of DWR Water Level Survey Wells Located within the 56 Selected Central Valley DAUs

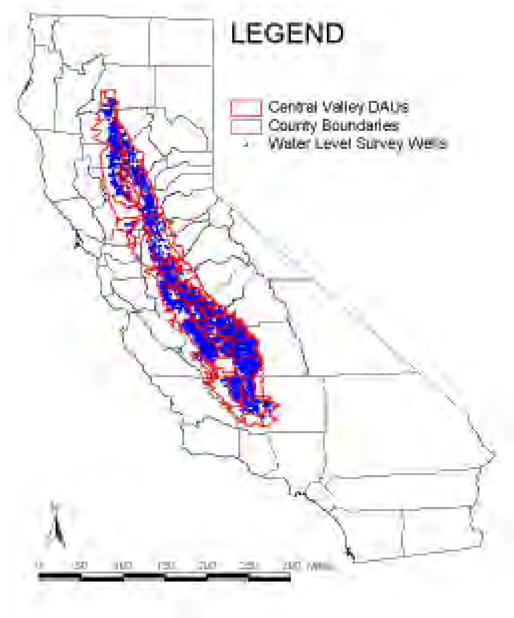
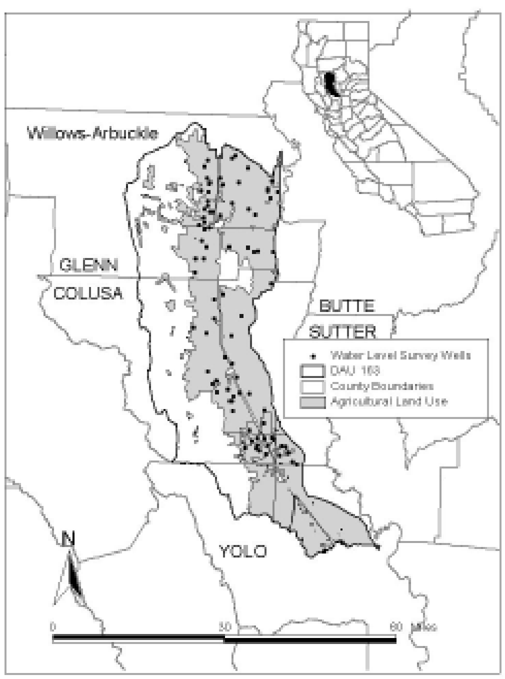


Figure 3.8: Location of DWR Water Level Survey Wells Located within Irrigated Agricultural Areas of DAU 163, Willows-Arbuckle

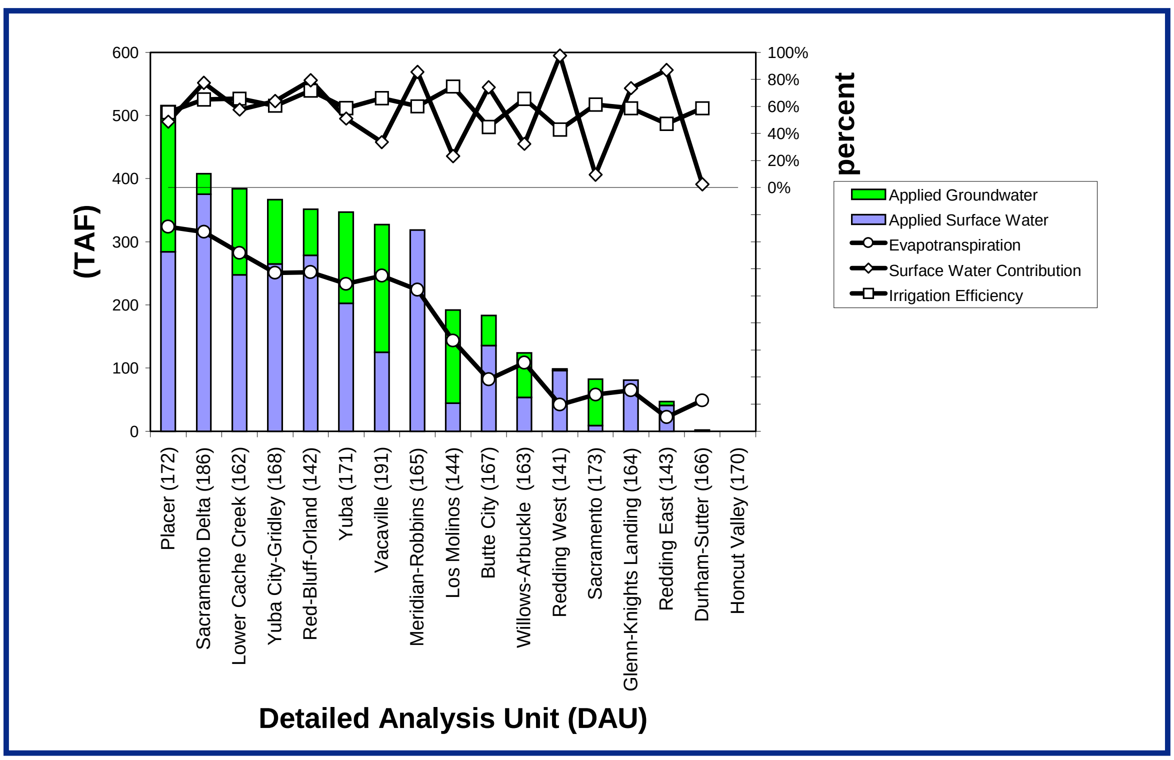


4.0 Results

Figures 4.1 through 4.3 present the results of the analysis to determine the current mix of surface water and groundwater utilization in DAUs located within the Sacramento River, San Joaquin River and Tulare Lake Hydrologic Regions. In each region the DAU have been sorted by the sum of the surface water (ASW) and groundwater (GSW) applied in the agricultural sector. The recorded value of evapotranspiration of applied water (ETAW) is also plotted on the left-hand volumetric scale. Calculated values of the irrigation efficiency (E) and agricultural surface water contribution (%SW) are plotted on the right-hand percent scale.

In examining these figures, the most attractive DAUs are those that utilize a mix of surface water and groundwater for irrigation, as this suggests that groundwater pumping could be replaced by *in lieu* deliveries of locally available surface water. The absolute amount of water used in agriculture is also important as it corresponds with the magnitude of the *in lieu* conjunctive use program that could occur. DAUs with low irrigation efficiencies are areas where improved water management might allow for a wider distribution of available surface water. DAUs in the San Joaquin River and Tulare Lake Hydrologic Regions with negative values of applied groundwater reflect the fact that AGW is calculated as a closure term in the water balance conducted for these regions combined with the fact that ASW exceeds ETAW in these units. DAUs without data are those for which no data could be obtained from the associated DWR regional office.

Figure 4.1: Relative Contribution of Surface Water and Groundwater to Irrigated Agriculture for DAUs in the Sacramento River Hydrologic Region



Results

Figure 4.2: Relative Contribution of Surface Water and Groundwater to Irrigated Agriculture for DAUs in the San Joaquin River Hydrologic Region

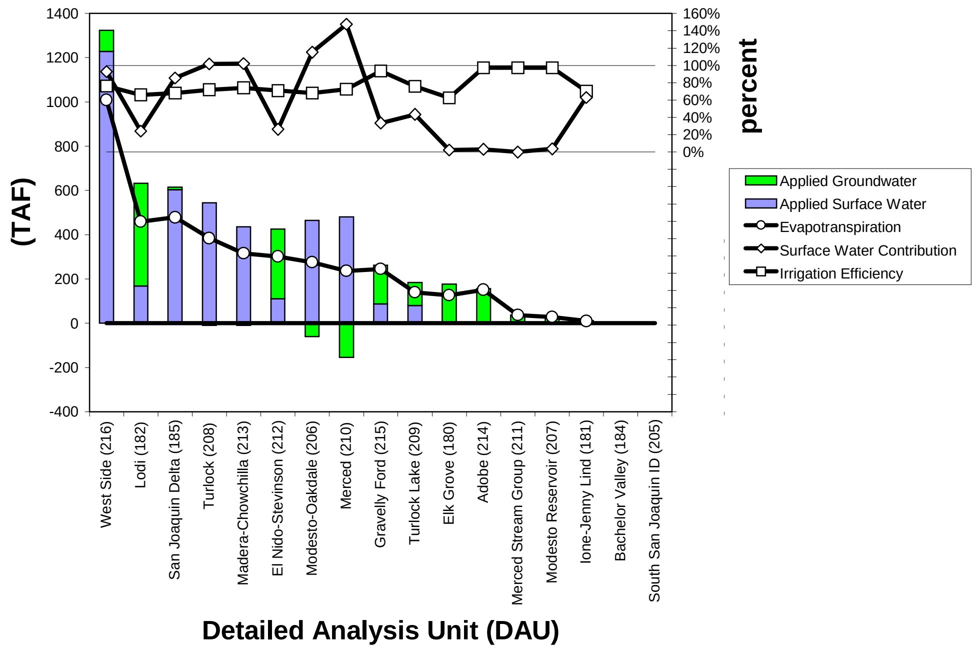
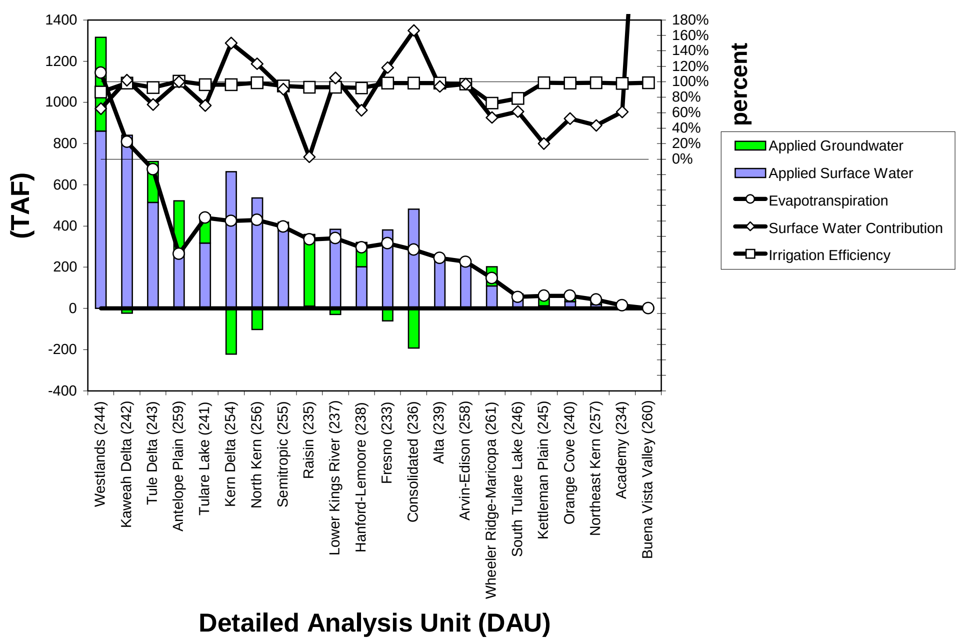


Figure 4.3: Relative Contribution of Surface Water and Groundwater to Irrigated Agriculture for DAUs in the Tulare Lake Hydrologic Region

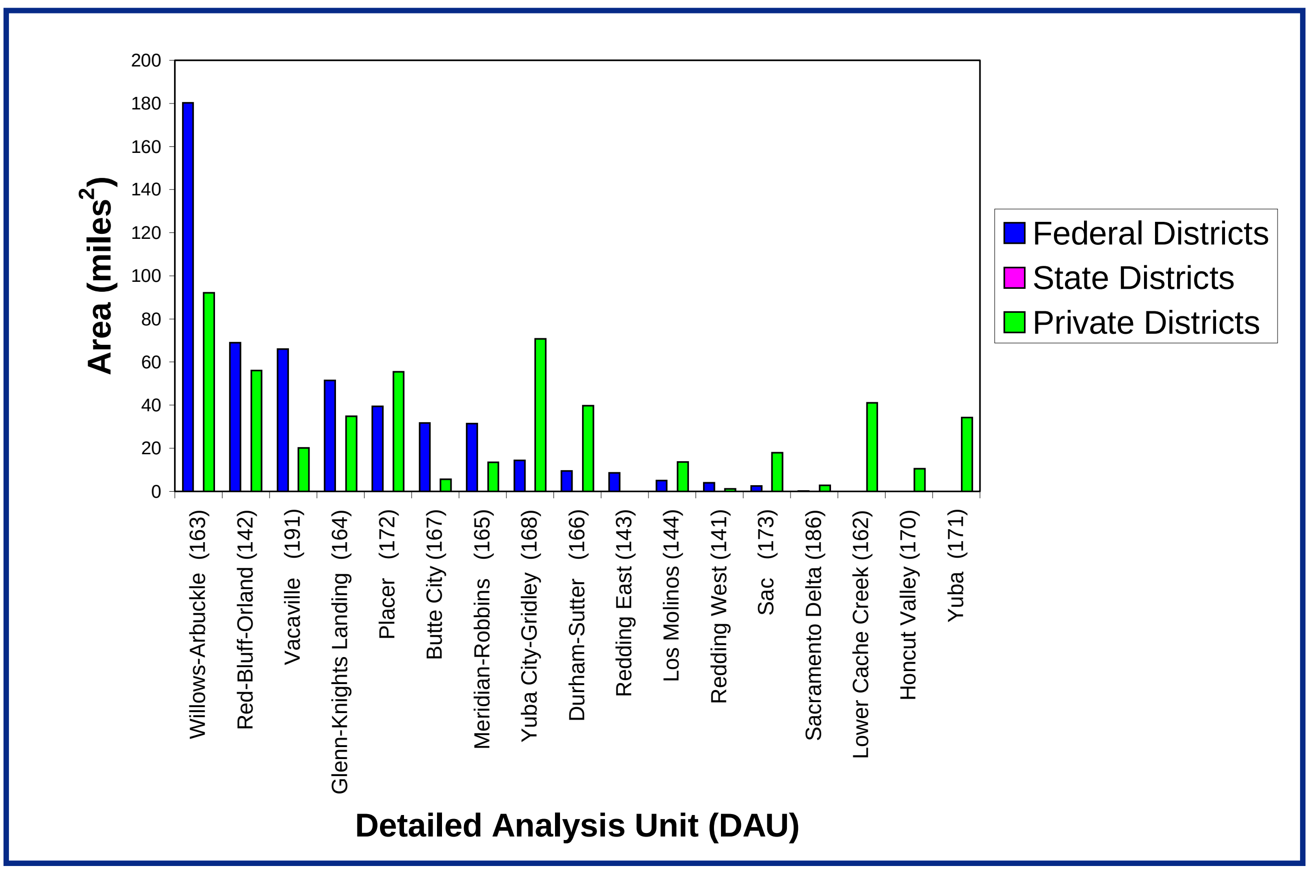


Results

Figures 4.4 through 4.6 contain the results of the spatial analysis on the proximity of unincorporated irrigated land to Federal, State and private water districts for the Sacramento River, San Joaquin River and Tulare Lake Regions. Only the area of the 1-mile buffers around water districts are included in these figures as these are the lands that could most easily receive surface water deliveries in lieu of groundwater pumping. Areas contained within the 2- and 3-mile buffers are reported in Appendix B, along with the data used to develop Figures 4.4 through 4.6. The DAUs are sorted by the amount of land in close proximity to Federal water districts in order to reflect the support that the USBR has provided to the effort. State water districts are not found within the Sacramento River Hydrologic Region, and the only one in the San Joaquin River Hydrologic Region, DAU 216 West Side, has virtually no unincorporated irrigated land in its immediate vicinity.

Figures 4.7 through 4.9 depict the results of the depth to water analysis for DAUs in the Sacramento River, San Joaquin River and Tulare Lake Hydrologic Regions. The very large DTW values observed in the Tulare Lake Hydrologic Region are probably due to the fact that many of the agricultural wells in this region are screened in the confined aquifer below the Corcoran Clay. A table summarizing the data found in these figures is summarized in Appendix C.

Figure 4.4: Unincorporated Irrigated Land within 1 Mile of Water Districts for DAUs Located within the Sacramento River Hydrologic Region



Results

Figure 4.5: Unincorporated Irrigated Land within 1 Mile of Water Districts for DAUs Located within the San Joaquin River Hydrologic Region

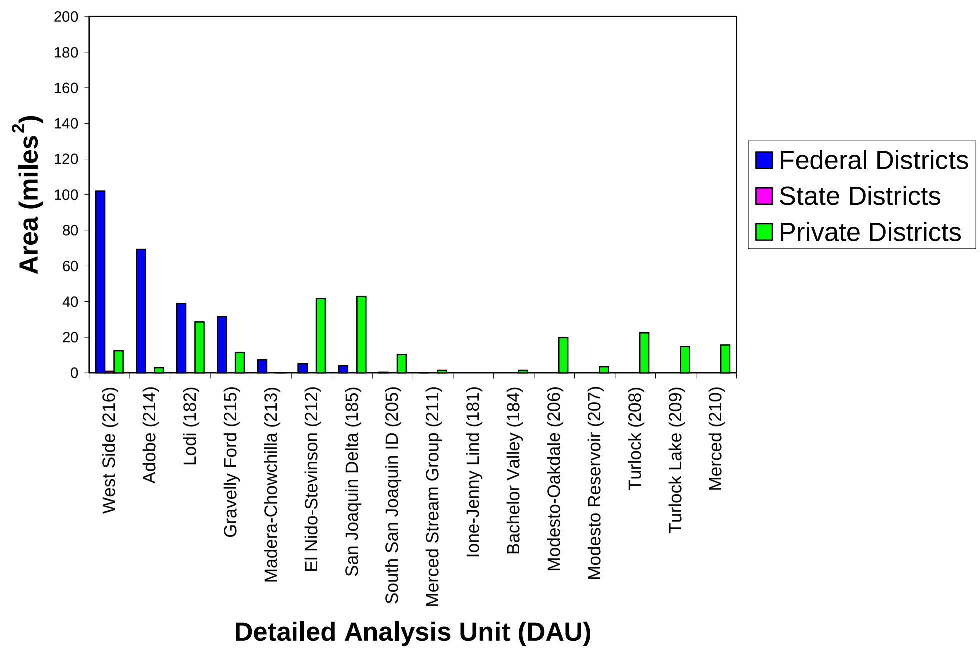


Figure 4.6: Unincorporated Irrigated Land within 1 Mile of Water Districts for DAUs Located within the Tulare Lake Hydrologic Region

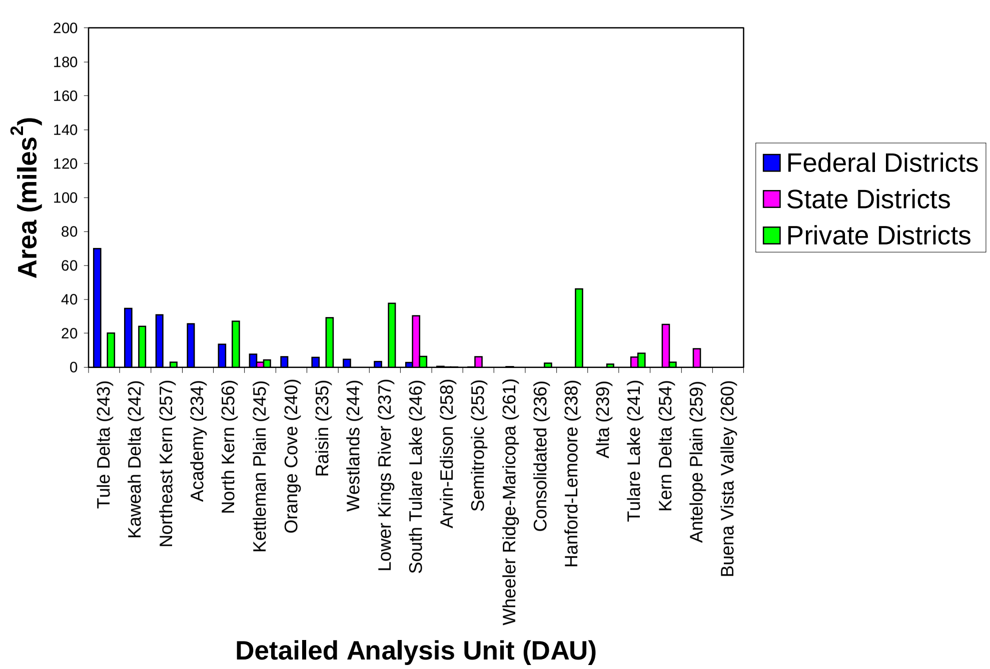


Figure 4.7: DTW in DAUs in the Sacramento River Hydrologic Region

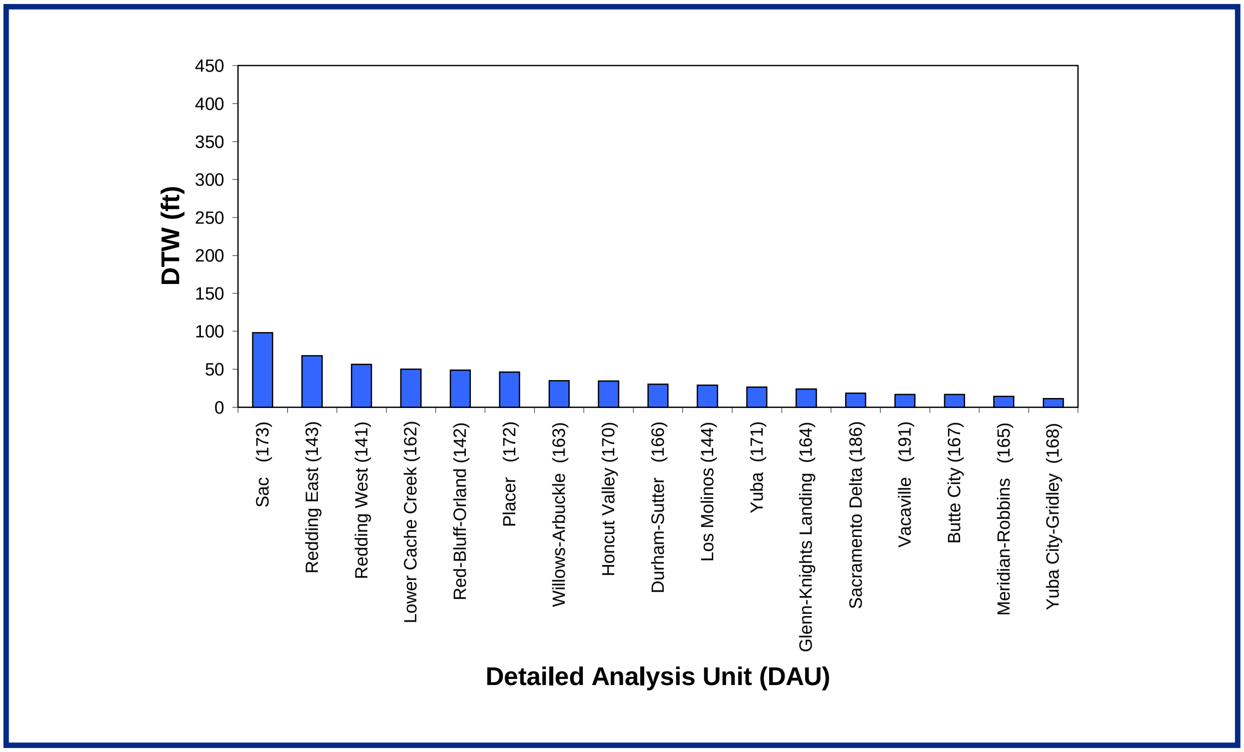


Figure 4.8: DTW in DAUs in the San Joaquin River Hydrologic Region

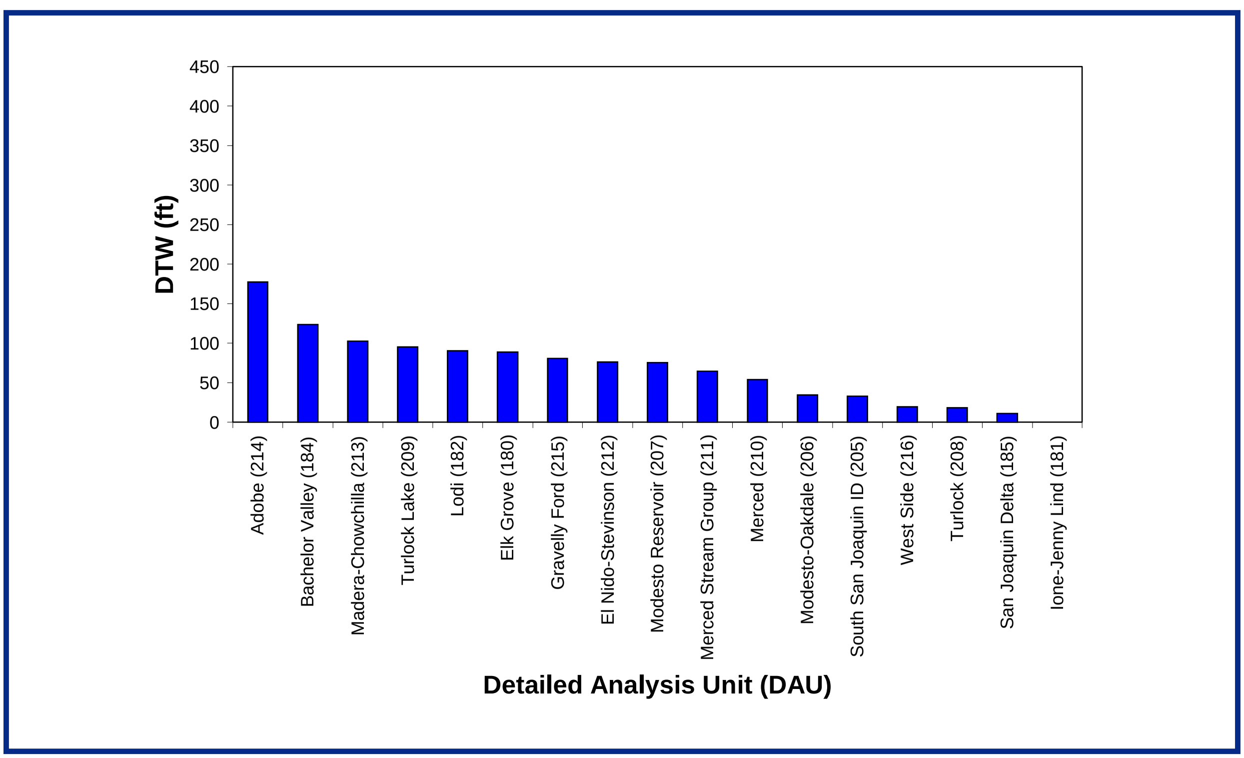
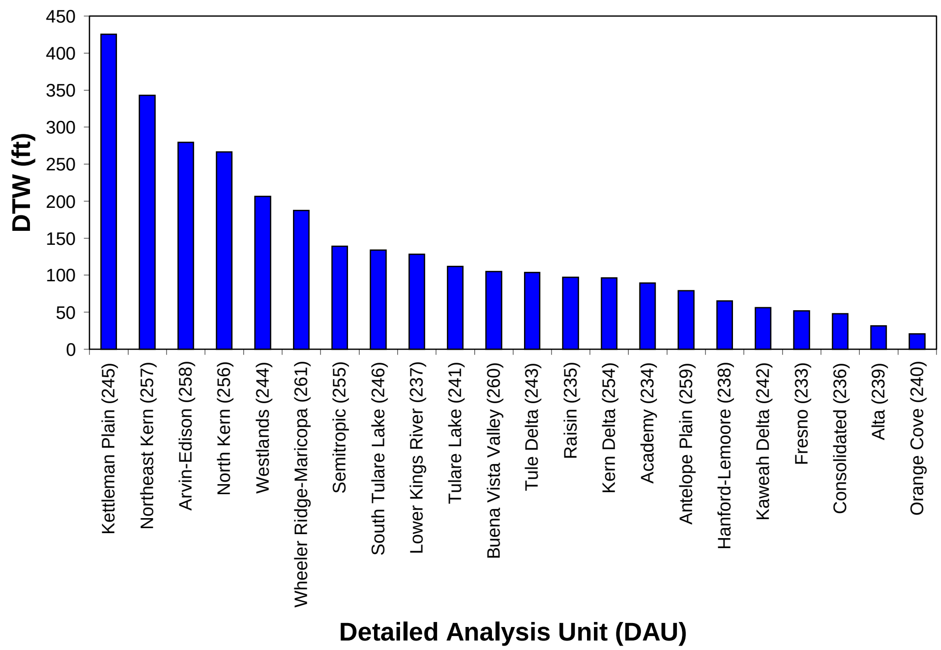


Figure 4.9: DTW in DAUs in the Tulare Lake Hydrologic Region



5.0 Analysis and Conclusions

Based on the results of analysis of the three evaluation criteria, several DAUs in each of the Hydrologic Regions emerge as attractive candidates for *in lieu* conjunctive water management. The first filter that was applied to identifying target DAUs was the mix of surface water and groundwater used in the agricultural sector. Table 5.1 includes DAUs where 20 to 70% of irrigation water is supplied by groundwater pumping. This level has been established because it reflects the fact that there is a significant reliance on groundwater pumping in the vicinity of the water districts endowed with locally important surface water rights that could potentially be managed to offset some groundwater pumping. The DAUs in Table 5.1 have also been screened to include only those that reported more than 20 TAF of total agricultural water use. Areas with smaller amounts of total agricultural water use were eliminated because they do not represent a significant opportunity from the perspective of system-wide conjunctive water management planning. The DAUs shown in bold have an estimated irrigation efficiency of less than 70%. These are areas where water management improvements may create the opportunity to expand the delivery of existing surface water supplies, although detailed analysis will be required to evaluate this opportunity since some percentage of the water not consumed by crops may be collected and used by other irrigators.

The second filter allied to the results was the proximity of water districts whose surface water delivery infrastructure would likely be extended to supply surface water in lieu of groundwater pumping.

Those DAUs listed in Table 5.1 with more than 10 miles^2 of unincorporated irrigated land within 1 mile of either Federal, State or private water districts in the DAU are listed in Table 5.2.

