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

Northern Sacramento Valley Conjunctive Water Management Investigation

Sponsored by
The Natural Heritage Institute
Glenn Colusa Irrigation District

Funded by the
California Department of Water Resources and the United States Bureau of Reclamation

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Executive Summary

Introduction

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

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

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

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

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

was a conjunctive management approach based on reservoir re-operation backstopped by several options for reducing the draw on reservoir storage when refill is insufficient.

Core Conjunctive Management Concept

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

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

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

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

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

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

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

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

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

Project Objectives and Principles

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

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

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

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

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

2. Achieve net environmental benefits, recognizing that there may be some tradeoffs among different environmental objectives and different times and locations: The Project would be operated to achieve or contribute to achieving certain environmental flow improvements in the mainstem Sacramento and Feather Rivers designed specifically to enhance ecologic functions important to the viability of protected species, particularly Chinook salmon. Three such tradeoffs are acknowledged in the Report:
    - Peak flood control releases, which may be environmentally beneficially, would be captured and released in a controlled pattern to achieve more tailored environmental and geomorphic benefits. In a sense, this is a strategy to use limited environmental water supplies in a more efficient manner.

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

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

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

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

Project Site Screening and Selection

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

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

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

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

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

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

Ecological Flow and Agricultural Water Supply Targets for Conjunctive Operations

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

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

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

For Chinook salmon:

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

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

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

For Riparian Habitat:

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

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

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

Initial Project Scenarios

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

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

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

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

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

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

TABLE ES-2
Project Scenarios Evaluated
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

TAF = thousand acre-feet

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

Analytic Tools

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

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

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

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

Performance of Initial Project Scenarios

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

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

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

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

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

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

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

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

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

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

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

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

Impacts of Project Groundwater Pumping

Impacts to Existing Groundwater Pumpers

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

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

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

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

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

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

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

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

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

[6] Data provided by California Department of Water Resources Northern District Office. 2009.
[7] May include monitoring wells, vapor recovery wells, or other wells not constructed for water supply purposes.

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

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

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

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

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

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

Impacts on Streamflow

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

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

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

[a]Includes the 7 streams listed below.

The Butte Creek analysis yielded the following key results:

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

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

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

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

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

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

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

Economic Analysis

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

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

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

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

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

Operational and Analytic Refinements Recommended by Project Operators

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

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

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

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

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

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

- Crop Idling for Reservoir Payback. The surface water model was modified to simulate crop idling as a payback mechanism to recover reservoir storage. This was done to reduce or avoid the need for project pumping, thereby reducing project costs and enhancing overall project cost-effectiveness. A number of assumptions and constraints were placed on crop idling operations, the main assumptions being that crop idling would be voluntary and incentive-driven and would

be limited in extent to no more than 20% of the irrigated area in GCID and the Butte Basin (WCWD and RID).

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

- Updating the CALSIM II baseline to include the smelt and salmon BOs had negligible effect on project performance.

- The addition of forecast-based operations together with minimum reservoir releases for water temperature compliance dramatically reduced project performance with respect to generating environmental flow releases and agricultural water supplies. Relative to initial conditions, benefits were reduced by one-half to two-thirds. The procedures developed for forecasting end-of-year reservoir storage were deliberately conservative to limit risks to carryover storage; however, the effect of the forecasts was to substantially reduce the estimated project water assets, which severely reduced both environmental flow releases and agricultural water supplies. The effect of minimum reservoir releases was to reduce the times when payback pumping can effectively recover reservoir levels, also diminishing project performance.

- Employing project pumping to assist in meeting Oroville Reservoir carryover targets is not effective because project pumping is called on frequently, to the extent that groundwater impacts could become problematic. Additionally, much of the water held in reservoir storage subsequently spills due to displacement with by surplus surface flows.

- Temporary crop idling is not an effective means of reservoir payback, primarily because crop idling decisions need to be made early in the season and involve making an irreversible commitment to participating growers for purchasing the water generated through crop idling regardless of whether the water can be held in upstream storage or put to beneficial use downstream. Modeling shows that too frequently temperature releases govern reservoir operations and the water generated by crop idling cannot be held in storage.

Fundamental Conclusions

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

Modeling of conjunctive operations reveals that the ability to recover reservoirs by pumping groundwater when they fail to recover sufficiently from surplus surface flows is constrained at times by

the need to sustain reservoir releases for temperature control, in order to provide desirable conditions for salmonids. In effect, the scale of conjunctive operations and the ability to generate one kind of environmental benefits (ecologic flows) is constrained by existing operational requirements for another kind of environmental benefits (temperature control). This tradeoff between different environmental water uses points to the need for comprehensive, holistic approaches to environmental water management. The analytical tools developed for this project are sufficient to support development of such approaches.

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

Recommended Further Investigation

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

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

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

1. Principal Findings and Conclusions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2. Introduction

2.1.Purpose

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

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

2.2.Evolution of Project Perspective and Scope

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

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

The scope of the investigation included technical, economic, institutional and outreach components. Technical work concentrated on developing coordinated groundwater and surface water models for

formulating and evaluating alternative conjunctive management strategies and project configurations. Model development consumed more time and a larger percentage of the project's resources than initially intended, which required reallocation of resources from the economic and institutional analyses. Robust outreach was conducted throughout the course of the effort at many different levels and in different forms.

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

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

2.3.Report Contents

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

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

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

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

2.4.Acknowledgements

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

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

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

3. Project Sponsors, Participants and Donors

3.1.Sponsors

3.1.1. Glenn Colusa Irrigation District

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

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

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

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

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

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

to Shasta Reservoir is less than 3.2 million acre-feet, GCID's total supply is reduced by 25 percent, to a total of 618,000 acre-feet.

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

3.1.2. Natural Heritage Institute

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

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

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

3.2. Participating Water Suppliers

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

3.2.1. Western Canal Water District

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

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

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

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

3.2.2. Richvale Irrigation District

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

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

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

3.3.Funding Agencies

3.3.1. Department of Water Resources

The mission of the California Department of Water Resources (DWR) is to manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments. To this end and in support of the legislative

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

Goal 2 Plan, design, const, operate, and maintain the State Water Project to achieve maximum flexibility, safety, and reliability.

Goal 3 Protect and improve the water resources and dependent ecosystems of statewide significance, including the Sacramento-San Joaquin Bay-Delta Estuary.

Goal 6 Support local planning and integrated regional water management through technical and financial assistance.

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

- Integration of flood protection and water supply systems to increase water supply reliability and flood protection, improve water quality, and provide for ecosystem protection and restoration.
- Re-operation of existing reservoirs, flood facilities, and other water facilities in conjunction with groundwater storage to improve water supply reliability, flood hazard reduction, and ecosystem protection and to reduce groundwater overdraft.
- Promotion of more effective groundwater management and protection and greater integration of groundwater and surface water resource uses.
- Improvement of existing water conveyance systems to increase water supply reliability, improve water quality, expand flood protection, and protect and restore ecosystems.

3.3.2. Bureau of Reclamation

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

ecosystems through the effective use of water.

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

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

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

3.4.Public Outreach

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

3.4.1. Public Outreach

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

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

3.4.2. Executive Briefings

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

TABLE 3-1
Chronological List of Outreach and Technical Team Meetings
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

3.4.3. Workshops

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

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

3.4.4. Technical and Other Team Meetings

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

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

4. Analytic Approach

4.1.Overview

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

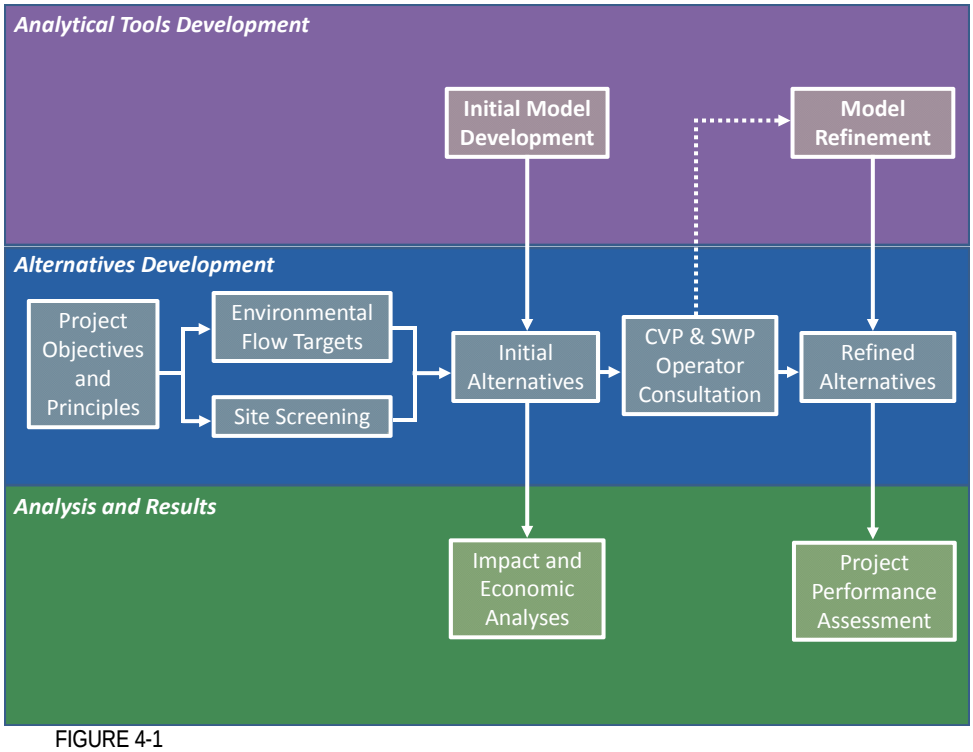

FIGURE 4-1
Project Analytical Components
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

The project's core conjunctive operations concept, site screening process and develop of environmental flow targets are discussed in detail in this section (Section 4). Initial model development and scenario

development and evaluation are discussed in Section 5, with Section 6 covering model and scenarios refinement and assessment of project performance. The relationship between the analytic components and report structure are presented below in Figure 4-2.

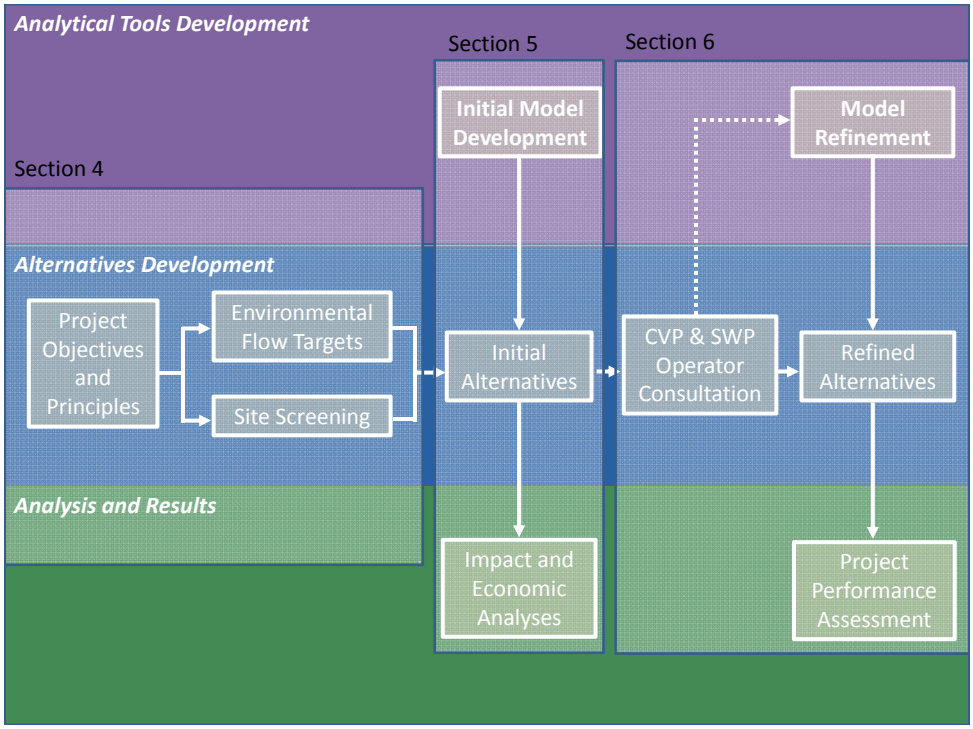

FIGURE 4-2
Relationship between Analytical and Report Organization
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

4.2. The Core Reservoir Re-operation and Payback Concept

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

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

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

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

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

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

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

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

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

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

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

4.3.Project Objectives, Design Principles and Constraints

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.4.Reservoir Payback Mechanisms

4.4.1. Groundwater Banking

Groundwater banking for reservoir payback involves making additional reservoir releases at certain times and storing the water in aquifers for recovery months or years later. Releases generally are made in above normal or wetter years with recovery occurring in relatively dry years. Surface water can be

placed in storage by artificial recharge (surface spreading or injection wells) or by supplying it to water users who would otherwise pump groundwater (in-lieu recharge). Conditions required for groundwater banking include available storage space in an aquifer where water can be retained over periods of several years and a feasible means of recharge. Typically, in-lieu recharge is more cost-effective than artificial recharge; however, in-lieu recharge requires that there is baseline groundwater pumping that can be suspended at times when additional reservoir releases are being made. Thus, in areas where groundwater pumping is negligible or would not occur when reservoir releases would be made, in-lieu recharge is not feasible.

4.4.2. Groundwater Pumping

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

4.4.3. Temporary Crop Idling

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

4.5. Project Site Screening

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

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

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

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

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

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

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

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

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

The following additional criteria were used to identify prospective sites:

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

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

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

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

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

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

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

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

4.6. Environmental Flow Objectives

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

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

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

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

4.6.1. General Approach and Rationale

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

The approach consists of five basic steps:

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

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

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

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

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

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

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

- Riparian Habitat Sustainability: Recruitment and maintenance of Fremont Cottonwood

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

The team relied on field data, modeling results, and studies, particularly the recent Nature Conservancy Study of the Sacramento River[12], to identify the minimum flows and critical thresholds to achieve each of the three types of objectives. Then historical and existing hydrology were analyzed to understand how the objectives may have been achieved under pre-dam conditions and to evaluate how existing hydrology may fall short of meeting those objectives. The gaps identified in this manner are the basis for identifying flow objectives.

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

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

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

Analysis of historical (pre-dam) hydrology and the habitat it created were analyzed to provide a reference point for identifying ecosystem restoration goals, recognizing that it is not possible to restore

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

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

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

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

For Chinook salmon:

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

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

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

For Riparian Habitat:

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

4.6.2. Representing Environmental Flow Objectives in the Surface Water Model

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

Each of the environmental flow objectives is described quantitatively below.

4.6.2.1. Geomorphic Flow Objectives

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

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

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

No objective specified in critical year types.

4.6.2.1. Riparian Establishment

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

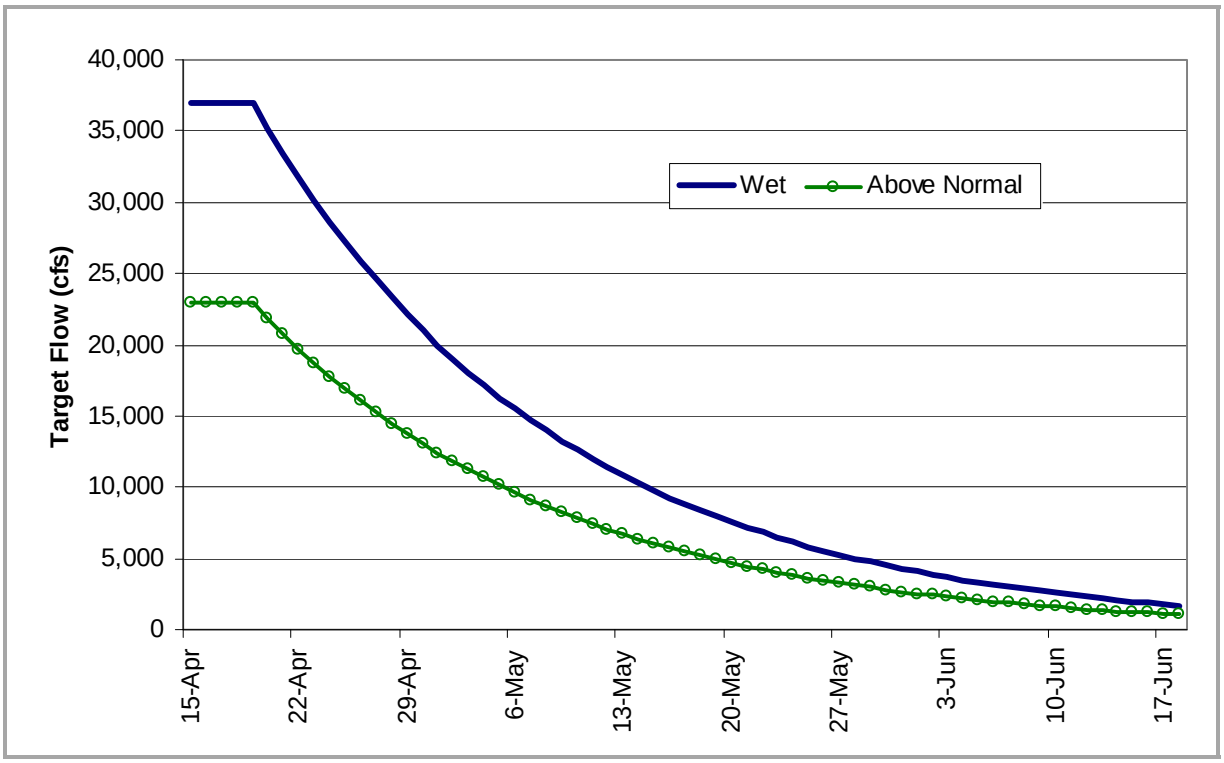

FIGURE 4-3
Sacramento River Riparian Establishment Objective
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

4.6.2.2. Spring Pulse Flows

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

4.6.2.3. Flood Plain Inundation

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

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

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

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

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

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

Note: No objective specified in critical year types

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

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

Note: No objective specified in critical year types

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

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

Note: No objective specified in critical year types

4.6.2.4. Prioritization of Environmental Flow Objectives and Decision Month

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

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

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

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

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

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

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

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

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

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

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

4.7. Agricultural Water Supply Objectives

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

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

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

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

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

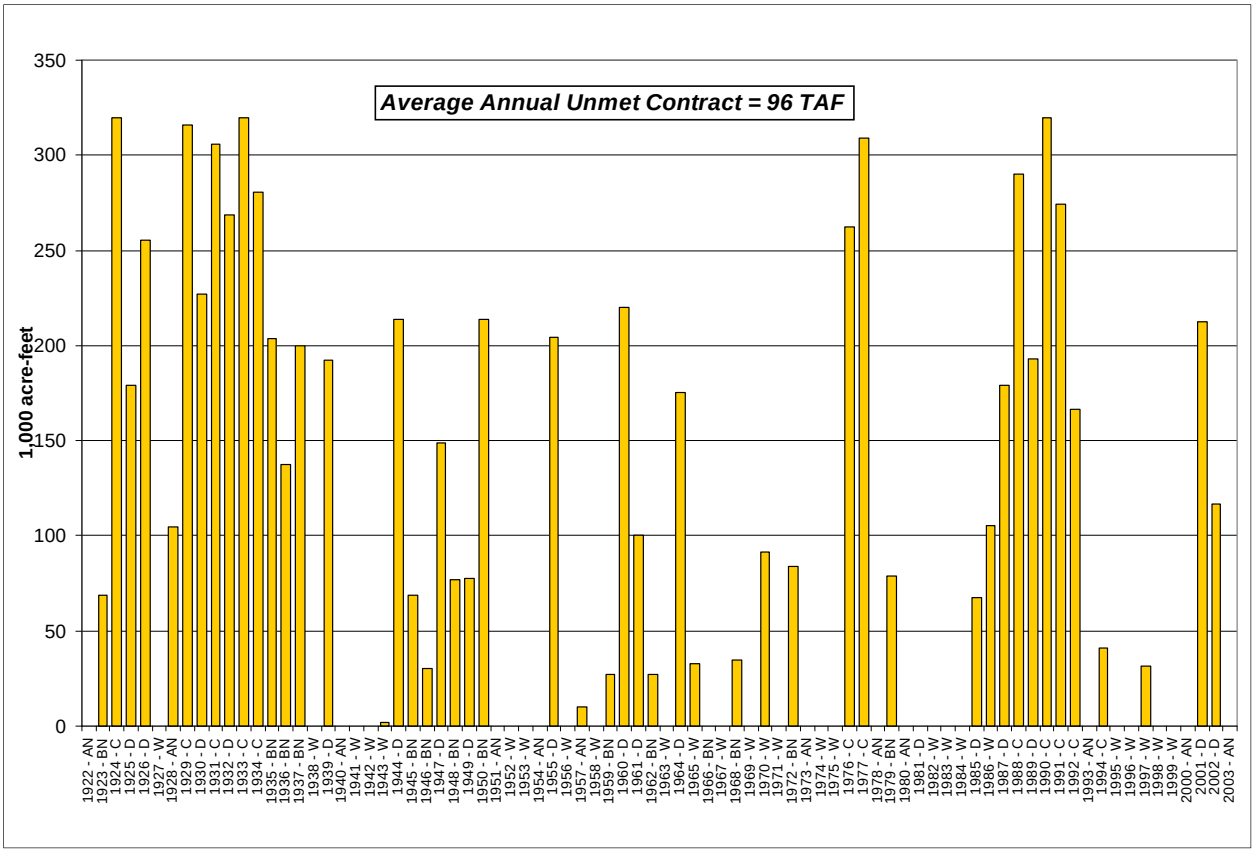

FIGURE 4-4
Unmet Agricultural Demand within TCCA Service Area
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

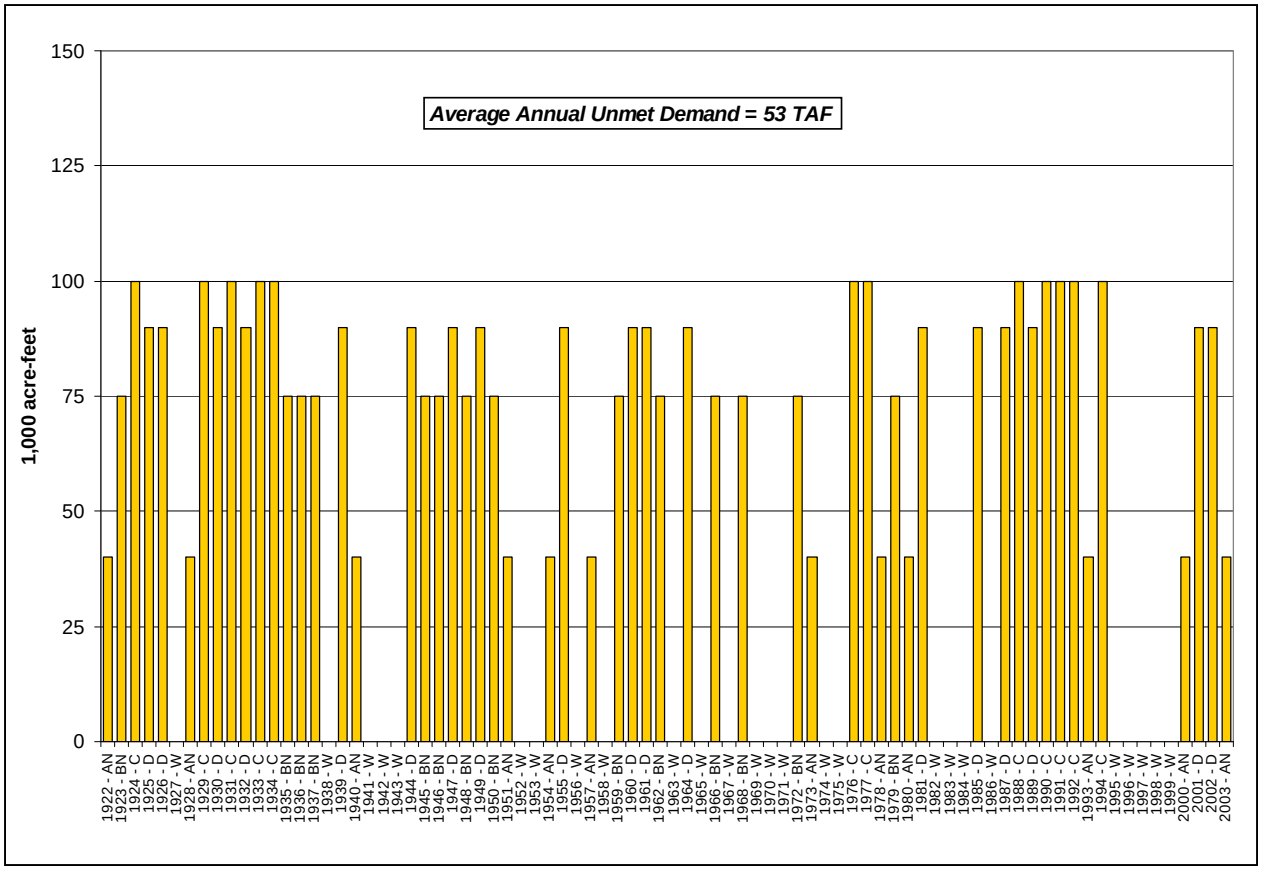

FIGURE 4-5
Assumed Unmet Agricultural Demand within Feather River System
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

5. Development and Assessment of Initial Project Scenarios

5.1. Initial Project Scenarios

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

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

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

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

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

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

TAF = thousand acre-feet

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

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

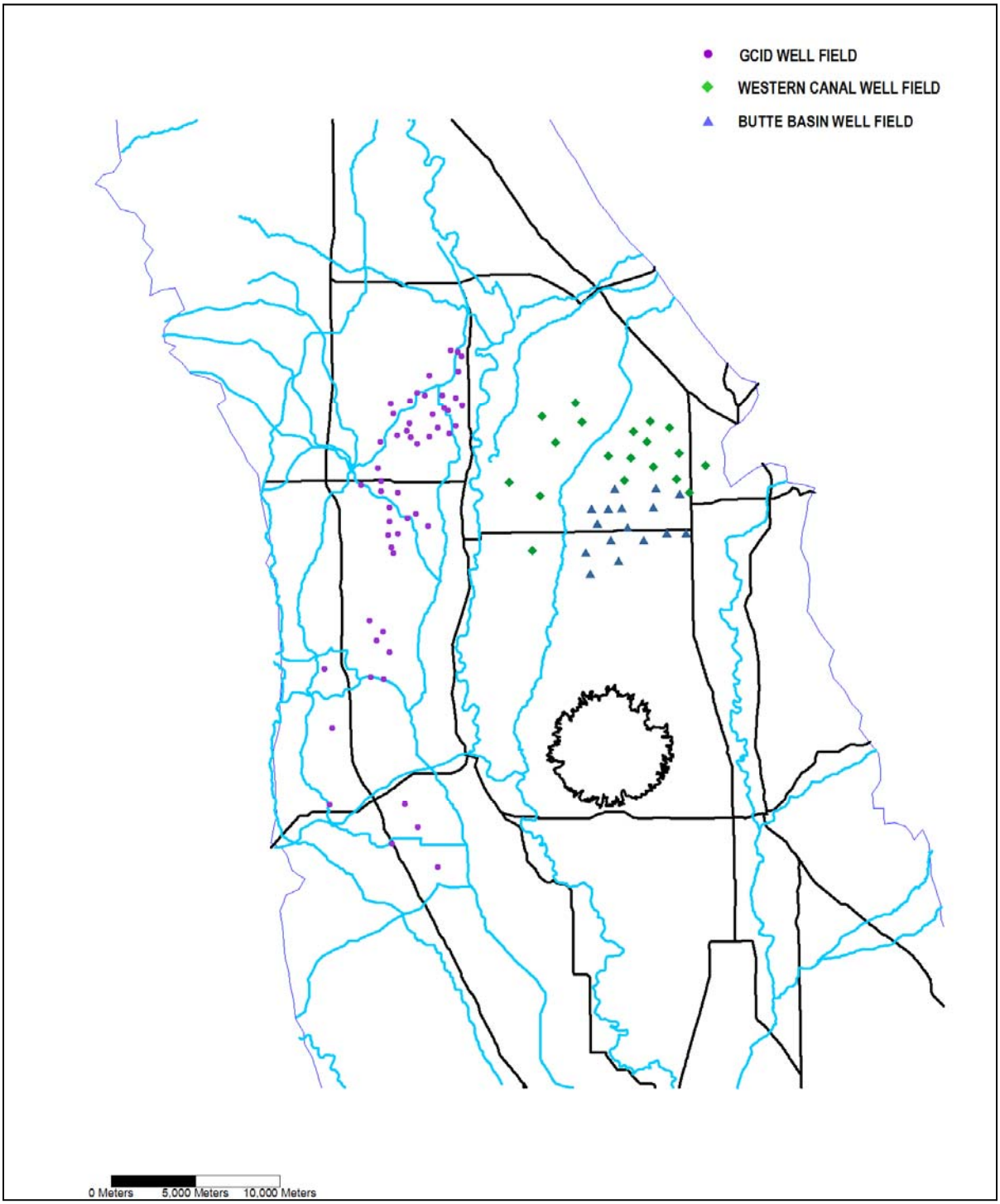

FIGURE 5-1
Existing Well Locations, 100 TAF GCID And 50 TAF RID and WCWD Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

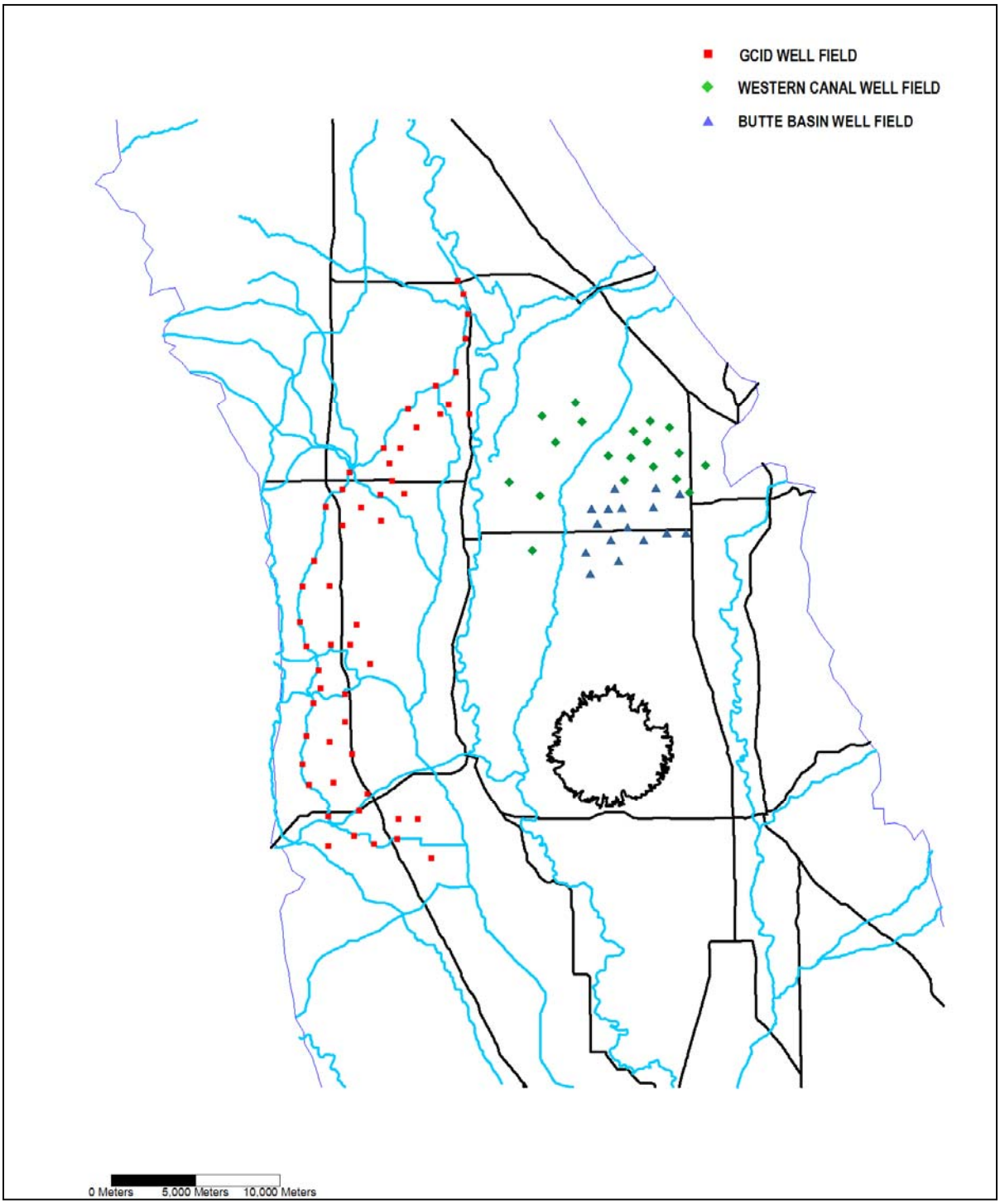

FIGURE 5-2
New Well Locations, 100 TAF GCID and 50 TAF Butte Basin Well Fields
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

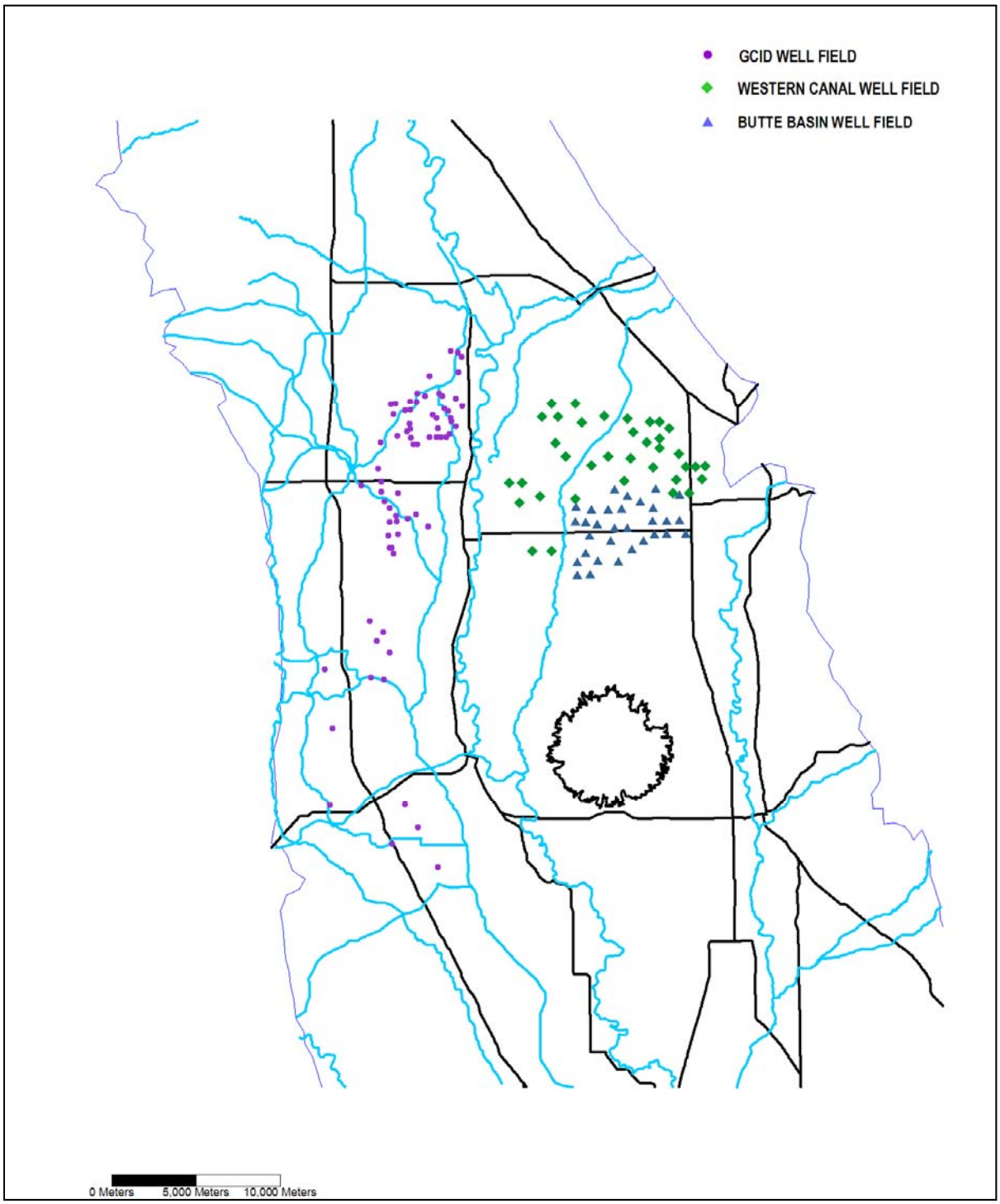

FIGURE 5-3
Existing Well Locations, 200 TAF GCID and 100 TAF Butte Basin Well Fields
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

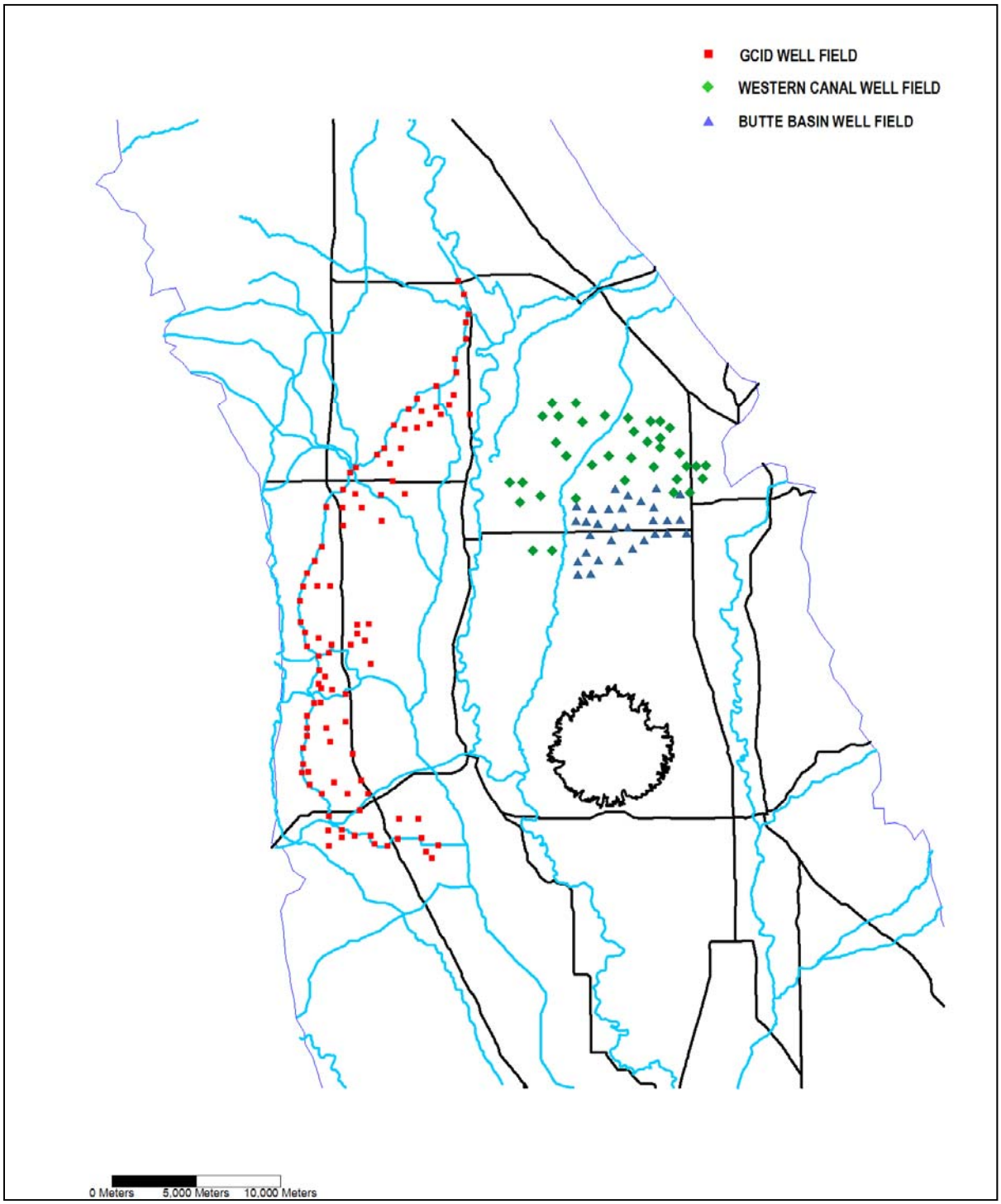

FIGURE 5-4
New Well Locations, 200 TAF GCID and 100 TAF Butte Basin Well Fields
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

5.2.Initial Model Approach and Development

5.2.1. Overview

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

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

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

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

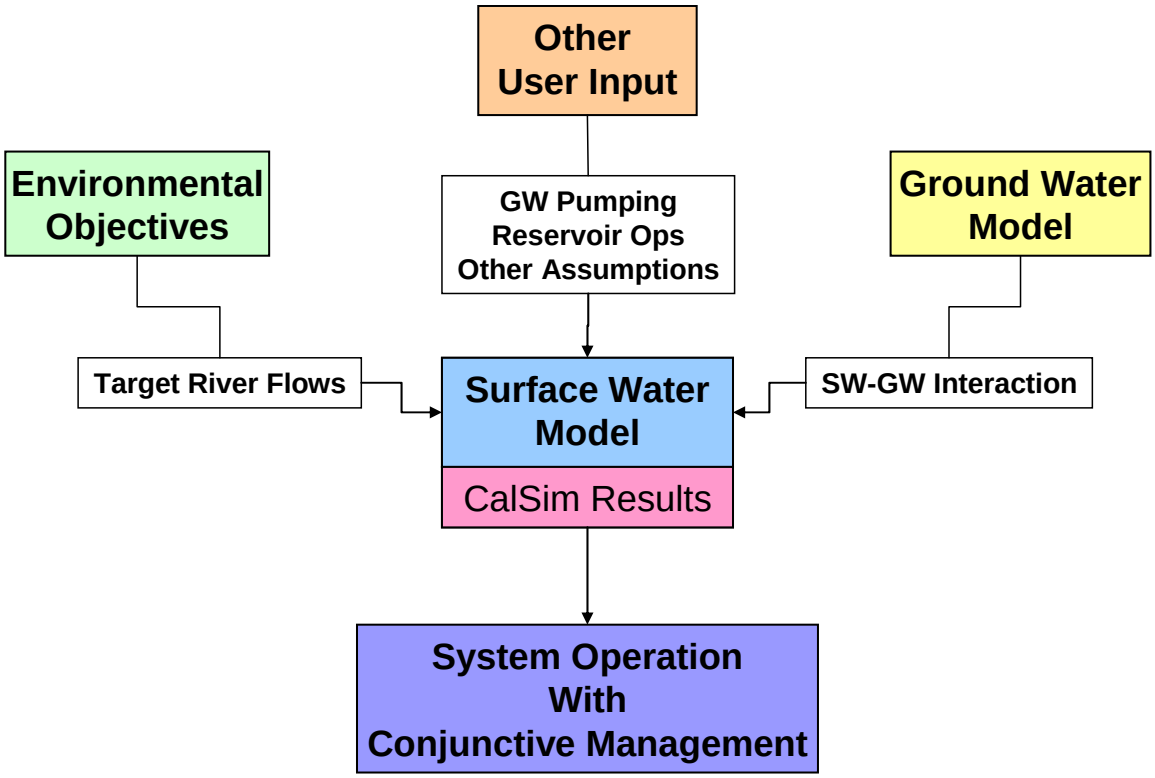

FIGURE 5-5
Surface Water Model Inputs and Operations
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

5.2.2. Surface Water Model

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

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

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

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

5.2.3. Groundwater Model

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

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

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

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

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

5.2.4. Surface and Groundwater Model Interaction

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

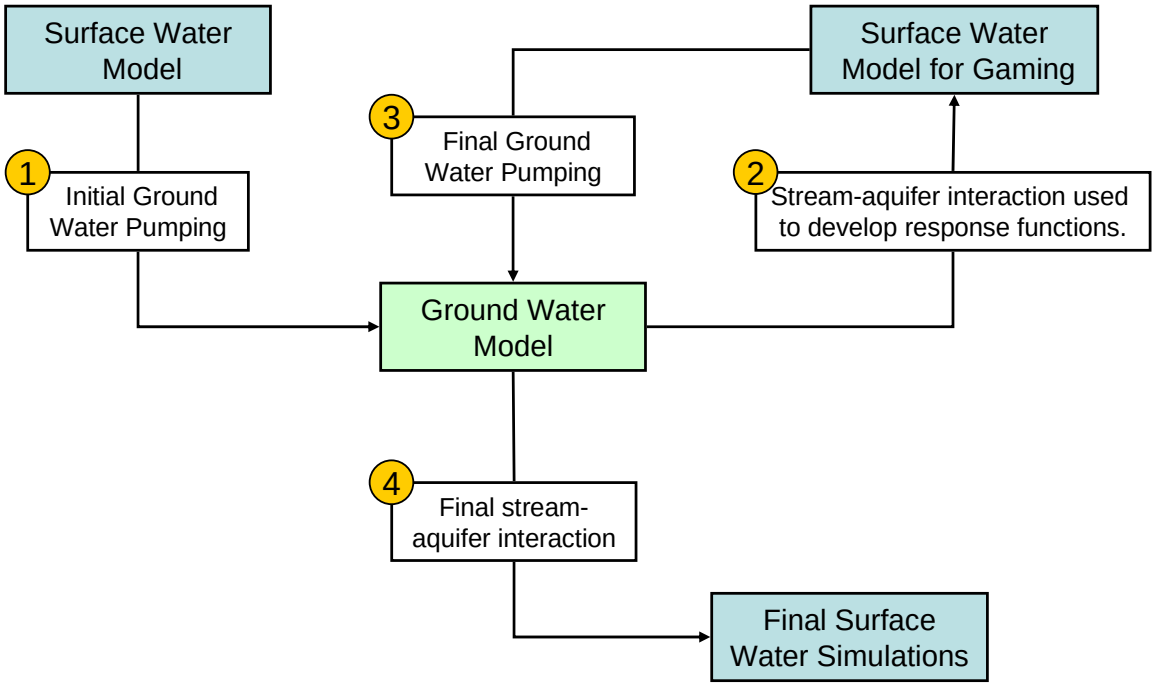

FIGURE 5-6
Surface Water and Groundwater Model Interaction
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

5.2.5. Qualifications

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

Additionally, mathematical modeling tools typically report results at a level of precision that exceeds their level of accuracy. For example, planning-level surface water models may provide estimates of water supply accurate to within a range of several thousand acre-feet, but results with a precision down to an acre-foot. Model results presented in subsequent sections are rounded to levels of precision

appropriate for comparison with results from other scenarios. Planning-level modeling tools used in this analysis are not necessarily accurate to this level.

5.3.Performance of Initial Scenarios

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

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

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

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

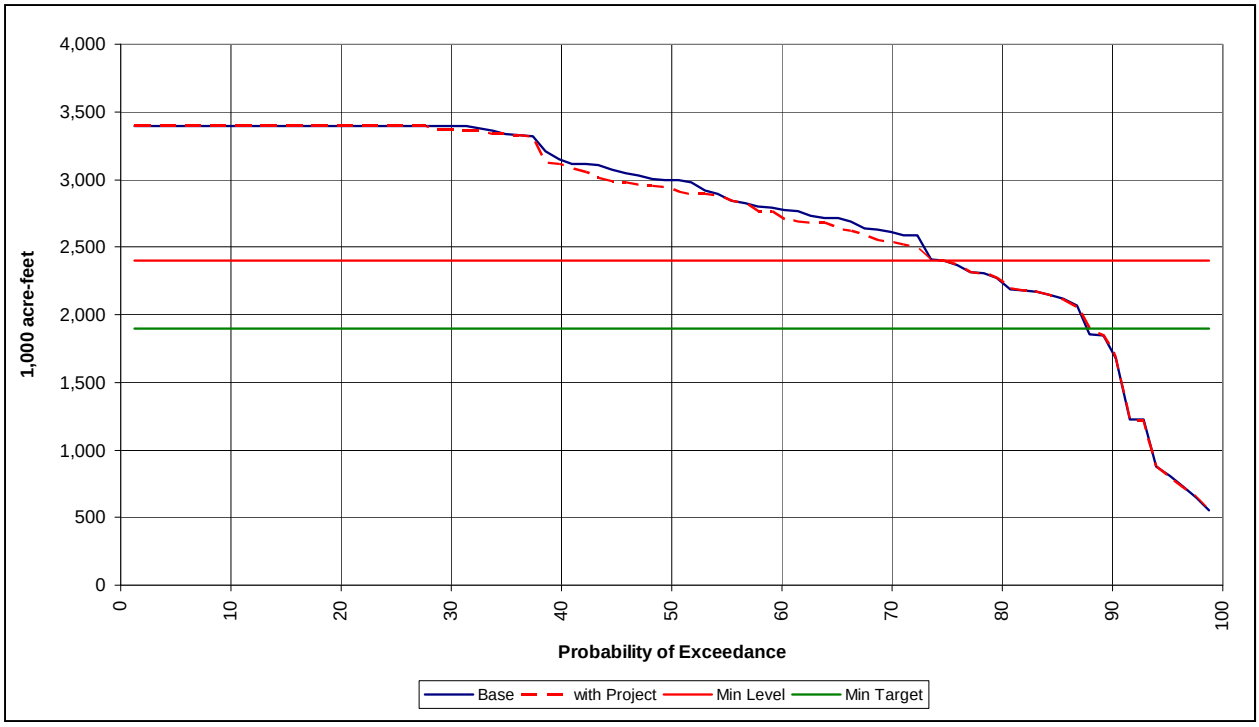

FIGURE 5-7
Shasta Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

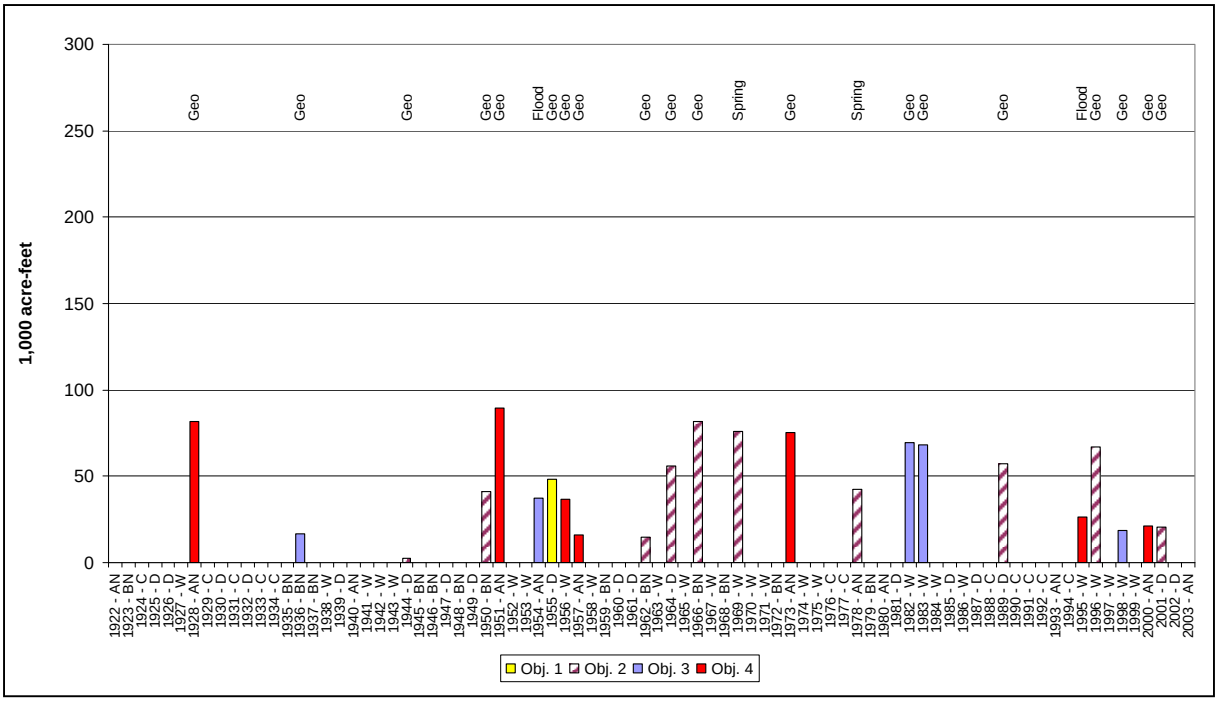

FIGURE 5-8
Sacramento River Environmental Objectives Met with Conjunctive Management, Scenarios 1, 3 And 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

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

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

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

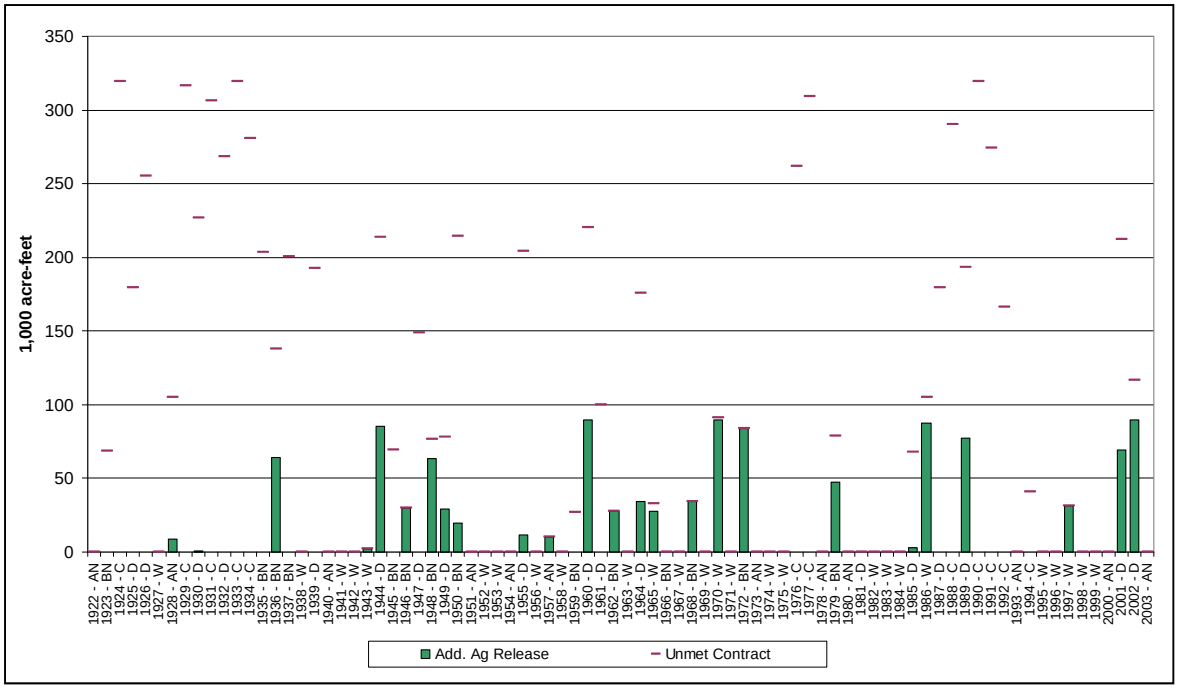

FIGURE 5-9
Sacramento River Additional Agricultural Demand Met with Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

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

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

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

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

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

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

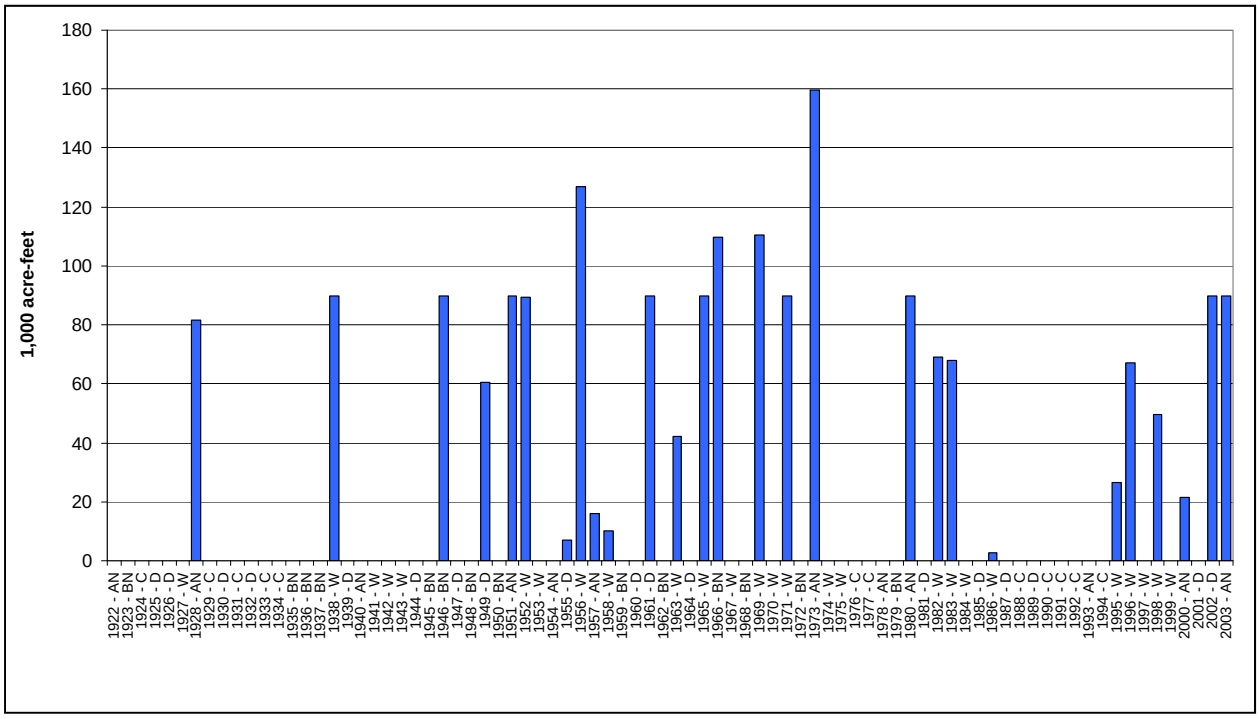

FIGURE 5-10
Refill of Shasta Reservoir from Surplus Surface Water, Scenarios 1, 3 And 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

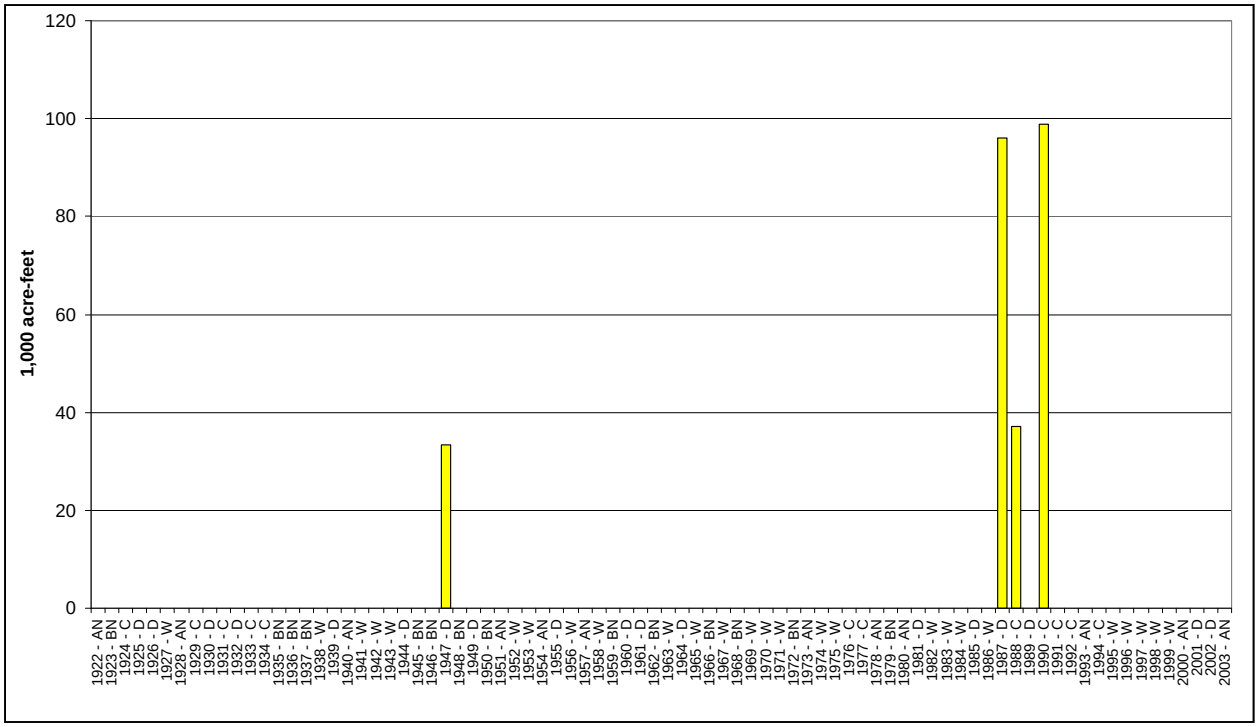

FIGURE 5-11
Refill of Shasta Reservoir from Conjunctive Management Pumping, Scenarios 1, 3 And 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

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

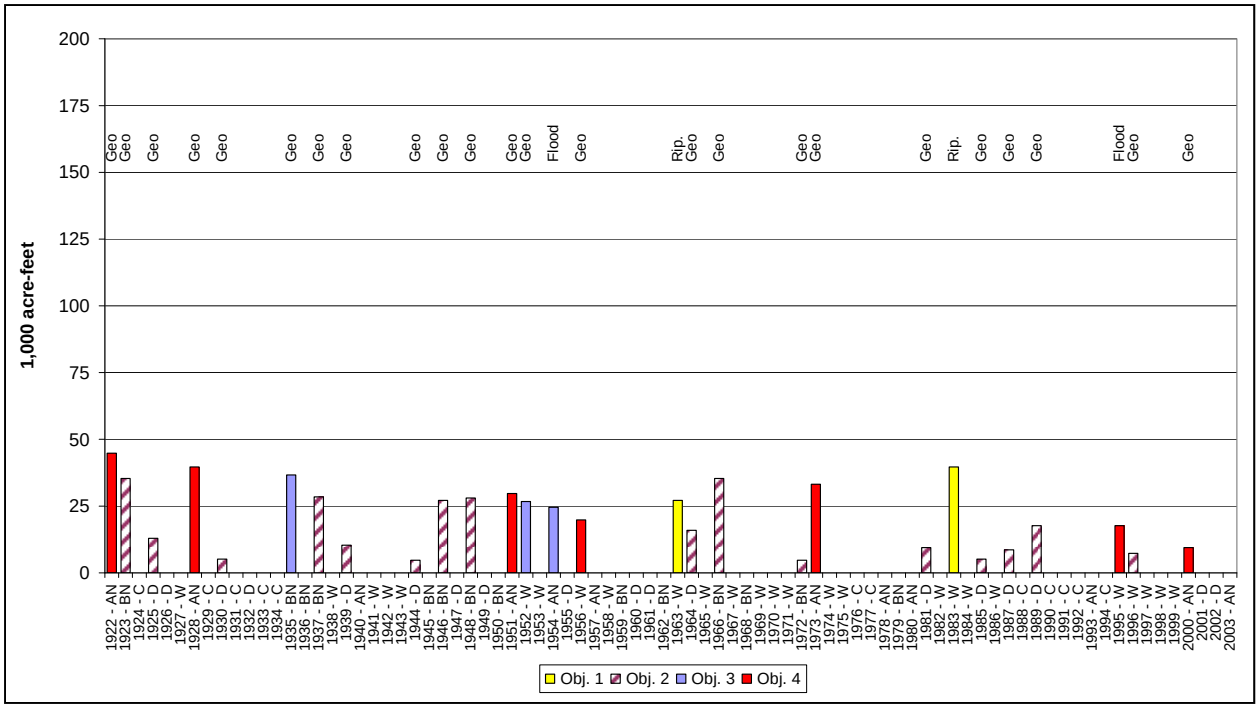

FIGURE 5-12
Feather River Environmental Objectives Met With Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

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

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

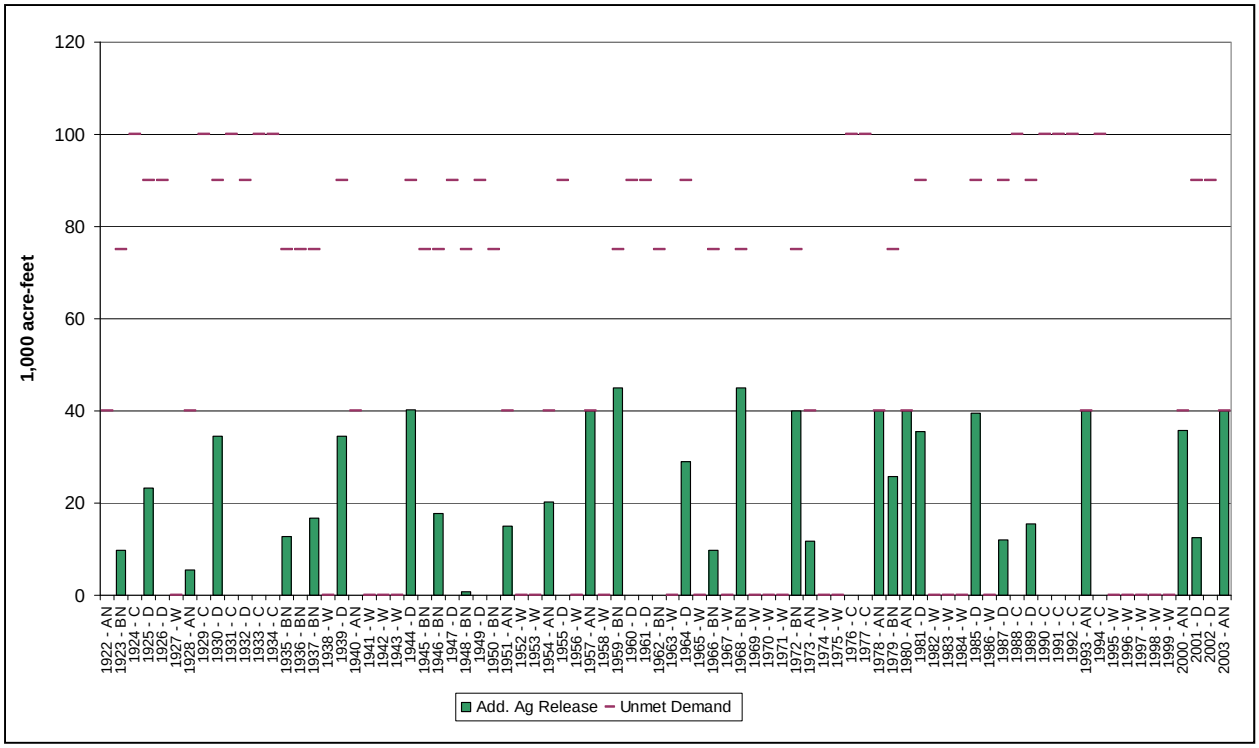

FIGURE 5-13
Feather River Additional Agricultural Demand Met with Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

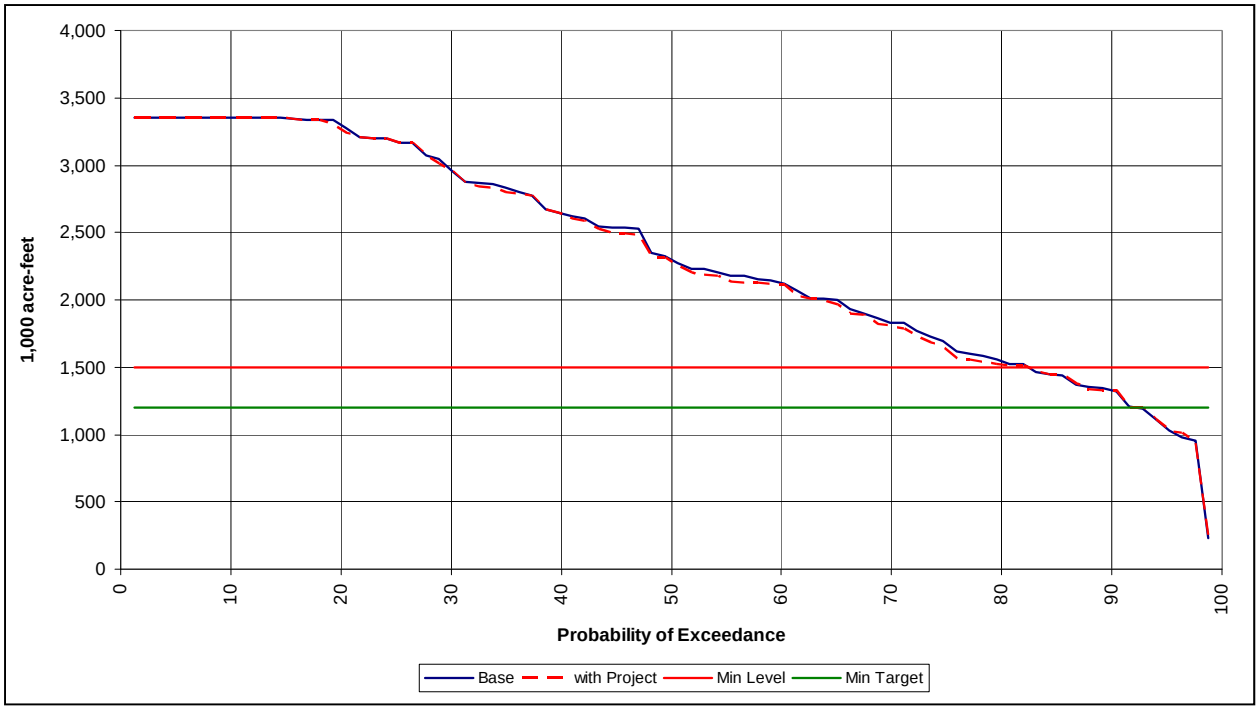

FIGURE 5-14
Oroville Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

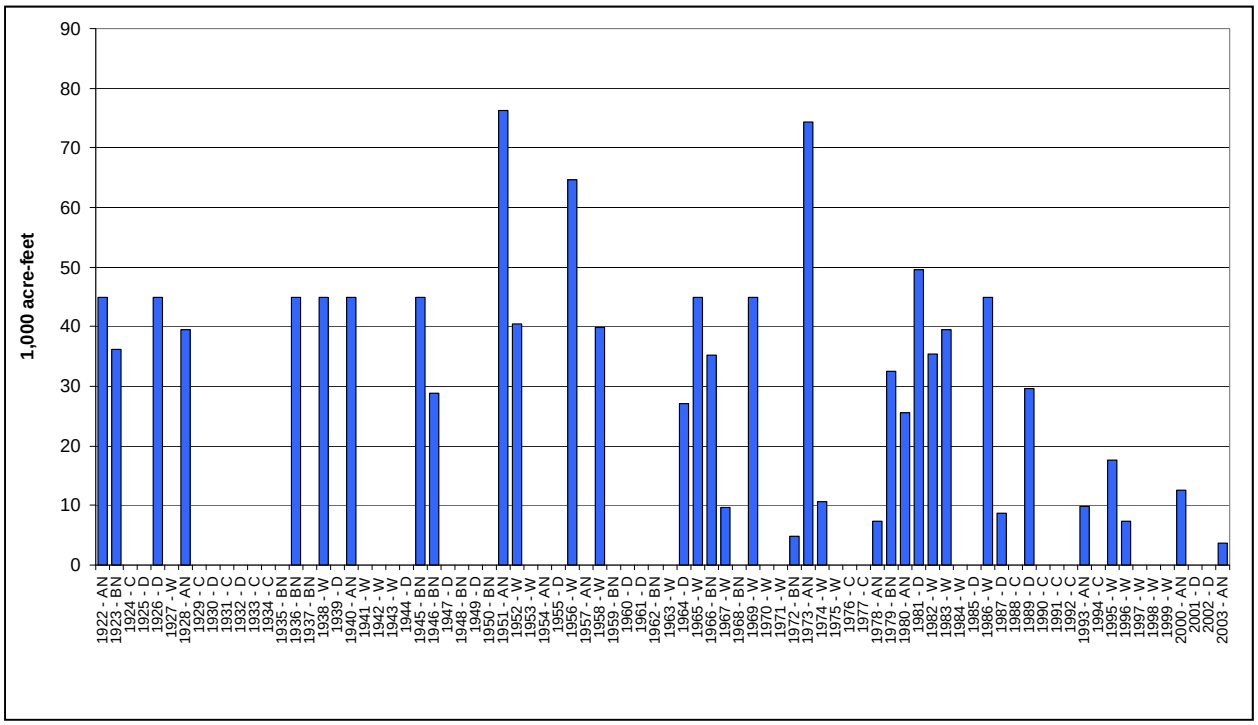

FIGURE 5-15
Refill of Oroville Reservoir from Surplus Surface Water, Scenarios 1, 3 and 4
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

5.3.3. Scenario2 – Shasta Reservoir and Sacramento River

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

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

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

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

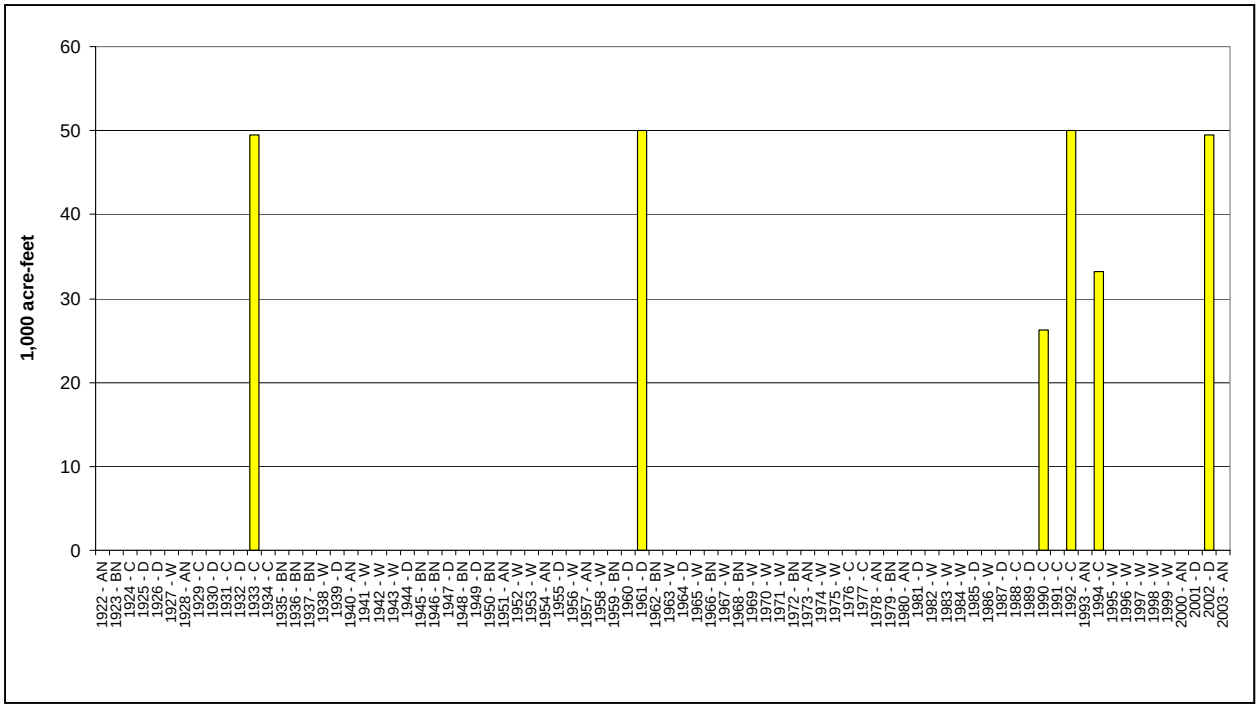

FIGURE 5-16
Refill of Oroville Reservoir from Conjunctive Management Pumping, Scenario 1
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