Table 5.1: Central Valley DAUs with > 20% and < 70% Reliance on Groundwater Pumping in the Agricultural Sector and > 20 TAF of Total Agricultural Water Use

DAU	Hydrologic Region	SW Contribution (%)	GW Contirbution (%)	ASW + AGW (TAF)
Red-Bluff-Orland (142)	Sacramento River	79.4%	20.6%	351.2
Lower Cache Creek (162)	Sacramento River	57.7%	42.3%	383.6
Willows-Arbuckle (163)	Sacramento River	32.4%	67.6%	123.9
Glenn-Knights Landing (164)	Sacramento River	73.5%	26.5%	80.8
Vacaville (191)	Sacramento River	33.6%	66.4%	327.0
Butte City (167)	Sacramento River	74.1%	25.9%	183.3
Yuba City-Gridley (168)	Sacramento River	63.9%	36.1%	366.6
Yuba (171)	Sacramento River	51.1%	48.9%	347.1
Placer (172)	Sacramento River	48.8%	51.2%	515.6
Sacramento Delta (186)	Sacramento River	77.5%	22.5%	407.8
Turlock Lake (209)	San Joaquin	43.4%	56.6%	184.2
Gravelly Ford (215)	San Joaquin	33.6%	66.4%	261.7
Hanford-Lemoore (238)	Tulare Lake	63.3%	36.7%	320.4
Orange Cove (240)	Tulare Lake	52.4%	47.6%	61.6
Tulare Lake (241)	Tulare Lake	69.2%	30.8%	453.8
Tule Delta (243)	Tulare Lake	70.7%	29.3%	712.8
Westlands (244)	Tulare Lake	65.4%	34.6%	1316.8
South Tulare Lake (246)	Tulare Lake	61.4%	38.6%	70.5
Northeast Kern (257)	Tulare Lake	43.5%	56.5%	42.8
Wheeler Ridge-Maricopa (261)	Tulare Lake	53.8%	46.2%	202.2

Table 5.2: Central Valley DAUs with > 10 Miles^2 of Unincorporated Irrigated Land within 1 Mile of Federal, State or Private Water Districts

DAU name	Hydrologic Region	Federal (miles^2)	State (miles^2)	Private (miles^2)
Red-Bluff-Orland (142)	Sacramento River	69.0	0.0	56.0
Lower Cache Creek (162)	Sacramento River	0	0.0	41.0
Willows-Arbuckle (163)	Sacramento River	180.3	0.0	92.1
Glenn-Knights Landing (164)	Sacramento River	51.5	0.0	34.9
Vacaville (191)	Sacramento River	66.0	0.0	20.1
Butte City (167)	Sacramento River	31.8	0.0	5.7
Yuba City-Gridley (168)	Sacramento River	14.3	0.0	70.8
Yuba (171)	Sacramento River	0	0.0	34.2
Placer (172)	Sacramento River	39.4	0.0	55.6
Turlock Lake (209)	San Joaquin	0.0	0.0	14.7
Gravelly Ford (215)	San Joaquin	31.7	0.0	11.4
Hanford-Lemoore (238)	Tulare Lake	0.0	0.0	46.2
Tule Delta (243)	Tulare Lake	69.9	0.0	20.1
South Tulare Lake (246)	Tulare Lake	2.7	30.2	6.3
Northeast Kern (257)	Tulare Lake	30.8	0.0	3.0

Finally, for the DAUs listed in Table 5.2, the depth to water evaluation criterion was applied. Table 5.3 lists those DAUs where the estimated depth to water in agricultural wells was at least 20 feet below ground surface. This value was selected to represent the fact that higher water levels associated with *in lieu* conjunctive water management should not be allowed to rise too close to the ground surface. If the starting water level is less than 20 feet, there may not be much opportunity to increase the amount of groundwater storage within the DAU.

Table 5.3: Central Valley DAUs where the Estimated Depth to Water in Agricultural Wells is at Least 20 Feet Below Ground Surface

DAU name	Hydrologic Region	DTW (ft)
Red-Bluff-Orland (142)	Sacramento River	48.9
Lower Cache Creek (162)	Sacramento River	50.3
Willows-Arbuckle (163)	Sacramento River	35
Glenn-Knights Landing (164)	Sacramento River	23.9
Yuba (171)	Sacramento River	26.4
Placer (172)	Sacramento River	46.1
Turlock Lake (209)	San Joaquin	95.3
Gravelly Ford (215)	San Joaquin	80.6
Hanford-Lemoore (238)	Tulare Lake	65.2
Tule Delta (243)	Tulare Lake	103.8
South Tulare Lake (246)	Tulare Lake	134.1
Northeast Kern (257)	Tulare Lake	343

The map in Figure 5.1 depicts the location of the Central Valley DAUs that have been identified as attractive locations for *in lieu* conjunctive water management based on the application of the three selected evaluation criteria. This map suggests that opportunities for *in lieu* conjunctive water management exist in all three of the Hydrologic Regions in the Central Valley, although the Sacramento River and Tulare Lake regions have larger amounts of land that could be easily incorporated into a program (see Table 5.2).

Based on the values of the various evaluation criteria, it is possible to develop a very rough estimate of the scale of the *in lieu* conjunctive use program that could be implemented in the DAUs identified in the screening process. This can be done in two ways. First the estimated available aquifer storage can be calculated as the product of the difference between the depth to water and a plane 10 feet below the land surface and the area of land within 1 mile of water districts adjusted by a specific yield in the case of wells with a DTW of less than 100 ft (assume 0.1) and the specific storage in wells with a DTW in excess of 100 ft (assume 0.01). The second estimate can be made by assuming that up to 10% of the allied surface water in a DAU could be used to offset up to 50% of groundwater pumping. The results of this analysis are found in Table 5.4. The first number is a proxy for the total available storage while the second number is a proxy for the amount of water that could be delivered to storage in a typical water year. Even given the coarse nature of these calculations it is evident that the scale of potential *in lieu* conjunctive water management opportunities in the Central Valley is very substantial. Further analysis of aquifer characteristics and water supply opportunities in these DAUs would help to refine these estimates.

Figure 5.1: Locations of Promising DAUs in the Central Valley

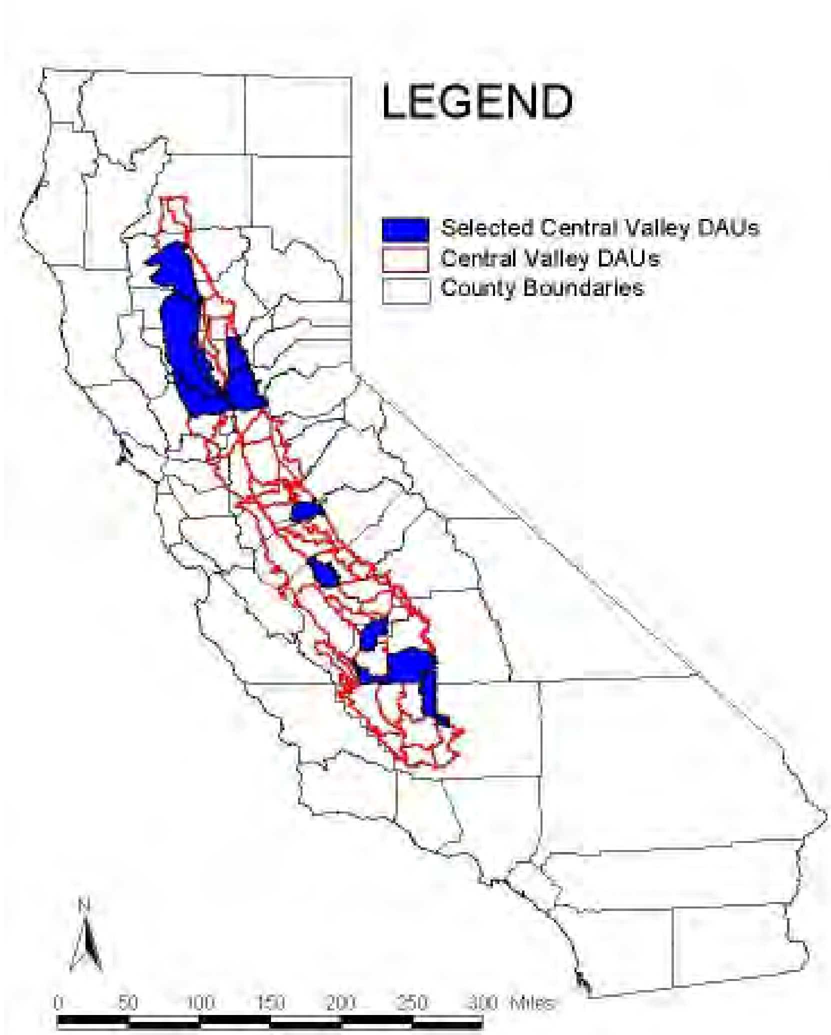


Table 5.4: Analysis of the Scale of Potential *In Lieu* Programs in the Central Valley

DAU name	Hydrologic Region	Area within 1 mile Federal (miles^2)	State (miles^2)	Private (miles^2)	DTW (ft)	Estimated Available Storage Federal (TAF)	State (TAF)	Private (TAF)	Available Water (TAF)
Red-Bluff-Orland (142)	Sacramento River	69.0	0.0	56.0	48.9	343.74	0.0	278.87	36.2
Lower Cache Creek (162)	Sacramento River	0	0.0	41.0	50.3	0.00	0.0	211.72	81.1
Willows-Arbuckle (163)	Sacramento River	180.3	0.0	92.1	35	577.09	0.0	294.57	41.9
Glenn-Knights Landing (164)	Sacramento River	51.5	0.0	34.9	23.9	91.66	0.0	62.01	10.7
Yuba (171)	Sacramento River	0	0.0	34.2	26.4	0.00	0.0	71.90	84.9
Placer (172)	Sacramento River	39.4	0.0	55.6	46.1	181.87	0.0	256.71	132.0
Turlock Lake (209)	San Joaquin	0.0	0.0	14.7	95.3	0.00	0.0	160.46	52.1
Gravelly Ford (215)	San Joaquin	31.7	0.0	11.4	80.6	286.03	0.0	103.33	86.9
Hanford-Lemoore (238)	Tulare Lake	0.0	0.0	46.2	65.2	0.00	0.0	326.58	58.9
Tule Delta (243)	Tulare Lake	69.9	0.0	20.1	103.8	4.20	0.0	1.21	104.4
South Tulare Lake (246)	Tulare Lake	2.7	30.2	6.3	134.1	0.21	2.40	0.50	13.6
Northeast Kern (257)	Tulare Lake	30.8	0.0	3.0	343	6.57	0.0	0.64	12.1
					Total =	**790.87**	**24.01**	**900.82**	**209.39**

Given the magnitude of the potential for *in lieu* conjunctive water management in the Central Valley, this component of a system-wide conjunctive water management strategy certainly merits further consideration. Information on this opportunity will be factored into future analyses conducted as part of this series, most notably, the evaluation of the potential for integrating conjunctive use into reservoir re-operation strategies that are also intended to enhance downstream fluvial processes, the "gaming" analysis of a series of conjunctive use configurations in the Central Valley, the economic optimization analysis, and the final feasibility study of and strategic plan for the initiative. In conclusion, however, even taken as a stand-alone piece of research, this analysis suggests that *in lieu* conjunctive water management can contribute to enhancing the performance of Federal, State and private surface water supplies in the coming decades.

6.0 References

DWR, 1998, *The California Water Plan Update, Bulletin 160-98,* The California Department of Water Resources, Sacramento, CA.

NHI, 1999, *A Feasibility Study of Maximal Scale Program of Groundwater Banking in California,* The Natural Heritage Institute, Berkeley, CA.

NHI, 2001a, *Designing Successful Groundwater Banking Programs in the Central Valley,* The Natural Heritage Institute, Berkeley, CA.

NHI, 2001b, *The Hydrogeologic Suitability of Potential Groundwater Banking Sites in the Central Valley of California,* The Natural Heritage Institute, Berkeley, CA.

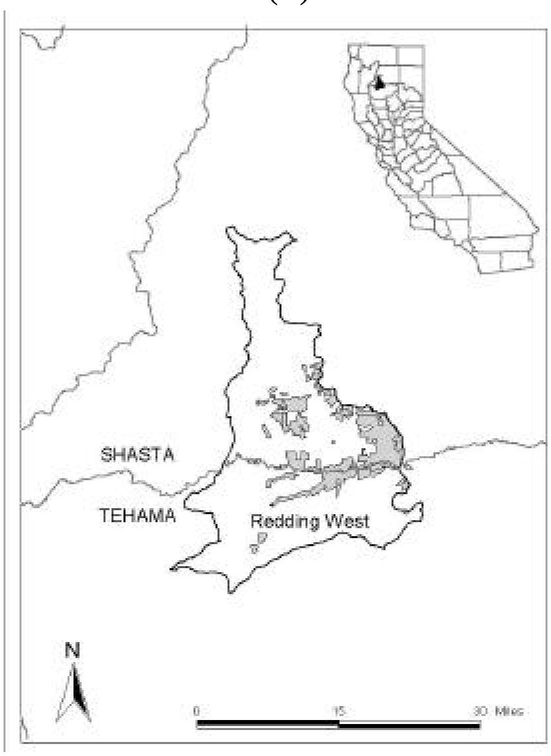
Winkler, E., 2002, personal communication.

Appendix A:

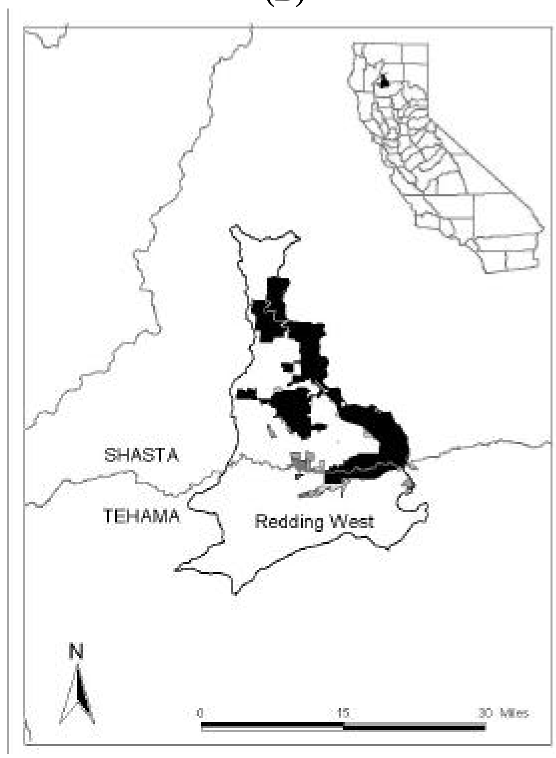
Maps Depicting the Spatial Analysis Conducted to Determine the Amount of Unincorporated Irrigated Land Located within 1, 2 and 3 Miles of the Federal, State and Private Water Districts Found in the 56 Central Valley Detailed Analysis Units

Figure A.1: DAU 141, Redding West, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

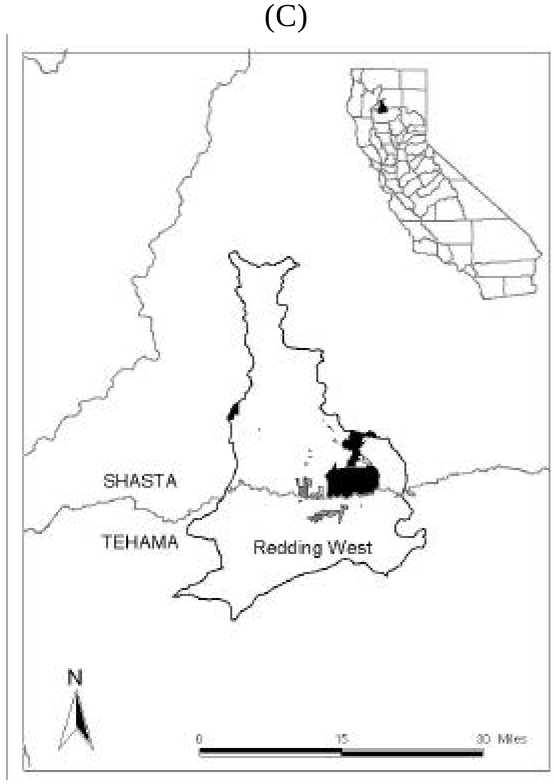
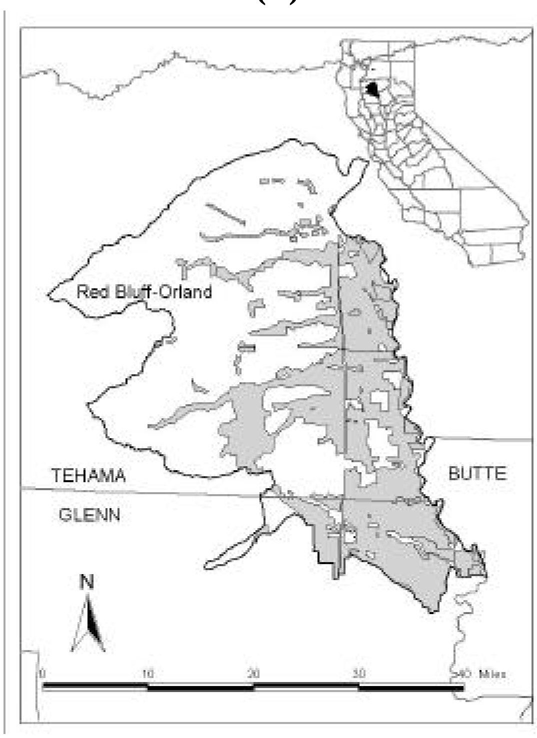


Figure A.2: DAU 142, Red Bluff-Orland, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



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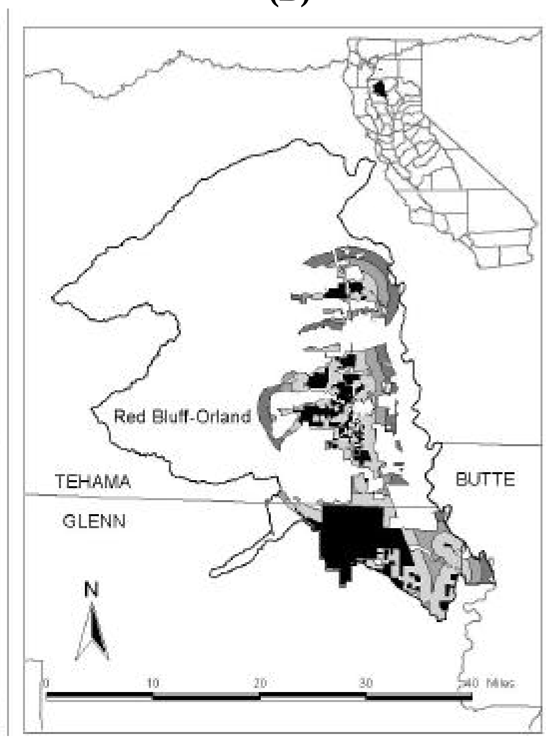


(C)

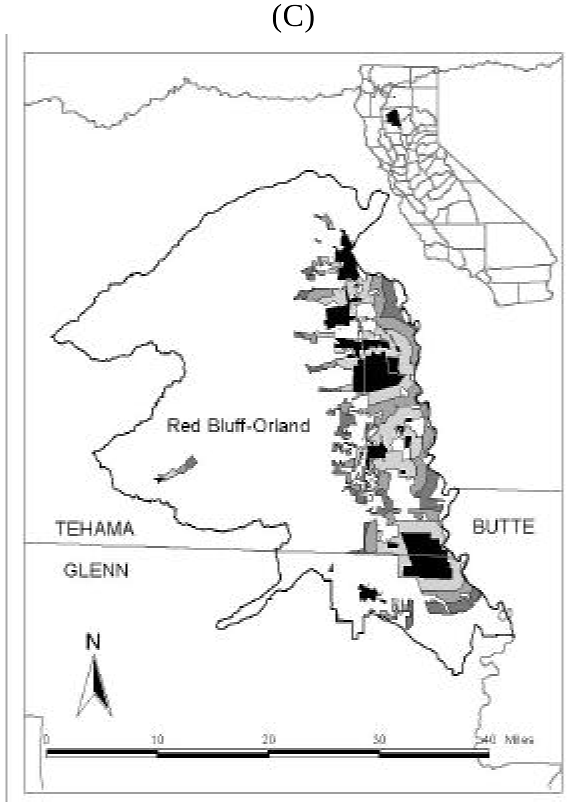
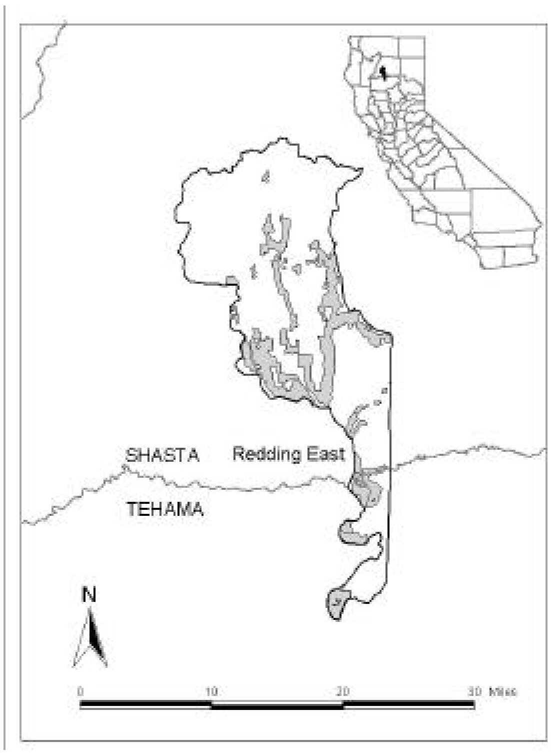


Figure A.3: DAU 143, Redding East, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B)

(A)



(B)

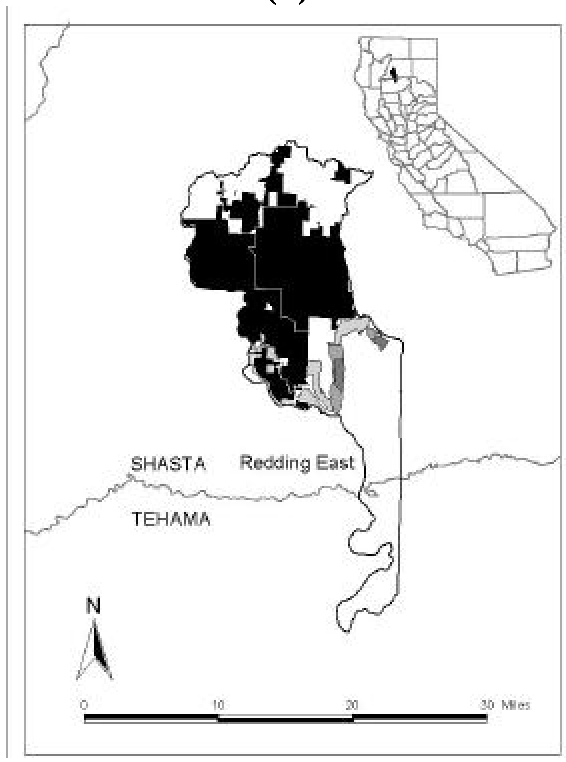
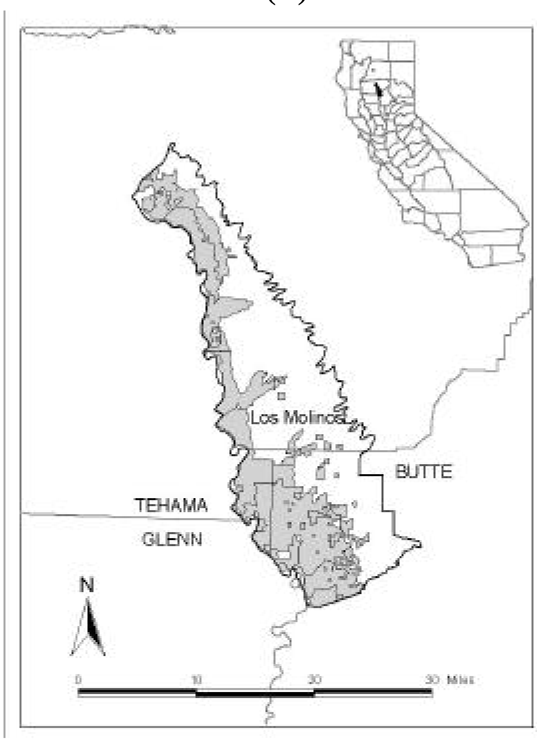
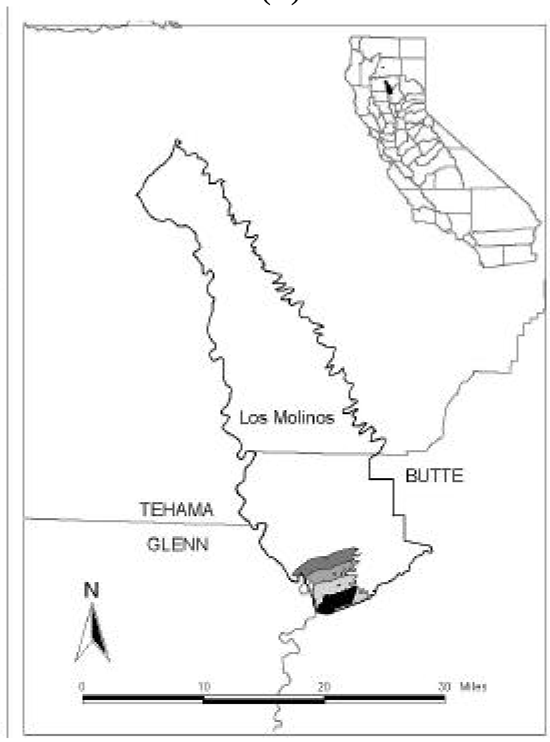


Figure A.4: DAU 144, Los Molinos, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



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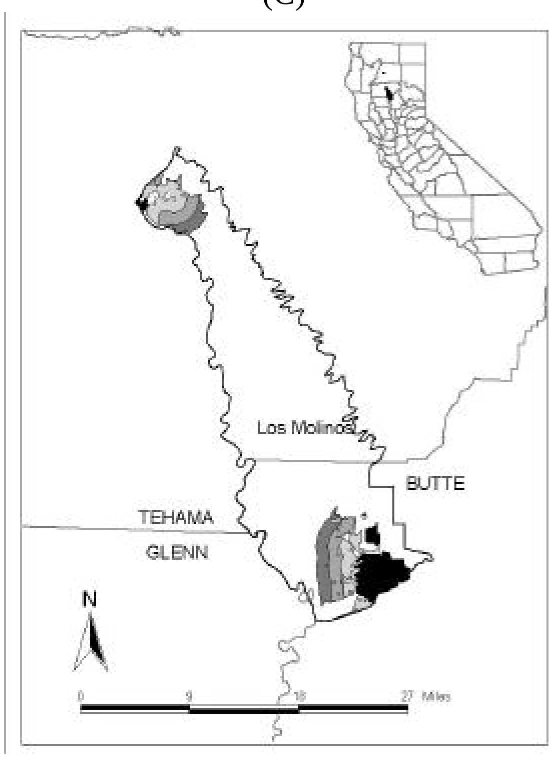
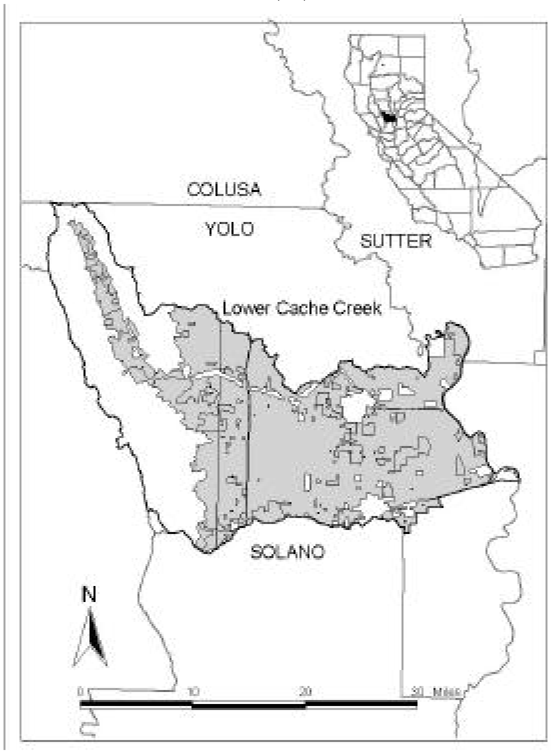


Figure A.5: DAU 162, Lower Cache Creek, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A)



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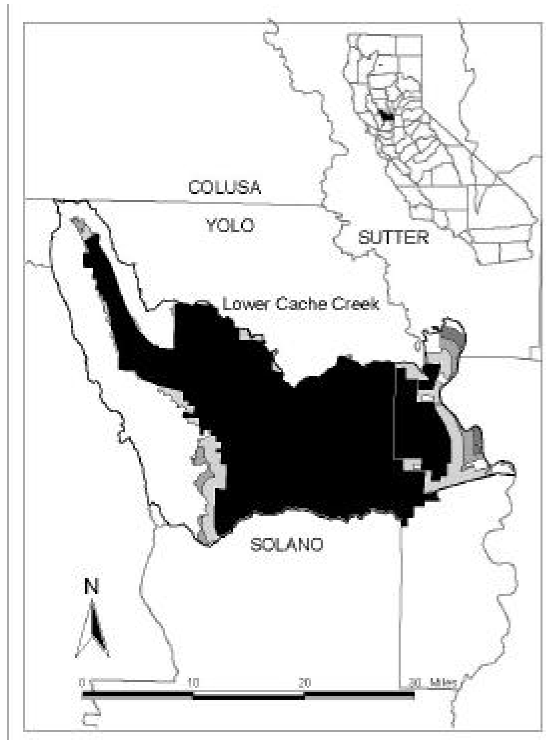
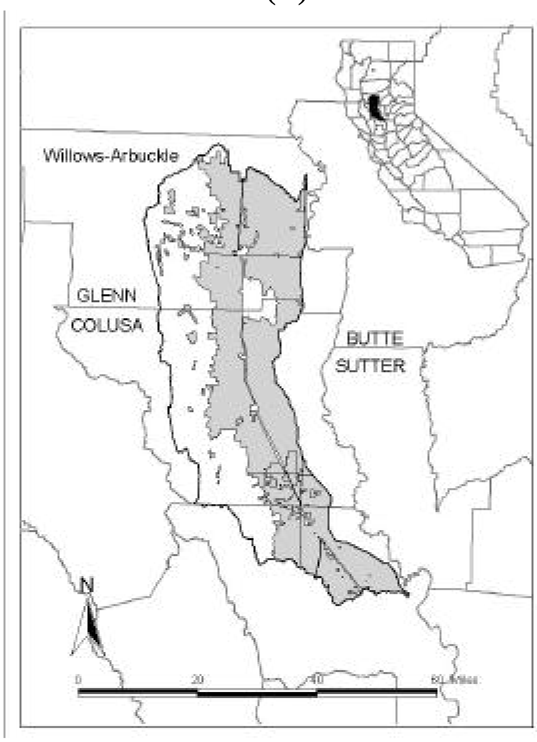


Figure A.6: DAU 163, Willows-Arbuckle, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



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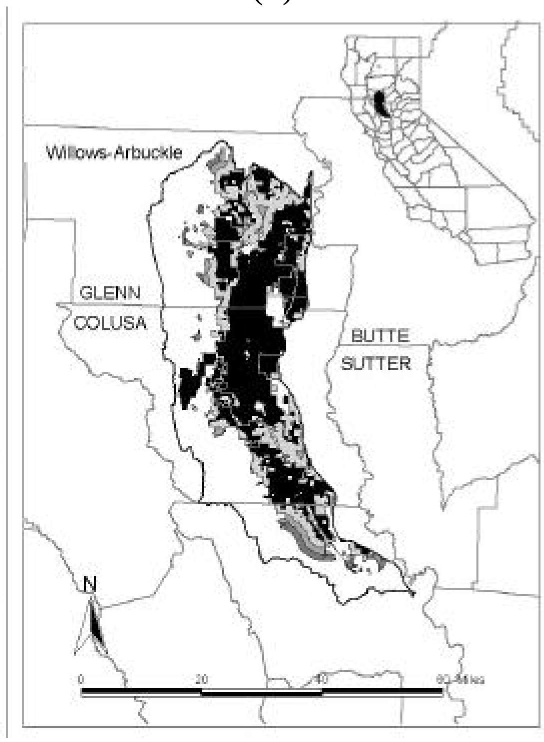


(C)

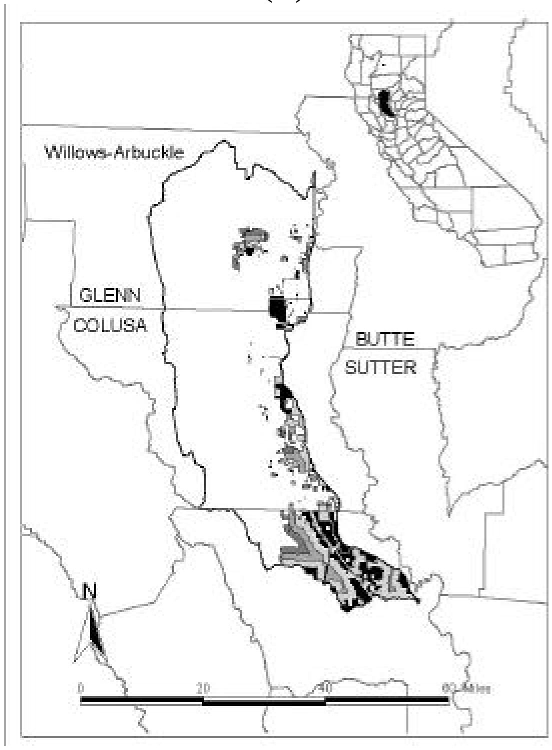
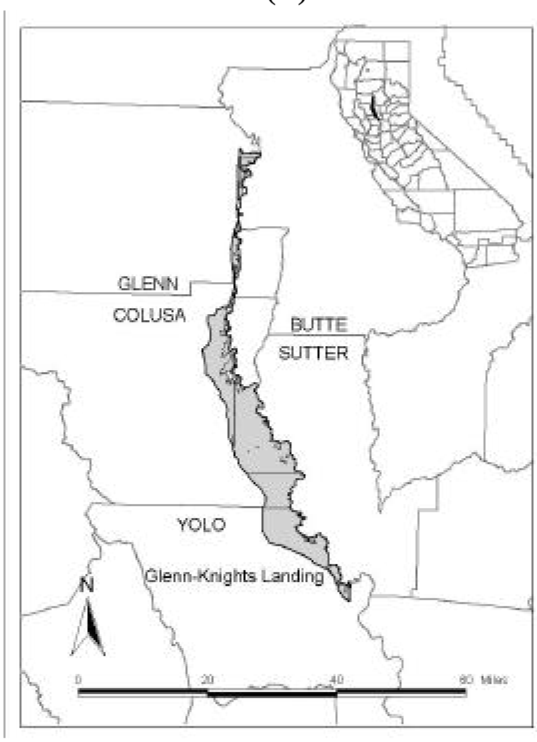


Figure A.7: DAU 164, Glenn-Knights Landing, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



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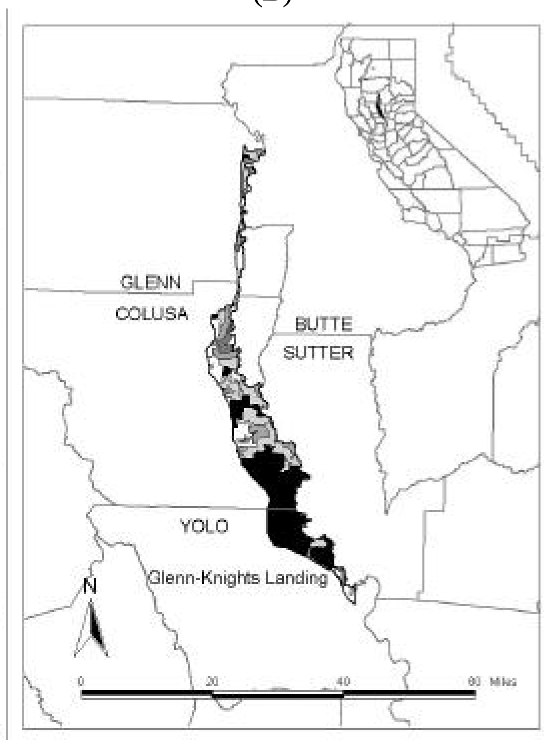


(C)

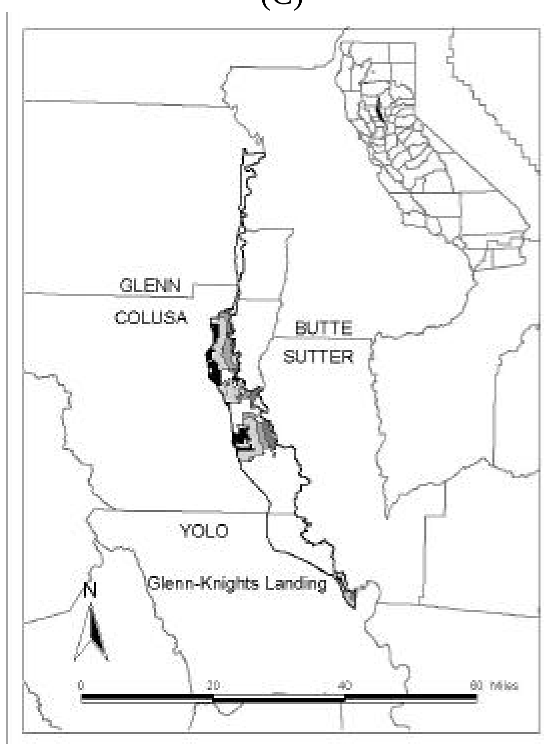
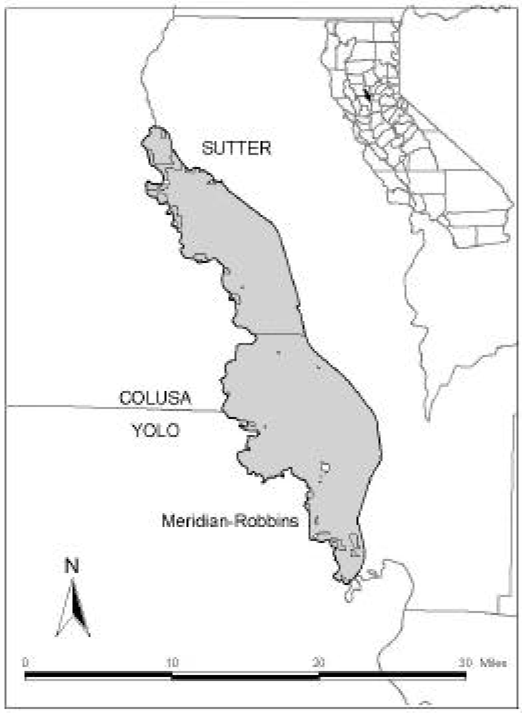
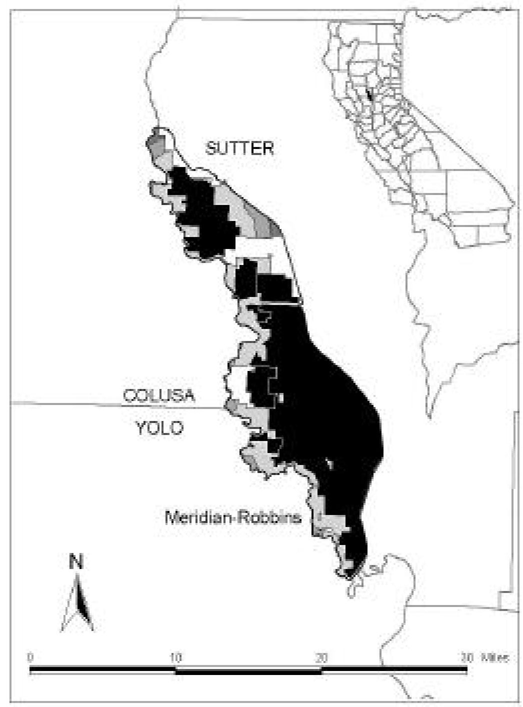


Figure A.8: DAU 165, Meridian-Robbins, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

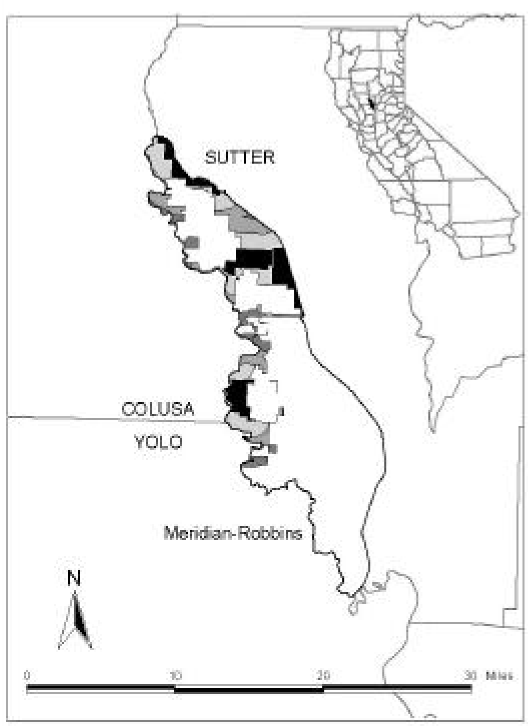
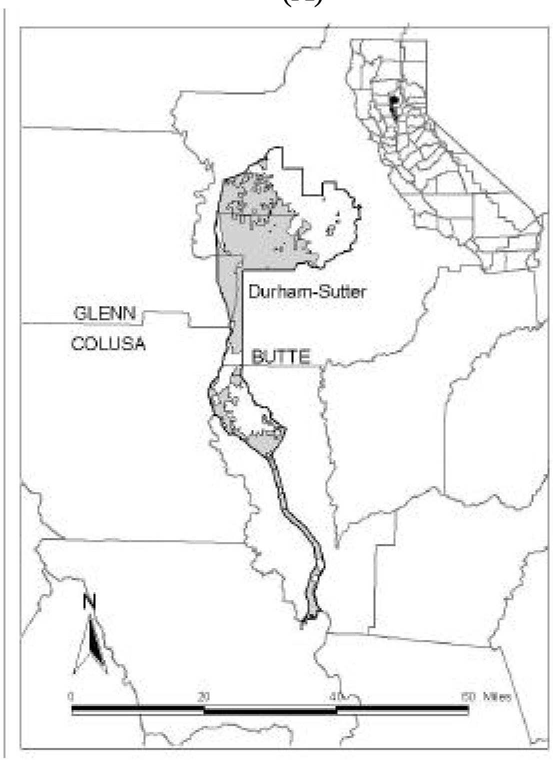
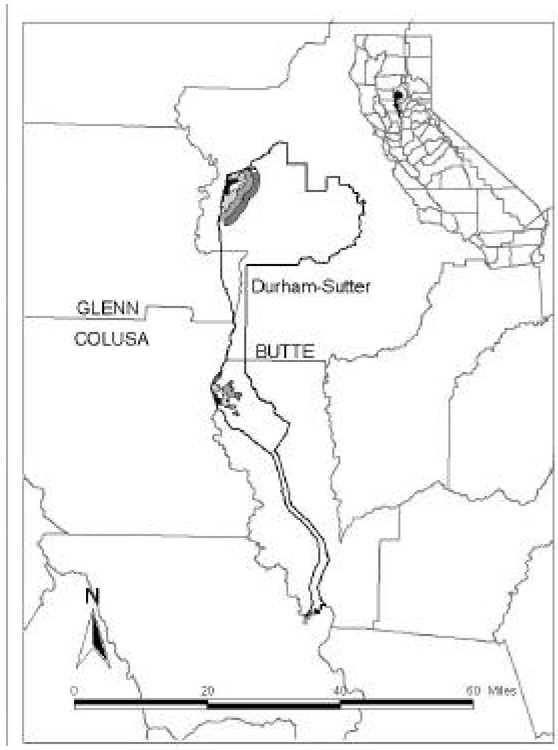


Figure A.9: DAU 166, Durham-Sutter, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

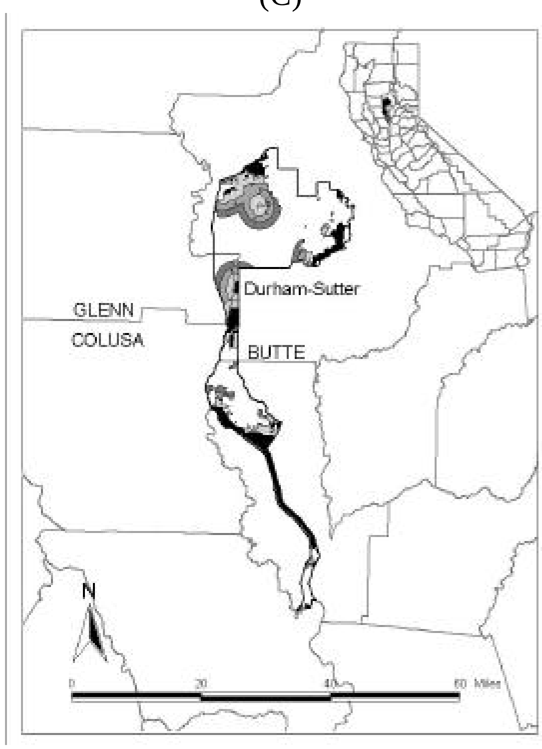


Figure A.10: DAU 167, Butte City, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

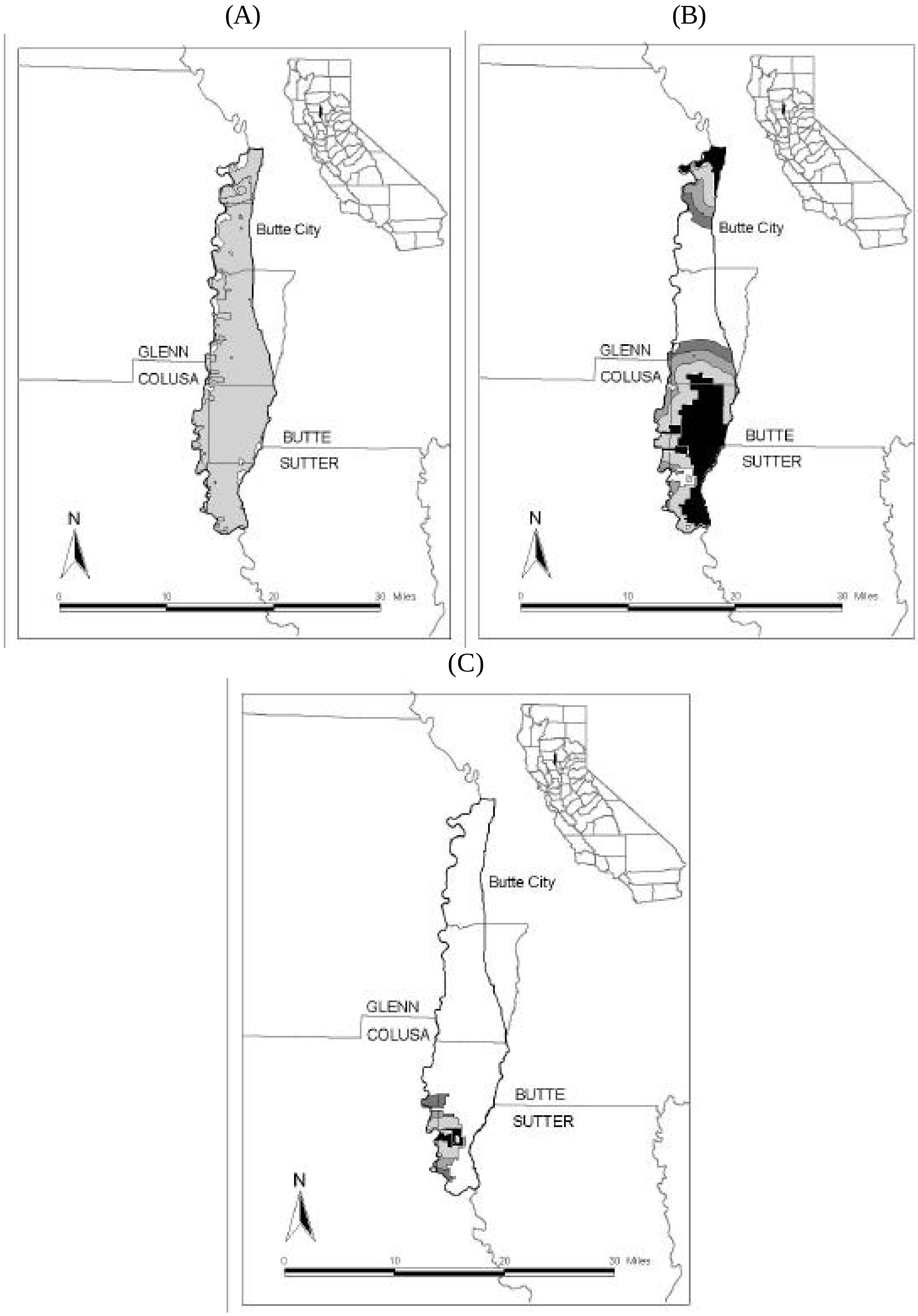
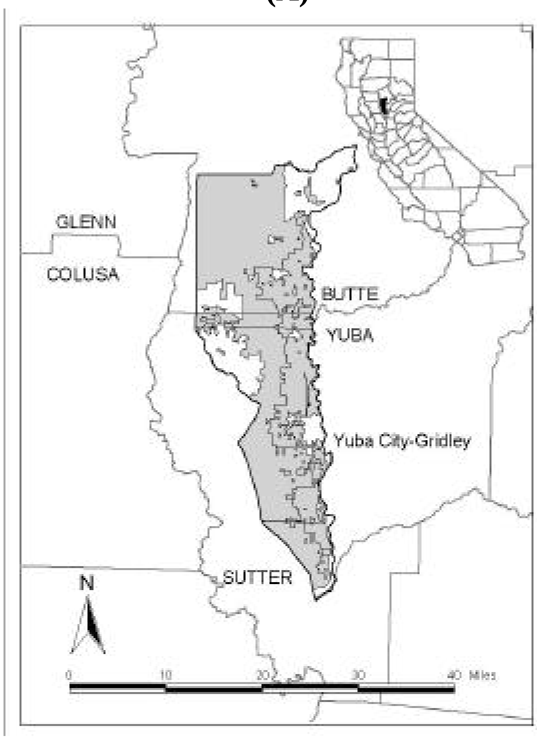
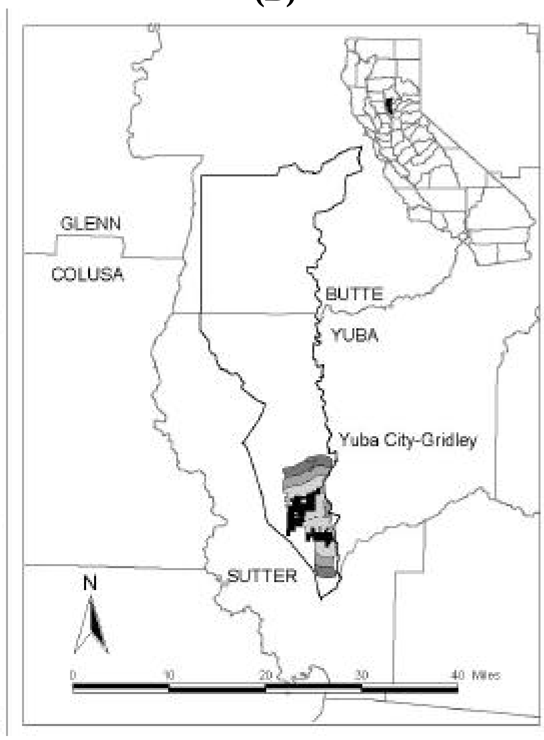


Figure A.11: DAU 168, Yuba City-Gridley, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

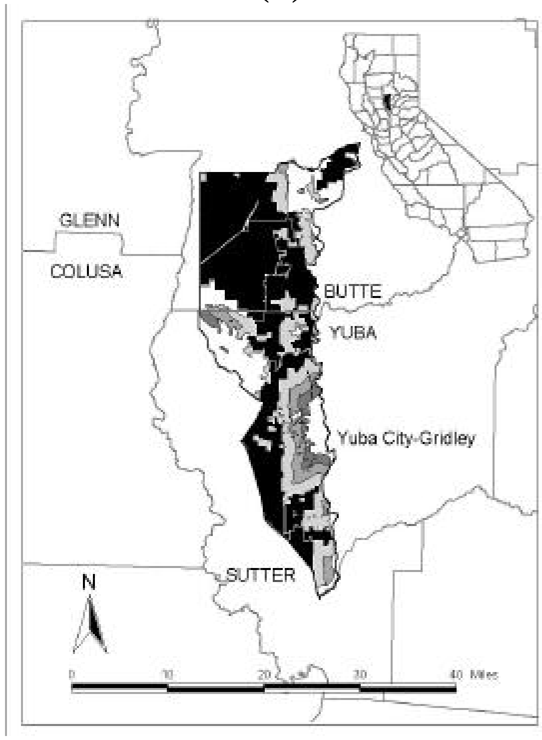


Figure A.12: DAU 170, Honcut Valley, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

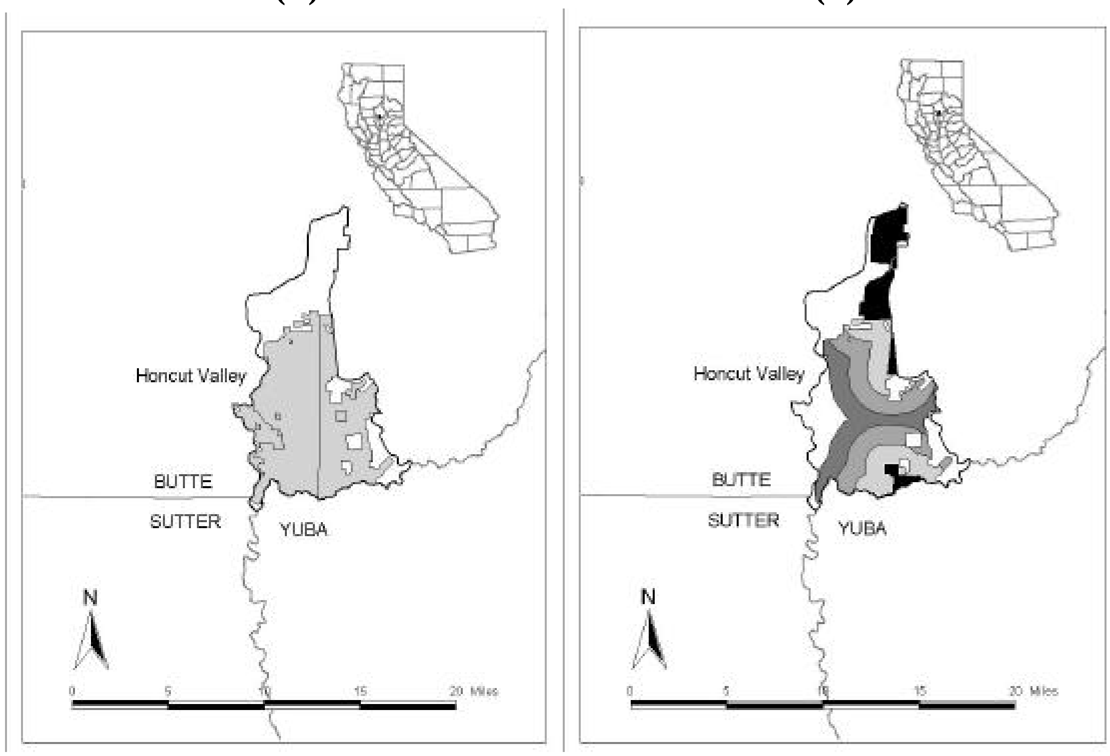


Figure A.13: DAU 171, Yuba, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

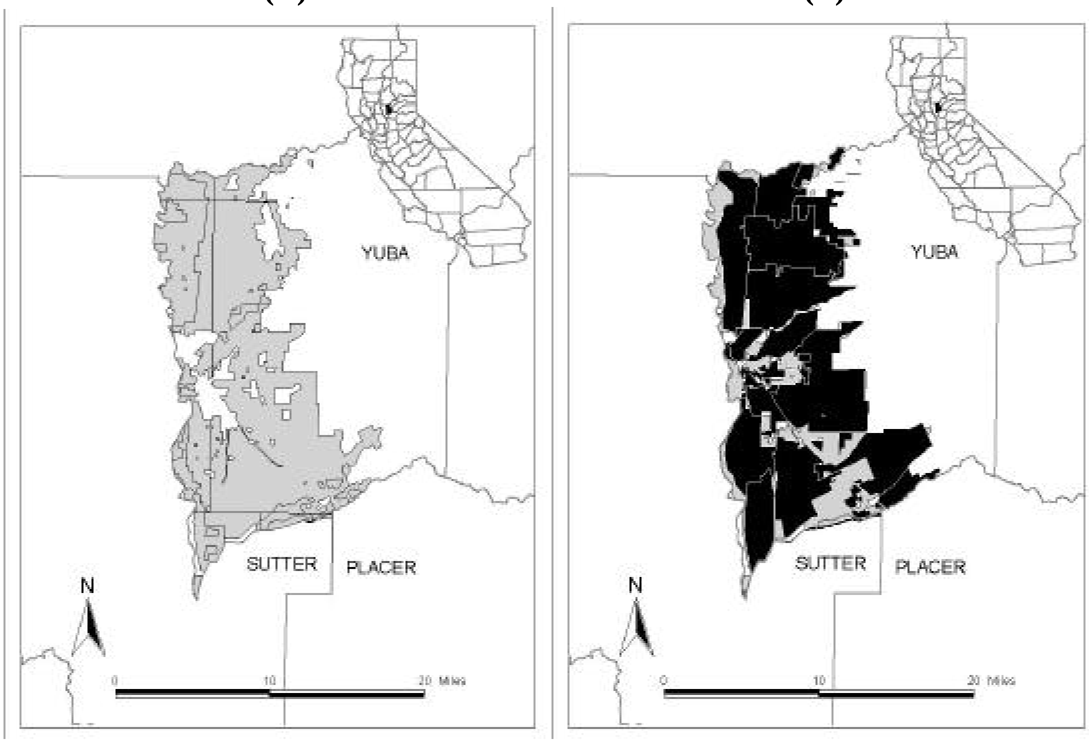
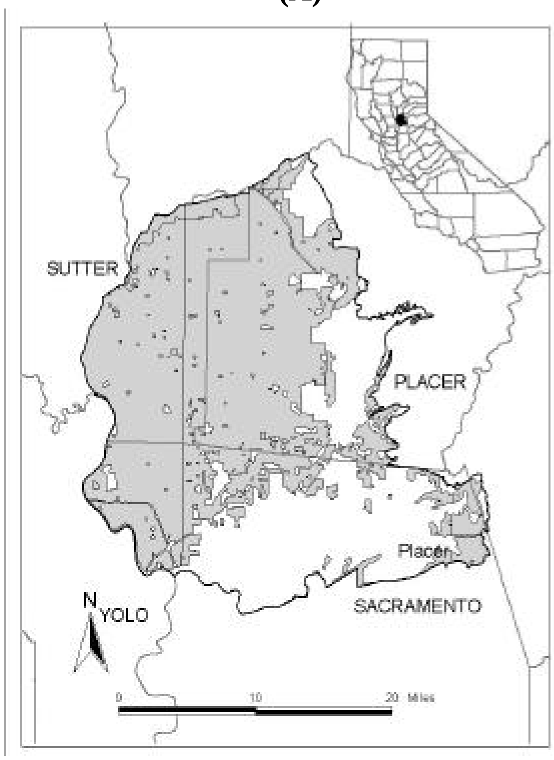
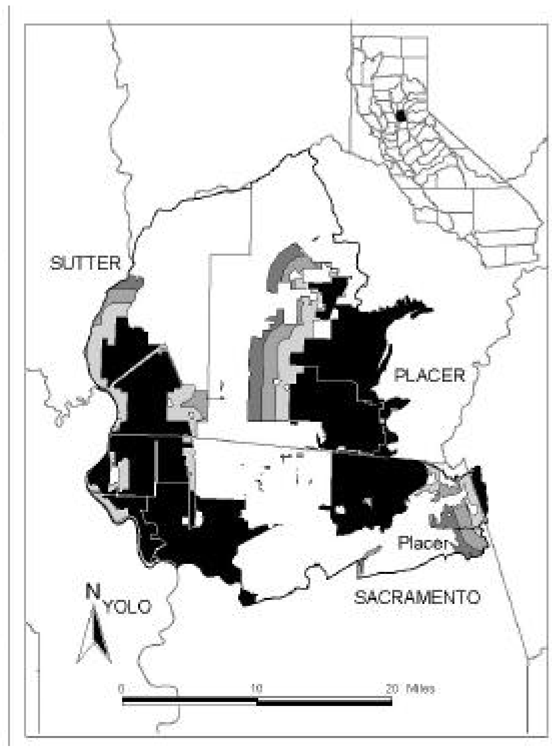


Figure A.14: DAU 172, Placer, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