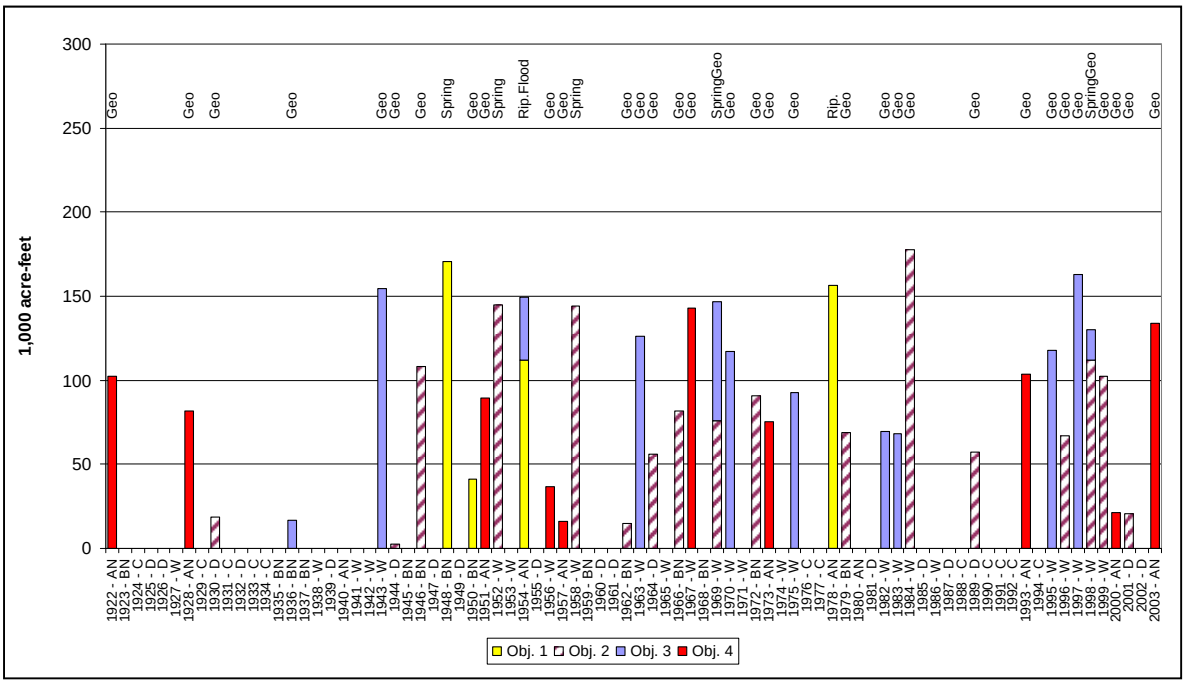

FIGURE 5-17
Sacramento River Environmental Objectives Met With Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

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

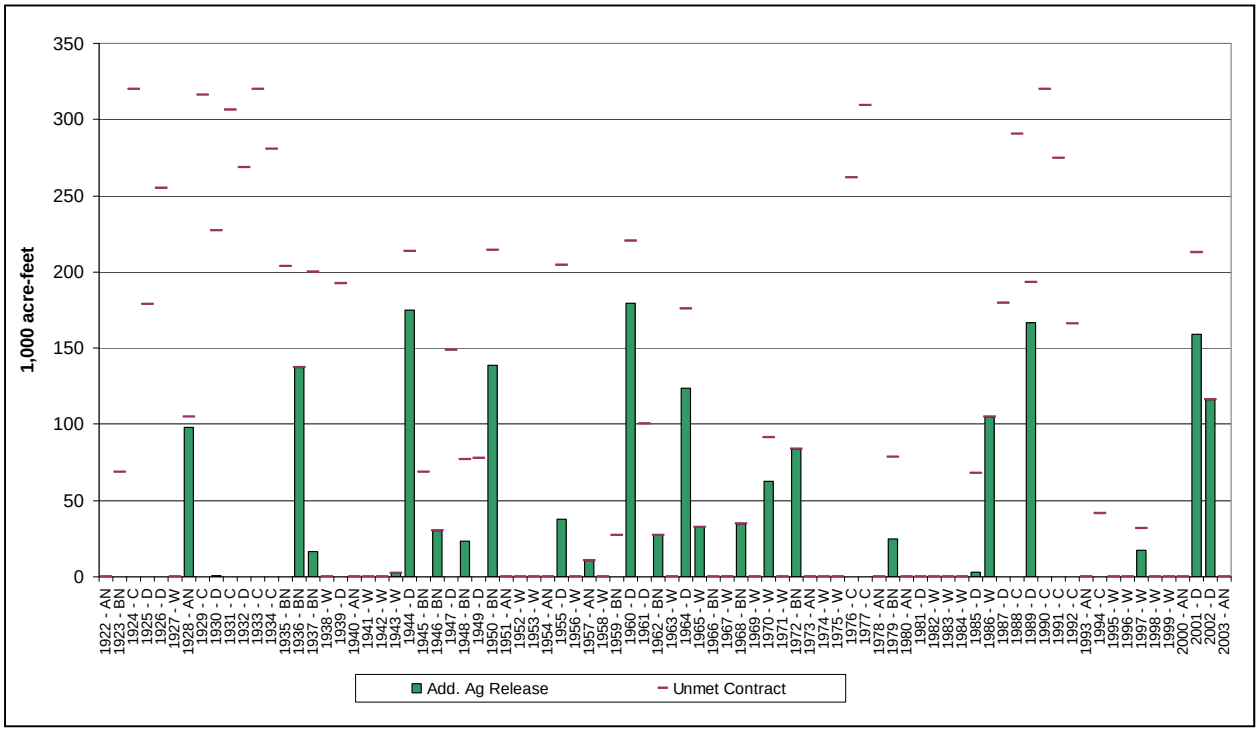

FIGURE 5-18
Sacramento River Additional Agricultural Demand Met With Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

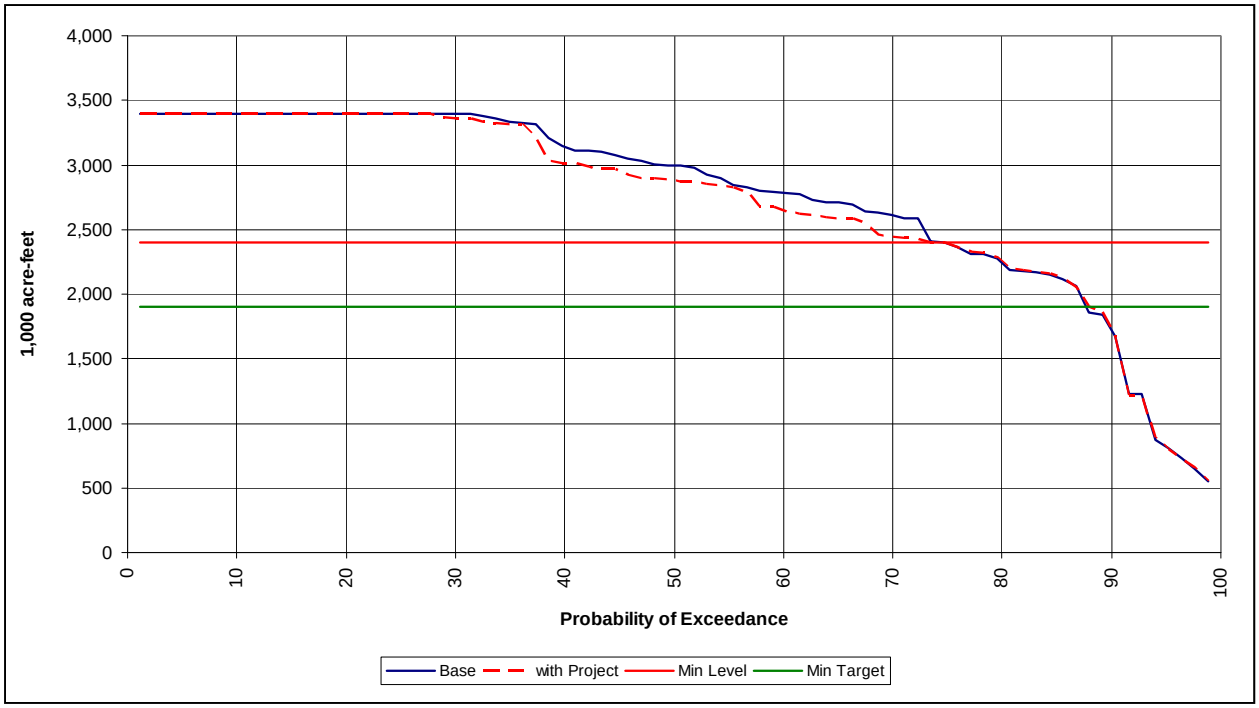

FIGURE 5-19
Shasta Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

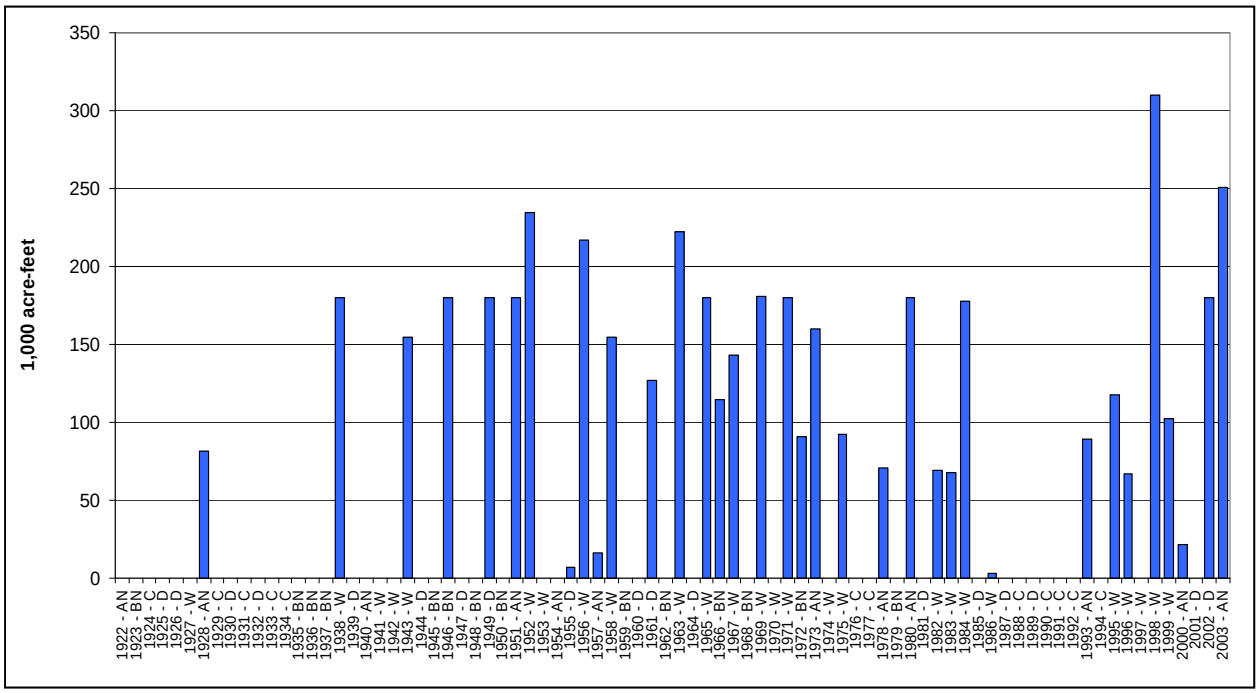

FIGURE 5-20
Refill of Shasta Reservoir from Surplus Surface Water, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

5.3.4. Scenario 2 – Oroville Reservoir and Feather River

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

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

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

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

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

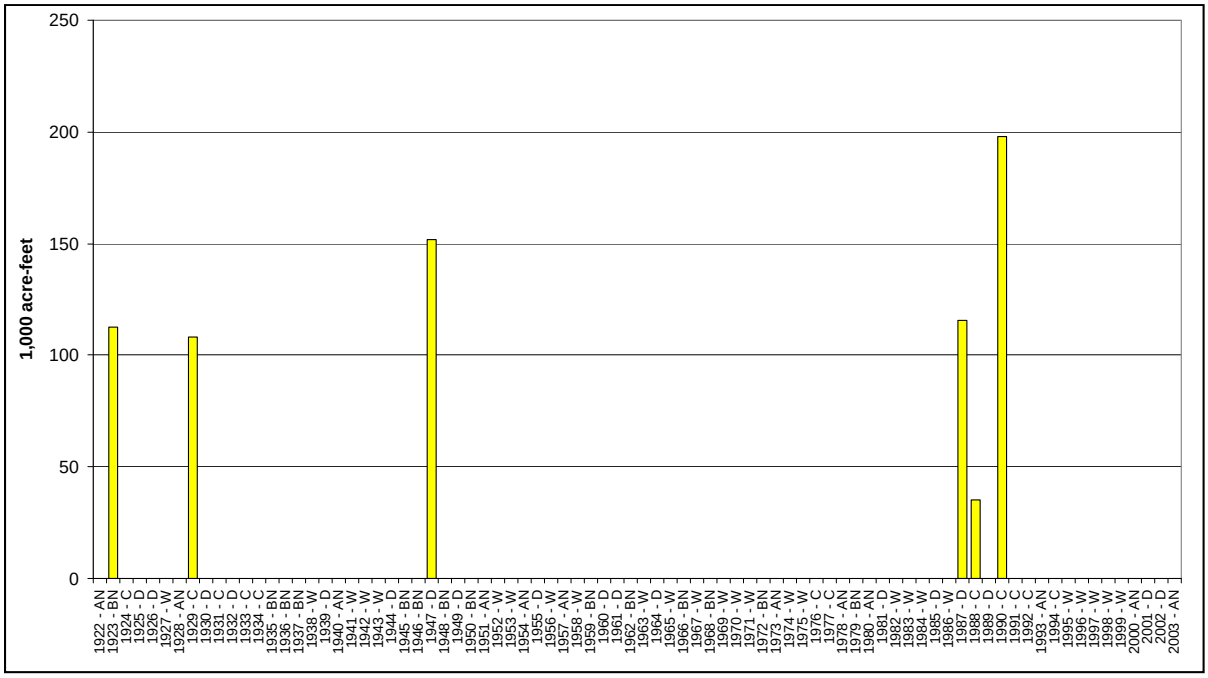

FIGURE 5-21
Refill of Shasta Reservoir from Conjunctive Management Pumping, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

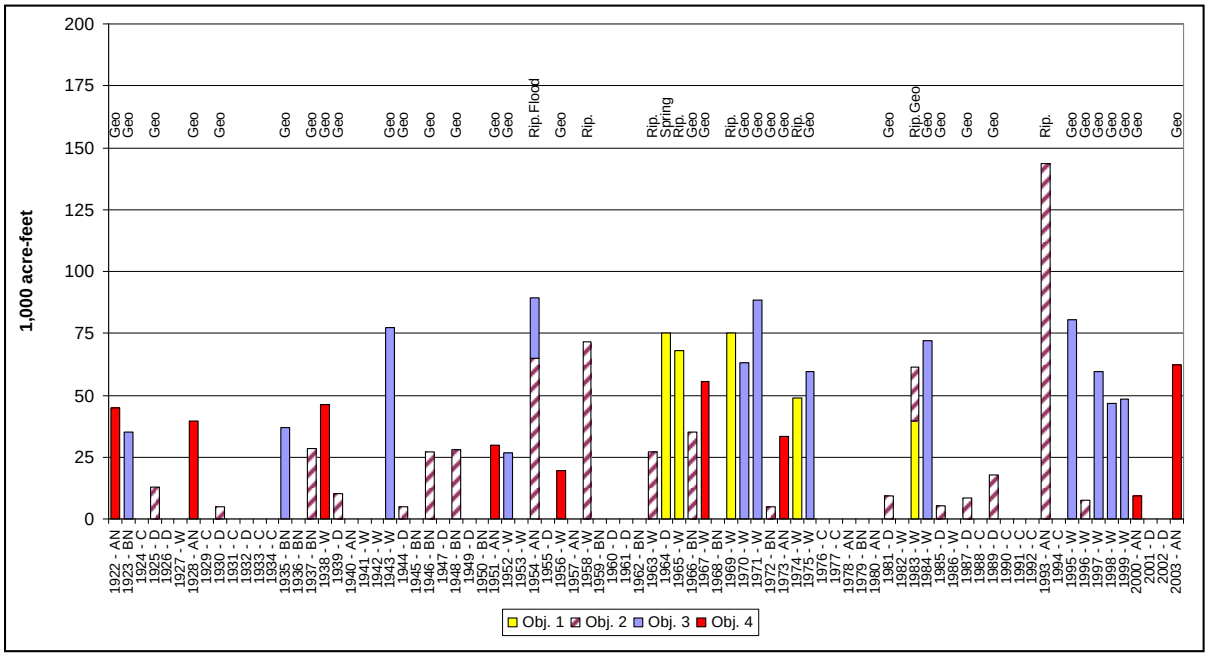

FIGURE 5-22
Feather River Environmental Objectives Met With Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

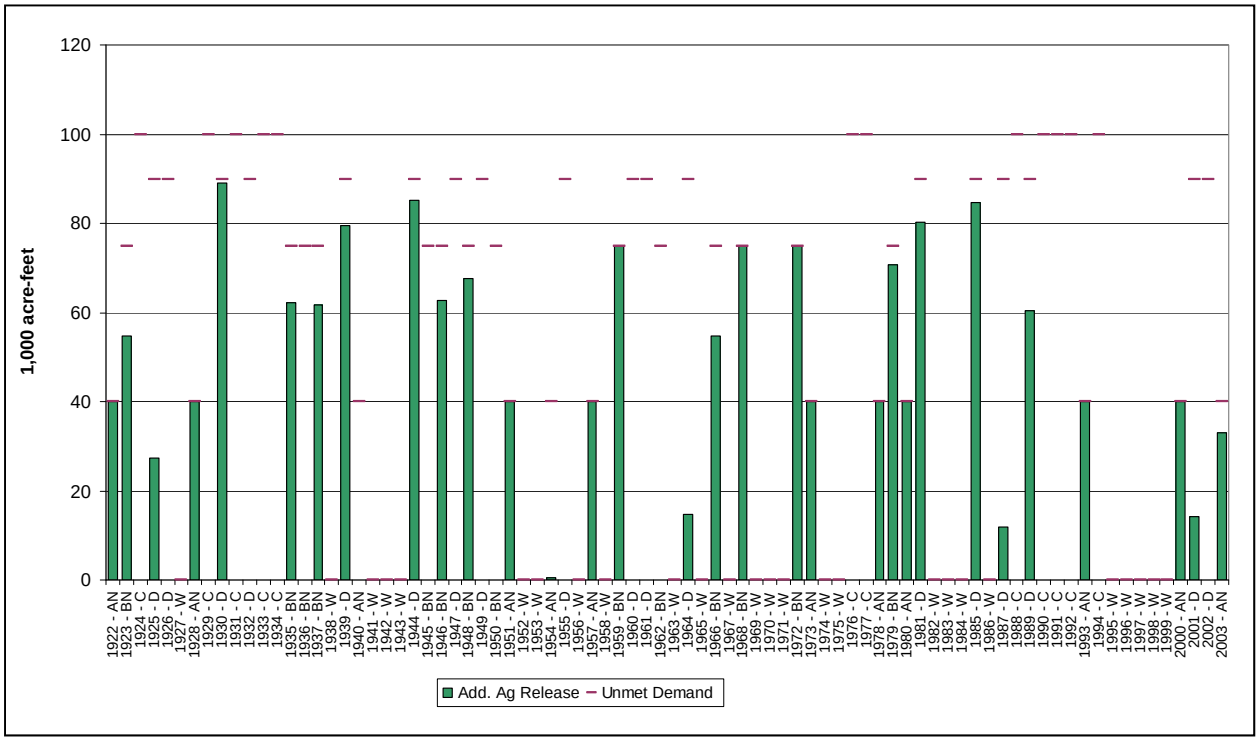

FIGURE 5-23
Feather River Additional Agricultural Demand Met with Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

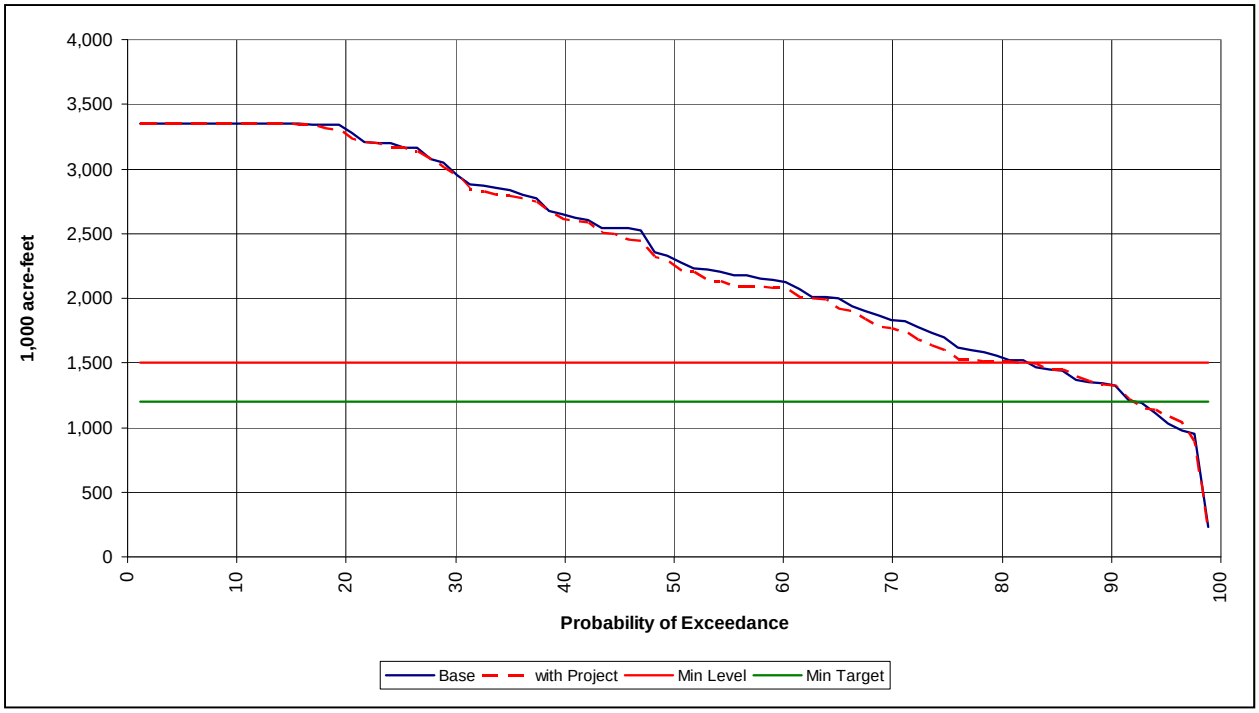

FIGURE 5-24
Oroville Reservoir September Storage Exceedance Probability with Conjunctive Management, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

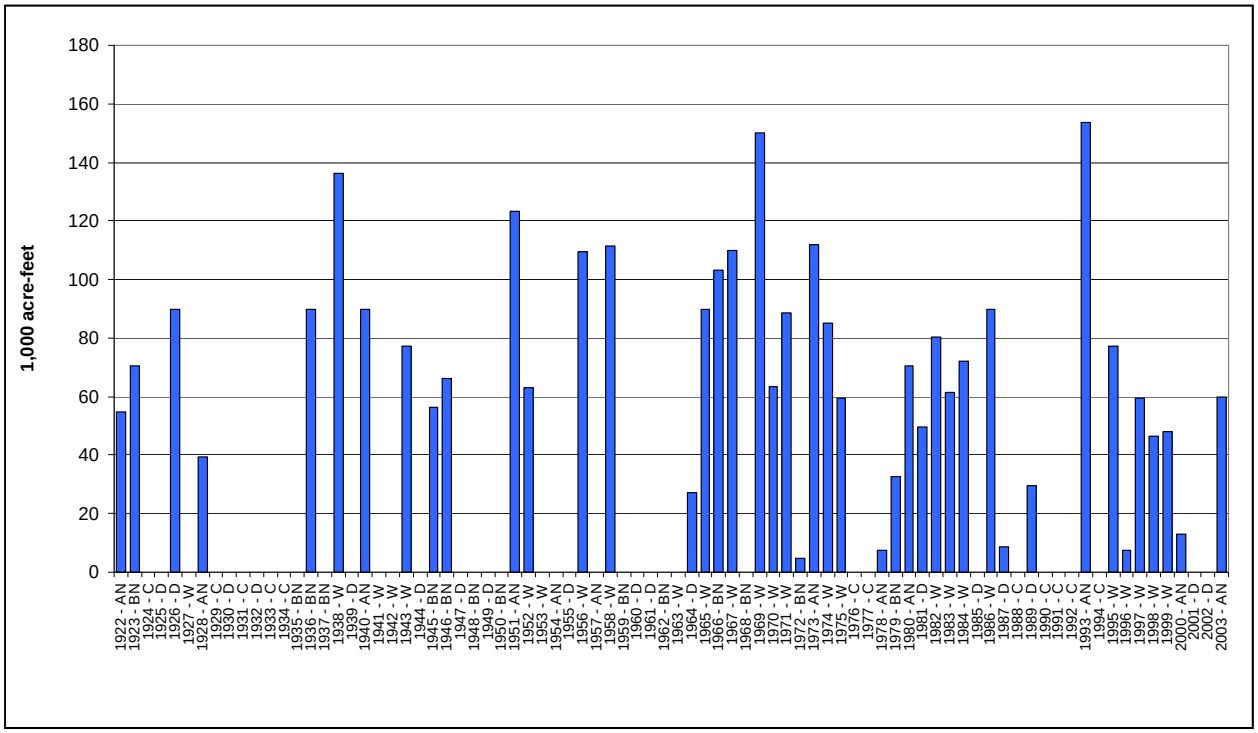

FIGURE 5-25
Refill of Oroville Reservoir from Surplus Surface Water, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

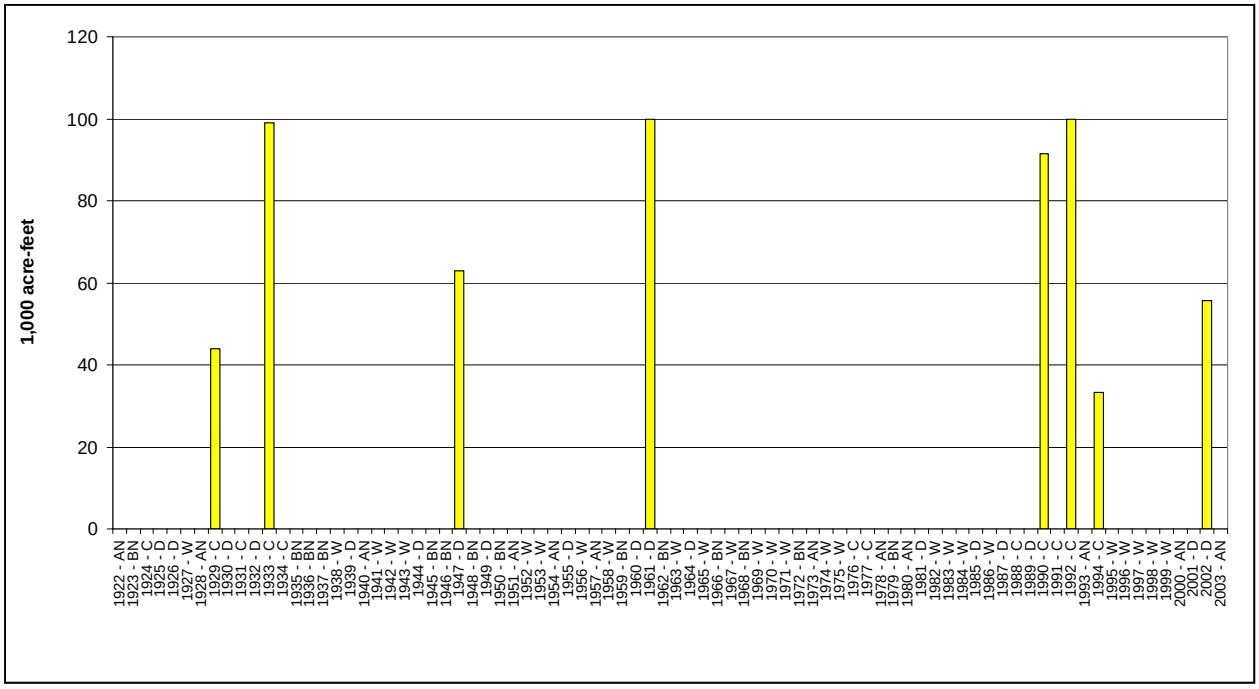

FIGURE 5-26
Refill of Oroville Reservoir from Conjunctive Management Pumping, Scenario 2
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

5.4.Impacts and Evaluation of Initial Scenarios

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

5.4.1. Impacts on Groundwater Users

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

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

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

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

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

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

[16] Domagalski, J.L., Knifong, D.L., Dileanis, P.D., Brown, L.R., May, J.T., Connor, Valerie, and Alpers, C.N. 2000. Water Quality in the Sacramento River Basin, California, 1994–98: U.S. Geological Survey Circular 1215. Available on-line at http://pubs.water.usgs.gov/circ1215/.
[17] Northern California Water Users Association. 2005. Sacramento Valley Groundwater: An approach to better understand and manage the Lower Tuscan groundwater resources for northern California. Available at: http://www.norcalwater.org/pdf/sacramento_valley_groundwater_0919.pdf.
[18] Data provided by California Department of Water Resources Northern District Office. 2009.
[19] May include monitoring wells, vapor recovery wells, or other wells not constructed for water supply purposes.

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

5.4.1.1. Occurrence of Project Pumping and Potential Impacts

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

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

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

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

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

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

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

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

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

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

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

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

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

5.4.1.2. Timing of Peak Interference Drawdown and Associated Impacts

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

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

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

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

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

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

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

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

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

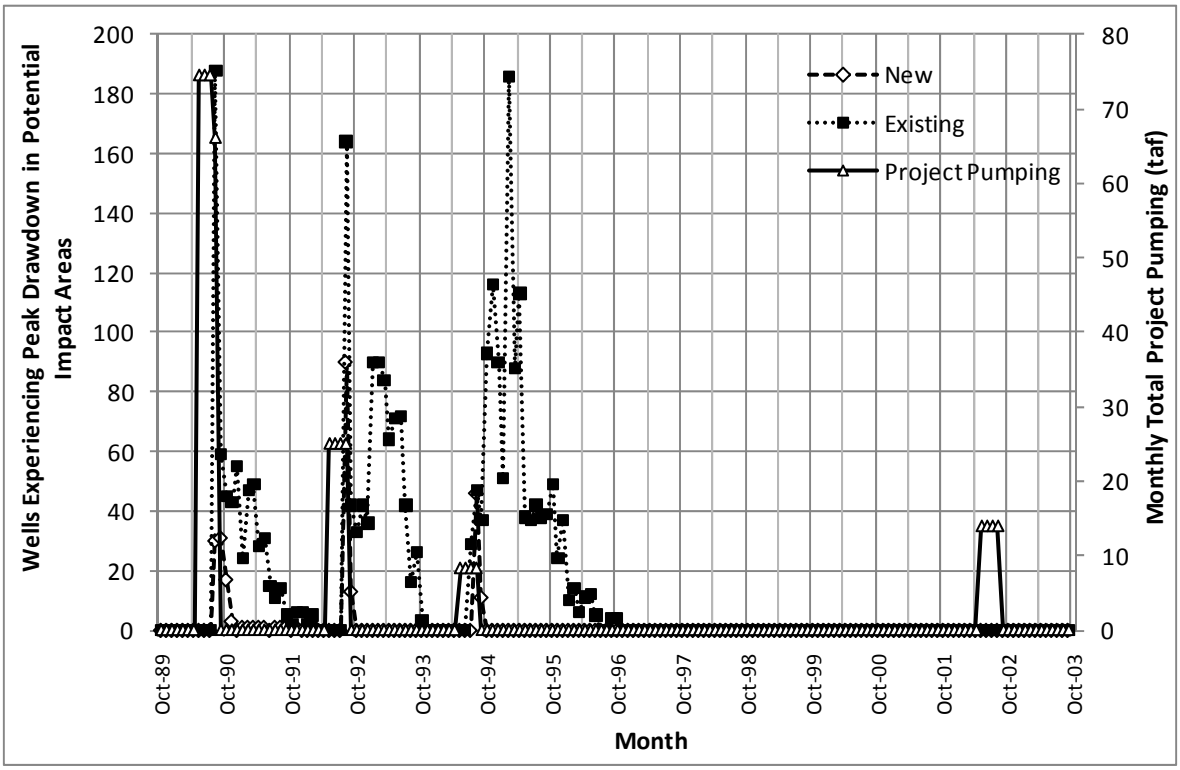

FIGURE 5-27
Project Pumping for 300 TAF Summer Pumping Scenarios and Number of Domestic Wells Experiencing Peak Interference Drawdown
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

5.4.1.3. Increase in Pumping Energy Costs

Project pumping will result in amounts of drawdown that will not be great enough to adversely impact yield in nearby wells in most cases; however, the drawdown will require all groundwater users (agricultural and domestic) to lift water from slightly greater depths, resulting in additional pumping costs. Additional pumping costs associated with increased lift were estimated for irrigation wells based on baseline groundwater pumping from the surface water model, interference drawdown from the groundwater model, estimated mean overall pumping plant efficiency for irrigation wells, and the estimated agricultural energy cost per kilowatt-hour. For domestic wells, additional pumping costs were

estimated based on baseline pumping estimated from the combination of spatially distributed U.S. Census data for 2000 and per-capita non-irrigation groundwater pumping for 2005 from USGS, interference drawdown from the groundwater model, estimated mean overall pumping plant efficiency for domestic wells, and the estimated residential energy cost per kilowatt-hour. Increased energy requirements and associated costs were estimated for individual sections within the Project area on a monthly time step for water years 1987 to 2003.

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

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

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

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

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

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

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

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

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

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

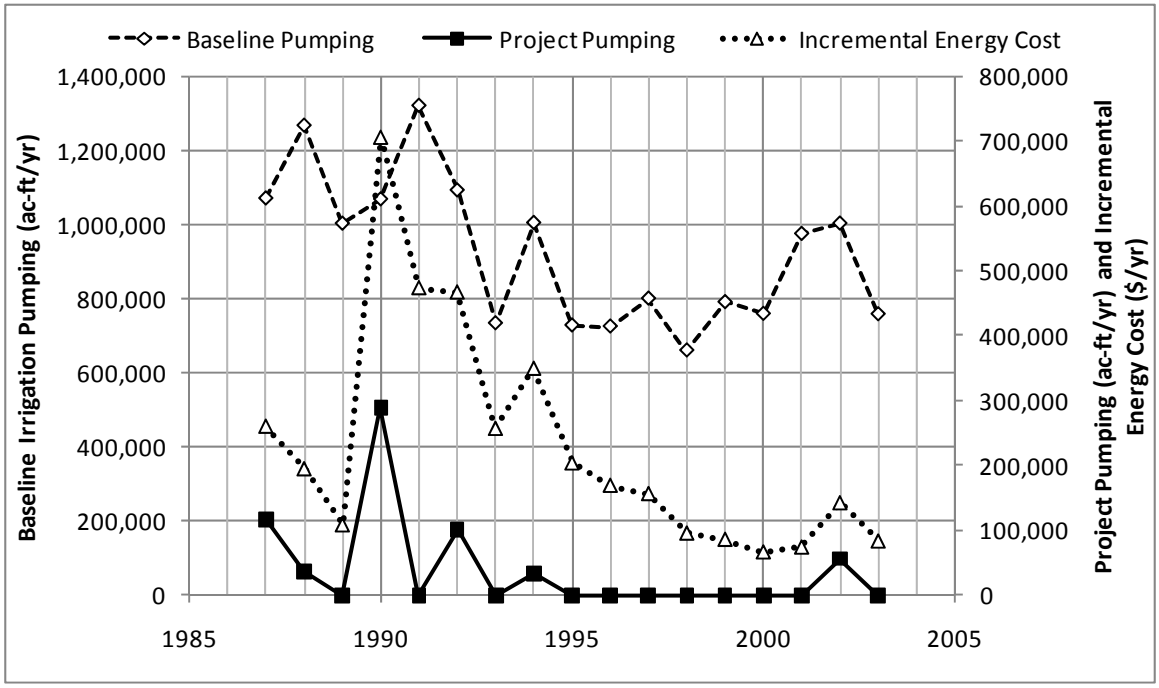

FIGURE 5-28
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, New Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

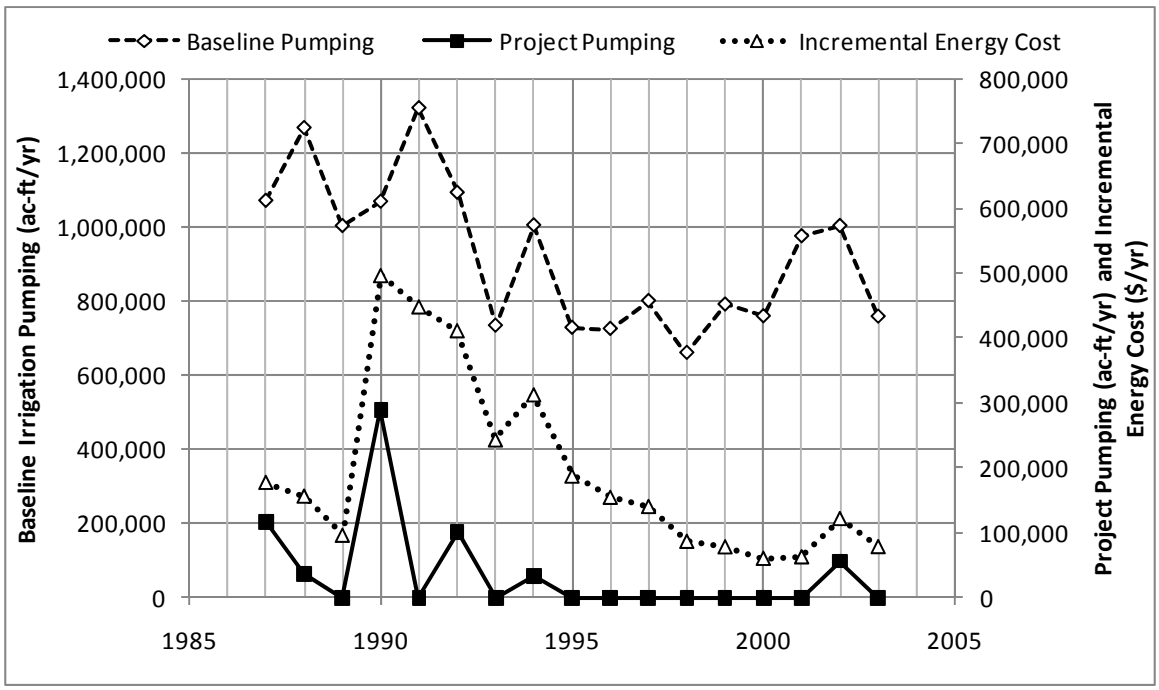

FIGURE 5-29
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, Existing Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Incremental energy costs are greatest in years when project pumping is greatest but are also directly proportional to the amount of baseline irrigation pumping, all else equal. Project pumping in 1990 results in interference drawdown that causes increased lift and associated increased energy costs for the years to follow. The incremental energy costs resulting from Project pumping with the new well field are substantially greater than the incremental energy costs for the existing well field in 1990, the year of maximum pumping in GCID and maximum total project pumping.

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

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

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

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

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

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

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

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

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

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

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

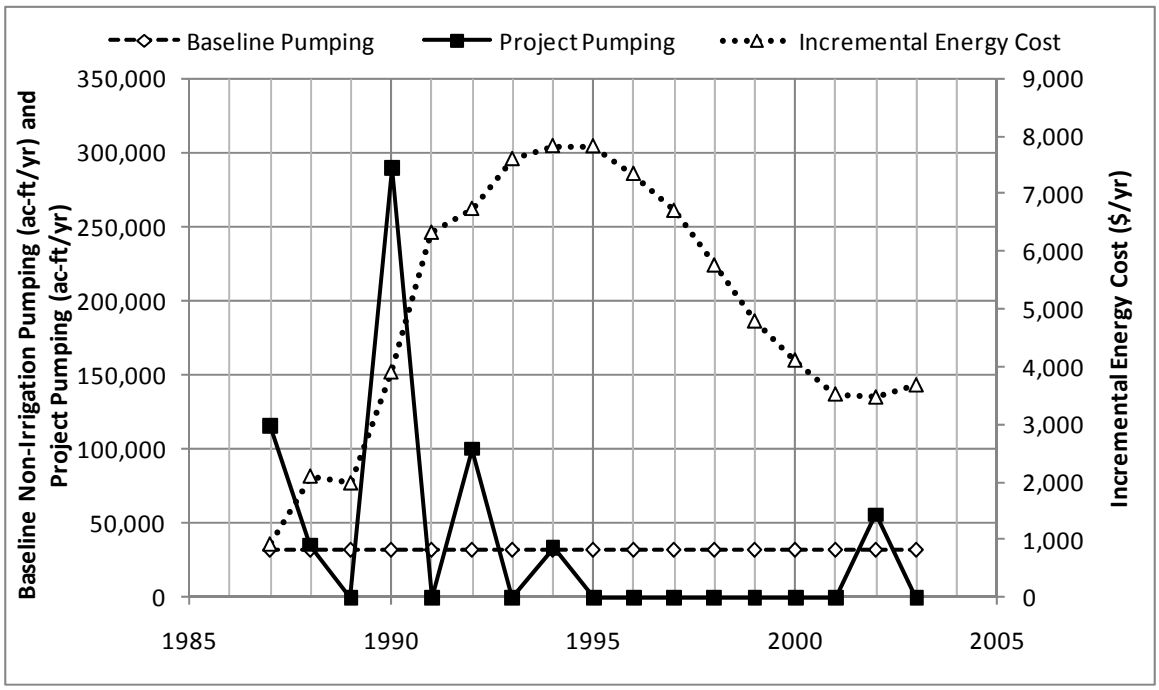

FIGURE 5-30
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, New Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

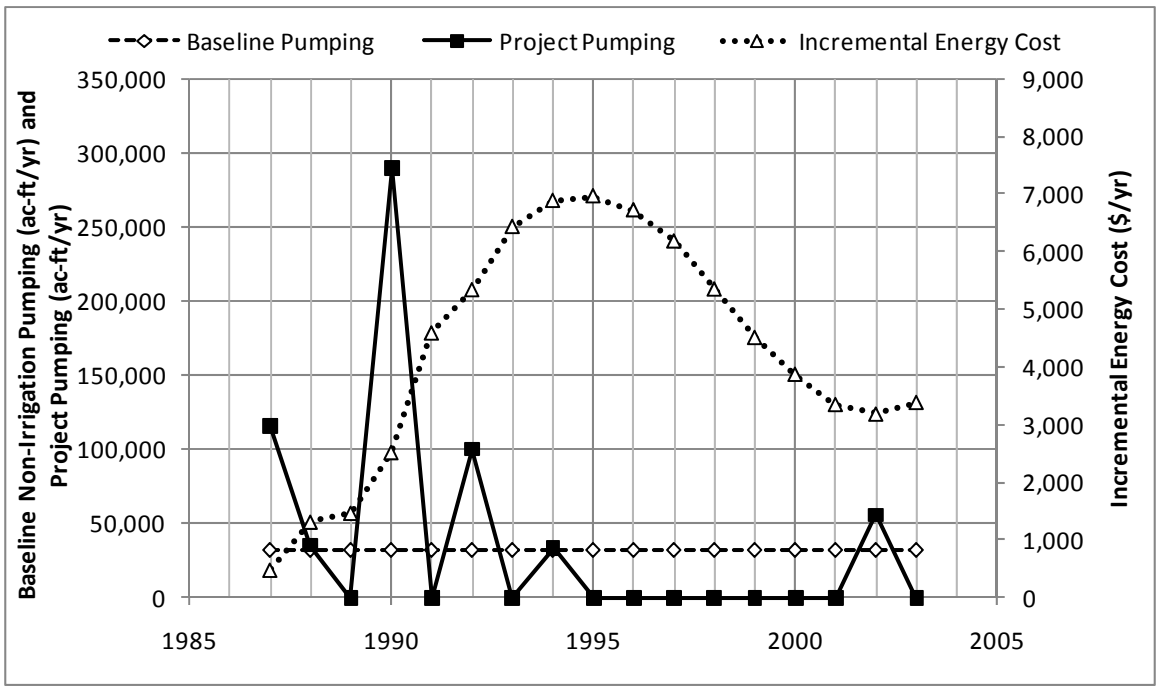

Figure 5-31
Annual Baseline Irrigation Pumping, Project Pumping, and Increased Energy Cost: 300 TAF Summer Pumping, Existing Well Field
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

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

5.4.1.4. Groundwater Levels

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

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

5.4.2. Impacts on Streamflow

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

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

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

Specific conclusions regarding surface water effects are as follows:

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

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

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

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

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

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

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

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

5.4.3. Stream Impact Analysis

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

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

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

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

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

5.5.Economic Analysis

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

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

5.5.1. Cost Assessment

The costs of the different scenarios are presented in Table 5-19, including costs capital outlays for project facilities (primarily existing production well rehabilitation or new well construction), project operation and maintenance, compensation for increased pumping costs (ag and domestic),

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

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

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

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

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

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

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

replacement of a certain number of domestic wells and project legal and administrative charges. These costs are described in detail in Appendix E. The present value of these costs based on a real discount rate of 3 percent ranges from $65M to $298M, with the lower cost scenarios being those relying on existing wells or having longer repayment pumping period and the higher costs scenarios being those relying on new wells and having shorter pumping periods. The scenarios that involve development of new wells are more expensive compared to their sister scenario using existing wells primarily because of the higher capital investment required to build the new wells. The capital cost is almost 60 percent higher to develop new wells than use existing wells.

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

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

5.5.2. Valuing Benefits

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

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

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

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

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

TABLE 5-20
Average Cost of Pumping and Releases for Each Pumping Scenario
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Scenario	Total Cost (PV)	Pumping Volume (AF)	Avg Cost of Pumping ($/AF)	Avg Annual Releases (AF)	Avg Cost of Annual Releases ($/AF)
1 300 TAF Summer New Wells	$289,528,604	1,307,759	$221	109,596	$79
2 300 TAF Summer Existing Wells	$212,399,624	1,307,759	$162	109,596	$58
3 150 TAF Summer New Wells	$134,846,308	523,547	$258	43,609	$93
4 150 TAF Summer Existing Wells	$93,584,886	523,547	$179	43,609	$64
5 150 TAF Fall New Wells	$209,645,410	608,963	$344	44,298	$142
6 150 TAF Fall Existing Wells	$143,647,345	608,963	$236	44,298	$97
7 150 TAF Summer & Fall New Wells	$87,558,597	574,129	$153	43,955	$60
8 150 TAF Summer & Fall Existing	$65,352,605	574,129	$114	43,955	$45

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

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

5.5.3. Results of Economic Analysis

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

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

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

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

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

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

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

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

5.6.Provisional Conclusions Guiding Refinement of Scenarios

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

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

The most significant conclusion is that the net benefits of Sacramento Valley conjunctive operations are strongly dependent on where the water could be marketed and the price received. If the water is sold in the Sacramento Valley at current market rates, the project appears not to be economically justified. On the other hand, if the water could be conveyed south of the Delta for storage in a groundwater bank and

sold at dry year market rates, the project appears to be economically viable. Of course, such an export operation would require resolution of current Delta conveyance and export constraints and further analysis beyond that performed in this phase of investigation.

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

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

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

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

6.1. Collaborative Workshops with CVP and SWP Operators

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

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

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

- Workshop #3: September 9, 2010. A meeting/gaming session was held with operators and the project team at which the surface water model was used to demonstrate effects of additional constraints suggested by the operators in Workshop #2. Generally these constraints reduced project benefits relative to the initial project scenarios and identified areas of risk due to project operations, particularly cold water pool management. Several options for additional analysis

were discussed at this meeting, including: revising operator constraints to be less conservative, temperature modeling to refine operating rules, and further modeling to identify system-wide effects.

6.2.Surface Water Model Refinements

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

6.2.1. Updated CALSIM II Baseline Conditions

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

6.2.2. Ability to Reduce Shasta Reservoir Releases to Recover Storage

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

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

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

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

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

TABLE 6-2
Ability to Reduce Oroville Release (cfs)
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

6.2.3. Forecast-Based Operations

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

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

6.2.4. Oroville Carryover Targets

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

6.2.5. Crop Idling for Reservoir Payback

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

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

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

TABLE 6-3
Summary of Rice Acreage and Maximum Acres for Crop Idling with each Project Area
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

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

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

6.3.Refined Model Simulation Results

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

The refined model resulted in differences between how the project operates with the CVP/Shasta Reservoir versus the SWP/ Oroville Reservoir. Therefore results and conclusions are presented below for the CVP and SWP, respectively.

6.3.1. CVP and Shasta Reservoir Results

6.3.1.1. Operations for Core Project Purposes

A comparison of initial and refined simulation results are presented in Table 6-4 for the 100 TAF and 200 TAF GCID project scales (pumping capacity). For the 100 TAF scale, project benefits are reduced by more than 50 percent, from 27 TAF to 12 TAF, with environmental releases reduced by almost two-thirds and agricultural deliveries reduced by half. Corresponding to the reduction in project benefits, reservoir payback is accomplished almost entirely by refill with surplus surface water. Project pumping is reduced from 4 years over the 82-year simulation to just 1 year and the maximum year pumping is reduced from 98 TAF to just 6 TAF. Average annual project pumping was 3 TAF.

TABLE 6-4
Comparison of Initial to Refined Simulation or Project Scenarios (Shasta/CVP)
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

			Project Benefits (TAF)			Reservoir Payback (TAF)			Project Pumping		
Scenario #	Project Scale (Pumping Capacity)	Model	Enviro. Release	Ag. Deliveries	Total Project Benefit	Surplus Surface Water	Project Groundwater Pumping	Total	Number of Years	Peak Year Pumping (TAF)	Peak Pumping Year
1, 3 and 4	100 TAF	Initial	13	14	27	24	3	27	4	98	1990
		Revised	5	7	12	12	0	12	1	6	1976
		Difference	-8	-7	-15	-12	-3	-15	-3	-92	N/A
2	200 TAF	Initial	45	22	67	58	9	67	6	195	1990
		Revised	15	8	23	23	0	23	1	6	1976
		Difference	-30	-14	-44	-35	-9	-44	-5	-189	N/A

Results for the 200 TAF project scale are even more dramatic, with project benefits reduced by roughly two-thirds for both environmental releases and agricultural deliveries. Even at this scale, reservoir refill is accomplished almost entirely with surplus surface water and negligible groundwater pumping.

The dramatically reduced benefits under the refined operations are due primarily to the effects of forecast-based operations added to the model. The forecast of September storage is deliberately conservative to avoid excess risk to reservoir storage; it is based on a 90 percent exceedance forecast for March runoff and 50 percent exceedance in later months. This frequently results in an under estimation of available project assets and therefore much smaller reservoir releases for environmental flows and agricultural water supplies compared to the initial modeling based on perfect storage forecasts.

The minimum Shasta (Keswick) release constraints prescribed by the operators, together with the forecast-based simulation, also resulted in some additional risk to reservoir carryover storage relative to baseline conditions. The risk was greatest when Shasta storage is below 2.0 MAF when project releases in one year are not refilled from surplus surface water in subsequent years and the project is not able to recover the storage deficit due to an inability to reduce reservoir releases and retain payback water into Shasta. The project is not able to recover the storage deficit due to the minimum Keswick release requirement prescribed by operators for purposes of complying with Sacramento River temperature requirements for protection of endangered species. Simulated project operations resulted in slightly diminished ability to meet Shasta carryover targets specified in the salmon BO relative to the CALSIM II baseline.

Because the minimum Keswick releases had such a strong effect on project performance, the model was used to test the sensitivity of Shasta carryover storage to relaxed minimum release targets relative to those specified by the operators. Relaxing the minimum releases by 2,000 cfs in all months (relative to

those listed in Table 6-1) revealed only limited potential to improve carryover storage conditions when below approximately 2.0 MAF. Because of the significant constraints posed to project operation by the Keswick releases, it was concluded that temperature modeling should be performed to better evaluate relaxed minimum reservoir releases and the resulting implications to temperature compliance operations.

6.3.1.2. Effectiveness of Temporary Crop Idling as a Payback Mechanism

The operator-prescribed constraints on the ability to retain payback water in Lake Shasta discussed above also apply to crop idling. However, there are additional factors associated with crop idling related to the timing of decision making and the inflexibility in when the water is produced that affect its performance as a payback mechanism.

As previously explained, crop idling decisions need to be made earlier in the season and involve making an irreversible commitment to participating growers for purchasing the water generated through crop idling regardless of whether or not the water can be held in upstream storage or put to beneficial use downstream.

A scenario was evaluated where idling provided 70 TAF of payback capacity (requiring idling of 21,000 acres of rice land) and groundwater pumping 130 TAF to achieve a total of 200 TAF of payback in GCID (corresponding to Scenario 2). Payback priority was placed on crop idling in order to minimize groundwater pumping. Under these assumed conditions, crop idling was called on about 1/3 of the time during the 82-year simulation, in most cases utilizing the maximum 70 TAF of payback capacity and associated land idling (21,000 acres). It was found that only 17 percent of the water generated by idling was actually retained in Shasta to recover reservoir storage due to much of the water being produced when minimum Shasta releases for temperature control were controlling. It was shown that the effectiveness of crop idling is sensitive to the magnitude of the specified minimum releases. When releases were relaxed by 2,000 cfs in all months as described above, the portion of idling payback water retained in storage increased to 58 percent and the frequency with which idling was called on was reduced.

As expected, placing priority on idling for reservoir payback was found to appreciably reduce the magnitude of groundwater pumping needed for Shasta payback.

While the effectiveness of crop idling probably could be improved through refinement in when and how it is called on, and despite the fact that it can be used to offset groundwater pumping for payback, it is doubtful that crop idling offers a cost-effective means of reservoir payback due to the risks associated with the early timing of the decision, the irreversible commitment to follow through once a decision has been made, and the inflexible pattern on which water is made available.

6.3.1.3. Operation for Cold Water Pool Management

During collaborative discussions with operators, interest was expressed in evaluating how project operations could be used to improve carryover storage and management of cold water resources in Lake Shasta. An additional analysis was conducted with the refined surface water model to estimate the upper limit of potential project contributions to carryover storage (based on 200 TAF of pumping capacity in GCID). The minimum Keswick release constraints discussed above were maintained for this analysis; however, it was assumed that project pumping capacity would be used whenever it was possible to back water into storage, regardless of storage conditions.

This analysis revealed that project pumping frequency and magnitude were significantly increased relative to the levels observed for operations for generating additional reservoir releases, probably to levels that would be problematic from the standpoint of groundwater impacts. Additionally, the analysis showed that most of the water placed in storage was subsequently lost as reservoir spillage due to the high probability of reservoir refill from runoff. This scenario was simulated with only groundwater pumping as a payback mechanism to simplify the analysis. Although crop idling is not precluded as a payback mechanism and could be explored, it is likely that it would perform even less efficiently due to the issues discussed above.

Operating the project in this manner to maintain Shasta storage is fundamentally in conflict with operations for increasing reservoir releases to generate project benefits; nevertheless, project reservoir releases were included in the simulation because they are fundamental to the project goals. As expected, benefits increase slightly due to project water stored in Shasta in previous years being available in subsequent years for release.

This scenario could be refined to limit pumping based on Shasta storage, thereby reducing both pumping and project spills and creating a more efficient operation; however, the high probability of reservoir refill from runoff puts project generated storage at high risk of spilling. Additionally, the relatively high frequency and large magnitudes of pumping involved would likely create unacceptable impacts. The scenario was useful for understanding the upper limit of conjunctive operations to increase carryover storage but it does not appear to be a feasible mode of project operation.

6.3.1.4. Yolo Bypass Inundation

The CVP and SWP operators also expressed interest in evaluating methods to increase the frequency, duration, and magnitude of flooding in the Yolo Bypass. Results from the initial analyses indicated the Yolo Bypass could be inundated more frequently if it was possible to notch the Fremont Weir, which currently blocks flow into the bypass below certain river stages, to allow inundation at lower river stages and flows. Weir modifications were the cause of increased Yolo Bypass inundation in 19 out of 20 years when the project (as opposed to base operations) inundated the bypass in the phase 1 analysis. Increased project releases inundated the bypass in the other year.

An additional analysis was conducted with the refined surface water model to estimate the upper limit of the ability of the project to increase inundation in the Yolo Bypass. This analysis included turning off all other environmental objectives to ensure inundation was the first priority objective every year and would not be affected by releases for lower priority objectives in previous years. It was revealed that the project would enable Yolo Bypass inundation in an additional 20 years relative to baseline operations; however, as with the initial analysis, all 20 years were due to weir modification, not additional project release. Therefore, in all years the water cost associated with inundating the Yolo Bypass exceeded project assets. This is not an unexpected result given the significant reduction in project assets caused by the addition of forecast-based operations as recommended by the project operators.

6.3.2. SWP and Oroville Reservoir Results

The results discussed below are for simulations made with the addition of forecast-based operations, restrictions on ability to reduce Oroville releases, and addition of carryover storage targets as described above. Additionally, it should be noted that updating the base conditions to include the smelt and salmon BOs had a more significant effect on Oroville operation than on Shasta operations. Operations under the smelt BO and salmon BO result in lower storage in Oroville. This occurs because winter and

spring Delta export restrictions reduce the SWP's ability to capture Delta surplus in those months, which results in increased reliance on Oroville storage releases into the Delta in the summer and early fall.

6.3.2.1. Operations for Core Project Purposes

A comparison of initial and refined simulation results are presented in Table 6-5 for the 50 TAF and 100 TAF Butte Basin project scales (pumping capacity). For the 50 TAF scale, project benefits are reduced by about 40 percent, from 17 TAF to 10 TAF, with agricultural deliveries being reduced by 50 percent and environmental releases by 30 percent. For both the initial and refined simulation about 80 percent of reservoir refill is accomplished by surplus surface water and 20 percent by project pumping, although the total refill is reduced in the refined simulation corresponding to the reduction in project benefits. Average annual project pumping is reduced from 3 TAF to 2 TAF, but the number of years of pumping and peak annual pumping are not appreciably reduced.

The disproportionate reduction of agricultural benefits noted above is due to the combination of lower base storage conditions, higher carryover storage targets, and assumptions on additional agricultural demands that are based on water year types. Lower base storages combined with higher carryover storage targets reduce the frequency and volume of project assets and typically result in assets being available in only wetter year types (when agricultural shortages tend not to occur). Additional agricultural demands are assumed to be higher in drier year types, when project assets are less, thereby reducing average annual project agricultural deliveries and shifting more of the deliveries into wetter year types. Overall, project benefits are reduced by 30 percent relative to the initial 100 TAF Butte Basin scenario.

TABLE 6-5
Comparison of Initial to Refined Simulation of Project Scenarios (Oroville/SWP)
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

			Project Benefits (TAF)			Reservoir Payback (TAF)			Project Pumping		
Scenario #	Project Scale (Pumping Capacity)	Model	Enviro. Release	Ag. Deliveries	Total Project Benefit	Surplus Surface Water	Project Groundwater Pumping	Total	Number of Years	Peak Year Pumping (TAF)	Peak Pumping Year
1, 3 and 4	50 TAF	Initial	7	10	17	14	3	17	6	50	1961, 1992
		Revised	5	5	10	8	2	10	5	49	1925
		Difference	-2	-5	-7	-6	-1	-7	-1	-1	N/A
2	100 TAF	Initial	23	20	43	36	7	43	8	100	1961, 1992
		Revised	18	9	27	24	3	27	6	99	1925
		Difference	-5	-11	-16	-12	-4	-16	-2	-1	N/A

Modification of carryover storage targets results in more frequent project pumping (or crop idling) and spill of project water stored in Oroville. Average annual pumping increases from

Additional pumping and storage also provides a slight increase in project agricultural and environmental benefits because water stored in Oroville is a project asset and available for meeting project objectives in future years. This results in a less efficient operation (with efficiency defined as refill of project releases for agricultural and environmental purposes from capture of surplus surface water as opposed to groundwater pumping), but a similar level of benefits.

6.3.2.2. Effectiveness of Temporary Crop Idling as a Payback Mechanism

As noted above (see Table 6-4), crop idling in the Butte Basin has the potential to provide approximately 50 TAF of water in a year by idling approximately 15,600 acres, or 20 percent of the rice acreage in Western Canal Water District and Richvale Irrigation District. A scenario was evaluated where idling

provided the 50 TAF of payback capacity noted above and groundwater pumping 50 TAF to achieve a total of 100 TAF of payback in GCID (corresponding to Scenario 2). Payback priority was placed on crop idling in order to minimize groundwater pumping.

Under these assumed conditions, crop idling was called on about 40 percent of the time during the 82-year simulation, in most cases utilizing the maximum 50 TAF of payback capacity and associated land idling (15,600 acres). It was found that about 50 percent of the 23 TAF of water generated by crop idling was retained in Oroville to recover reservoir storage with the remainder spilled.

As expected, placing priority on idling for reservoir payback was found to appreciably reduce the magnitude of groundwater pumping needed for Oroville payback. Average annual payback pumping was reduced from 20 TAF to 10 TAF.

6.4.Conclusions Drawn from Refined Model and Scenario Analyses

Several conclusions were drawn from the refined modeling and scenario analyses to guide development of project scenarios that are most likely to provide cost-effective opportunities for achieving the environmental and water supply benefits possible through conjunctive operation Sacramento Valley surface water and groundwater reservoirs. These conclusions are discussed below:

1. The input and recommendations provided by CVP and SWP operators for refining project scenarios reflect the challenges and risks that they routinely face in balancing project operations for water supply and complying with environmental regulations governing project operations. In particular, as described above, project operators were primarily interested in conjunctive operations for the purpose of maintaining reservoir levels when reservoir storage dropped below certain thresholds as a means of observing carryover storage and increasing the probability of complying with temperature standards. While logical from a risk management perspective, operating conjunctively for this purpose cuts deeply into the ability to generate additional water supplies for environmental releases and water supply. Additionally, the efficiency of reservoir payback operations is reduced appreciably because much of the project water placed in storage eventually spills due to subsequent reservoir refill from surplus flows.

   These findings reveal important and complex tradeoffs among environmental objectives that are embedded in project operations. By definition, producing additional water supplies to dedicate to environmental flows without infringing on base supplies to CVP and SWP contractors involves making additional reservoir releases. However, increasing reservoir releases reduces reservoir storage and unavoidably introduces some additional risk to coldwater pool management.

2. The minimum Keswick releases specified by the CVP operators as surrogates for temperature targets in the Sacramento River dramatically reduce the effectiveness of reservoir payback operations because payback is possible only when reservoir releases exceed the minimum specified values. This reduces the time during which water generated by payback operations can actually be used to offset reservoir releases. This is another manifestation of the tradeoffs among environmental objectives, with the objective of maintaining river temperature constraining the ability to operate conjunctively for other environmental benefits.

3. The general conclusion to be drawn from 1) and 2) above is that the tradeoffs among environmental objectives call for further investigation and development of operating strategies and criteria that best balance competing objectives for maximum net environmental benefit.

Addressing this need is foundational to moving ahead with development of conjunctive management strategies for the Sacramento Valley. However, until tradeoffs among environmental objectives are reconciled, planning must account for the operational constraints as they are currently defined.

4. Crop idling is an inefficient payback mechanism in comparison to groundwater pumping. The main reasons are that crop idling must be triggered early in the year before farmers commit to planting crops, which introduces additional risk in forecasting the need for the payback water, and that once the commitment is made, it cannot be undone. These factors result in frequent, unnecessary crop idling with associated lost production, with much of the water made available being lost as reservoir spillage or surplus Delta outflow. The original attraction to temporary crop idling was that it does not require up front capital investment and can be exercised as needed on a year to year basis. However, the inefficiencies revealed through the simulations suggest that crop idling is likely to be a less viable, and undoubtedly less acceptable, payback mechanism as compared to groundwater pumping, especially if pumping can be achieved with existing groundwater production wells to minimize required capital inputs.

5. All of the various suggestions for refinement of the project scenarios and model have the effect of either reducing project benefits (relative to the initial analysis) or reducing the efficiency of payback operations, thereby detracting from project cost-effectiveness.

Based on these conclusions, further planning and modeling proceeded within a framework defined by the following parameters:

1. The project baseline will be represented by a CALSIM II run that includes the effects of the smelt and salmon BO's.

2. Forecast based operations will be used because they are more realistic.

3. Restrictions on reservoir releases as specified by CVP and SWP operators will be observed because they are the best available representation of temperature compliance conditions.

4. The objective will be to generate benefits through additional environmental releases and water supplies, not through operations to sustain reservoir levels.

5. Payback operations will be based on groundwater pumping, not temporary crop idling.

6.5.Analysis of Project Scale

Within the planning and modeling framework defined above, a set of model runs was made for the two project areas to examine the relationship between project payback capacity, simulated project pumping and project benefits. In addition to the parameters specified above, a decision was made to use a summer and fall payback pumping period, rather than summer only, to maximize the opportunity for payback operations, thereby minimizing the constraint posed by minimum reservoir releases. The results are presented and discussed separately for the two project areas.

6.5.1. GCID/CVP-Shasta

A set of 11 model runs were made with specified payback pumping ranging from 20 TAF to 300 TAF and all other model parameters held constant. This wide range was selected to better understand project

performance from the surface water perspective and does not reflect an assumption or an assertion that annual pumping volumes of up to 300 TAF would be feasible in GCID. Results are summarized Table 6-6.

TABLE 6-6
GCID/CVP-Shasta Average Annual Project Benefits, Reservoir Payback and Project Pumping in Relation to Project Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Avg. Annual Project Benefits (TAF)			Average Annual Reservoir Payback (TAF)			Project Pumping		
Payback Pumping Capacity	Enviro. Release	Ag. Deliveries	Total	Surplus Surface Water	Groundwater Pumping	Total	Peak Annual Pumping	Percentage of Payback Capacity Used	Peak Pumping Year
20	0	3	3	3	0	3	3	15%	1930
40	1	4	5	5	0	5	6	15%	1930
60	3	4	7	7	0	7	9	15%	1930
80	4	5	9	9	0	9	11	14%	1930
100	5	7	12	12	0	12	11	11%	1930
120	7	8	15	15	0	15	11	9%	1930
150	11	8	19	19	0	19	11	7%	1930
200	15	8	23	23	0	23	11	6%	1930
240	20	9	29	28	1	29	96	40%	1939
270	24	7	31	30	1	31	98	36%	1939
300	25	7	32	30	2	32	98	33%	1939

It can be seen that, as pumping capacity increases, average annual project benefits are initially weighted in favor of agricultural deliveries but then switch in favor of environmental releases when capacity exceeds about 120 TAF. This is due primarily to environmental release targets being large and being made only when they can be completely satisfied. Smaller pumping capacities and associated project assets reduce the likelihood of being able to make these large releases. In contrast, agricultural deliveries are typically smaller than environmental releases and do not need to be fully satisfied; thus, some agricultural releases are possible even with very small project pumping capacities. Project benefits in relation to project pumping capacity are plotted in Figure 6-1.

It is important to note that the average annual total project benefit (sum of environmental releases and agricultural deliveries) is much smaller than the specified pumping capacity over the full capacity range evaluated. As previously discussed, this stems primarily from the nature of forecast-based operations and the associated conservative estimates of project assets used to avoid excessive risk to reservoir storage.

As expected, average annual reservoir payback is weighted strongly in favor of surplus surface water over the full range of pumping capacity, due to priority being placed on refill from surplus surface flows and pumping being called on only when needed. Simulated average annual project pumping is negligible until the specified pumping capacity exceeds 200 TAF, and then is modest on an average annual basis.

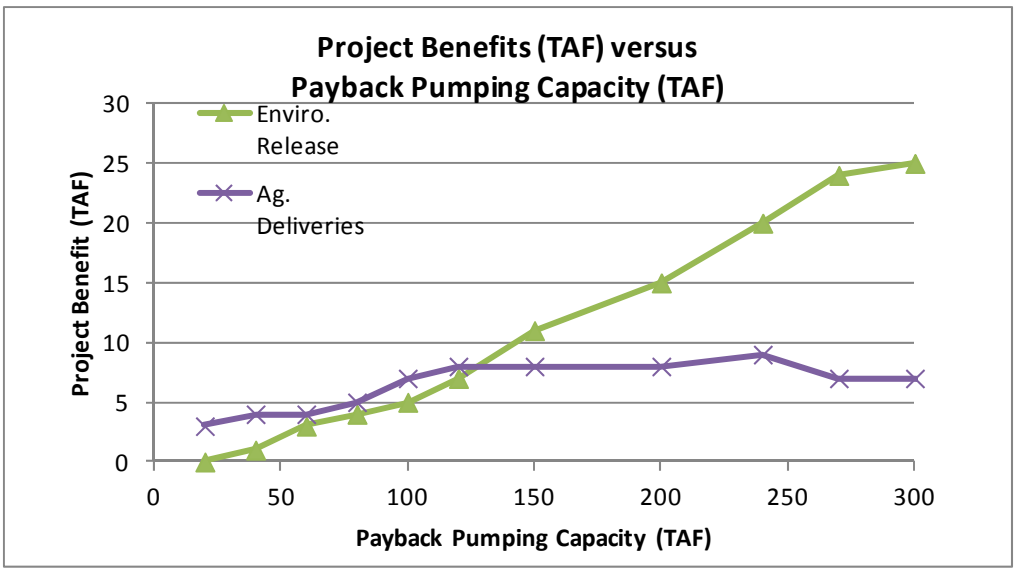

FIGURE 6-1
GCID/CVP-Shasta Average Annual Project Benefits in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Peak year pumping is negligible below a pumping capacity of 200 TAF, ranging between 3 TAF and 11 TAF (Table 6-6, Figure 6-2). Above pumping capacity 200 TAF, when larger project assets are available and large environmental releases become possible, peak year pumping increases appreciably, utilizing more of the available pumping capacity. However, even at these levels, simulated peak year pumping is less than half of the pumping capacity. This is explained by the same factors discussed above in relation project benefits being small in relation to pumping capacity. Additionally, simulated pumping is constrained when minimum Keswick releases govern and it is not possible to hold payback water in storage.

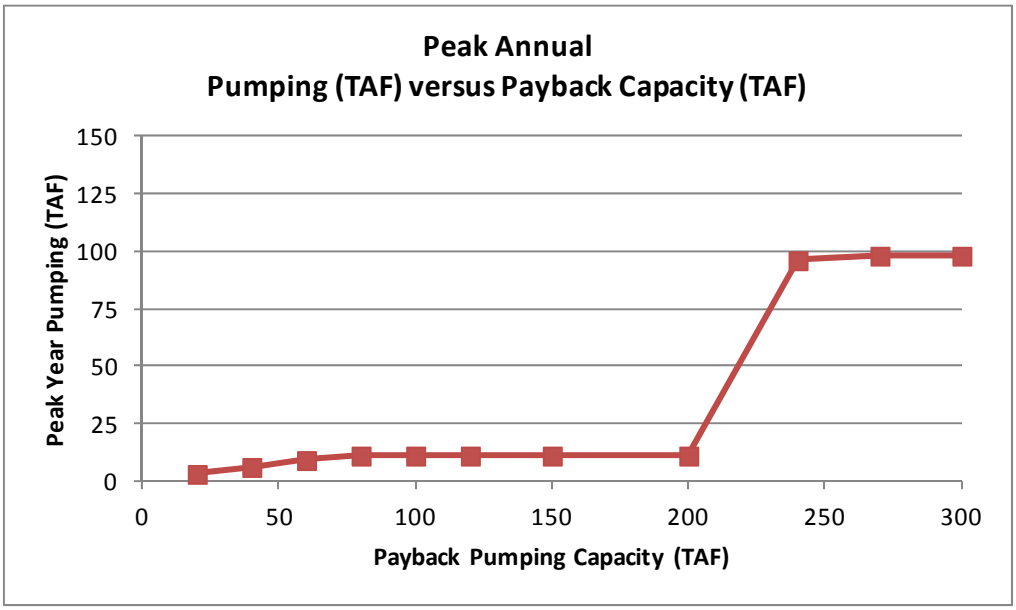

FIGURE 6-2
GCID/CVP-Shasta Peak Annual Project Pumping in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

6.5.2. Butte Basin/SWP-Oroville

A set of model runs analogous to those made for GCID were also made for the Butte Basin, with specified payback pumping ranging from 20 TAF to 300 TAF and all other model parameters held constant. As noted above, this wide range was selected to better understand project performance from the surface water perspective and does not reflect an assumption or an assertion that annual pumping volumes of up to 300 TAF would be feasible in Butte Basin. Results, summarized in Table 6-7, are similar to those for GCID, with certain exceptions.

TABLE 6-7
Butte Basin/SWP-Oroville Average Annual Project Benefits, Reservoir Payback and Project Pumping in Relation to Project Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

	Avg. Annual Project Benefits (TAF)			Average Annual Reservoir Payback (TAF)			Project Pumping		
Payback Pumping Capacity	Enviro. Release	Ag. Deliveries	Total	Surplus Surface Water	Groundwater Pumping	Total	Peak Annual Pumping	Percentage of Payback Capacity Used	Peak Pumping Year
20	0	3	3	2	1	3	12	60%	1925
40	3	4	7	6	1	7	24	60%	1925
60	8	5	13	11	1	12	36	60%	1925
80	13	7	20	17	2	19	48	60%	1925
100	18	9	27	24	3	27	59	59%	1925
120	19	10	29	26	3	29	71	59%	1925
150	19	11	30	26	4	30	89	59%	1925
200	23	9	32	29	4	33	91	46%	1925
240	36	10	46	41	4	45	125	52%	1955
270	42	11	53	47	5	52	130	48%	1955
300	51	10	61	55	5	60	130	43%	1955

Similar to GCID, as pumping capacity increases, average annual project benefits are initially weighted in favor of agricultural deliveries but switch more quickly in favor of environmental releases. Above about 40 TAF of pumping capacity, environmental benefits gradually increase while agricultural deliveries plateau at about 10 TAF above 100 TAF of capacity. The factors explaining this are generally the same as for GCID. Project benefits in relation to project pumping capacity are plotted in Figure 6-3.