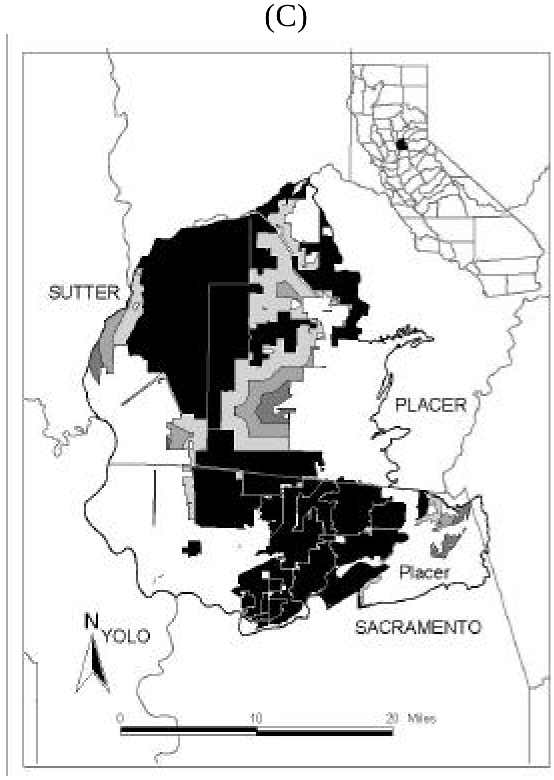
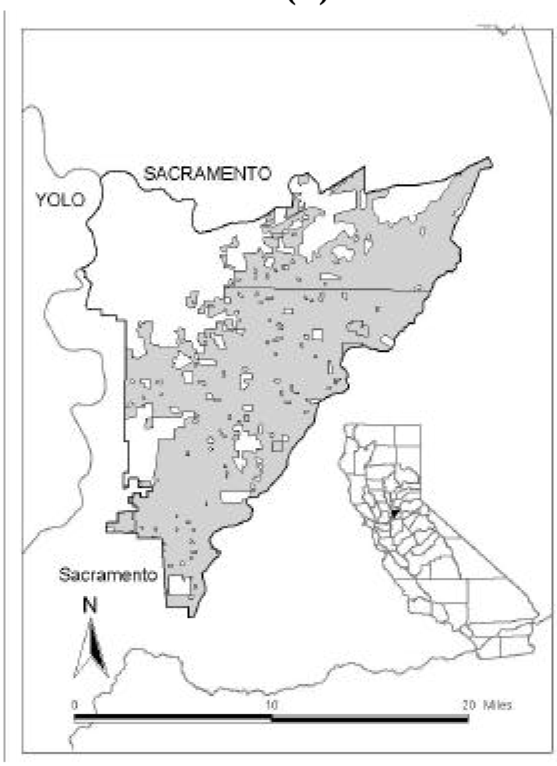
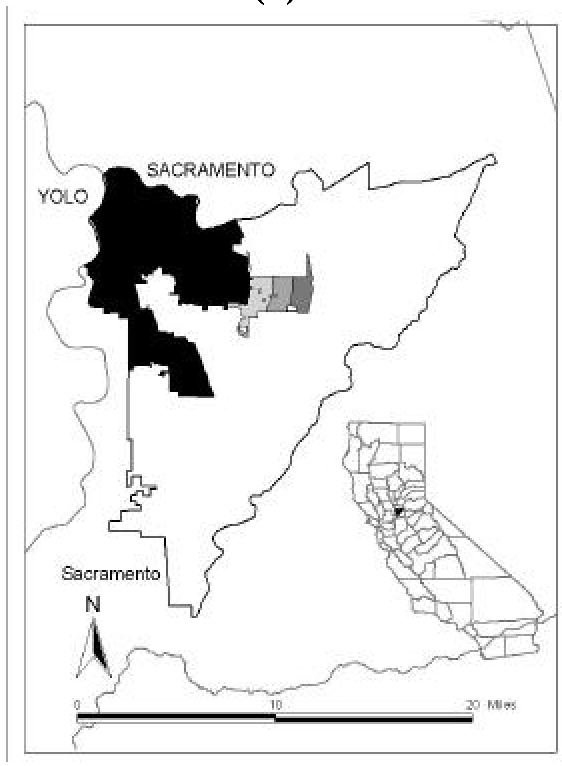


Figure A.15: DAU 173, Sacramento, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

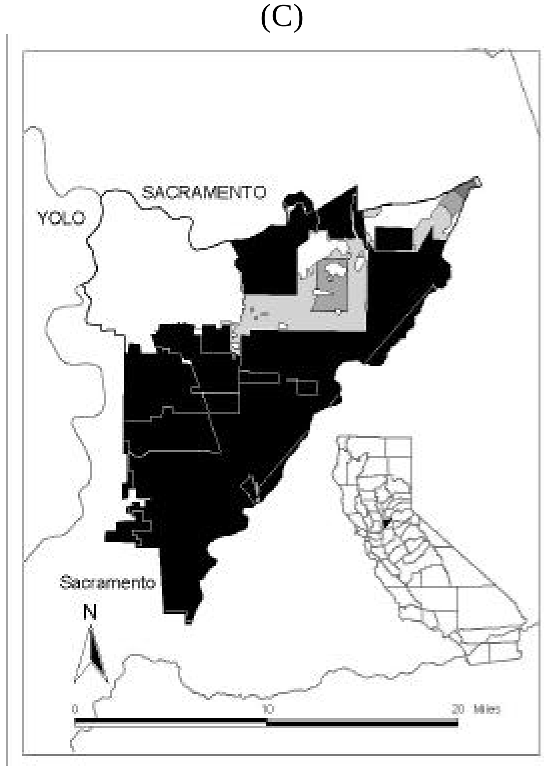
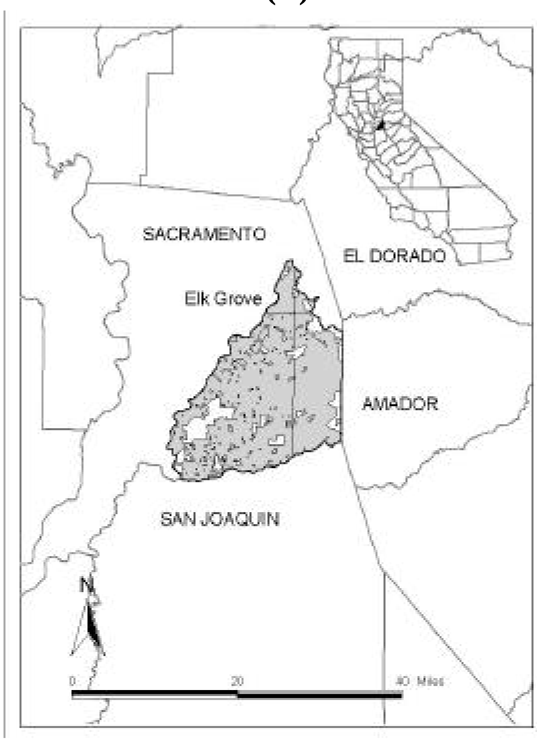


Figure A.16: DAU 181, Elk Grove, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)

(C)

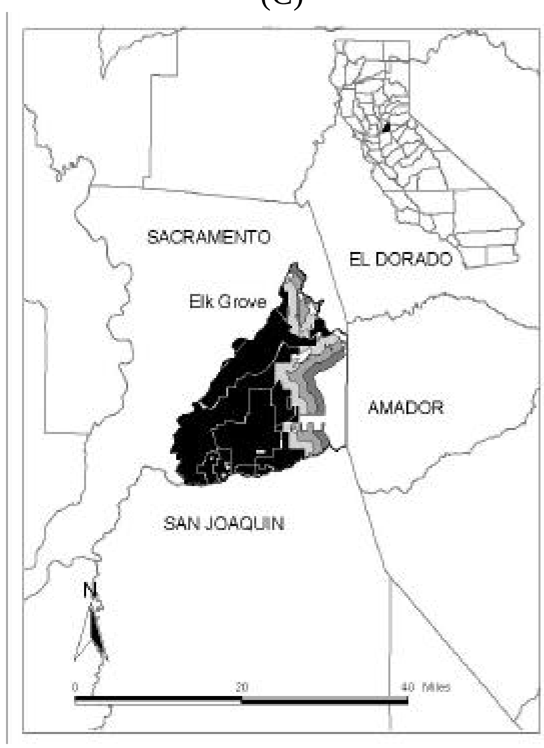


Figure A.17: DAU 181, Ione-Jenny Lind, Water Districts Receiving Water from Private Water Supplies (■) that Cover the Entire Detailed Analysis Unit

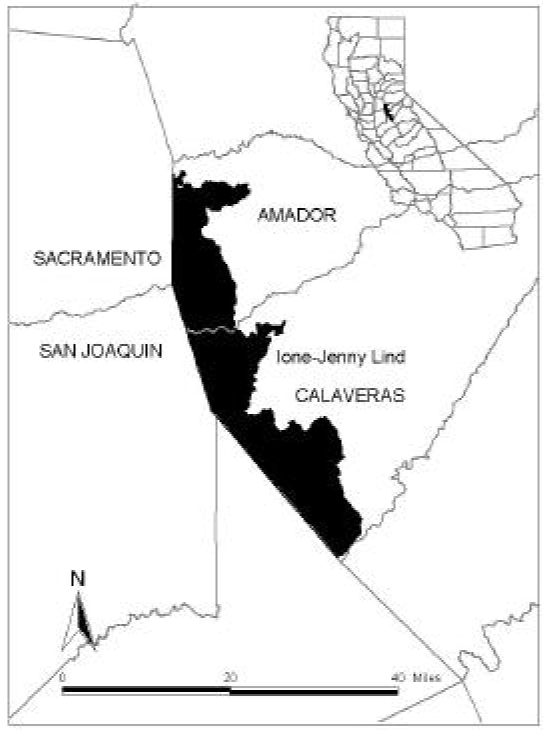
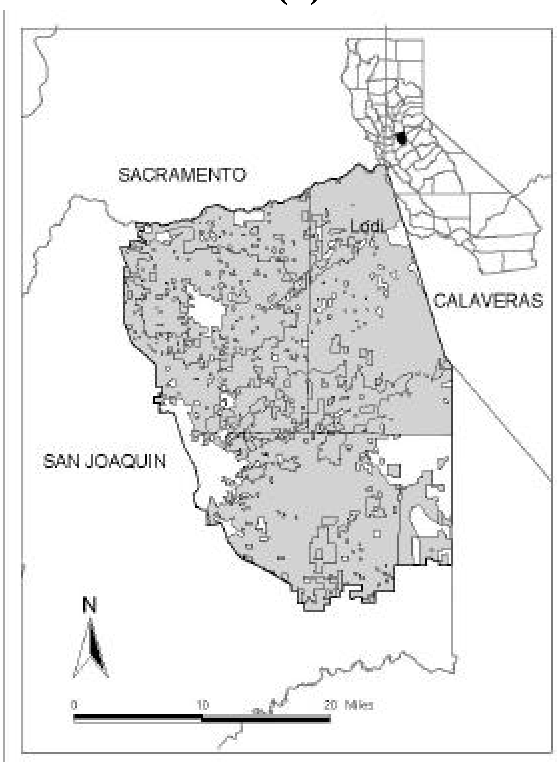
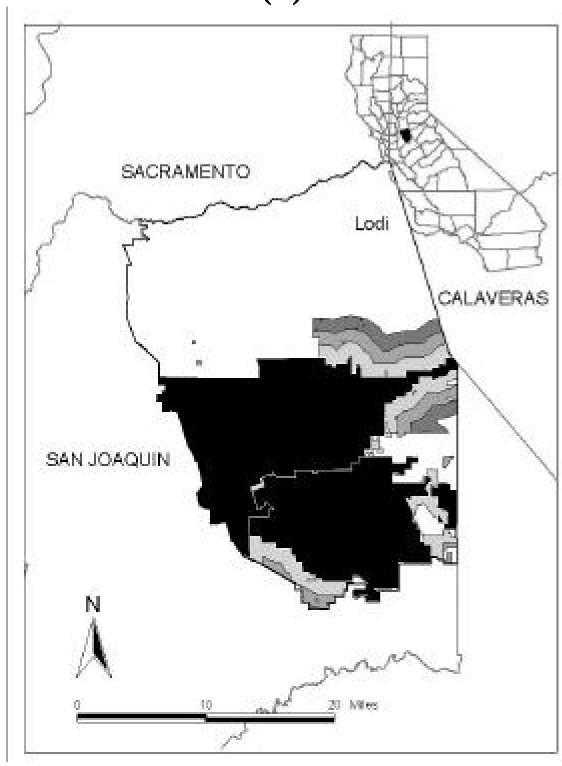


Figure A.18: DAU 182, Lodi, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

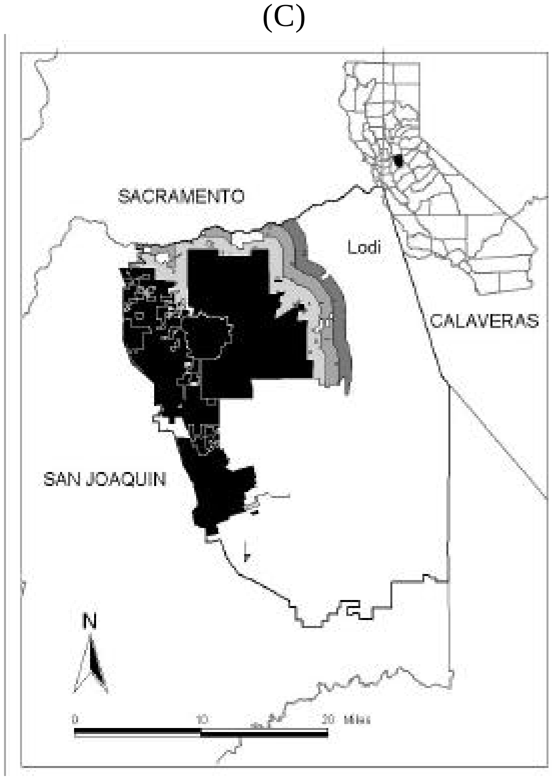


Figure A.19: DAU 184, Bachelor Valley, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

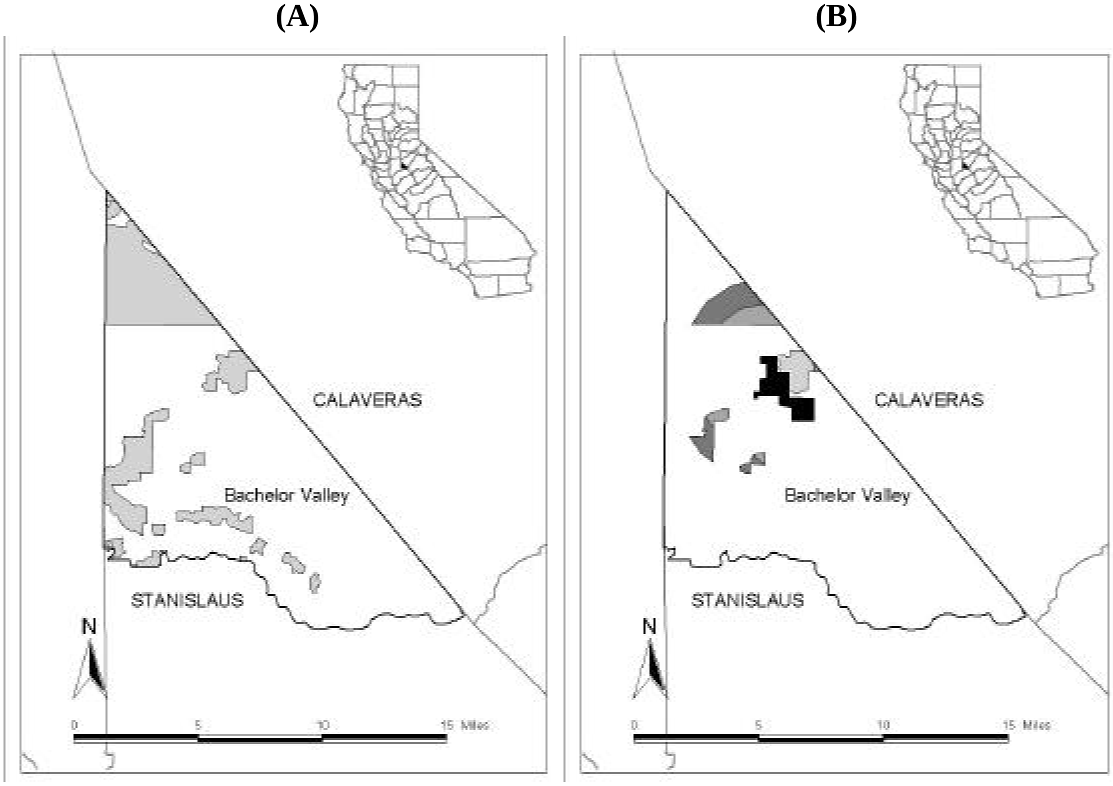
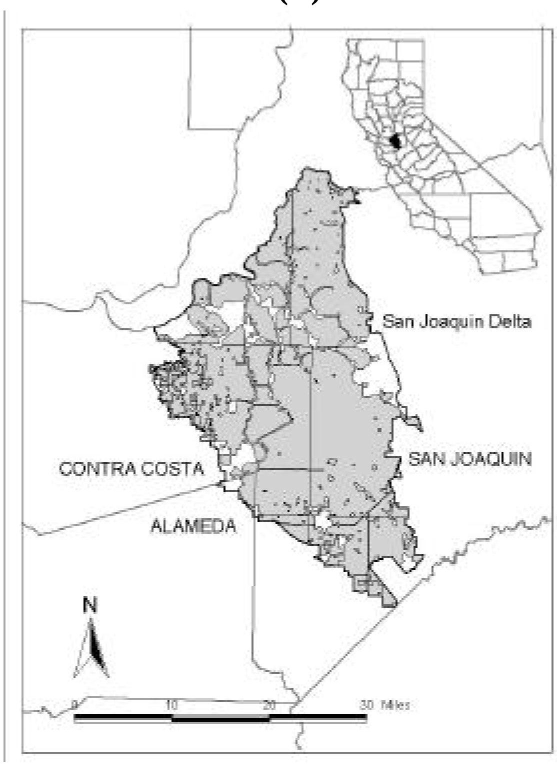
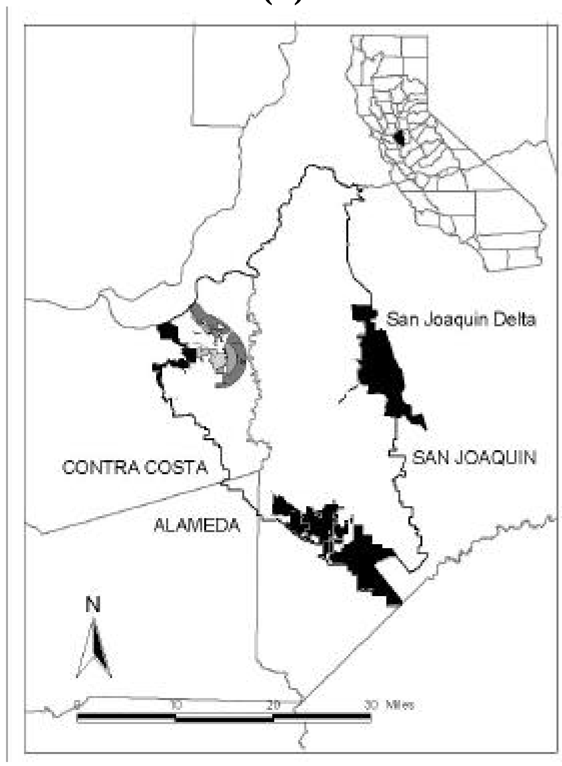


Figure A.20: DAU 185, San Joaquin Delta, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

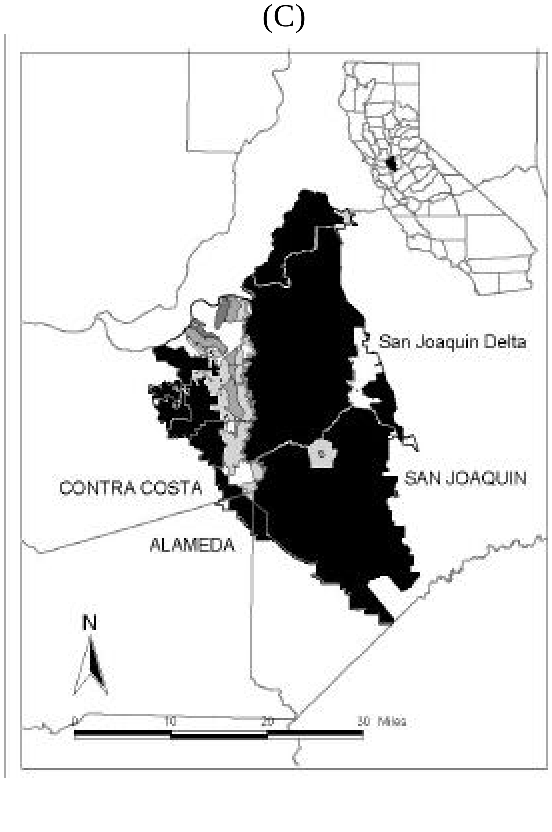
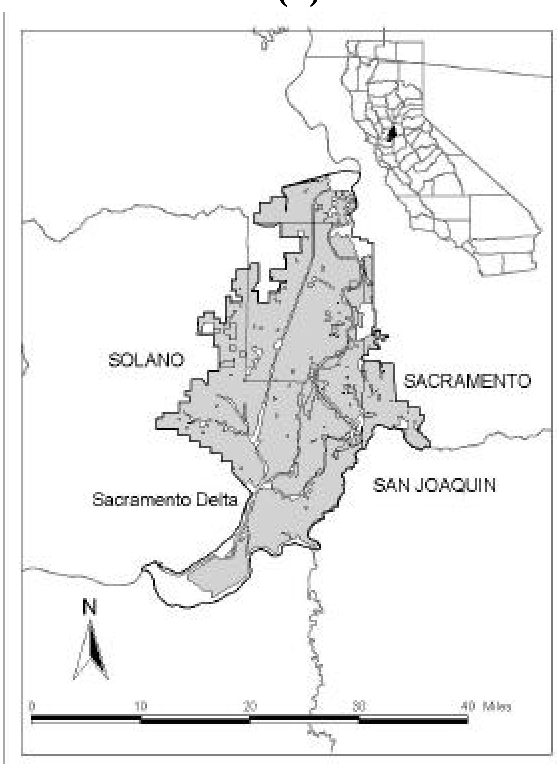


Figure A.21: DAU 186, Sacramento Delta, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)

(C)

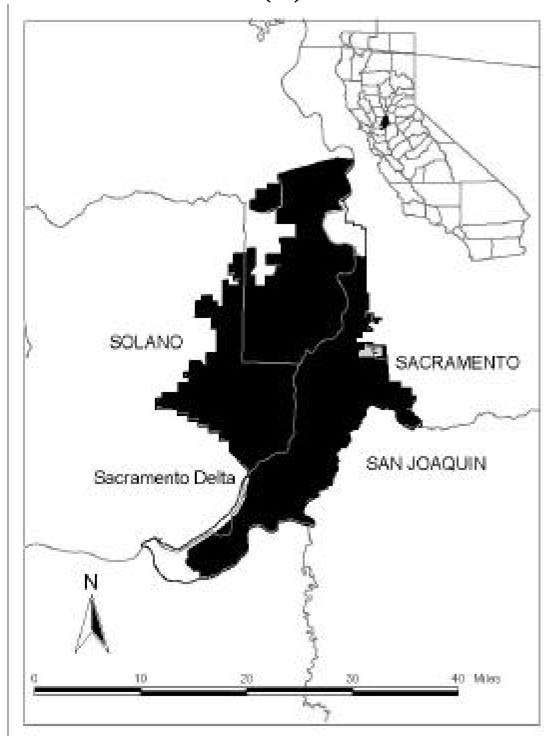
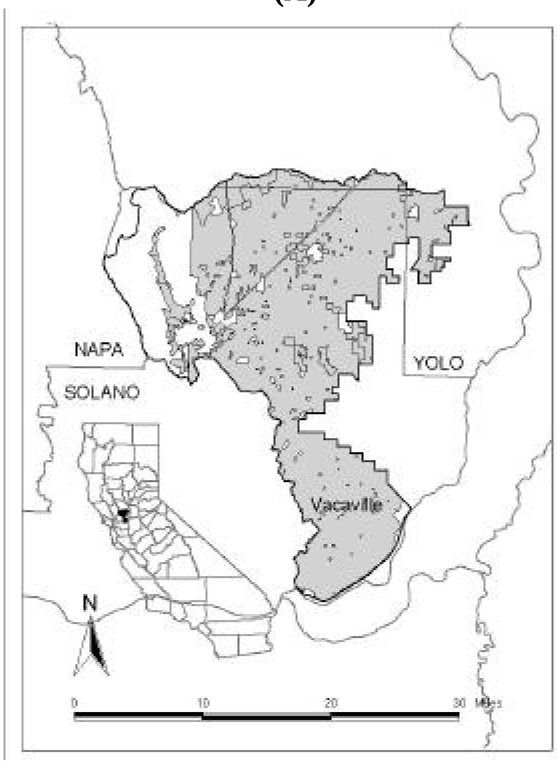
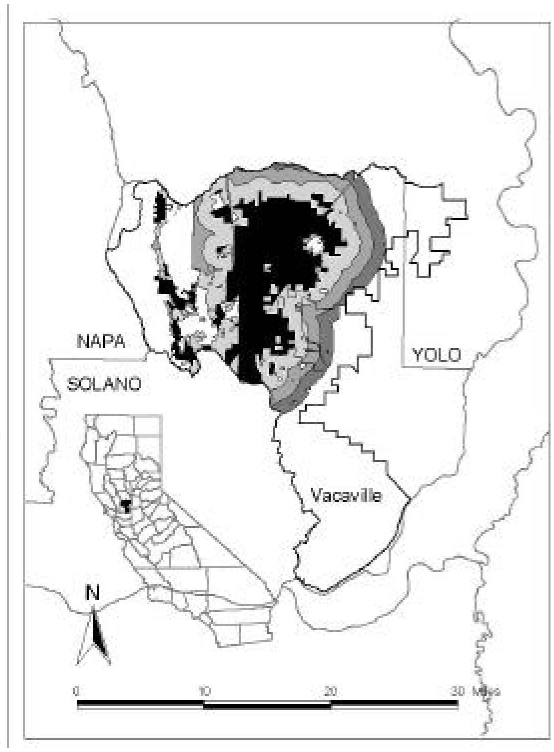


Figure A.22: DAU 191, Vacaville, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

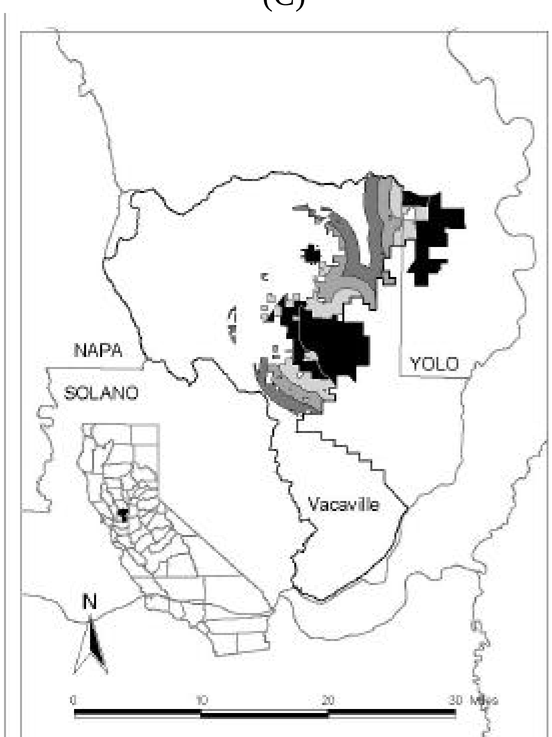
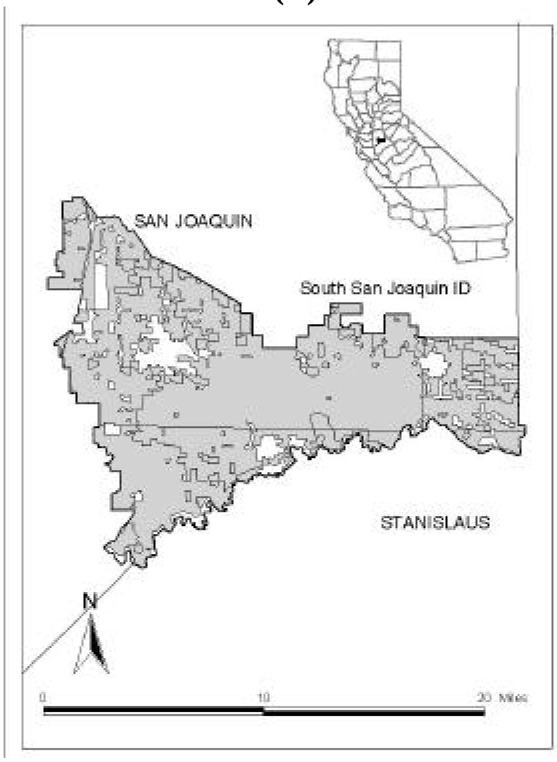
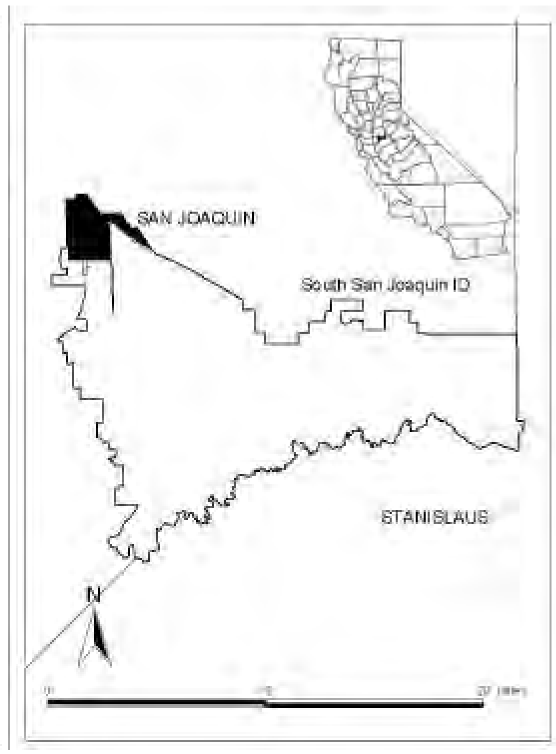


Figure A.23: DAU 205, South San Joaquin ID, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

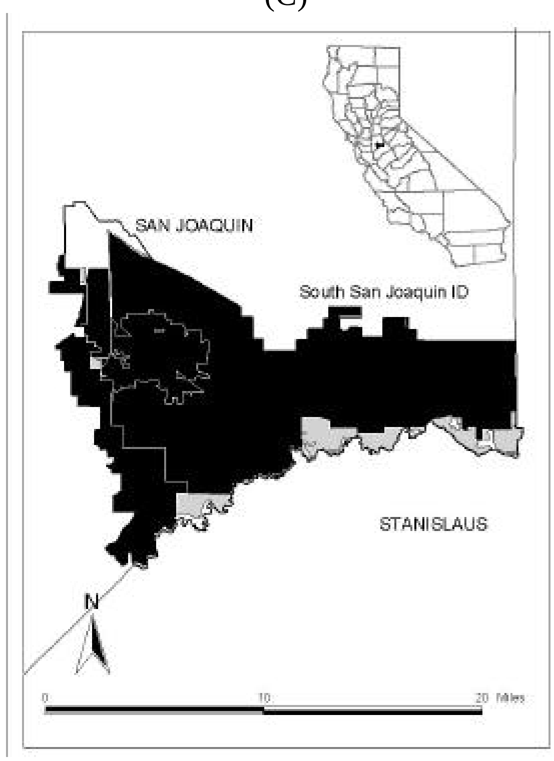


Figure A.24: DAU 206, Modesto-Oakdale, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

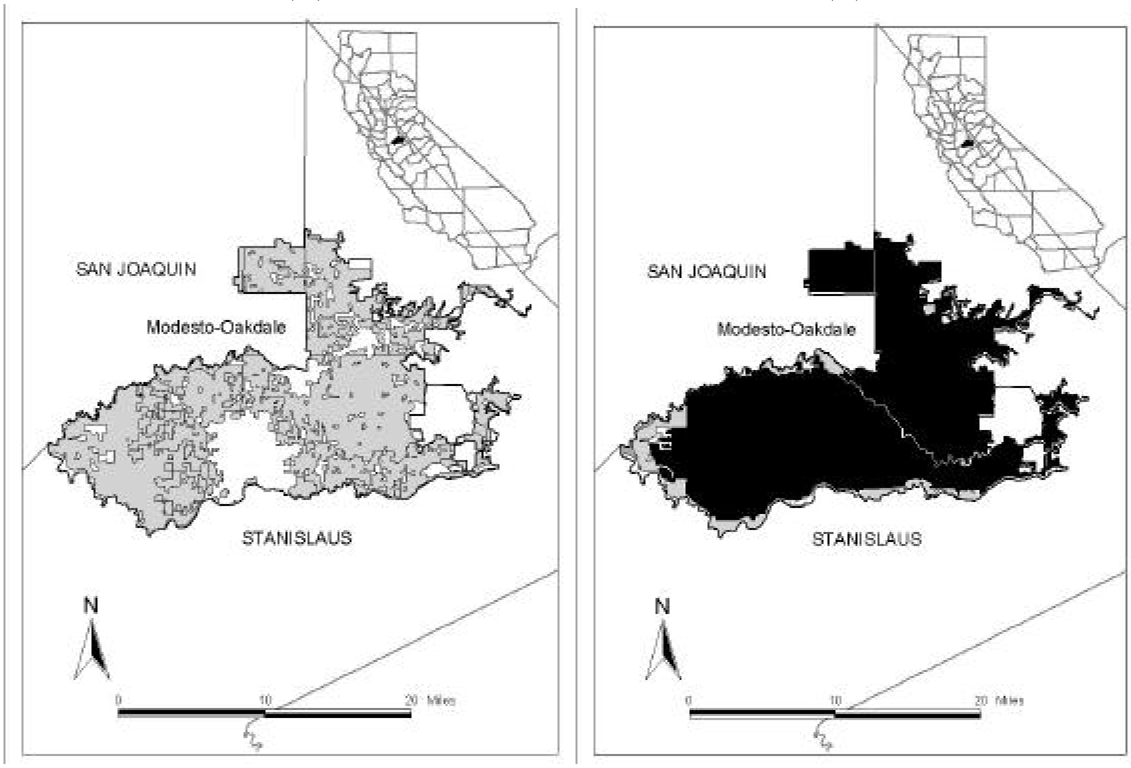


Figure A.25: DAU 207, Modesto Reservoir, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

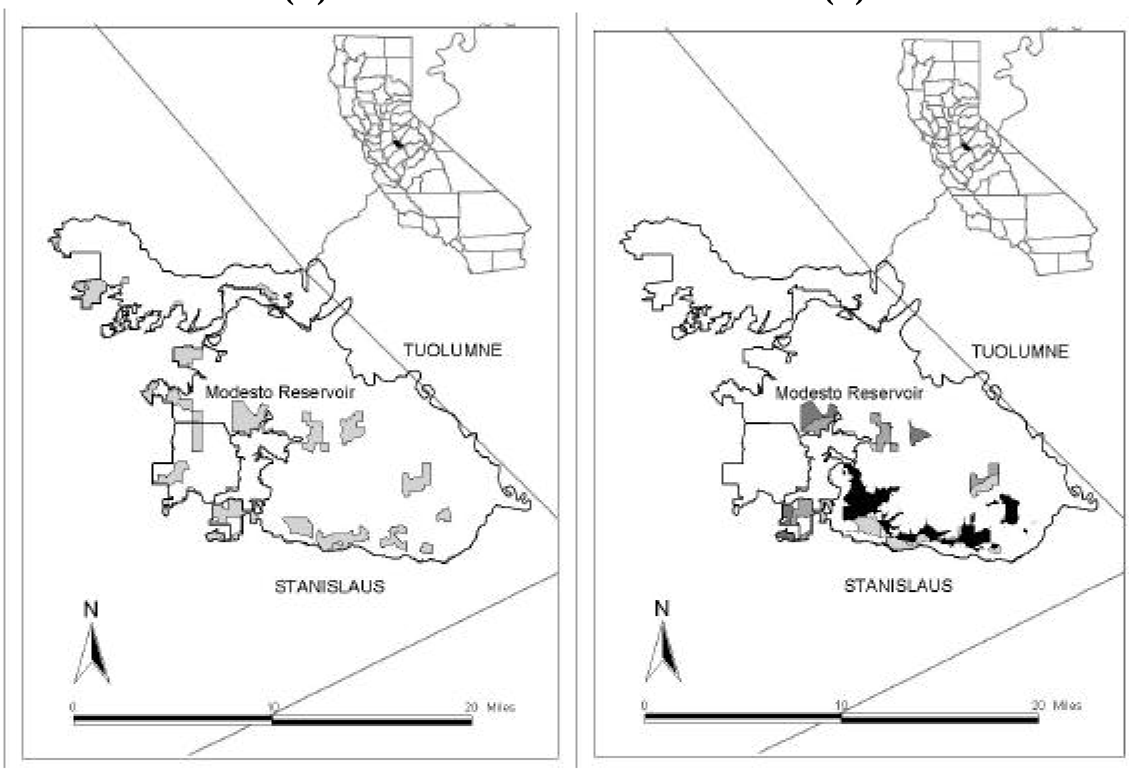


Figure A.26: DAU 208, Turlock, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

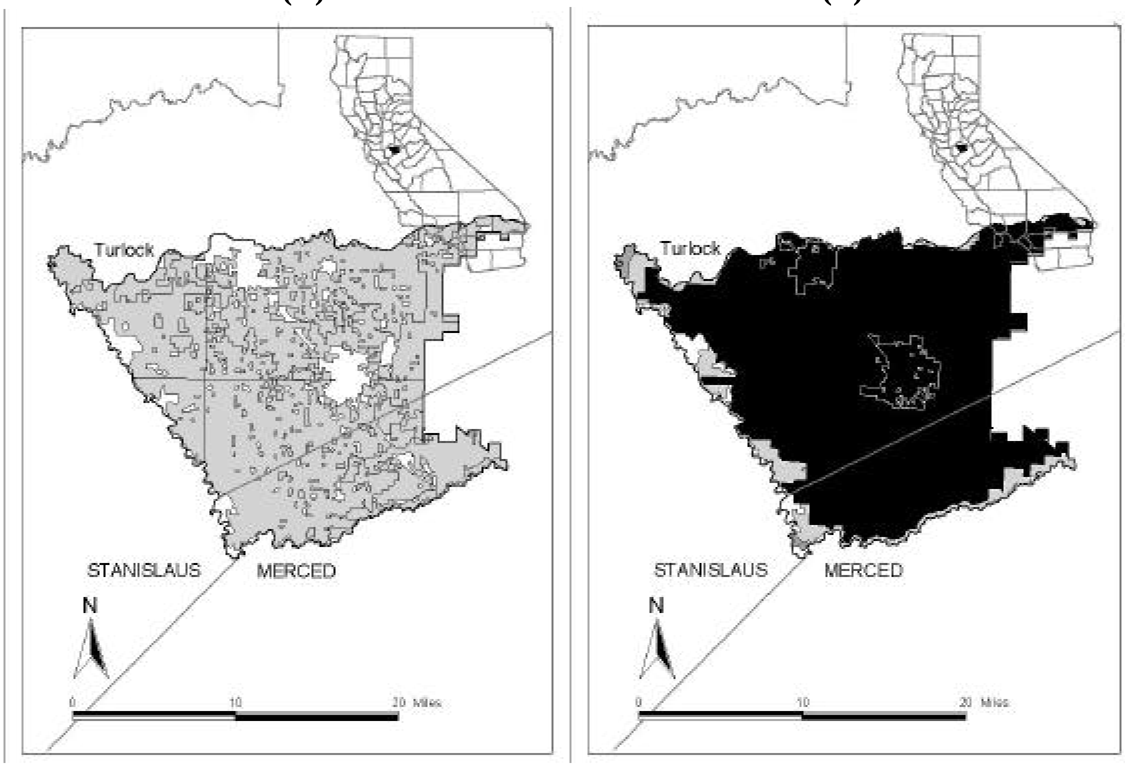


Figure A.27: DAU 209, Turlock Lake, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

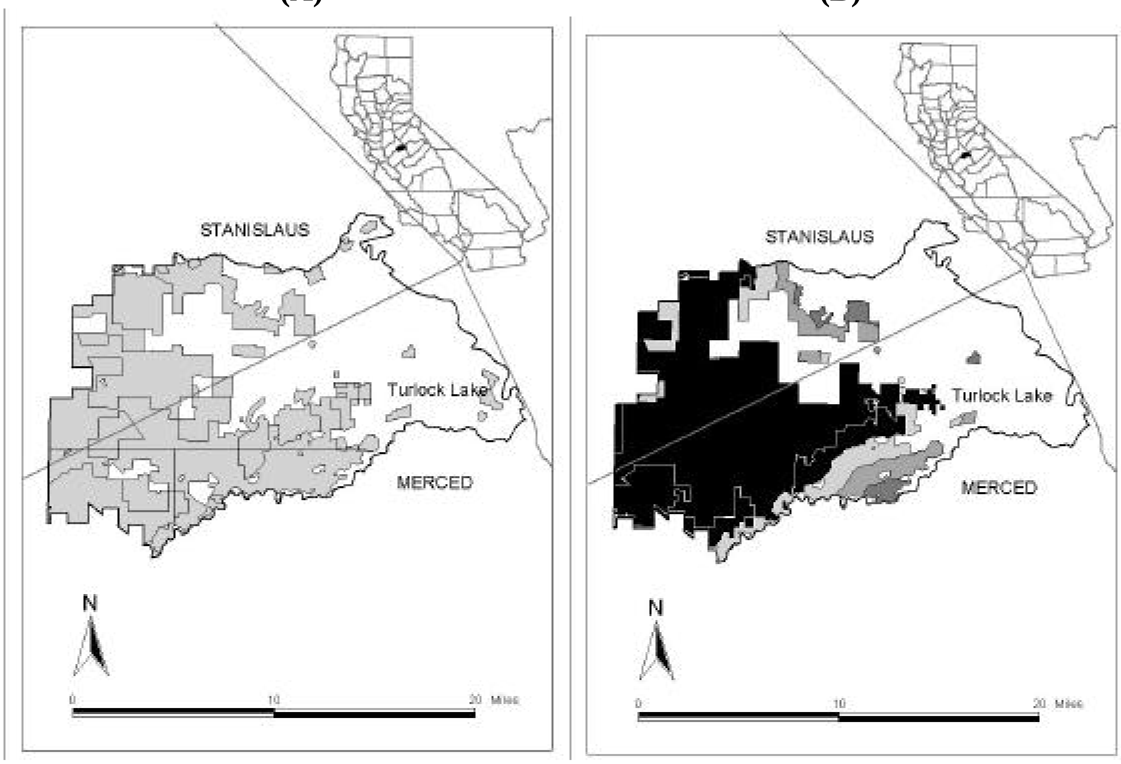


Figure A.28: DAU 210, Merced, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

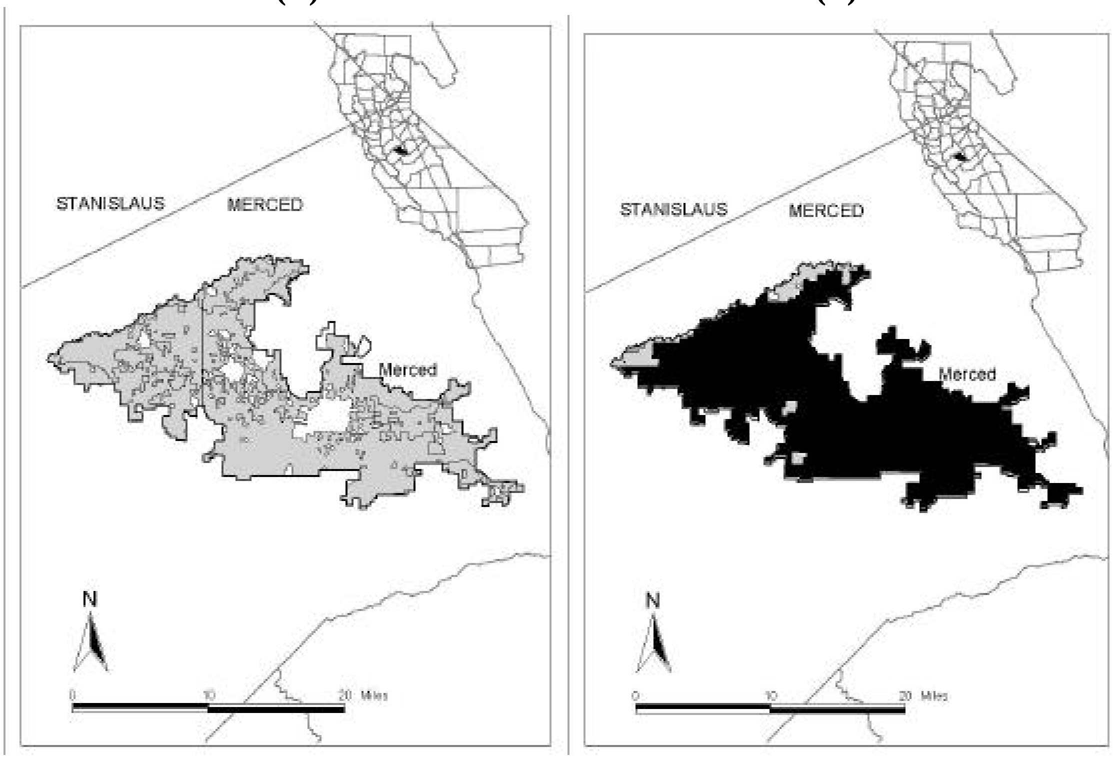
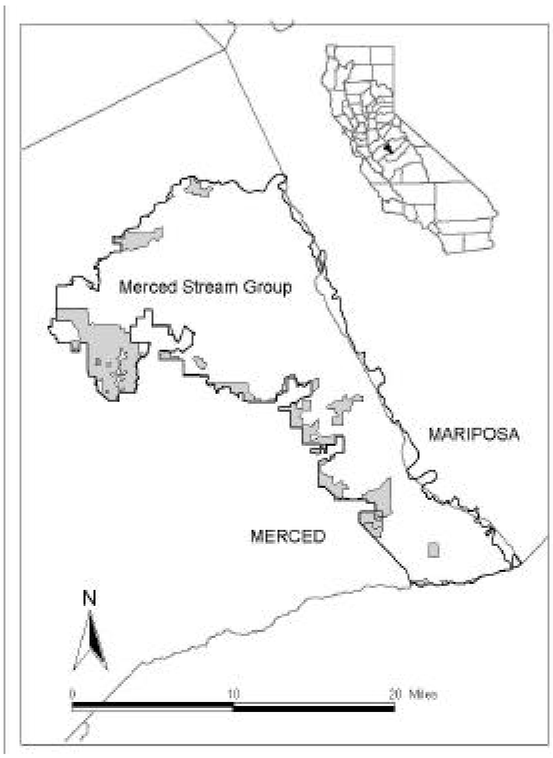
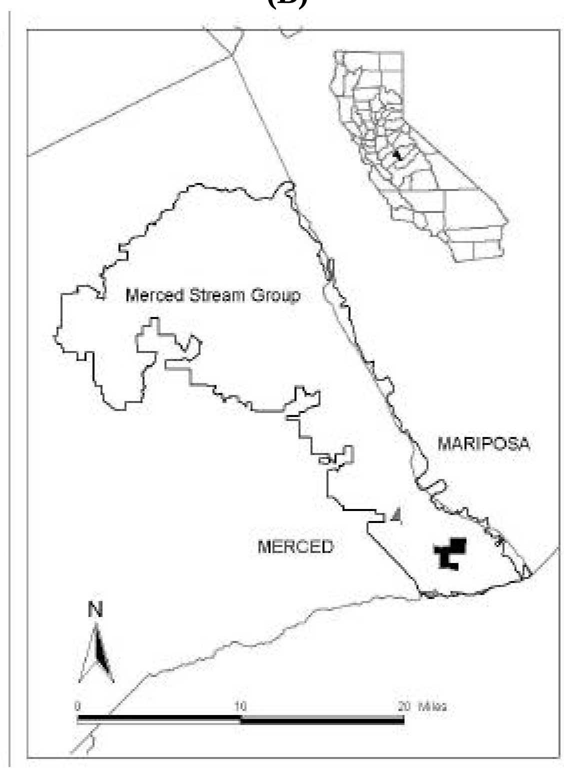


Figure A.29: DAU 211, Merced Stream Group, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

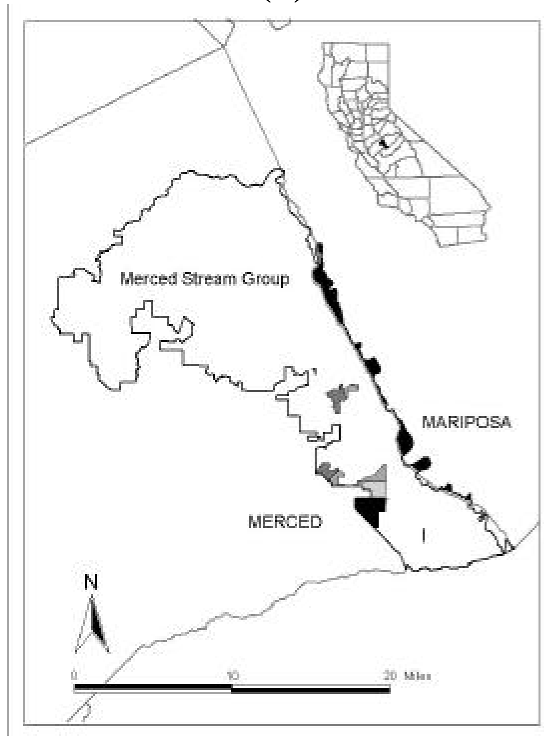
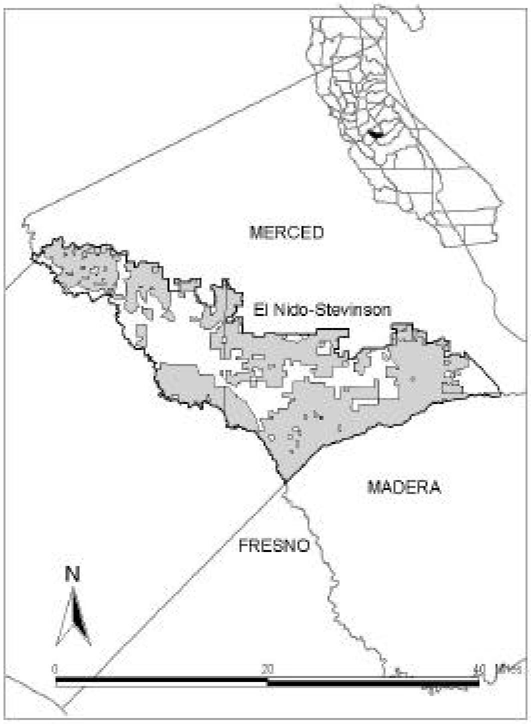
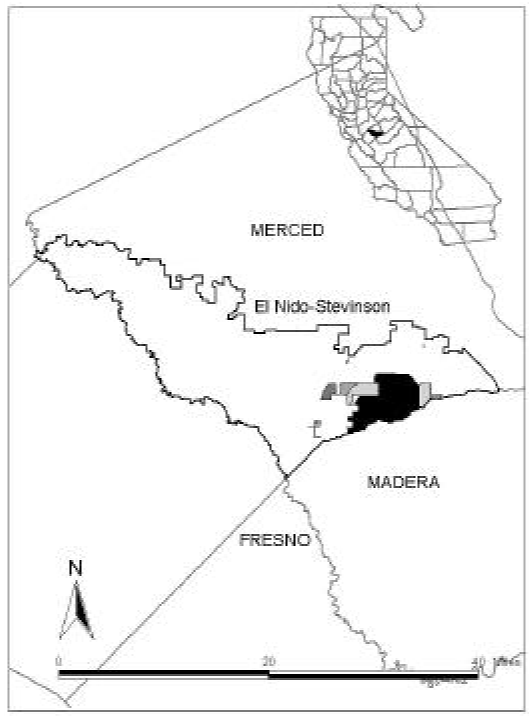


Figure A.30: DAU 212, El Nido-Stevinson, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ), and 3 ( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

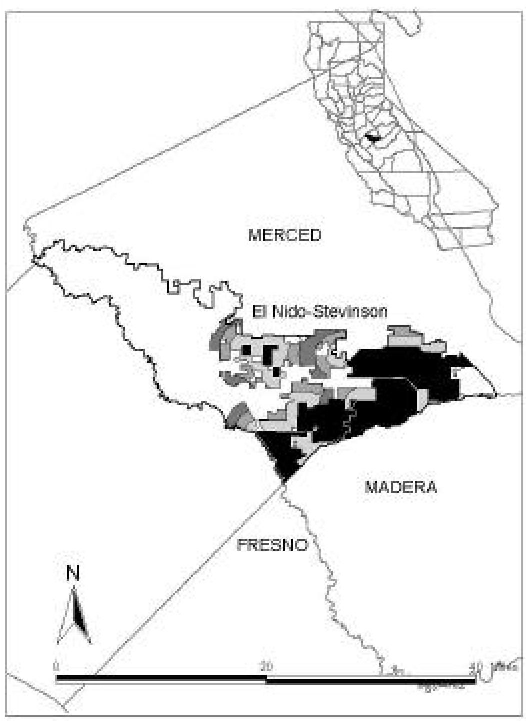
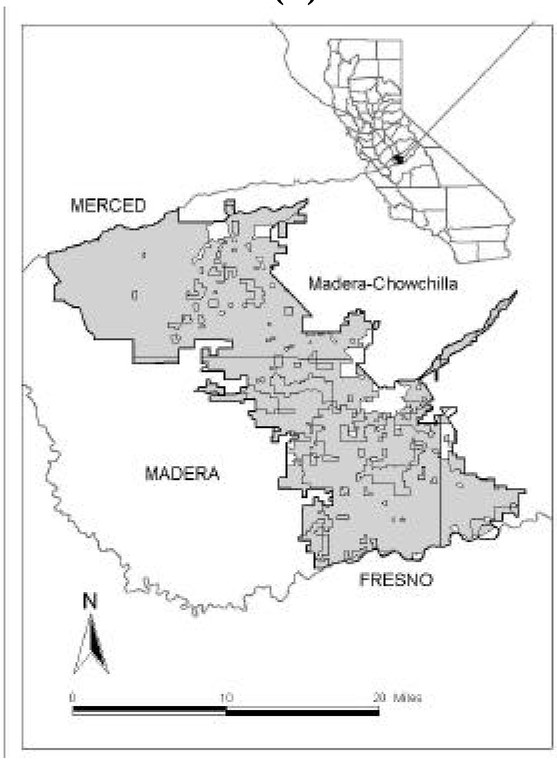
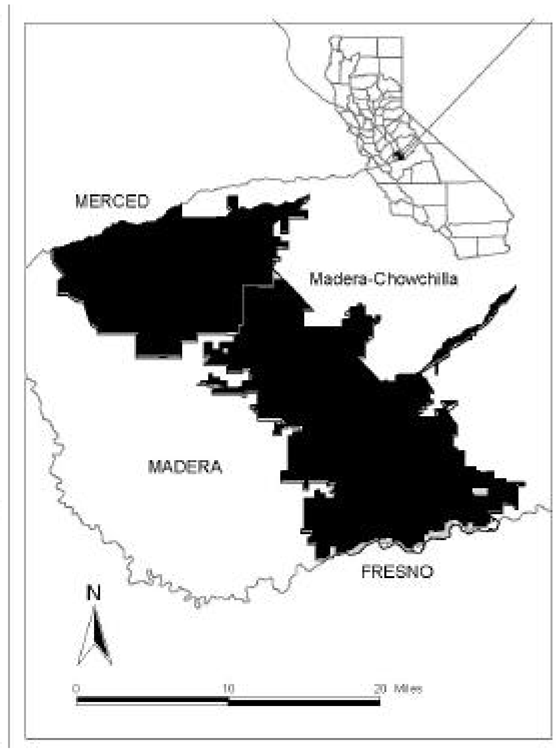


Figure A.31: DAU 213, Madera-Chowchilla, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ), and 3 ( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

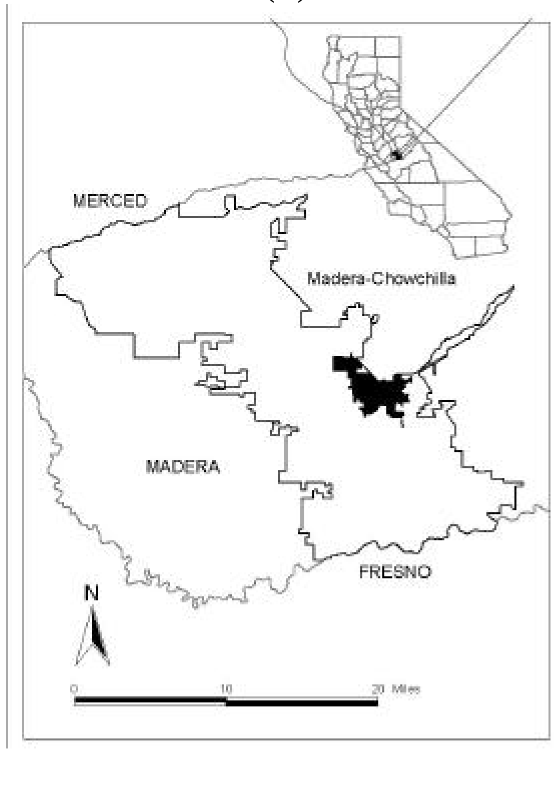
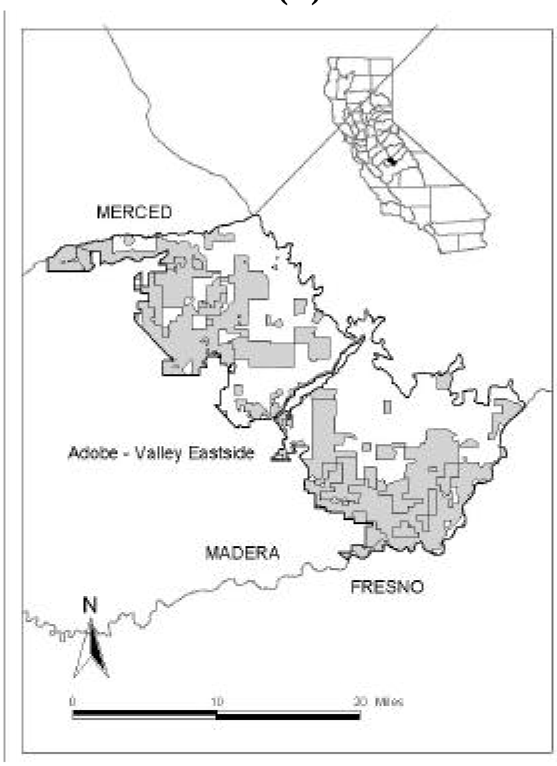
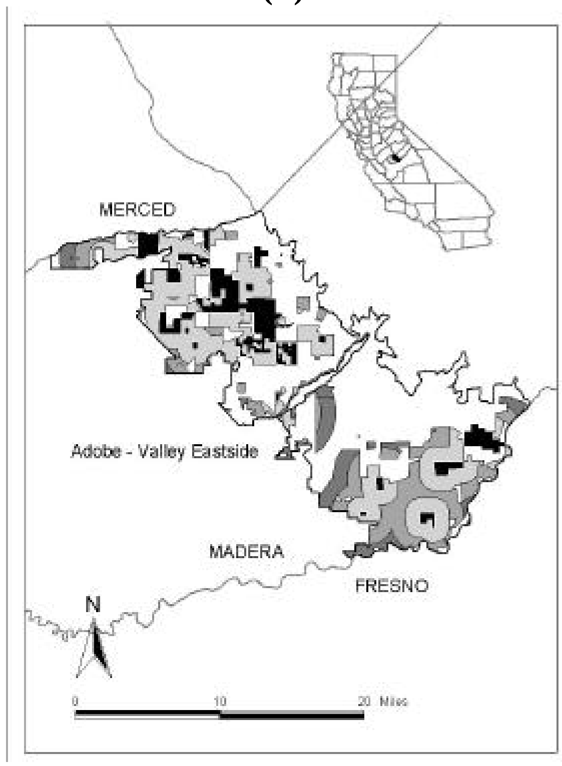


Figure A.32: DAU 214, Adobe-Valley Eastside, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

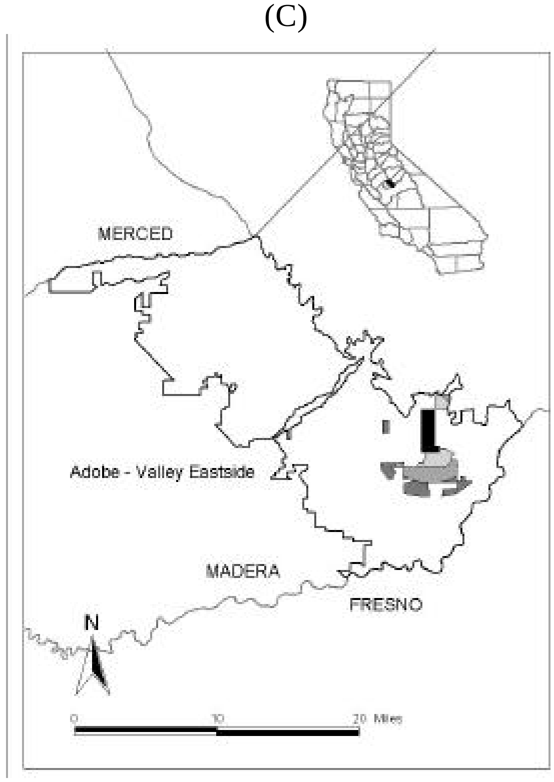
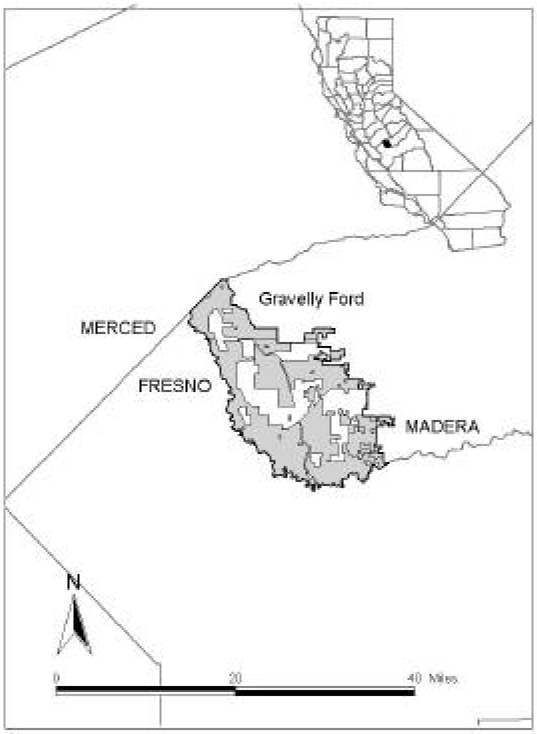
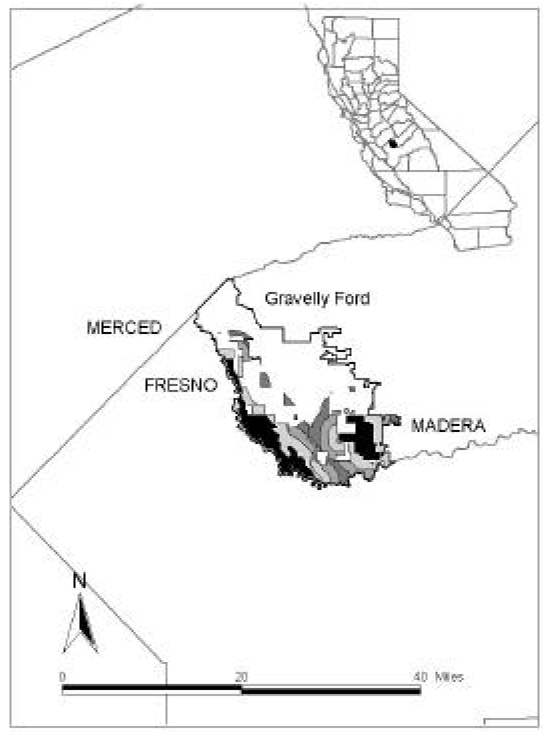