As in GCID, the average annual total project benefit (sum of environmental releases and agricultural deliveries) is small relative to the specified pumping capacity over the full capacity range evaluated.

As expected, average annual reservoir payback is weighted strongly in favor of surplus surface water over the full range of pumping capacity, due to priority being placed on refill from surplus surface flows and pumping being called on only when needed. However, in contrast to GCID, both refill from surplus surface water and from project pumping increase gradually over the full range of project pumping.

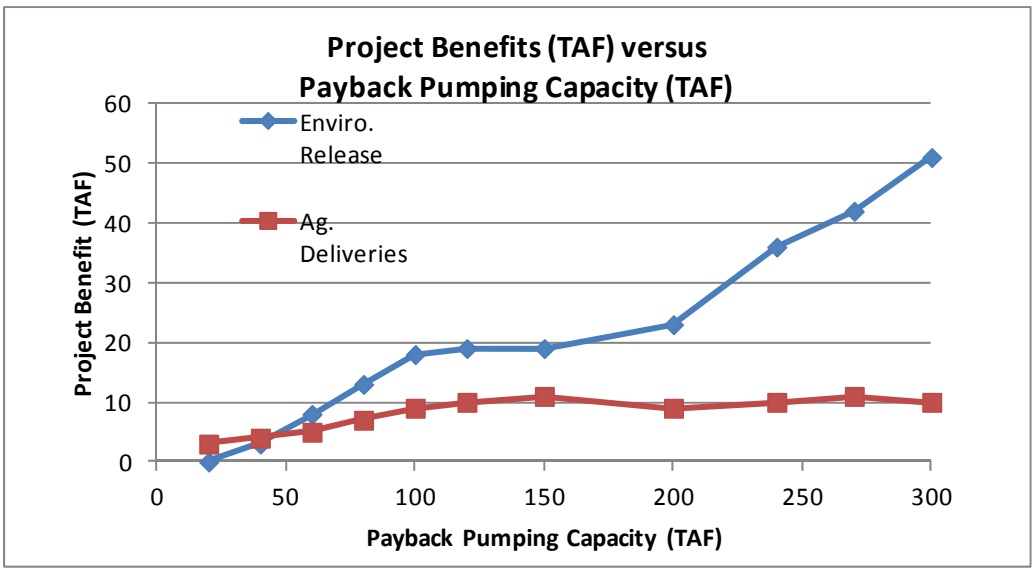

FIGURE 6-3
Butte Basin/SWP-Oroville Average Annual Project Benefits in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

Somewhat different than in GCID, peak year pumping increases more or less in proportion and is larger relative to project pumping capacity (Table 6-7, Figure 6-4). Peak year pumping ranges from 12 TAF to 130 TAF, representing between 43 percent and 60 percent of specified pumping capacity.

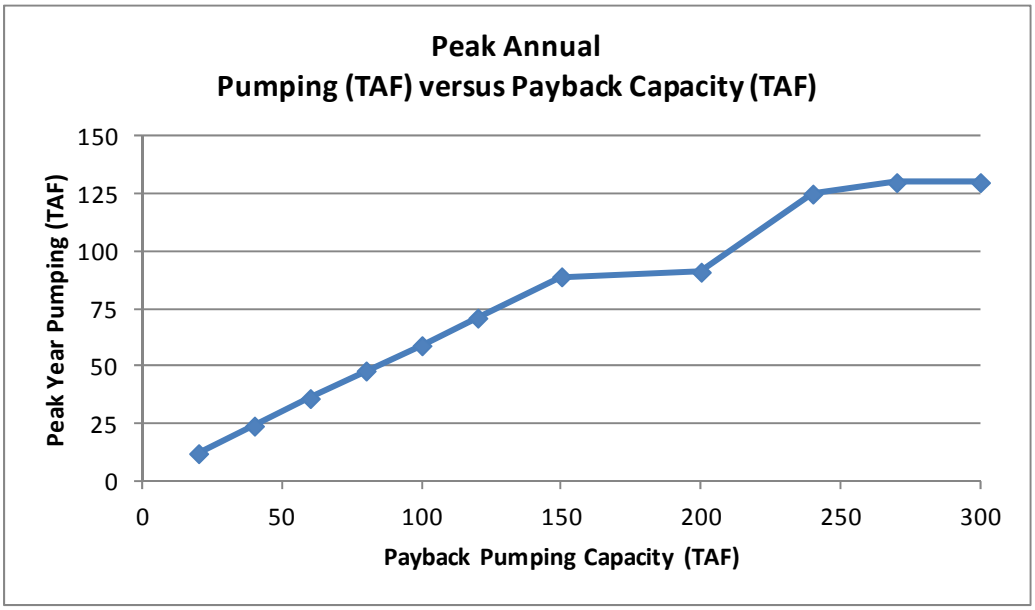

FIGURE 6-4
Butte Basin/SWP-Oroville Peak Annual Project Pumping in Relation to Payback Pumping Capacity
Northern Sacramento Valley Conjunctive Water Management Investigation Final Report

6.5.3. Discussion

The most important revelation from the foregoing analysis of project scale is the significant underutilization of payback pumping capacity in both project locations. Over the 82-year period of analysis and the range of payback capacities evaluated (20 TAF to 300 TAF), the maximum annual

payback pumping in GCID was just 40 percent (at 240 TAF capacity; see Table 6-7) and was just 60 percent of capacity in Butte Basin (between capacity 20 and 80 cfs; see Table 6-7). Average annual pumping is even more extreme in both locations, with less than 1 percent of capacity used on average in GCID and less than 2 percent used on average in Butte Basin.

The low utilization of project pumping capacity stems in part from the conservative nature of the forecast September reservoir storage, which tends to underestimate project assets, and in part from constraints on payback pumping posed by minimum reservoir releases made for temperature control purposes. However, regardless of its cause, the low utilization of project pumping capacity combined with its high capital cost is economically infeasible and indicates that other approaches should be pursued to enhance project economics. One alternative would be to not attempt to recover reservoir levels reduced by project operations and instead incur some level of increased risk that CVP and SWP water deliveries would be reduced. This approach violates one of the original project principles, but may be a reasonable solution all factors considered. This idea is explored further as a recommendation for further investigation (see Section 7).

7. Recommendations for Further Investigation

The seminal conclusion of this investigation is that re-operating Shasta and Oroville Reservoirs in conjunction with operation of Sacramento Valley groundwater aquifers could produce appreciable additional water supplies with low risk to CVP and SWP reservoir storage levels and water deliveries, including requirements to maintain environmentally mandated water temperatures under most conditions. While an economically feasible in-Valley operation scenario was not identified by the investigation, prospects of a viable formulation appear promising and further development and integration of the core concept appears warranted.

The particular topics described in the following sections are in the opinion of the project team the highest priority issues to be addressed moving ahead. These are primarily technical in nature, involving reconciling tradeoffs among different types of environmental water uses, more detailed water temperature modeling, refined reservoir payback operations, integration with south of Delta groundwater banking and refinement of analytic tools.

Beyond the technical factors lie significant institutional and social challenges that would need to be addressed if there is sufficient interest in advancing the project toward implementation. These include the following:

- Developing protocols and procedures for real-time operations decisionmaking that are more nuanced and realistic than the procedures and criteria that have been used to simulate conjunctive operations for planning purposes. Ultimately, these procedures would need to be integrated into the Coordinated Operations Agreement, which governs the combined operation of the CVP and SWP.

- Developing project governance structures among local political jurisdictions. This phase of project planning was conducted without regard to ultimate project sponsorship. The presumption, however, is that a Sacramento Valley conjunctive water management project like that described in this document would most logically be sponsored and operated by a coalition of local political jurisdictions, potentially including counties and existing water suppliers (local districts).

- Developing formulae for allocating project benefits and costs, which would be needed to develop a plan for financing project implementation, if the project moves ahead.

7.1. Reconcile Tradeoffs among Environmental Project Functions

A major revelation of this investigation is that opportunities for enhancement of Sacramento and Feather River ecologic functions (as well as opportunities to produce additional water supplies for in-Valley uses) are dramatically constrained by existing environmental requirements placed on CVP and SWP operations. In particular, the study revealed that CVP operations are frequently governed by releases for temperature compliance in the Sacramento River below Shasta, which has the effect of reducing the ability to recover Shasta by project pumping because pumped water cannot be retained in storage. In effect, the magnitude of the water asset that could be developed through conjunctive operations is diminished, which reduces the ability to fulfill the geomorphic, flood plain inundation and spring pulse flow objectives identified by the study.

Efforts are urgently needed to establish the relative benefits of alternative, competing environmental water uses so that ecosystem functions can be restored and species can be recovered while overall water use efficiency is enhanced. This calls for cooperation and compromise among the various fish and wildlife management agencies as well as ongoing research and adaptive management.

7.2.Refine Reservoir Operation Rules Based on Temperature Modeling

In the simulations conducted for this investigation, water temperature objectives were represented indirectly by minimum reservoir releases provided by project operators. These flows are based on operator judgment and provided useful guidance for investigation thus far. However, because the minimum flows were found to dramatically reduce the efficiency of payback operations, as noted above, it is recommended that more sensitive operating rules be developed through application of temperature models.

The recommended approach is to conduct a series of parametric CALSIM II model runs where operating objectives and constraints are held constant while minimum reservoir releases are varied over a range between the relatively conservative flows that were used in this investigation down to flows that would likely be inadequate to achieve temperature targets. Then one (or possibly more) of the existing temperature models would operate on the CALSIM II outputs to estimate the water temperatures that would occur under each flow regime. This would presumably provide insights into the nature of water temperature fluctuations as they relate to flows, time of year and other factors, and provide a basis for developing more sensitive operating rules. The refined rules would then be incorporated into the surface water model for use in formulating, comparing and evaluating project scenarios.

7.3.Refine Reservoir Payback Pumping Strategies and Costs

The investigation revealed that developing new groundwater production wells for payback pumping is not cost-effective because the wells are expensive, they are called on only infrequently and their operation for recovering reservoirs is limited by other operation requirements, particularly, by reservoir releases made to comply with temperature requirements. Large investment in capital works that are rarely used simply does not make good economic sense. This is why temporary crop idling was investigated as an alternative payback mechanism, because costs are incurred only when idling is called on. Unfortunately, however, crop idling is not compatible with the project's operational requirements and would be triggered in many cases when it is not ultimately needed or the water generated cannot be held in storage.

In the next phase of work, three alternative payback strategies should be explored. Each of these is described below; however, it should be kept in mind that the strategies could be combined for optimal project performance.

7.3.1. Revised Temporary Crop Idling

The investigation revealed that temporary crop idling is not an efficient form of reservoir payback, mainly because much of the water generated by crop idling is either later found to not be needed or is stored in project reservoirs and subsequently spills. These outcomes result from the decision to exercise crop idling being made in February when forecasts of September reservoir storage are relatively uncertain. Once made the commitment to idle land (by paying voluntarily enrolled growers) is irreversible and the water generated is frequently not used.

Rather than make the decision to idle land in February, the possibly of making the decision later, when better forecasts of reservoir storage can be made, should be explored. Under this arrangement, growers

would commit to growing their crops but they would enter voluntarily into agreements that would allow the project to interrupt water supplies at any time. For example, a grower might commit to growing a corn crop on the usual schedule with a certain probability that he would be asked to suspend irrigation with surface sometime during the crop season. He would be required to suspend irrigation in exchange for payments designed to compensate for lost production. (Alternatively, the grower could access a groundwater source and continuing irrigation. The farther into the season the idling call was made, the more incentive the grower would have to find an alternative water supply to finish the crop.) A crop that is particularly well suited to mid-season irrigation interruption is alfalfa because, when water is withheld, the crop goes dormant as soil moisture is depleted and resumes growth when irrigation is resumed.

Analysis would focus on the cost and efficiency of generating payback water in this manner.

7.3.2. Incurring Managed Increased Risk to Reservoir Carryover Storage

The objective of paying reservoirs back is to avoid impacts to water supply due to project operations. Analyses to date reveal that re-operated reservoirs frequently recover from surplus surface flows and need to be paid back only infrequently. Given infrequent need for and high cost of reservoir payback, one alternative is simply to deal with the occasional shortages caused by project operations when they occur. Essentially this means passing water supply shortages on to existing CVP and SWP water users. The first step in exploring this option would be to characterize the frequency and magnitude of water supply shortages and then develop strategies for compensating water users accordingly. For example, some users might alternative supplies that could be called on or conservation measures that could be invoked to deal with temporary shortages.

7.3.3. Sharing Private Groundwater Wells

Two options for establishing project groundwater pumping capacity have been explored thus far, including constructing new groundwater production wells and purchasing existing groundwater wells from willing sellers. Both of these are expensive options. The objective of further investigation would be to explore ways to access existing private wells in a manner that avoids the full capital outlay associated with new well construction (or existing well purchase) yet offers reasonably reliable access to payback capacity for project operations, when needed. This would be approached through interviews with landowners to test their willingness and the terms under which they would share production well costs and groundwater supplies with the project.

7.4.South of Delta Groundwater Banking

As previously noted, this investigation was conducted consistent with its original Sacramento Valley focus. Accordingly, reservoir releases made for project environmental purposes were tracked into the Delta but no analyses were performed to estimate whether or to what extent those inflows might be exported from the Delta. The economic analysis did reveal that project economics are dramatically improved if project water supplies could be sold at the higher rates associated with south of Delta water markets compared to Sacramento Valley rates. Beyond higher water sales revenues, banking project water in south of Delta groundwater banks might reduce reliance on Sacramento Valley reservoir payback operations. For example, there may be times when CVP and SWP reservoir releases can be reduced in exchange for water withdrawn from south of Delta groundwater banks. However, this is unlikely to be the case in very dry conditions when reservoir releases are being made exclusively for temperature control and not for export. Operations analyses are needed to reveal whether such opportunities exist.

A major challenge to the analysis will be the current uncertainty in Delta conveyance capacity and operating conventions, presently under consideration in development of the Bay-Delta Conservation Plan.

7.5.Develop System-wide Project Accounting Conventions

The central tenant of the conjunctive operations strategy developed through this project is that existing project beneficiaries can be kept whole while additional environmental flow and water supply benefits are generated. Keeping existing beneficiaries whole requires that an accounting be maintained of project assets, debts and repayment. In the simulations conducted for the project, operational changes (incremental project releases and refill) were isolated in either Shasta or Oroville and therefore easily accounted for. In actual operations, such an explicit accounting would not be practical considering that operations are highly interconnected and effects would likely be distributed among CVP and SWP reservoirs. This point was emphasized by the CVP and SWP project operators.

The purpose of this task would be to identify and evaluate alternative approaches to accounting for the effects of conjunctive operations on reservoir operations throughout the CVP and SWP systems. One approach would be to keep two sets of records, once for actual operations and another set for hypothetical operations as if the project was not operating. This is not considered to be practical or advisable due to the uncertain and, at times, arbitrary nature of maintaining the shadow records. Instead, a more practical approach would be to develop simplified accounting conventions based on simulated project operations.

7.6.Update and Refine Surface Water and Groundwater Models

The surface water and groundwater models developed for this investigation were adequate for planning level analyses but should be refined if further investigations are conducted. The main opportunities for improvements are as follows:

- A preliminary assessment of the accuracy of SACFEM at matching a limited number of historic hydrographs was performed, and the model appears to generally replicate historically observed water levels quite well over the 22-year period of simulation (1982 through 2003). It is recommended that a rigorous transient calibration be conducted of the SACFEM groundwater model to observed historic water level hydrographs across the valley. This effort would help improve the level of confidence that the model is accurately simulating transient patterns in groundwater levels seen historically.

- Another area of potential SACFEM refinement is to further evaluate hydrology of smaller unregulated tributaries across the valley, specifically to better understand timing and magnitude of groundwater recharge that occurs from these surface water features. In the current analysis, it was assumed that unregulated streams were dry from June through October. While this assumption is reasonable, it is likely that behavior of these streams is more complex. Further, some of these tributary streams are used as conveyance facilities to deliver water within various water districts. This would result in streams being active over summer months, and potential sources of recharge to the groundwater system. An analysis of these stream characteristics could improve the accuracy of the simulation of recharge sources to the groundwater system, especially over the summer months.

- Conjunctive management operations as simulated for this investigation may have impacts on the generation and use of CVP and SWP hydropower. For example, in some years, making large reservoir releases for certain environmental objectives may be constrained by power plant capacities and may occur at times when power is less valuable. A better understanding of these constraints and simulation of resulting effects is necessary if further investigation is undertaken.

- Analysis presented in this report focused on operation of only part of the CVP/SWP system. Shasta and Oroville Reservoirs and the Sacramento and Feather Rivers are part of a larger system that is operated in a coordinated manner. Simulation of only part of the system may underestimate benefits or impacts to other areas of the system. Preliminary analysis of systemwide effects based on how conjunctive management operations change, Delta inflows need to be refined and expanded to other areas of the system

Appendices

Appendix A
Materials from October 21, 2010 and
December 8, 2010 Public Meetings

October 21, 2010
Public Meeting Materials

Northern Sacramento Valley
Conjunctive Water Management Investigation

Public Workshop

Glenn-Colusa Irrigation District Main Pump Station
7854 County Road 203
Hamilton City, California

October 21, 2010

3:00 to 5:00 PM

Workshop Objectives

- Provide a status report on the investigation progress
- Listen/Respond to stakeholder questions
- Describe next steps to investigation, public meetings, and final report

Agenda

1. Welcome, Introductions, Workshop Process
2. Workshop Objectives
3. Recent Regulatory and Legislative Changes and Impacts
4. Investigation Review and Update – Presentation
5. Q&A
6. Regional Water Issues
7. Next Steps
8. Closing

Northern Sacramento Valley Conjunctive Water Management Investigation
Public Meeting
October 21, 2010
GCID Pump Station
Hamilton City, California
Sign in Sheet

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Northern Sacramento Valley Conjunctive Water Management Investigation
Public Meeting
October 21, 2010
GCID Pump Station
Hamilton City, California
Sign in Sheet

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Northern Sacramento Valley Conjunctive Water Management Investigation
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Name	Address	City, State & Zip	Telephone #	e-mail
Bruce Smith	1334 Arbutus Ave	Chico CA	1-530-343-0105	BSMITH1236@aol.com
Todd Greene	400 W 1st St. ~~Chico~~	Chico,	530 898 5541	tjgreene@csuchico.edu

Northern Sacramento Valley Conjunctive Water Management Investigation

The Glenn-Colusa Irrigation District and
The Natural Heritage Institute

October 21, 2010

Today's Workshop Objectives

- Provide a status report on the investigation progress
- Listen/Respond to stakeholder questions
- Describe next steps to investigation, public meetings, and final report

Motivating Factors - Regulatory and Legislative Changes

- Significant Values are at Risk: Regional Sustainability
  - Environmental
  - Water supply
  - Economy
- New Challenges
  - SWRCB Flow Report: 75% unimpaired flow to the Delta November-June
  - DFG Report confirms similar flow needs
  - Delta species (smelt) dominate, salmon at risk
  - Delta Stewardship Council: All Delta all the time
  - Scott Valley/Siskiyou County Groundwater Pumping Lawsuit
- The Past is the past, How do we control our destiny?
- Historical operations and uses are constantly changing
- Local needs and flexibility are now challenged in the Delta context
- Increasing costs and fees
- Long term stability and reliability?

Emerging Values

- What does the region want, what values should be protected?
  - Water supply reliability (surface/groundwater)?
  - Environmental protection/enhancement, both instream and terrestrial?
  - System sustainability, what is it?
  - Others…?
- What strategies should be pursued to achieve regional goals?
  - Status quo?
  - Regional water investigations and planning?
  - Others…?
- Just say no…will that do?

Overview of Investigation to Date

Program Objective

- Examine whether and how operation of groundwater aquifers in the Sacramento Valley could be integrated with operation of existing surface water reservoirs to produce additional firm water supplies
- Potential benefits:
  - Improved water supply reliability (local, regional, State)
  - Ecosystem restoration (Sacramento and Feather Rivers)
  - Improved Delta inflow per BDCP
  - Increased operational flexibility (CVP, SWP, local)
  - Buffer effects of climate change

Program Requirements

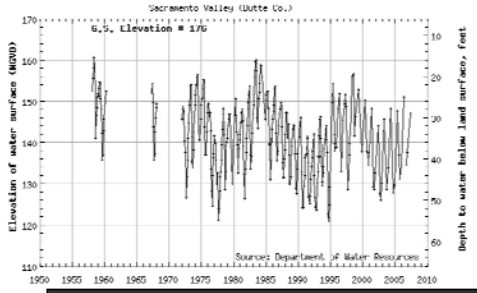
- New net benefits for Sacramento Valley environment and water users
- CVP and SWP commitments honored (to the extent they presently are)
- No unmitigated impacts to existing groundwater users
- Economic feasibility

Initial Site Screening

What Makes for an Attractive Water Banking Site?

- Groundwater conditions
  - Available aquifer storage space
  - Viable recharge mechanism
  - Productive groundwater wells
  - Suitable GW quality
- Surface water conditions
  - Surplus flows at times
  - Connection to CVP, SWP or other surface water reservoirs
  - Dual SW and GW use option
- Impacts/mitigation
  - Isolation from important surface streams
  - Isolation from existing groundwater production wells
  - Ability to mitigate or compensate impacts that cannot be avoided

Typical Sacramento Valley GW Hydrograph (Butte Co.)

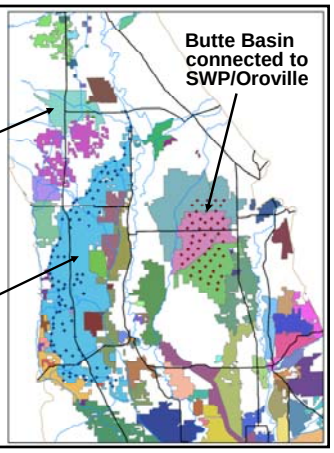


Early Finding: Traditional water banking generally not viable in the Sacramento Valley due to lack of aquifer storage space.

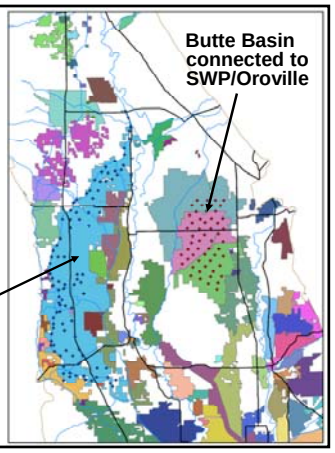
Re-operate Surface Reservoirs with Groundwater "Backstop"

- Reservoir re-operation
  - Additional releases to meet program objectives
  - Hope for reservoir refill from surplus surface flows
  - Honor existing CVP and SWP delivery obligations and operations constraints
- Groundwater operation
  - Pump groundwater to "repay" reservoirs if storage conditions put contract deliveries or temperature control at risk
  - Groundwater used in lieu of surface entitlements that then remain in storage

Three Sites Identified



Two Sites Selected for Modeling



Re-operation Conceptual Example

- Release water from CVP and/or SWP reservoirs to meet project objectives:
  - Unmet local ag demands
  - Regional environmental flow targets
- <u>If reservoirs refill</u>, no subsequent GW pumping is needed
- <u>If reservoirs do not refill</u>, pump GW and forego use of surface water in following year as needed for reservoir "payback"
- New SW supplies can be generated with infrequent additional GW pumping, because reservoirs refill most years

Project Scenarios Defined by Groundwater Pumping Capacity and Season

Scenario	Groundwater Pumping Capacity (thousand acre-feet)			Pumping Season
	GCID (CVP)	Butte Basin (SWP)	Total	
1	100	50	150	summer
2	200	100	300	summer
3	100	50	150	fall
4	100	50	150	summer & fall

All scenarios modeled with an existing (shallow) and new (deep) well field to reveal range of potential impacts to streams and existing pumpers.

Surface Water Model Results

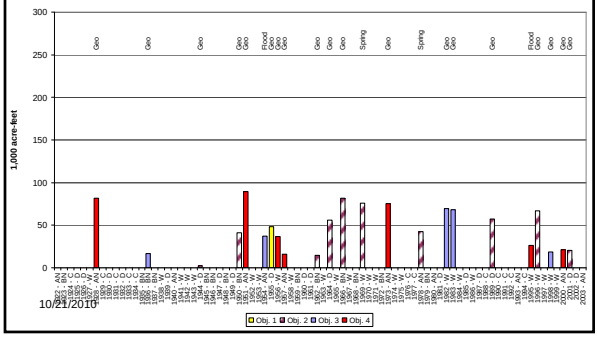
(Example for Scenario 1, Shasta/CVP, 100 TAF Pumping Capacity in GCID)

- Environmental flow releases
- Agricultural deliveries
- Refill from surplus surface water
- Refill from groundwater pumping

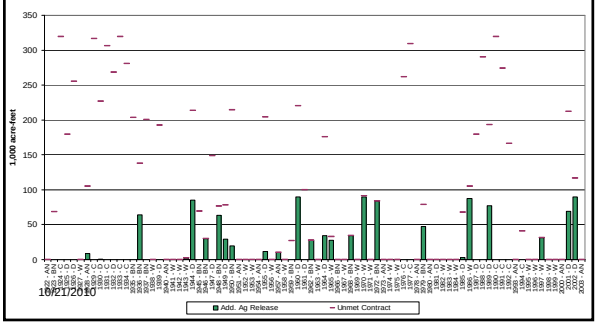
Environmental Flow Objectives

- Geomorphic
  - Single day large event
  - February or March
- Riparian establishment
  - Five day large flow with 60 day recession
  - April start
- Flood plain inundation
  - Single day large event with 45 day recession
  - Between February and April
- Spring pulse flow
  - Simulate more natural spring runoff period

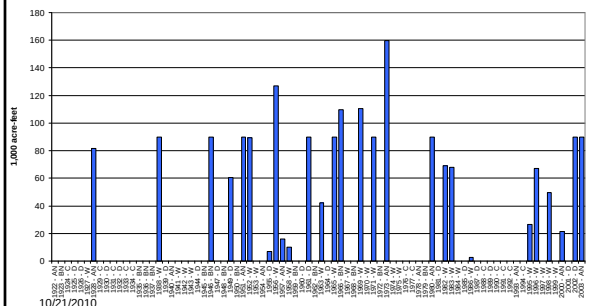
Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Environmental Flow Releases



Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Sac River Agricultural Deliveries



Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Refill from Surplus Surface Water



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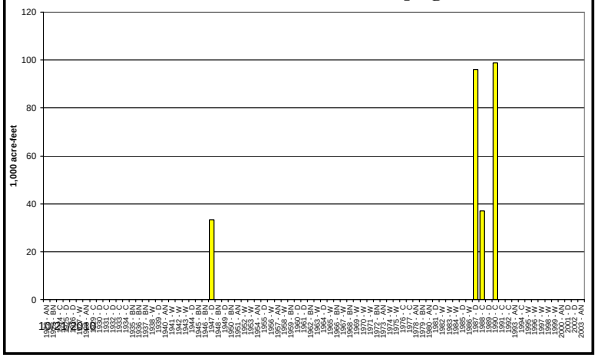
Scenario 1—CVP/Shasta
100 TAF Pumping Capacity in GCID
Refill from Groundwater Pumping



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SW Modeling Summary
(Annual averages 1922-2003, taf)

Scenario	CVP/Sacramento River				SWP/Feather River			
	Env. Rel.	Ag. Del.	Refill from SW	GW Pump	Env. Rel.	Ag. Del.	Refill from SW	GW Pump
1,3 and 4	13	14	24	3	7	10	14	3
2	45	22	58	9	23	20	36	7

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SW Modeling Summary
(Average in years of occurrence 1922-2003, taf)

Scenario	CVP/Sacramento River				SWP/Feather River			
	Env. Rel.	Ag. Del.	Refill from SW	GW Pump	Env. Rel.	Ag. Del.	Refill from SW	GW Pump
1,3 and 4	94	46	70	70	49	27	32	44
2	187	75	139	123	95	52	72	75

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Project Impacts Due to Additional Groundwater Pumping

- Streamflow
  - Butte Creek in affected area
  - Other critical streams not in affected areas
  - Ephemeral streams not analyzed
- Groundwater levels and existing wells
  - Well yield impacts
  - Incremental pumping costs (due to additional lift)

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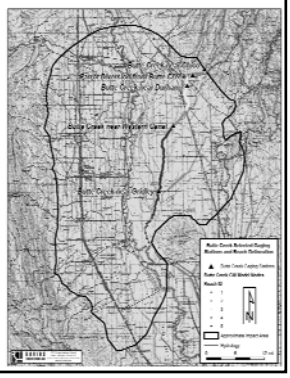
Butte Creek Impacts

- Develop baseline flow from available gauging stations
- Synthesize "with-project" flows based on cumulative reductions in streamflow from changes in stream leakance from GW model



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Butte Creek Impacts

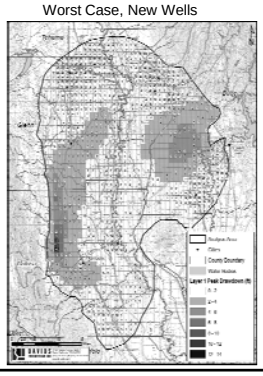
- No impact in upper reaches (primary spawning and holding areas)
- Greatest flow reduction in Jan. – Mar.
  - During times of highest discharge
- Greatest % reduction in summer/early fall
  - Spring-run have already migrated
  - Steelhead just beginning to enter stream
- Rarely drops below in-stream standards
  - June during early '90s drought
- Tradeoffs between Butte Creek impacts and main stem benefits

Impacts to Existing Wells

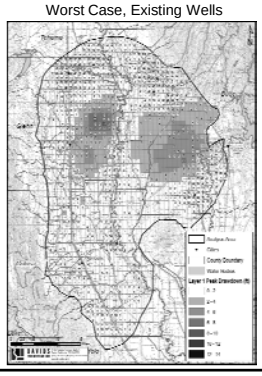
- Used DWR well inventory data
- No appreciable impact on irrigation well performance
  - Increased pumping costs accounted for
- Some impact on non-irrigation wells
  - 9,000 non-irrigation wells in analysis area
  - Up to ~800 non-irrigation wells in impact zones
  - Maximum of 25 (0.2%) to 284 (3%) of wells needing deepening or replacement

Groundwater Levels and Impacts to Wells

Potential Impact Zones:
Worst Case, New Wells



Potential Impact Zones:
Worst Case, Existing Wells



Incremental Pumping Costs

Summary Statistics of Interference Drawdown by Pumping Scenario

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

Incremental Pumping Costs

Summary Statistics of Total Increased Annual Energy Costs to Maintain Existing Groundwater Pumping for Irrigation.

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

(Incremental costs for non-irrigation pumping on the order of $3000 - $5000 per year depending on pumping scenario)

Benefit-Cost Summary

All present values in million dollars [2009]

Scenario				
No.	**Description**	**Benefits**	**Costs**	**Benefit – Cost**
1	150 TAF Summer, New Wells	73	135	-62
1	150 TAF Summer, Existing Wells	73	94	-21
2	300TAF Summer, New Wells	183	290	-107
2	300 TAF Summer, Existing Wells	183	212	-29
3	150 TAF Fall, New Wells	74	210	-136
3	150 TAF Fall, Existing Wells	74	144	-70
4	150 TAF Summer & Fall, New Wells	73	88	-15
4	150 TAF Summer & Fall, Existing Wells	73	65	8

Latest Activities and Findings

Exploring Operations for Additional Environmental Benefits

- Consultation with CVP and SWP operators
- Complying with temperature requirements of greatest concern
  - Operators provided "unofficial" operations criteria for modeling
- Operating for temperature benefit involves tradeoffs with project environmental flow objectives

Temporary Crop Idling to Reduce Payback Cost

- Investigated crop idling as an alternative to GW pumping for reservoir payback
  - Voluntary, incentive driven
- Less cost-effective than pumping due to:
  - High cost: crop idling decisions have to be made early before hydrologic conditions are known
  - Marginal effectiveness: not all of the avoided water use results in reservoir payback

Principal Findings to Date

- SWP and CVP operational requirements are complex and constraining
  - Must honor all Project commitments and operations rules
  - Cold water pool management has dominant effect
- Cost of payback water is appreciable
  - Groundwater pumping
  - Temporary crop idling
- Project cost-effectiveness is marginal
  - Use of Sac groundwater to "backstop" entails mitigation costs
  - Project water produced in wetter years because it cannot be banked
  - Modest value of water in Sac Valley

Concluding Phase 1

Final Phase 1 Steps

- Technical
  - Frame existing operational constraints and tradeoffs
  - Formulate and model best performing scenario under existing conditions
  - Analyze impacts and economics
- Final Report: draft, final
- Public meetings (between draft and final)
- Scope Phase 2 of Investigation
- Continue regional dialogue

Question & Answer

Discussion

Northern Sacramento Valley Conjunctive Water Management Investigation
Conjunctive Water Management Investigation
Public Workshop
Meeting Notes
October 21, 2010

Present: Thad Bettner, General Manager, GCID
Grant Davids, Davids Engineering
John Clerici, Outreach Communications Specialist
Gregory Thomas, President, Natural Heritage Institute
Walter Bourez, MBK Engineers
Lee Bergfield, MBK Engineers
Cynthia F. Davis, Director of Communications, GCID
Laurie Merrill Murray, Executive Assistant, GCID

Thad Bettner, General Manager, Glenn-Colusa Irrigation District, welcomed the attendee's and introduced consultant John Clerici, outreach communications specialist, Grant Davids of Davids Engineering, Gregory Thomas, President of Natural Heritage Institute, Walter Bourez, MBK Engineers, and Lee Bergfield, MBK Engineers.

Mr. John Clerici called the public meeting to order at 3 p.m. and explained ground rules for participation during the meeting. Approximately 50 members of the public attended (see sign-in sheet).

Mr. Bettner reported that there is currently a significant risk for water in the north state. The State Water Resources Control Board released a flow report that calls for the current state of the Delta. The report recommends that 75% of all runoff goes to the Delta, and farmers in the Sacramento Valley cannot rely on a 25% supply. The Delta Stewardship Council – all the Delta – all the time. The Council is looking upstream for fixes to the Delta. Scott Valley – Siskiyou County groundwater historical operations are changing. New rules will be set up to serve

the Delta. Water supply reliability. Change is upon us, outside factors are upon us.

Grant Davids presented a PowerPoint presentation, and provided information on the investigation covering the last four years. Examined how operation of aquifers in the Sacramento Valley environmental and water users. CVP and SWP have commitments to honor.

The following are general categories (in bold) of interest with some specific comments/questions as examples.

Voracity and specificity with the technical tools used to perform the evaluation.

Some commenters asserted that more detail was required in the areas of the economic analysis such as the value assigned to the groundwater, impacts to specific segments of the agricultural community, etc.

One person asked if the time-step used to develop the groundwater model (monthly) didn't miss some spatial or temporal peculiarities associated with a specific location.

Would like to see more sophistication in terms of groundwater, particularly as it relates to permanent crops/orchards.

Why no critical dry years used in the analysis?

One lady questioned the impacts of groundwater pumping in the valley and its impacts on foothill aquifers. I assume she is confusing the Tuscan Formation and the Lower Tuscan aquifer.

Impacts as described in the investigation.

One foot impact to Big Chico Creek is a big deal in the summer.

What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

What are the critical recharge months in the upper reaches? In the area in general?

How the project works.

Frequency and severity of payback vs the benefits.

What are the benefits? This was a particular challenge for the Feather River folks. Some examples might help.

How will the reservoir releases be measured? When will we know that water needs to be repaid (what triggers payback)? How does the payback water get used?

Which aquifer are we talking about (deep or surface)? Does this study (can this study) be expanded to show the total groundwater picture?

Where does the water for environmental enhancements come from?

Do commitments still exist if Delta mandates are imposed?

Real project drivers.

Why are we here? There were water rights hearings before (she mentioned NHI but I did not get it all). The elephant in the room is junior water rights holders south of the Delta that are trying to get at our water. We need to save this area?

Land use and cropping decisions in the San Joaquin Valley were also sighted, as well as local growth concerns.

Water transfers and GCID's role in them. How do they benefit the region?

Desire to be part of the discussion.

More meetings to work out the information with the public. Time of day and location, and more focused in terms of subject matter.

There are a lot of resources available from the local groups and individuals. We can help but you need to talk to us more proactively.

Many of these questions do not have clear answers, or are not answerable within the context of the investigation. Some of them like wanting more specific economic analysis or reducing the time-step on the model may either be impractical, or are better left to the more extensive environmental analysis required a the project level.
However providing concrete answers when they are available, as well as providing more detail around how an example project might function, its benefits and impacts, can only help to improve stakeholder understanding of what we have in mind.

I have some thoughts about how we can structure our response but would like to hear what the team has to say before discussing them further.

These are the questions and comments from the 10-21 workshop as I wrote them down. Some appear in the text above as well.

How does this relate to the planning process (city and county general plans)?

Why no critical dry years used in analysis? Doesn't make sense.

The information is going to be used and not used appropriately. There seems to be a lot of pumping.

Confused about the water storage issue. Growth and demand is south of delta which is where he water would seem to go. There is a great deal of risk and uncertainty with what you are doing.

Where does the water for environmental enhancements come from (surface or groundwater)?

Which aquifer are we talking about (deep or surface)? Does this study (can this study) be expanded to show the total groundwater picture?

What's the local/regional share of the 2.5 million af groundwater pumping figure? Need to be more specific.

What is the time step on the groundwater model? We notice changes weekly and even daily based on pumping. May not be reflected in the model.

Explain how there can be no impact in upper reaches of creeks? Does valley pumping impact aquifers in foothills (they think so)? Does the Tuscan aquifer extend into the foothills (Tuscan Formation vs Tuscan Aquifer?)

What are the critical recharge months in the upper reaches? In the area in general?

Seems like more detailed investigation needed to determine impacts of valley pumping on upper reaches.

What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

Payback issue needs to be explained. How does it work? Accounting?

1 foot of drop in local streams (Big Chico) are significant. Team needs perspective on this.

There are a lot of resources available from the local groups and individuals. We can help but you need to talk to us more proactively.

What is meant by “marginal impacts” at Butte Creek?

What if you end up pumping more than you expect (as a response to prolonged drought)?

Why are we here? There were water rights hearings before (she mentioned NHI but I did not get it all). The elephant in the room is Junior water rights holders south of the Delta that are trying to get at our water. We need to save this area?

Needs more community meetings, but thinks this effort might harm the area. Mentioned drought water bank.

Did you assign any value to the water in the aquifer?

Impacts of local land use decisions need to be taken in account? Have they been?

Explain the externalities in the economic impacts evaluation.

Public wants assurance that there is adequate thought going into monitoring and mitigation.

Can you do just reservoir re-operation without doing the pumping for repayment?

Do commitments still exist if Delta mandates are imposed?

What are the existing contractual obligations?

Would like to see more sophistication in terms of groundwater, particularly as it relates to permanent crops/orchards.

Clarification requested on groundwater and surface water.

Models are tools – assign value to aquifer. Add to next agenda.

December 8, 2010
Public Meeting Materials

Northern Sacramento Valley
Conjunctive Water Management Investigation

Public Workshop

Masonic Lodge
1110 W. East Avenue
Chico, CA 95926

December 8, 2010

6:00 to 8:00 PM

Workshop Objectives

- Respond to questions from October 21, 2010 workshop

Agenda

1. Welcome, Introductions, Workshop Process
2. Discuss questions from 10-21 Workshop
    a. How does the proposed project work?
    b. Investigation Tools and Data
    c. Project Benefits
    d. Project Impacts
3. Next Steps/Closing

Public Workshop

Northern Sacramento Valley
Conjunctive Water Management Investigation

December 8, 2010

6:00 p.m. – 8:00 p.m.

Masonic Lodge
1110 W. East Avenue
Chico, CA 95926

The Glenn-Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) are in the process of evaluating water management opportunities in the northern Sacramento Valley. This effort, the Northern Sacramento Valley Conjunctive Water Management Investigation (Investigation), is nearing completion of several years of work with a draft final report currently under preparation.

This workshop is being sponsored specifically to provide responses to the questions and comments received at the Investigation workshop held on October 21, 2010. Topics to be addressed include potential project benefits and impacts, conjunctive operations concepts, project economics, and other issues brought up at the previous session. Time will be allowed for the public to engage in a discussion of the questions and answers and relevant issues related to the Investigation.

Northern Sacramento Valley
Conjunctive Water Management Investigation

Public Workshop

December 8, 2010

Background
On October 21, 2010, the Glenn-Colusa Irrigation District (GCID) and Natural Heritage Institute (NHI) held a public workshop to provide a status report on their Northern Sacramento Valley Conjunctive Water Management Investigation. Meeting participants were also provided an opportunity to ask questions of the investigation team.

As a result of the significant number of questions and comments provided by attendees, GCID and NHI agreed to hold a follow-up workshop. The purpose of the workshop is two-fold: to either respond to questions that could not be addressed at the last meeting, or provide clarification to questions that were answered but warranted additional follow-up; and, to allow for more substantive dialogue between the investigation team and stakeholders on these issues.

Organizing Questions
Questions and comments from the October workshop varied widely but seemed to be focused in four critical areas:

1. Project Operations (How does the proposed project work?)
2. Investigation Tools and Data
3. Project Benefits
4. Project Impacts

These four categories were used to develop the format for today's workshop. For discussion purposes, and to facilitate providing responses, comments were put into the form of a question, and multiple questions of similar nature were consolidated into a single question. Additionally, the technical team assessed which questions could be answered within the context of the current investigation, and which questions either cannot be resolved by this phase of the investigation, or required a venue more suited to a longer-term regional dialogue. The majority of questions fell into the first group and will be responded to in this workshop.

Questions by Category

Project Operations (How does the proposed project work?)

- Can you do just reservoir re-operation without doing the pumping for repayment?
- Where does the water for environmental enhancements and other project benefits come from?
- How does the payback water get used?
- How do the project benefits compare to the frequency and magnitude of payback?
- How would the reservoir releases be measured?
- How would it be determined that water needs to be repaid…what triggers reservoir payback?
- Which aquifer are we talking about, the deep or shallow?
- Does the study address the total groundwater picture?
- What are the existing contractual obligations?
- Public wants assurance that there is adequate thought going into monitoring and mitigation.

Investigation Tools

- Why are critical dry years not used in the analysis?
- What is the time-step used to develop the groundwater model? Is the time-step appropriate for capturing localized effects of day to day well operation and aquifer response?
- Were economic impacts beyond just project costs and benefits considered, such as impacts to specific segments of the agricultural community?

Project Benefits

- What are the project benefits?
- Are there benefits to the groundwater systems and were they considered in the economic analysis?

Project Impacts

- What are the impacts of groundwater pumping in the valley on foothill aquifers?
- What are the critical recharge months in the upper reaches? In the area in general?
- Project pumping may be a small share of Valley wide pumping but what proportion is it of pumping within the project area?
- Is the interconnection between streams and underlying aquifers sufficiently defined to predict the effects of even modest changes in groundwater levels (e.g., Butte and Big Chico Creeks)?
- What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

Northern Sacramento Valley Conjunctive Water Management Investigation
Public Meeting
December 8, 2010
Masonic Lodge
Chico, California
Sign in Sheet

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Northern Sacramento Valley Conjunctive Water Management Investigation

Public Workshop

December 8, 2010

The Glenn-Colusa Irrigation District and
The Natural Heritage Institute

Workshop Objective & Process

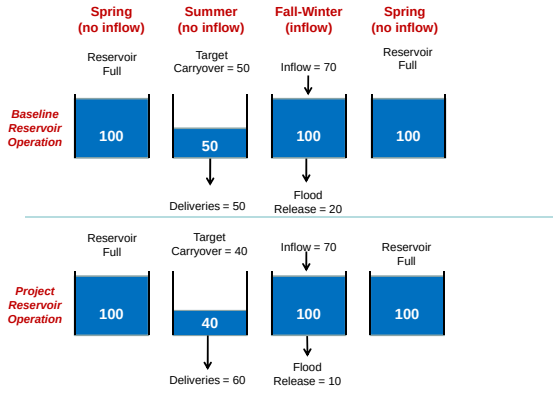
- Objective
  - Respond to questions from October 21, 2010 workshop 1
- Process
  - Organized questions into topics
  - Describe each topic
  - Provide response
  - Engage in discussion

How Does The Proposed Project Work?

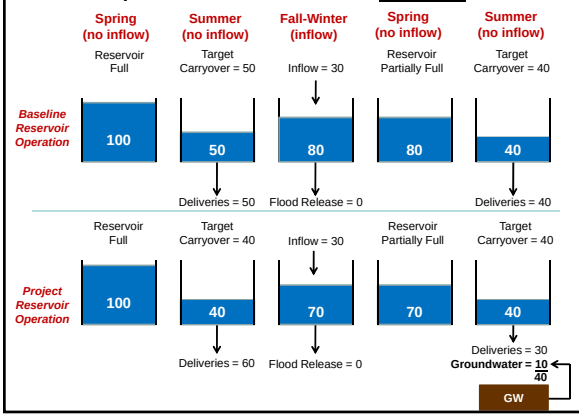
Re-operate Surface Reservoirs with Groundwater "Backstop"

- Reservoir re-operation
  - Additional releases to meet program objectives (North of Delta water supply and environmental enhancement)
  - Expect reservoir refill from surplus surface flows
  - Honor existing CVP and SWP delivery obligations and operations constraints
- Groundwater operation
  - Pump groundwater to "repay" reservoirs if storage conditions put contract deliveries or temperature control at risk
  - Groundwater used in lieu of surface entitlements that then remain in storage
  - Minimize or avoid GW impacts

Re-Operation Case 1- Reservoir Refills



Re-operation Case 2- Reservoir Does Not Refill



Project Performance Summary

Project Scenario 2 Evaluated with Revised Model Including Biological Opinions, Forecast-based Operation and Minimum Reservoir Release Criteria

Performance Metric	Sac R (Shasta)	Feather R (Oroville)
Total number of years in simulation (1922-2003)	82	82
Number of years no project releases made	62	45
Number of years project releases made	20	37
Average annual (82 years) project release, (TAF) (Roughly 2/3 environmental and 1/3 ag benefits) **Cumulative benefit over 82 years (TAF) =**	25 **2,050**	30 **2,460**
Maximum year project release (TAF) (Includes environmental and ag)	180	102
Number of years "payback" pumping is needed	4	11
Average annual (82 years) project pumping (TAF) **Cumulative pumping over 82 years (TAF) =**	2 **164**	9 **738**
Maximum year project pumping (TAF) (Maximums do not occur in same year)	100	100
Average annual (82 years) reservoir refill from surplus flows (TAF)	23	23
Spillage of payback water	0	-2

Questions

How Does The Proposed Project Work?

- Can you do just reservoir re-operation without doing the pumping for repayment?
- Where does the water for environmental enhancements and other project benefits come from?
- How does the payback water get used?
- How do the project benefits compare to the frequency and magnitude of payback?

Questions, continued

How Does The Proposed Project Work?

- How would the reservoir releases be measured?
- How would it be determined that water needs to be repaid…what triggers reservoir payback?
- Which aquifer are we talking about, the deep or shallow?
- Does the study address the total groundwater picture?

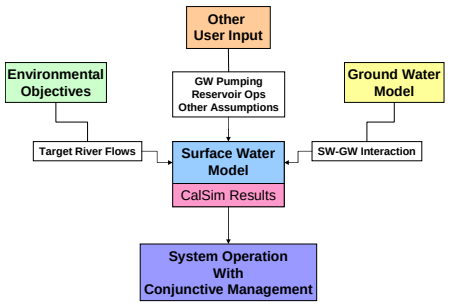
Questions, continued

How Does The Proposed Project Work?

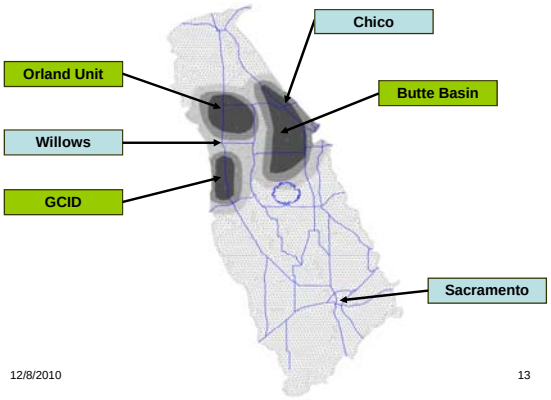
- What are the existing contractual obligations?
- Public wants assurance that there is adequate thought going into monitoring and mitigation.

Investigation Tools and Data

Overview of Analysis Tools



Groundwater Model Area and Grid Density



Groundwater Flow Model

- Regional scale with high spatial detail
  - 5,950 square miles (3.8 million acres)
  - 88,922 surface nodes
  - 7 vertical layers
- Aquifer properties based on analysis of more than 1,000 production wells
- Calibration
  - Static calibration for year 2000
  - Water levels from 257 monitoring wells
- Monthly time step, 1982 through 2003

Surface Water Operations Model

- Spreadsheet-based for ease and speed of operation
- Re-operates Shasta and Oroville Reservoirs relative to a baseline condition depicted by CalSim II outputs (1922 through 2003)
- Driven by additional target deliveries for:
  - Environmental restoration in Sac and Feather Rivers
  - Unmet Sac Valley agricultural demands
- Various operational constraints
- Uses generalized SW-GW interaction functions derived from GW model

Questions

Investigation Tools and Data

- Why are critical dry years not used in the analysis?
- What is the time-step used to develop the groundwater model? Is the time-step appropriate for capturing localized effects of day to day well operation and aquifer response?
- Were economic impacts beyond just project costs and benefits considered, such as impacts to specific segments of the agricultural community?

Project Benefits

Questions

Project Benefits

- What are the project benefits?
- Are there benefits to the groundwater systems and were they considered in the economic analysis?

Project Benefits

- Increased Sac Valley surface water supply
  - More local benefit (water supply) from CVP and SWP
  - Reduced overall reliance on Sac Valley groundwater, though increased local pumping in certain years
- Improved habitat in Sac and Feather Rivers through
  - Recovery of salmon populations
  - Ecosystem sustainability

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Project Impacts

Questions

Project Impacts

- What are the impacts of groundwater pumping in the valley on foothill aquifers?
- What are the critical recharge months in the upper reaches? In the area in general?
- Project pumping may be a small share of Valley wide pumping but what proportion is it of pumping within the project area?

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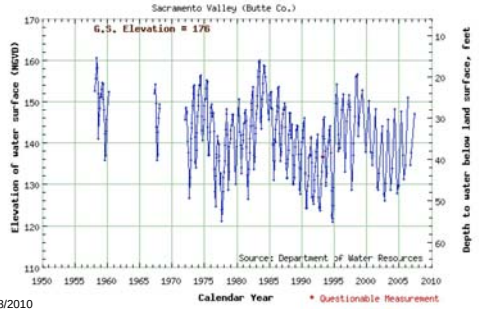
Typical Sacramento Valley GW Hydrograph (Butte Co.)



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Sacramento Valley Water Uses and Sources by County

		Butte	Colusa	Glenn	Tehama	Shasta	Totals
	Local Surface Water (includes FRSC)						
	Agricultural	571 TAF	4 TAF	71 TAF	98 TAF	28 TAF	771 TAF
	Wildlife Refuges	47 TAF	0 TAF	14 TAF	0 TAF	0 TAF	61 TAF
W	Municipal & Industrial	14 TAF	0 TAF	0 TAF	1 TAF	0 TAF	15 TAF
A	Fall Ag Flood / Private Wetland Mgmt	231 TAF	0 TAF	31 TAF	1 TAF	0 TAF	263 TAF
T	**Totals:**	**862 TAF**	**4 TAF**	**116 TAF**	**100 TAF**	**28 TAF**	**1,110 TAF**
E	*Federal Project Water (CVP & USCE)*						
R	Agricultural	22 TAF	760 TAF	554 TAF	38 TAF	116 TAF	1,489 TAF
	Wildlife Refuges	11 TAF	43 TAF	23 TAF	0 TAF	0 TAF	76 TAF
S	Municipal & Industrial	0 TAF	0 TAF	0 TAF	1 TAF	33 TAF	34 TAF
U	Fall Ag Flood / Private Wetland Mgmt	3 TAF	89 TAF	65 TAF	1 TAF	0 TAF	159 TAF
P	**Totals:**	**36 TAF**	**892 TAF**	**642 TAF**	**40 TAF**	**149 TAF**	**1,759 TAF**
	Ground Water						
L	Agricultural	350 TAF	175 TAF	426 TAF	210 TAF	8 TAF	1,169 TAF
Y	Wildlife Refuges	8 TAF	0 TAF	1 TAF	0 TAF	0 TAF	8 TAF
	Municipal & Industrial	43 TAF	7 TAF	10 TAF	24 TAF	36 TAF	119 TAF
	Fall Ag Flood / Private Wetland Mgmt	11 TAF	8 TAF	8 TAF	0 TAF	0 TAF	28 TAF
	Totals:	**411 TAF**	**190 TAF**	**445 TAF**	**234 TAF**	**44 TAF**	**1,323 TAF**
	Sub-Total (Prime) Supply	**1,309 TAF**	**1,087 TAF**	**1,203 TAF**	**373 TAF**	**221 TAF**	**4,192 TAF**

Peak Year Project Pumping (100 TAF[1]) in Relation to Estimated Annual Baseline Pumping

Area	Estimated Baseline Pumping (TAF)	Project Pumping as % of Area Baseline
Butte County	411	24%
Glenn and Colusa Counties	635	16%
Butte, Glenn and Colusa Counties	1,046	10%
Northern Sacramento Valley (Butte, Glenn, Colusa, Tehama and Shasta Counties)	1,323	8%
Entire Sacramento Valley (Source: GW model water budgets)	2,500 +/-	4%

[1] Peak year project pumping is 100 TAF in the Butte Basin and in GCID but the two not occur in the same year based on the 1922 through 2003 modeling

Questions
Project Impacts

- Is the interconnection between streams and underlying aquifers sufficiently defined to predict the effects of even modest changes in groundwater levels (e.g., Butte and Big Chico Creeks)?

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Questions, continued
Project Impacts

- What is the extent of the impact on domestic (and other wells)? You show 0 to 6 feet, but you also say that near the wells that are pumping payback water it could be 50 or 60 feet? Even a few feet can have a large impact. This needs to be clarified.

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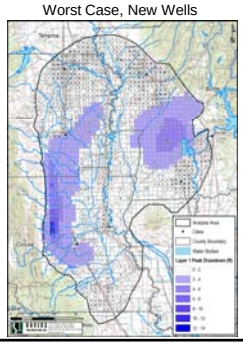
Comparison of Drawdown from Modeling and Averaged for Impact Analysis

Potential Impact Zones: Worst Case, New Wells



Regional Aquifer Drawdown in Aug 1990 , Scenario 1, New Well Field

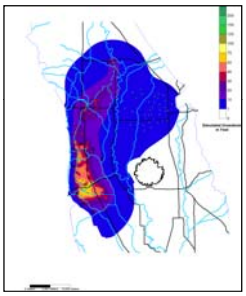


Figure 11-15, p.11-16 from Modeling Report, Feb 2010

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Next Steps

- Draft and Final Investigation Report
- Additional public meetings
- Phase 2

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Appendix B
Sacramento Valley Conjunctive Water Management
Technical Investigation Modeling Report

Report

Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Prepared for

Glenn Colusa Irrigation District and the Natural Heritage Institute

February 2010

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Preface

This report was prepared by CH2M HILL and MBK Engineers for Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI).The report documents technical analyses conducted to examine potential future coordinated operation of Sacramento Valley groundwater aquifers with California's State Water Project and the federal Central Valley Project. The work was enabled by state and federal grant funds.

Principal investigators were Peter Lawson of CH2M HILL and Walter Bourez and Lee Bergfeld of MBK Engineers. Program management and technical oversight were provided by Grant Davids of Davids Engineering on behalf of GCID and NHI.

Any questions regarding the information presented in this report should be addressed to GCID, NHI, or Davids Engineering.

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Acronyms and Abbreviations

ac-ft	acre-feet
bgs	below ground surface
cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento-San Joaquin River Delta
DEM	Digital Elevation Model
DWR	California Department of Water Resources
GCID	Glenn Colusa Irrigation District
GIS	geographic information system
gpd	gallon per day
gpm	gallon per minute
NHI	Natural Heritage Institute
OCAP	Operations Criteria and Plan
Reclamation	Bureau of Reclamation
RMS	root mean square error
SACFEM	Sacramento Valley Groundwater Model
Sacramento River Index	Sacramento River Water Year Type Index
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TCCA	Tehama-Colusa Canal Authority

Executive Summary

Project Description

Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) are conducting an analysis of conjunctive management opportunities in the Sacramento Valley (Project). The purpose is to examine whether and how groundwater production from the Lower Tuscan Aquifer and related deep aquifers in the Sacramento Valley can be integrated with the operations of existing surface water reservoirs to produce additional water to satisfy unmet agricultural demands in the Valley (preferentially), or south of the Sacramento-San Joaquin River Delta (Delta). A secondary objective is to evaluate the potential to increase the operational flexibility of these reservoirs so that they can contribute to meeting environmental flow targets in the Sacramento and Feather Rivers.

Technical Analysis

The Project includes conducting planning-level technical analyses and modeling of the following:

- How conjunctive management projects may operate
- How additional water supplies may be developed
- How reservoirs can be reoperated to generate environmentally beneficial flow patterns
- What effects the Project could have on both the surface and groundwater systems in the Sacramento Valley.

This report documents the development of the surface water and groundwater modeling tools used in the analysis, the assumptions made during the development process, and presents results of the modeling analyses.

Technical analysis was performed using two models: one for the surface water system and one for the groundwater system. The surface water model was developed to analyze operations of conjunctive management projects, reservoir operations, environmental objectives, and agricultural water demands quickly for a variety of different project, operations, and objectives. The surface water model was used in gaming sessions and by members of the project team to understand benefits, risks, and limitations of various conjunctive management configurations.

A regional groundwater model was also developed to simulate the effects of conjunctive management operations on the aquifer system with a spatial resolution at project sites capable of evaluating effects on a well field scale. The groundwater model was used to investigate differences in aquifer drawdown and changes in stream-aquifer interaction for different pumping capacities, seasons, and well field configurations.

The two models were used in an interactive fashion to simulate project operations and better understand the interactions between the surface water and groundwater systems. The surface water model was used to determine timing and quantity of conjunctive management pumping. Pumping time series were then simulated in the groundwater model and changes in stream-aquifer interactions were input back into the surface water model to understand how those changes might affect system operations.

Technical analyses were performed at a planning level to help prove concepts and define potential conjunctive management configurations and operations. Analyses were conducted for general projects, locations, and operations. More specific and refined analysis will be required as specific projects are defined. Most of the analyses contained herein were conducted in a comparative (rather than absolute) manner, and results must be interpreted with this in mind. Comparisons of benefits and impacts between different scenarios or well fields help inform decisions on what projects work better than others.

Projects, Operations, and Scenarios

The project team developed an initial list of nine prospective project sites and screened these down to two project sites for more in-depth analysis and modeling. One project site is located within GCID and is integrated with the Central Valley Project's (CVP) operation of Shasta Reservoir. The second project site is located in Western Canal Water District and Richvale Irrigation District (Butte Basin) and integrated with the State Water Project's (SWP) operation of Oroville Reservoir.

The team used its understanding of annual aquifer drawdown and recovery to develop a conjunctive operation configuration that relies primarily on re-operation of existing reservoirs to achieve the project objectives, drawing on groundwater as a backstop. The term "backstop" refers to the potential to use groundwater supplies on a temporary basis to make up for shortfalls in surface water supplies due to modified operations. Groundwater provides an additional source of water to protect surface water reservoirs from being excessively depleted. This type of operation offers different opportunities and challenges than conventional groundwater banking. Surface water is not banked in the aquifer in wet years and recovered during dry years. Instead, additional water is released from surface reservoirs for delivery to meet Project objectives (unmet local irrigation demands and environmental flow targets). These releases result in lower end-of-year reservoir storage levels and more reservoir space available to capture winter runoff.

The goal of this operation is to develop additional water supply by refilling reservoir space vacated by additional Project releases with captured surplus surface water that otherwise would be released for flood control. In years when refill is not complete, Project pumping produces groundwater for use in Project areas in lieu of surface water deliveries that would otherwise be made from reservoirs. This allows an equivalent volume of water to remain in reservoir storage to recover from prior year project releases.

This mode of conjunctive operation, in which reservoir operation is used as the primary means to develop new water supply and groundwater is used infrequently as a backstop, is highly efficient because it reduces the frequency and volume of groundwater pumping in comparison to conventional groundwater banking operations. Groundwater pumping is

relied upon only as needed to maintain reservoir storage when refill from surplus winter flows is insufficient.

In some years, conditions in the Sacramento Valley may be so critically dry that Project pumping would be suspended altogether. For instance, if groundwater levels were already at levels of concern (according to county Basin Management Objectives or other standards), Project wells would be turned off and the Project would generate no new supplies under these conditions.

Project operations were simulated for the four different conjunctive management scenarios summarized in Table ES-1.

TABLE ES-1
Summary of Project Scenarios Evaluated
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

TAF = thousand acre-feet

Additionally, pumping for each scenario was evaluated for two different well fields. The first well field simulated pumping from existing wells screened in the current aquifer production zones at depths between 100 and 500 feet. The second well field simulated pumping from new wells screened in the deep aquifers at depths between 900 and 1,100 feet.

Results and Conclusions

Table ES-2 presents a summary of results for each scenario and well field configuration. Water supply results are average annual new water supplies developed to meet project objectives. Groundwater results show only the peak impacts to groundwater levels and streams.

Table ES-2 shows that for the two pumping capacities evaluated, the average annual additional water supply is approximately one third of pumping capacity. Additionally, approximately 85 percent of the new water supply developed comes from capture of surplus surface water with the remaining 15 percent from additional groundwater pumping. Average annual groundwater pumping volumes are the result of infrequent but large pumping quantities up to the total project capacity in a given year.

Surface water operations and the resulting groundwater pumping are primarily driven by reservoir storage levels. Therefore, differences in the season of conjunctive management pumping evaluated with Scenarios 3 and 4 have little effect on water supply. However, the duration of the pumping season has a more significant effect on the magnitude of drawdown produced in the aquifer system, and results in differences in projected stream impacts.

TABLE ES-2
Summary of Results for Each Project Scenario and Well Field Configuration
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Pumping Capacity (TAF)				Source of New Water Supply			Max Local Drawdown[a] (feet)		
Scenario	**GCID**	**Butte Basin**	**Pumping Season**	**New Water Supply[b] (TAF)**	**Surplus Surface Water[b] (TAF)**	**GW Pumping[b] (TAF)**	**Well Field**	**GCID**	**Butte Basin**	**Peak Streamflow Impact[c] (cfs)**
1	100	50	Summer	44	38	6	Existing	30-40	<10	54
							New	~100	10-20	53
2	200	100	Summer	110	94	16	Existing	~100	20-30	111
							New	~200	20-30	105
3	100	50	Fall	44	38	6	Existing	40-50	10-20	80
							New	~125	30-40	90
4	100	50	Summer and Fall	44	38	6	Existing	20-30	<10	64
							New	40-50	10-20	65

[a]Maximum local drawdown is the maximum monthly simulated drawdown within the pumped aquifer for that particular conjunctive management project during the period of simulation

[b]Annual Average

[c]Peak stream impact is the maximum monthly aggregated reduction in stream flow for all streams explicitly simulated in the groundwater model during the period of simulation

Note:

cfs = cubic feet per second

Table ES-2 shows that for a given project production capacity, the greatest drawdown occurs during fall pumping simulations because pumping occurs over 3 months, resulting in higher instantaneous rates. An intermediate magnitude of drawdown is observed for pumping over a 4-month summer period, and the least drawdown is predicted for the 7-month summer/fall pumping period.

Production of groundwater from new wells screened in the deeper aquifer results in greater drawdown than pumping the same quantities at the same rates from existing wells. This is because the pumping from new wells is assumed to occur from the 200-foot thickness that comprises model layer 6 (approximately 900 to 1,100 feet below ground surface ([bgs]), whereas the pumping from existing wells occurs from the approximate 400-foot thickness of the regional aquifer (200 to 600 feet bgs). This greater aquifer thickness provides a significantly greater aquifer transmissivity to provide water to the pumping wells, and therefore less drawdown is simulated for a given pumping rate. Additionally, the new well field for the GCID Project is assumed to be located closer to the low permeability bedrock that borders the western edge of the alluvial aquifer; therefore, less water is available to satisfy pumping demands. These assumptions, combined with the larger pumping volumes, help explain why the differences in drawdown between a new and existing well field are larger in the GCID Project than the Butte Basin Project.

Simulated drawdown near the Butte Basin Project is lower than simulated drawdown near the GCID Project. This is due to a combination of lower overall production rates and a greater production well spacing.

Comparisons of peak streamflow impacts between scenarios show that higher production rates generally result in greater peak impacts with the exception of a comparison between Scenario 1 and 4. Differences in peak stream impacts between Scenarios 1 and 4 can be explained by the timing of when ephemeral streams are simulated to flow in the model. The peak drawdown effects for Scenario 4 were evaluated in November (the end of the production season), when west side ephemeral streams are assumed to be active. These streams provide an additional source of recharge to the aquifer system, resulting in a lesser magnitude of predicted draw-down. This can also be seen in the cumulative peak stream impact, which is greater for Scenario 4 than for Scenario 1.

Lower project pumping rates of Scenarios 1 and 4 predict similar peak stream impacts for new and existing well fields. Moderate production rates in Scenario 3 show greater peak impacts of new wells than those produced by existing wells. At the highest production capacity in Scenario 2 the existing well field produces greater peak impacts to streams than the new well field.

SECTION 1

Introduction and Background

Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) are conducting an analysis of conjunctive management opportunities in the Sacramento Valley (Project). The purpose is to examine whether and how groundwater production from the Lower Tuscan Aquifer and related deep aquifers in the Sacramento Valley can be integrated with the operations of existing surface water reservoirs to produce additional water to satisfy unmet agricultural demands in the Valley (preferentially), or south of the Delta. A secondary objective is to evaluate potential to increase the operational flexibility of these reservoirs so that they can contribute to meeting environmental flow targets in the Sacramento and Feather Rivers.

The Project planning area encompasses the entire Sacramento River basin, although primary attention focuses on areas of the northern Sacramento Valley. This includes portions of Butte, Colusa, Glenn, and Tehama counties. Operational strategies developed do not necessarily depend on the Lower Tuscan and related deep aquifers, or any particular portion of the groundwater system for that matter. The strategies are generally applicable wherever productive aquifers exist regardless of their depth or extent.

The scope of the planning effort includes technical analyses with emphasis on surface water and groundwater modeling to define conjunctive management operations and their benefits and impacts. This report provides specific documentation on modeling tools developed for this analysis, projects and scenarios simulated, and model results. Additionally, the report supports preliminary engineering analyses and development of project cost and benefit estimates to allow for economic evaluation of prospective projects.

Any new groundwater pumping in the Sacramento Valley would have at least temporary effects on groundwater conditions and could affect existing groundwater users and flow in rivers and streams. Therefore a major component of the Project is to address risks to existing water users and streams. Risk management strategies that will be investigated include risk avoidance and minimization, such as locating and designing production wells in ways to isolate impacts, and risk mitigation to compensate for effects that cannot be avoided. An overarching principle of the Project is that existing water users, at a minimum, would not be adversely impacted and preferably will benefit from conjunctive operations.

SECTION 2

Conclusions

2.1 Surface Water System

Conjunctive management in which groundwater pumping capacity is used as a backstop to allow more aggressive operation of surface water reservoirs in the Sacramento Valley may be an efficient method to increase water supply. More aggressive operation of reservoirs produces additional water supply primarily through capture of surplus surface water and to a lesser extent through additional groundwater pumping. Table 2-1 summarizes average annual water supply developed for agricultural and environmental objectives and the source of additional supply, either surplus surface water or groundwater, for the two different project capacities evaluated.

TABLE 2-1
Summary of Average Annual Water Supply Benefits and Source of Additional Supply
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

Project Capacity	Additional Water Supply (TAF)			Capture of Surplus Surface Water	Additional Groundwater Pumping
	Agricultural	Environmental	Total		
150 TAF	24	20	44	38	6
300 TAF	42	68	110	94	16

Table 2-1 shows that for the two capacities evaluated, additional water supply is approximately one-third of project groundwater pumping capacity. Additionally, approximately 85 percent of the water supply developed comes from capture of additional surface water with the remaining 15 percent from additional groundwater pumping. Average annual groundwater pumping volumes are the result of infrequent but large pumping quantities up to the total project capacity in a year.

Surface water operations and the resulting groundwater pumping are primarily driven by reservoir storage levels. Therefore the season of conjunctive management pumping whether summer, fall, or summer and fall has only minor operational affects. However, pumping season may have more significant effects on aquifers and current groundwater users.

Additional important conclusions can be drawn from the sensitivity/tradeoff analysis. Projects with larger pumping capacities tend to contribute more toward meeting environmental objectives, while smaller capacity projects contribute more to agricultural objectives for the following two reasons:

- Water costs associated with meeting environmental objectives are typically high and require larger project capacities to meet.
- Environmental objectives were assumed to be all-or-nothing thresholds while any additional water supply could be used to meet agricultural objectives.

These two factors also result in the two objectives being less competitive for additional water supply than may be expected. A different prioritization between the two objectives did not result in a one-for-one tradeoff of benefits.

Tradeoff analysis also provided insight into risks associated with more and less aggressive conjunctive management operations. For the surface water system, these risks are focused on reservoir storage levels and ability to meet contract requirements and temperature control criteria in future years if reservoirs are drawn down too far.

Sensitivity analysis conducted when environmental flow targets were varied demonstrated that for most objectives changes of 10 percent did not erase, or greatly increase, project benefits. Therefore, conjunctive management projects, as defined in this study, could likely be used to meet environmental objectives, even with the uncertainty inherent in flow targets and real-time operations.

Conjunctive management operations within the Sacramento Valley may make additional water supply available south of Delta if reservoir releases to meet environmental objectives can be exported. There exists some ability to export these releases when not considering export restrictions for the protection of Delta smelt. However, export restrictions as proposed in the recently release Operations Criteria and Plan (OCAP) Biological Opinion likely reduce or eliminate this potential benefit.

2.2 Groundwater System

The eight simulations described in this study were designed to test four different project scenarios while holding remaining variables constant. Parameters evaluated in the four scenarios included quantity of groundwater pumped, duration of production (which influences production rate), seasonality of production, and spacing and location of production well fields, including proximity to surface streams. Conclusions are divided into those regarding groundwater level effects followed by those regarding effects on surface water flows. Drawdown estimates provided are regional drawdown estimates. The magnitude of local drawdown adjacent to individual production wells will be significantly greater.

2.2.1 Groundwater Levels

Production of 150 TAF of groundwater from existing wells over the summer (May through August) results in a maximum drawdown of approximately 40 feet in the pumped aquifer, whereas production of 300 TAF of groundwater results in a maximum of approximately 75 feet of drawdown.

Production of 150 TAF of groundwater from new deeper wells over the same months results in a maximum of approximately 75 feet of drawdown in the pumped aquifer, whereas the production of 300 TAF of groundwater results in approximately 150 feet of drawdown.

Production of 150 TAF of groundwater from existing wells over the fall period (September through November) results in a maximum drawdown of about 50 feet in the pumped aquifer compared to a maximum of approximately 40 feet of drawdown if the same production occurs in the summer.

Production of 150 TAF of groundwater from new deeper wells over the fall period results in a maximum of approximately 125 feet of drawdown in the pumped aquifer compared to a maximum of approximately 75 feet of drawdown if the same production occurs in the summer.

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

Production of 150 TAF of groundwater from new deeper wells over the summer/fall period results in a maximum of approximately 50 feet of drawdown in the pumped aquifer compared to a maximum of approximately 75 feet of drawdown if the same production occurs in the summer only.

For a given project production capacity, the greatest drawdown is observed in fall pumping simulations because the pumping occurs over 3 months, resulting in the highest instantaneous rate. An intermediate magnitude of drawdown is observed for the 4-month summer period, and the least drawdown is predicted for the 7-month summer/fall pumping cycle.

The production of groundwater from the deeper aquifer from new production wells results in the greatest predicted magnitude of drawdown. This is because the pumping is simulated to occur in a 200-foot thickness of model Layer 6 (approximately 900 to 1,100 feet bgs) whereas the pumping from existing wells is assumed to occur from wells screened throughout the approximately 400-foot thickness of the regional aquifer (200 to 600 feet bgs). Further, the new well field identified on the western side of the valley is located further west, relative to the location of the existing wells, transferring the groundwater pumping stresses closer to the low permeability bedrock which borders the western edge of the alluvial aquifer.

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

2.2.2 Effects on Surface Water Flows

Peak effects on stream flow due to groundwater production in the Sacramento Valley are summarized in Table 2-2.

TABLE 2-2
Peak Effects on Streamflow from Conjunctive Management Operations
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Stream	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**
All Streams	54	53	111	105	80	90	64	65
Butte Creek	13	12	72	69	50	48	39	33

TABLE 2-2
Peak Effects on Streamflow from Conjunctive Management Operations
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Stream	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**	**Existing (cfs)**	**New (cfs)**
Sacramento River – GCID to Wilkins Slough	42	37	32	28	16	18	16	15
Feather River	3	3	6	6	4	4	4	4
Little Chico Creek	3	3	6	5	4	3	4	3
Salt River	1	5	5	8	2	5	2	5
Stone Coral Creek	6	9	11	15	7	10	6	9
Stony Creek	4	5	7	7	4	6	4	4

Specific conclusions regarding surface water effects are as follows:

- The higher pumping rates associated with the 300-TAF projects clearly result in significantly larger peak stream impacts.
- For a conjunctive management project of a given size, new well fields pumping from deeper aquifers tend to produce greater peak stream impacts on western streams than pumping from existing wells tapping the regional aquifer. This is likely due to the greater magnitude of drawdown predicted on the western side of the valley from new wells as discussed above. Effects on eastern and central streams (Sacramento River) are similar.
- When looking at the cumulative peak impacts to all streams, the lower project pumping rates (150 TAF over 4 or 7 months) predict similar peak impacts for both new and existing well fields. At moderate production rates (150 TAF over 3 months), peak impacts of new wells is greater than those produced by existing wells. At the highest production capacity (300 TAF over 4 months), the existing well field produces greater peak impact to streams than the new well field.
- For all projects evaluated, peak stream impacts occur in 1990, as do peak impacts on the Sacramento River. This is also generally true of the west side streams of Stone Corral and Stony Creek.
- For all projects evaluated, peak stream impacts on the east side streams (Little Chico Creek and Butte Creek) occur in early 1995. One exception is that for the 300 TAF projects, peak impact on Butte Creek occurs in early 1993.
- Peak impacts on the Feather River occur in late 1994 or early 1995.

SECTION 3

Technical Analysis and Modeling

Technical analysis and modeling of conjunctive management operations require consideration of both surface water and groundwater systems and their interaction. This project developed and used models that simulate each system using similar water demands and system operations. Information is passed between the models to depict conjunctive management operations and effects between the surface and groundwater systems. These tools were developed to simulate and compare a baseline condition and a project condition to determine benefits and effects of conjunctive management.

Technical analyses were performed at a planning level to help prove concepts and define potential conjunctive management configurations and operations. Analyses were conducted for general projects, locations, and operations. More specific and refined analysis will be required as specific projects are defined. Most of the analyses contained herein were conducted in a comparative, rather than absolute, manner, and results must be interpreted as such. Comparisons of benefits and impacts between different scenarios or well fields help inform decisions on what projects work better than others. Interpretation of the results should not be interpreted in a highly predictive manner, such as pumping "X" amount of groundwater results in a deficit of "Y" stream flow, or release of "A" volume of water from a reservoir accomplishes "B" amount of environmental restoration.

3.1 Objectives of Groundwater Analysis

Conjunctive water management, or groundwater substitution projects, can result in depressing local groundwater levels, which could affect yields and performance of nearby water supply wells and cause a reduction of groundwater discharge to surface streams or direct leakage from streams to underlying aquifers. Timing these impacts is critical, especially for surface water. Acceptable impacts to surface water flows during certain times of year might be unacceptable during other parts of the year. As part of the technical analysis, a numerical groundwater modeling tool was developed to evaluate impacts of proposed conjunctive water management projects on groundwater levels and streamflows near proposed project sites. The groundwater model is regional in scale, covering the Sacramento Valley Groundwater Basin. This model uses transient surface water budgets developed from spatially referenced land use data, water district operations, surface water availability, and required supplementary groundwater pumping to meet agricultural demands. Specific objectives of the groundwater modeling effort included the following:

- Calculating transient valley-wide and project-specific drawdown in groundwater levels resulting from implementing conjunctive management projects at two general locations with the northern Sacramento Valley.
- Quantifying transient impacts to streams resulting from implementing conjunctive management projects.

- Considering the effects of operating conjunctive water management projects in both wet and dry hydrologic periods and operating projects only in certain selected years within a longer hydrologic period.

3.2 Objectives of Surface Water Analysis

A surface water model was developed to simulate coordinated operation of select Central Valley Project (CVP) and State Water Project (SWP) reservoirs with conjunctive management projects. The surface water model was designed for use in gaming sessions and to help improve understanding of tradeoffs associated with different project objectives and operations. Specific objectives of the surface water modeling included the following:

1. Quantifying additional water supply that might be developed with conjunctive management projects and how that water supply can be used to meet agricultural and environmental objectives.
2. Understanding how conjunctive management projects might change the operation of CVP and SWP reservoirs, including effects on storage, spills, and risks to existing contracts and cold water pool management.
3. Understanding tradeoffs and risks associated with different conjunctive management operations, project sizes, and project objectives.
4. Improving understanding of how changes in stream-aquifer interactions might result in changes to the surface water system.
5. Understanding the effects on other parts of the system, including other reservoirs, hydropower operations, the Sacramento-San Joaquin River Delta (Delta), and south-of-Delta water supplies.

SECTION 4

Current Basin Groundwater Conditions

The initial intent of the Project was to identify areas within the Sacramento Valley groundwater basin in which groundwater levels were significantly lowered due to agricultural pumping for extended periods of time and persisted through the winter recharge period. Conditions of this type would indicate the presence of a large unsaturated aquifer volume that could be used to implement a put-then-take groundwater banking program. Under a program of this type, surface water is delivered to existing groundwater users in the target area during years of above average precipitation, resulting in a replenishing aquifer storage characterized by increased groundwater levels. When dry conditions return to the area, groundwater held in storage within the aquifer is pumped to yield additional supply to meet project objectives.

The first step in the evaluation process was to identify areas within the Sacramento Valley groundwater basin that would be suitable for a put-then-take type conjunctive management project. This was done by collecting and evaluating numerous historical groundwater level hydrographs from wells throughout the basin. Results of this analysis indicated that while numerous areas within the basin show drawdown during the irrigation season, groundwater levels in most areas essentially recover during subsequent winter months, with the exception of the occurrence of multiple years of critically dry conditions. Figures 4-1 through 4-15, which depict historic groundwater fluctuations in wells distributed throughout the valley. The conclusion from this analysis was that a put-then-take water bank was not feasible in the Sacramento Valley north of the American River Basin. Providing surface water for irrigation demands in lieu of groundwater does not result in increased groundwater in storage because groundwater levels recover due to natural recharge over the winter months.

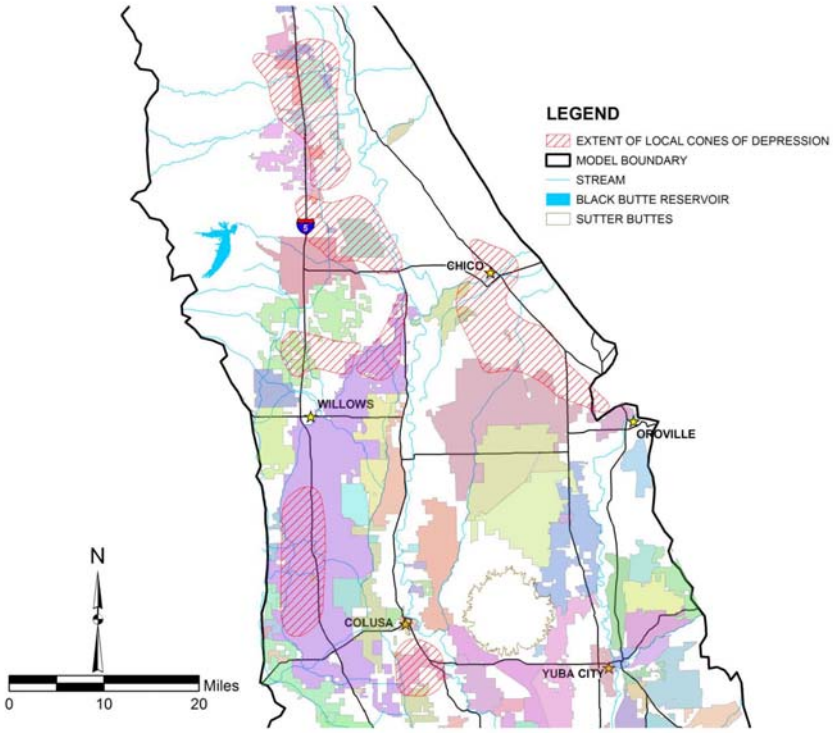


FIGURE 4-1
GROUNDWATER CONDITION STUDY AREAS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

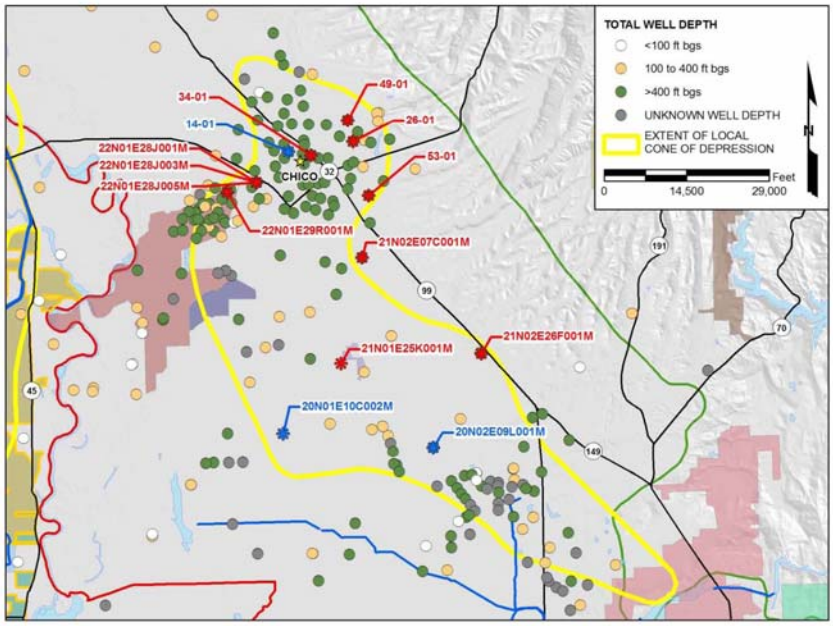


FIGURE 4-2
WELLS EVALUATED IN THE CHICO-DURHAM AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

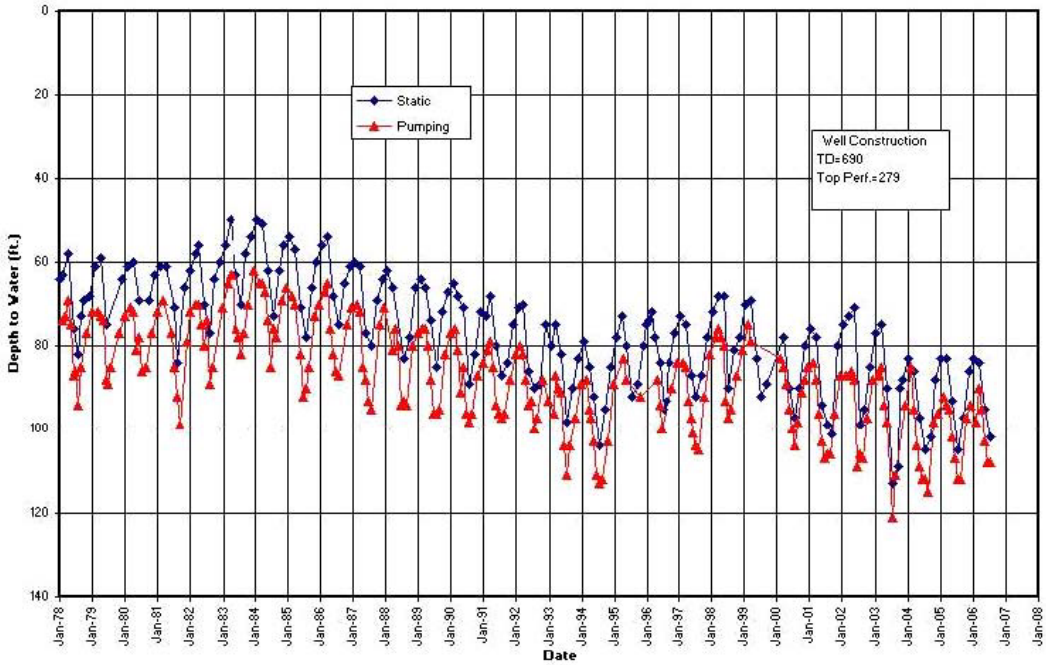


FIGURE 4-3
HYDROGRAPH OF CAL WATER WELL 34-01
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

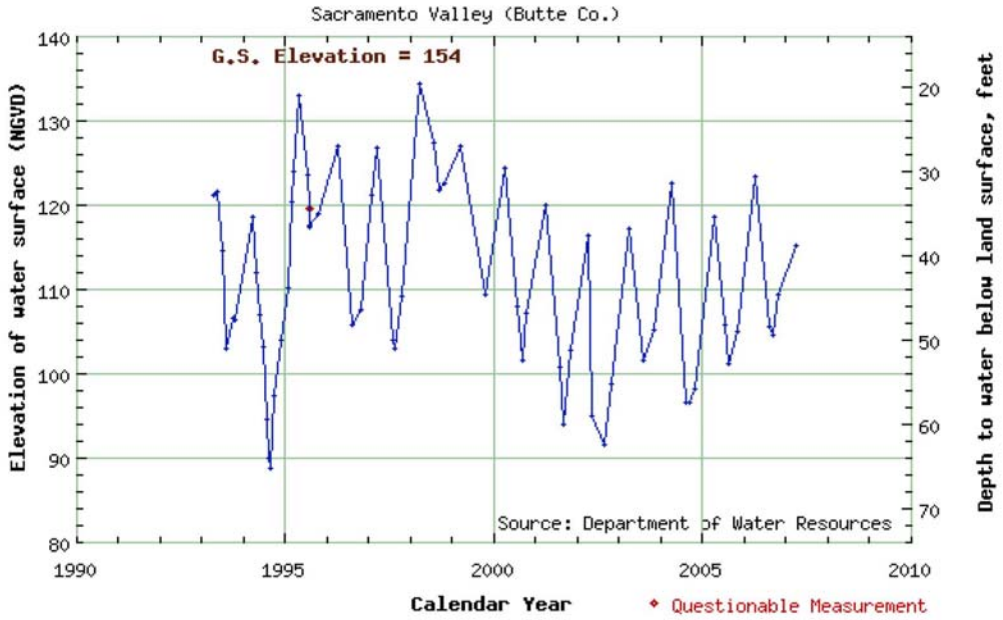


FIGURE 4-4
HYDROGRAPH OF WELL 21N01E25001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

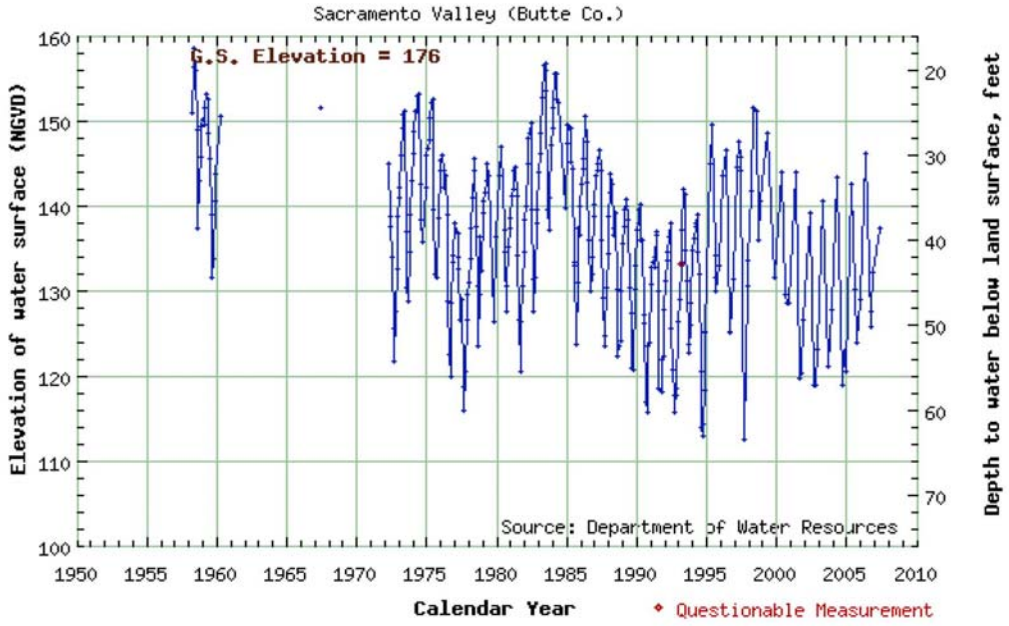


FIGURE 4-5
HYDROGRAPH OF WELL 22N01E28J001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

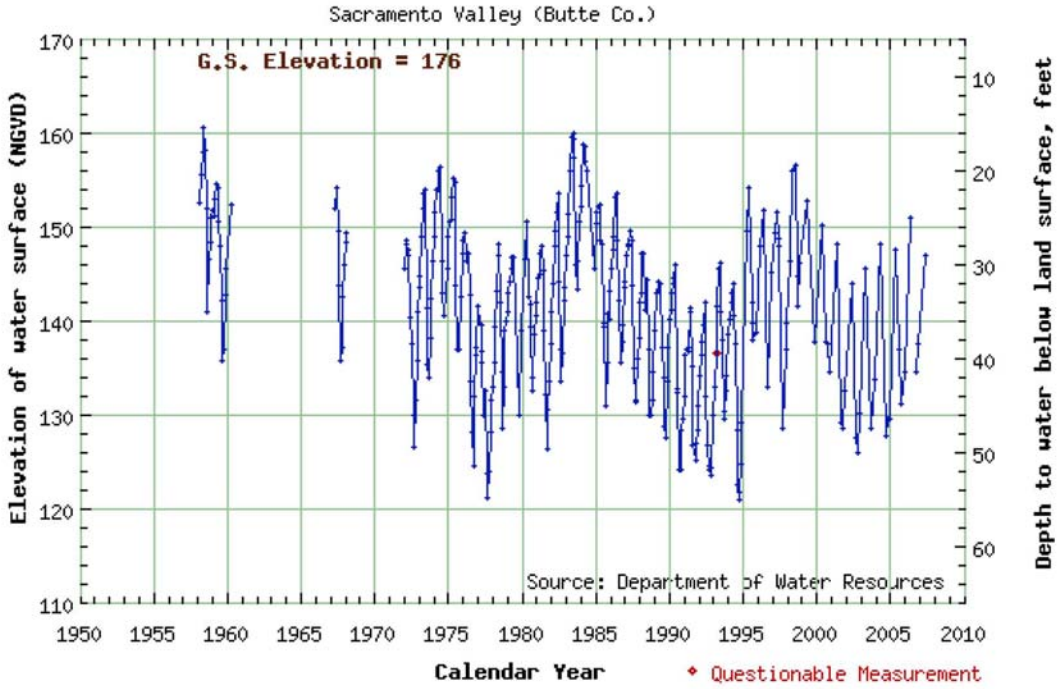


FIGURE 4-6
HYDROGRAPH OF WELL 22N01E28J003M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

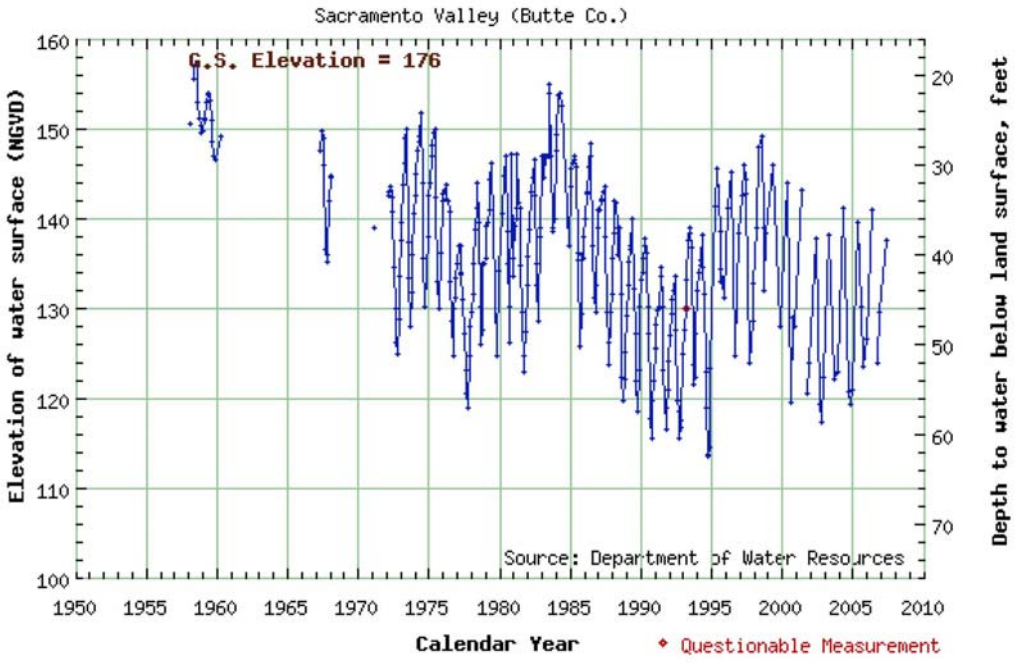


FIGURE 4-7
HYDROGRAPH OF WELL 22N01E28J005M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

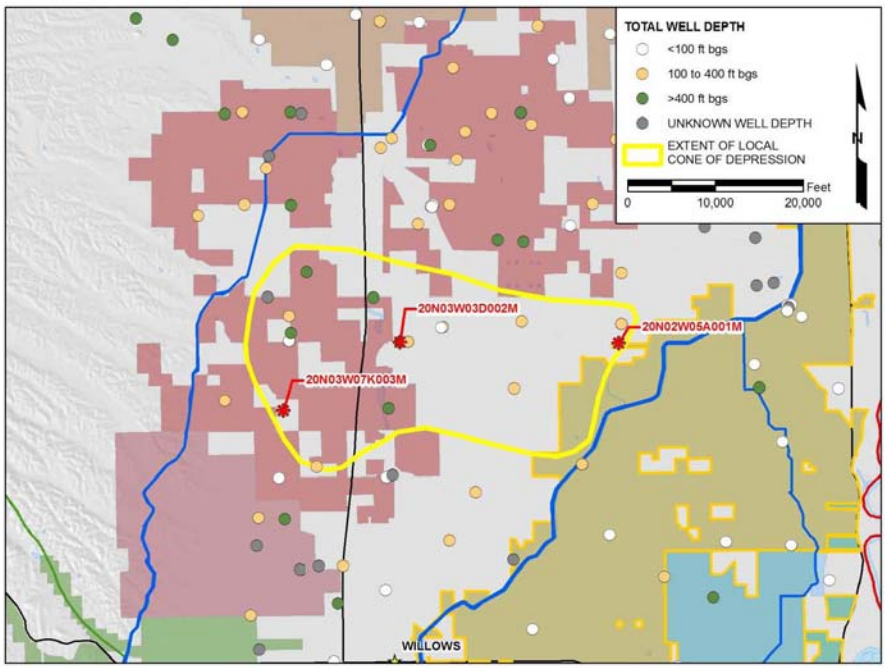


FIGURE 4-8
WELLS EVALUATED IN THE ORLAND-ARTOIS WATER DISTRICT AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

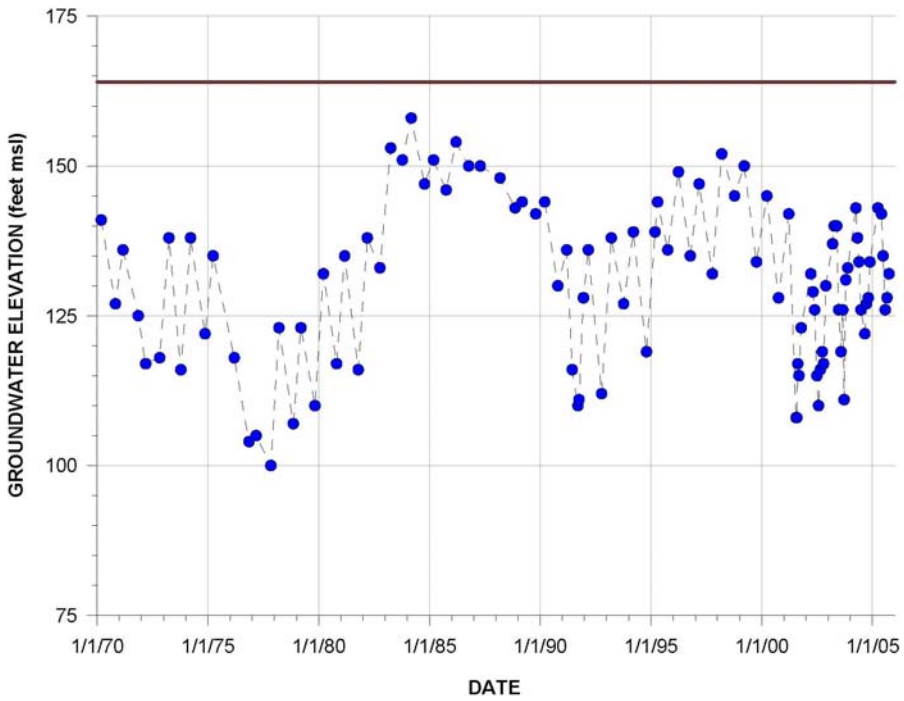


FIGURE 4-9
HYDROGRAPH OF WELL 20N03W03D002M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

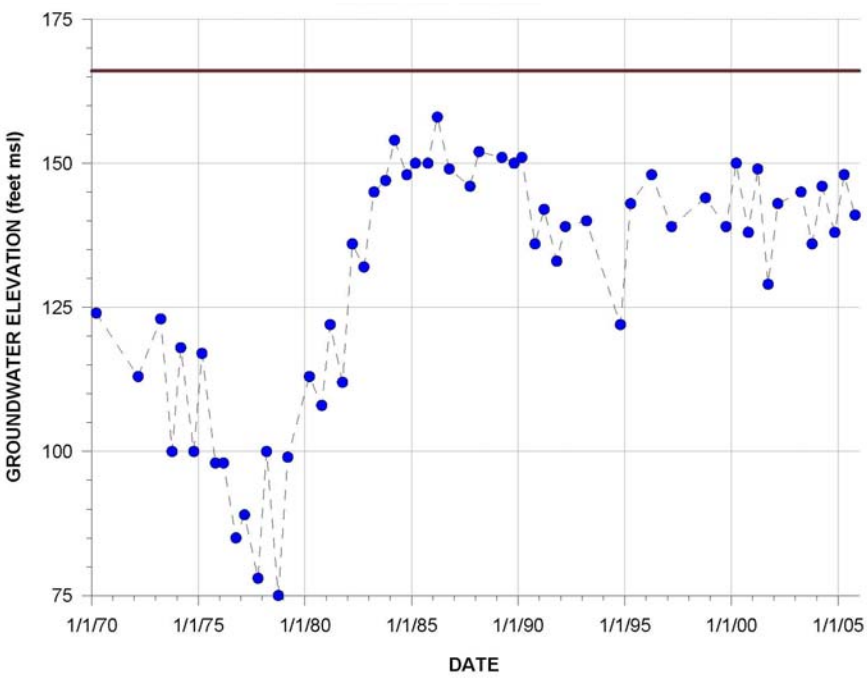


FIGURE 4-10
HYDROGRAPH OF WELL 20N03W07K003M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

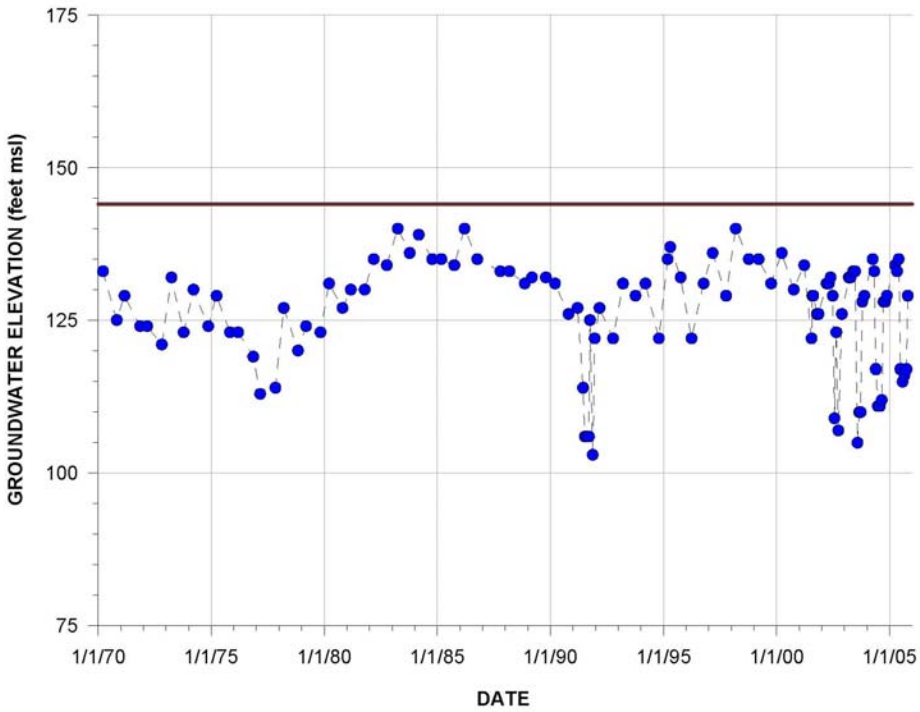


FIGURE 4-11
HYDROGRAPH OF WELL 20N02W05A001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

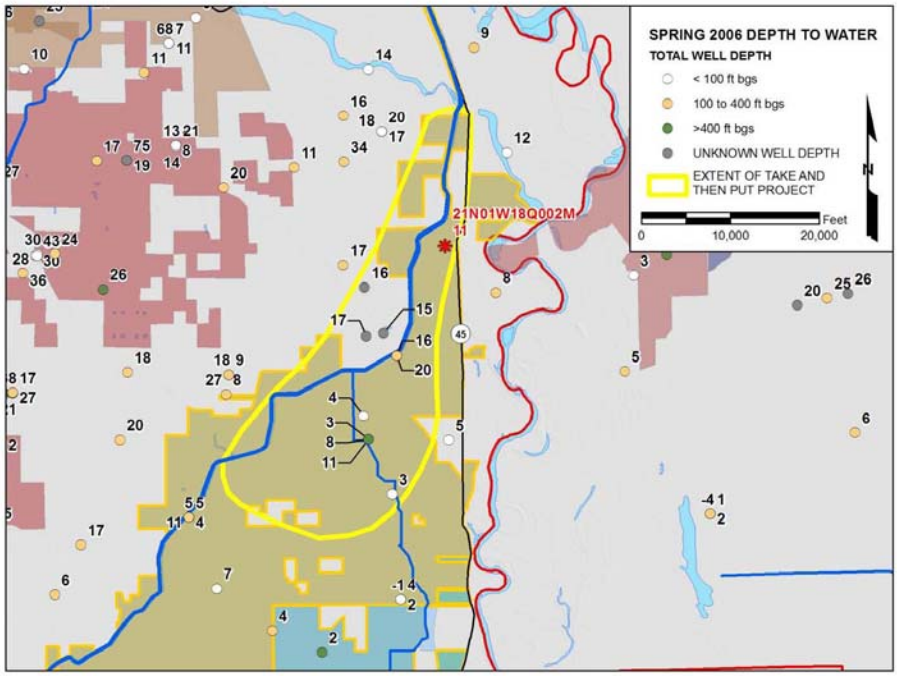


FIGURE 4-12
WELLS EVALUATED IN THE NORTHERN GCID WATER DISTRICT AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

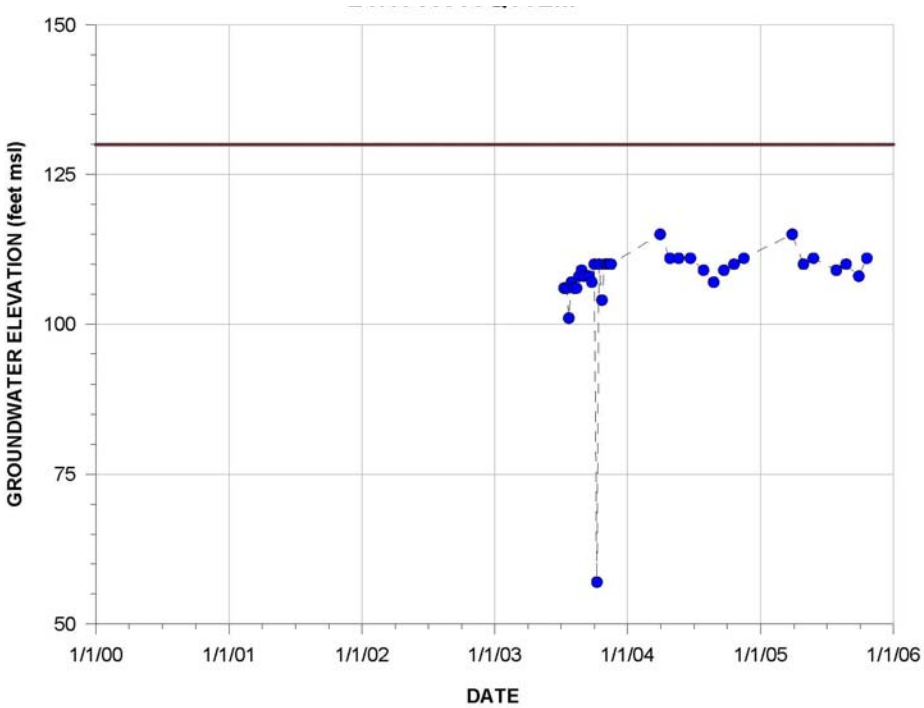


FIGURE 4-13
HYDROGRAPH OF WELL 21N01W18Q002M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

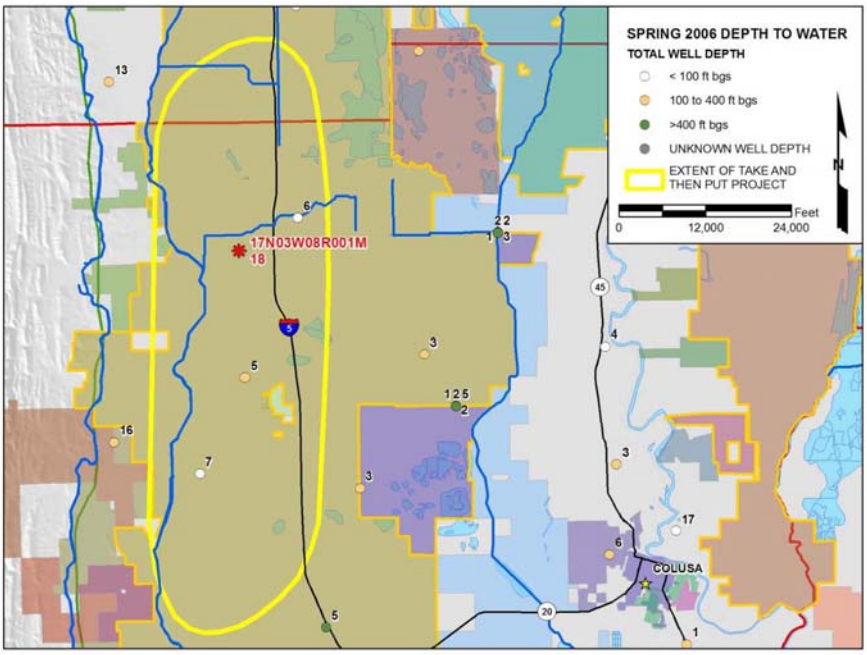


FIGURE 4-14
WELLS EVALUATED IN THE CENTRAL GCID WATER DISTRICT AREA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

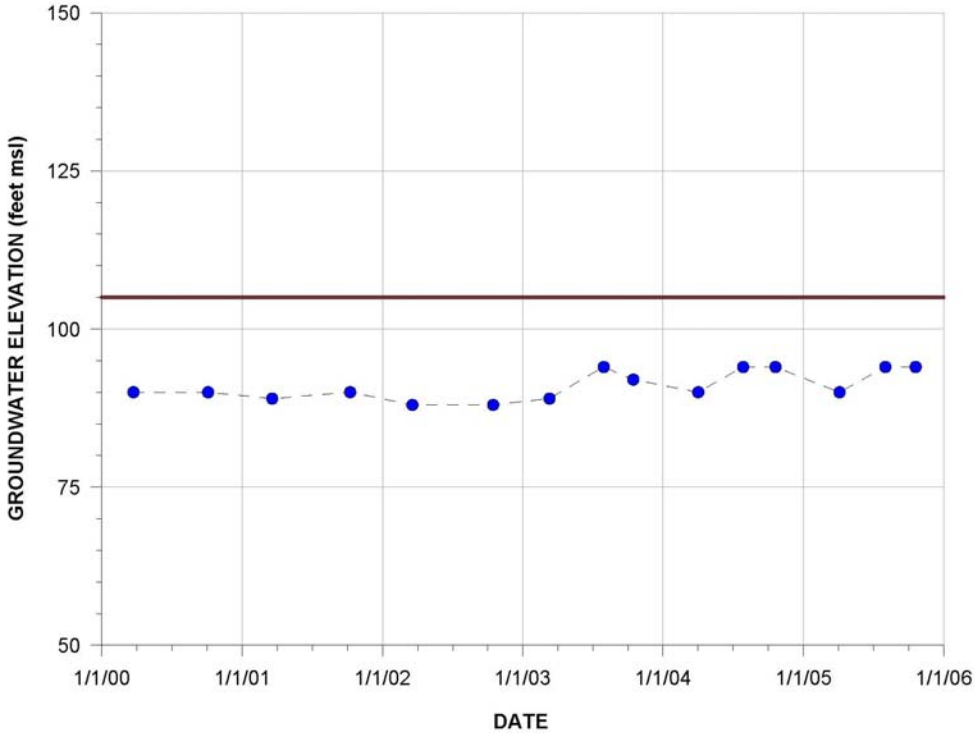


FIGURE 4-15
HYDROGRAPH OF WELL 17N03W08R001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

SECTION 5

General Operational Scenario

The team used its understanding of annual aquifer drawdown and recovery to develop a conjunctive operation configuration that relies primarily on re-operation of existing reservoirs to achieve the project objectives, drawing on groundwater as a backstop. The term "backstop" refers to the potential to use groundwater supplies on a temporary basis to make up for shortfalls in surface water supplies due to modified project operations. Groundwater provides an additional source of water to protect surface water reservoirs from being excessively depleted. This type of operation offers different opportunities and challenges than the conventional put-then-take groundwater banking discussed above. Surface water is not banked in the aquifer in wet years and recovered during dry years. Instead, additional water is released from surface reservoirs for delivery to meet Project objectives (unmet local irrigation demands and environmental flow targets). These releases result in lower end-of-year reservoir storage levels and more reservoir space available to capture winter runoff.

The goal of this operation is to develop additional water supply by refilling reservoir space vacated by additional Project releases with surplus surface water that otherwise is released for flood control. In years when refill is not complete, Project pumping produces groundwater for use in Project areas in lieu of surface water deliveries that would otherwise be made from reservoirs. This allows an equivalent volume of water to remain in reservoir storage to recover from prior year project releases.

This mode of conjunctive operation, in which reservoir operation is used as the primary means to develop new water supply and groundwater is used infrequently as a backstop, is highly efficient because it reduces the frequency and volume of pumping as compared to traditional banking operations. Groundwater pumping is relied upon only as needed to maintain reservoir storage when refill from surplus winter flows is insufficient.

In some years, conditions in the Sacramento Valley may be so critically dry that Project pumping would be suspended altogether. For instance, if groundwater levels were already at levels of concern (according to county Basin Management Objectives or other standards), Project wells would be turned off and the Project would generate no new supplies under these conditions.

SECTION 6

Initial Project Site Identification

The project team completed a systematic, qualitative assessment of conditions within the Sacramento Valley to identify particular areas in which conjunctive operations appear promising. This process did not conclusively identify the very best or most feasible sites, but did identify particularly promising sites for conjunctive operations.

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

- Areas in which existing groundwater levels may be lower than surrounding areas and overlying lands are supplied almost exclusively from groundwater. This type of site may provide the potential for storage of surplus surface water in underlying aquifers.
- Areas in which minimal groundwater pumping exists because overlying areas are supplied almost exclusively from surface water. This type of site may provide a potential area for groundwater extraction.

6.1 Initial Project Sites

An initial list of project sites was developed from a review of groundwater maps and knowledge of the Sacramento Valley. Sites were identified by the overlying water district, though projects did not strictly conform to water district boundaries. Information considered in this analysis included the location, water source, existing surface water contracts, infrastructure available and additional infrastructure necessary for delivery of surface water and extraction of groundwater, conceptual operations, and information on existing groundwater conditions. Table 6-3 summarizes this information for the nine initial sites.

6.2 Selection Criteria

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

TABLE 6-1
Initial Project Sites and Parameters
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

These nine sites were evaluated based on whether they could meet project objectives of providing additional water supply to meet agricultural and environmental objectives, an estimate of the volume of water that may be developed, and relative (compared to the other sites) ease and cost of integrating the project with existing surface water systems.

The following additional criteria were used to identify prospective sites:

- Availability of reliable surface water supplies that could be substituted with groundwater to enable conjunctive operations
- The presence of highly productive, underlying groundwater aquifers that could be economically developed
- The ability to locate and design production wells in a manner that would minimize effects on existing groundwater users and surface streams

6.3 Selected Project Sites and Operational Scenarios

Using the selection criteria described in Section 5.2, the Project identified two sites on which to conduct more refined analyses with surface and groundwater modeling tools. The GCID and Butte Basin Projects, supplied by the CVP and SWP, respectively, provided the potential to develop the largest quantity of water compared to other sites, and are already well integrated with the surface water system.

Additionally, the Stony Creek Fan and Orland Project was identified as a third potential project. However, upon further investigation into potential groundwater pumping capacities and the ability to integrate the project with the Sacramento River system, it was determined that this project would not be modeled during this phase of the project. This project is retained for additional analysis in future phases of investigation.

6.3.1 Glenn-Colusa Irrigation District Project

GCID is the largest, single Sacramento River diverter, serving about 141,000 acres of irrigated land and 20,000 acres of managed waterfowl habitat within its gross service area of 170,000 acres. GCID is served by the CVP (pursuant to underlying senior water rights) and is underlain by productive aquifers. There are about 200 existing private wells in GCID, but groundwater production in most years is small. Conjunctive management operations would utilize wells within GCID as a backstop for a more aggressive operation of Shasta Reservoir.

6.3.2 Butte Basin Project

The initial project site of Western Canal Water District was expanded to include neighboring Richvale Water District. These districts are all served by the SWP (pursuant to underlying senior water rights) and are adjacent to each other comprising a total irrigated area of roughly 110,000 acres. They are generally underlain by productive groundwater systems and there is limited existing use of groundwater. Conjunctive management operations would utilize wells within the two districts as a backstop for a more aggressive operation of Oroville Reservoir.

SECTION 7

Modeling Overview

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

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

The surface water model treats the groundwater system as a source of water and does not simulate groundwater flows or conditions. It does, however, include features to account for estimated effects of groundwater pumping on stream flow accretion and depletion through use of functions derived from complementary simulations of pumping in the groundwater model. These functions provided a coarse but adequate representation of stream-aquifer interaction so that the surface water model could be used for gaming sessions without having to operate the groundwater model. Final scenarios were evaluated using actual changes in stream-aquifer interaction based on complimentary groundwater model simulations.

Figure 7-1 illustrates inputs to the surface water model and resulting simulation of conjunctive management projects integrated into CVP and SWP operations.

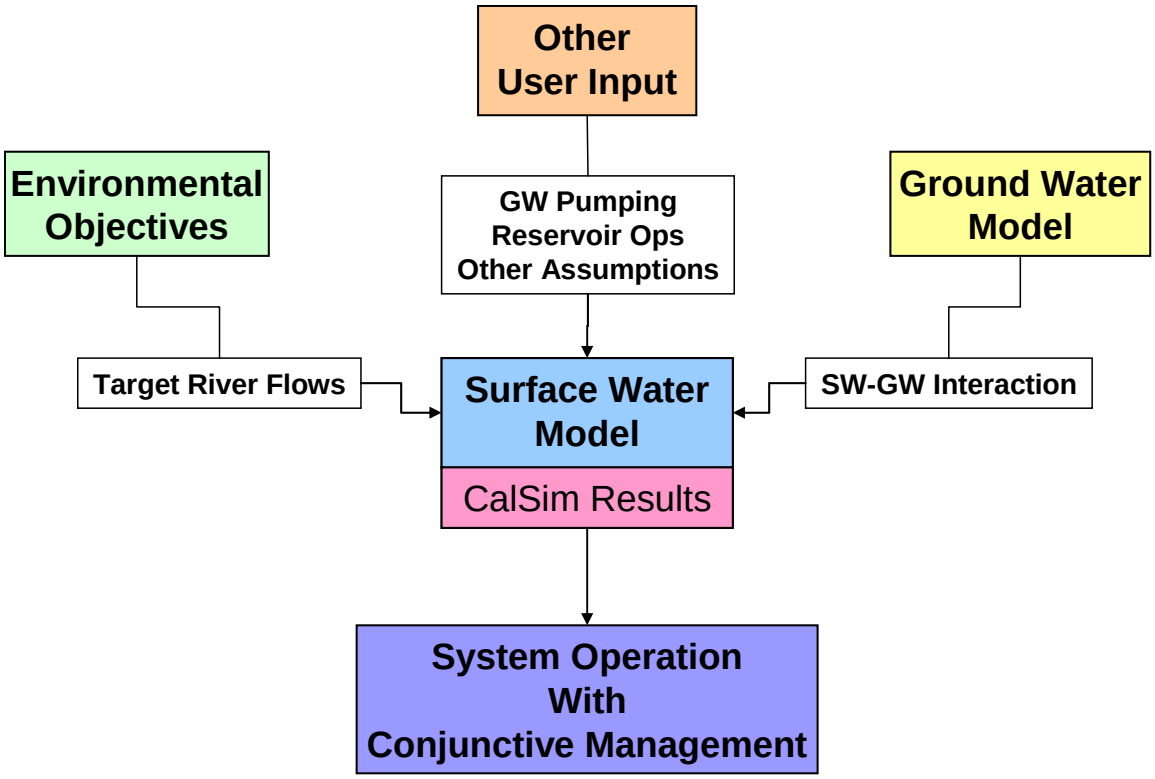


FIGURE 7-1
SURFACE WATER MODEL INPUTS AND OPERATIONS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

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

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

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

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

SECTION 8

Groundwater Model

MicroFEM© (Hemker, 1997), an integrated groundwater modeling package developed in The Netherlands, was chosen to simulate the groundwater flow systems in the Sacramento Valley Groundwater Basin. The current version of the program (3.60) has the ability to simulate up to 25 layers and 250,000 surface nodes. MicroFEM© is capable of modeling saturated, single-density groundwater flow in layered systems. Horizontal flow is assumed in each layer, as is vertical flow between adjacent layers.

MicroFEM© was the chosen modeling platform for both basins for the following reasons:

- The finite-element scheme allowed the construction of a model grids covering large geographic areas (over 5,955 square miles in the Sacramento Valley Groundwater Basin) with coarse node spacings outside of the simulated project areas and finer node spacings in areas of interest (e.g., near potential project areas). The finer node spacing near simulated production wells provides greater resolution of simulated groundwater levels and stream impacts.
- The graphical interface allows rapid assignment of aquifer parameters and allows proofing of these values by graphical means.
- The flexible post-processing tools allow for rapid evaluation of transient water budgets for model simulations and identification of changes to stream discharges and other water fluxes across the model domain.

8.1 Geologic Setting

The Sacramento Valley Groundwater Basin is a north-northwestern trending asymmetrical trough filled with as much as 10 miles of both marine and continental rocks and sediment (Page, 1986). On the eastern side, the basin overlies basement bedrock that rises relatively gently to form the Sierra Nevada, and on the western side, the underlying basement bedrock rises more steeply to form the Coast Ranges. Marine sandstone, shale, and conglomerate rocks that generally contain brackish or saline water overlie the basement bedrock. The more recent continental deposits, overlying the marine sediments, contain fresh water. These continental deposits are generally 2,000 to 3,000 feet thick (Page, 1986). The depth (below ground surface [bgs]) to the base of fresh water typically ranges from 1,000 to 3,000 feet (Bertoldi et al., 1991).

In the Sacramento Valley Groundwater Basin, groundwater users pump primarily from deeper continental deposits. Groundwater is recharged by deep percolation of applied surface water and rainfall, infiltration from streambeds, and lateral inflow along the basin boundaries. The quantity and timing of snowpack melt and precipitation events are the predominant factors affecting the surface water and groundwater hydrology, and peak runoff in the basin typically lags peak precipitation by 1 to 2 months (Bertoldi et al., 1991).

8.2 Hydrology

The Sacramento River is the main surface water feature in the Sacramento Valley Groundwater Basin. It has several major tributaries draining the Sierra Nevada, including the Feather, Yuba, and American Rivers. Stony, Cache, and Putah Creeks drain the Coast Range and are the main westside tributaries of the Sacramento River.

8.3 Model Construction

8.3.1 Spatial Grid

The SACFEM model grid consists of 88,922 nodes and 177,095 elements. Nodal spacing varies from as large as 5,800 feet (1,750 meters) near the model boundary and in areas with no water management projects to as small as 500 feet (150 meters) in areas where groundwater production is being investigated. Three zones of refined nodal spacing are located throughout the model domain in proximity to the areas that were previously identified as showing the greatest potential for successful conjunctive water management operations (NHI, 2007). These three areas are located in the west-central portion of GCID, the areas southwest of Chico encompassing the Western Canal and Richvale Water Districts, and the area east of Black Butte Lake on the Stony Creek Fan (see Figure 8-1).

The finer spacing in these areas of interest allows for a more refined estimate of the groundwater levels and groundwater-surface-water interaction in the potential project areas. The model boundary represents the extent of the freshwater aquifer in the Sacramento Valley.

8.3.2 Vertical Layering

The total model thickness represents the thickness of the freshwater aquifer (less than 3,000 micromhos per centimeter) as defined by Berkstresser (1973) and subsequently refined in the northern portion of the valley by the California Department of Water Resources (DWR) (2002). For the southern portion of the model area, defined by Berkstresser data, elevation contour lines of the base of fresh water, along with information from boring locations (point measurements of the elevation of the base of fresh water) were digitized and used to generate an x, y, z file containing the elevation of the base of fresh groundwater at regularly spaced intervals. For the northern portion of the model area, the locations of the geologic cross-sections were plotted, along with the estimated base of freshwater elevations obtained from the cross-section information, and a base of freshwater elevation contour map was constructed. These data sets were then merged to yield a single interpretation of the structural contour map of the base of freshwater across the Sacramento Valley. This map is presented on Figure 8-2.

Total Aquifer Thickness

To develop a total aquifer thickness distribution and, therefore, a total model thickness distribution, it was necessary to develop a groundwater elevation contour map and subtract the depth to the base of freshwater from the groundwater elevation contour map. The water level calibration targets for this groundwater modeling tool are the steady-state groundwater heads measured in calendar year 2000. Therefore, to develop a target groundwater elevation

contour map, all available groundwater elevation measurements in the DWR Water Data Library were obtained from DWR central and northern district staff. These measurements were primarily collected biannually during spring and fall periods, and these values were averaged at each well location to compute an average water level at each well point. These values were then contoured, in conjunction with the streambed elevations for the 37 major streams included in the model, to develop a target groundwater elevation contour map for the year 2000. The distribution of the elevation of the base of freshwater was subtracted from this groundwater elevation contour map to yield an estimate of the distribution of the total aquifer thickness across the model domain.

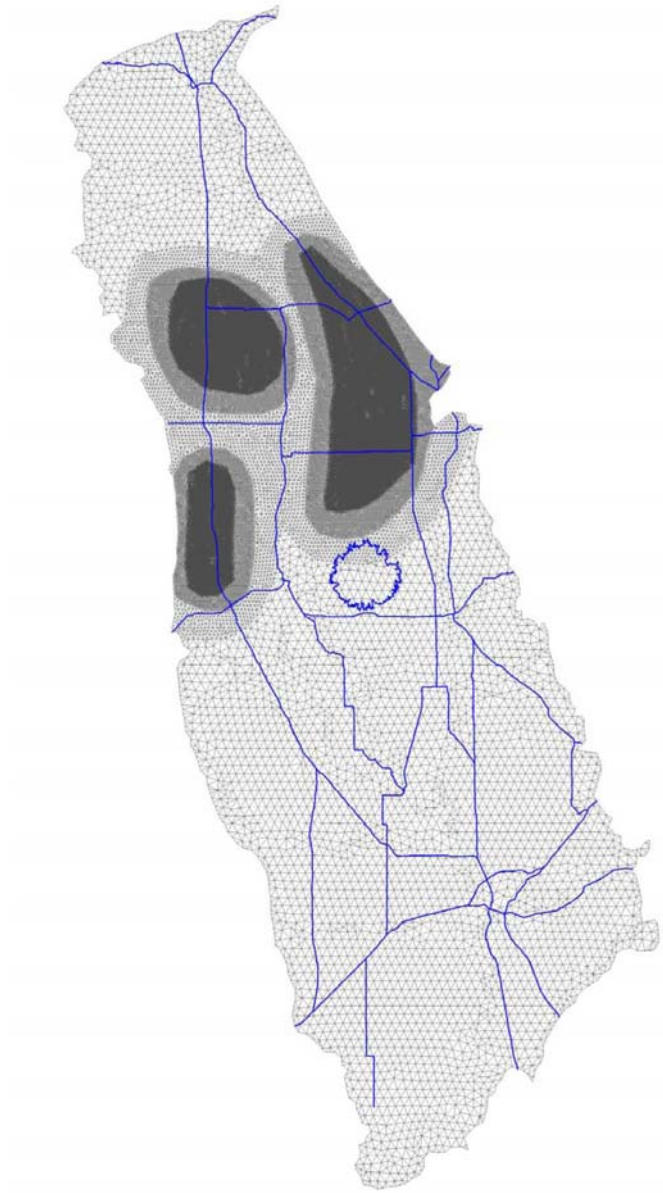


FIGURE 8-1
SACFEM FINITE ELEMENT GRID, LOWER TUSCAN CONJUNCTIVE WATER MANAGEMENT INVESTIGATION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

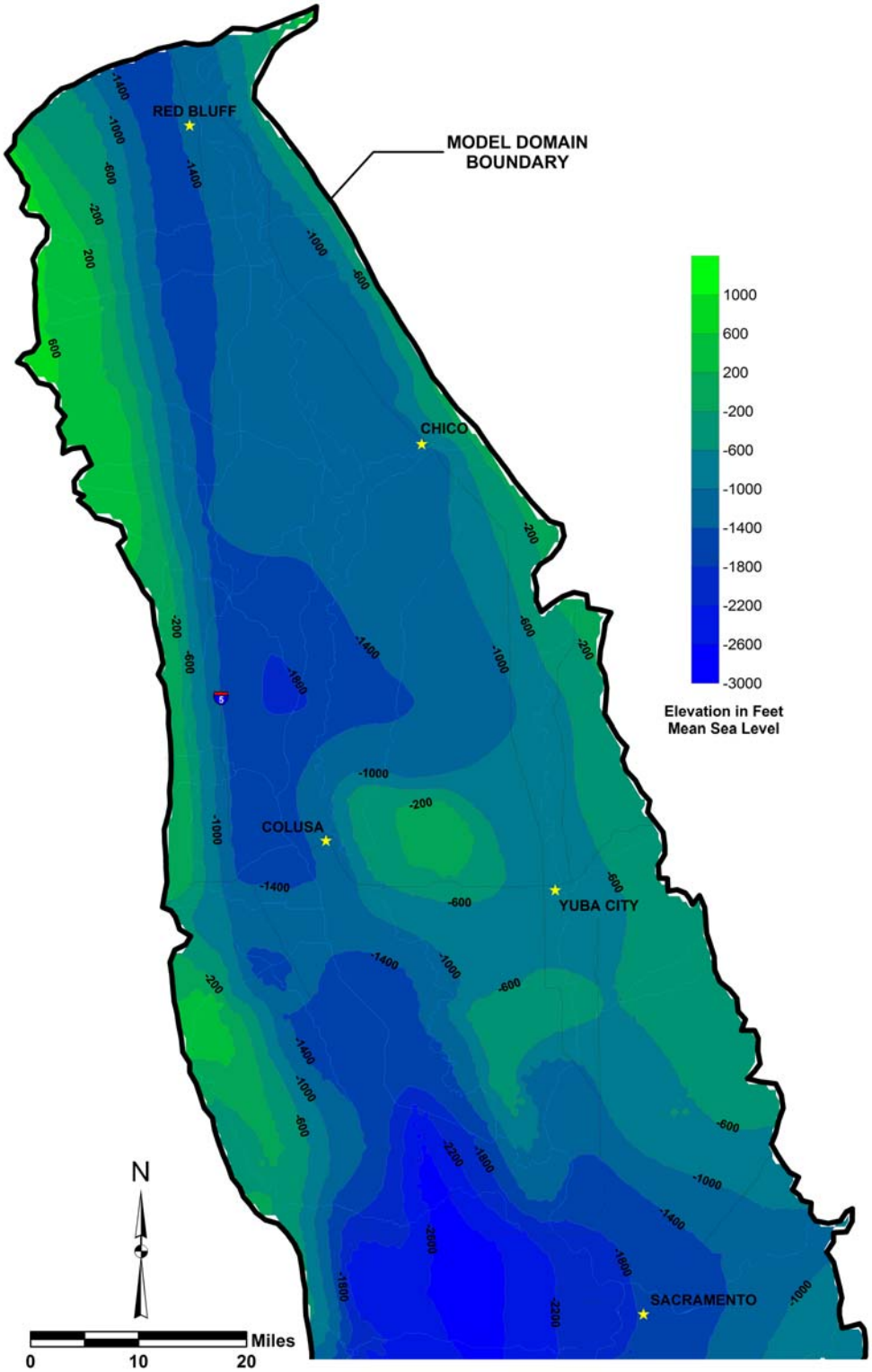


FIGURE 8-2
DEPTH TO FRESHWATER LOWER TUSCAN CONJUNCTIVE WATER MANAGEMENT INVESTIGATION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Model Layer Thickness

Because one of the primary objectives of this analysis was to investigate the potential to implement conjunctive water management projects within the lower Tuscan aquifer, the strategy used to layer the model was to assign two layers to explicitly represent this aquifer system: layers 6 and 7. Where the lower Tuscan is present, the elevation of the top of layer 6 was defined by the structural contour surface of the top of the lower Tuscan. Two layers were assigned to represent this unit because in many areas of the model, the depth to the base of freshwater (the base of the model) is as much as 900 feet below the upper surface of the lower Tuscan. Groundwater production wells drilled into the lower Tuscan would almost certainly be screened over a much smaller depth interval. To represent this condition in the model, layer 6 was assigned a thickness of between 200 and 250 feet, with the remaining lower Tuscan thickness assigned to layer 7. The exception to this convention is in the northeastern portion of the model near the City of Chico. The lower Tuscan outcrops in the foothills above Chico; therefore, in these areas, all layers of the model represent the lower Tuscan aquifer. Moving west from Chico, a transition zone exists where a decreasing number of layers represent the lower Tuscan until it is limited to layers 6 and 7. In areas where the lower Tuscan is not present, the thicknesses of layers 6 and 7 represent 18 and 27 percent of the total aquifer thickness, respectively.

Layers 1 through 5 represent shallower producing zones within the valley. The thicknesses of these layers were assigned based on a specified percentage of the available aquifer thickness at a given location, to provide multiple depth zones within which to assign regional pumping. The assumed layer thicknesses for layers 1 through 5 were also selected to reflect typical screened intervals of production wells in the Sacramento Valley. Layer 1 represents approximately 6 percent of the total aquifer thickness, except along certain portions of model perimeter where the total aquifer thickness became very small. In these areas, layer 1 thickness was increased to up to 24 percent of the total aquifer thickness to improve numerical stability of flow calculations. The thicknesses of layers two through four each represent approximately 10 percent of the total aquifer thickness, and the thickness of layer 5 represents approximately 15 percent of the total aquifer thickness.

8.3.3 Boundary Conditions.

A combination of no-flow, specified flux, and head-dependent boundary conditions were used to simulate the groundwater flow system within the Sacramento Valley.

Head-Dependent Boundaries.

Rivers. A head-dependent boundary condition was chosen to simulate the streams within the Sacramento Valley. The MicroFEM© wadi system was used to implement streams within the model domain. MicroFEM©'s wadi package calculates the magnitude and direction of nodal fluxes based on the relative values of the user specified stream stage (wh1) and the calculated head in the upper aquifer (h1), but is limited by a critical depth (wl1). When calculated groundwater elevations fall below this critical depth, it is assumed that the water table de-couples from the river system, and the leakage rate from the river to the aquifer becomes constant. The equations that govern operation of the wadi package are as follows:

Groundwater discharge to a stream is simulated if h1 >wh1:

$$Q_{inflow} = a * (h1 - wh1) / \ | \ wc1 \ | \quad (1)$$

In coupled streams (groundwater elevation is above the stream bottom elevation), groundwater recharge from a stream is simulated if h1 <wh1:

$$Qinflow = a * (wh1 - h1) / \ | \ wc1 \ | \quad (2)$$

In de-coupled streams (groundwater elevation is below the stream bottom elevation), groundwater recharge from a stream is simulated:

$$Qinflow = a * (wh1 - wl1) / \ | \ wc1 \ | \quad (3)$$

Where:

Q = volumetric flux

a = nodal area

h1 = simulated groundwater elevation in layer 1

wh1 = simulated stream stage

wl1 = stream bottom elevation

wc1 = resistance across the streambed

Nodal area is a grid-dependent parameter that can be automatically calculated within MicroFEM©. In general, the nodal area around a node that represents a discrete reach in a stream is greater than the surface area of that stream along the reach in the field. The effective resistance term (wc1) incorporates an areal correction factor to account for this discrepancy. Additionally, streambed resistance terms account for the relationship between the streambed sediments and aquifer properties in the upper half of model layer 1 when calculating stream seepage. River resistances are calculated as follows:

$$wc1 = ((Dr/Kr) +((0.5 * mt1)/Kv1))* (a/LW) \quad (4)$$

Where:

Dr = thickness of streambed sediments

Kr = vertical hydraulic conductivity of streambed sediments

mt1 = thickness of model layer 1

Kv1 = vertical hydraulic conductivity of model layer 1

L = stream length represented by the model node

W = field-width of the wetted river channel within the stream reach represented by L

Most major streams in the Sacramento Valley were included in the groundwater flow model. A total of 37 streams are represented. Stream locations and elevations were digitized from existing base maps and USGS topographic quad sheets and imported into the model domain. Stream length within a given node is a grid-dependent variable calculated by MicroFEM© at each river node. The stream-length term is generally overestimated by MicroFEM© at stream confluences. Manual corrections of this term were made where necessary. Streambed thickness was assumed to be 3.28 ft (1 meter) for all river nodes.

Assumptions of streambed Kv were based on the type of streambed deposits expected based on stream size. Wetted stream width was calculated from aerial photographs at two locations along each stream.

Drains. Drain boundary conditions were specified across the top surface of the model excluding nodes where wadi boundaries exist. Drain boundary conditions are head-dependent boundaries that allow the transfer of water out of the model domain only. The elevation of the drain boundaries were set at the land surface. The drain boundaries were included in the model to represent a combination of surficial processes that occur in areas of shallow groundwater including evapotranspiration and groundwater discharge to the surface.

Groundwater discharge to a drain is simulated if h1 >dh1:

$$Q_{outflow} = a * (h1 - dh1) / \ | \ dc1 \ | \ \text{(where a = nodal area)} \quad (5)$$

Groundwater discharge to a drain if h1 <dh1:

$$Q_{outflow} = 0 \quad (6)$$

The parameter dc1 represents the drain conductance and is a measure of the resistance to flow across the drain boundary. The dc1 parameter is computed as:

$$dc1 = ((Td/Kd) \quad (7)$$

Where:

Td is the drain interface thickness and Kd is the hydraulic conductivity of the drain materials.

Specified Flux Boundaries. There are three sets of specified flux boundary conditions used in the SACFEM model. They represent the following three primary components of the agricultural water budget:

- Deep percolation of applied water and precipitation along with agricultural pumping
- Mountain front recharge
- Urban pumping

Deep Percolation of Applied Water and Precipitation and Agricultural Pumping. The first set reflects the deep percolation of precipitation and applied water across the valley, as well as the regional agricultural pumping. The deep percolation flux values were applied to every surface node in the model. The pumping stresses due to agricultural and urban pumping were applied at selected locations in model layers 2 through 4. These layers were selected as they represent the common depths of production wells within the valley. The spatial distribution and magnitudes of these fluxes were derived from the surface water budget calculations described in greater detail in the subsection titled Surface Water Budget.

Mountain Front Recharge. The second set of specified flux boundary conditions represent the subsurface inflow of precipitation falling within the Sacramento River Watershed but outside the extent of the model domain. To estimate these flux values, the USGS 10-meter Digital Elevation Model (DEM) along with existing hydrography geographic information system (GIS) coverages for the Sacramento Valley were used to delineate the drainage areas

that are tributary to the model domain but fall outside of the rivers watersheds explicitly represented in the model. It is these areas that can contribute water to the model domain but are not accounted for in the wadi boundary conditions defined in the model. Once the areas of these watersheds were defined, they were intersected with (PRISM) rainfall data using GIS PRISM tools, and the volume of precipitation falling on the watershed computed. Based on the computed total volume of precipitation, the deep percolation to the groundwater system was calculated using the empirical relationship developed by Turner (1991).

$$DP = (PPT-2.32)*(PPT)^{0.66} \quad (8)$$

Where:

DP = Average annual deep percolation of precipitation (in/yr)
PPT = Annual precipitation (in/yr)

Following is a summary of the process that was used to estimate the quantity of subsurface inflow, otherwise known as mountain front recharge:

1. The area of each drainage basin tributary to the model domain that is not represented by streams explicitly simulated in SACFEM was computed using a GIS-based analysis of the land surface topography. The extent of these smaller watersheds is shown on Figure 8-3.
2. Each drainage area polygon was then intersected with a GIS coverage of annual average rainfall estimated using the PRISM model (reference). This distribution of annual average rainfall was then used to calculate the total volume of rainfall falling on the watershed, and an overall average rainfall rate computed (inches per year).
3. The average rainfall rate was then used to compute a deep percolation quantity using the relationship between annual rainfall and deep percolation rate developed by Turner (1991).
4. The annual volume of deep percolation computed in step 3 was then converted into monthly values based on the monthly distribution of stream flow measured in unregulated sections of Deer Creek. These monthly deep percolation quantities were then introduced at the model domain boundary of each small watershed polygon using injection wells into layer 1. The quantity applied to each model boundary node was proportional to boundary length of each element versus to the total boundary length of the drainage polygon.

Urban Pumping. The final set of specified flux boundary conditions reflect urban pumping within the model domain. The distribution of agricultural pumping developed using the surface water budgeting methodologies described in the Surface Water Budget subsection do not include urban pumping. To estimate the quantity of urban pumping to apply to the model the year 2000 census data were used. Each municipal area with a population greater than 5,000, that uses groundwater as a source of municipal supply, was assigned a pumping volume based on an annual average per capita value of 250 gallons per capita per day. The urban pumping assigned to the Chico area as well as several northern Sacramento County municipal areas required a higher per capita rate to match the observed groundwater elevations in those areas. The monthly variability in urban pumping quantity was distributed based on typical seasonal trends for municipal water use.

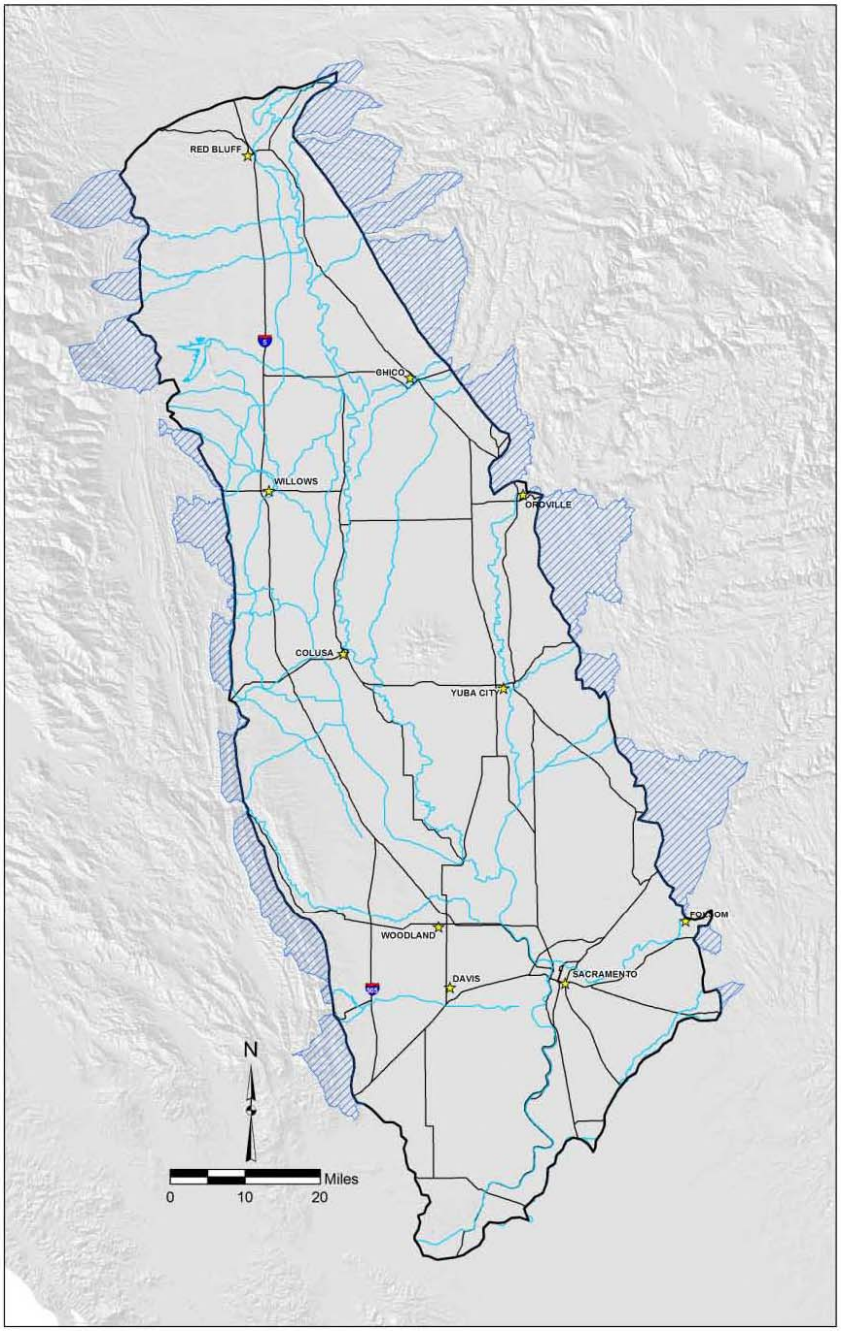


FIGURE 8-3
EXTENT OF POLYGONS USED TO ESTIMATE MOUNTAIN FRONT RECHARGE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

No-Flow Boundaries. A no-flow boundary was specified across the bottom boundary of the model, representing the freshwater/brackish water interface.

8.3.4 Surface Water Budget

One of the most critical components to the successful operation of the SACFEM model is computation of transient surface water budget components. These water budget components were estimated based on a variety of spatial information including land use, cropping patterns, source of irrigation water, surface water availability in different year types and locations, and the spatial distribution of precipitation. Surface water budget components included in the model are deep percolation of applied water, deep percolation of precipitation, and agricultural pumping.

Surface water budgets were developed by intersecting existing GIS data developed by DWR with the groundwater model grid to develop land use for each groundwater model node. Additionally, GIS data on water districts and surrounding areas were used to identify district and non-district areas. The resulting intersection provided land use, water district, and water source information for each of the approximately 89,000 groundwater model nodes.

A semiphysically based soil moisture accounting model and historical precipitation data were used to simulate the root zone and calculate applied water demand and deep percolation past the root zone for each node. Calculated deep percolation was split between applied water and precipitation based on the season and the availability of water from each source.

Calculated values for deep percolation were compared to estimated values prepared by DWR's Northern District for the year 2000. Northern District staff calculated detail water budgets in 2000 that included some of the best available estimates of regional deep percolation. In some areas soil parameters in the root zone model were adjusted to provide similar volumes of deep percolation. However, considerable uncertainty still exists in any estimate of regional deep percolation because soil conditions vary widely and it is not possible to measure deep percolation on a regional basis.

The total demand for applied water was used in conjunction with the water source and water district attributes from the GIS intersection to estimate agricultural groundwater pumping. Some areas are supplied solely from groundwater and calculated total applied water demand represents groundwater pumping. Other areas are supplied by a mix of groundwater and surface water. For these areas, estimates of the availability of surface water each year were made to determine the fraction of applied water demand met from surface and groundwater. In these areas, additional information on the overlying water district was combined with district water rights and contracts to estimate available surface water. For example, districts within the Tehama Colusa Canal Authority have water contracts with the Bureau of Reclamation (Reclamation) that receive different allocations each year. An estimate of those allocations from an existing level of development simulation of CVP operations was used to calculate the availability of surface water for groundwater model elements within those districts. Any remaining applied water demand, after consideration of available surface water, is assumed to be met from groundwater pumping.

Annual values of calculated agricultural pumping for the Sacramento Valley were reviewed and compared well to the generally accepted estimate of approximately 2.5 million acre-feet (DWR, 2005).

8.3.5 Aquifer Properties

The distribution of aquifer properties across the Sacramento Valley is poorly understood. In certain areas with significant levels of groundwater production, the collection of aquifer test data, and the measurement of historic groundwater level trends in response to known groundwater production rates have provided valuable information on aquifer properties. However in the majority of the valley, these data are not available.

To estimate the spatial distribution of aquifer properties across the model domain for this numerical modeling effort, a database of well productivity information was used. In consultation with DWR staff, a database was obtained that included all of the specific capacity yield data that were available from well log records. These data were compiled along with well construction information for each production well to yield a representative data set of well productivity across the valley. Wells that did not have available construction data were omitted from further consideration. To protect owner privacy, the exact location of each well was modified by DWR staff to reflect the center of the section in which each well was located. This modification in well location did not adversely affect the use of the data to estimate the spatial distribution of aquifer properties, given the extremely large area encompassed by the model domain. The total number of wells in the database within the model domain used in this analysis was approximately 1,000 wells.

The intent of the modeling analysis described herein is to simulate the operation of high-productivity irrigation wells screened within the major producing zones in the valley to support conjunctive water management projects. Therefore, the aquifer properties that are of primary interest are those of the major aquifer zones tapped by large-diameter irrigation wells. The well database described above was filtered to remove data obtained from tests on low yield and/or shallow domestic type wells. All test data from wells that reported a well yield below 100 gallons per minute (gpm) were eliminated from consideration as was the test data from wells with a total depth of less than 100 feet. The only exception to this second consideration was for wells that were located along the basin margins, where aquifers are thin, that reported what appeared to be valid test results. Data from these wells was considered as they were often the only data available in the basin margin areas.

Once the data set for consideration was finalized, the reported specific capacity data for each well was used to estimate an aquifer transmissivity for that location. The relationship used to estimate aquifer transmissivity was the following form of a simplified version of the Jacob non-equilibrium equation:

$$Sc = T/2000 \tag{9}$$

Where:

Sc = specific capacity of an operating production well (gpm per foot of drawdown)
T = aquifer transmissivity (gallon per day [gpd] per foot)

After a transmissivity estimate was computed for each location, the transmissivity value was divided by the screen length of the production well to yield an estimate of the aquifer hydraulic conductivity. The final step in the process was to smooth the hydraulic conductivity field to provide regional scale information. Individual well tests produce aquifer productivity estimates that are local in nature, and may reflect small scale aquifer heterogeneity that is not necessarily representative of the basin as a whole. To average these

smaller scale variations present in the data set, a FORTRAN program was developed that evaluated each independent hydraulic conductivity estimate in terms of the available surrounding estimates. When this program is executed, each K value was considered in conjunction will all other K values present within a user-specified radius, and the geometric mean of the available K values calculated. This geometric mean value is then assigned as the representative regional K value for that location. The radius used in this analysis was 10,000 meters, or approximately 6 miles. The point values obtained by this process were then kriged to develop a hydraulic conductivity distribution across the model domain. The aquifer transmissivity at each model node within each model layer was then computed at the geometric mean K values at that node times the thickness of the model layer. Insufficient data were available to attempt to subdivide the data set into depth varying K distributions and it was therefore assumed that the computed mean K values were representative of the major aquifer units in all model layers. Effectively this approach averages the aquifer K values at a given location. In reality, there is certainly vertical heterogeneity present in the Sacramento Valley aquifer system. However any inaccuracies in the assumed vertical distribution of K values will result primarily in local scale errors in computed vertical gradients. In the extremely heterogeneous aquifer system of the Sacramento Valley, it is the distribution of total aquifer transmissivity, along with the imposed water budget boundary conditions, that determine the regional distribution of hydraulic head. The efficacy of this approach at replicating the observed transient water level fluctuations across the valley will be demonstrated in the calibration section discussion below. The final distribution of hydraulic conductivity used in the SACFEM model is shown on Figure 8-4.