Figure A.33: DAU 215, Gravelly Ford, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

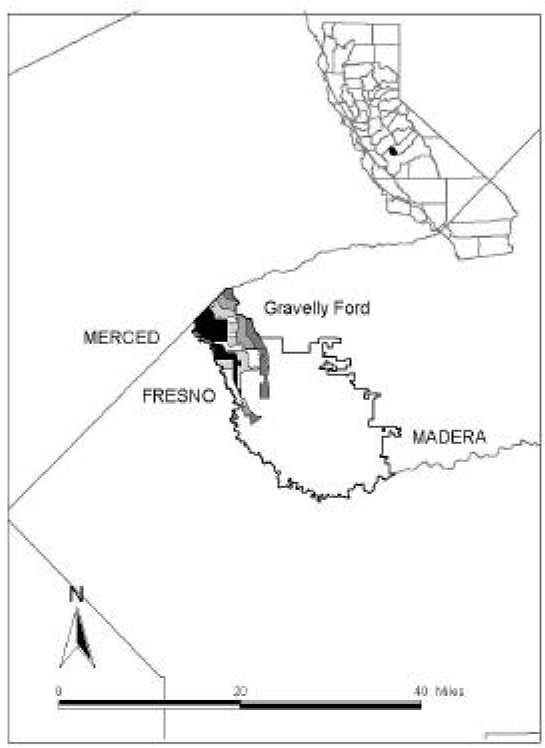


Figure A.34: DAU 216, West Side, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (C), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (D)

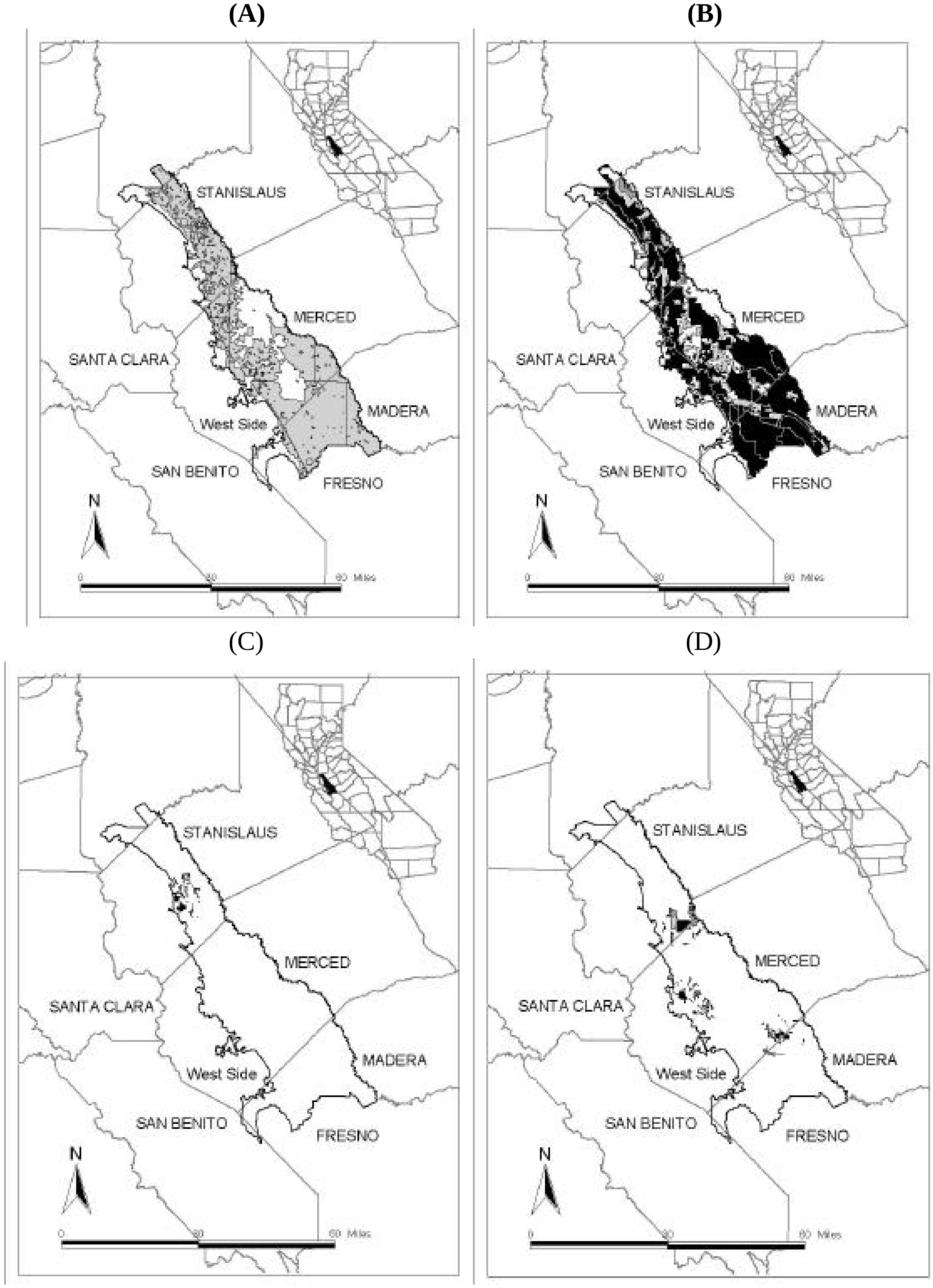
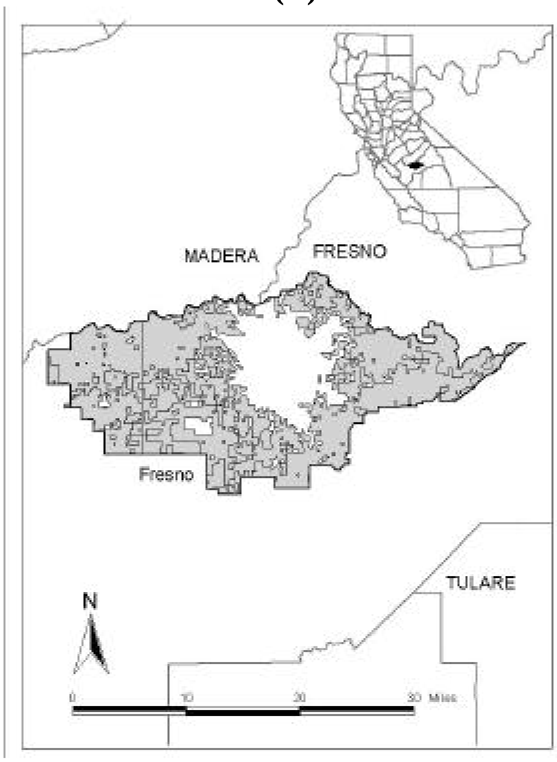
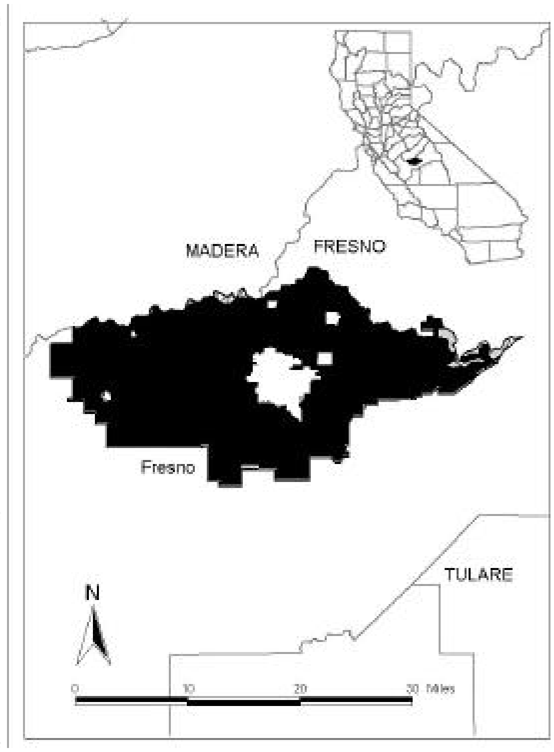


Figure A.35: DAU 233, Fresno, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

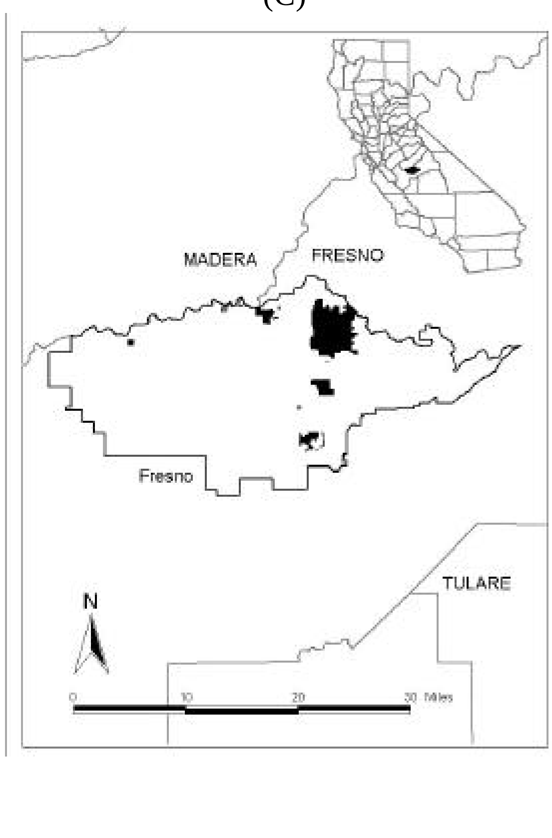


Figure A.36: DAU 234, Academy, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B)

(A) **(B)**

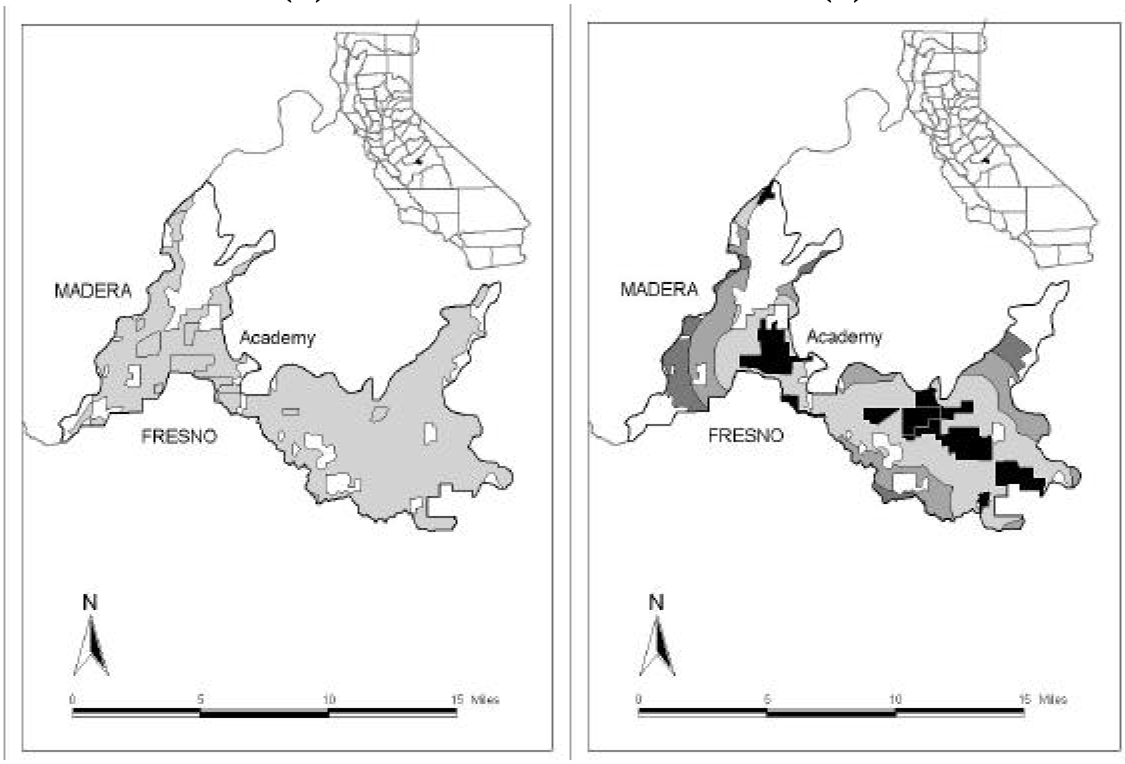
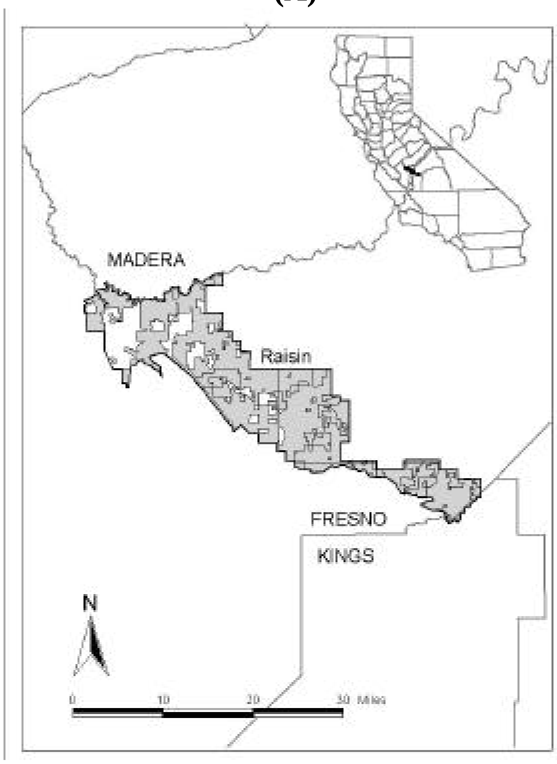
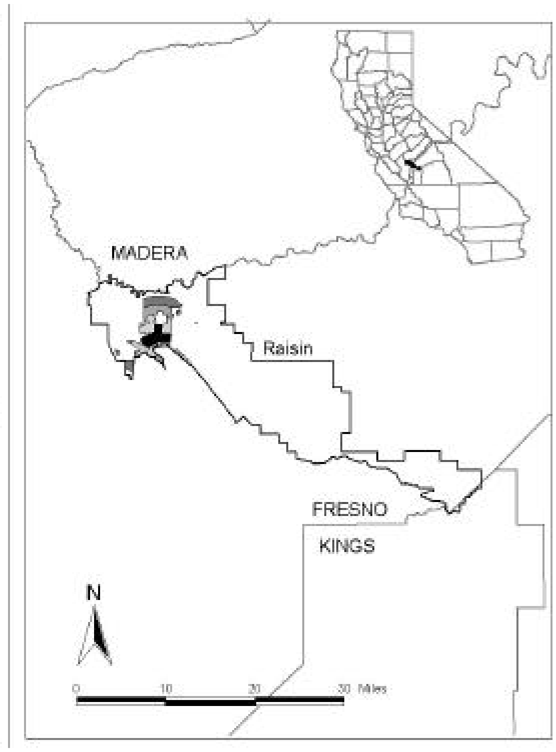


Figure A.37: DAU 235, Raisin, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

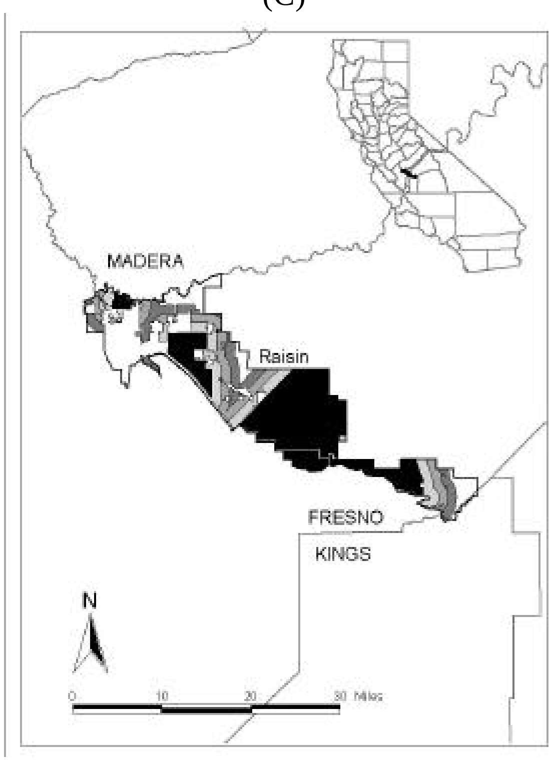


Figure A.38: DAU 236, Consolidated, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) **(B)**

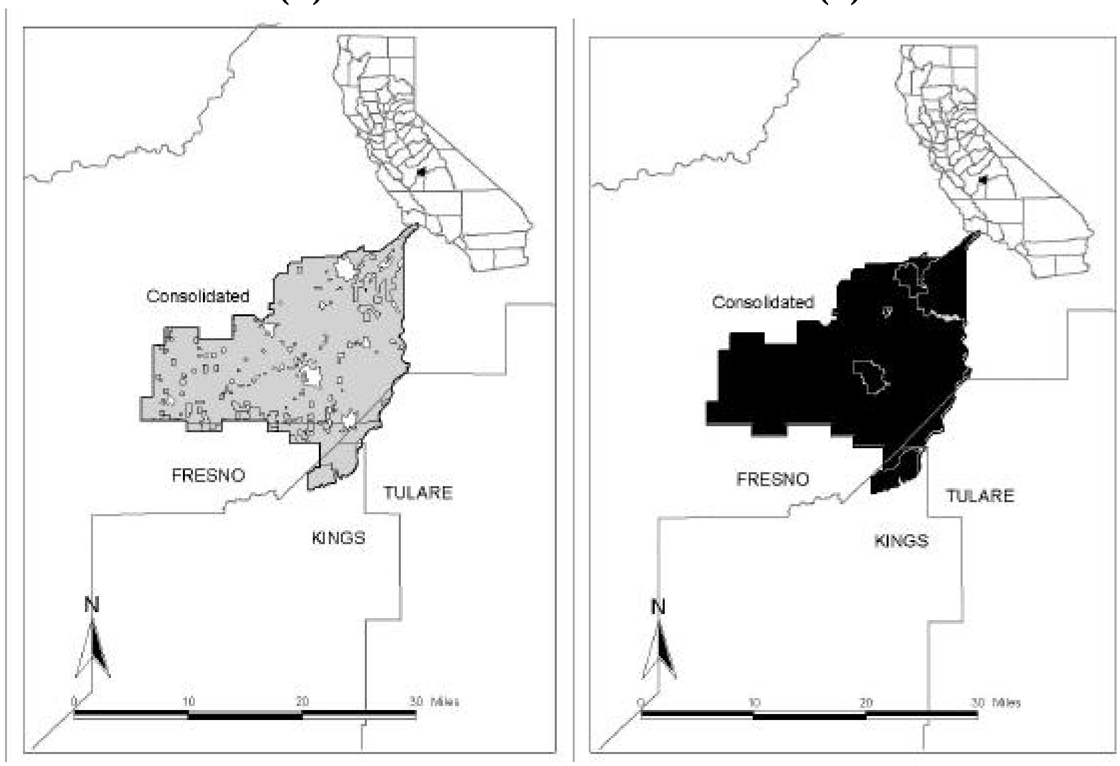
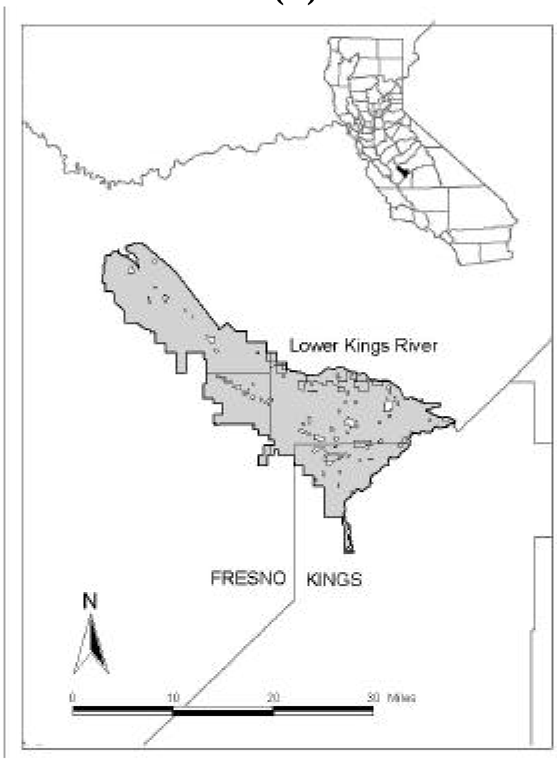
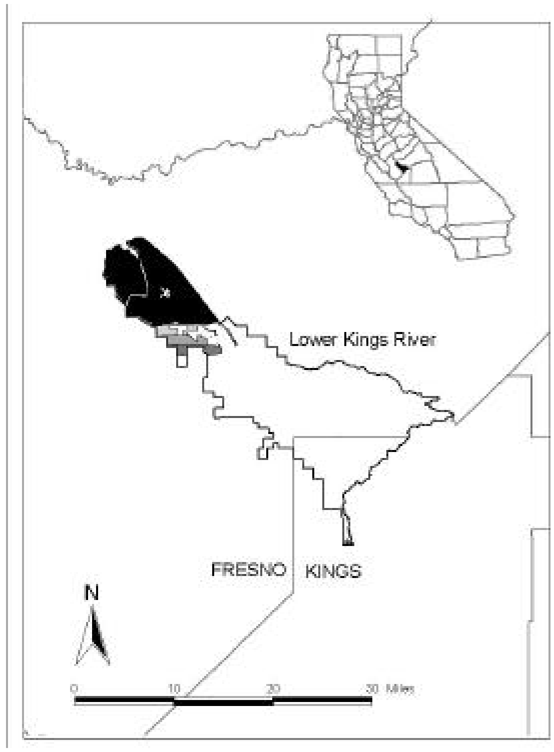


Figure A.39: DAU 237, Raisin, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

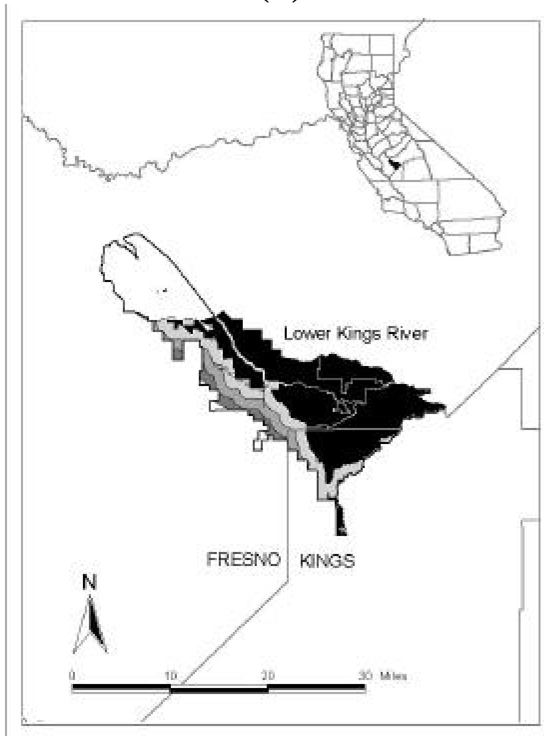


Figure A.40: DAU 238, Hanford-Lemoore, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) (B)

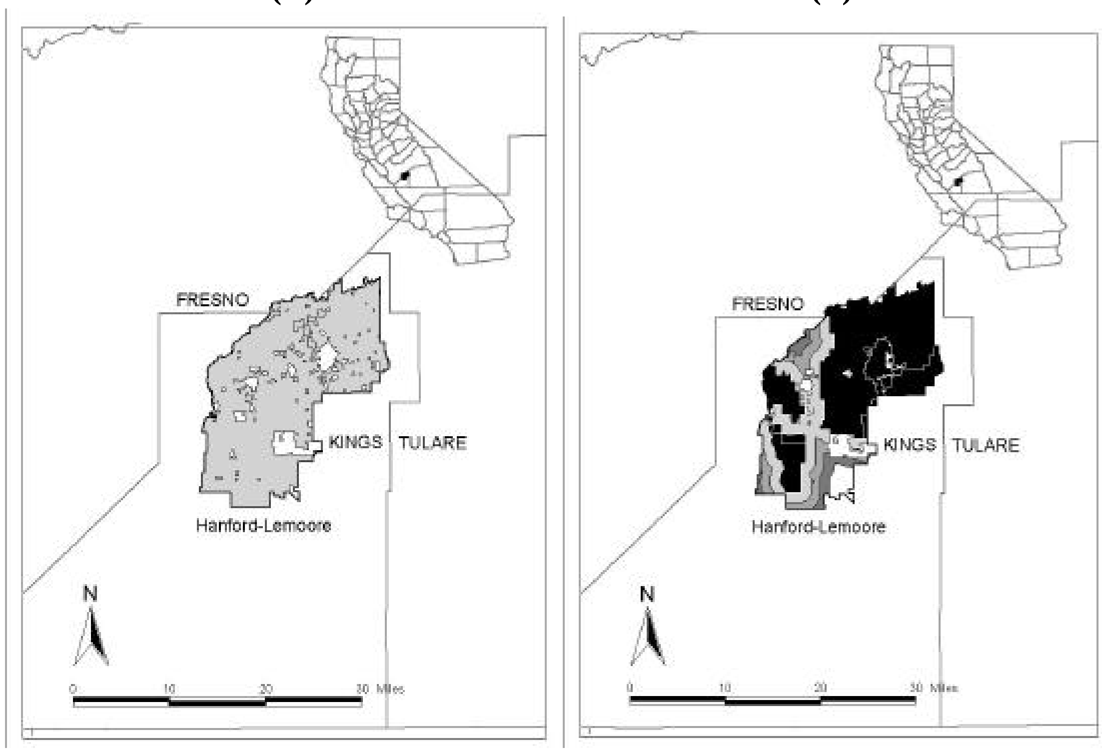


Figure A.41: DAU 239, Alta, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Private Water Districts (B)

(A) (B)

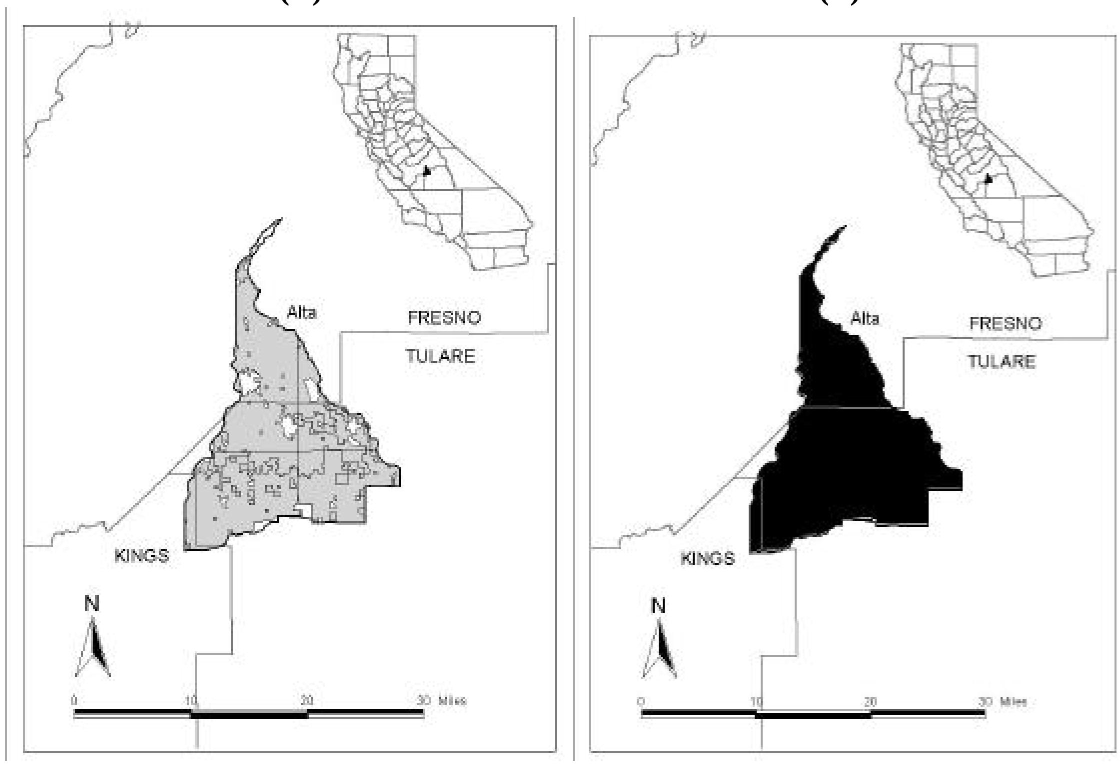
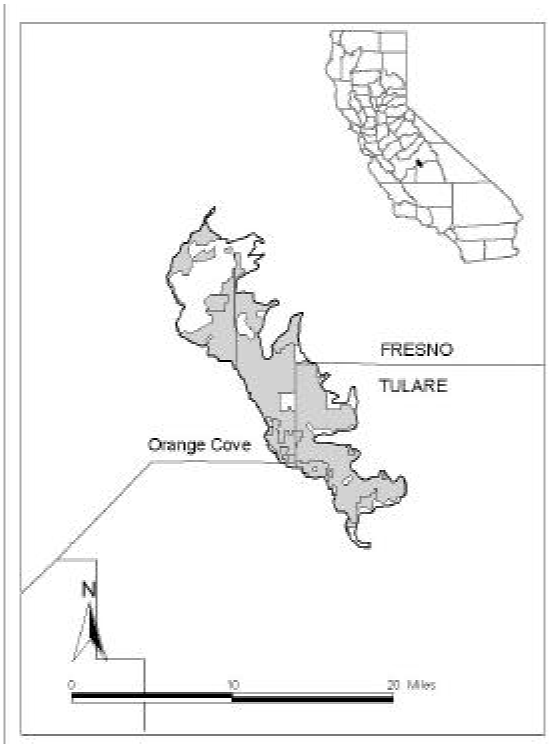


Figure A.42: DAU 240, Orange Cove, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B)

(A)



(B)

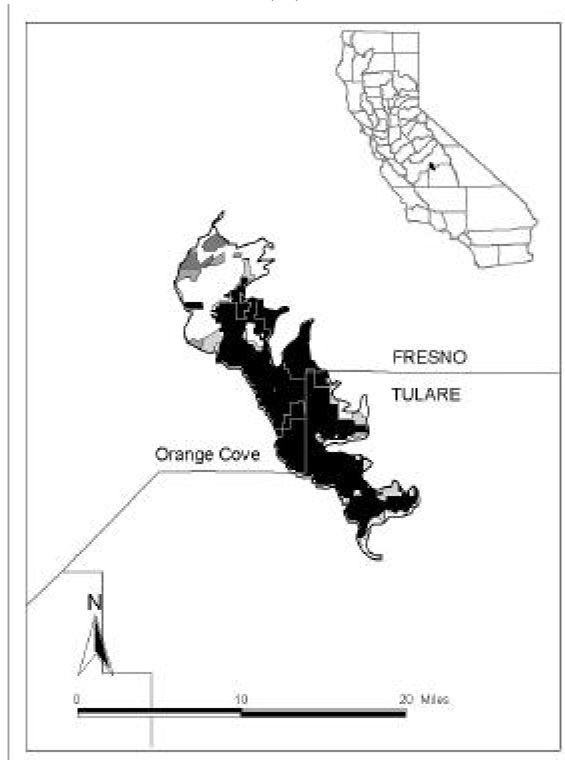
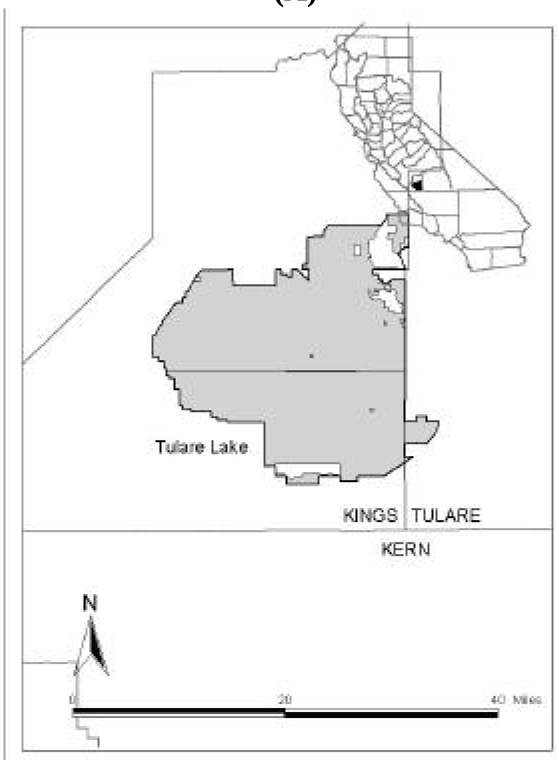
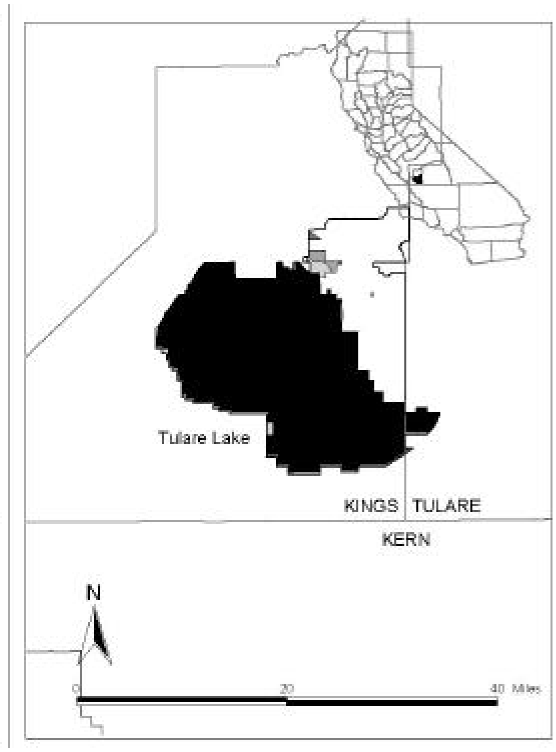


Figure A.43: DAU 241, Tulare Lake, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of State Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

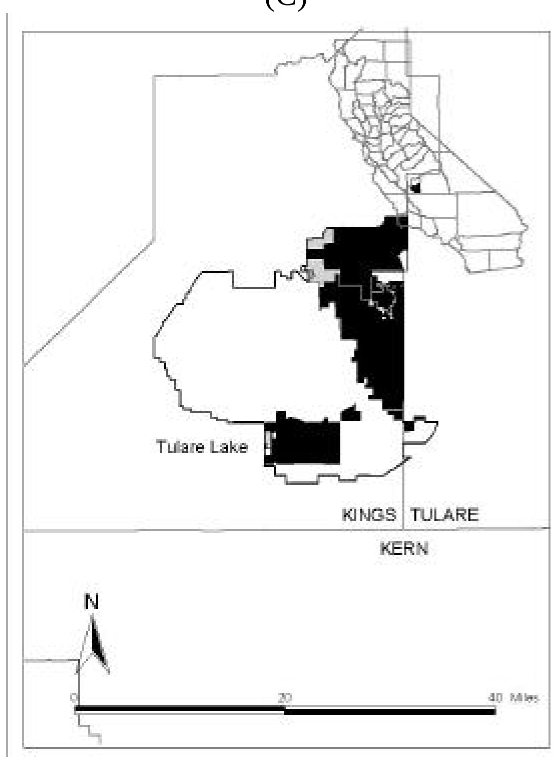
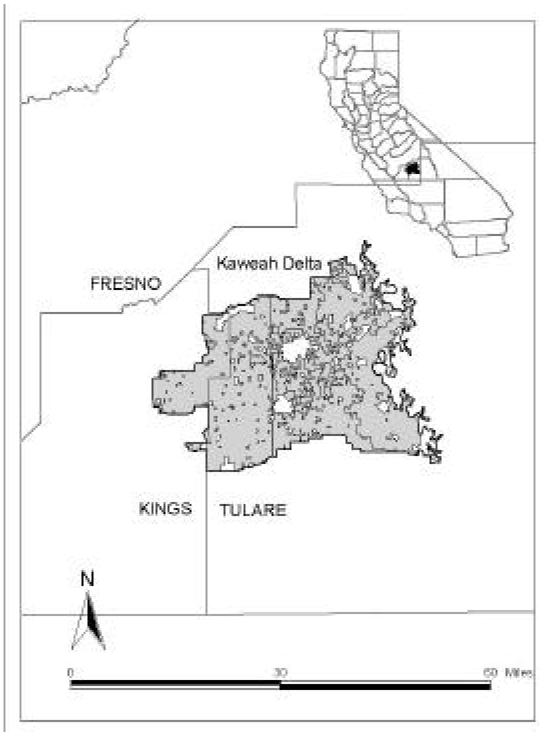
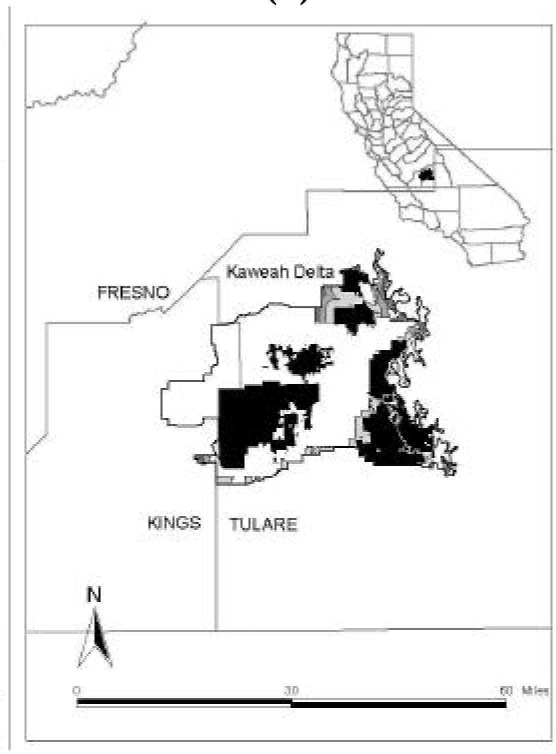


Figure A.44: DAU 242, Kaweah Delta, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

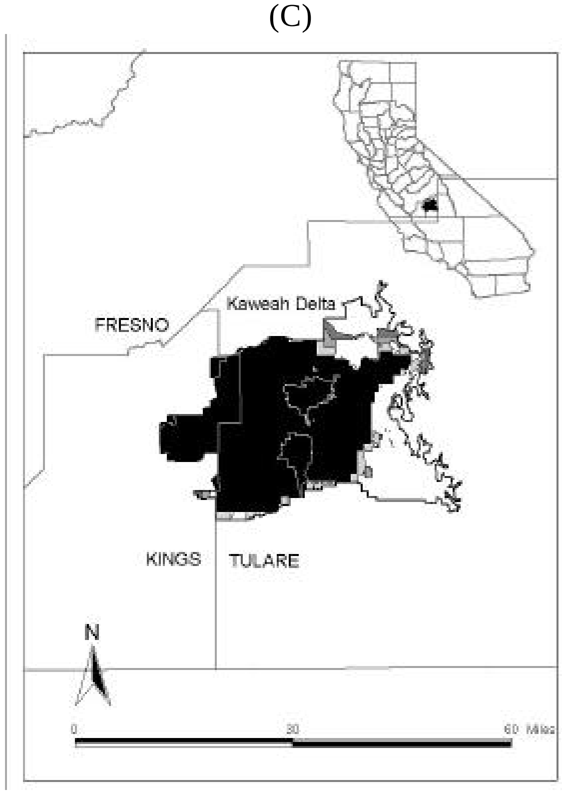
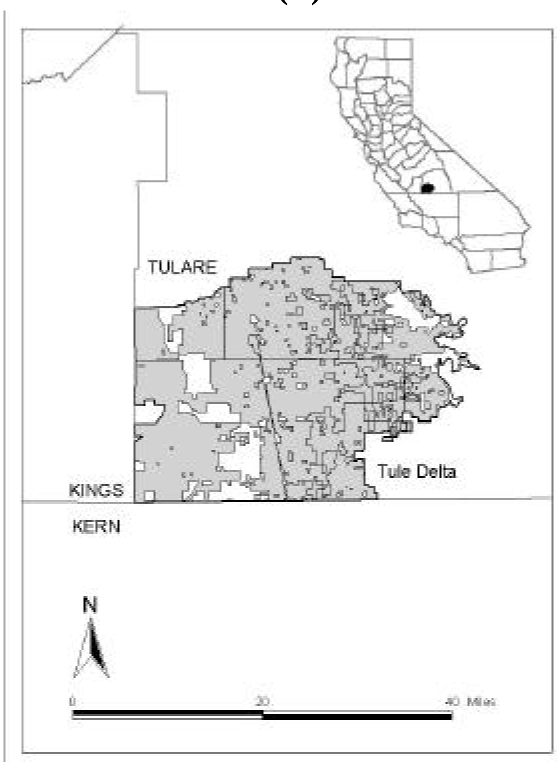
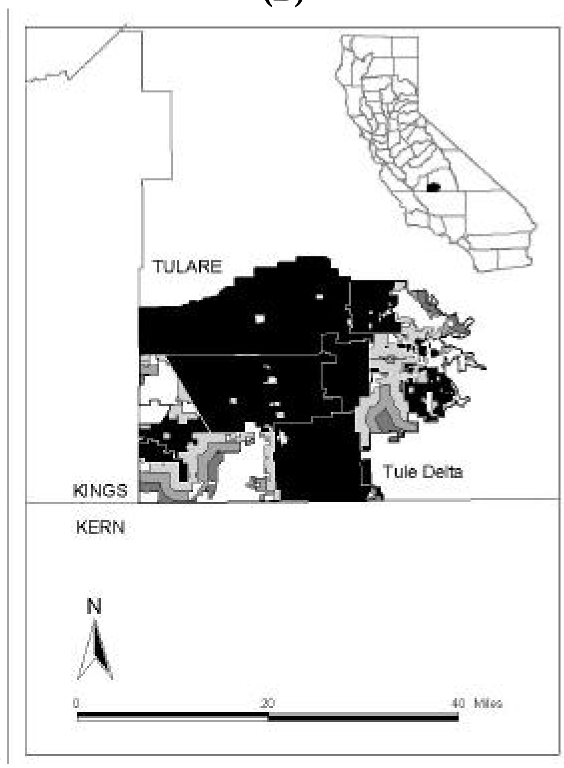


Figure A.45: DAU 243, Tule Delta, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

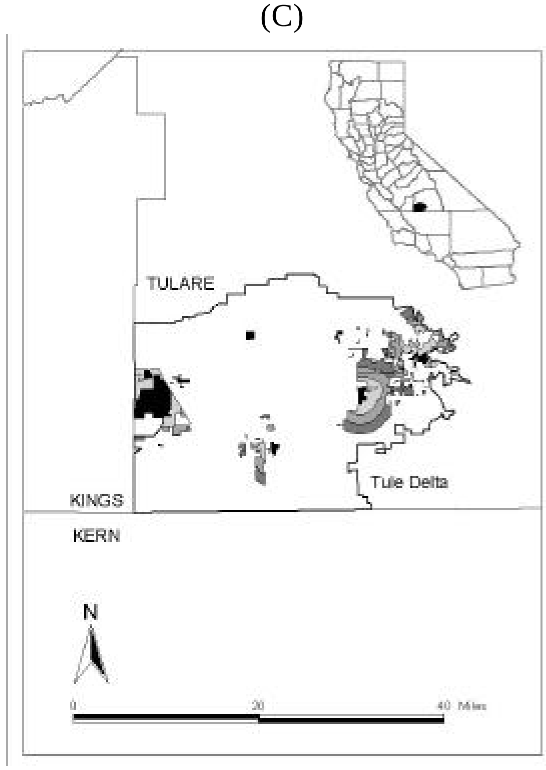
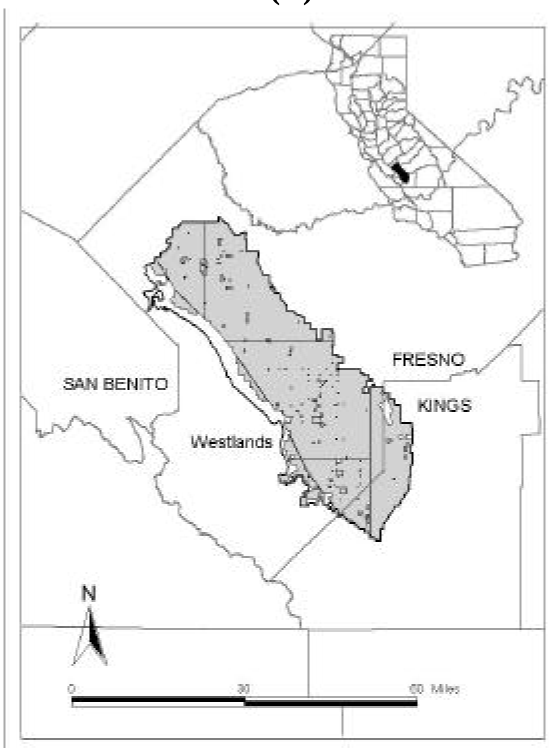


Figure A.46: DAU 244, Westlands, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B)

(A)



(B)

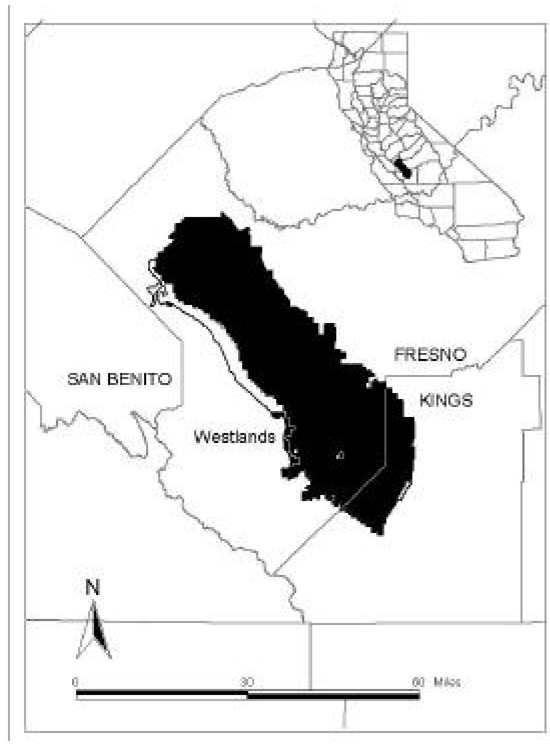
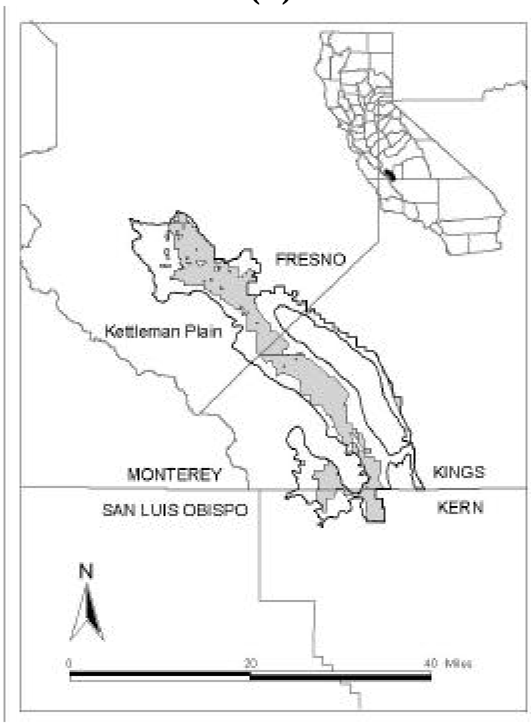
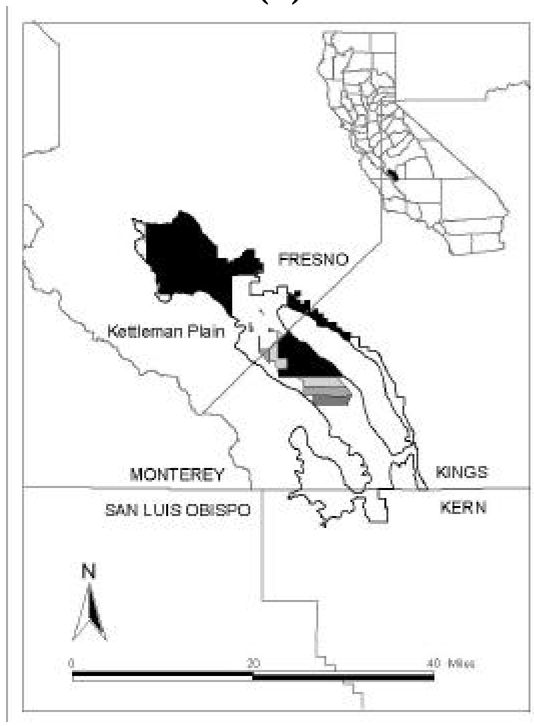


Figure A.47: DAU 245, Kettleman Plain, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (C), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (D)

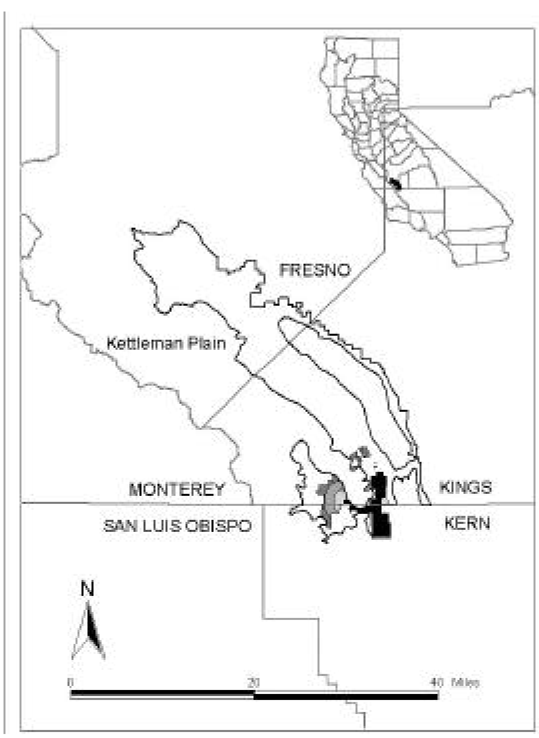
(A)



(B)



(C)



(D)

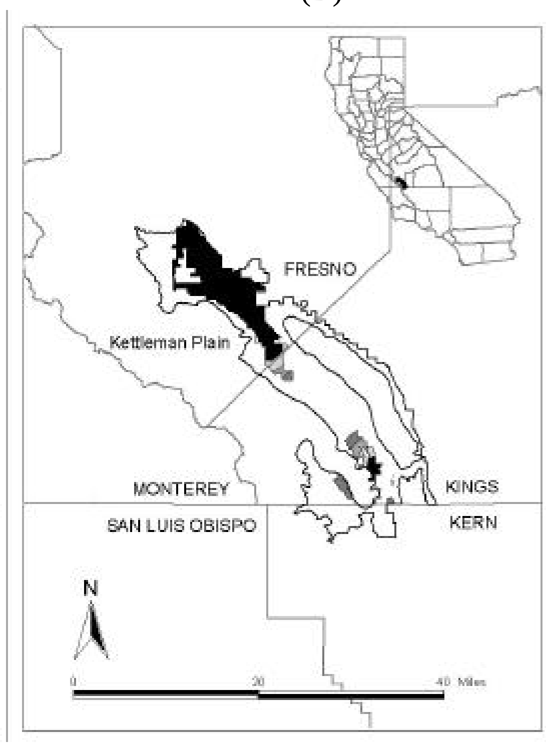
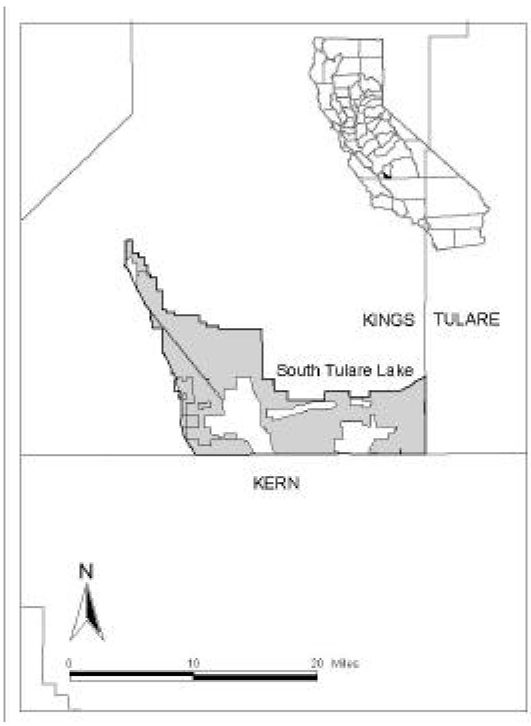
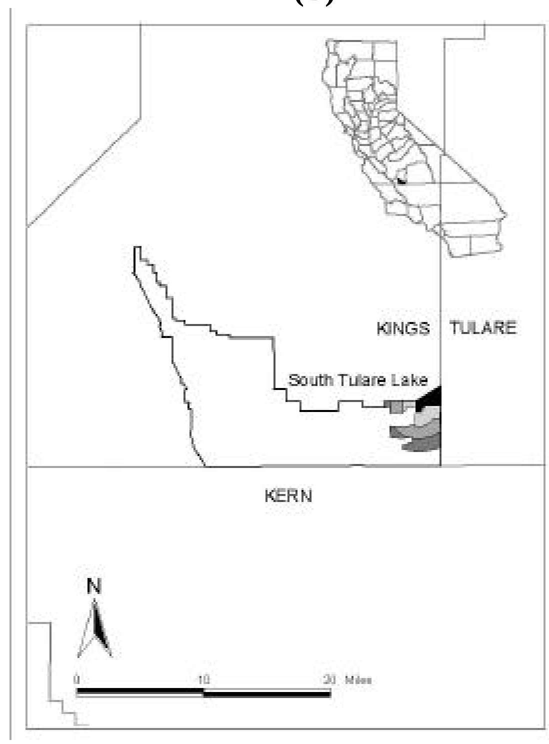


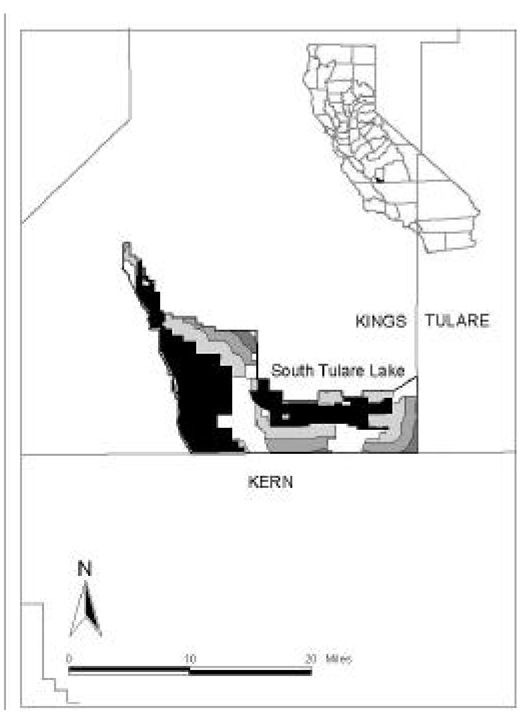
Figure A.48: DAU 253, South Tulare Lake, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (C), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (D)

(A) **(B)**





(C)(D)



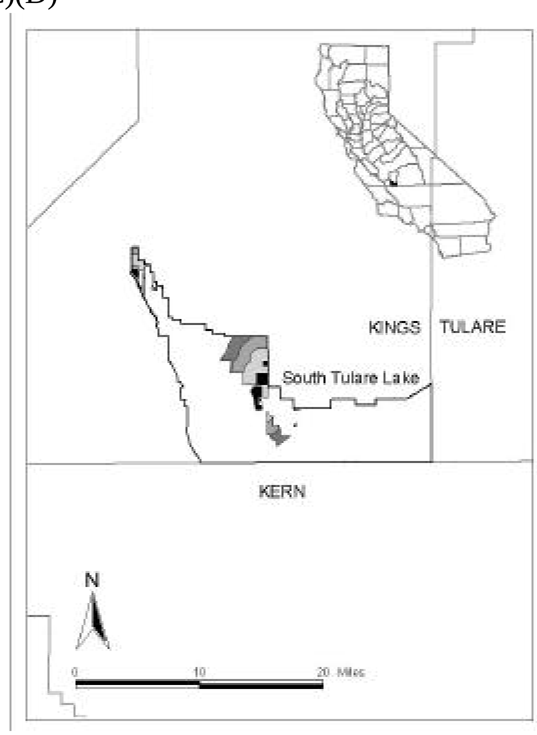
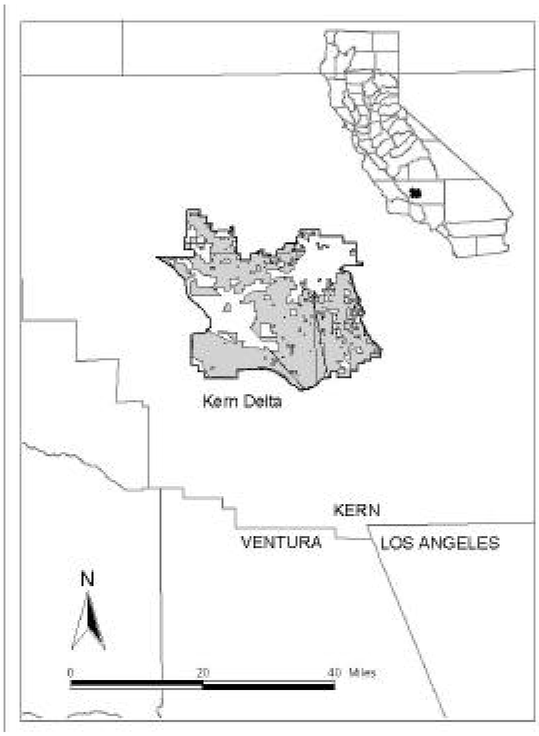
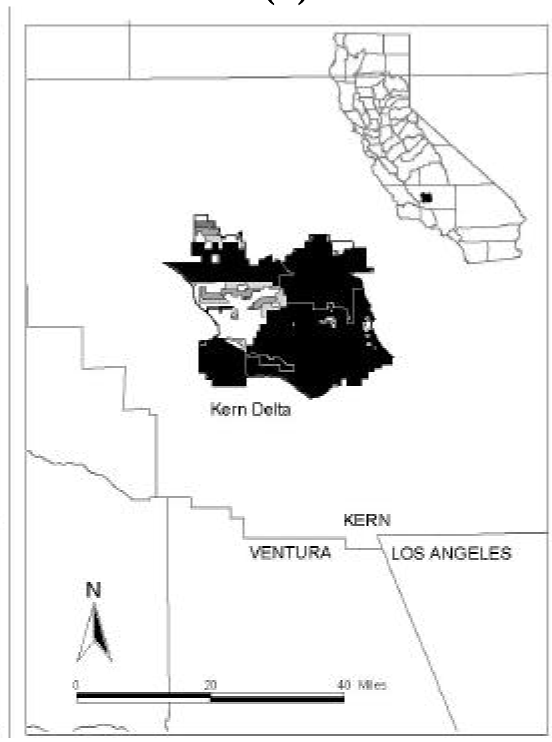


Figure A.49: DAU 254, Kern Delta, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of State Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

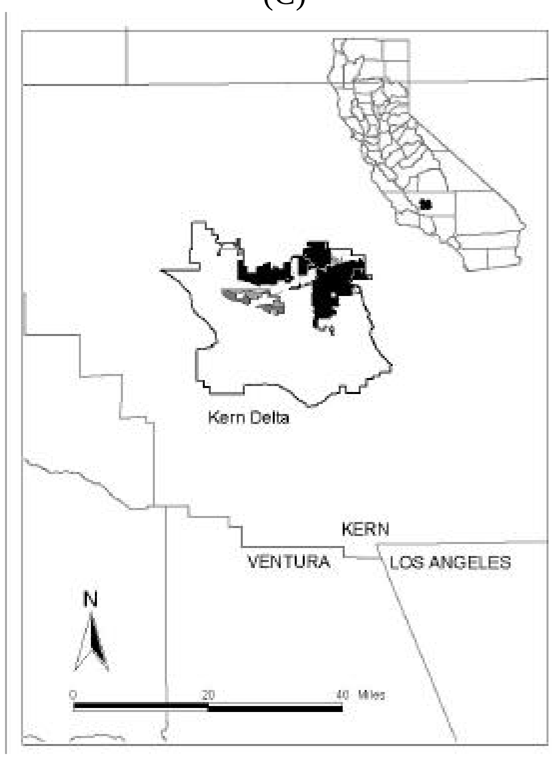


Figure A.50: DAU 255, Semitropic, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (C)