Model Calibration

Calibration Approach. The calibration approach used to develop the modeling tool described herein was significantly influenced by the resources available to fund the project. While a fully transient calibration approach, wherein the model is used to replicate groundwater levels and flow conditions throughout some period of record would be the more desirable approach, the resources were not available to fund such an effort. Instead, a more limited steady-state calibration approach was implemented. In a steady-state calibration process, the monthly water budget components for a selected period are averaged, and the model is calibrated to both average groundwater levels and stream discharges that occur during the calibration period. The calibration period selected for this effort was calendar year 2000. Calendar year 2000 was selected because it is the most recent year where water budget information is available that was characterized by average hydrologic conditions. A calendar year instead of a water year was used to facilitate the development of average groundwater elevation calibration targets. The available water-level data were obtained from DWR, and much of that data are collected in the spring and the fall. If a water year was used, the cut-off between water years is the end of September, which coincides with the mid-point of the fall sampling event. The result would be that when average groundwater elevation values were calculated, some of the measurements would be from October of the previous year and some would be from September of the subsequent year, which would introduce error in the data set, especially if the year types were different. The use of a calendar year eliminates this potential for error.

While a rigorous transient calibration was not possible as part of this effort, because the model was being used to simulated transient operation of conjunctive water management

projects, simulated transient groundwater elevations were compared to observed groundwater elevation hydrographs from a collection of monitoring wells located throughout the model domain. The period of record over which the transient analysis was performed was water years 1982 through 2003. Therefore, simulated and observed transient groundwater elevations were compared over this period as well.

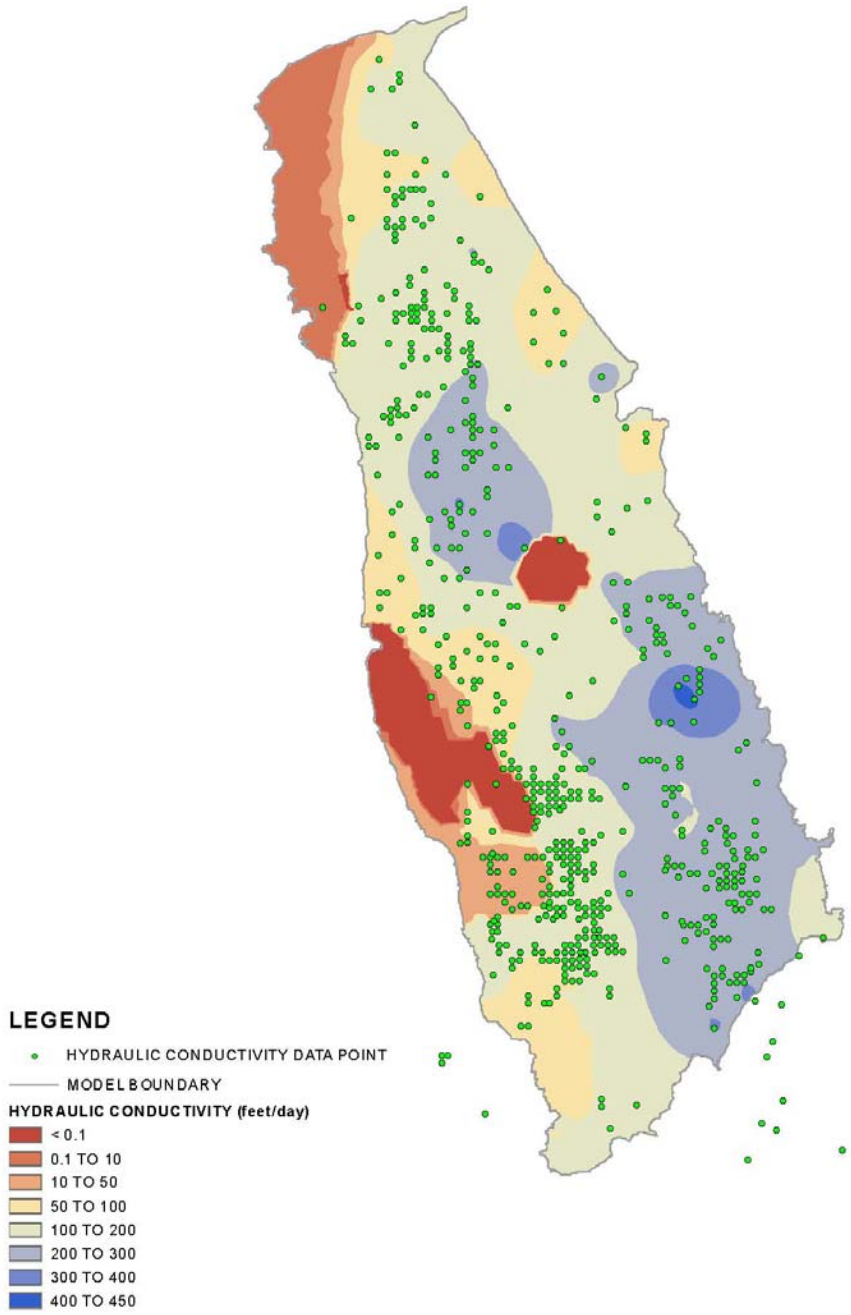


FIGURE 8-4
SACFEM HYDRAULIC CONDUCTIVITY DISTRIBUTION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Steady-State Calibration Targets. Several quantitative and qualitative calibration targets were used in the calibration process. These calibration targets are as follows:

- Average year 2000 groundwater elevations (257 wells used as calibration targets)
- Areas of gaining and losing streams (approximate)
- Approximate water budget quantities (order of magnitude comparison as no accurate estimates are available)
- Approximate calibration to transient groundwater levels measured between water years 1982 and 2003

Water Budget Modification. During the calibration process, it was anticipated that some adjustment to the water budget components computed using the previously described methodology would be necessary to obtain an acceptable degree of calibration. A water budget analysis performed on the raw input data provided by the root zone model, combined with simulated groundwater heads from model runs using that deep percolation data, suggested that the prescribed deep percolation rates in the northern (Red Bluff) and southern (Davis/Woodland) areas were too high. Deep percolation rates were reduced in these areas, resulting in a significant improvement in calibration residuals. To run the model is a transient mode, it was also necessary to make similar adjustments to the prescribed transient monthly deep percolation rates obtained from the root zone model. This was accomplished by computing the percent reduction in deep percolation that was required at each model node to obtain an acceptable steady-state calibration. It was then assumed that these same nodal reduction percentages were applicable to the monthly deep percolation estimates throughout the transient simulation period. While no rigorous transient calibration was performed, simulated groundwater levels over the 1982 though 2003 transient simulation period were compared to hydrographs of observed data at several locations across the model domain.

Steady-State Calibration to Year 2000 Groundwater Elevations. A graphical measure of the state of calibration is to develop a scattergram that plots the simulated versus the measured groundwater elevation at each target calibration well. A plot of this type is shown on Figure 8-5. A perfect fit between simulated and observed groundwater elevations would plot as a 45 degree line (slope = +1.0, Y-intercept=0). As can be seen on Figure 8-5, the simulated heads generated by the SACFEM model show good agreement between simulated and observed groundwater levels. This implies that the model is providing accurate estimates of the steady state groundwater elevations and flow directions that exist in the vicinity of the potential project sites evaluated under this conjunctive water management evaluation program.

Another quantitative measure of calibration that is commonly used is to calculate the root mean square error (RMS) divided by the range of observations. As a rule of thumb, a well calibrated regional model will have an RMS/range of less than 10 percent, and a well calibrated local scale mode will have an RMS/range of less than 5 percent. The RMS/range of the steady state calibration presented here is 4.6 percent, well below the 10 percent criterion.

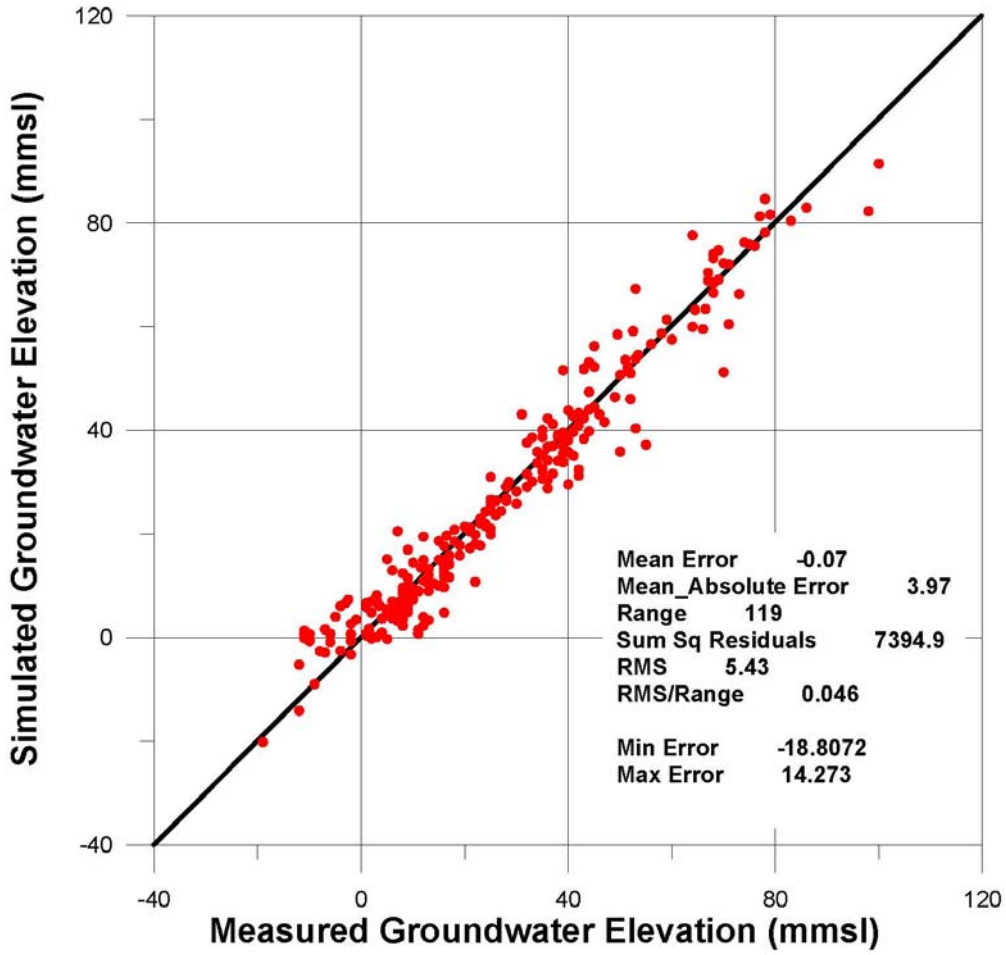


FIGURE 8-5
SACFEM CALIBRATION SCATTERGRAM
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Calibrations to Gaining and Losing Stream Segments. In the Sacramento Valley, a further qualitative calibration target is the identification of stream segments that are gaining flow through groundwater discharge versus losing flow to groundwater recharge. While the exact distribution of stream reaches that gain or lose flow due to surface water/ groundwater interaction are not fully delineated, and this relationship changes over time with fluctuating groundwater levels and stream stages, a general pattern can be observed. The major trunk streams such as the Sacramento, Feather, and American Rivers tend to gain flow, especially in their lower reaches, while the smaller upper tributaries near the basin margin tend to lose flow to the groundwater system. The stream reaches predicted by the model to gain or lose flow to the groundwater aquifer are shown on Figure 8-6. The pattern predicted by the calibrated groundwater flow model is reasonably consistent with the generally accepted pattern described above. The distribution shown on Figure 8-6 should be considered an average condition with greater stream lengths gaining groundwater during wet periods with higher groundwater levels and greater stream lengths losing water to the aquifer system during dry periods with lower groundwater levels.

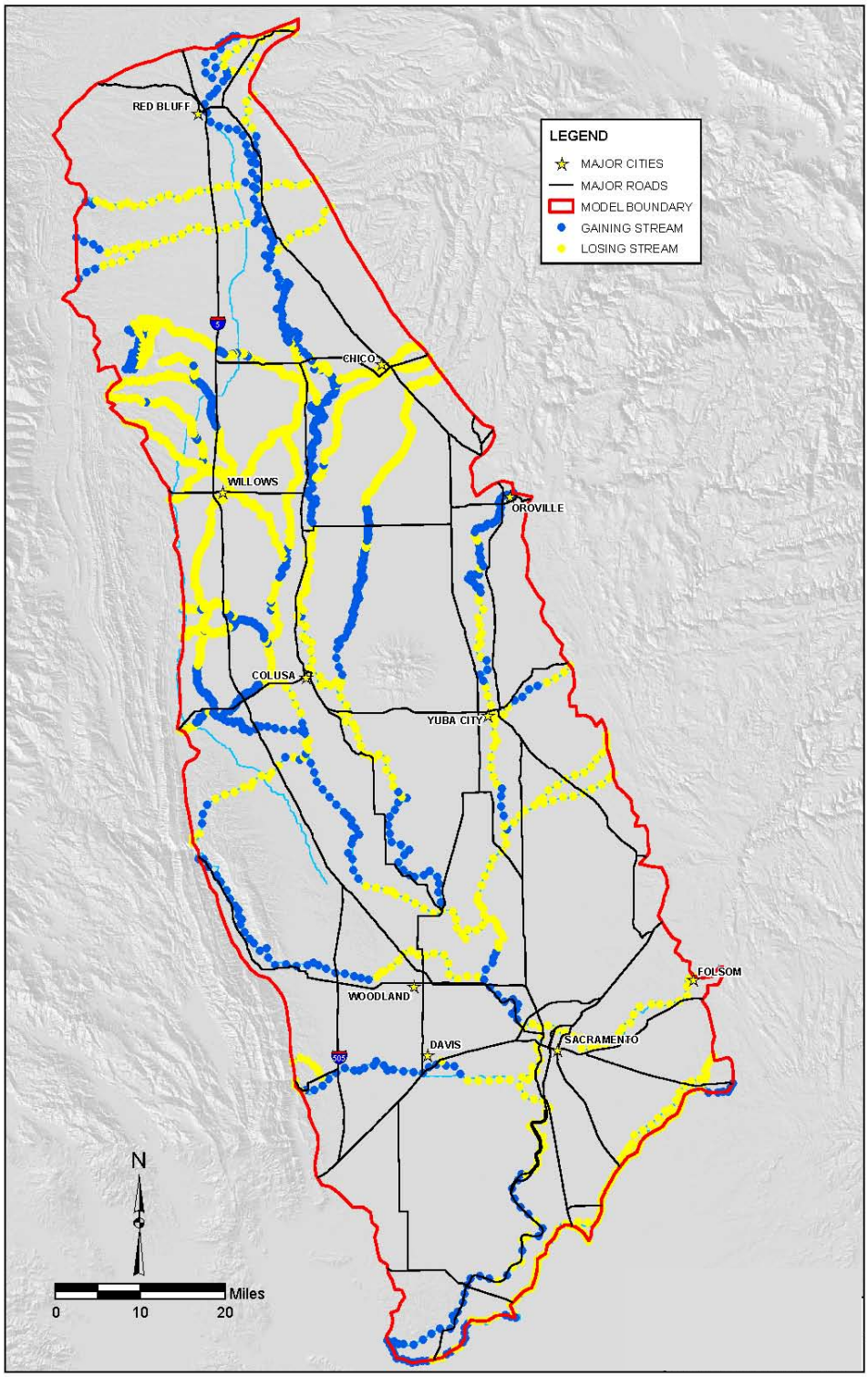


FIGURE 8-6
SIMULATED GAINING AND LOSING STREAM REACHES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Calibration to Steady-State Water Budget. The magnitude of the water budget components derived from the steady-state calibration run are summarized in Table 8-1. While exact comparative estimates are not available for most of these components, rough estimates are available. For example, the 2000 calibration simulation estimates a combined 2.5 million acre-feet (ac-ft) of groundwater pumping within the model domain, which agrees reasonably well with the generally accepted value of between 2.5 million and 3 million ac-ft of groundwater withdrawal in an average year. Similarly, while no independent estimates of the quantity of groundwater that discharges to the Sacramento River are available, the average simulated value of 975 cubic feet per second (cfs), which represents approximately 2 to 4 percent of mean annual flow measured at the Freeport gauge, seems reasonable.

TABLE 8-1
Average Annual or Year 2000 SACFEM Water Budget Summary
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	ac-ft	cfs
Recharge		
Deep Percolation of Precipitation	1,398,461	1,932
Deep Percolation of Applied Water	865,131	1,195
Mountain Front Recharge	495,507	684
Seepage from Streams to Groundwater	816,848	1,128
Total Recharge	3,575,947	4,939
Discharge		
Agricultural Pumping	2,417,506	3,339
Urban Pumping	451,507	624
Groundwater Discharge to Streams	705,999	975
Total Discharge	3,575,012	4,938

Preliminary Transient Calibration. While the SACFEM model has not undergone a rigorous transient calibration, a comparison of simulated and observed groundwater elevations from Water Year 1982 through 2003 was performed to assess the performance of the model at simulating historic groundwater elevation trends. This step was necessary because the SACFEM model is being used to forecast the performance of various conjunctive water management projects during the 1982 through 2003 period, and it was necessary to determine the accuracy of the model at replicating the transient groundwater elevations that occurred over that period. The ability of the model to match observed transient heads is also an indication of the accuracy of the assumed transient water budget components being used in the model. The period 1982 though 2003 was used because it includes wet periods, such as the winter of 1983, and dry periods, such as the 1988 through 1992 drought. Using a climatic period of this type allows assessment of the effects of highly variable climatic conditions on conjunctive water management project operations and subsequent effects on groundwater levels and stream flows.

The accuracy of the model running in transient mode was assessed using two different methods. The first was to evaluate the ability of the SACFEM model to replicate the results of the final steady-state calibration run within a longer transient simulation. This was done by running the transient model using a monthly time step from water year 1982 though 2003, retrieving the simulated monthly head values for calendar year 2000, and averaging them to obtain a data set that should theoretically match the steady-state calibration data. The comparison of the simulated calendar year 2000 steady-state heads with the head values obtained by averaging the simulated monthly head values obtained from the transient simulation over the same period is shown on Figure 8-7. It is clear from this figure that the average calendar year 2000 heads computed from the results of the transient simulation almost exactly match the simulated steady-state heads obtained from the final calibration run. This suggests that after running the SACFEM model for 19 years (1982 though 2000) using estimates of the historic transient monthly water budget stresses, the model is still capable of providing a very accurate calibration to the year 2000 conditions.

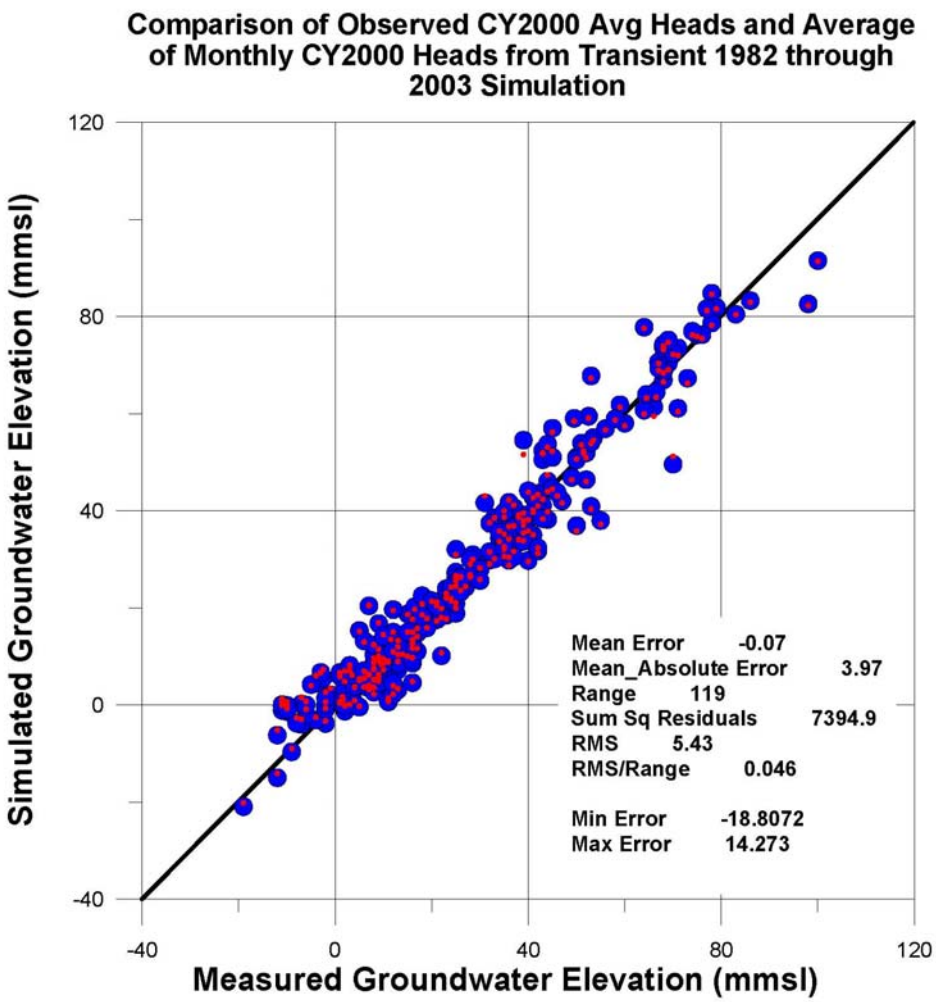


FIGURE 8-7
REPLICATION OF STEADY-STATE CALIBRATION HEADS WITHIN A 23 YEAR TRANSIENT SIMULATION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

The second method used to assess the accuracy of the SACFEM model of simulating transient groundwater elevations was to compare simulated monthly groundwater elevations with measured groundwater elevations in monitoring wells over this same 1982 though 2003 period. These comparisons are shown on Figures 8-8 through 8-15. These results suggest that in most cases, the model provides a fairly accurate depiction of transient groundwater elevations throughout the time period evaluated. Several of the hydrographs show differences between the simulated and measured heads, but in each case the trends of both data sets are similar but displaced by several feet. It is likely that small adjustments in water budget fluxes or aquifer properties in those areas will improve agreement.

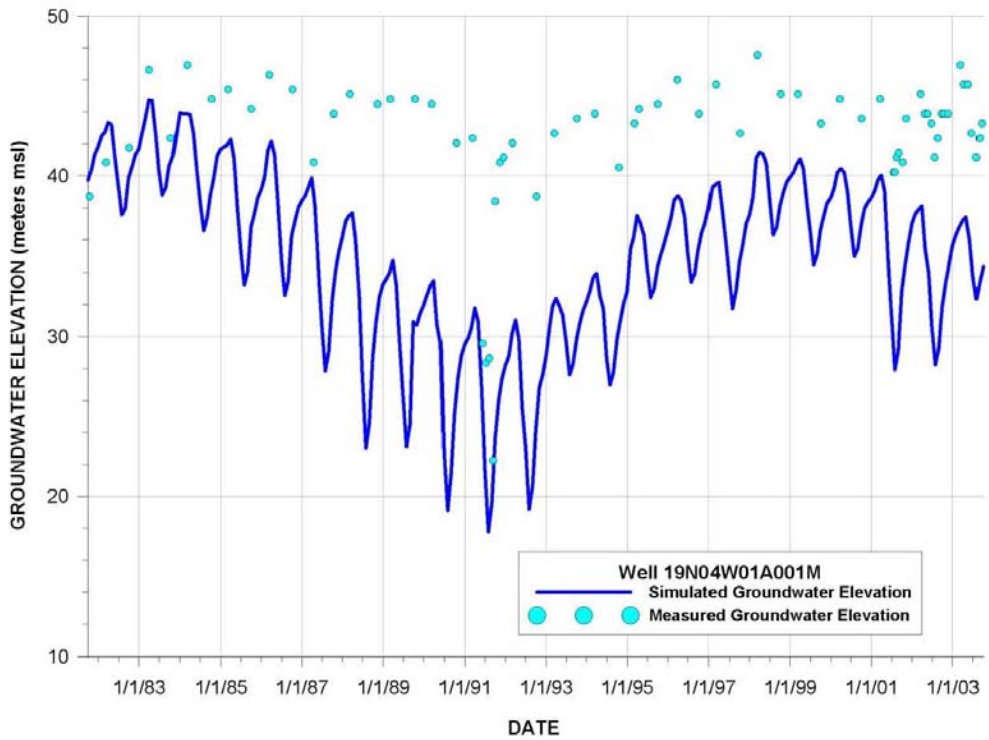


FIGURE 8-8
TRANSIENT CALIBRATION COMPARISON: WELL 19N04W01A001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

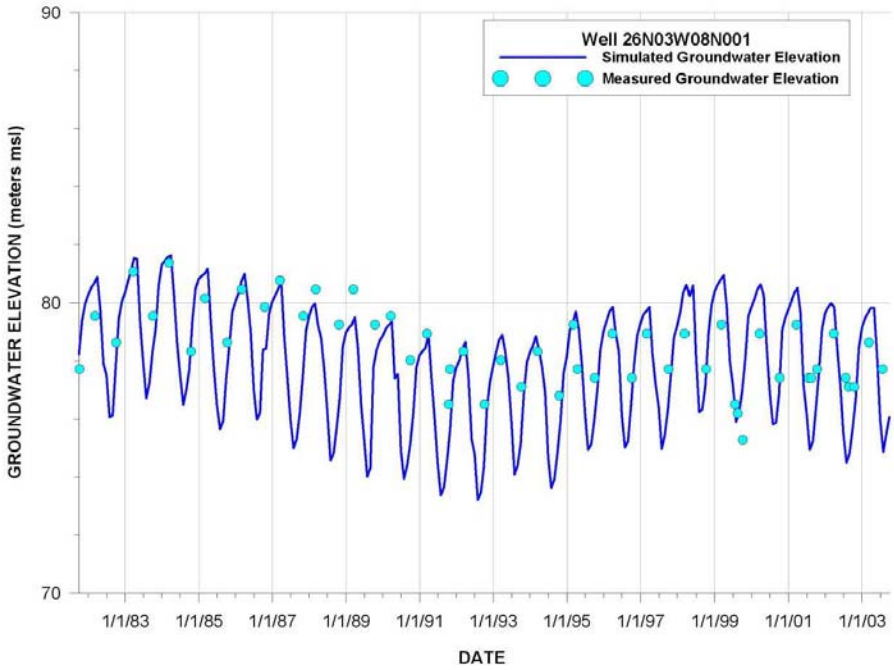


FIGURE 8-9
TRANSIENT CALIBRATION COMPARISON: WELL 26N03W08N001
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

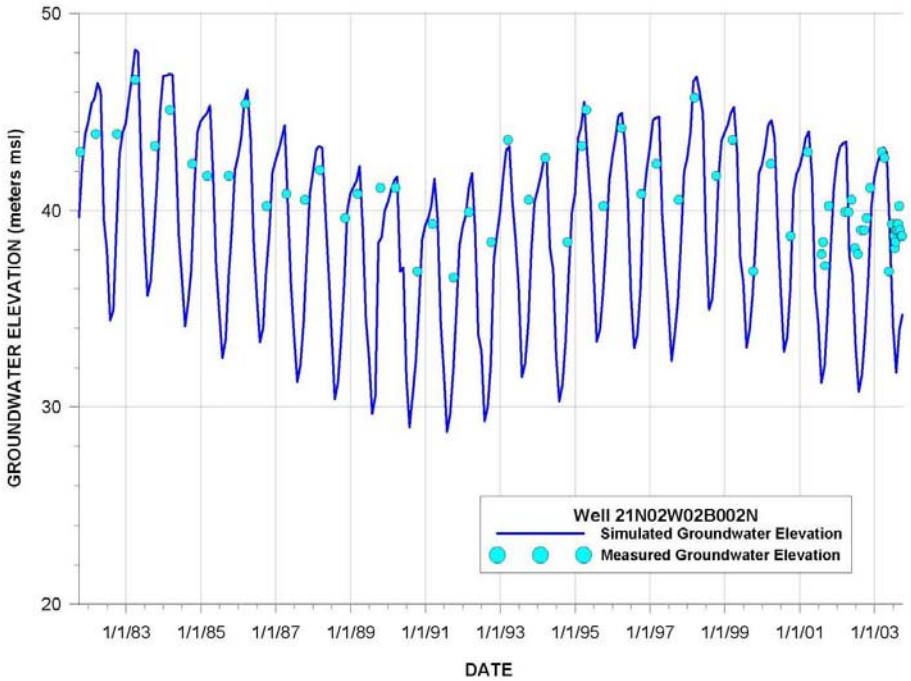


FIGURE 8-10
TRANSIENT CALIBRATION COMPARISON: WELL 21N02W02B0020N
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

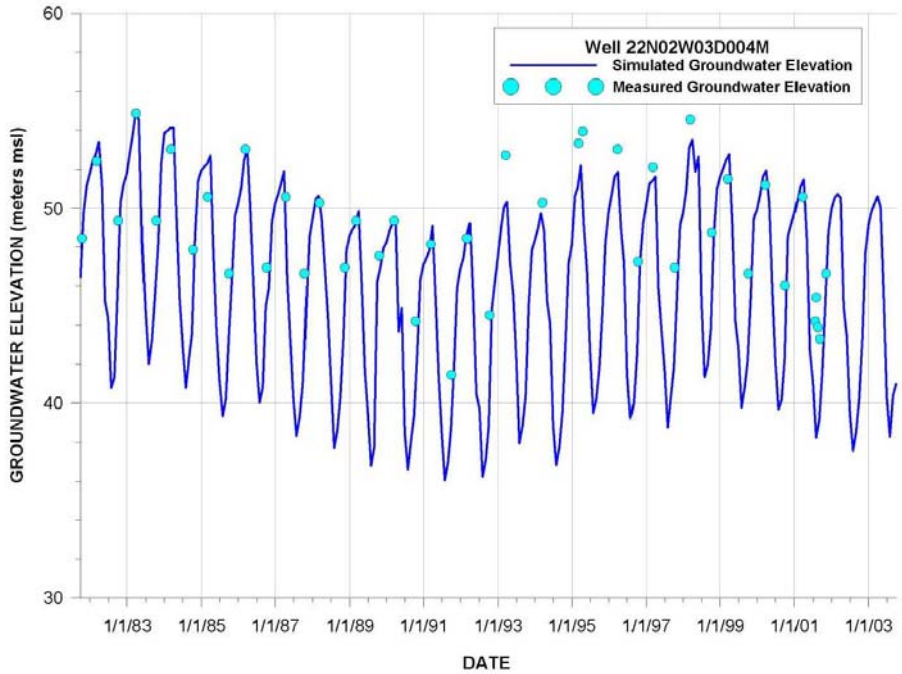


FIGURE 8-11
TRANSIENT CALIBRATION COMPARISON: WELL 22N02W03D004N
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

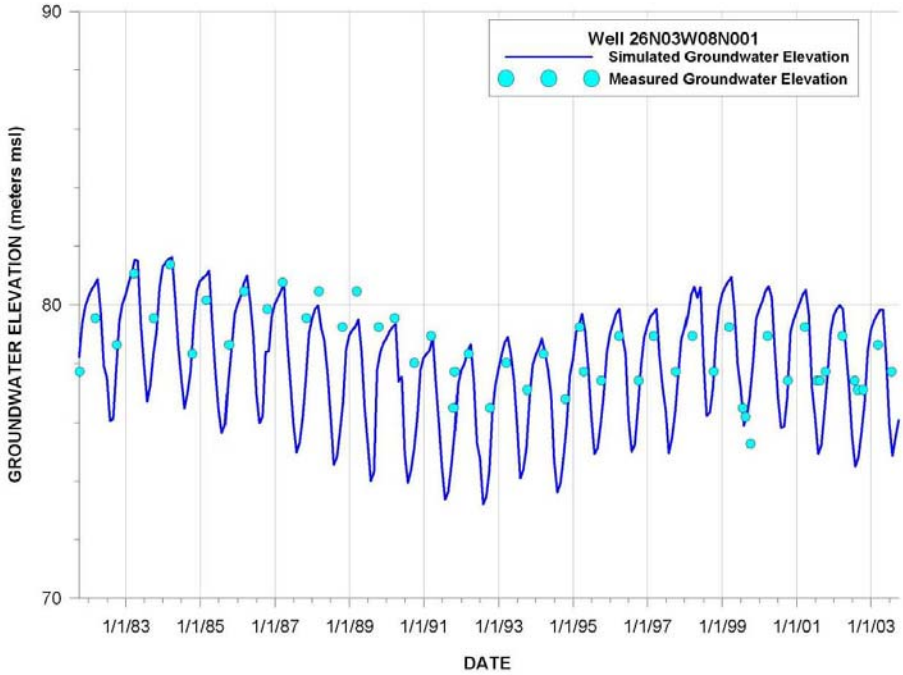


FIGURE 8-12
TRANSIENT CALIBRATION COMPARISON: WELL 26N03W08N001
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

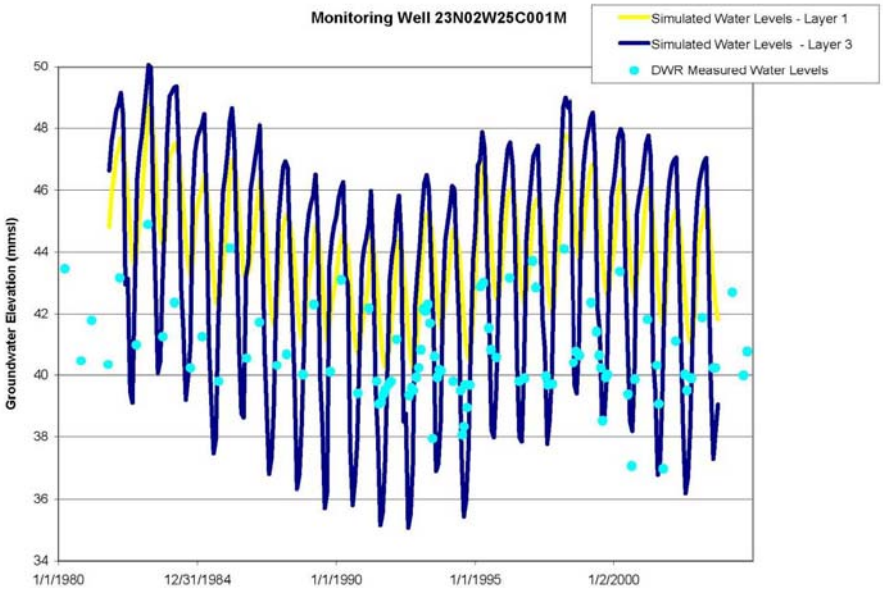


FIGURE 8-13
TRANSIENT CALIBRATION COMPARISON: WELL 23N02W25C001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

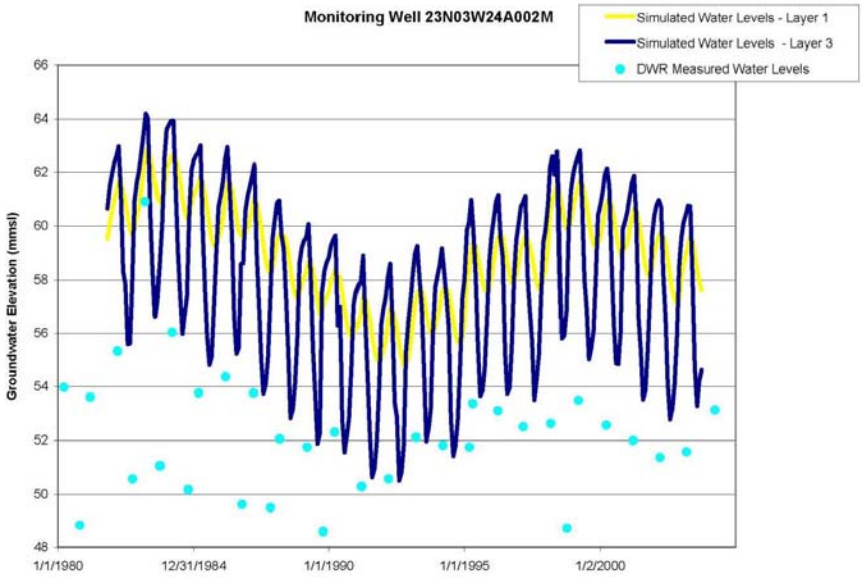


FIGURE 8-14
TRANSIENT CALIBRATION COMPARISON: WELL 23N03W24A002M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

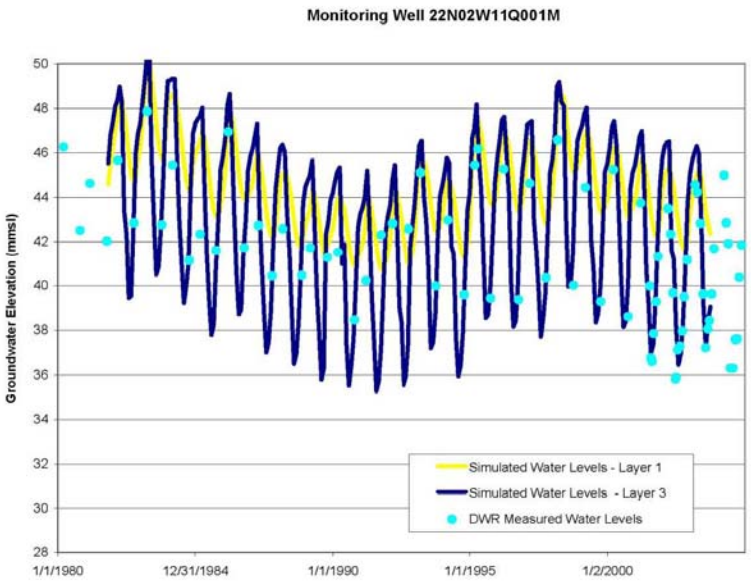


FIGURE 8-15
TRANSIENT CALIBRATION COMPARISON: WELL 22N02W11Q001M
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

SECTION 9

Surface Water Model

Effective analysis of conjunctive management projects and operations requires simulation of both the surface and groundwater systems. As described above, conjunctive management operations for this project are closely related to surface reservoir operations and conditions throughout the CVP and SWP. Therefore a surface water model that includes CVP and SWP reservoir operations and conditions was developed to evaluate conjunctive management projects.

9.1 Modeling Approach

The best tool currently available for planning level analyses of the CVP/SWP system is the CalSim II model, developed jointly by DWR and Reclamation. CalSim II is a planning model designed to simulate operations of CVP and SWP reservoirs and water delivery system, flood control operating criteria, water delivery policies, instream flow and Delta outflow requirements, and hydroelectric power generation operations. CalSim II is the main systemwide hydrologic model being used by DWR and Reclamation to conduct planning and impact analyses of potential projects.

CalSim II is a simulation by optimization model. The model simulates operations by solving a mixed-integer linear program to maximize an objective function for each month of the simulation. CalSim II was developed to simulate the operation of the CVP and SWP for defined physical conditions and a set of regulatory requirements. The model presently simulates these conditions using 82 years of historical hydrology from water year 1922 through 2003. CalSim II simulates regulatory conditions specified in State Water Resources Control Board (SWRCB) Decision 1641 (D-1641); the Central Valley Project Improvement Act b(2), including non-discretionary and discretionary actions; and limited water transfer operations.

CalSim II is a complex optimization model that can give surprising, unintended results when used to simulate complex operations. Additionally, runtimes for CalSim II models are typically several hours, making it inappropriate for use in gaming sessions and for rapid evaluation of many different scenarios.

The approach used for this project is to rely on CalSim II to depict CVP/SWP operations and system conditions and then model incremental changes in CVP/SWP operations that reflect possible conjunctive management projects. The result of this approach is a surface water model of the CVP/SWP system that layers conjunctive management operations for use in gaming sessions to quickly investigate numerous scenarios and operations, and can be used to test sensitivities and tradeoffs associated with certain key assumptions. The surface water model was designed to be easily adapted for use with various CalSim II simulations.

9.2 System Baseline Assumptions

A CalSim II simulation of the existing level of development (approximately 2004), regulatory conditions, and resulting operation of the CVP and SWP is the basis for surface water modeling. This simulation was developed by the Common Assumptions Project to provide a generally accepted model baseline for use in CALFED surface storage investigations. Key assumptions for the baseline CalSim II simulation are provided in Appendix A.

The existing level of development was used, as opposed to a future level of development, because of the need for consistency in land use data used in the surface water groundwater models. Existing level of development GIS land use data were used in the development of the surface water budgets for the groundwater model. Existing level of development information is also less speculative as to how land use may change in the coming decades. Simulation of a future level of development would require assumptions on future land use and the spatial distribution of that land use throughout the Sacramento Valley.

9.2.1 Surface Water Model Operations

The surface water model simulates operations of conjunctive management projects and their interaction with CVP and SWP reservoirs to meet project objectives (satisfying presently unmet agricultural water demands and targeted environmental flows and durations) based on results of a CalSim II simulation of existing system operations. The following sections define and describe individual aspects of model operation. This section concludes with a description of how the individual pieces interact to simulate system operations with conjunctive management.

9.2.2 Environmental Objectives

The surface water model simulates conjunctive management operations to increase water supply within the Sacramento Valley. The additional water supply can be used to meet a combination of agricultural water demands and environmental flow objectives. Environmental flow objectives were developed by National Heritage Institute staff and documented in *Developing Ecologically Based Flow Targets for the Sacramento and Feather Rivers* (Cain and Monohan, 2008). Different flow objectives were developed for the Sacramento and Feather Rivers.

All flow objectives are simulated as all-or-nothing thresholds, meaning the model will release water to meet the flow objective only if the full target flow can be sustained for the specified duration. As discussed in the NHI report, environmental objectives are based on the magnitude and duration of flows required to replicate certain ecological and geomorphic processes.

Environmental objectives are specified and prioritized by water year type. The Sacramento River Water Year Type Index (Sacramento River Index), sometime referred to as the 40-30-30 Index, is used to classify each year as either wet, above normal, below normal, dry, or critical.

Geomorphic

Geomorphic releases are short-duration, high-flow events for the purpose of sediment transport, channel migration, and flood plain processes, such as inundation and fine sediment transport. Geomorphic releases are targeted from March through April and are only required to last several hours. The surface water model simulates geomorphic events lasting one day due to the ramping requirements when making these large releases from reservoirs. Table 9-1 presents geomorphic flow objectives for Sacramento and Feather Rivers.

TABLE 9-1
Geomorphic Flow Objectives for Sacramento and Feather Rivers
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

No objective specified in critical year types.

Riparian Establishment

The purpose of riparian establishment flows is to recruit and grow cottonwoods in the riparian areas along the rivers. Riparian establishment flows are designed to assist in several phases of early cottonwood growth including seedbed preparation, seed germination, and seedling growth. These flows also create periodic large-scale disturbances of the riparian zone. Riparian establishment objectives (see Figure 9-1) are specified for the period of mid-April through mid-June to coincide with the cottonwood reproductive cycle. Riparian recruitment flows are large-magnitude flows for extended periods of time and are typically only possible during years of above average runoff. Therefore these objectives are only specified in years classified as wet or above normal by the Sacramento River Index.

Figure 9-1 illustrates the shape of the of riparian establishment objectives. The objective begins with a high-flow event held for a period of 5 days followed by a 60-day recession limb when the target each day is 5 percent less than the previous day's target. Table 9-2 summarizes the objectives for both the Sacramento and Feather Rivers.

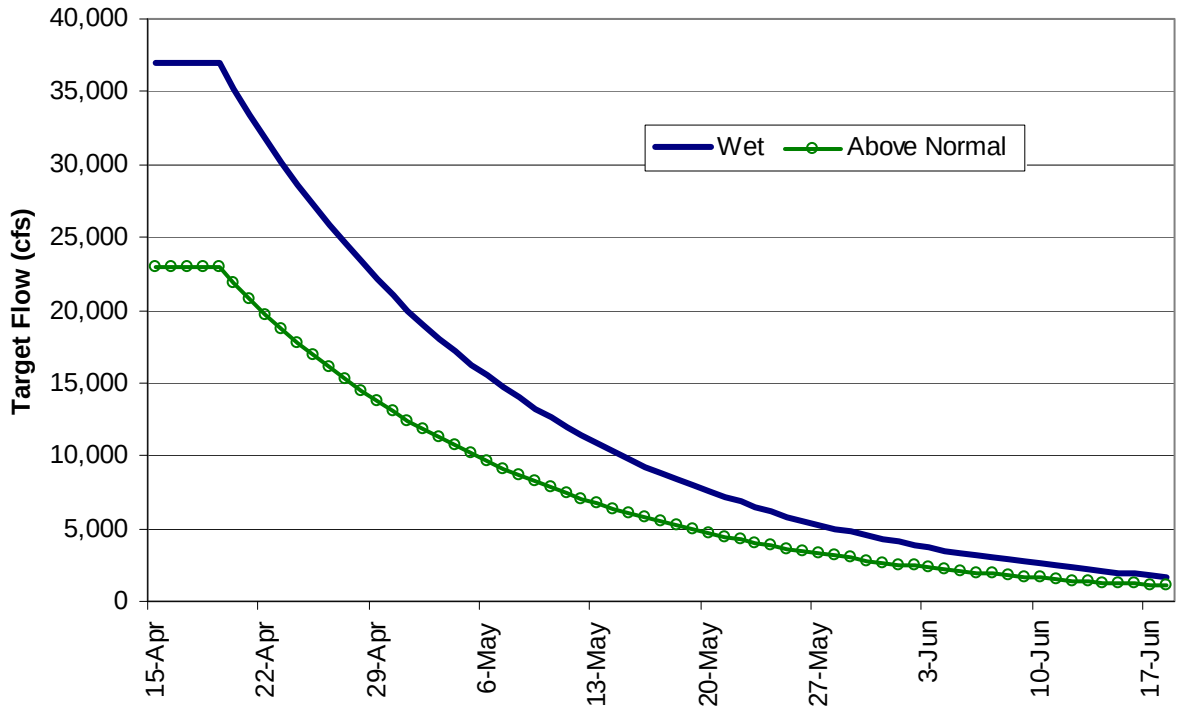


FIGURE 9-1
SACRAMENTO RIVER RIPARIAN ESTABLISHMENT OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

TABLE 9-2
Riparian Establishment Objectives
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Note:

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

Spring Pulse

Spring pulse flows are designed to simulate a portion of the historic unimpaired runoff of the river to help create suitable flow conditions and temperatures for Chinook salmon migration. These flows also are designed to help maintain and recruit spawning habitat and avoid scour when eggs are in redds. Spring pulse flow targets are specified in all but critical year types, though the magnitude and duration of the target is reduced in years with less runoff. Tables 9-3 and 9-4 summarize the spring pulse objectives.

TABLE 9-3
Sacramento River Spring Pulse Objective
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Note: No objective specified in critical year types

TABLE 9-4
Feather River Spring Pulse Objective
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Note: No objective specified in critical year types

Flood Plain Inundation

Inundation of the Sutter and Yolo Flood Bypass channels is another environmental objective. It is assumed for this study that the weirs that currently block flow into the bypasses below certain river stages can be modified to allow inundation at lower river stages and flows. Inundation of the flood bypasses provides rearing habitat for juvenile salmonids. These inundation flows are targeted to correspond with outmigration of salmonids in the spring months and designed to last for 45 days. Flood plain inundation flows can be set for one of three different time-periods in the surface water model: February 15 to March 30, March 1 to April 15, or March 15 to April 30. Table 9-5 presents flood inundation objectives for Sacramento and Feather Rivers.

TABLE 9-5
Flood Plain Inundation Objective for Sacramento and Feather Rivers
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Note: No objective specified in critical year types

Cold Water Pool Management

The surface water model includes an environmental objective of increasing the flexibility of cold water pool management. This objective increases cold water pool volume in subsequent years by reducing summer reservoir releases (thereby increasing storage) in the current year by the volume of groundwater being pumped. This volume of water is then held in the reservoir through the winter and can increase cold water pool in following years. This operation occurs in years when fall reservoir storage is forecasted to be low. Low fall storage levels reduce the chance that any water stored will spill during the subsequent winter. However, operators may not be able to reduce summer releases in these years and still meet temperature control criteria in the current year. For example, summer releases from Lake Shasta in 2008 were typically controlled by temperature control criteria, not downstream irrigation demands. Therefore, it would not have been possible to offset reservoir releases with groundwater pumping. The surface water model is able to show the times and volumes of water potentially available to meet the cold water pool management objective, but a more thorough analysis with temperature models is needed to further evaluate the feasibility of this operation.

9.2.3 Agricultural Water Supply Objectives

The surface water model simulates the unmet agricultural demand within the Sacramento Valley based on hydrology, the underlying CalSim II simulation of CVP and SWP operations, and user input. Unmet agricultural demands are estimated to provide an understanding of the ability of conjunctive management to increase Sacramento Valley water supplies. Unmet agricultural demands are simulated differently for the Sacramento and the Feather River systems.

Sacramento River

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

Figure 9-2 illustrates the annual unmet agricultural demand as a function of simulated allocations to the TCCA for each year of the study.

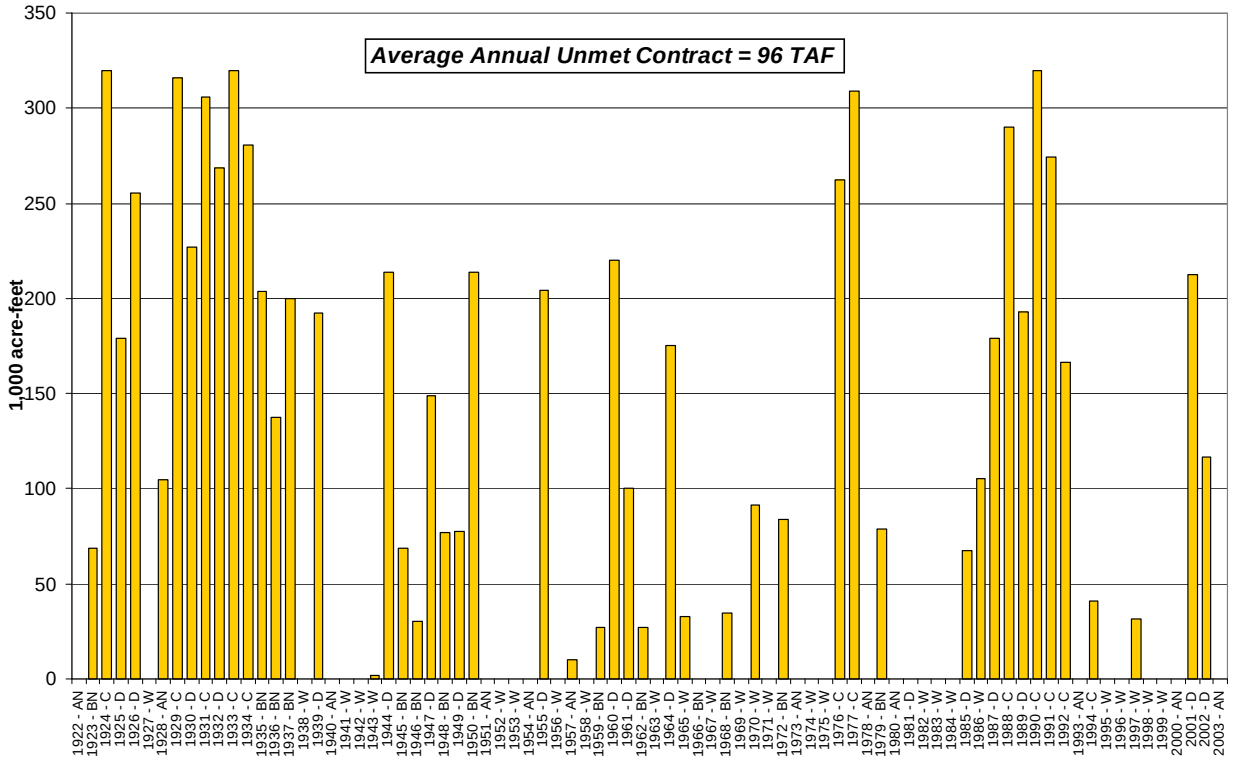


FIGURE 9-2
UNMET AGRICULTURAL DEMAND WITHIN TCCA
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

The annual unmet demand illustrated above is assumed to occur on a typical agricultural demand pattern during the irrigation season. The gaming model simulates conjunctive management operations and attempts to meet all or a portion of this demand when it occurs from reservoir release of project assets.

Feather River

The majority of SWP contractors on the Feather River system have reliable water supplies with the exception of a few small contractors. There are no existing SWP contractors with large, frequently unmet agricultural demands in the Butte Basin. Therefore a more general unmet agricultural demand is defined for the Feather River based on user input. Table 9-6 summarizes the assumed unmet agricultural demand that can be met from Feather River supplies in the surface water model.

TABLE 9-6
Assumed Unmet Agricultural Demand within the Feather River System
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Figure 9-3 illustrates the annual volume of demand based on the assumptions in Table 9-6.

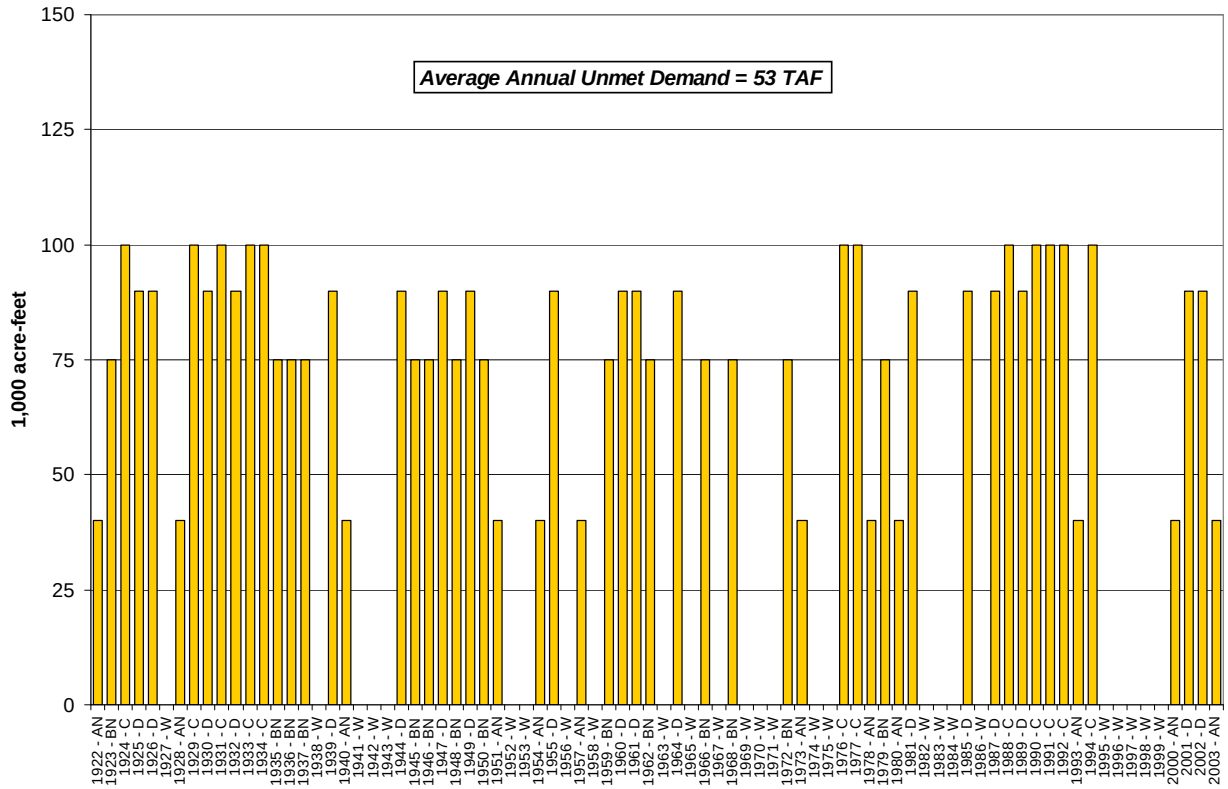


FIGURE 9-3
ASSUMED UNMET AGRICULTURAL DEMAND WITHIN FEATHER RIVER SYSTEM
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

9.2.4 Project Site Assumptions

Two project sites were selected for modeling. Project sites within GCID and the Butte Basin were simulated in the surface water model to determine the volume and timing of ground-water pumping and to better understand tradeoffs between groundwater pumping capacity and project benefits in the surface water system.

Each conjunctive management project site is defined in the model by several variables including maximum annual groundwater pumping capacity, monthly volumes of project pumping, and estimates of how pumping will affect stream-aquifer interactions. The estimated effects on stream-aquifer interaction were derived from iterative simulations between the surface and groundwater models.

The surface water model was developed to quickly evaluate a wide range of project pumping capacities and operations. Results of these sensitivity analyses (presented in later sections) led to evaluation of the following two different project pumping capacities or sizes: 1) 100 TAF in GCID and 50 TAF in Butte Basin, and 2) 200 TAF in GCID and 100 TAF in Butte Basin. Additionally, it was assumed that there would be no additional project pumping in years when surface water allocations are reduced in GCID or the Butte Basin. GCID's surface water allocations are reduced in years classified as "Shasta Critical" based on Sacramento River inflow into Shasta Reservoir. Feather River Settlement Contracts in the Butte Basin received reduced allocations under similar conditions on the Feather River.

Project Assets

Project assets are the volume of water that could potentially be made available through conjunctive management and the volume of additional water that could be released from CVP and SWP reservoirs to meet environmental flow targets or for additional agricultural water supply. Additional reservoir releases are possible because of the availability of groundwater pumping in the conjunctive management project, which serves as a "backstop" against drawing down reservoirs too far. Project assets are calculated each year considering reservoir storage conditions and available groundwater pumping capacity. A reservoir storage target table is used to determine how far operators may be willing to draw down reservoirs for different levels of available groundwater pumping capacity. Table 9-7 is an example for Shasta Reservoir that was a conjunctive management project in GCID with a maximum of 100 TAF of annual pumping capacity.

TABLE 9-7
Example Shasta Reservoir Storage and Project Assets
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

End of September Storage (TAF)	Project Asset (TAF)
Less than or equal to 2,400	0
Greater than 2,500	100

Table 9-7 shows that if end-of-September storage in Shasta Reservoir is forecasted to be less than 2,400 TAF, there are no project assets; therefore, no additional reservoir releases will be made. When forecasted end of September Shasta storage exceeds 2,500 TAF, additional reservoir releases up to the full 100 TAF of pumping capacity may be made to meet project objectives. The maximum project asset is the maximum annual pumping capacity because this represents the maximum backstop available to recover the reservoir in future years, if needed. The model interpolates if storage is between 2,400 and 2,500 TAF so that project operations do not draw Shasta Reservoir storage below 2,400 TAF. A conservative minimum end of September storage of 2,400 TAF was selected as a minimum to avoid any potential impacts.

Project assets also take into account any existing storage deficit, relative to baseline storage, in upstream reservoirs that may be carried over from project operations in previous years. Thus, the cumulative storage deficit over any series of years cannot exceed the annual groundwater pumping capacity of the conjunctive management project.

Water Cost

The surface water model compares environmental flow objectives with base flows that occur under existing system operations to determine additional reservoir releases necessary to meet each environmental objective. This additional release, calculated for the duration of the objective, is referred to as the water cost associated with meeting each environmental object. Water cost is expressed as a volume of water. Water cost for each objective is compared to available project assets to determine which objectives can be met. Figure 9-4 provides an example of water cost calculation for meeting a spring pulse objective.

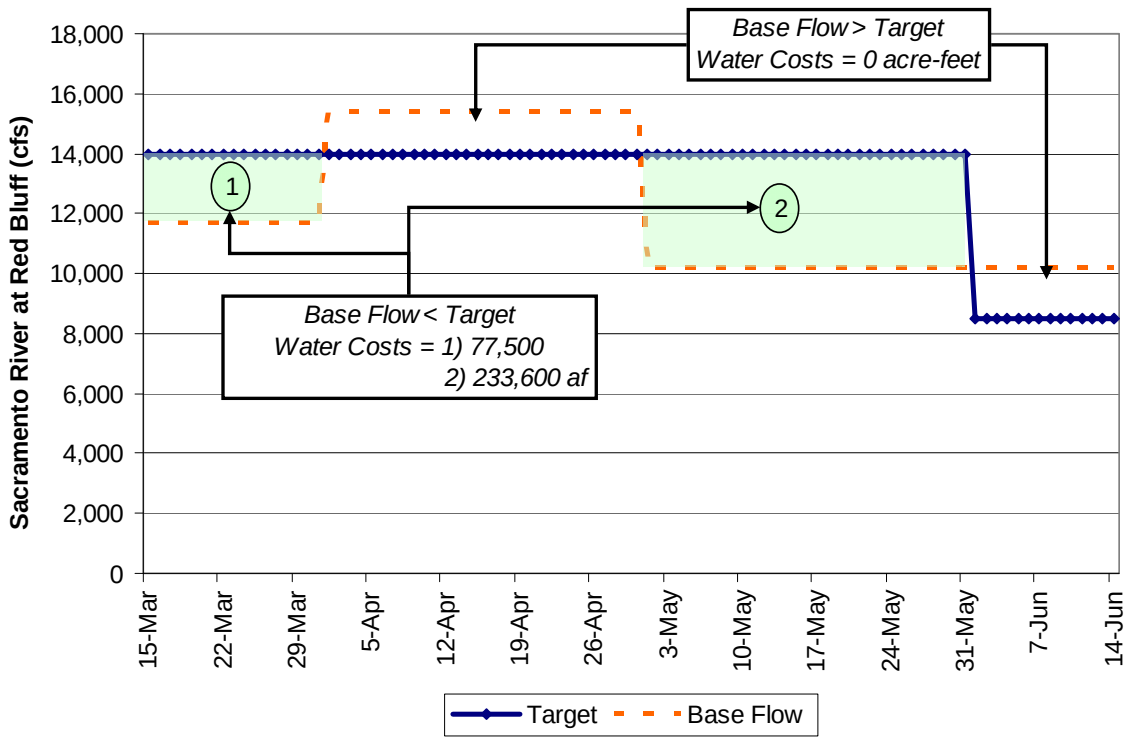


FIGURE 9-4
EXAMPLE WATER COST FOR MEETING SPRING PULSE OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

The water cost for meeting agricultural objectives is equal to the unmet agricultural demands for any year.

Prioritization

Environmental objectives are prioritized through a combination of user input and the frequency with which the various objectives are satisfied. Considering the frequency of when objectives have been satisfied places higher priority on objectives that have not been met in recent years relative to those that have. For example, if the spring pulse objective is

typically the highest priority in an above normal year but was met in the previous year (either in the base condition or with a project release) it may be desirable to shift the highest priority to the flood plain inundation objective instead.

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

Table 9-8 contains the relative priority matrix developed by the project team for use in the surface water model. Lower numbers are higher priorities.

TABLE 9-8
Relative Priority Matrix for Environmental Objectives
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

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

Table 9-9 provides an example prioritization calculation for a hypothetical wet year on the Feather River system.

TABLE 9-9
Example Prioritization of Environmental Objectives, Feather River, Wet Year
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

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

Decision Month

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

Agricultural Water Supply Objective

After determining which, if any, environmental objectives will be met from project assets the model calculates the remaining project assets available to meet any unmet agricultural demands. This operation wherein environmental objectives were met first and agricultural objectives second was used because environmental objectives are all-or-nothing thresholds, often with large water costs. In many years, all or a portion of project assets are available after making releases for environmental objectives. Simulations where agricultural water supply was prioritized first did not show significant increases in agricultural water supply deliveries, but significantly reduced the ability to meet environmental objectives. This analysis is presented in the section on sensitivity analysis.

Reservoir Release Logic

Figure 9-5 provides a flow chart of model decisions and operations for determining which objectives will be met from additional reservoir releases.

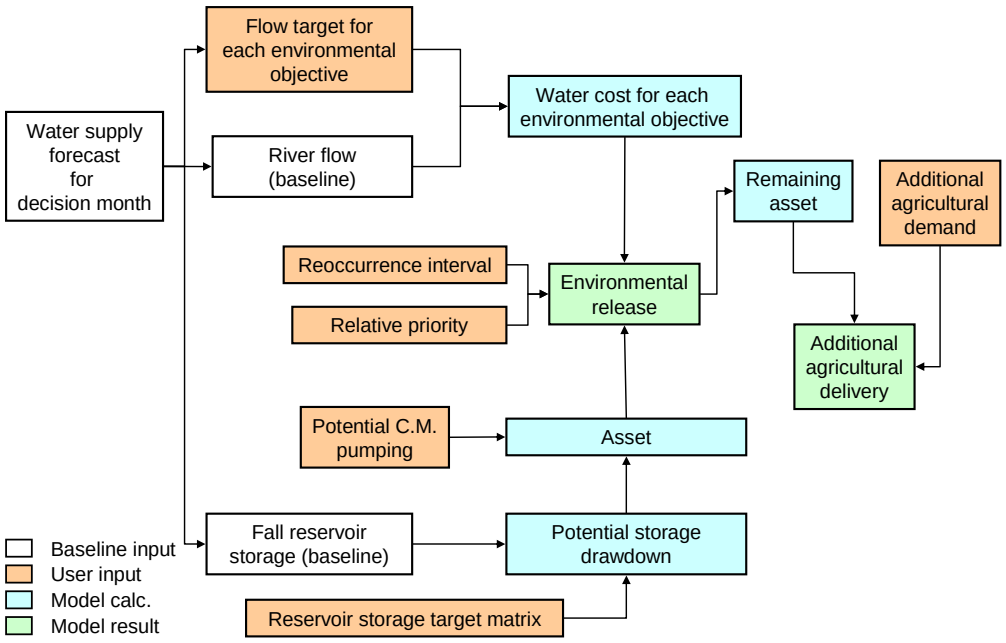


FIGURE 9-5
SURFACE WATER MODEL LOGIC FLOWCHART
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

The bottom of Figure 9-5 illustrates the steps associated with calculating project assets while the top illustrates the calculation of water costs and additional reservoir release. Assets and water costs are compared, according to the prioritized environmental objectives to determine any additional reservoir release for environmental objectives. Remaining assets and unmet agricultural demand are used to determine additional agricultural delivery from the reservoirs.

Groundwater Pumping Logic

Additional reservoir releases result in lower reservoir storage conditions relative to the baseline condition (without the conjunctive management project). Reservoir storage is refilled in the model from one of the following two sources: water that would have otherwise been released for flood control purposes or an increase in groundwater pumping to meet demands that otherwise would be met from the reservoir.

The surface water model simulates these operations by drawing down reservoir storages to make additional releases for project objectives and tracking the storage deficit relative to the baseline. In many instances storage deficits are refilled by water that would otherwise be released for flood control purposes (surplus surface water). Additional groundwater pumping is required when reservoirs are depleted prior to a series of dry years in which they do not fill. The surface water model uses fall reservoir trigger levels to determine when pumping is needed. These triggers are 2,400 TAF for Shasta Reservoir and 1,500 TAF for Lake Oroville. Therefore, if project operations result in reservoir storages below these levels pumping will occur to refill the minimum of any deficit caused by project operations or up to these levels.

Project pumping can be specified to occur over the summer season (May through August) the fall season (September through November) or a combination of both (May through November). Regardless of the selected season the total quantity of water to be pumped is spread evenly across the entire season to avoid turning pumps on and off and to reduce the number of groundwater production wells needed. Different seasons and pumping durations were selected to test the effects of pumping at different times and rates.

9.3 Surface and Groundwater Model Interaction

Evaluation of conjunctive management projects requires simulation of both surface water and aquifer systems. However, regional groundwater models with the needed level of refinement to adequately simulate pumping projects require run times that prohibit their use in gaming situations and for quickly evaluating multiple scenarios. Therefore, the surface water and groundwater model were used in an iterative fashion to simulate conjunctive management operations in both systems (see Figure 9-6).

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

final project scenarios. Pumping time series from the final project scenarios were then provided to the groundwater model for final simulation and resulting changes in stream-aquifer interactions associated with the pumping schedules were input back into the final surface water simulations.

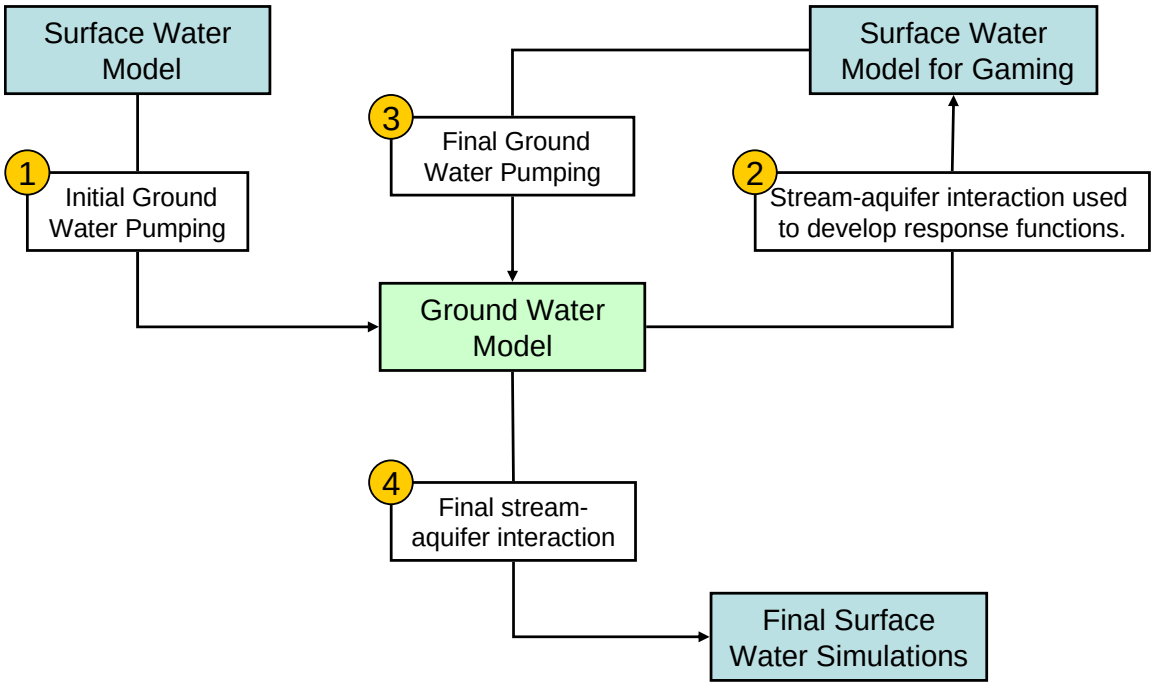


FIGURE 9-6
SURFACE WATER AND GROUNDWATER MODEL INTERACTION
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

SECTION 10

Level of Analysis

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

Additionally, mathematical modeling tools typically report results at a level of precision that exceeds their level of accuracy. For example, planning-level surface water models may provide estimates of water supply accurate to within a range of several thousand acre-feet, but results with a precision down to an acre-foot. Surface water model results presented in subsequent sections are generally rounded to the nearest 1,000 acre-feet. Groundwater draw down is reported in approximately 10-foot increments, and changes in stream-aquifer interaction are reported to the nearest cfs. Results are reported to these levels of precision for comparison with results from other scenarios. Planning-level modeling tools used in this analysis are not necessarily accurate to this level.

SECTION 11

Project Scenario Results

The following section presents results from four different project scenarios. All scenarios are based on two conjunctive management projects, one in GCID and the other in the Butte Basin. Surface water modeling results are presented first and include the ability to meet environmental and agricultural objectives, the resulting effects on reservoirs, and how reservoirs are refilled with the capture of surplus surface water and conjunctive management pumping.

Groundwater model results are presented after surface water model results. Groundwater model results include plots of peak aquifer drawdown and changes in stream-aquifer interaction. For each scenario, the groundwater model was used to evaluate two different well fields. The first well field option uses existing wells screened in the current aquifer producing zones. The second well field simulates all new wells pumping from the deep aquifer. Figures 11-1 through 11-4 illustrate these well fields for the two different project pumping capacities simulated in the four scenarios.

Plots of additional reservoir releases to meet flow requirements after accounting for changes in stream-aquifer interaction are presented after groundwater model results.

11.1 Scenario 1 – 100 TAF GCID, 50 TAF Butte Basin, Summer Pumping

Scenario 1 is defined by two conjunctive management projects with maximum seasonal groundwater pumping capacities of 100 TAF in GCID and 50 TAF in the Butte Basin. Environmental objectives and unmet agricultural demands are as presented in preceding sections. The pumping season spans 4 months of the irrigation season from May through August. The model first determines ability to meet environmental objectives and then uses remaining project assets to meet agricultural demands. Sensitivity to prioritization of environmental objectives and agricultural demands was evaluated and is explained in subsequent sections of this report.

The following series of plots summarize the annual operations with conjunctive management. The first series of plots summarize Sacramento River and Shasta Reservoir operations and the second series summarize Feather River and Oroville Reservoir operations. Plots are arranged in order of how operations occur each year. In winter and spring months, additional water is released from reservoirs to satisfy environmental objectives. During summer months additional water is released to meet agricultural demands. The result is that fall reservoir storage levels are lower than they would be under operations without conjunctive management projects, as shown on Figure 11-5. Reservoir storage space is typically refilled with surplus surface water during subsequent winter and spring periods. If reservoirs do not refill with surplus surface water and fall reservoir storage levels are forecasted to be low, reservoirs are refilled by pumping groundwater in conjunctive management projects and holding a similar volume of surface water in the reservoir.

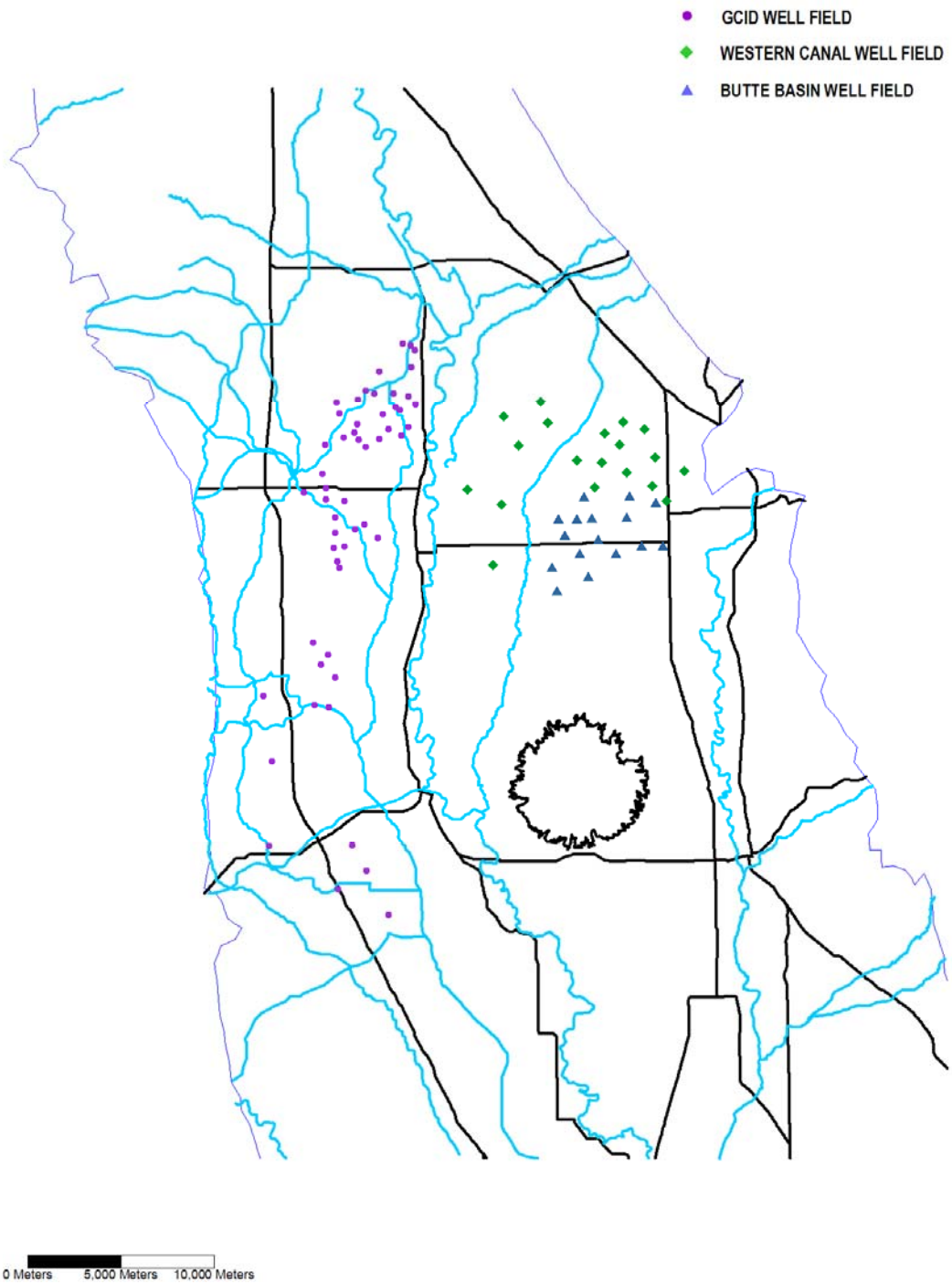


FIGURE 11-1
EXISTING WELL LOCATIONS, 150-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

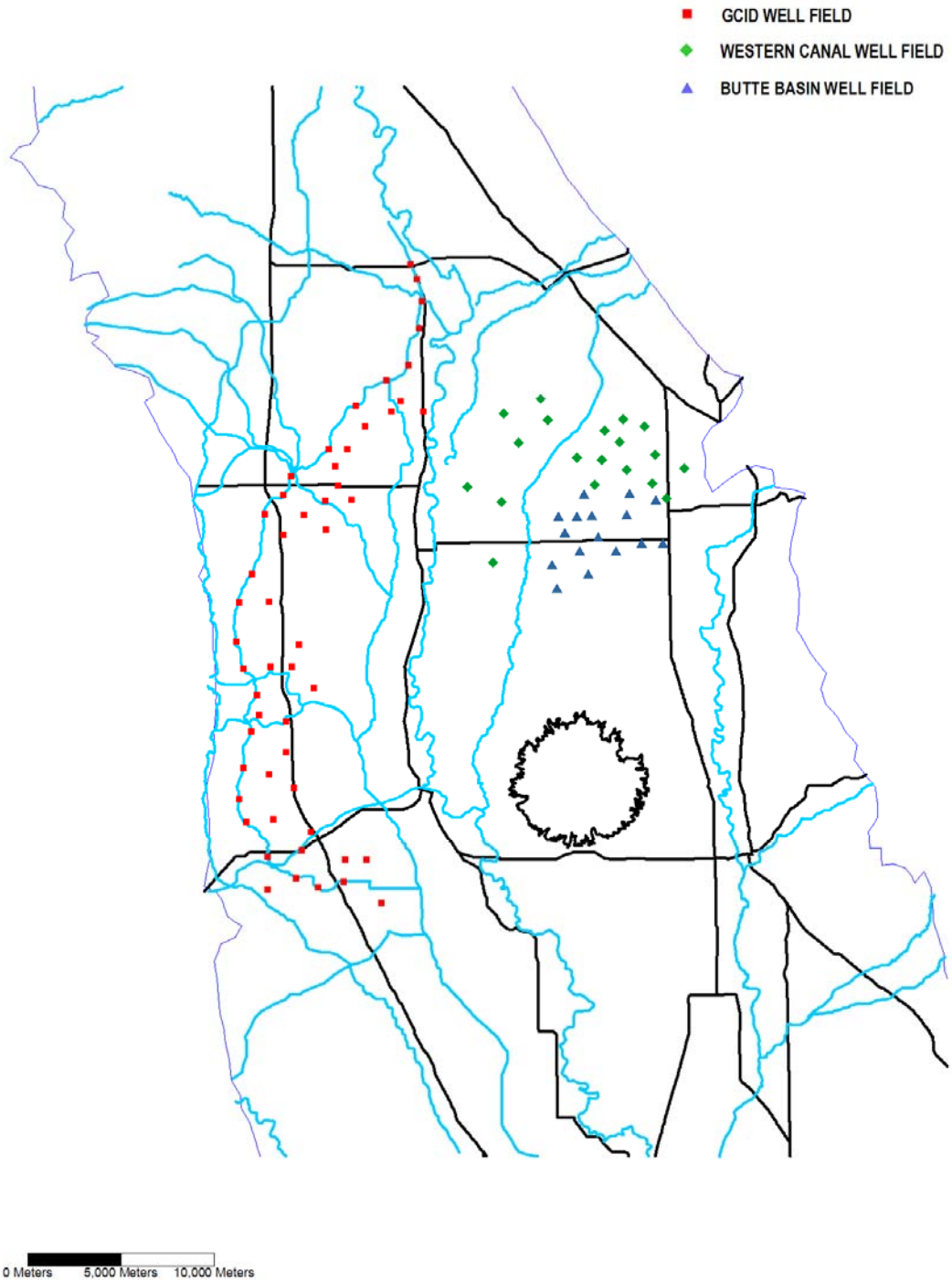


FIGURE 11-2
NEW WELL LOCATIONS, 150-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

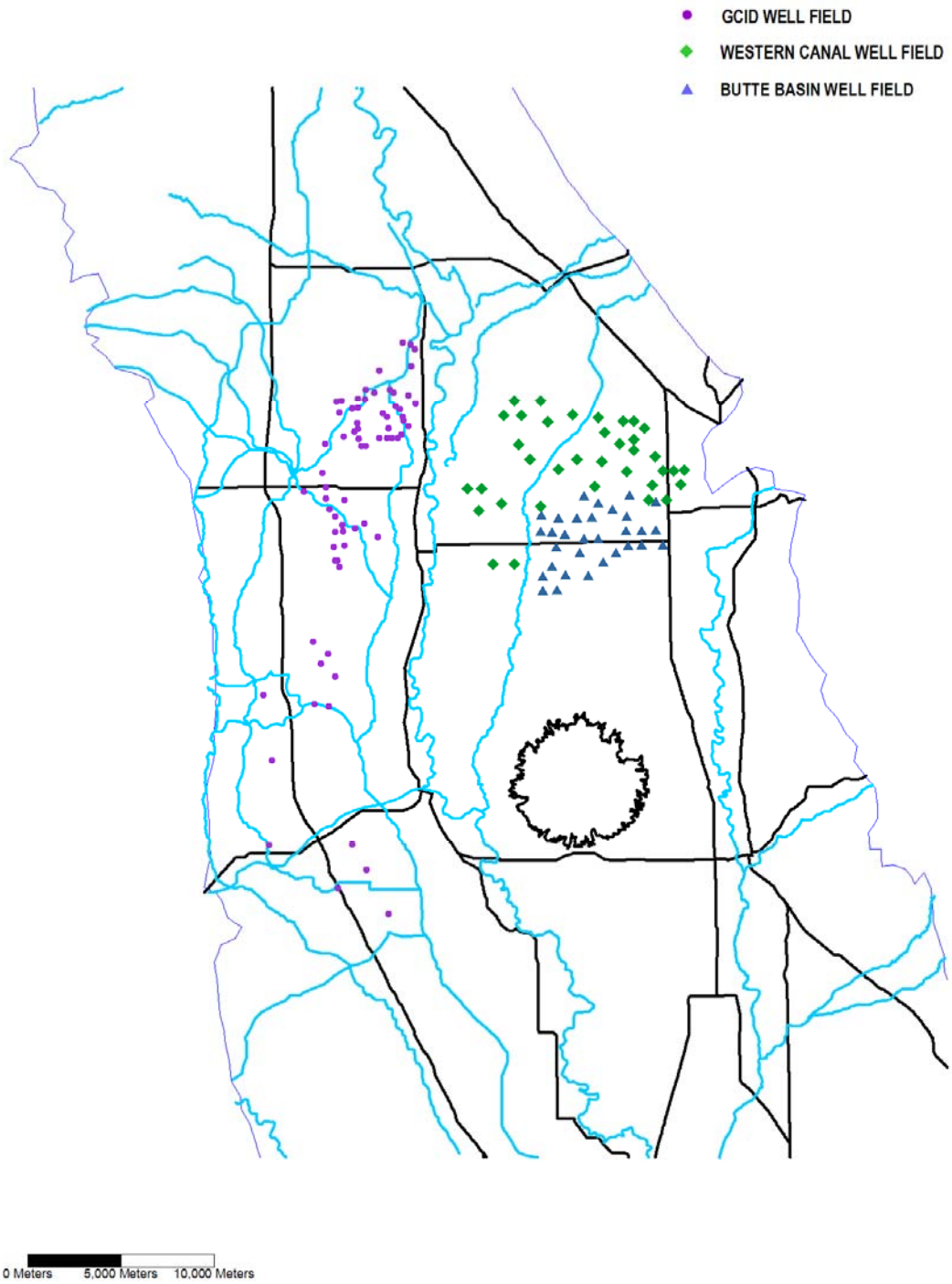


FIGURE 11-3
EXISTING WELL LOCATIONS, 300-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

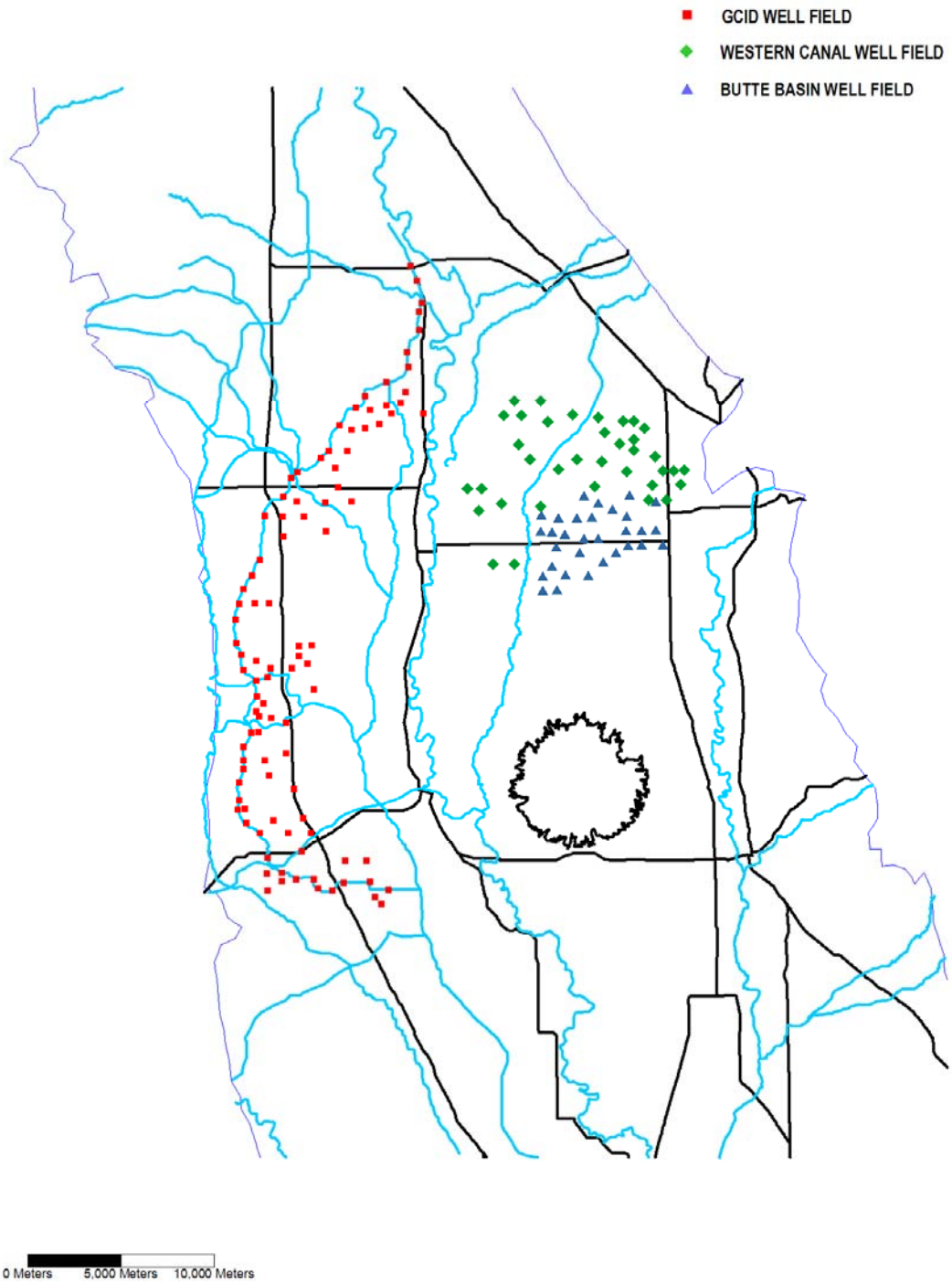


FIGURE 11-4
NEW WELL LOCATIONS, 300-TAF WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

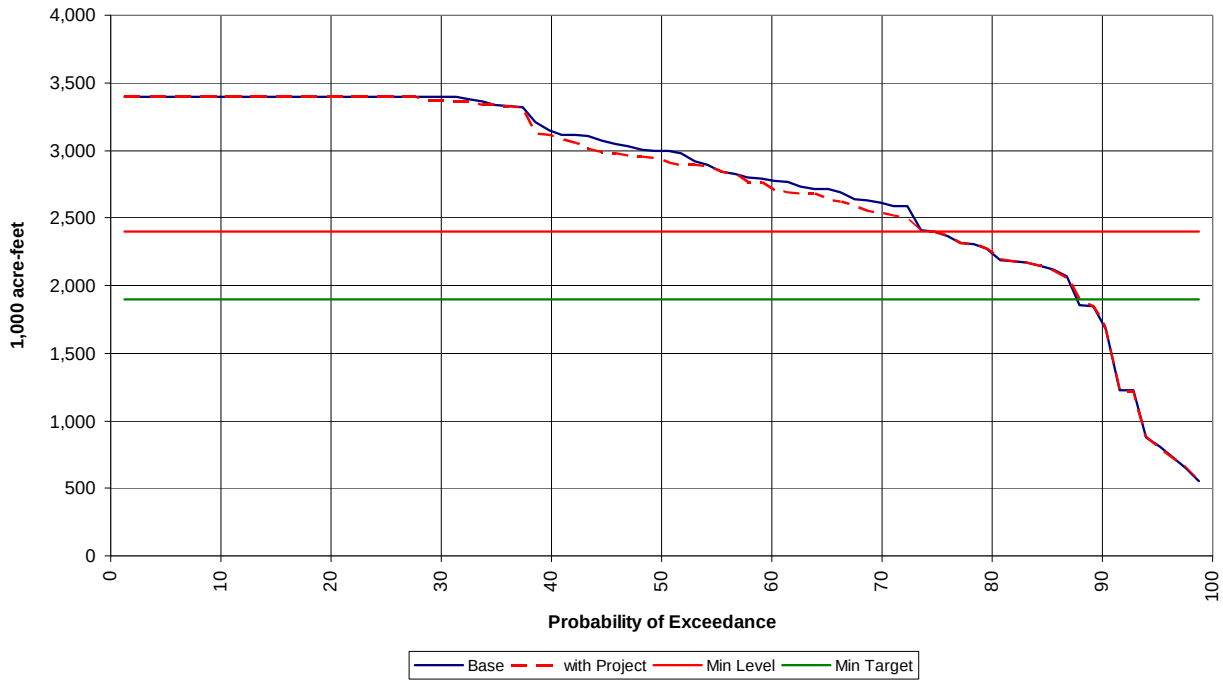


FIGURE 11-5
SHASTA RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.1.1 Shasta Reservoir and Sacramento River

Figure 11-6 illustrates annual volumes of water released to satisfy various environmental objectives on the Sacramento River. Color-coded bars and the legend refer to relative priority of objectives in each year. For example, in 1928 the red bar indicates that water was released to meet objective 4, the lowest priority objective. The type of objective, either geomorphic (Geo), riparian recruitment (Rip), spring pulse (Spring), or flood plain inundation (Flood) is labeled above the corresponding bar. Geomorphic objectives are met most frequently due to lower water costs associated with the short duration objective. Average annual release for environmental objectives is 13 TAF.

Figure 11-6 shows only years when environmental objectives are met through project release. Environmental objectives are also met at times under existing system operation. This information is summarized in Table 11-1. For the flood plain inundation objective, the project includes modifications to the Freemont Weir to allow inundation with less Sacramento River flow. The existing Fremont Weir crest limits inundation of the Yolo Bypass for flows less than approximately 62,000 cfs. The project assumes it is possible to modify the weir to allow inundation with flows of approximately 35,000 cfs. Therefore this objective can be met by the project; either under base condition flows between 35,000 and 62,000 cfs (base condition flows in excess of 62,000 cfs meet the objective in the base condition) or through additional reservoir release to create flows of approximately 35,000 cfs. Results presented in Table 11-1 show the flood plain objective is met in 20 years with the project, though there are only 2 years with releases for this objective illustrated on

Figure 11-6. This indicates that the objective was met with base condition flows between 35,000 and 62,000 cfs (without additional reservoir release) in 18 years.

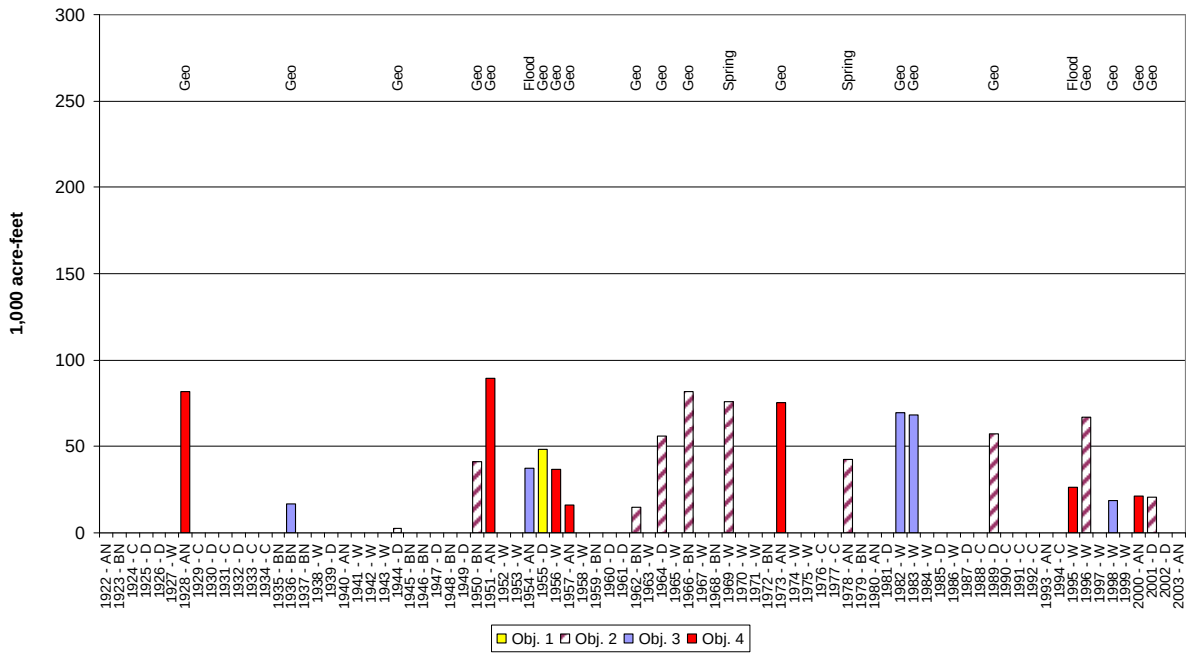


FIGURE 11-6
SACRAMENTO RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

TABLE 11-1
Number of Years Sacramento River Environmental Objectives are Met, Scenario 1
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

In some years, an objective may be met with base condition flows either before or after it is met with project releases during that same year. Results presented in Table 11-1 account for these occurrences and assume the objective is met in the base condition to prevent double counting in any year. For example, Figure 11-6 shows that releases were sufficient to meet the geomorphic objective in 19 of the 82 years analyzed. However, in 1 year (1956) the objective was met both under base conditions and then simulated to be met through project release. Results presented in Table 11-1 only show this objective being met during base condition flows to prevent potential double counting.

Figure 11-7 illustrates annual releases from Shasta Reservoir to meet additional agricultural demand in the TCCA service area. Dashed lines show unmet contract supply from CalSim II results and green bars illustrate the portion of unmet contract supply satisfied with

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

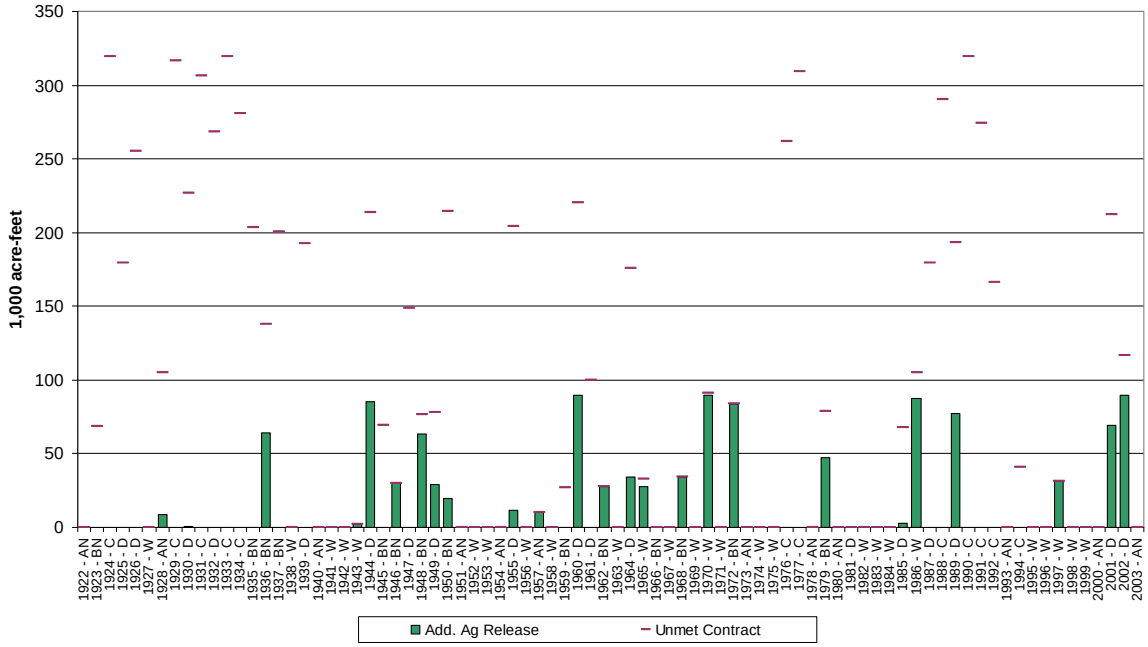


FIGURE 11-7
SACRAMENTO RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-7 illustrates that in many years when unmet contract supply for the TCCA is highest, there are no deliveries with conjunctive use. This is because in these years, project assets are typically low, either because fall reservoir storage is forecast to be low and no additional releases would be made or it is a Shasta Critical year and additional groundwater pumping for conjunctive management is assumed to be zero.

Additional reservoir releases for either environmental objectives or for additional agricultural delivery result in lower fall carryover storage in Lake Shasta. Figure 11-5 illustrates this with a probability of exceedance plot for end of September storage conditions. The solid blue line indicates fall storage conditions under base (without project) conditions. The red dashed line indicates conditions with conjunctive management. A solid red line at 2,400 TAF indicates the level when conjunctive management operations would not occur to limit the risk to cold water pool management in future years. Storage conditions below the solid green line at 1,900 TAF are when conjunctive management operations attempt to increase storage by pumping groundwater and holding water in Shasta above base levels.

Figure 11-5 illustrates that fall storage levels are lower in approximately 45 percent of the years and only when end of September storage is above 2,400 TAF. In wet years, when fall storage is at the flood control level of 3,400 TAF, releases in spring may refill in later months within the same year resulting in no change in fall storage conditions.

Figure 11-8 illustrates how storage deficits presented on Figure 11-5 are frequently refilled by the capture of surplus surface water. Surplus is water that would otherwise be released from the reservoir to maintain flood control storage and is not diverted downstream. This water is now stored in reservoir space created by making additional releases to meet agricultural and environmental objectives. Refill from surplus surface water occurs in 29 years with an average annual refill of 70 TAF in those years. Average annual refill with surplus surface water for the 82-year simulation is approximately 24 TAF.

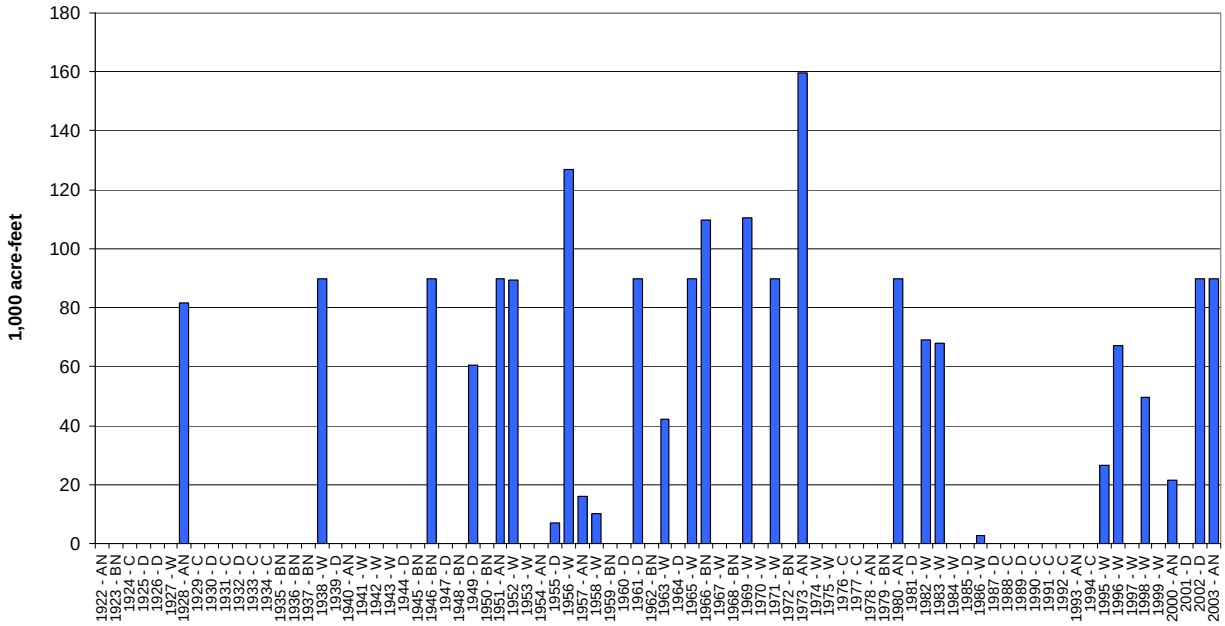


FIGURE 11-8
REFILL OF SHASTA RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

In some years, following additional reservoir releases for agricultural and environmental objectives, there is no surplus surface water, and reservoir storage levels continue to decline putting future water supplies and cold water pool management at risk. In these years groundwater pumping in the conjunctive management projects is used to recover reservoir storage levels. Figure 11-9 illustrates this annual pumping. Conjunctive management pumping occurs in 4 of the 82 years simulated, or 5 percent of years. The average annual pumping in those years is 70 TAF. The average annual pumping for the entire 82-year simulation is approximately 3 TAF with a maximum annual pumping of nearly the full 100 TAF of capacity. Pumping typically occurs in drier year types when reservoirs do not refill with surplus surface water.

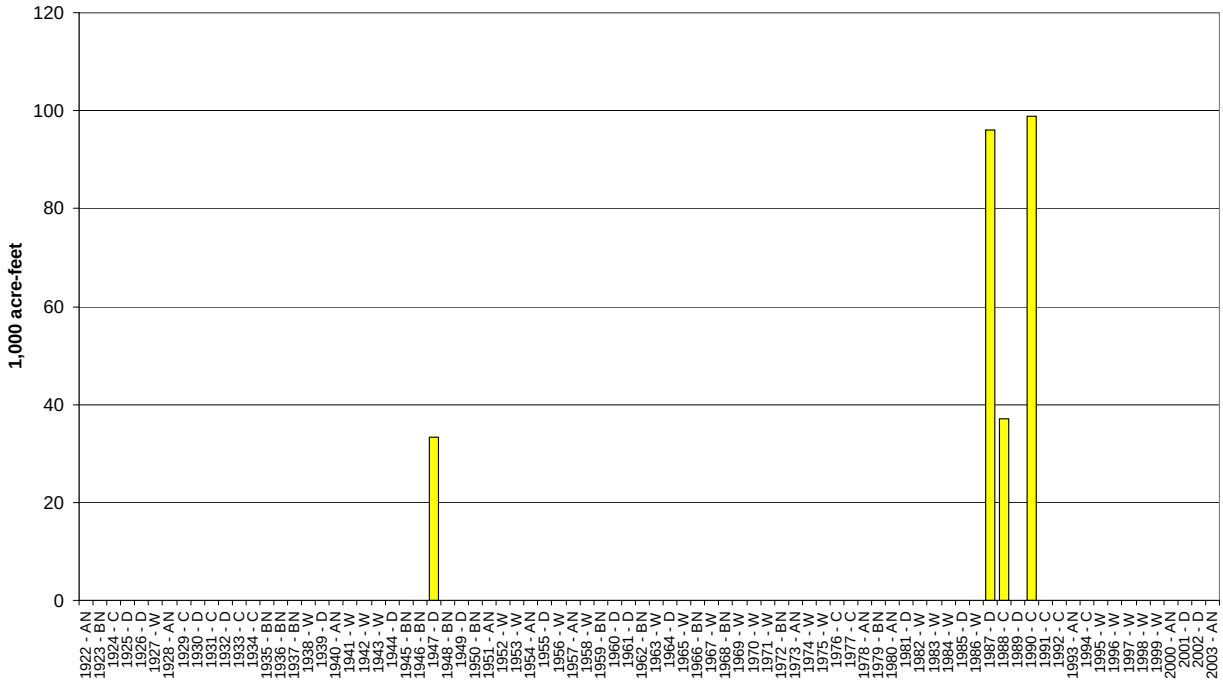


FIGURE 11-9
REFILL OF SHASTA RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Over the 82-year simulation period, additional reservoir releases are made in 37 years, or 45 percent of the years. Reservoir refill is accomplished with surplus surface flows in 29 years and with project pumping in 4 years. The number of years with additional releases exceeds the number of years with refill because reservoir storage deficits do not have to be completely refilled before making additional releases, as long as the total reservoir storage deficit does not exceed the capacity of the project to refill the reservoir in a single year. Of the total average annual additional releases of 27 TAF (14 TAF for agriculture and 13 TAF for environmental objectives), 24 TAF is refilled from surplus surface water and 3 TAF from conjunctive management pumping.

11.1.2 Oroville Reservoir and Feather River

Figure 11-10 illustrates annual volumes of water released to meet environmental objectives on the Feather River. Hydrology and operations on the Feather River result in meeting different objectives in different years compared to the Sacramento River. Similar to the Sacramento River operations, the geomorphic objective is satisfied most frequently due to lower water cost associated with meeting the shorter duration objective. Average annual release for environmental objectives on the Feather River is 7 TAF.

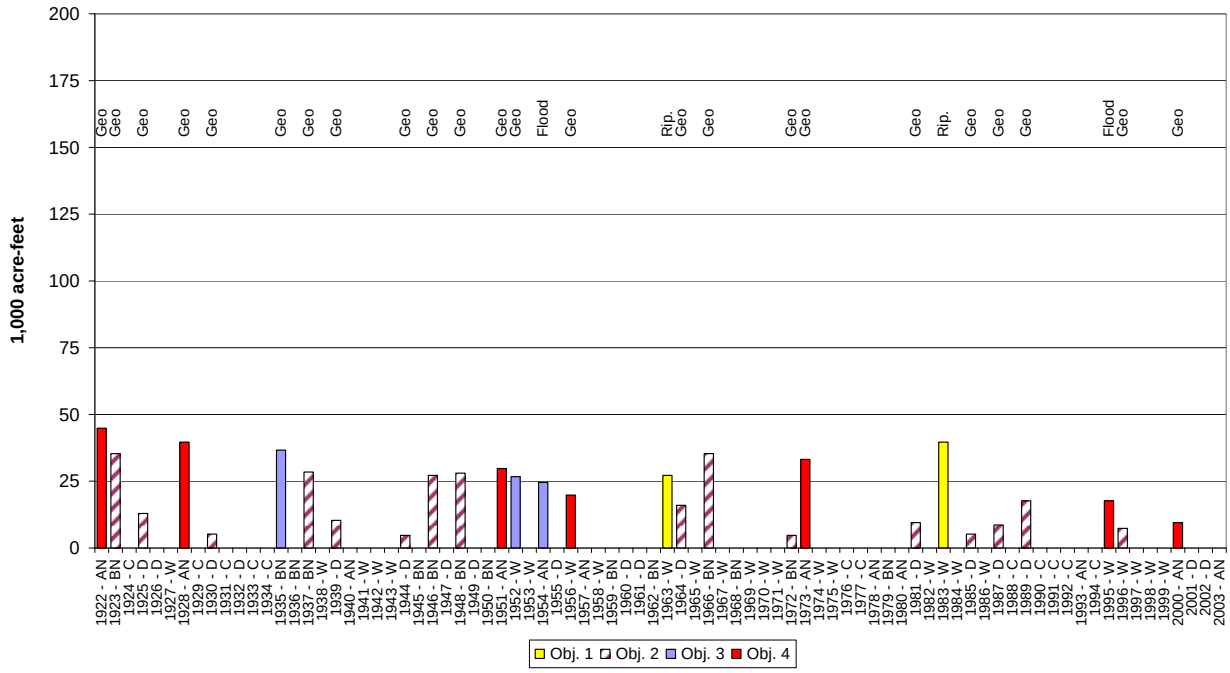


FIGURE 11-10
FEATHER RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Table 11-2 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 11-7. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

TABLE 11-2
Number of Years Feather River Environmental Objectives are Met, Scenario 1
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Figure 11-11 illustrates additional agricultural deliveries possible with conjunctive management on the Feather River. Dashed lines relate to assumed unmet demands within the Feather River basin and correspond to the Sacramento Valley Index. Similar to operations on the Sacramento River, project assets do not allow additional releases for either environmental or agricultural objectives during drier year types when agricultural demands are

higher. Additional agricultural releases are made in 30 of the 82 years simulated, or approximately 37 percent of the years. The average release in those years is 27 TAF, while the average annual agricultural delivery over the 82-year simulation period is 10 TAF.

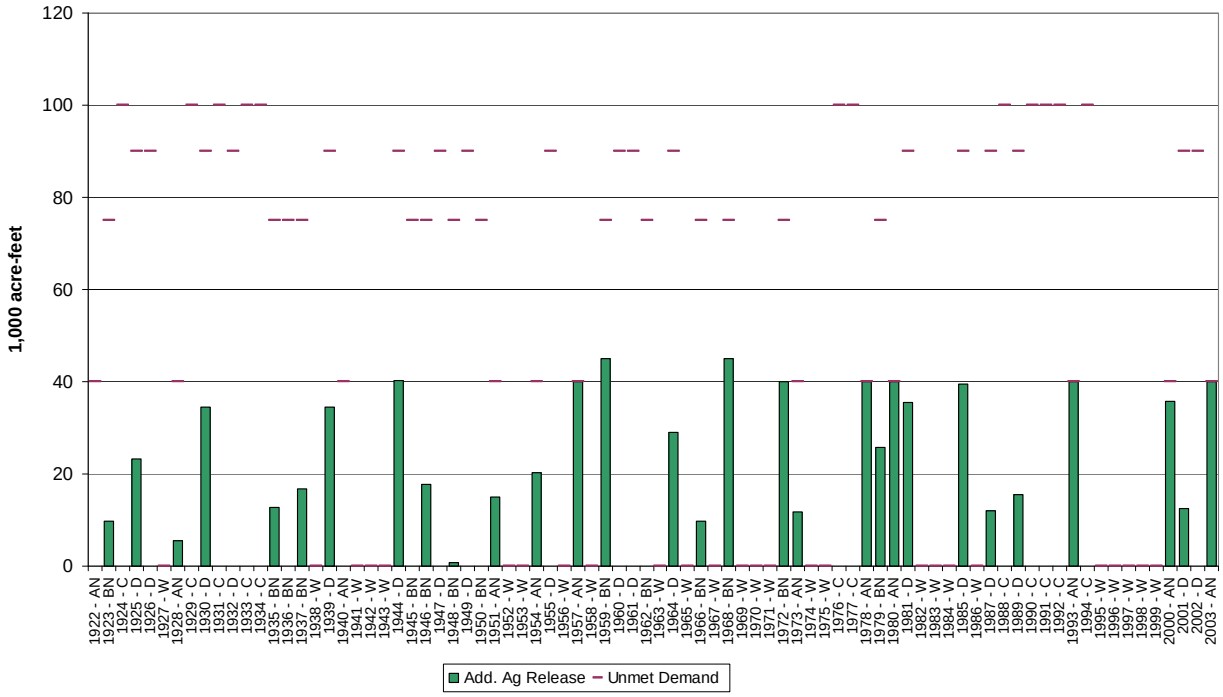


FIGURE 11-11
FEATHER RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 11-12 illustrates how conjunctive management operations result in slightly lower Oroville Reservoir fall storage conditions in approximately 60 percent of the years. Fall storage is not affected below the minimum level of 1,500 TAF. The solid green line at 1,200 TAF denotes target storage for cold water pool management when conjunctive management may be used to increase storage.

Figure 11-13 shows how storage space created in Oroville Reservoir through additional releases for agricultural and environmental objectives is frequently refilled with surplus surface water. Refill from surplus surface water occurs in 37 years with an average annual refill of 32 TAF in those years. The average annual refill with surplus for the 82-year simulation period is 14 TAF.

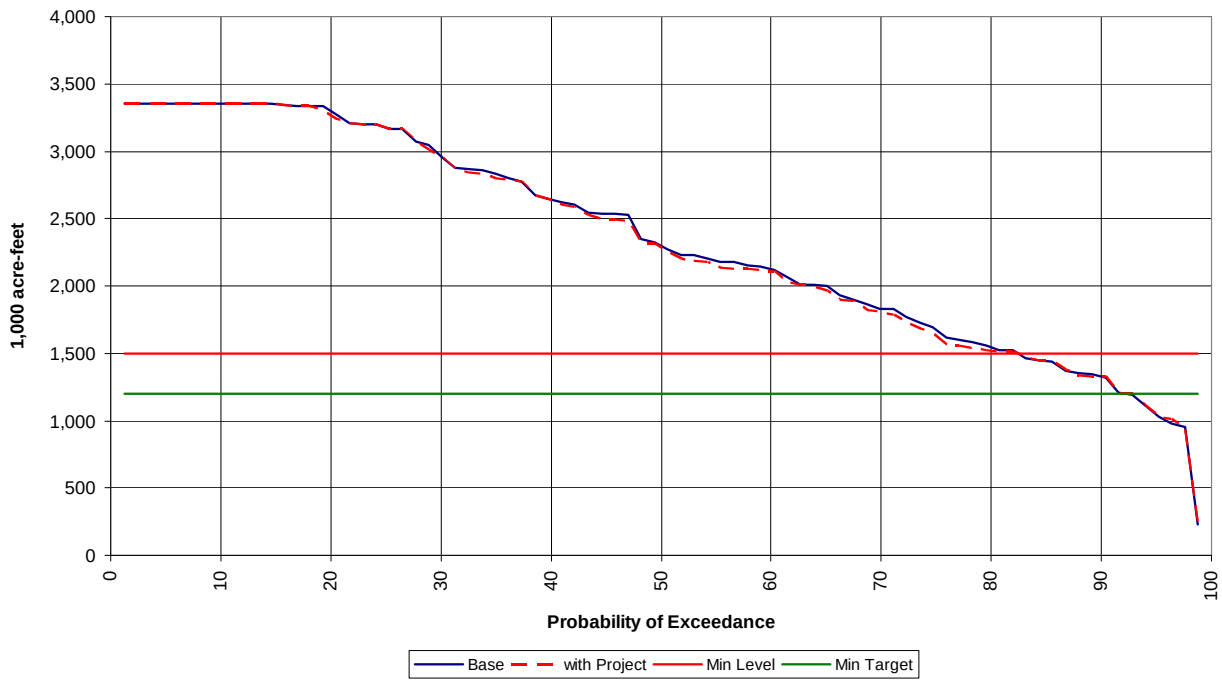


FIGURE 11-12
OROVILLE RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

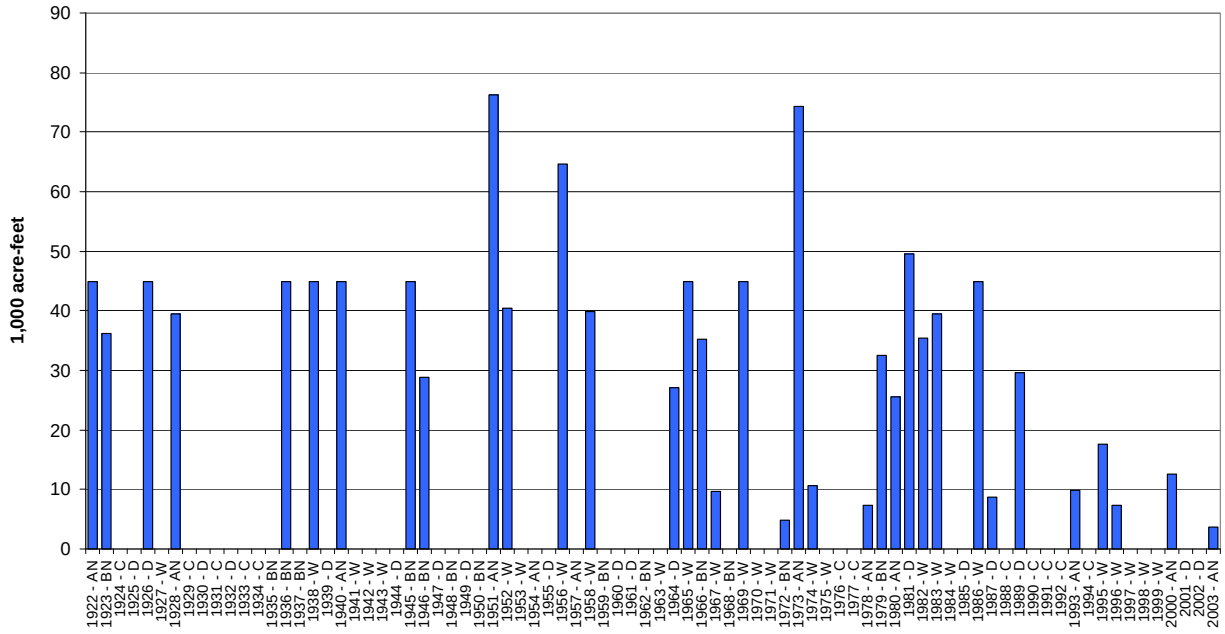


FIGURE 11-13
REFILL OF OROVILLE RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-14 presents annual conjunctive management pumping in the Butte Basin project. Conjunctive management pumping occurs in 6 of the 82 years simulated or 7 percent of the years. The average annual pumping in those years is 44 TAF. The average annual pumping for the entire 82-year simulation is approximately 3 TAF with a maximum annual pumping of the full 50 TAF of pumping capacity.

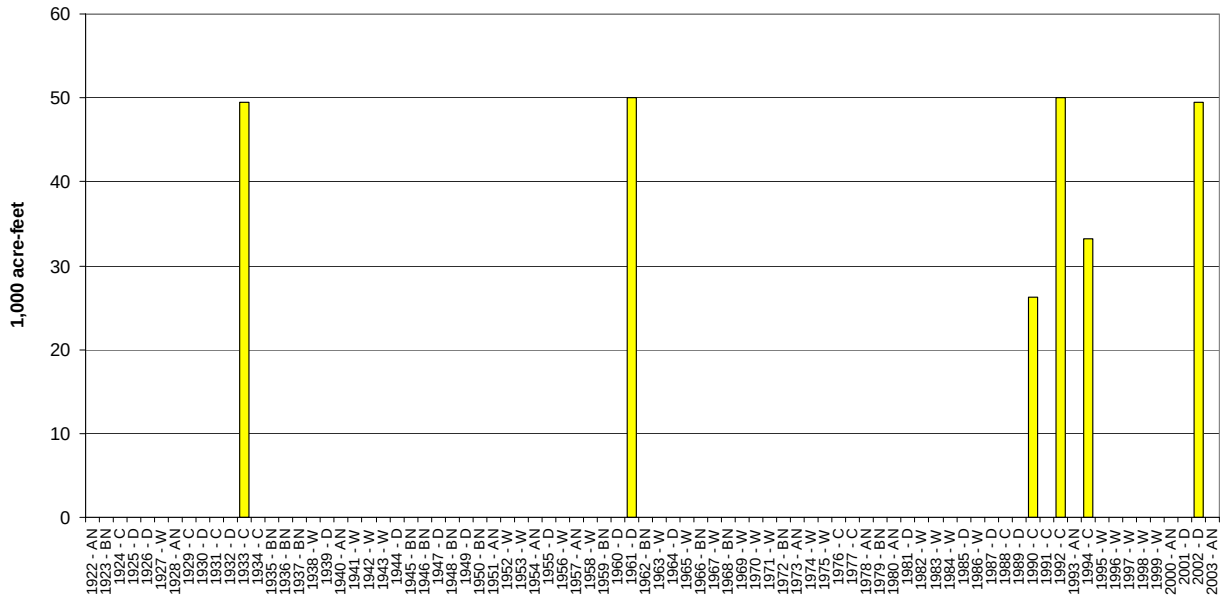


FIGURE 11-14
REFILL OF OROVILLE RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Over the 82-year simulation period, additional reservoir releases are made in 37 years, or 45 percent of the years. Reservoir refill is accomplished with surplus surface flows in 37 years and with project pumping in 6 years. The number of years with refill exceeds the number of years with additional release because reservoir storage deficits may not completely refill in a single year, but instead refill over the course of several years. In summary, of total average annual additional releases of 17 TAF (10 TAF for agriculture and 7 TAF for environmental objectives), 14 TAF is refilled from surplus surface water and 3 TAF from conjunctive management pumping.

11.1.3 Groundwater Results

Existing Well Field

Monthly pumping for Scenario 1, illustrated on Figures 11-9 and Figure 11-14 for the GCID and Butte Basin projects, respectively, was simulated in the groundwater model for the existing well field shown on Figure 11-1. All discussions provided in this section referring to the existing well field reflect simulated drawdown in the regional aquifer. All discussions referring to the new well field reflect simulated drawdown in the deeper aquifer. Production would occur through existing wells screened in the regional aquifer at depths of 100 to

500 feet. Results of this simulation are summarized on Figures 11-15 through 11-17. Peak drawdown in groundwater levels associated with implementation of this scenario is presented on Figure 11-15. This figure depicts simulated drawdown in the pumped aquifer during August 1990. Maximum pumping rates under this alternative occur during 1990 and the drawdown distribution at the end of August represent the approximate maximum drawdown that will occur under this scenario. Figure 11-15 shows that the area of greatest drawdown occurs in the northern GCID area at a magnitude of 30 to 40 feet. Drawdown in the Butte Basin is negligible and is confined to the close vicinity of the production wells.

Simulated impacts to surface streams under Scenario 1 for an existing well field are summarized on Figures 11-16 and 11-17. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-16 suggests that the peak cumulative impact to all surface water flows will be approximately 54 cfs in the summer of 1990, with a flow reduction of just more than 40 cfs forecasted to occur on the Sacramento River, and a flow reduction of approximately 13 cfs on Butte Creek. The peak impact to the Sacramento River will also occur in the late summer of 1990 while the peak impact on Butte Creek is forecasted to occur in early 1993. Peak impacts to stream flows on smaller tributary streams are less than about 6 cfs as shown on Figure 11-17.

The time of year in which impacts to rivers and streams are simulated to occur is a critical factor in assessing their significance. Typical flows in the Sacramento River at Wilkins Slough are on the order of 6,000 to 7,000 cfs in late summer and fall months with minimum flows for the historical period of 1980 through 2006 of 3,000 to 4,000 cfs. Therefore, the impacts reflected on Figure 10-16 represent a small percentage of total flow. Average summer and fall flows in the Feather River directly below Thermalito Afterbay are on the order of 2,000 to 3,000 cfs with minimum flows for the same historical period of approximately 1,000 cfs. Flows in Butte Creek near Chico average approximately 110 to 150 cfs with minimum flows of 50 cfs in some fall months. Therefore, simulated impacts to Butte Creek represent a larger percent of minimum or typical flows than impacts to the Sacramento or Feather Rivers.

Figure 11-16 illustrates stream flow reductions for the groundwater model simulation period. Reductions in the Sacramento River between GCID (Hamilton City) and Wilkins Slough show larger spikes during years with pumping in the GCID project and smaller increases during years with pumping in the Butte Basin project. Butte Creek reductions follow the opposite pattern with larger increases during years with pumping in the Butte Basin project and smaller increases in years with pumping in the GCID project. Reductions in all modeled streams show increases in years with pumping in either project. The annual cycle of increasing and decreasing reductions in all streams is due to the ephemeral nature of smaller streams. More reductions occur in winter months when smaller streams are simulated to be flowing and less reductions in summer when smaller streams are assumed to be dry.

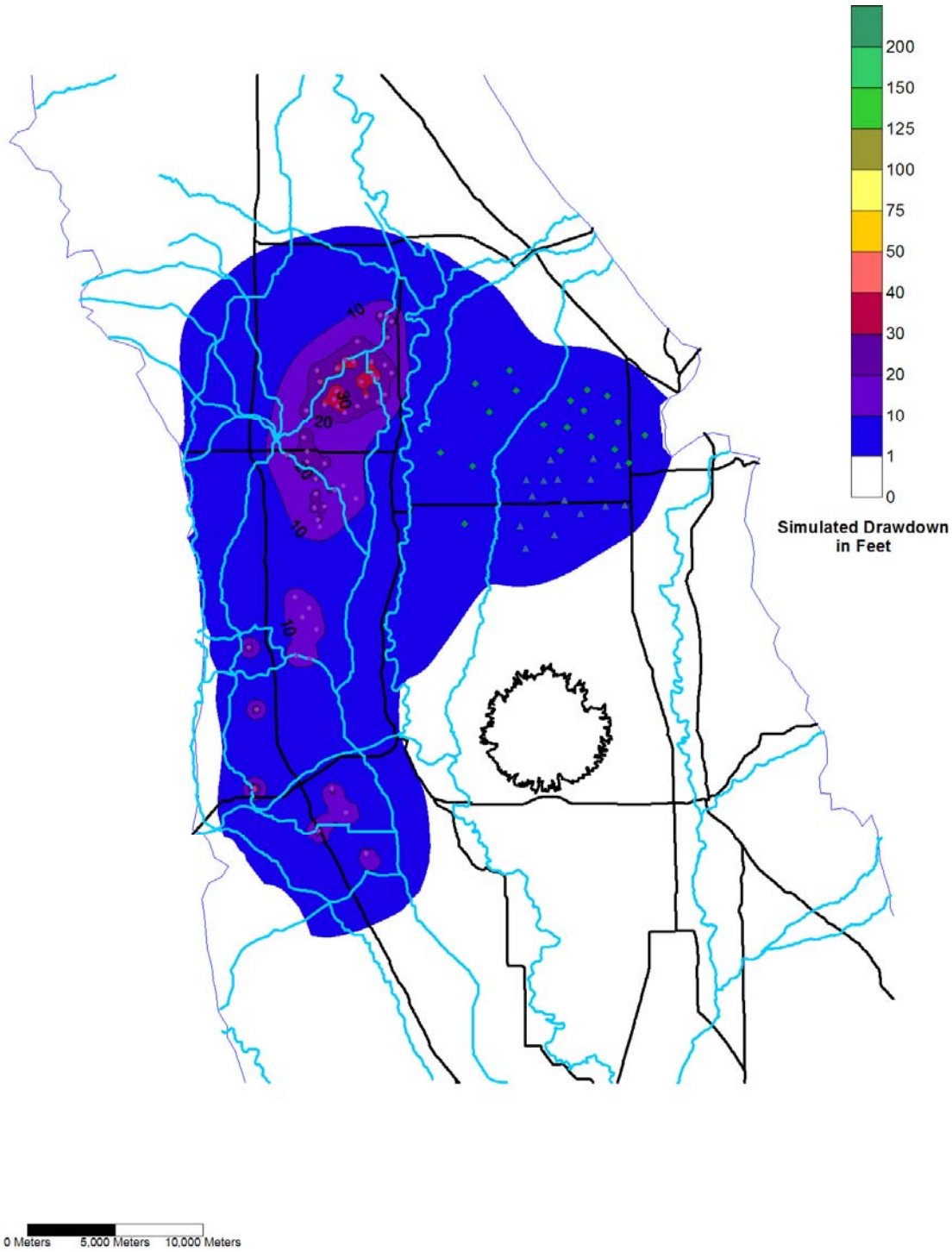


FIGURE 11-15
SIMULATED EXTENT OF DRAWDOWN IN THE REGIONAL AQUIFER IN AUG 1990, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

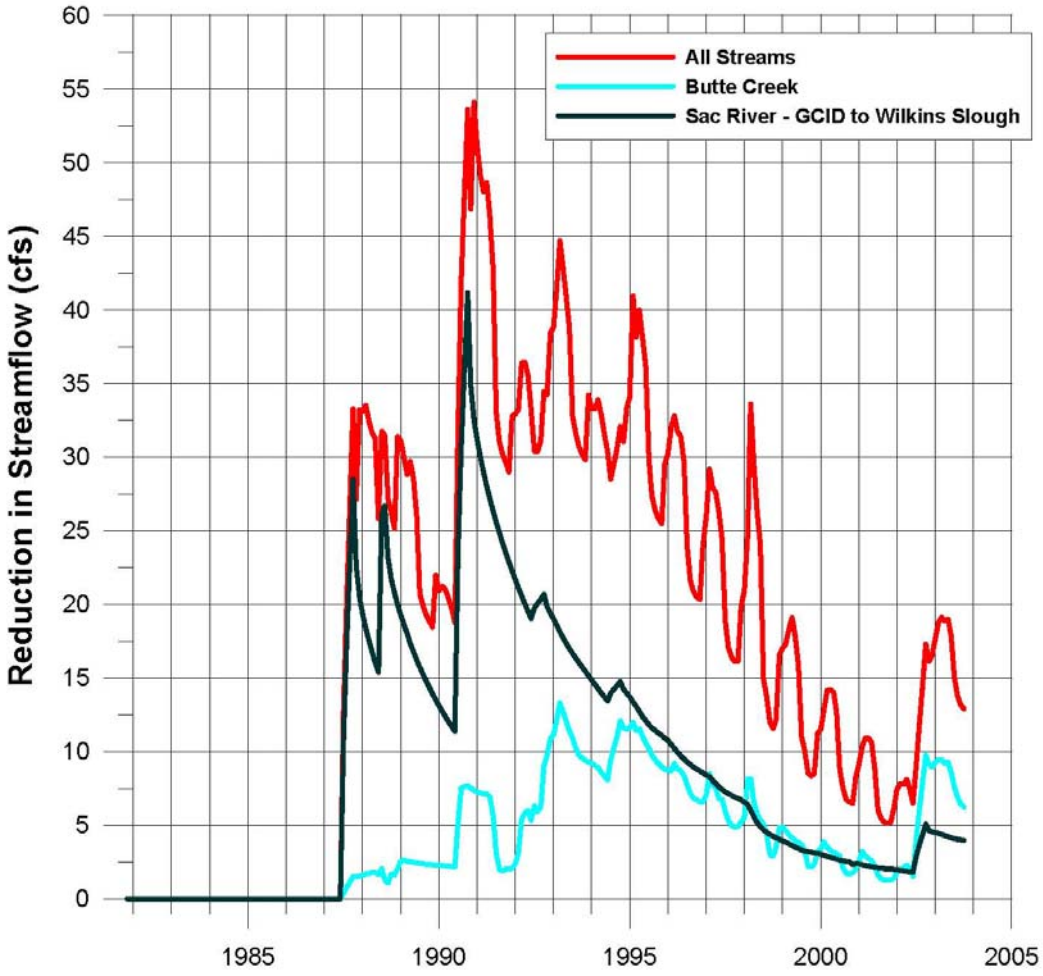


FIGURE 11-16
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

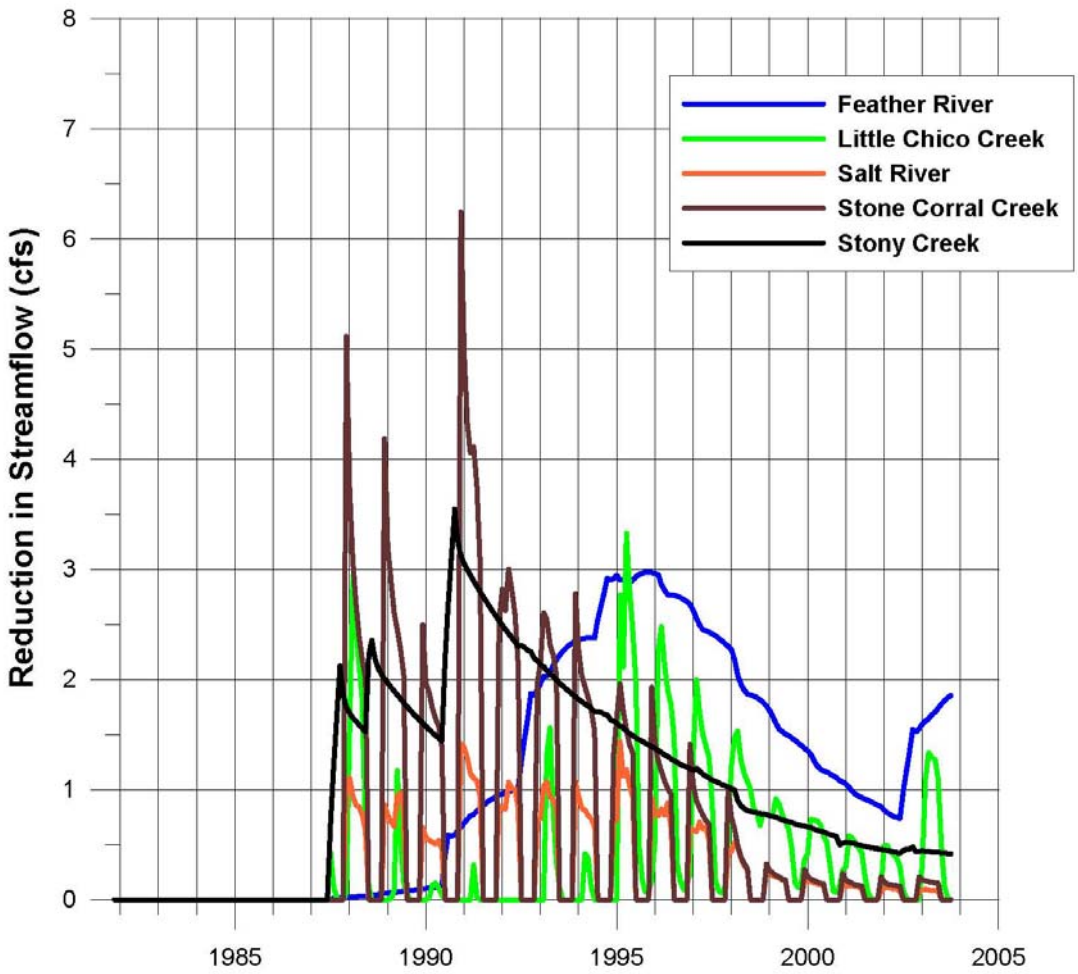


FIGURE 11-17
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Reservoir Release for Recharge

Stream reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. The timing of when stream reductions occur and conditions in the surface water system determine if and how the surface water system may respond. For example, if stream reductions tend to occur in winter months of years with above average precipitation there may be little or no response required by upstream reservoirs to a decrease in stream flow. Alternatively, if stream reductions occur during fall months of years with below average precipitation, upstream reservoirs may be required to make additional releases to ensure compliance with flow or water quality requirements in the surface water system.

The surface water system is sometimes referred to as being in a “balanced” or “surplus” condition. Balanced conditions occur when upstream reservoirs are releasing water to meet specific downstream requirements for flow, diversions, water quality, or to support Delta

exports. Surplus conditions typically occur when upstream reservoirs are releasing water for flood control purposes or tributary inflow below reservoirs results in surplus conditions. It is possible for parts of the system to be in balanced conditions while others are in surplus conditions. For example, if Shasta Reservoir is releasing water to maintain minimum required flow at the navigation control point (a location near Wilkins Slough) the system is in balance between Shasta and Wilkins Slough and reduction in Sacramento River flow or its tributaries upstream of Wilkins Slough may require additional release from Shasta. Simultaneously there may be surplus flow in the Sacramento River below Wilkins Slough or the Delta, and reduction in stream flow downstream of Wilkins Slough may require additional release from Shasta.

Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-18 and 11-19 present annual additional releases from Shasta and Oroville, respectively, for Scenario 1 pumping from an existing well field.

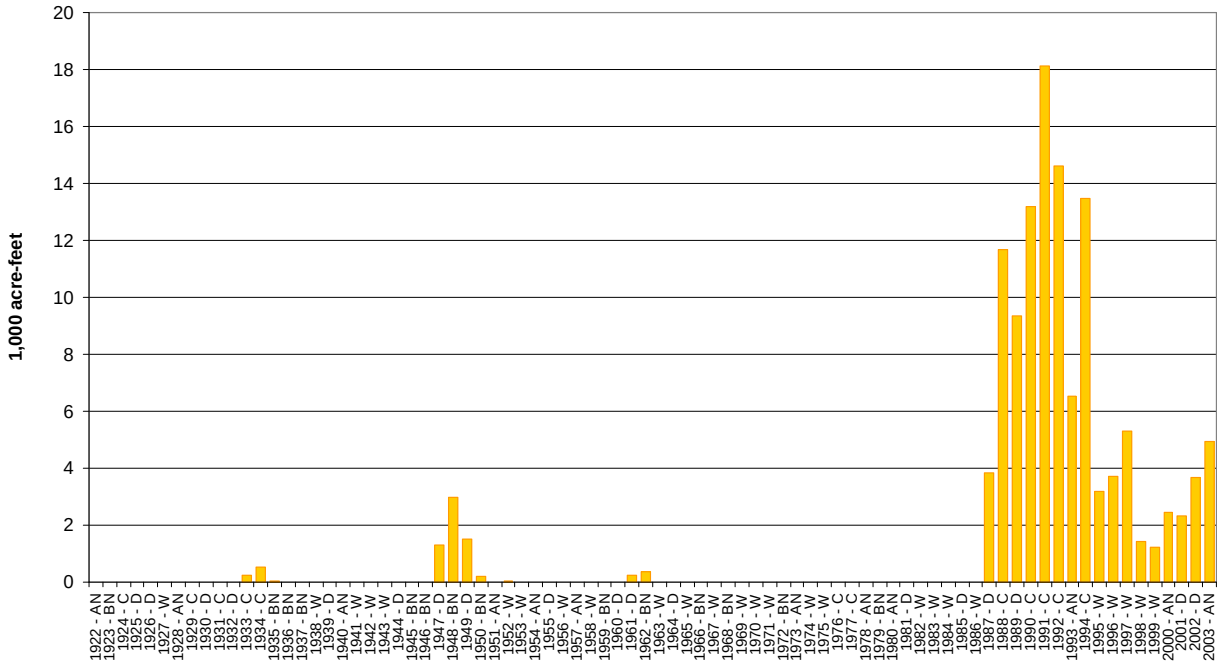


FIGURE 11-18
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

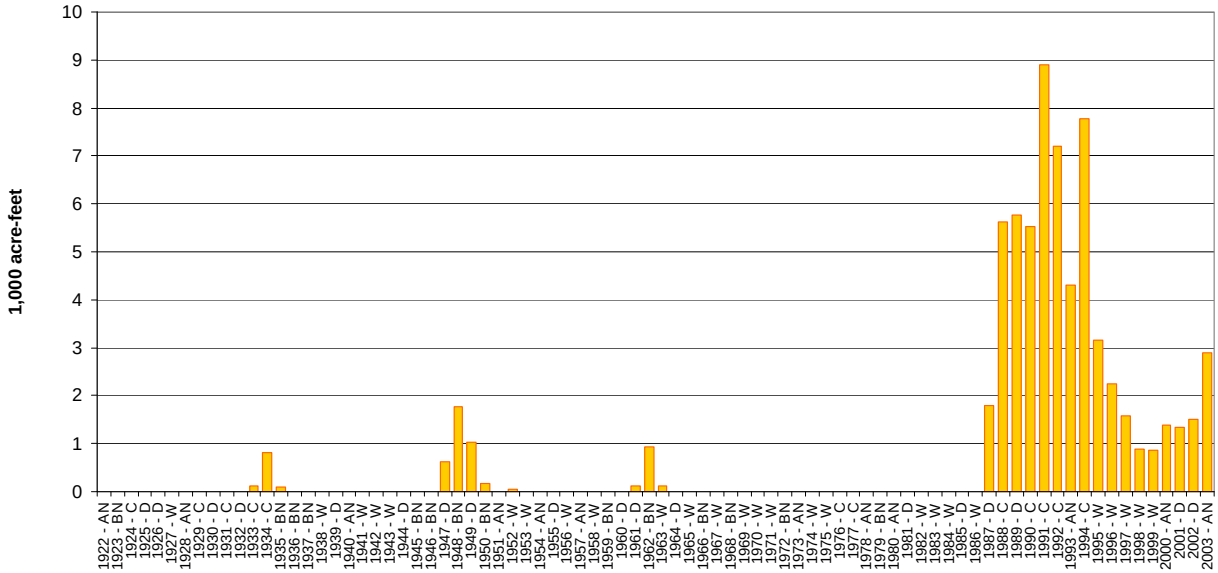


FIGURE 11-19
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-18 and 11-19 also illustrate that in multiple years with higher levels of pumping, such as the simulation from 1987 through 1994, upstream reservoirs may have to release a small volume of additional water to compensate for increases in streamflow reductions. These results reflect the precision of both the groundwater and surface water models but not necessarily the accuracy of these models. Annual releases from Oroville Reservoir of 3 TAF in any year are far beyond the accuracy of planning level models. Results are presented to demonstrate potential effects and to illustrate concepts.

New Well Field

The same monthly pumping time series for Scenario 1 was also simulated in the well field shown on Figure 11-2. Production would occur through new wells screened in the deeper aquifer units at a depth of 900 to 1100 feet. Results of this simulation are summarized on Figures 11-20 through 11-22. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-20. This figure depicts simulated drawdown in the pumped aquifer, during August 1990. The figure shows that the area of greatest drawdown occurs in the western GCID area at a magnitude of up to 100 feet. Drawdown in Butte Basin is the range of 10 to 20 feet.

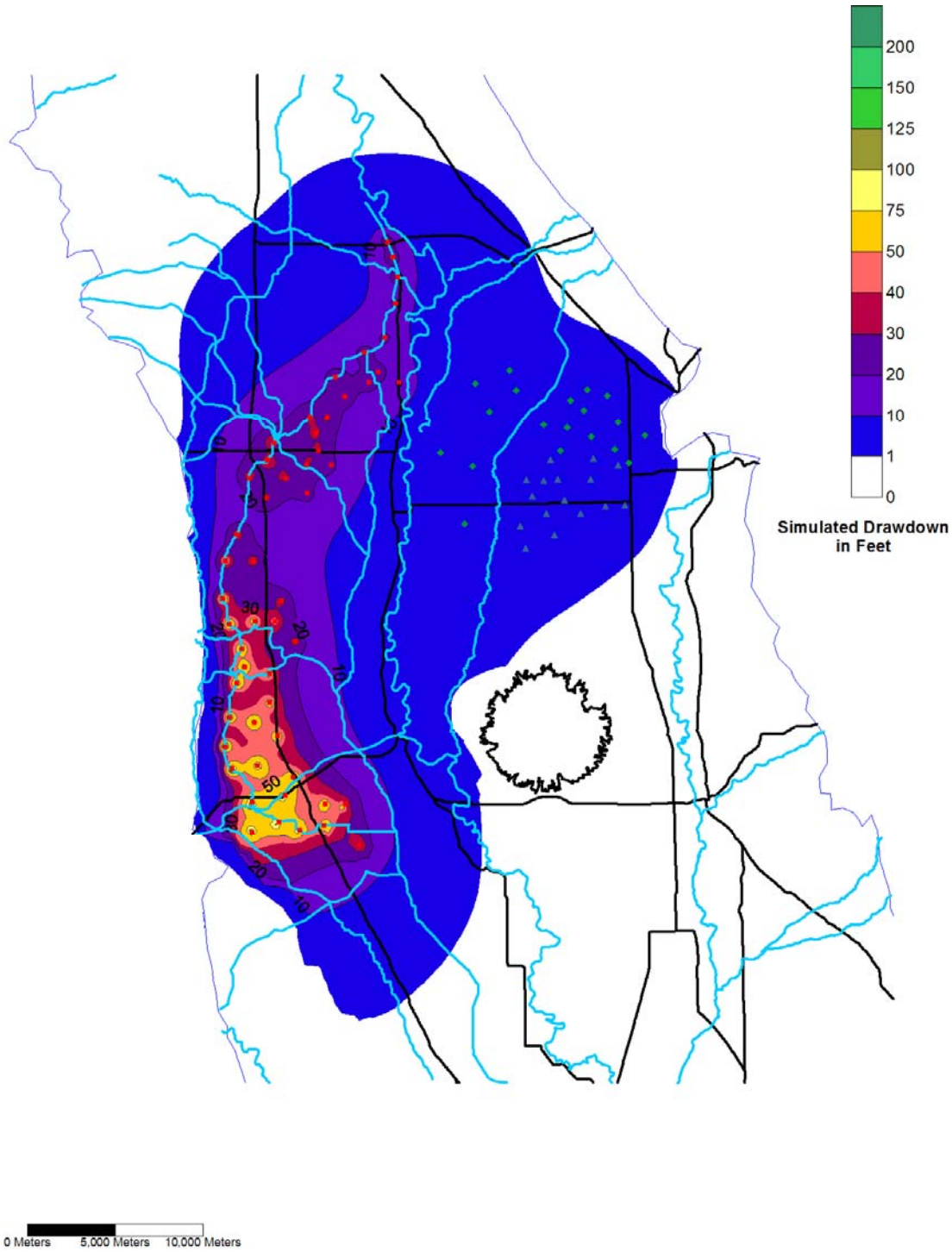


FIGURE 11-20
SIMULATED DRAWDOWN IN THE DEEP AQUIFER IN AUG 1990, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 1 for a new well field are summarized on Figures 11-21 and 11-22. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek,

with smaller impacts estimated to occur to surrounding streams. Figure 11-21 suggests that the peak cumulative impact to all surface water flows will be a reduction of about 52 cfs in the late fall of 1990, while a flow reduction of just over 36 cfs is forecast to occur on the Sacramento River while a flow reduction of approximately 12 cfs is predicted on Butte Creek. The peak impact to the Sacramento River will also occur in the late fall of 1990, while two similar peak impacts occur on Butte Creek in early 1993 and the fall of 1994. Peak impacts to stream flows on smaller tributary streams peak at less than about 9 cfs as shown on Figure 11-22.