(A) **(B)**

(C)

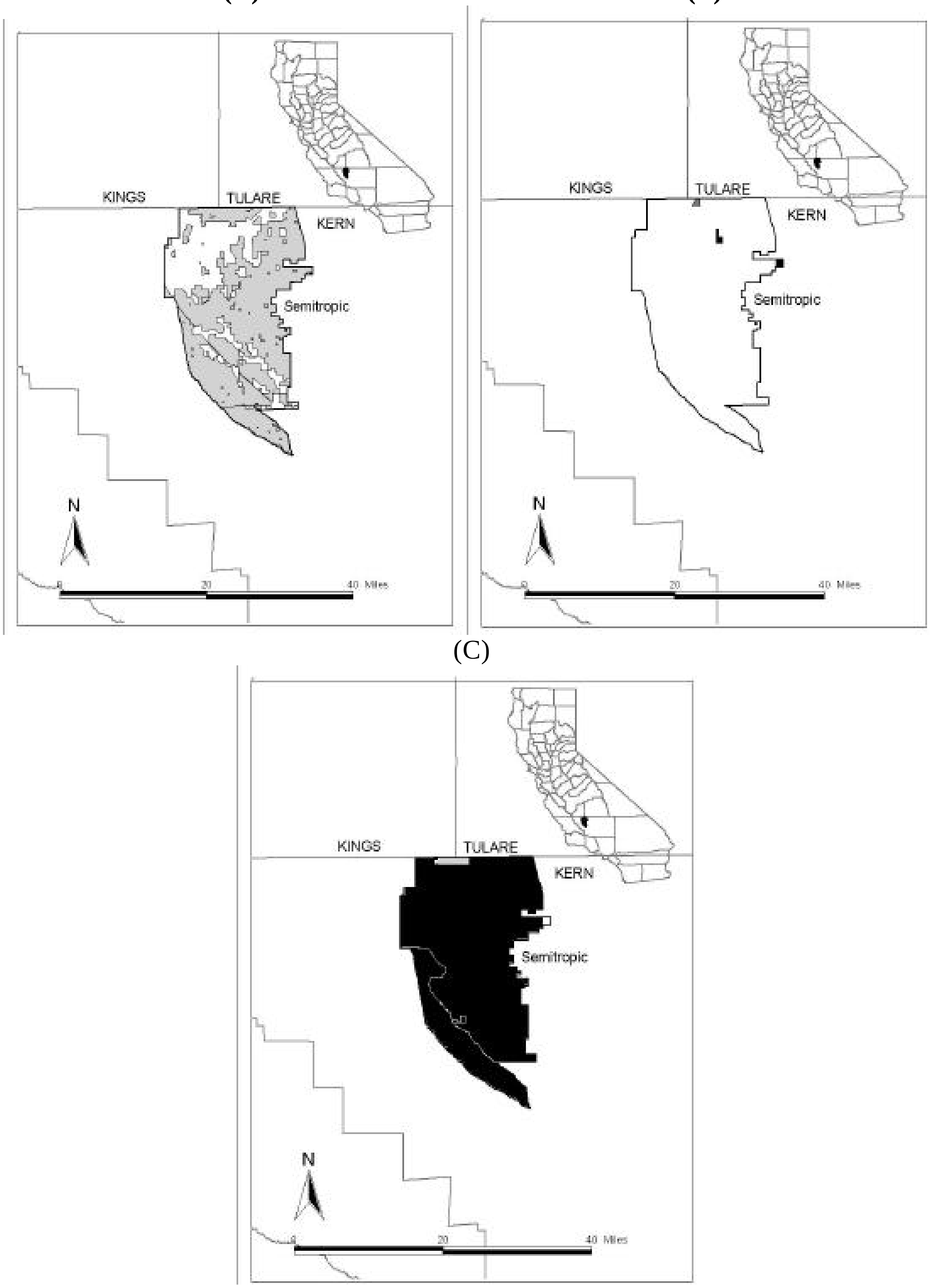
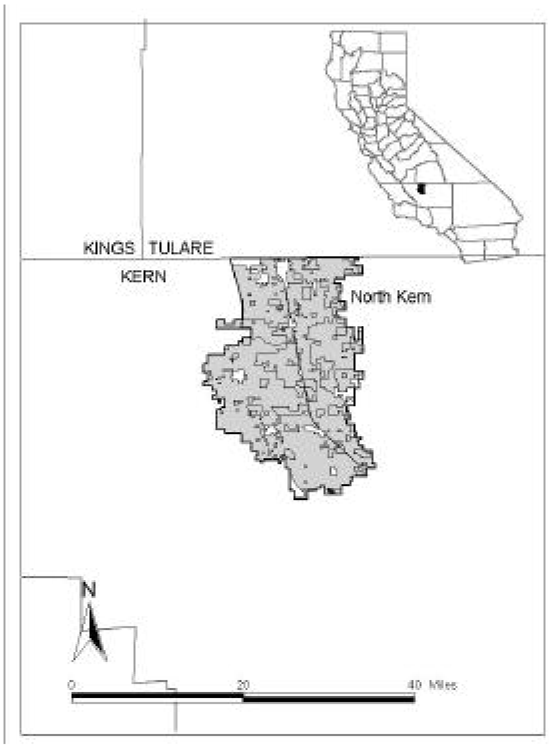
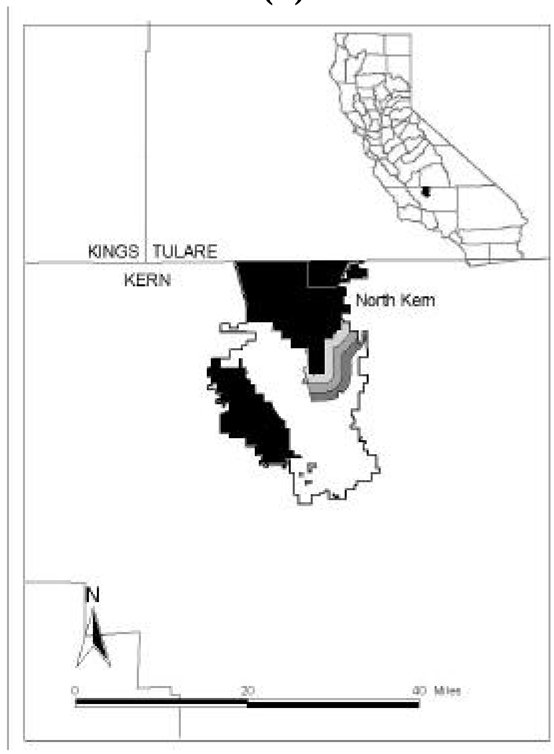


Figure A.51: DAU 256, North Kern, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

(A)



(B)



(C)

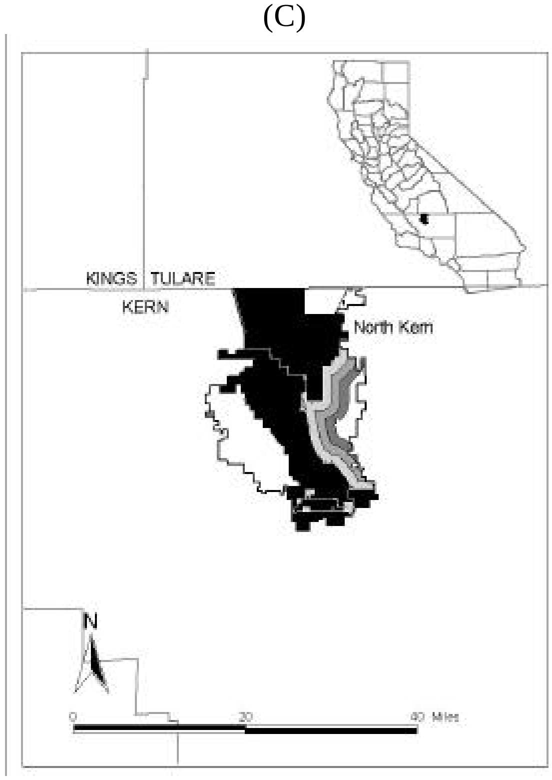
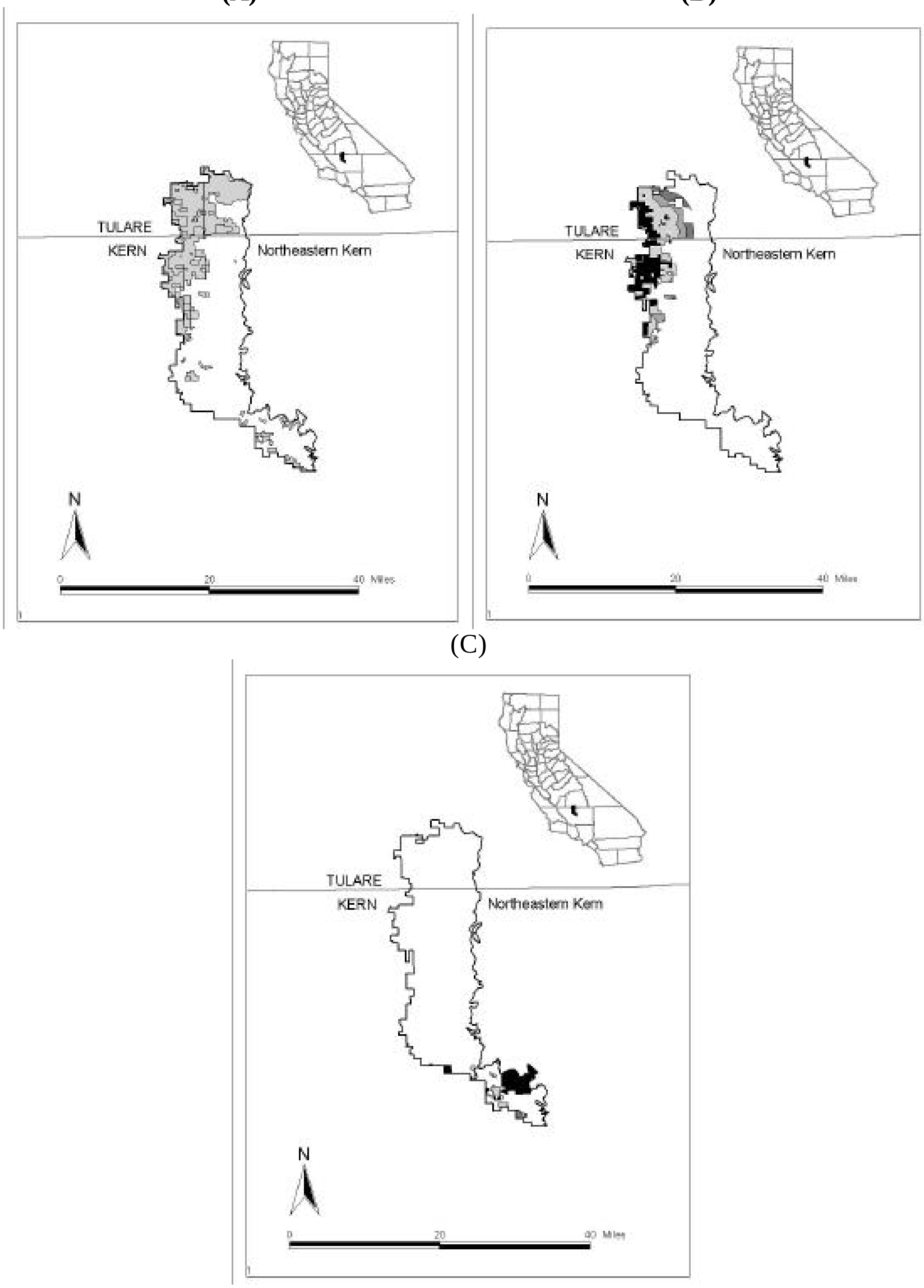


Figure A.52: DAU 257, Northeast Kern, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of Private Water Districts (C)

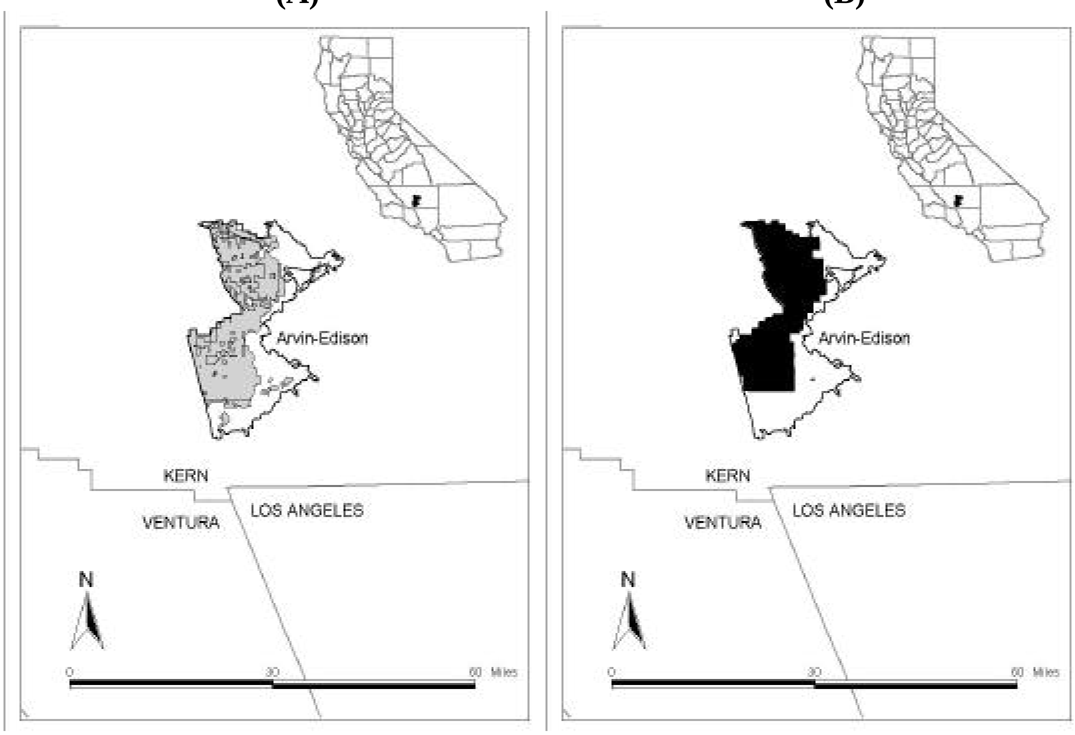
(A) **(B)**



(C)

Figure A.53: DAU 258, Arvin-Edison, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (C), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (D)

(A) **(B)**



(C)(D)

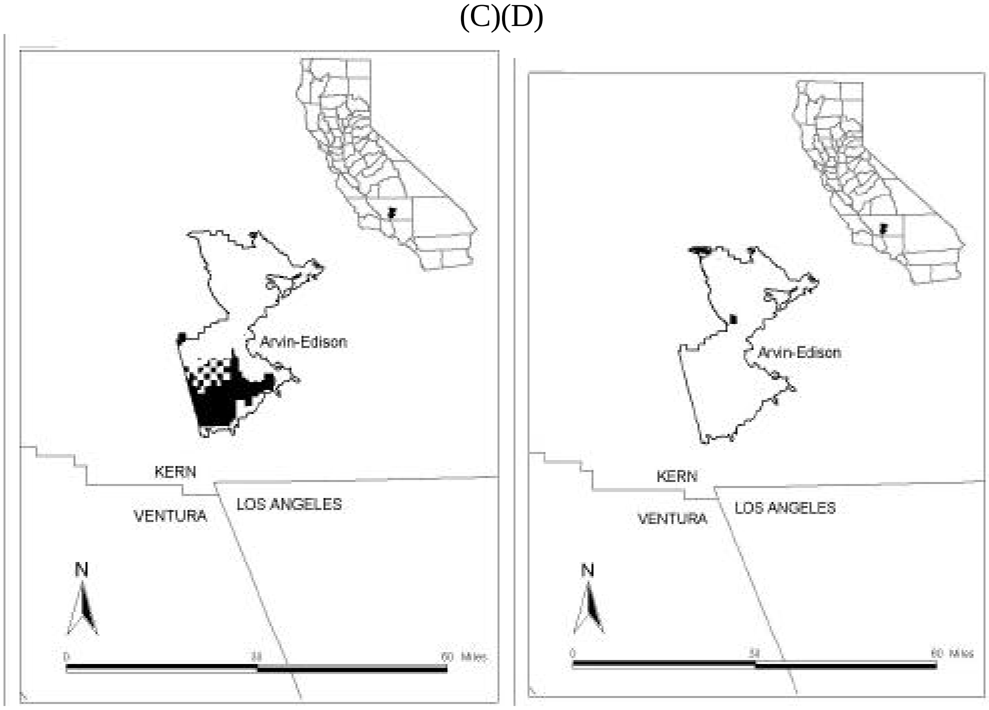
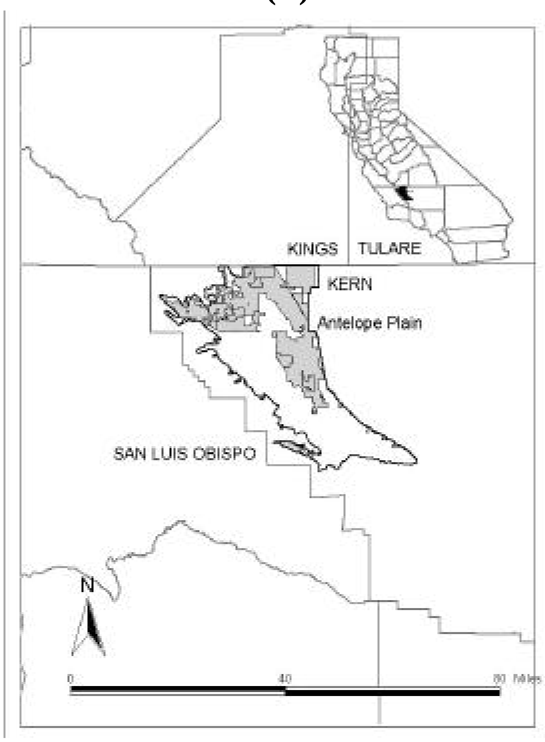


Figure A.54: DAU 259, Antelope Plain, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of State Water Districts (B)

(A)



(B)

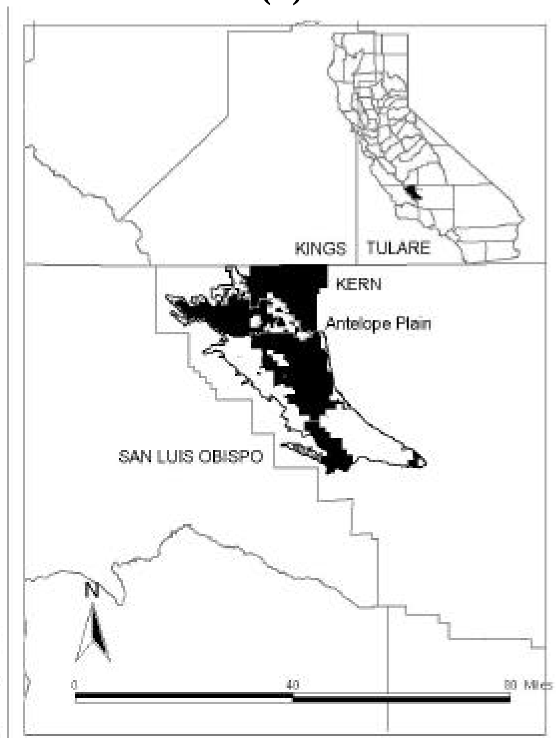


Figure A.55: DAU 260, Buena Vista Valley, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of State Water Districts (B)

(A) **(B)**

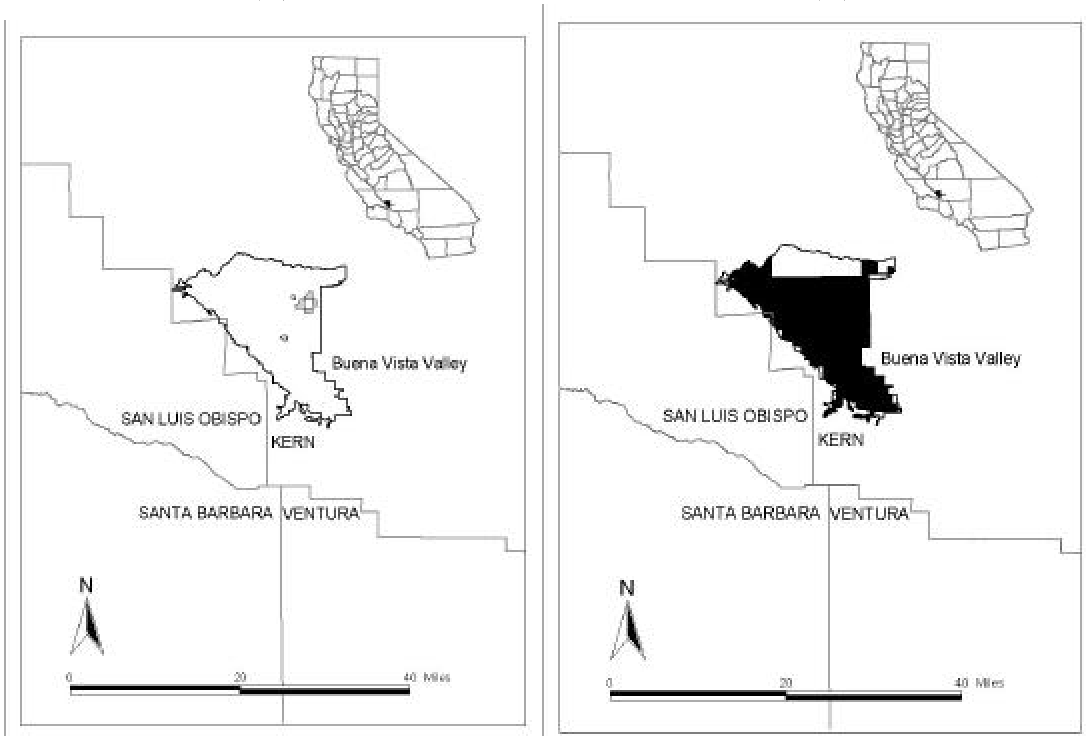


Figure A.56: DAU 261, Wheeler Ridge-Maricopa, Irrigated Agricultural Areas (A), Unincorporated Irrigated Land within 1( ), 2( ) and 3( ) Miles of Federal Water Districts (B), Unincorporated Irrigated Land within 1 ( ), 2( ) and 3( ) Miles of State Water Districts (C)

Appendix B:

Tabular Summary of the Spatial Analysis Conducted to Determine the Amount of Unincorporated Irrigated Land Located within 1, 2 and 3 Miles of the Federal, State and Private Water Districts Found in the 56 Central Valley Detailed Analysis Units

Table B.1: Amount of Unincorporated Irrigated Land within 1, 2 and 3 Miles of Water Districts in the 56 Central Valley DAUs

	Land within 1 Mile of Exisitng Districts			Land within 2 Miles of Exisitng Districts			Land within 3 Miles of Exisitng Districts		
DAU name	Federal (miles^2)	State (miles^2)	Private (miles^2)	Federal (miles^2)	State (miles^2)	Private (miles^2)	Federal (miles^2)	State (miles^2)	Private (miles^2)
Redding West (141)	4.0	0.0	1.1	3.8	0.0	2.3	2.5	0.0	2.5
Red-Bluff-Orland (142)	69.0	0.0	56.0	30.1	0.0	40.6	27.8	0.0	26.3
Redding East (143)	8.5	0.0	0.0	3.3	0.0	0.0	2.2	0.0	0.0
Los Molinos (144)	5.1	0.0	13.6	3.9	0.0	11.8	5.0	0.0	10.4
Lower Cache Creek (162)	0.0	0.0	41.0	0.0	0.0	11.4	0.0	0.0	4.2
Willows-Arbuckle (163)	180.3	0.0	92.1	30.1	0.0	40.8	21.3	0.0	21.1
Glenn-Knights Landing (164)	51.5	0.0	34.9	24.2	0.0	17.6	7.8	0.0	8.4
Meridian-Robbins (165)	31.3	0.0	13.5	5.2	0.0	8.3	1.2	0.0	4.9
Durham-Sutter (166)	9.6	0.0	39.7	11.6	0.0	32.5	11.9	0.0	29.2
Butte City (167)	31.8	0.0	5.7	16.3	0.0	2.5	8.9	0.0	3.0
Yuba City-Gridley (168)	14.3	0.0	70.8	7.9	0.0	23.5	7.1	0.0	10.9
Honcut Valley (170)	0.0	0.0	10.5	0.0	0.0	13.3	0.0	0.0	10.9
Yuba (171)	0.0	0.0	34.2	0.0	0.0	0.1	0.0	0.0	0.0
Placer (172)	39.4	0.0	55.6	21.7	0.0	19.6	16.8	0.0	26.4
Sac (173)	2.4	0.0	17.8	1.9	0.0	4.5	1.8	0.0	0.6
Elk Grove (180)	10.7	0.0	34.5	14.2	0.0	23.9	11.4	0.0	15.3
Ione-Jenny Lind (181)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lodi (182)	39.0	0.0	28.5	22.4	0.0	17.9	15.6	0.0	14.3
Bachelor Valley (184)	0.0	0.0	1.5	0.0	0.0	1.7	0.0	0.0	3.4
San Joaquin Delta (185)	3.9	0.0	42.9	5.0	0.0	14.1	10.3	0.0	4.5
Sacramento Delta (186)	0.1	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Vacaville (191)	66.0	0.0	20.1	37.3	0.0	21.5	25.6	0.0	21.4
South San Joaquin ID (205)	0.4	0.0	10.2	0.0	0.0	0.2	0.0	0.0	0.0
Modesto-Oakdale (206)	0.0	0.0	19.7	0.0	0.0	1.2	0.0	0.0	0.0
Modesto Reservoir (207)	0.0	0.0	3.5	0.0	0.0	3.8	0.0	0.0	2.5
Turlock (208)	0.0	0.0	22.4	0.0	0.0	1.7	0.0	0.0	0.0
Turlock Lake (209)	0.0	0.0	14.7	0.0	0.0	10.1	0.0	0.0	3.9
Merced (210)	0.0	0.0	15.5	0.0	0.0	0.4	0.0	0.0	0.0
Merced Stream Group (211)	0.1	0.0	1.3	0.4	0.0	1.6	0.3	0.0	1.9
El Nido-Stevinson (212)	5.0	0.0	41.7	1.7	0.0	20.4	1.7	0.0	14.3
Madera-Chowchilla (213)	7.3	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.1
Adobe (214)	69.2	0.0	2.9	33.7	0.0	4.0	16.6	0.0	3.9
Gravelly Ford (215)	31.7	0.0	11.4	18.8	0.0	7.8	14.3	0.0	10.1
West Side (216)	101.9	0.9	12.5	8.9	1.1	5.1	2.2	1.1	6.7
Fresno (233)	6.3	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.6
Academy (234)	25.6	0.0	0.0	13.6	0.0	0.0	5.1	0.0	0.0
Raisin (235)	5.8	0.0	29.2	4.4	0.0	31.8	5.3	0.0	28.0
Consolidated (236)	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Lower Kings River (237)	3.4	0.0	37.7	3.9	0.0	17.0	3.1	0.0	8.9
Hanford-Lemoore (238)	0.0	0.0	46.2	0.0	0.0	20.8	0.0	0.0	11.1
Alta (239)	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Orange Cove (240)	6.1	0.0	0.0	1.9	0.0	0.0	2.1	0.0	0.0
Tulare Lake (241)	0.0	6.0	8.2	0.0	2.3	1.6	0.0	0.6	0.4
Kaweah Delta (242)	34.7	0.0	24.1	13.5	0.0	11.2	9.4	0.0	9.6
Tule Delta (243)	69.9	0.0	20.1	31.6	0.0	37.9	17.8	0.0	17.9
Westlands (244)	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kettleman Plain (245)	7.7	3.0	4.3	5.8	8.6	2.9	4.3	4.3	5.1
South Tulare Lake (246)	2.7	30.2	6.3	4.1	17.7	5.6	3.6	4.1	3.5
Kern Delta (254)	0.0	25.1	3.0	0.0	14.7	6.2	0.0	3.8	7.3
Semitropic (255)	0.2	6.1	0.0	0.4	0.0	0.0	0.9	0.0	0.0
North Kern (256)	13.6	0.0	27.1	11.0	0.0	17.2	10.5	0.0	12.7
Northeast Kern (257)	30.8	0.0	3.0	10.1	0.0	0.5	5.6	0.0	1.0
Arvin-Edison (258)	0.4	0.2	0.2	0.0	0.0	0.2	0.1	0.0	0.2
Antelope Plain (259)	0.0	10.8	0.0	0.0	3.5	0.0	0.0	1.3	0.0
Buena Vista Valley (260)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wheeler Ridge-Maricopa (261)	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.3	0.0

Appendix C:

Tabular Summary of the Depth to Water Observed in Wells Located in the Agricultural Areas of the 56 Central Valley DAUs

Table C.1: Average Fall 1999 Depth to Water in DWR Water Level Survey Wells Found in the Agricultural Areas of the 56 Central Valley DAUs

DAU name	Average DTW (ft)
Redding West (141)	56.3
Red-Bluff-Orland (142)	48.9
Redding East (143)	67.7
Los Molinos (144)	28.9
Lower Cache Creek (162)	50.3
Willows-Arbuckle (163)	35
Glenn-Knights Landing (164)	23.9
Meridian-Robbins (165)	14.4
Durham-Sutter (166)	30.2
Butte City (167)	16.7
Yuba City-Gridley (168)	11.4
Honcut Valley (170)	34.4
Yuba (171)	26.4
Placer (172)	46.1
Sac (173)	98.3
Elk Grove (180)	88.9
Ione-Jenny Lind (181)	--
Lodi (182)	90.3
Bachelor Valley (184)	123.5
San Joaquin Delta (185)	10.9
Sacramento Delta (186)	18.6
Vacaville (191)	16.9
South San Joaquin ID (205)	32.8
Modesto-Oakdale (206)	34.6
Modesto Reservoir (207)	75.3
Turlock (208)	18.4
Turlock Lake (209)	95.3
Merced (210)	53.8
Merced Stream Group (211)	64.4
El Nido-Stevinson (212)	76.2
Madera-Chowchilla (213)	102.5
Adobe (214)	177.6
Gravelly Ford (215)	80.6
West Side (216)	19.4
Fresno (233)	51.8
Academy (234)	89.5
Raisin (235)	97.2
Consolidated (236)	47.8
Lower Kings River (237)	128.6
Hanford-Lemoore (238)	65.2
Alta (239)	31.7
Orange Cove (240)	20.8
Tulare Lake (241)	112
Kaweah Delta (242)	56.3
Tule Delta (243)	103.8
Westlands (244)	206.4
Kettleman Plain (245)	425.5
South Tulare Lake (246)	134.1
Kern Delta (254)	96.3
Semitropic (255)	139.2
North Kern (256)	266.7
Northeast Kern (257)	343
Arvin-Edison (258)	279.3
Antelope Plain (259)	79.1
Buena Vista Valley (260)	105
Wheeler Ridge-Maricopa (261)	187.6