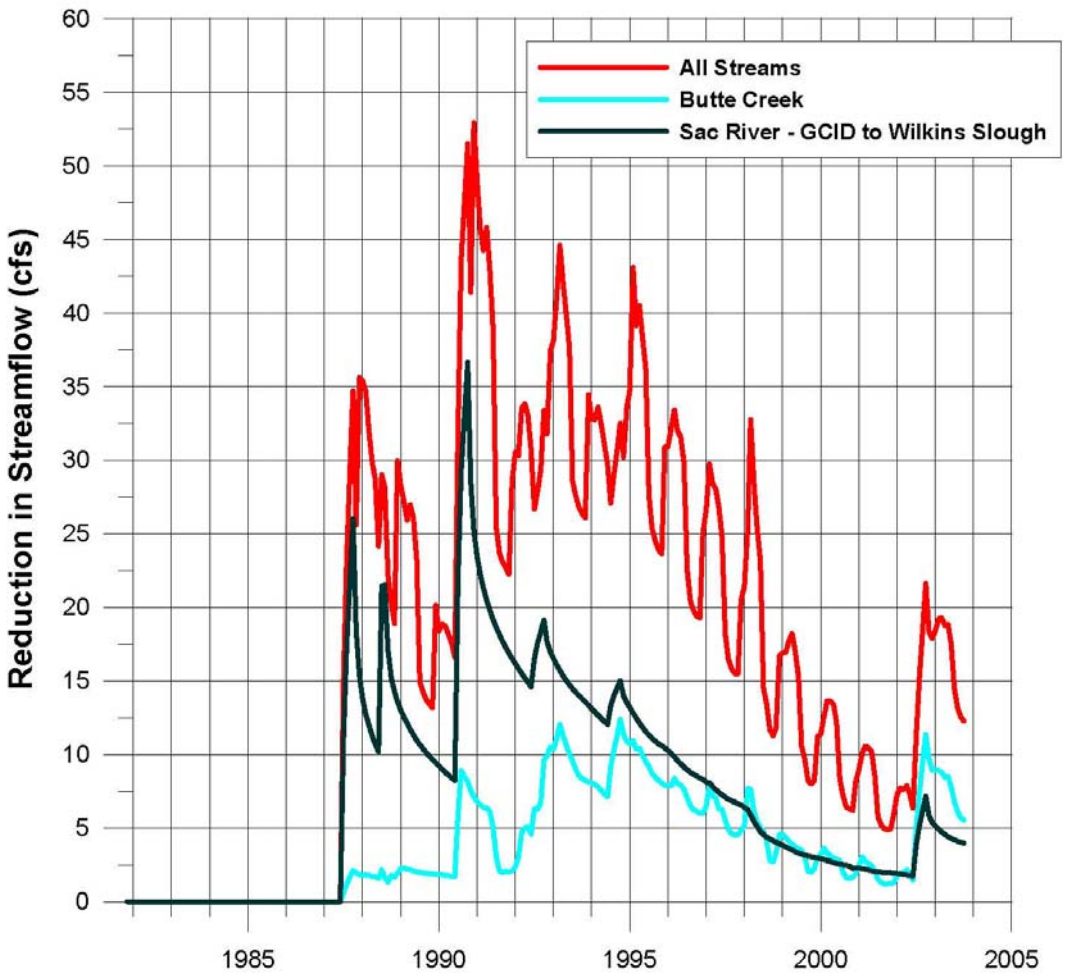


FIGURE 11-21
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

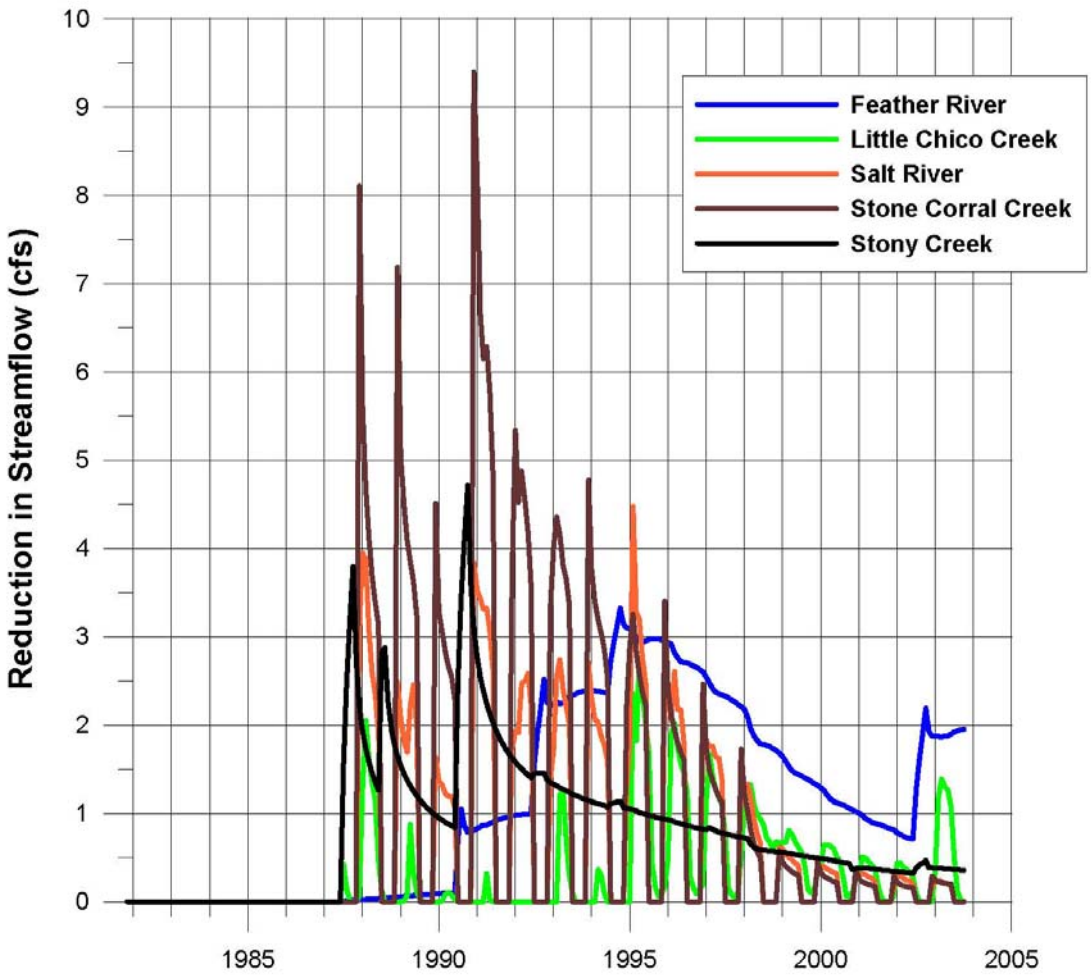


FIGURE 11-22
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-23 and 11-24 present annual additional releases from Shasta and Oroville, respectively, for Scenario 1 pumping from a new well field.

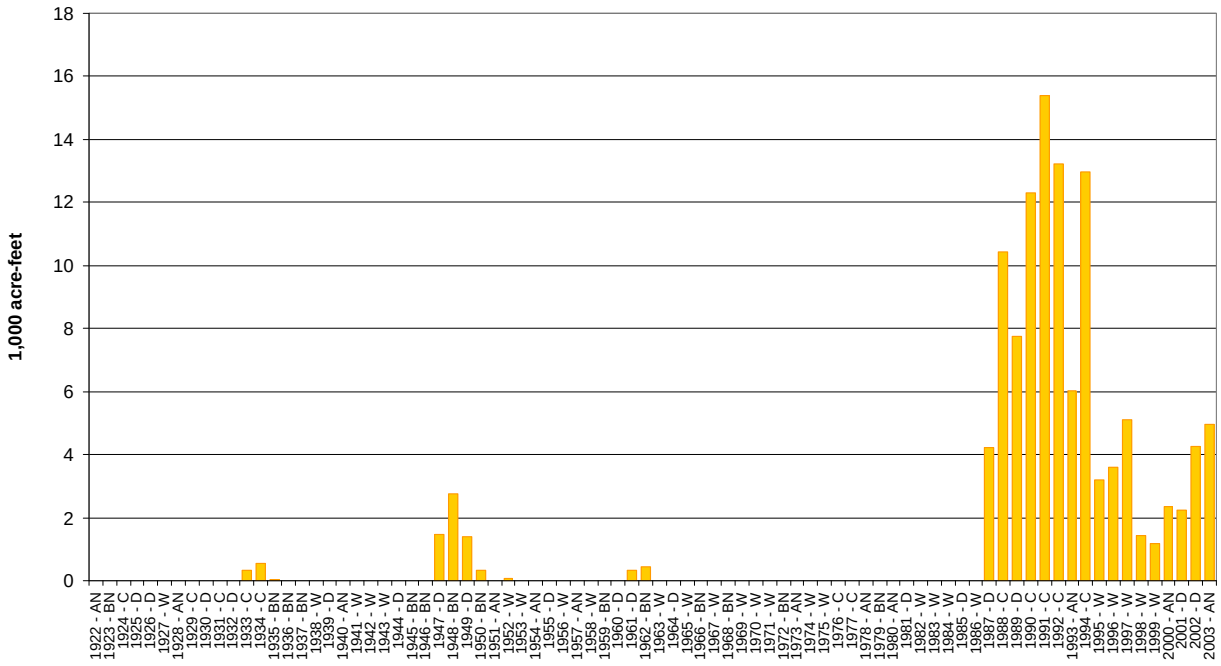


FIGURE 11-23
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

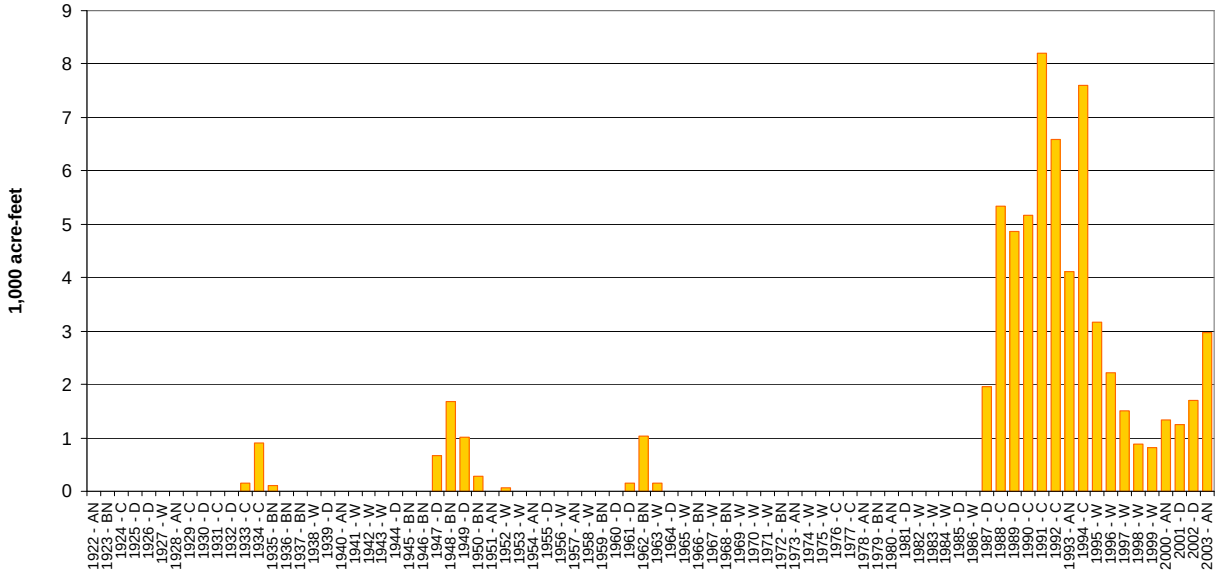


FIGURE 11-24
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 1 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-23 and 11-24 illustrate peak annual reservoir releases to compensate for stream reductions may be slightly less for a new well field than for the existing well field, but annual releases are similar for either well field.

11.2 Scenario 2 – 200 TAF GCID, 100 TAF Butte Basin, Summer Pumping

Scenario 2 is defined by two conjunctive management projects with maximum seasonal pumping capacities of 200 TAF in GCID and 100 TAF in the Butte Basin. This scenario is the same as Scenario 1 but with twice the pumping capacity at each project.

11.2.1 Shasta Reservoir and Sacramento River

Figure 11-25 illustrates annual volumes of water released to satisfy various environmental objectives on the Sacramento River. The geomorphic objective is met most frequently due to lower water cost associated with the short duration, but the larger pumping capacity increases project assets and allows other objectives to be met more frequently than in Scenario 1. Additionally, in some years more than one objective may be met as indicated by stacked bars. Average annual release for environmental objectives under Scenario 2 is 45 TAF.

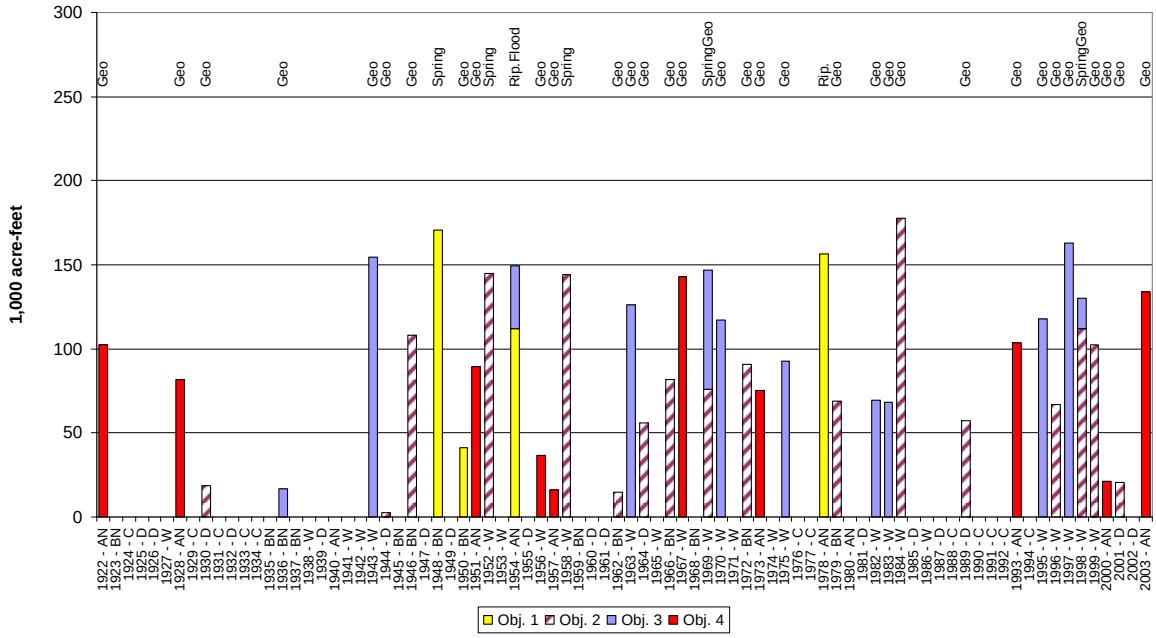


FIGURE 11-25
SACRAMENTO RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-25 shows only years when environmental objectives are met through project release. Environmental objectives may also be met under the base operations of the system.

Table 11-3 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include those years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 11-25. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

TABLE 11-3
Number of Years Sacramento River Environmental Objectives are Met, Scenario 2
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Figure 11-26 illustrates annual release from Shasta to meet additional agricultural demand in the TCCA service area. Additional agricultural releases are made in 24 of the 82 years simulated, or approximately 29 percent of the years. The average release in those years is 75 TAF, while the average annual agricultural delivery over the 82-year simulation period is 22 TAF. Additional agricultural deliveries are made in many of the same years as in Scenario 1, but at higher volumes.

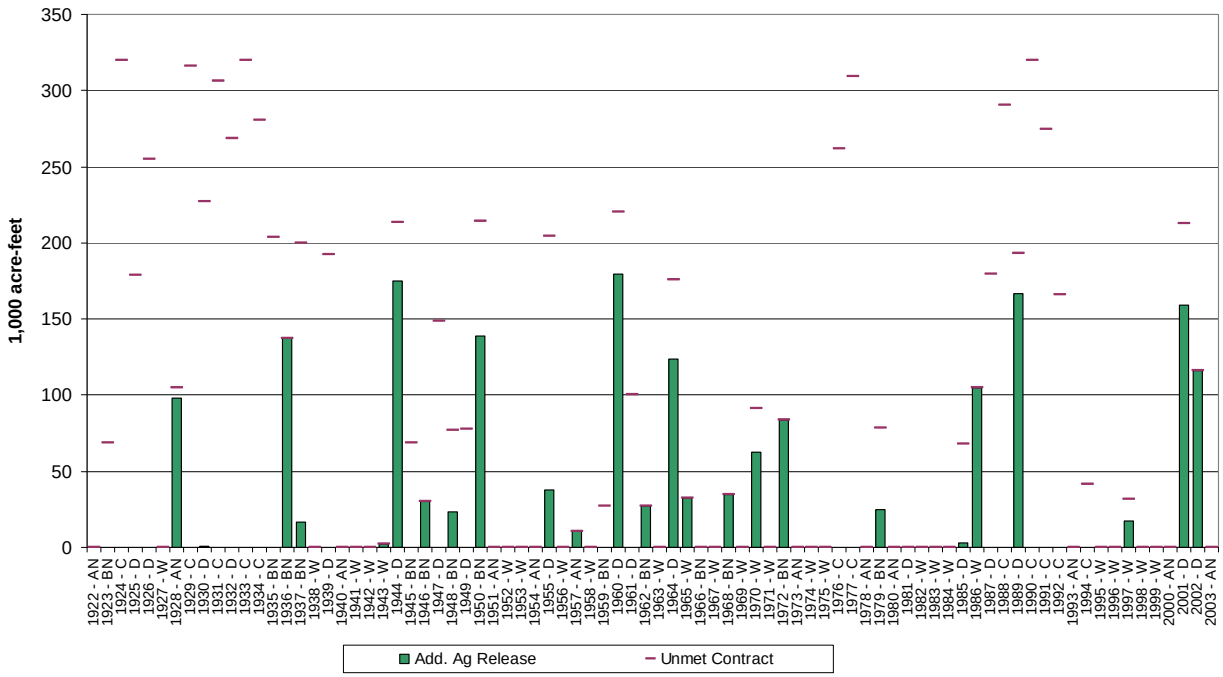


FIGURE 11-26
SACRAMENTO RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Additional reservoir releases for either environmental objectives or for additional agricultural delivery result in lower fall carryover storage in Lake Shasta. Figure 11-27 illustrates that fall storage levels are lower in approximately 45 percent of the years and only when end of September storage is more than 2,400 TAF. During these years fall storages are lower compared to Scenario 1 because larger pumping capacity allows for more aggressive operation of the reservoir. Additionally, a small increase in fall storage below the 1,900 TAF target may also be possible.

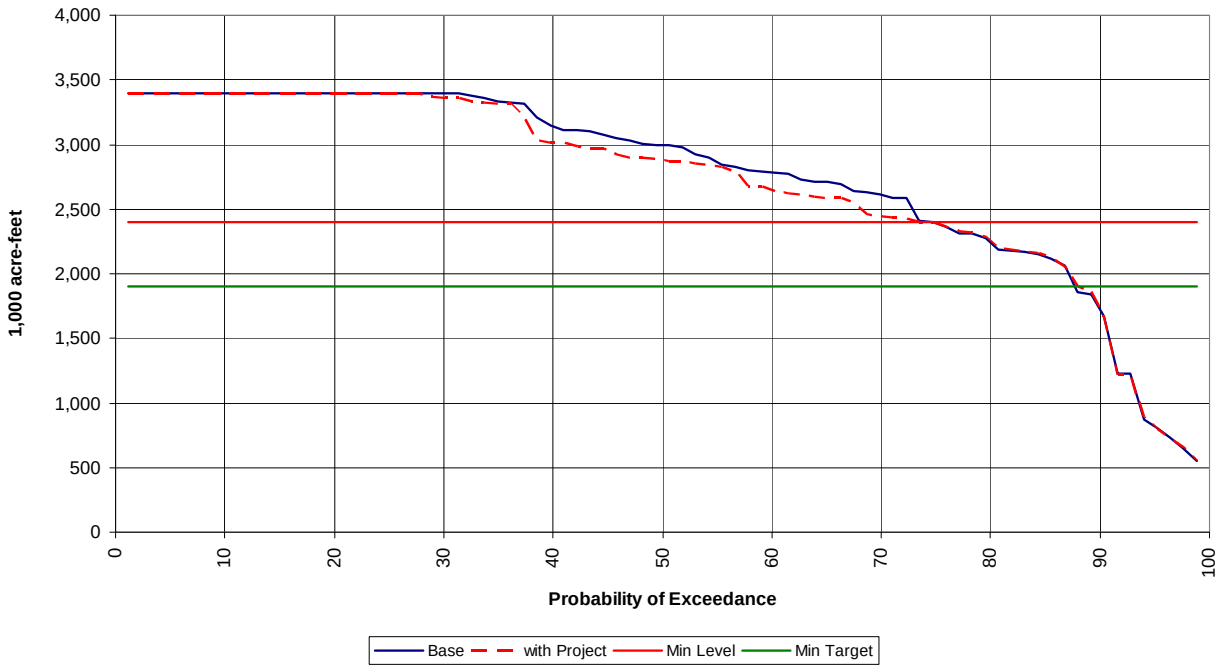


FIGURE 11-27
SHASTA RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-28 illustrates how storage deficits presented on Figure 11-27 are frequently refilled by capture of surplus surface water. Refill with surplus surface water occurs in 35 years with an average annual refill of 139 TAF in those years. Average annual refill with surplus surface water for the 82-year simulation is approximately 58 TAF.

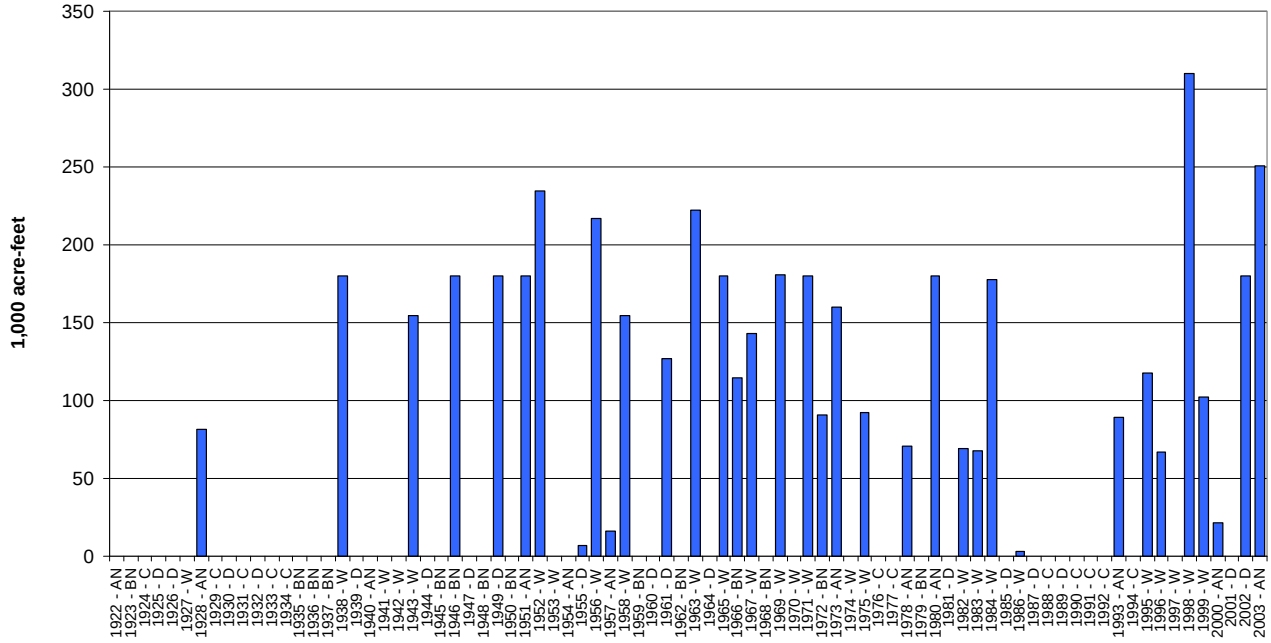


FIGURE 11-28
REFILL OF SHASTA RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-29 illustrates annual conjunctive management groundwater pumping for Scenario 2. Conjunctive management pumping occurs in 6 of the 82 years simulated, or 7 percent of years. The average annual pumping in those years is 123 TAF. The average annual pumping for the entire 82-year simulation is approximately 9 TAF with a maximum annual pumping of nearly the full 200 TAF of capacity. Pumping typically occurs in drier year types when reservoirs do not refill with surplus surface water.

Over the 82-year simulation period, additional reservoir releases are made in 48 years, or 59 percent of the years. Reservoir refill is accomplished with surplus surface flows in 35 years and with project pumping in 6 years. The number of years with releases exceeds the number of years with refill because reservoir storage deficits do not have to be completely refilled before making additional releases, as long as the total reservoir storage deficit does not exceed the capacity of the project to refill the reservoir in a single year. In summary, of total average annual additional releases of 67 TAF (22 TAF for agriculture and 45 TAF for environmental objectives), 58 TAF is refilled from surplus surface water and 9 TAF from conjunctive management pumping.

11.2.2 Oroville Reservoir and Feather River

Figure 11-30 illustrates annual volumes of water released to meet environmental objectives on the Feather River. Similar to the Sacramento River operations, the geomorphic objective is satisfied most frequently, but increased groundwater pumping capacity allows for more aggressive reservoir operations allowing other objectives to also be satisfied. Average annual release for environmental objectives on the Feather River is 23 TAF.

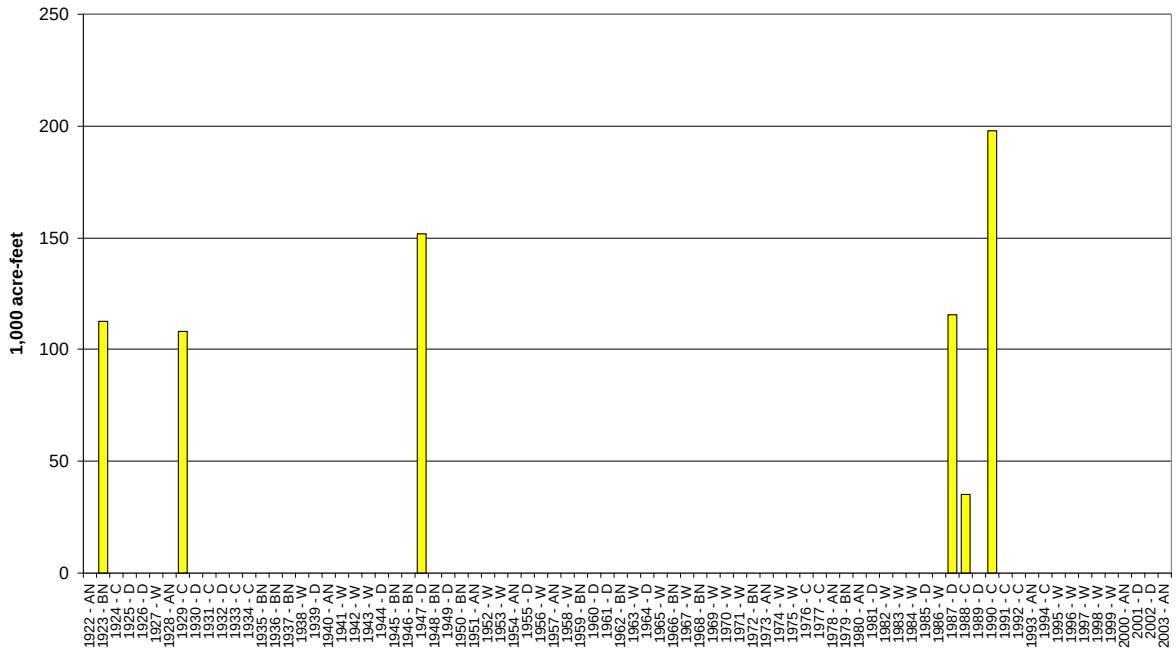


FIGURE 11-29
REFILL OF SHASTA RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

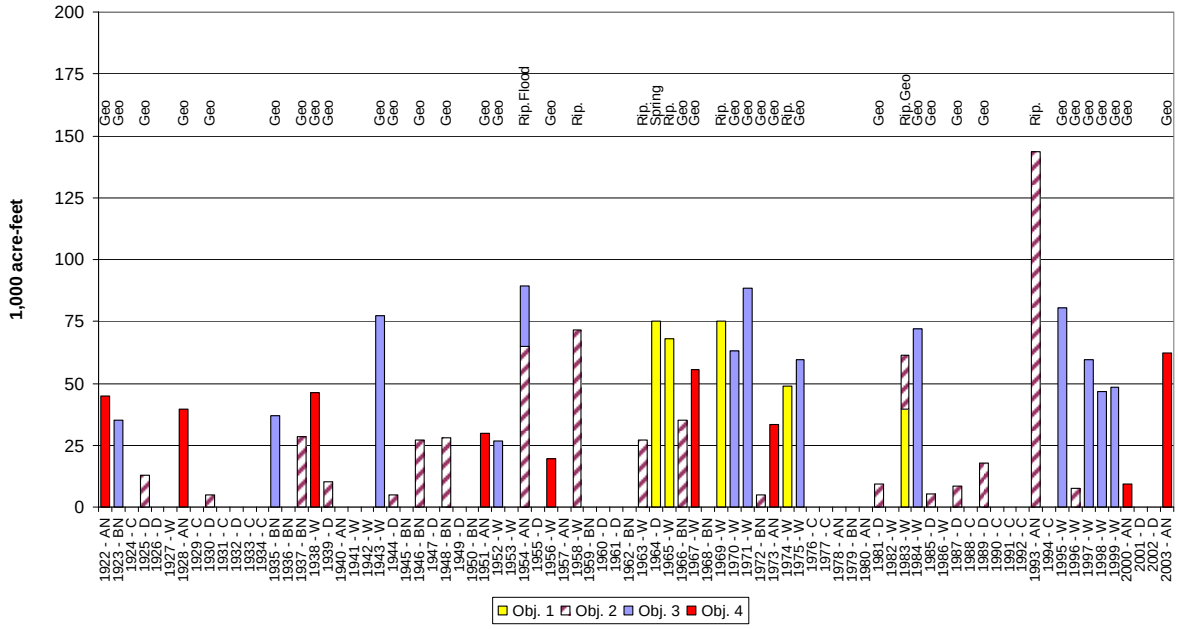


FIGURE 11-30
FEATHER RIVER ENVIRONMENTAL OBJECTIVES MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Table 11-4 provides a summary of the number of times each objective is met by reservoir release and under base operations on the Feather River. Values reported in the table for the geomorphic objective only include those years when the objective is not met under base operations. Therefore this value is less than the number of releases shown on Figure 11-30. The flood plain inundation objective can be met with the project under base condition flows with the modified weir, or with a combination of project releases and the modified weir.

TABLE 11-4
Number of Years Feather River Environmental Objectives are Met, Scenario 2
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

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

Figure 11-31 illustrates additional agricultural deliveries under Scenario 2. Additional agricultural releases are made in 30 of the 82 years simulated, or approximately 37 percent of the years. The average annual release in those years is 52 TAF, while the average annual agricultural delivery over the 82-year simulation period is 20 TAF.

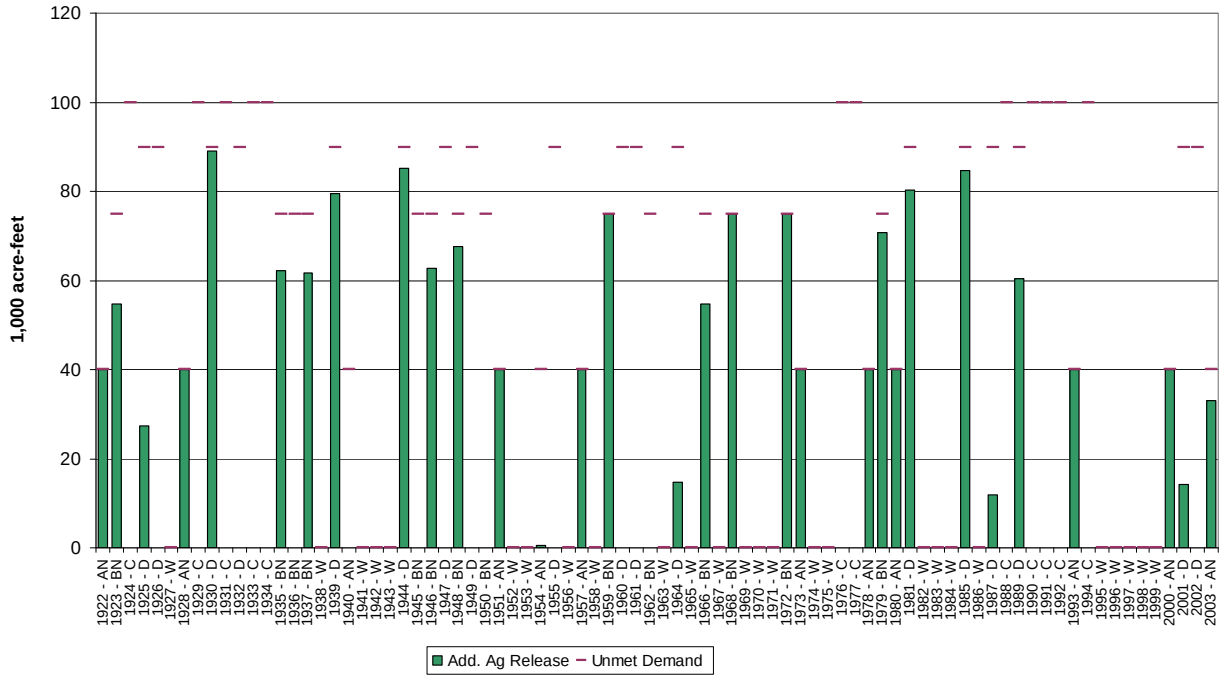


FIGURE 11-31
FEATHER RIVER ADDITIONAL AG. DEMAND MET WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-32 illustrates how conjunctive management operations result in lower Oroville fall storage conditions in approximately 60 percent of the years. Fall storage may be increased in a few years when it is below the minimum target level of 1,200 TAF.

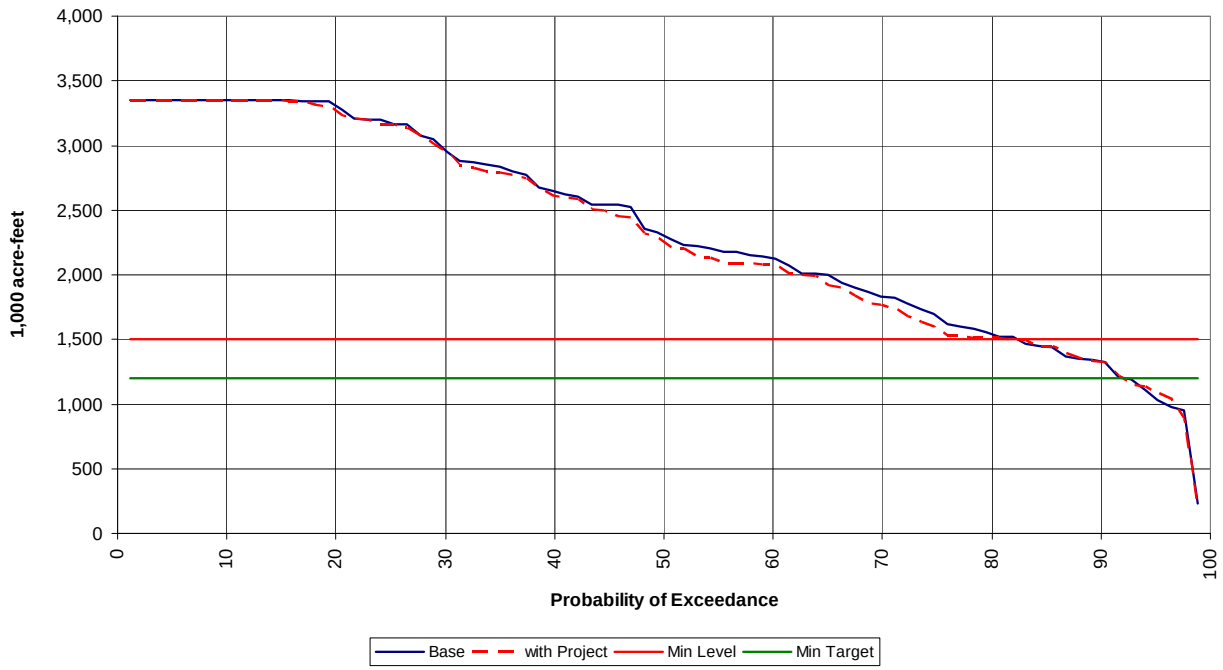


FIGURE 11-32
OROVILLE RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-33 shows how storage space created in Oroville Reservoir through additional releases for agricultural and environmental objectives is frequently refilled with surplus surface water. This occurs in 43 years with an average annual refill of 72 TAF in those years. Average annual refill with surplus for the 82-year simulation period is approximately 36 TAF.

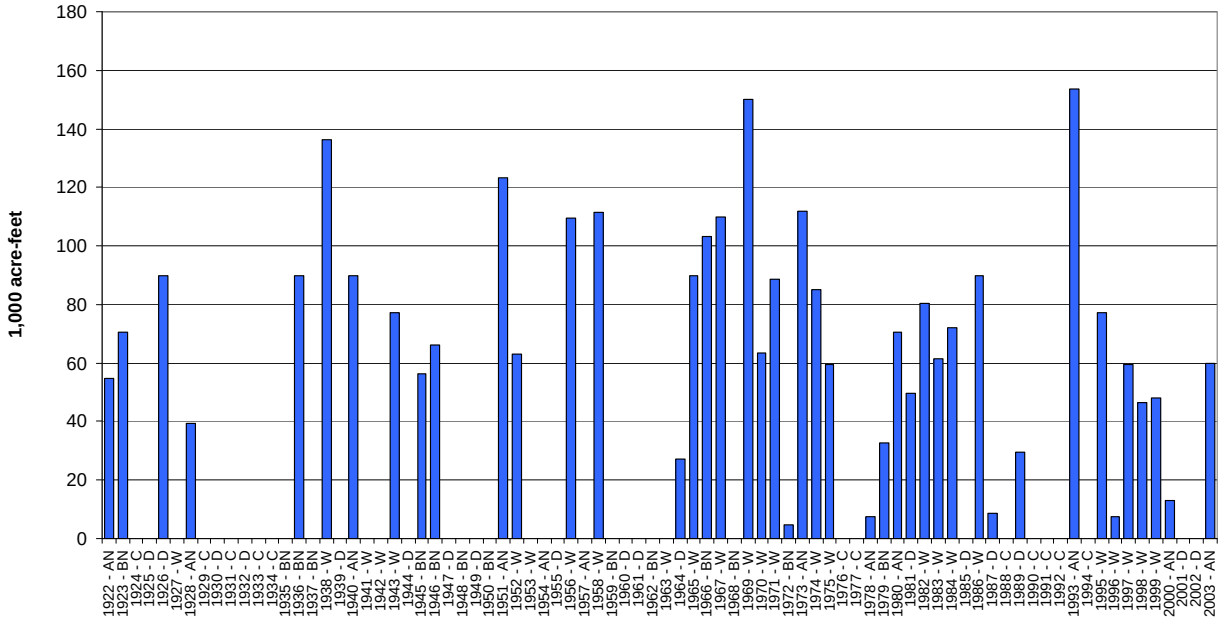


FIGURE 11-33
REFILL OF OROVILLE RESERVOIR FROM SURPLUS SURFACE WATER, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 11-34 presents the annual conjunctive management pumping in the Butte Basin project for Scenario 2. Conjunctive management pumping occurs in 8 of the 82 years simulated or 10 percent of the years. The average annual pumping in those years is 75 TAF. The average annual pumping for the entire 82-year simulation is approximately 7 TAF with a maximum annual pumping of the full 100 TAF of pumping capacity.

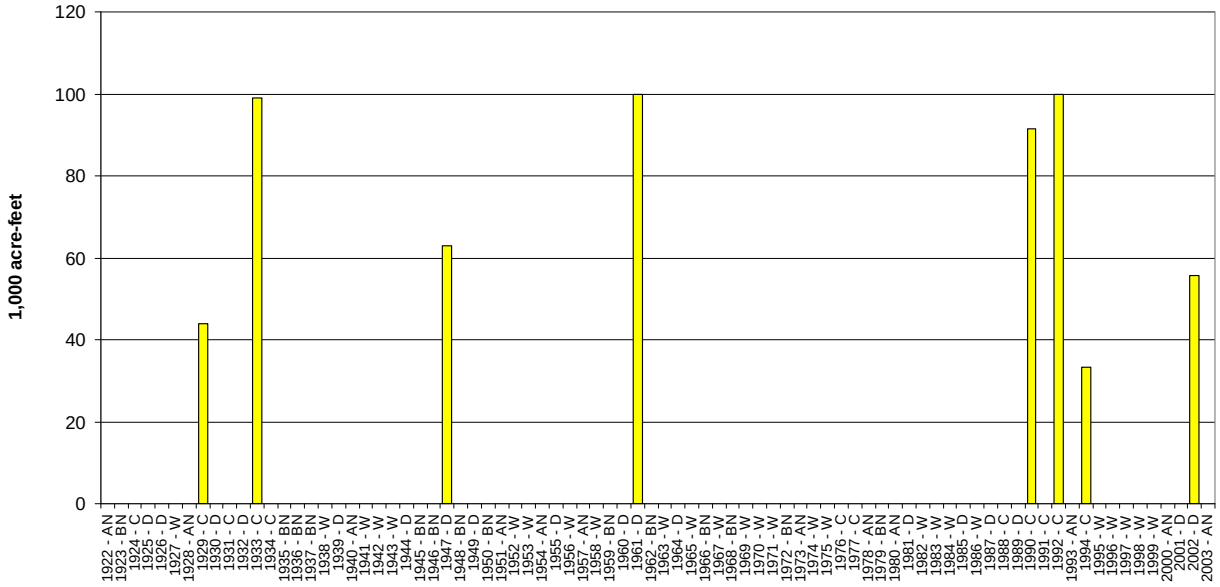


FIGURE 11-34
REFILL OF OROVILLE RESERVOIR FROM CONJUNCTIVE MANAGEMENT PUMPING, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Over the 82-year simulation period, additional reservoir releases are made in 51 years, or 62 percent of the years. Reservoir refill is accomplished with surplus surface flows in 43 years and with project pumping in 8 years. For Scenario 2 on the Feather River system, out of total additional releases of 43 TAF (23 TAF for agriculture and 20 TAF for environmental objectives), 36 TAF is refilled from surplus surface water and 7 TAF from conjunctive management pumping.

11.2.3 Groundwater Results

Existing Well Field

Results of pumping for Scenario 2 using the existing well field shown on Figure 11-3 are summarized on Figures 11-35 through 11-37. Peak drawdown in groundwater levels associated with implementation of this scenario is presented on Figure 11-35. This figure depicts simulated drawdown in the pumped aquifer, during August 1990. Maximum pumping rates under this alternative occur during 1990. Figure 11-35 shows that the area of greatest drawdown occurs in the northern GCID area at a magnitude of up to 100 feet.

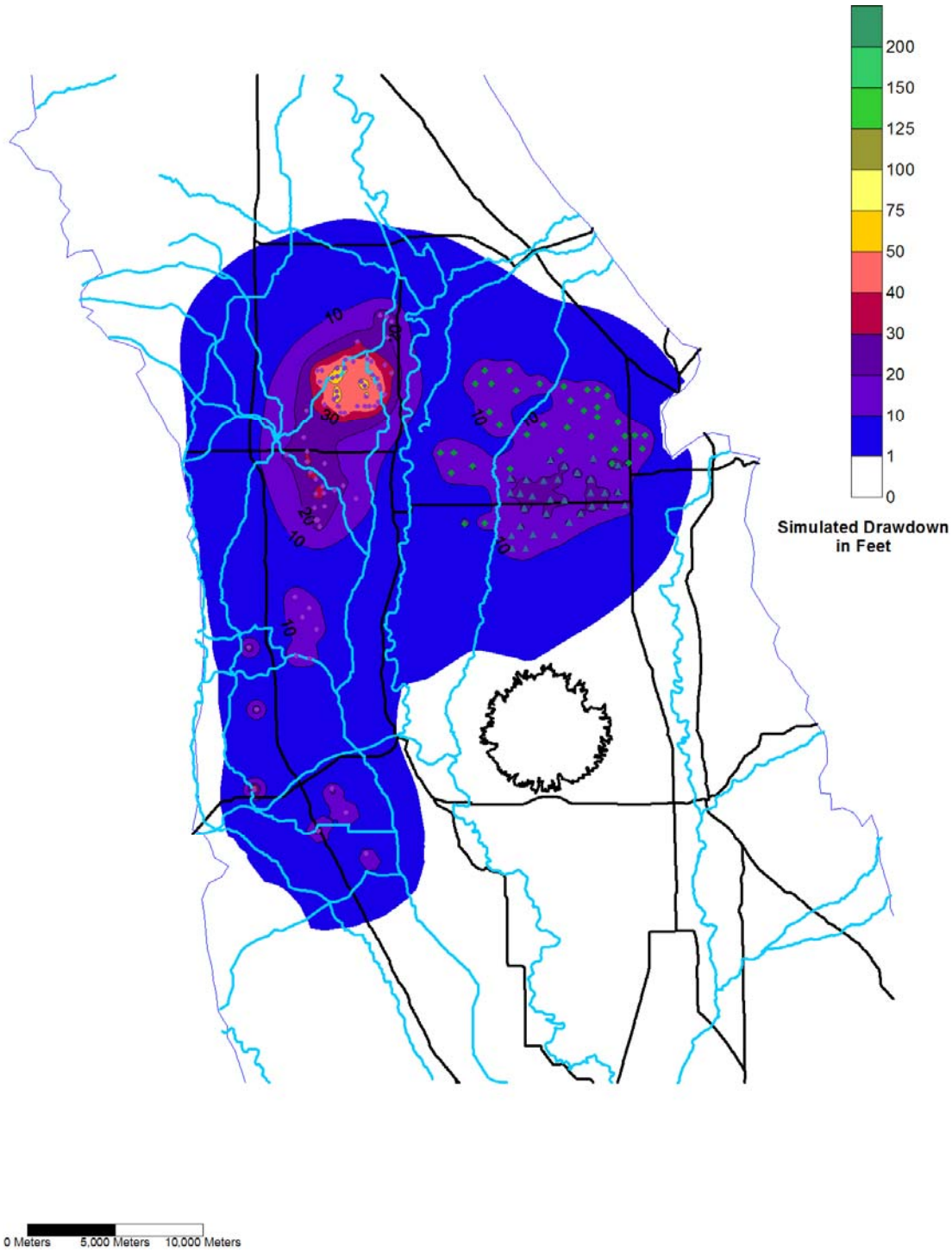


FIGURE 11-35
SIMULATED DRAWDOWN IN THE REGIONAL AQUIFER IN AUG 1990, SCENARIO 2 -EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 2 using an existing well field are summarized on Figures 11-36 and 11-37. These figures show that the greatest impact to surface streams will occur to the Sacramento River between GCID and Wilkins Slough and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-36 suggests that the peak cumulative impact to all surface water flows will be about 110 cfs in summer of 1990, while a peak impact of just over 70 cfs is predicted to occur on the Sacramento River and a peak impact of about 32 cfs is estimated to occur on Butte Creek. Peak impact to the Sacramento River will occur in late summer of 1990 while peak impact on Butte Creek is forecast to occur in early 1993. Peak impacts to stream flows on smaller tributary streams peak at less than about 11 cfs as shown on Figure 11-37.

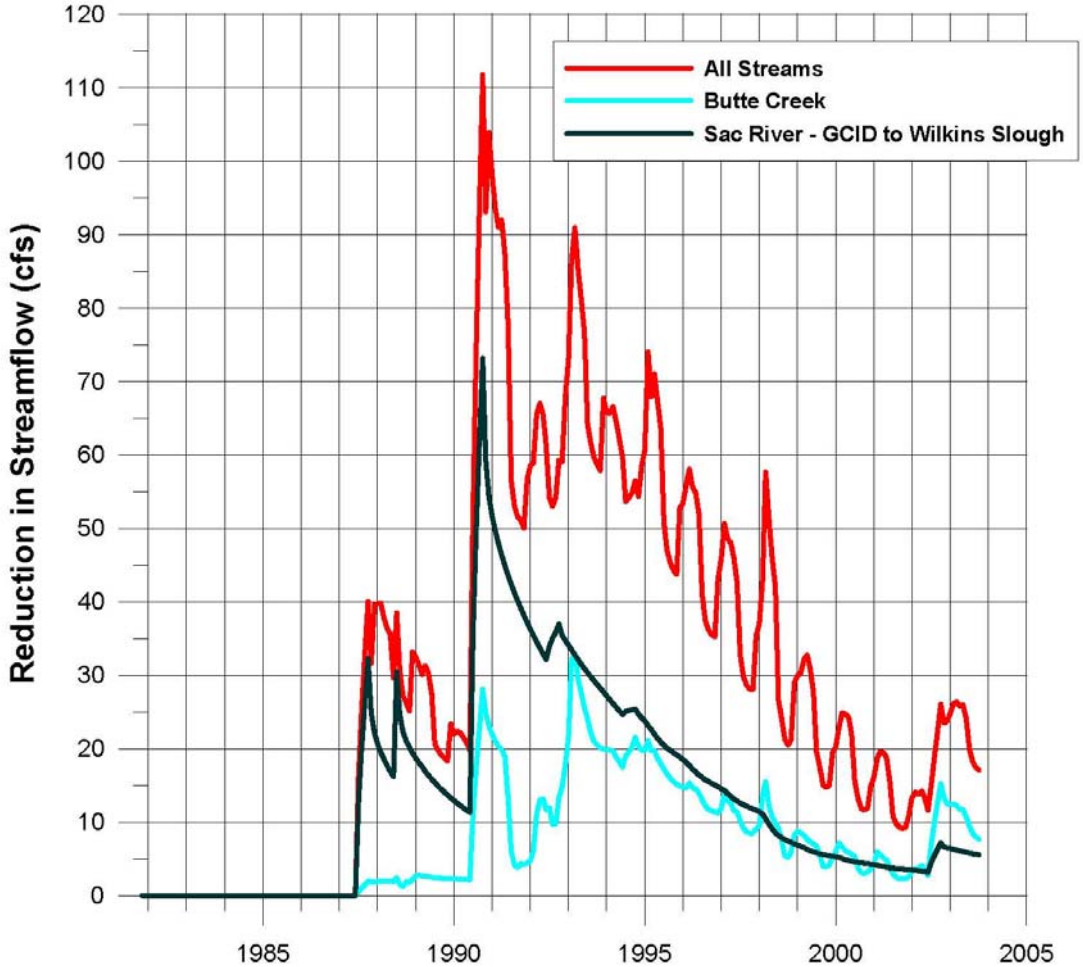


FIGURE 11-36
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 2 -EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

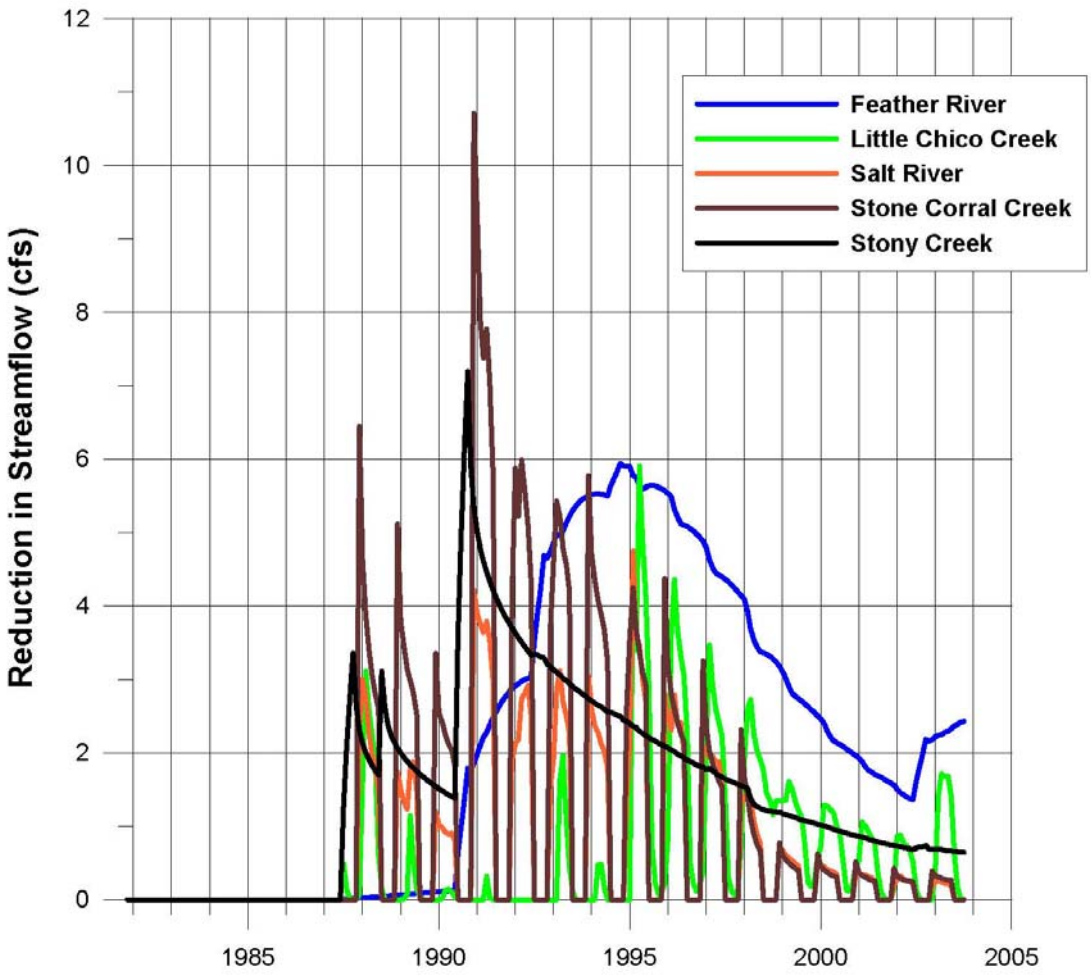


FIGURE 11-37
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 2 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.2.4 Reservoir Release for Recharge

Streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-38 and 11-39 present annual additional releases from Shasta and Oroville, respectively, for Scenario 2 pumping from an existing well field.

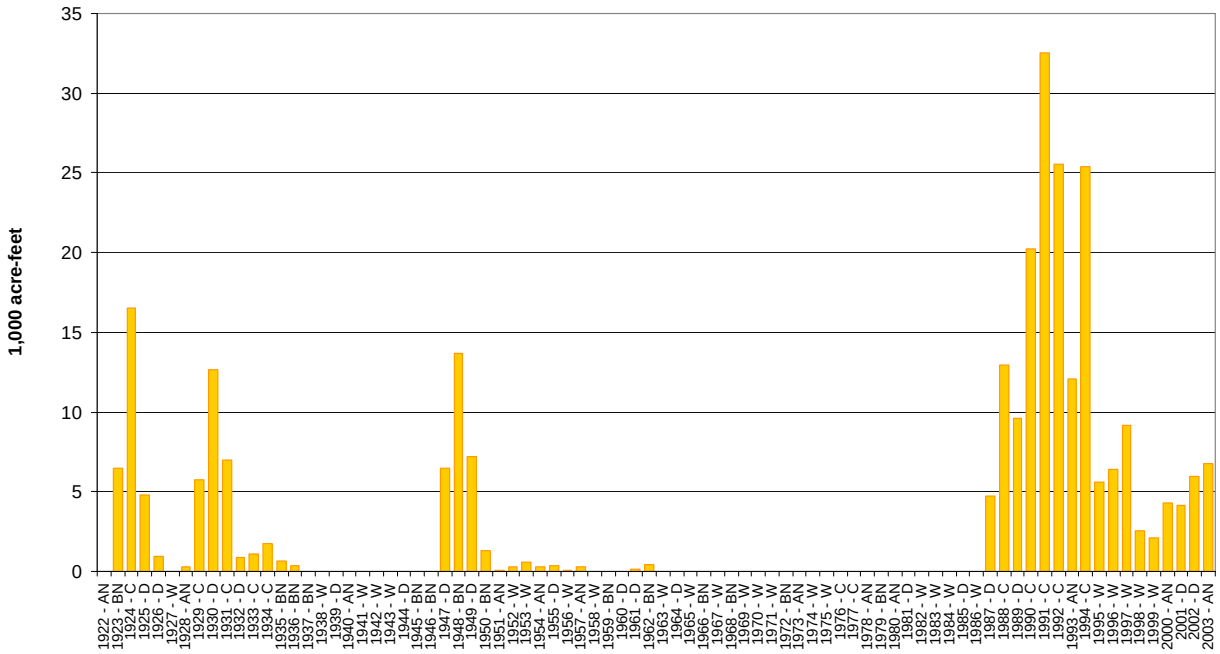


FIGURE 11-38
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

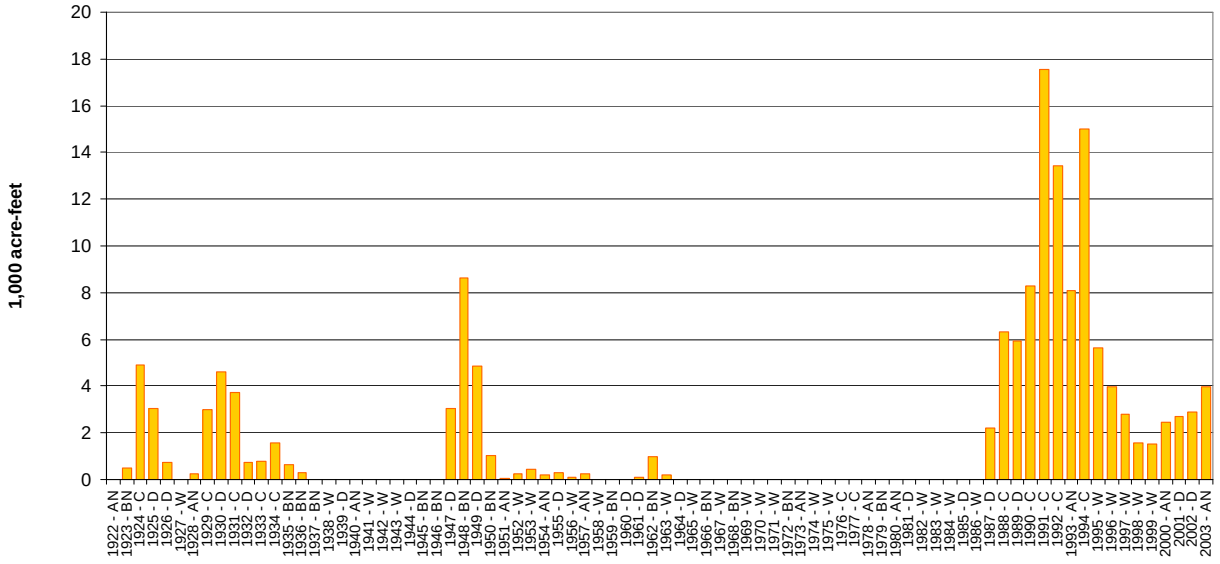


FIGURE 11-39
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-38 and 11-39 illustrate that annual release from Shasta and Oroville to compensate for stream losses from conjunctive management pumping increase under Scenario 2 due to increased pumping frequency and quantity and the resulting increase in streamflow reductions.

New Well Field

Groundwater results for Scenario 2 using a new well field pumping from the deep aquifers are summarized on Figures 11-40 through 11-42. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-40. This figure depicts simulated drawdown in the pumped aquifer during August 1990; the area of greatest drawdown occurs in the western GCID area at a magnitude of up to 200 feet.

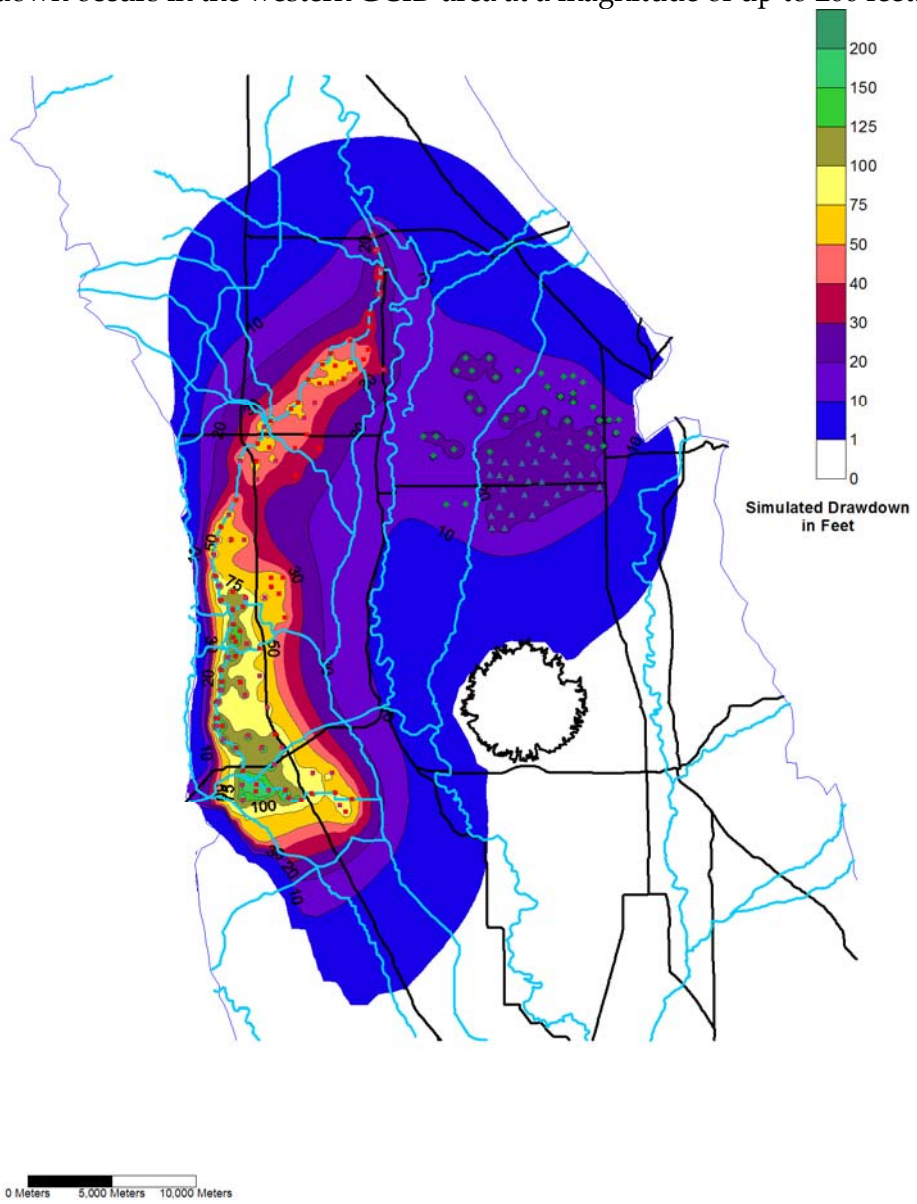


FIGURE 11-40
SIMULATED DRAWDOWN IN THE DEEP AQUIFER IN AUG 1990, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Simulated impacts to surface streams under Scenario 2 with a new well field are summarized on Figures 11-41 and 11-42. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-41 suggests that the peak cumulative impact to all surface water flows will be about 105 cfs in the late fall of 1990, and that a peak flow reduction of just less than 70 cfs will occur on the Sacramento River while a peak flow reduction of about 27 cfs will occur on Butte Creek. Peak impact to the Sacramento River will also occur in late fall of 1990 while two similar peak impacts occur on Butte Creek in early 1993 and the fall of 1994. Impacts to stream flows on smaller tributary streams peak at less than about 15 cfs, as shown on Figure 11-41.

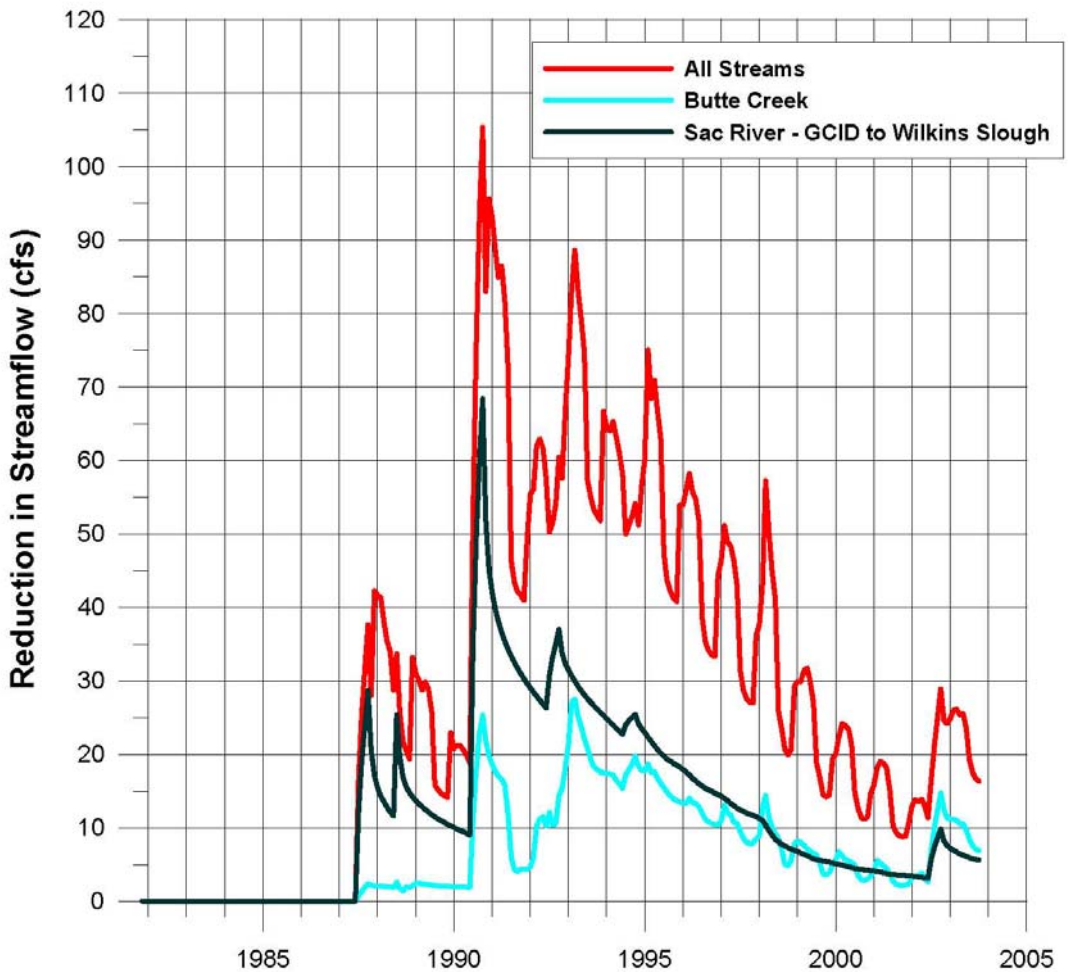


FIGURE 11-41
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 2 -NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

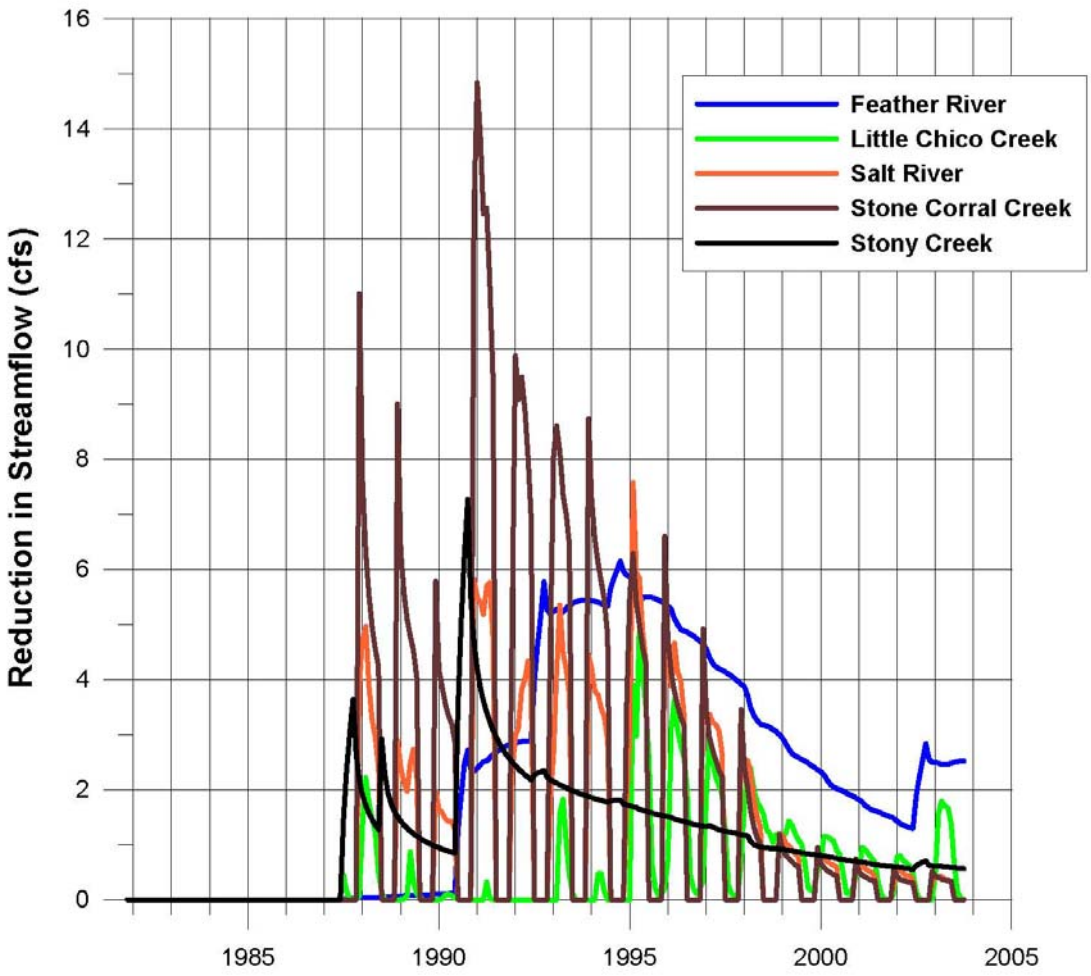


FIGURE11-42
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes to upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions upstream, reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-43 and 11-44 present annual additional releases from Shasta and Oroville, respectively, for Scenario 2 pumping from a new well field.

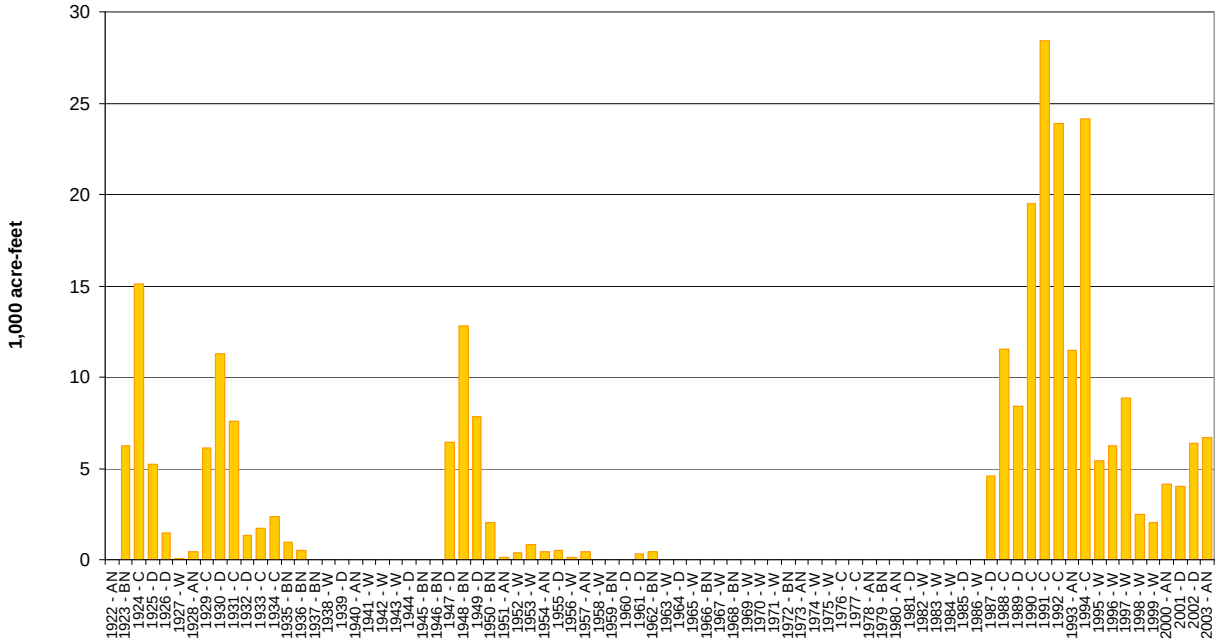


FIGURE 11-43
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

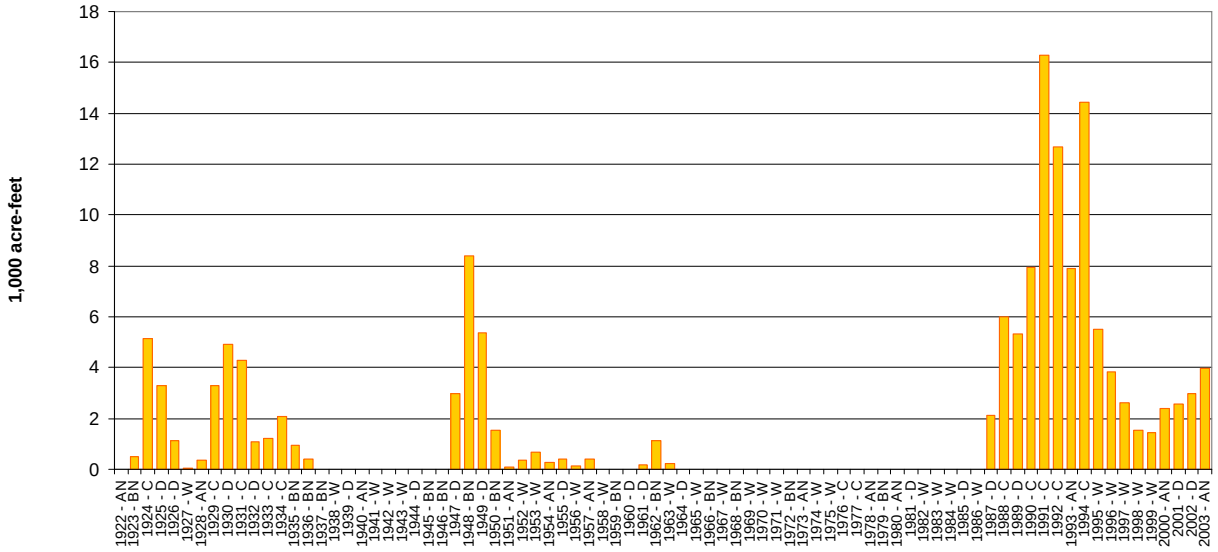


FIGURE 11-44
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 2 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-43 and 11-44 show smaller peak reservoir releases to compensate for conjunctive management pumping for a new well field screen in the deep aquifer than for pumping existing wells. This reflects smaller streamflow reductions for a new well field at the higher pumping volumes simulated in Scenario 2.

11.3 Scenario 3 – 100 TAF GCID, 50 TAF Butte Basin, Fall Pumping

Scenario 3 has the same general reservoir release strategies and groundwater pumping capacities as Scenario 1. The difference is the season for conjunctive management pumping. Under Scenario 3 conjunctive management pumping for the purpose of recovering reservoir storage levels is conducted from September through November. Instead of offsetting irrigation season demands, this pumping is assumed to offset demands for rice straw decomposition and waterfowl habitat.

Shifting the conjunctive management pumping season may have several benefits. First, peak drawdown in the aquifers and resulting effects on nearby wells would occur outside of the primary pumping season for most existing wells. Second, a greater portion of aquifer recharge may occur during the winter rainy season when the surface water system is more likely to be in a surplus condition. Third, it may be easier to reduce fall reservoir releases to recover reservoir levels in the fall of dry years and still meet existing temperature control criteria on the Sacramento River.

A majority of results for Scenario 3 are the same as for Scenario 1 because spring and summer surface water operations do not change. The same environmental objectives are met, and the average annual releases for both environmental and agricultural objectives are the same. Reservoir refill for both Shasta and Oroville occurs with the same mix and timing of surplus surface water and groundwater pumping. There are minor differences in end of September storage in each reservoir under Scenario 3. These differences are in years when conjunctive management pumping occurs, but is not yet complete, by the end-of-September. Figures 11-45 and 11-46 illustrate this effect for both Shasta and Oroville.

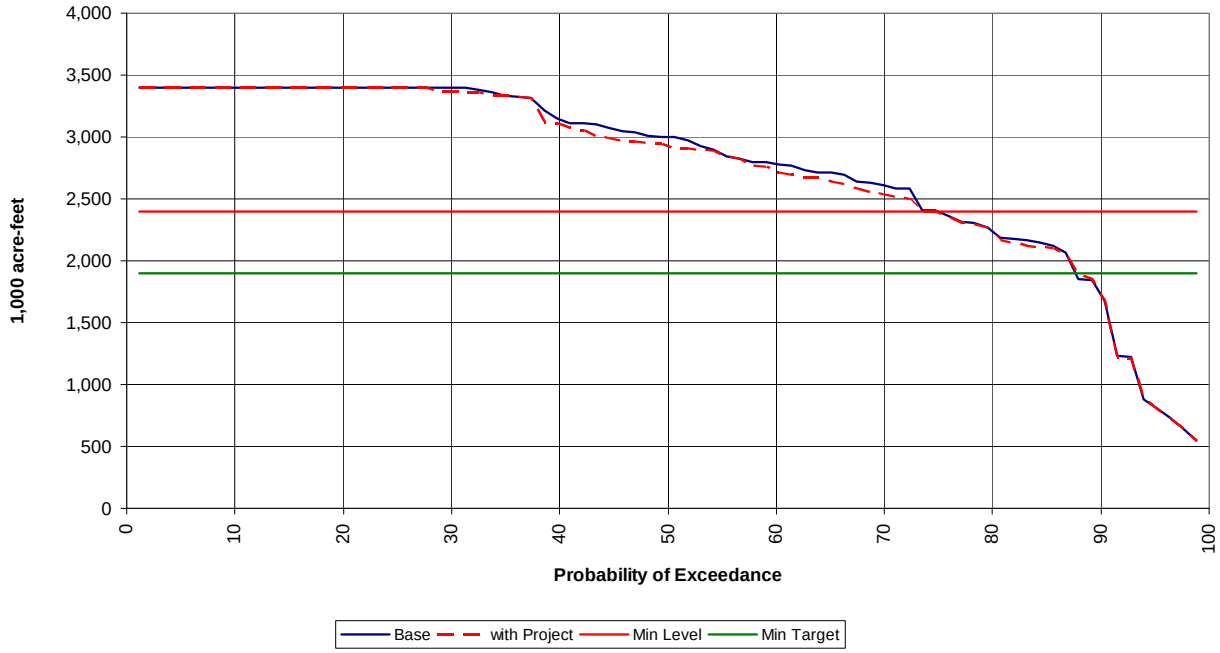


FIGURE 11-45
SHASTA RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 3
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-45 shows some minor differences between base conditions and Scenario 3 when end-of-September Shasta storage levels are below 2,400 TAF. In these years, conjunctive management pumping is occurring September through November so that the reservoir is recovered by the end of November and there is no risk to future water supplies or cold water pool.

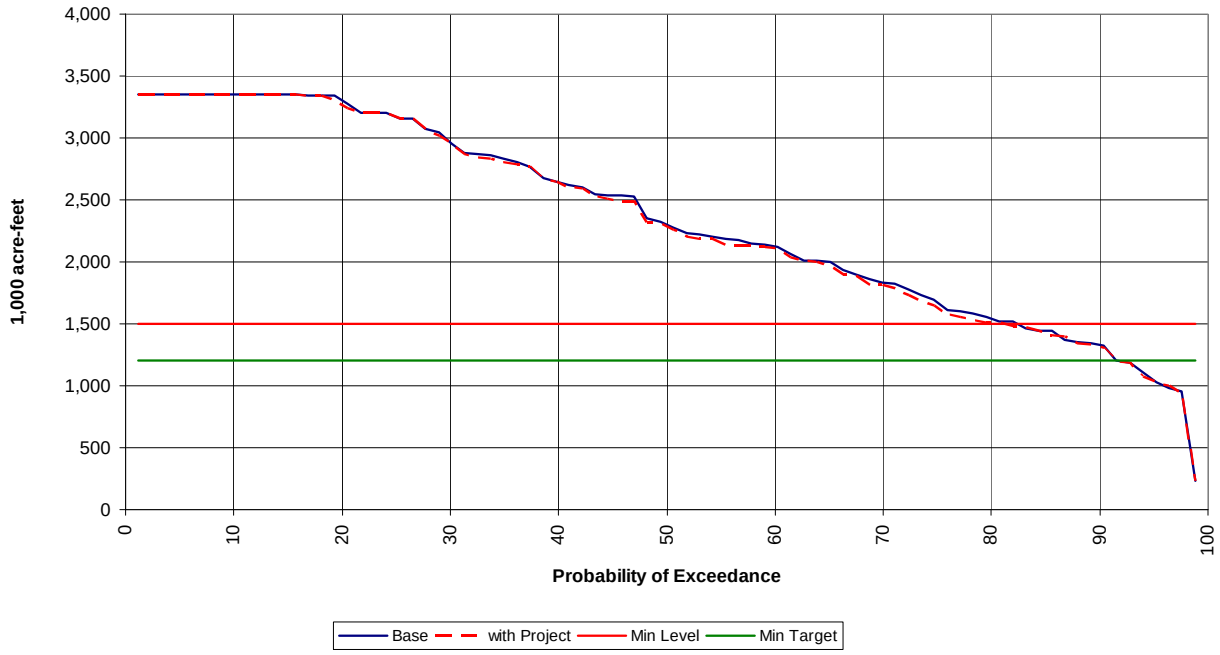


FIGURE 11-46
OROVILLE RESERVOIR SEPTEMBER STORAGE EXCEEDANCE PROBABILITY WITH CONJUNCTIVE MANAGEMENT, SCENARIO 3
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 11-46 illustrates a similar effect on Oroville Reservoir, but it is less clear due to the smaller difference between base and with project storages.

11.3.1 Groundwater Results

Existing Well Field

Results of pumping for Scenario 3 with an existing well field are summarized on Figures 11-47 through 11-49. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-47. This figure depicts simulated drawdown in the pumped aquifer during November 1990. Maximum pumping rates under this alternative occur during 1990. Figure 11-47 shows that the area of greatest drawdown occurs in the northern GCID area at a magnitude of up to 50 feet.

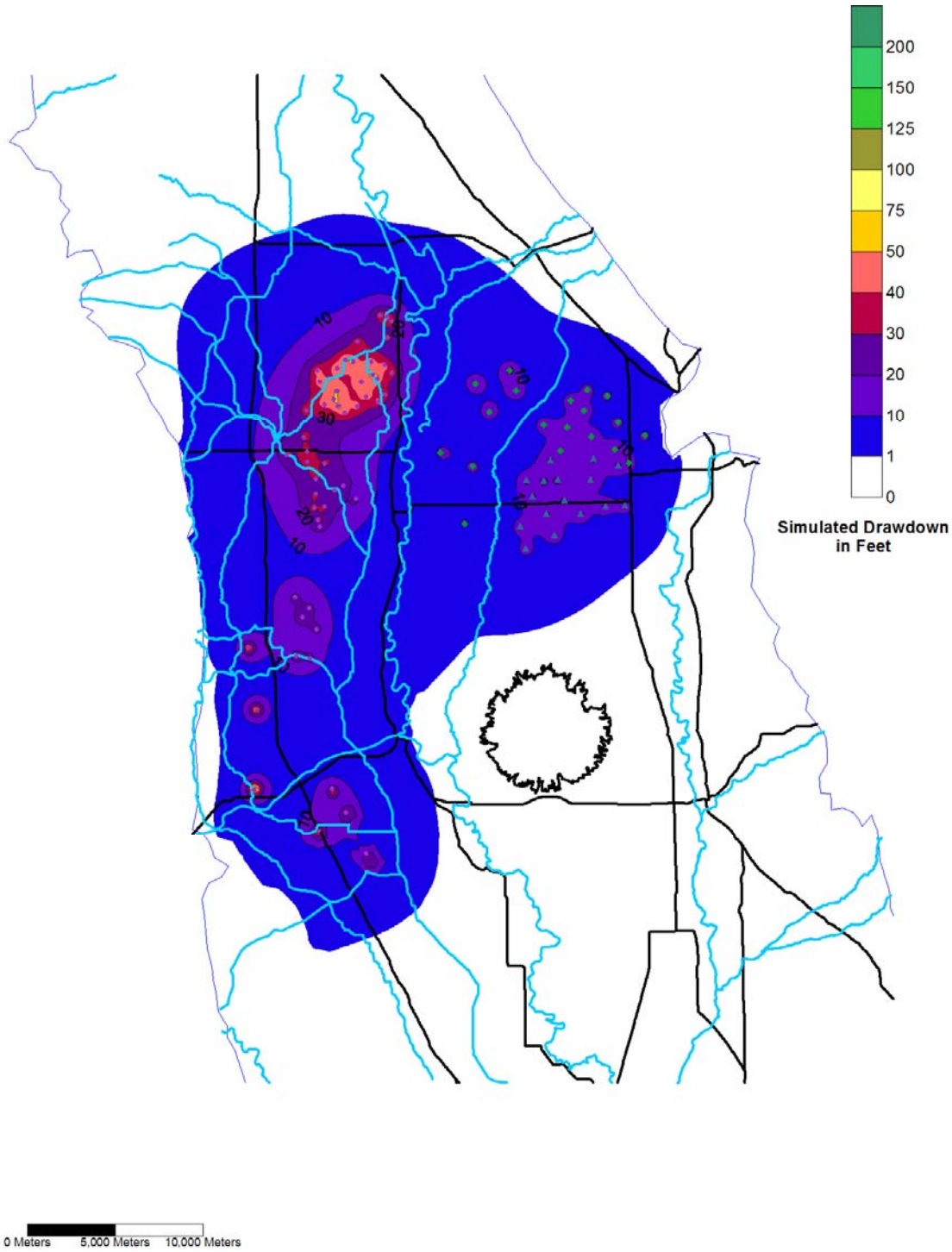


FIGURE 11-47
SIMULATED DRAWDOWN IN THE REGIONAL AQUIFER IN NOV 1990, SCENARIO 3 -EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 3 with an existing well field are summarized on Figures 11-48 and 11-49. These figures show that the greatest impact to surface streams will occur to the Sacramento River (between GCID and Wilkins Slough) and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-48 suggests that peak cumulative impact to all surface water flows will be approximately 80 cfs in the summer of 1990, with a flow reduction of approximately 50 cfs forecast to occur on the Sacramento River and a flow reduction of approximately 18 cfs on Butte Creek. Peak impact to the Sacramento River will also occur in late summer of 1990 while peak impact on Butte Creek is forecasted to occur in late 1994. Peak impacts to stream flows on smaller tributary streams peak at less than approximately 7 cfs, as shown on Figure 11-48.

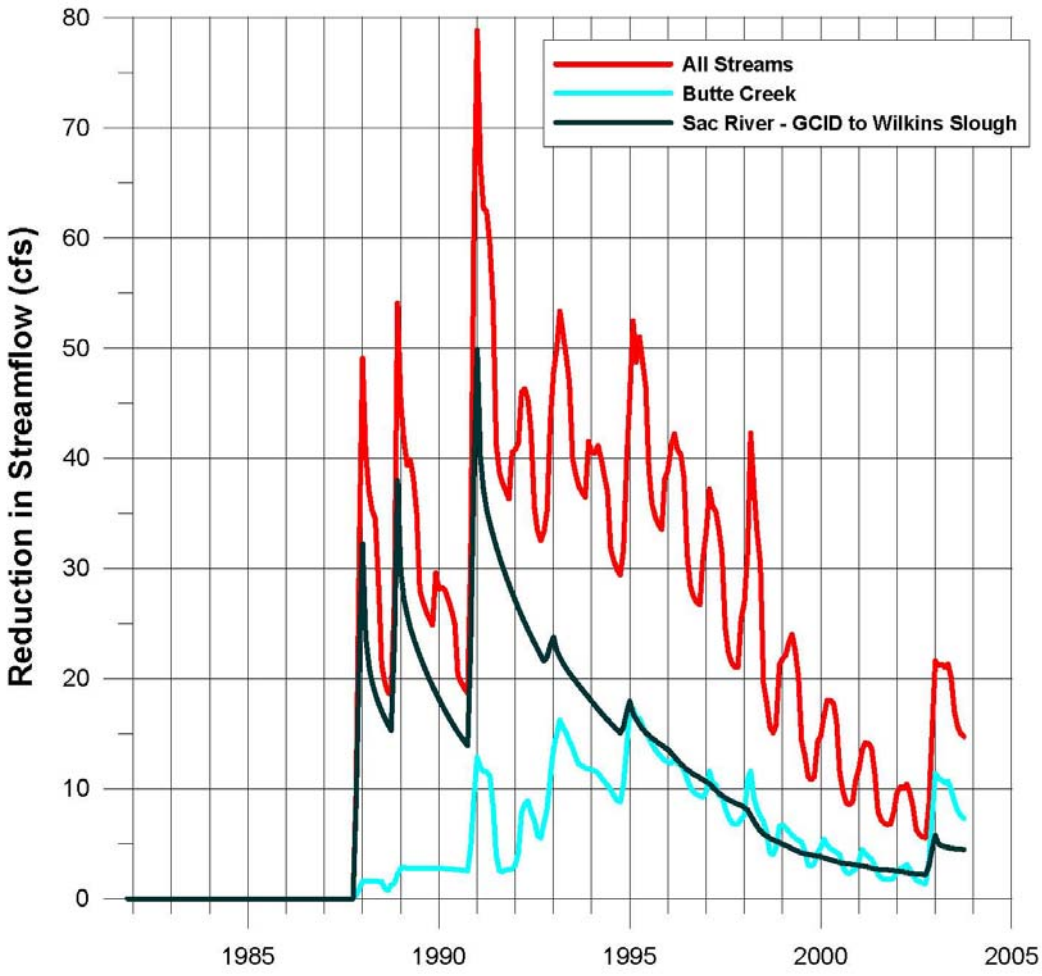


FIGURE 11-48
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

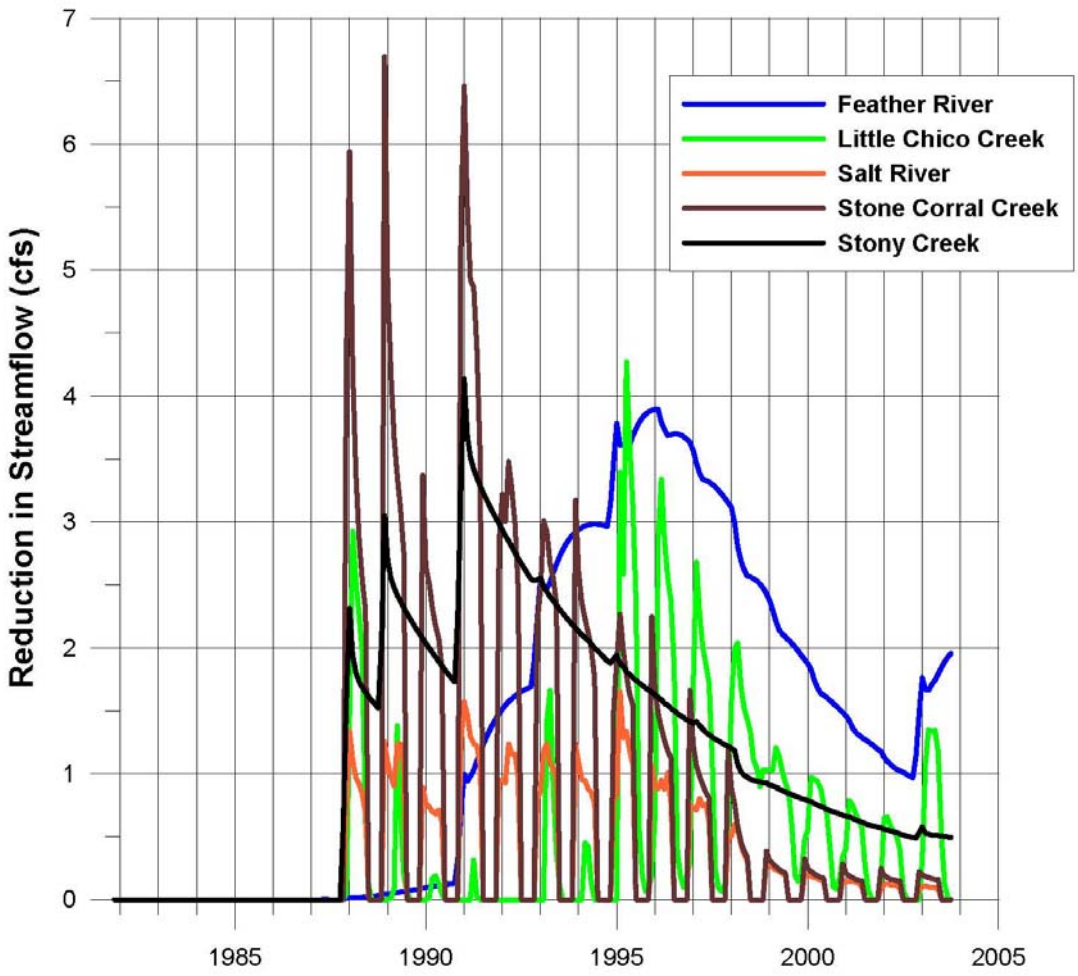


FIGURE 11-49
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes to upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-50 and 11-51 present annual additional releases from Shasta and Oroville, respectively, for Scenario 3 pumping from an existing well field.

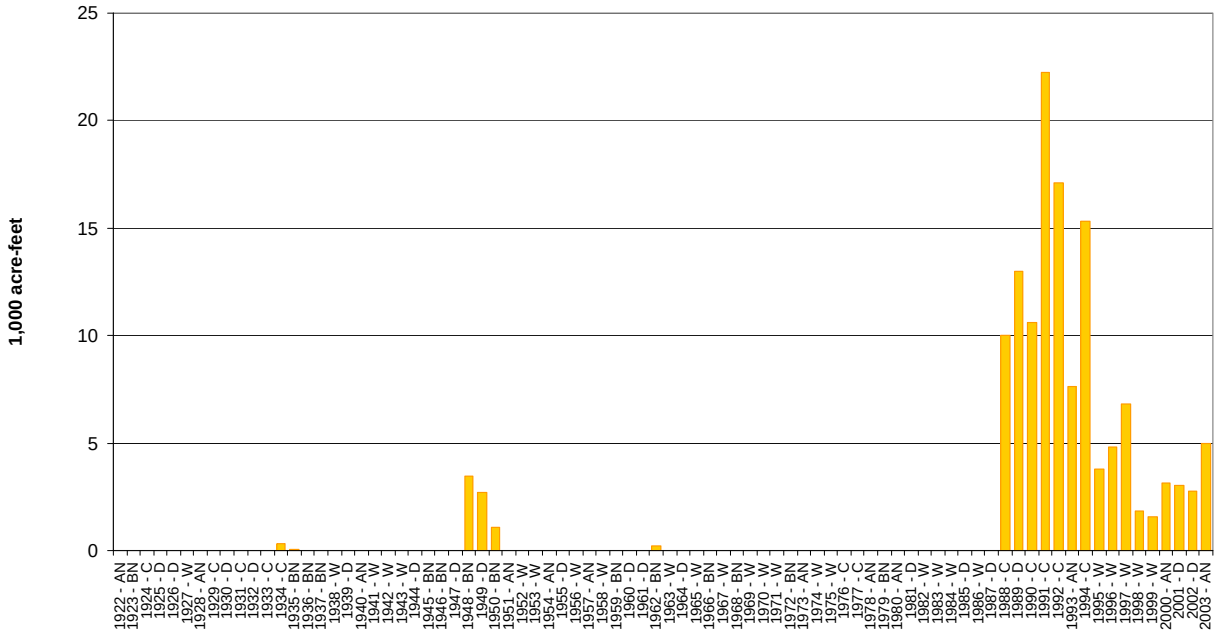


FIGURE 11-50
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

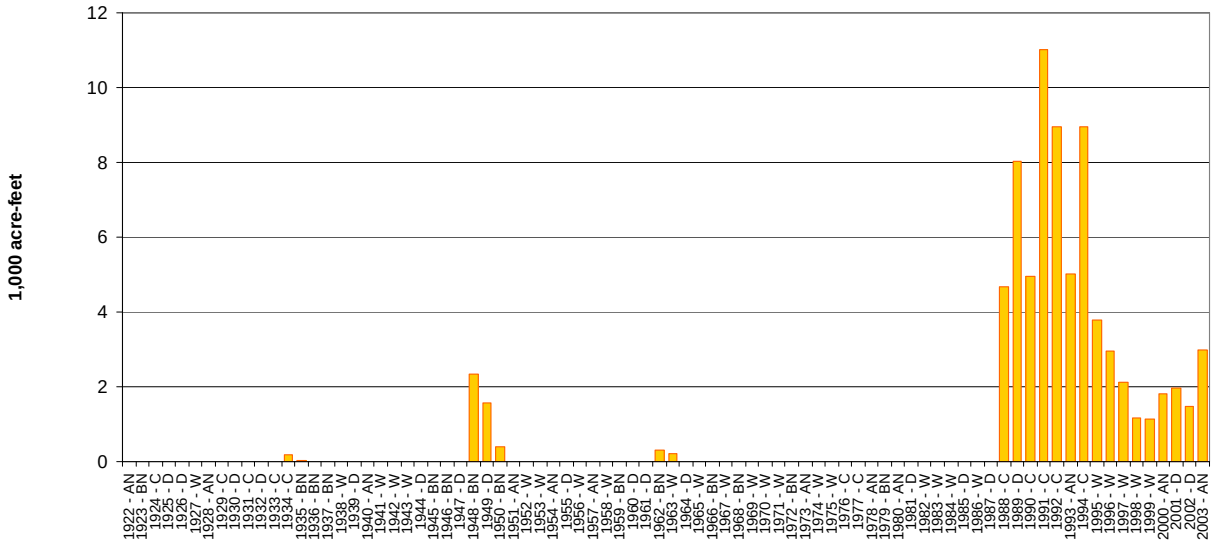


FIGURE 11-51
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-50 and 11-51 show that peak annual releases are larger under Scenario 3 for the more condensed fall pumping season than under Scenario 1. General timing and volumes are similar between the two scenarios.

New Well Field

Results of Scenario 3 with a new well field are summarized on Figures 11-52 through 11-54. The peak drawdown in groundwater levels associated with the implementation of this alternative is presented on Figure 11-52. This figure depicts the simulated drawdown in the pumped aquifer, during November 1990. The maximum pumping rates under this alternative occur during 1990. It can be seen from the figure that the area of greatest drawdown occurs in the western GCID area at a magnitude of up to 125 feet.

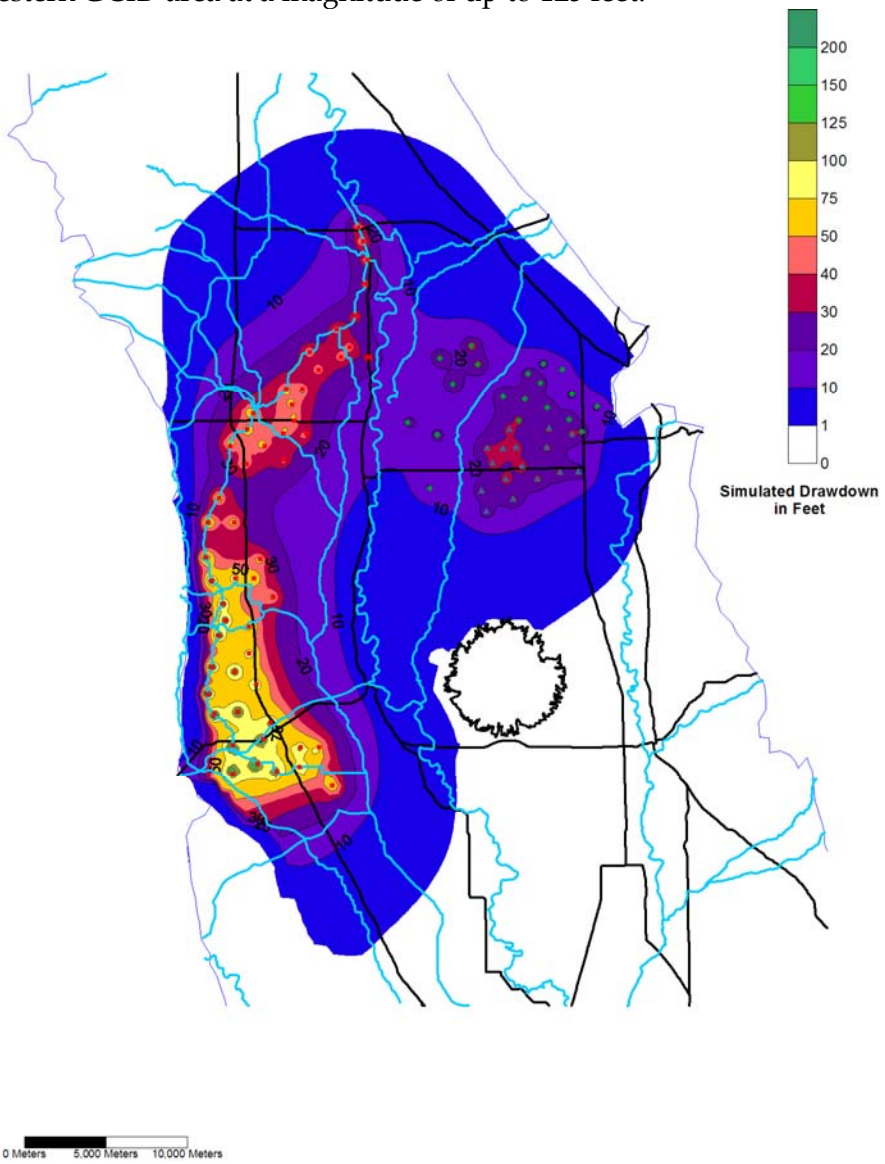


FIGURE 11-52
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 3 with a new well field are summarized on Figures 11-53 and 11-54. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-44 suggests that the peak cumulative impact to all surface water flows will be a reduction of about 90 cfs in December 1990, while a flow reductions of just more than 48 and 18 cfs is forecasted to occur on the Sacramento River and Butte Creek, respectively. Peak impact to the Sacramento River will also occur in December 1990 while peak impact predicted on Butte Creek will occur in December 1994. Peak impacts to stream flows on smaller tributary streams peak at less than about 10 cfs as shown on Figure 11-54.

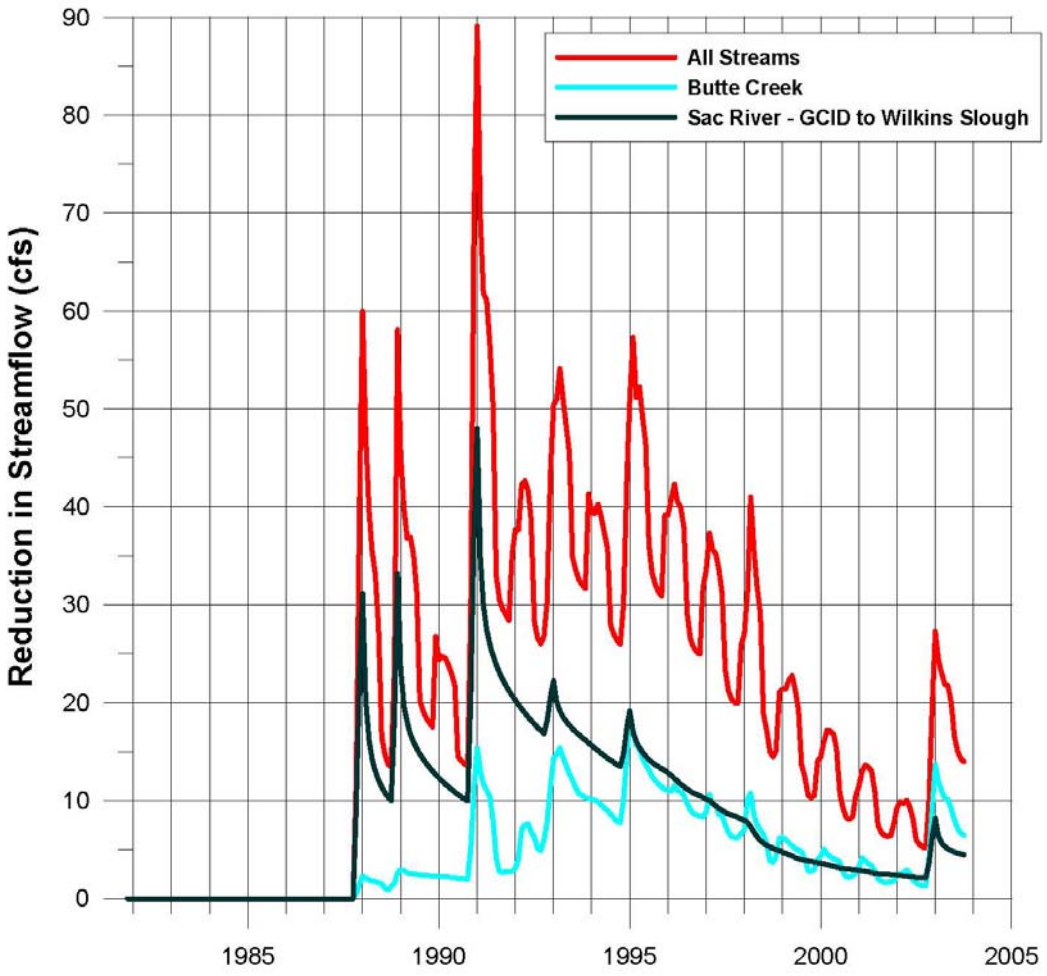


FIGURE 11-53
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 3 -NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

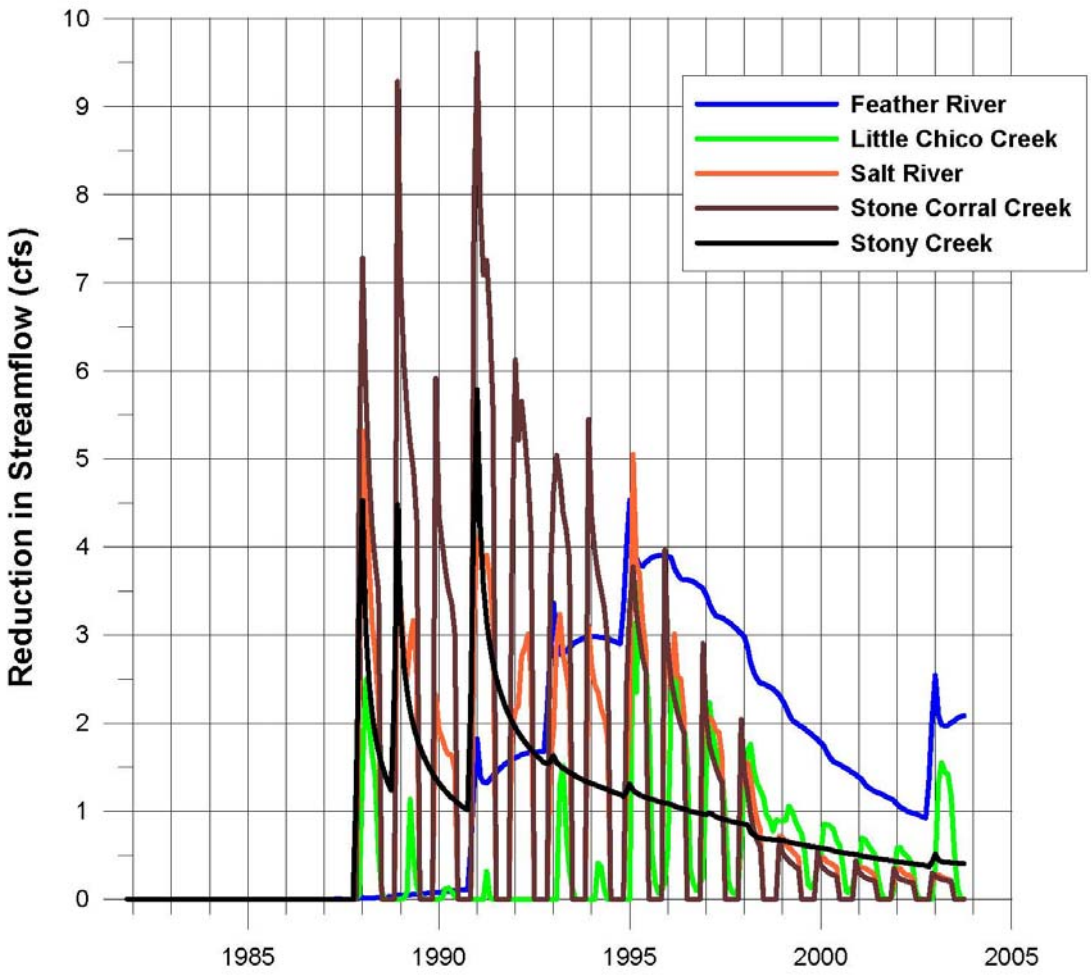


FIGURE 11-54
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 3 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Reservoir Release for Recharge

Streamflow reductions, due either to increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-55 and 11-56 present annual additional releases from Shasta and Oroville, respectively, for Scenario 3 pumping from a new well field.

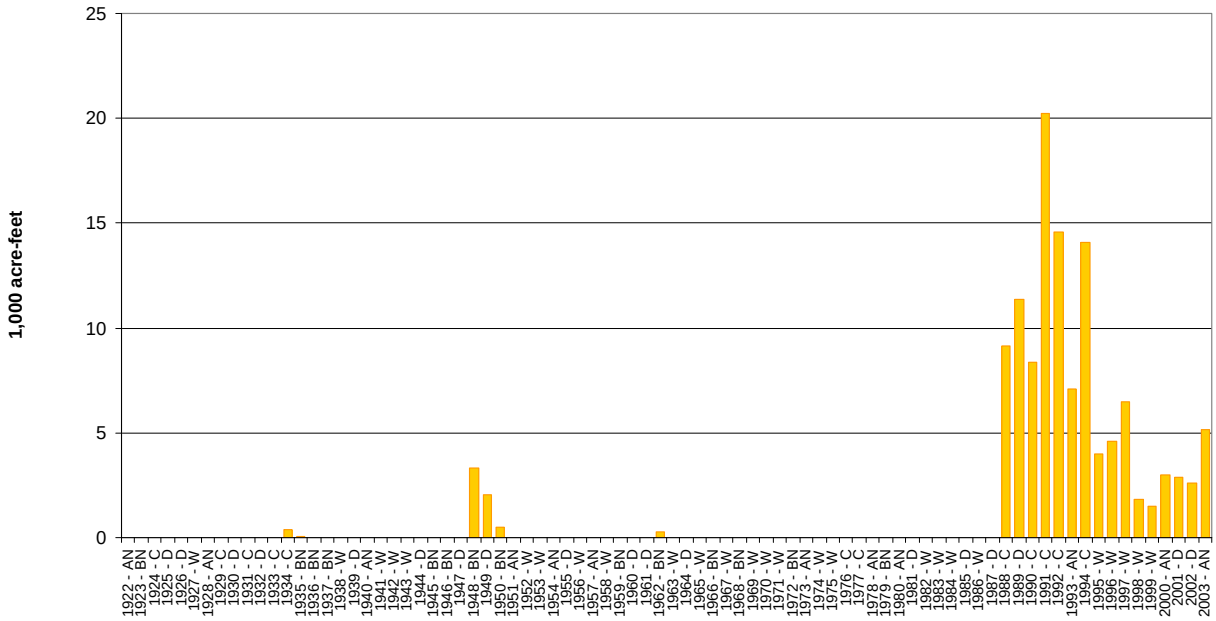


FIGURE 11-55
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

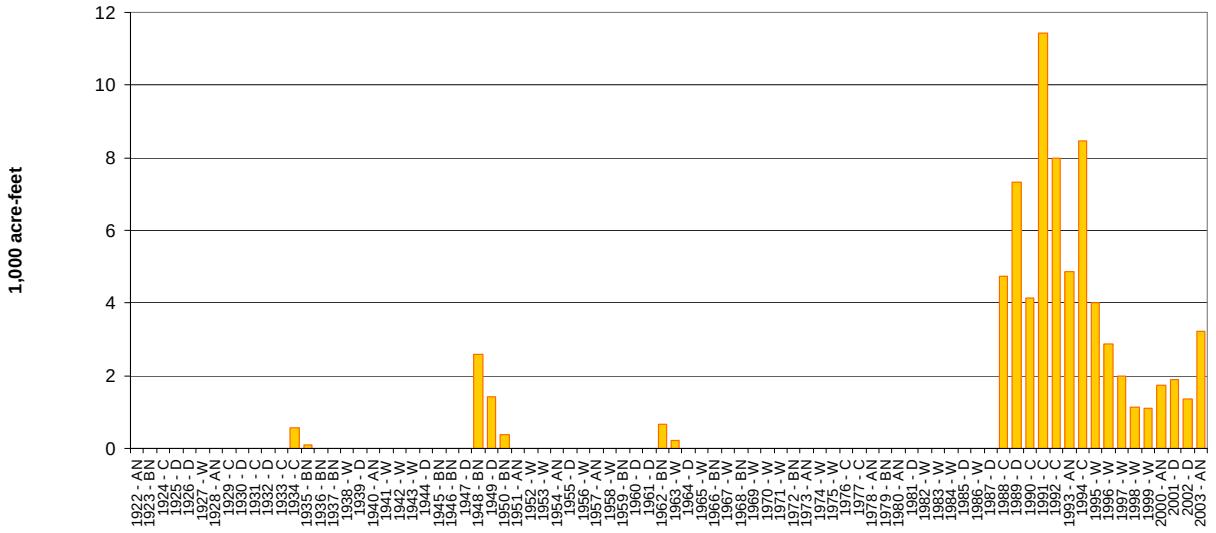


FIGURE 11-56
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 3 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-54 and 11-55 illustrate that maximum annual release from Shasta for a new well field is less than for the existing well field, while results are essentially the same on the Feather River.

11.4 Scenario 4 – 100 TAF GCID, 50 TAF Butte Basin, Summer and Fall Pumping

Scenario 4 has the same general reservoir release strategies and groundwater pumping capacities as Scenarios 1 and 3. The difference is again the season for conjunctive management pumping. Under Scenario 4 conjunctive management pumping is conducted in both the summer and fall from May through November. This pumping is used to offset both irrigation season demands and demand for rice straw decomposition water. Pumping over an extended period may provide benefits by reducing the quantity of water that must be pumped in any given month, thereby reducing the size and/or number of wells needed. Additionally, spreading pumping over a longer period may reduce drawdown and stream impacts.

Surface water results for Scenario 4 are similar to those presented for Scenario 1. The same environmental objectives are met, and the average annual releases for both environmental and agricultural objectives are the same. Reservoir refill for both Shasta and Oroville occurs with the same mix and timing of surplus surface water and groundwater pumping. Changes in end-of September storage in the reservoirs presented above for Scenario 3 are smaller in magnitude because under Scenario 4 the majority of conjunctive management pumping has occurred prior to the end of September. The minor differences seen under Scenario 4 are difficult to discern and are therefore not presented.

11.4.1 Existing Well Field

Results for Scenario 4 with an existing well field are summarized on Figures 11-57 through 11-58. Peak drawdown in groundwater levels associated with implementing this alternative is presented on Figure 11-57. This figure depicts simulated drawdown in the pumped aquifer, during November 1990. Maximum pumping rates under this alternative occur during 1990, and the drawdown distribution at the end of November represents approximately the maximum drawdown that will occur under this scenario. Figure 11-57 that the area of greatest drawdown occurs in northern GCID at a magnitude of less than 30 feet.

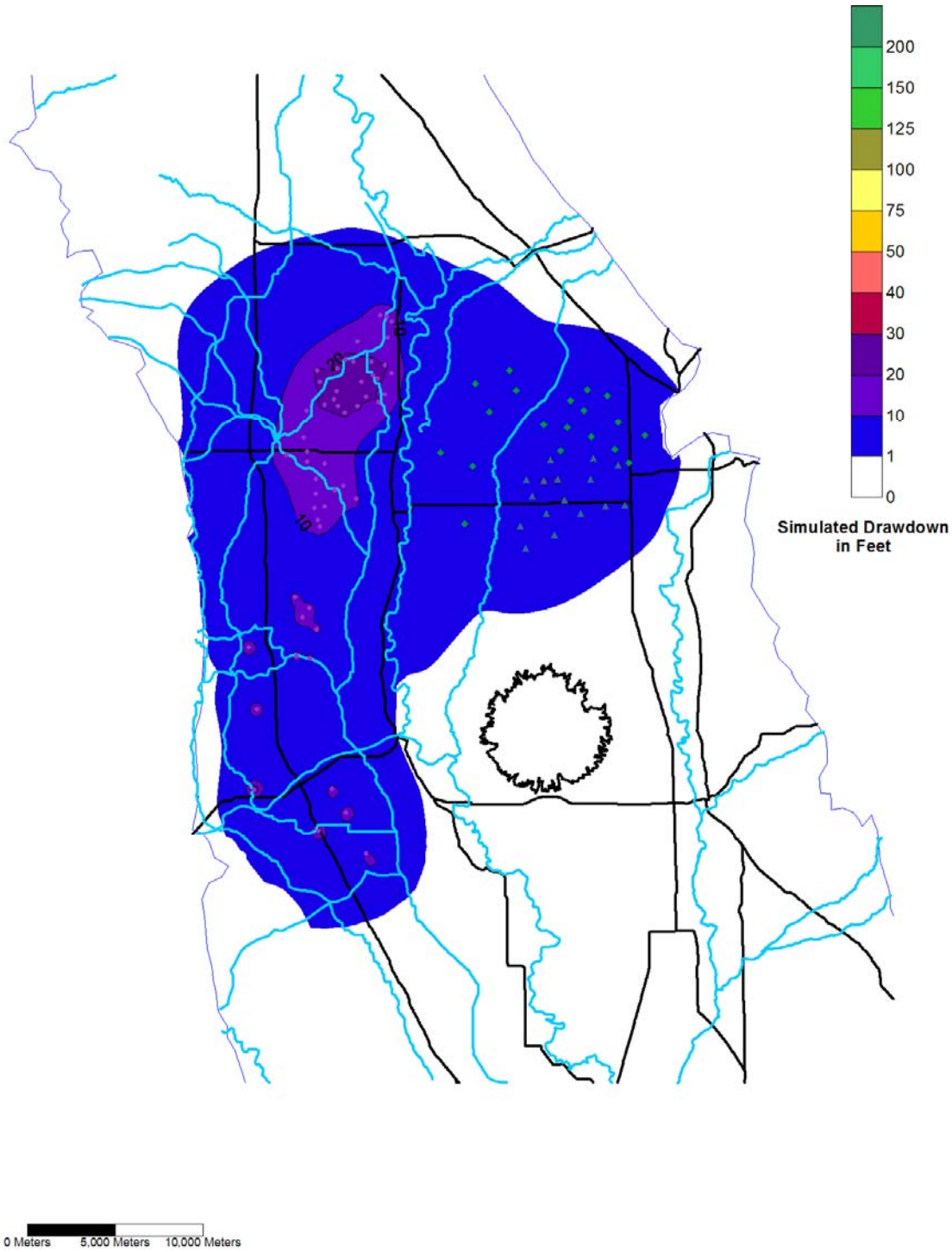


FIGURE 11-57
SIMULATED DRAWDOWN IN THE REGIONAL AQUIFER IN NOV 1990, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams under Scenario 4 with an existing well field are summarized on Figures 11-58 and 11-59. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-58 shows that the peak cumulative impact to all surface water flows will be approximately 64 cfs in December 1990, with a flow reduction of just less than 40 cfs forecasted to occur on the Sacramento River and a flow reduction of about 15 cfs on Butte Creek. Peak impact to the Sacramento River will also occur in December of 1990 while the peak impact on Butte Creek is forecast to occur in late 1995. Peak impacts to stream flows on smaller tributary streams peak at less than approximately 6 cfs, as shown on Figure 11-59.

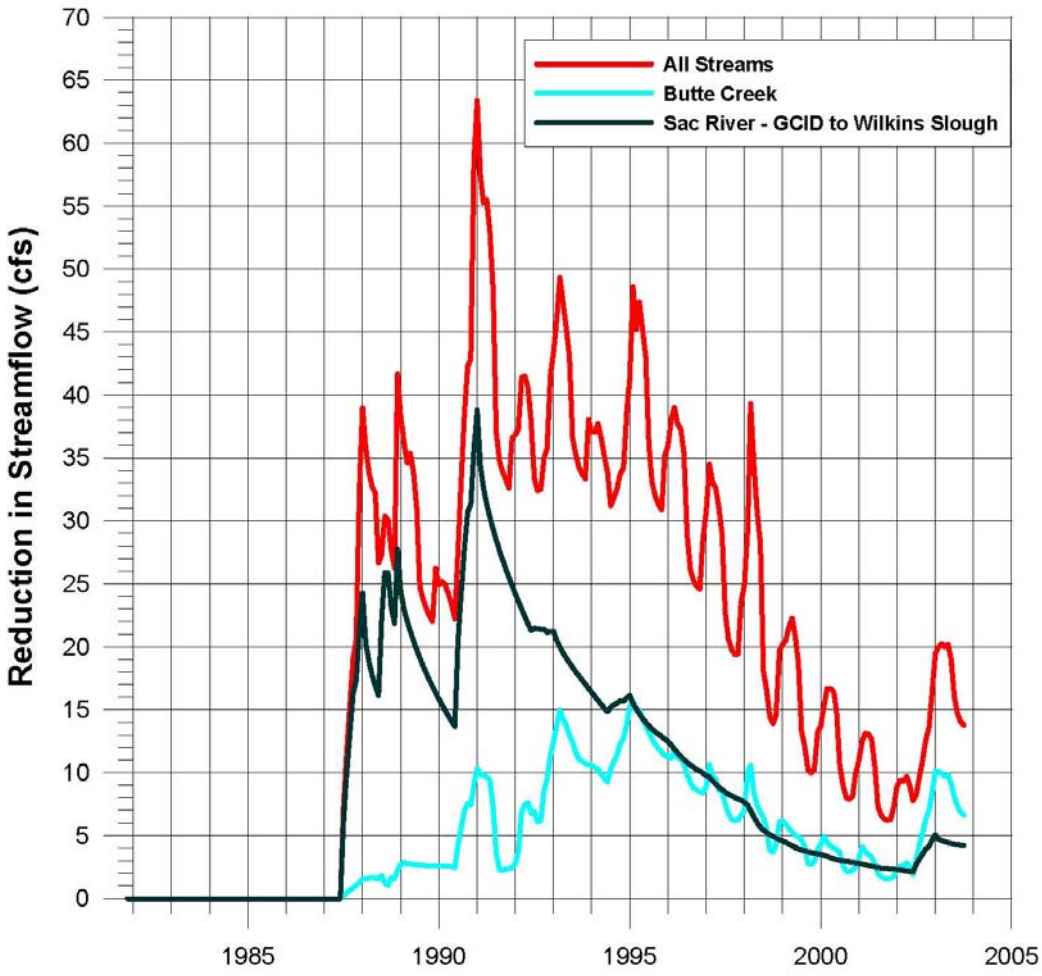


FIGURE 11-58
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

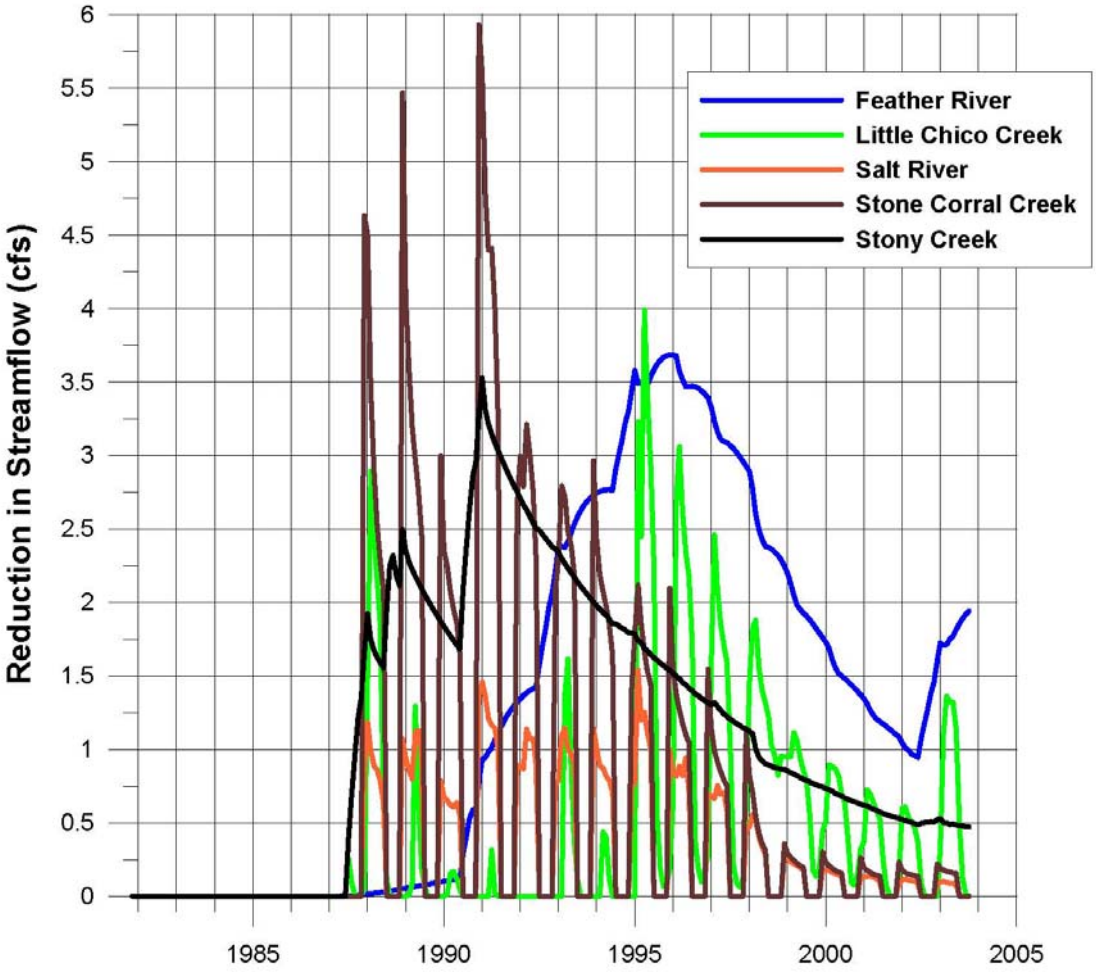


FIGURE 11-59
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.4.2 Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions upstream, reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-60 and 11-61 present annual additional releases from Shasta and Oroville, respectively, for Scenario 4 pumping from an existing well field.

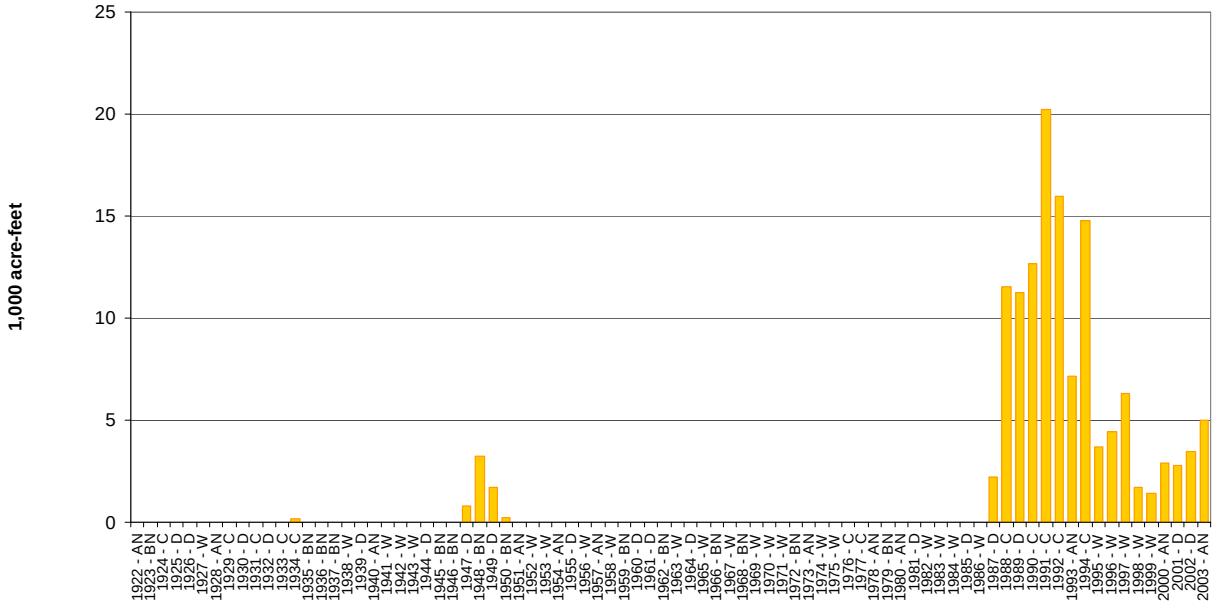


FIGURE 11-60
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

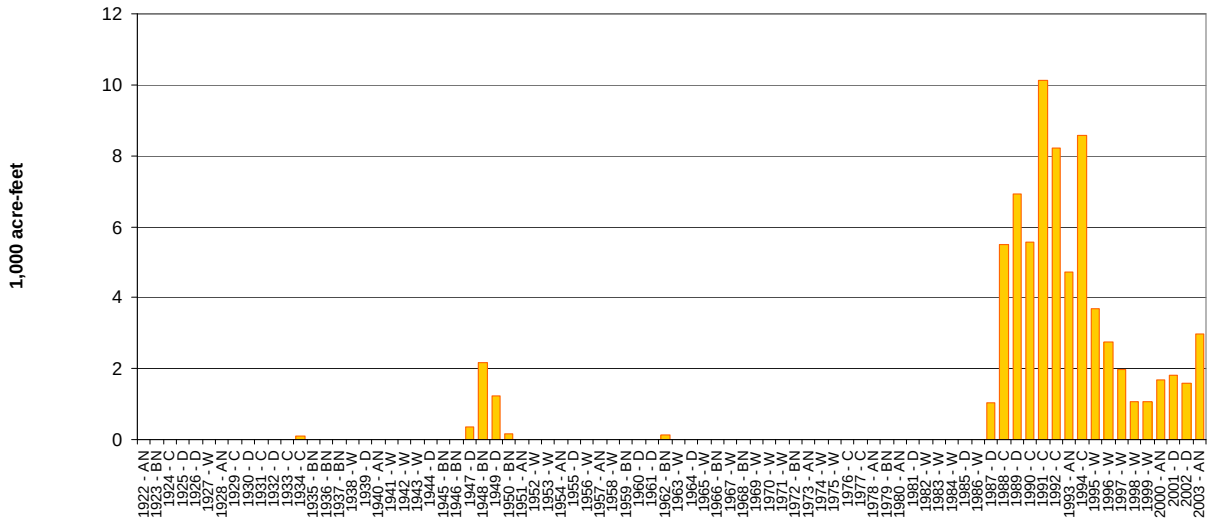


FIGURE 11-61
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - EXISTING WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figures 11-60 and 11-61 indicate that the pattern and volume of additional reservoir release for Scenario 4 is similar to that for Scenarios 1 and 3 with the maximum annual release approximately between those two scenarios.

11.4.3 New Well Field

Results of simulation of pumping from a new well field under Scenario 4 are summarized on Figures 11-62 through 11-64. Peak drawdown in groundwater levels associated with implementation of this alternative is presented on Figure 11-62. This figure depicts simulated drawdown in the pumped aquifer during November 1990. Maximum pumping rates under this alternative occur during 1990, and the drawdown distribution at the end of November represents approximately the maximum drawdown that will occur under this alternative. It can be seen from the figure that the greatest drawdown occurs in the western GCID area at a magnitude of up to 50 feet.

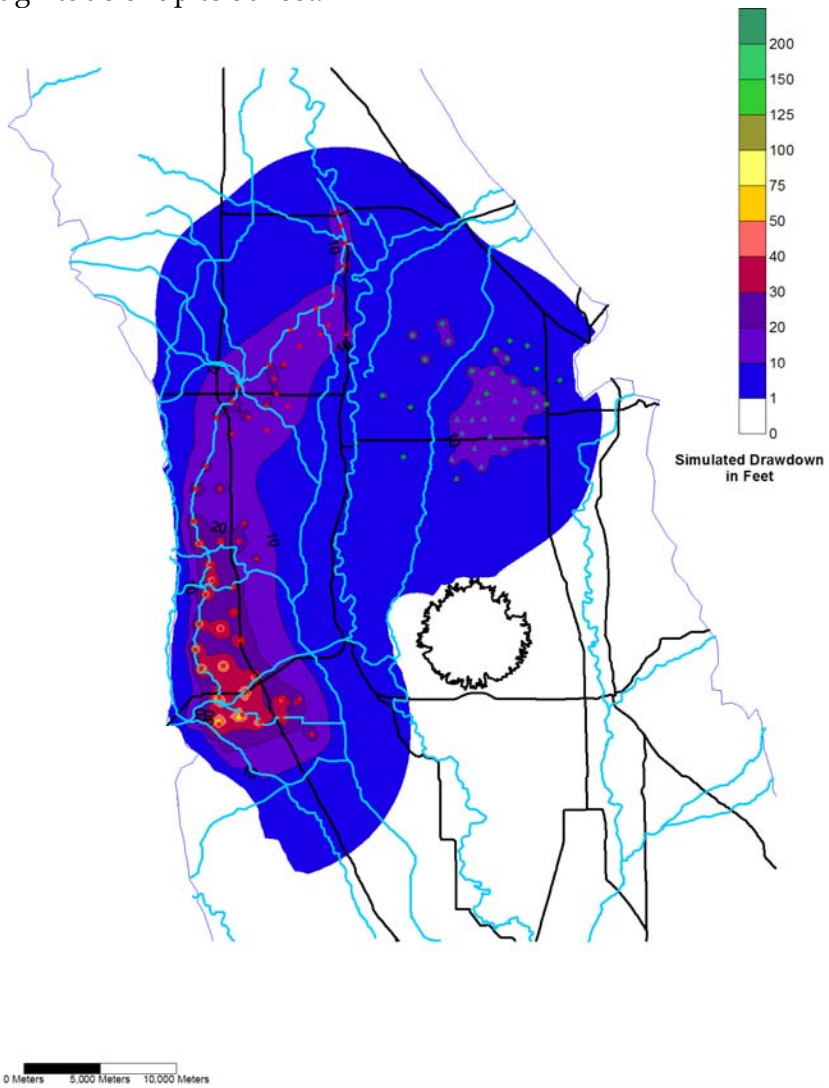


FIGURE 11-62
SIMULATED DRAWDOWN IN THE DEEP AQUIFER IN NOV 1990, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Simulated impacts to surface streams for Scenario 4 with a new well field are summarized on Figures 11-63 and 11-64. These figures show that the greatest impact to surface streams will occur to the Sacramento River, between GCID and Wilkins Slough, and Butte Creek, with smaller impacts estimated to occur to surrounding streams. Figure 11-63 shows that peak cumulative impact to all surface water flows will be a reduction of approximately 65 cfs in December 1990, while a flow reduction of just more than 33 cfs is forecasted to occur on the Sacramento River and a flow reduction of about 15 cfs is predicted on Butte Creek. Peak impact to the Sacramento River will also occur in December 1990 while peak impacts on Butte Creek occur in December 1995. Peak impacts to stream flows on smaller tributary streams peak at less than about 9 cfs, as shown on Figure 11-64.

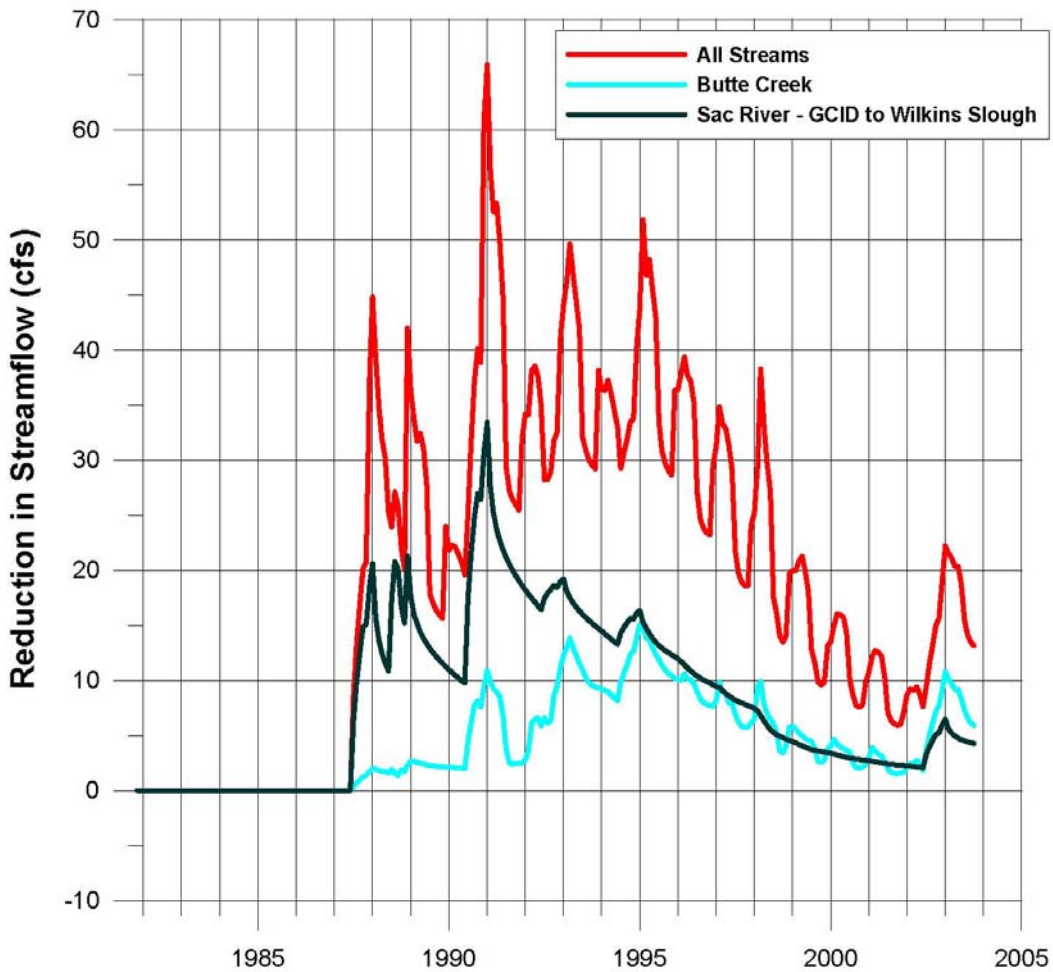


FIGURE 11-63
SIMULATED REDUCTION IN STREAMFLOW TO MAJOR STREAMS, SCENARIO 4 -NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

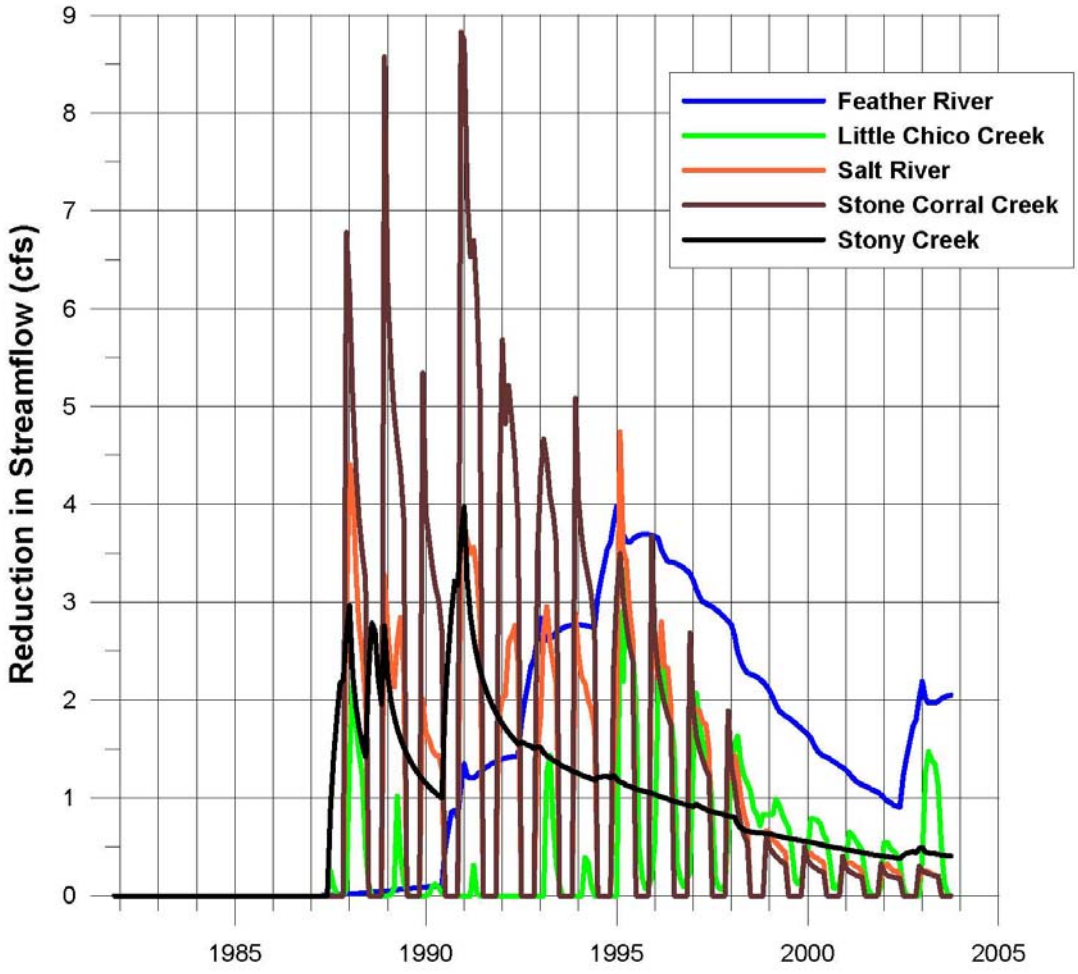


FIGURE 11-64
SIMULATED REDUCTION IN STREAMFLOW TO MINOR STREAMS, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

11.4.4 Reservoir Release for Recharge

Streamflow reductions, due to either increased stream loss to aquifers or decreased aquifer flow into streams, may result in changes in upstream reservoir operations. Time series of simulated streamflow reductions from the groundwater model were input back into the surface water model to determine system conditions at times when reductions occur. Depending on location and timing of reductions, upstream reservoirs may be required to make additional releases to compensate for streamflow reductions due to groundwater pumping. System conditions, either balanced or surplus, were determined from the CalSim II simulation of CVP/SWP operations. Additional releases from Shasta and Oroville were simulated and tracked in the surface water model. Figures 11-65 and 11-66 present annual additional releases from Shasta and Oroville, respectively, for Scenario 4 pumping from a new well field.

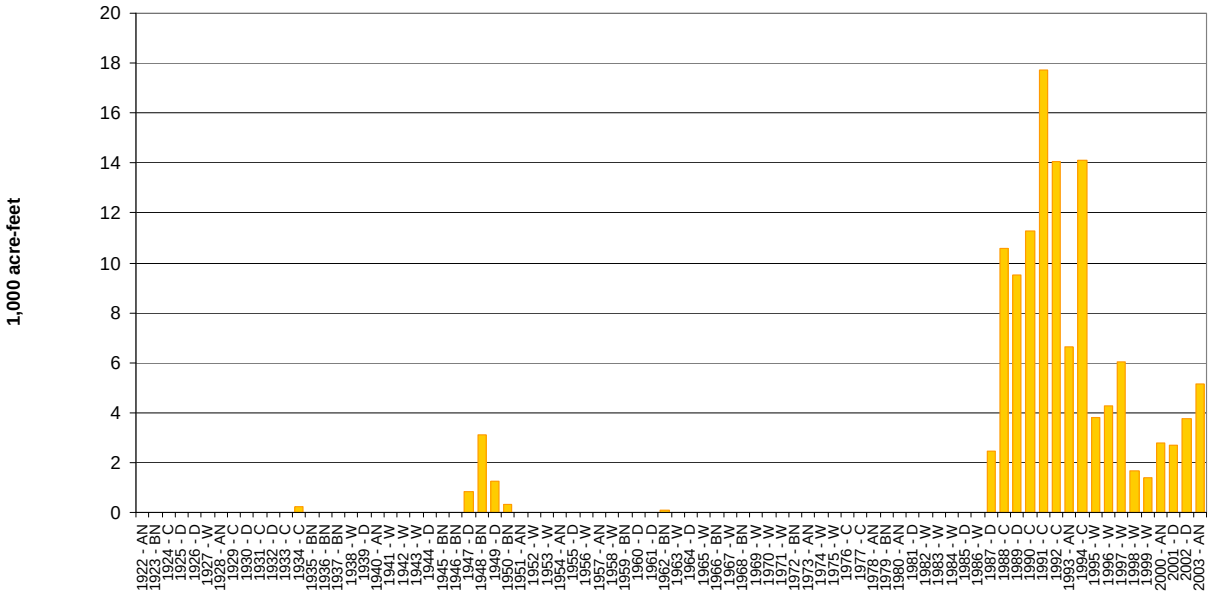


FIGURE 11-65
ANNUAL ADDITIONAL RELEASE FROM SHASTA RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

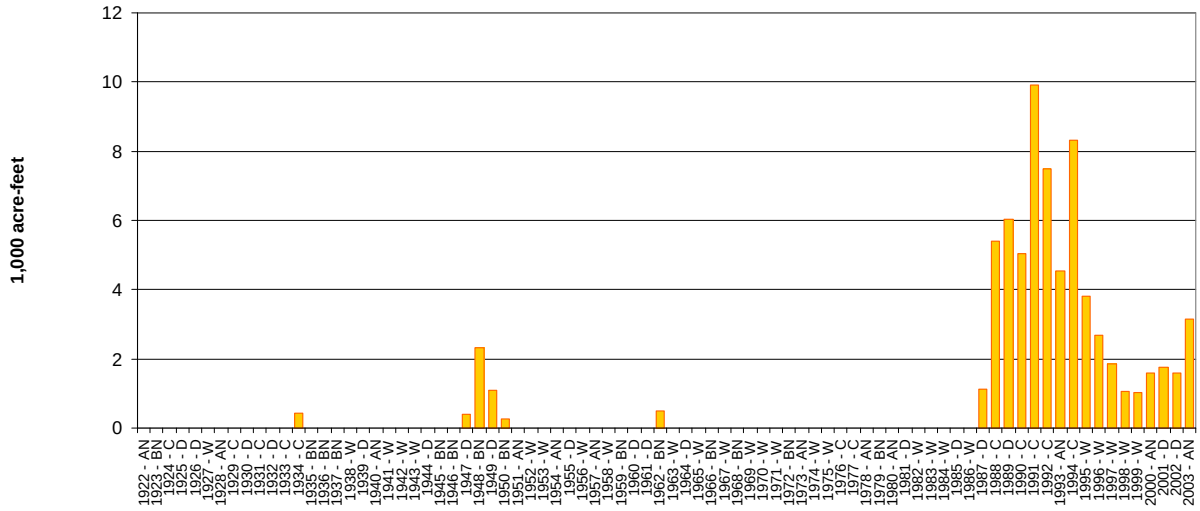


FIGURE 11-66
ANNUAL ADDITIONAL RELEASE FROM OROVILLE RESERVOIR TO COMPENSATE FOR CHANGE IN STREAM-AQUIFER INTERACTION, SCENARIO 4 - NEW WELL FIELD
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

SECTION 12

Sensitivity Analysis and Tradeoffs

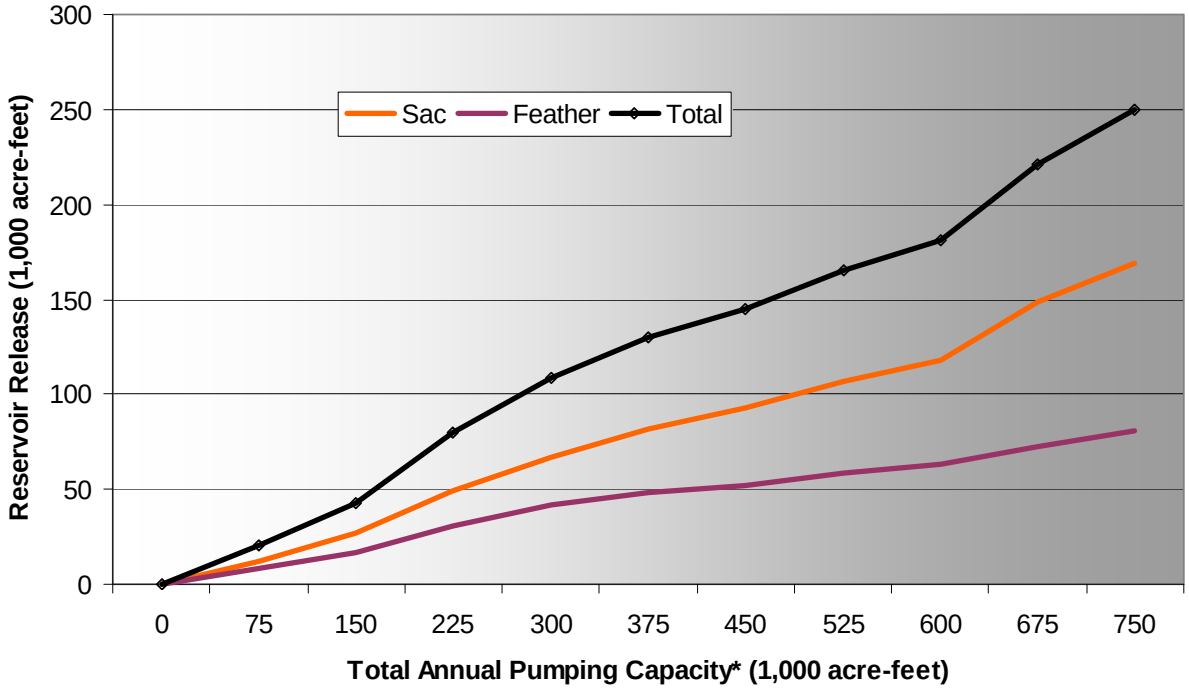
Simulation results presented in the previous section represent specific project sites and operations developed during the course of the analysis. Additional understanding of tradeoffs between certain key parameters and objectives can be gained from using the model in a sensitivity analysis mode in which or a limited number of parameters are varied while holding all other assumptions constant. This section presents results and conclusions for a limited set of model runs focused on better understanding key project inputs and assumptions.

Sensitivity analysis was conducted for several purposes. Sensitivity to parameters, such as project pumping capacity, was evaluated to assist in sizing potential projects. A range of environmental objectives were evaluated because considerable uncertainty exists in the development of objectives, and evaluating a range of possible objectives can help determine how much more or less conjunctive management could contribute to higher or lower flow targets. Evaluating various pumping periods and well field configurations was used to understand how aquifers respond to different pumping magnitudes and durations and the effects on stream-aquifer interactions.

12.1 Pumping Capacity

The surface water model was used to simulate a wide range of project pumping capacities and determine project benefits. Results of these simulations were one factor considered in determining final project capacities. The surface water model was used to simulate a range of pumping capacities to determine if certain capacities provided higher levels of project benefits. Project benefits were summarized as average annual reservoir release for both agricultural and environmental objectives.

Figure 12-1 illustrates that project benefits increase at different rates for different ranges of pumping capacities. For example, the incremental benefit of an additional 75 TAF of pumping capacity is greater when increasing pumping capacity from 150 to 225 TAF of total capacity than it is when increasing from 75 to 150 TAF, as illustrated by the steeper slope in the line. Benefits of incremental increases are smaller from 300 to 600 TAF (less steep line) and then increase again above 600 TAF. However, Figure 12-1, is shaded at the higher pumping capacities because projects of this size are not feasible and are not proposed for this project.



**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-1
TOTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
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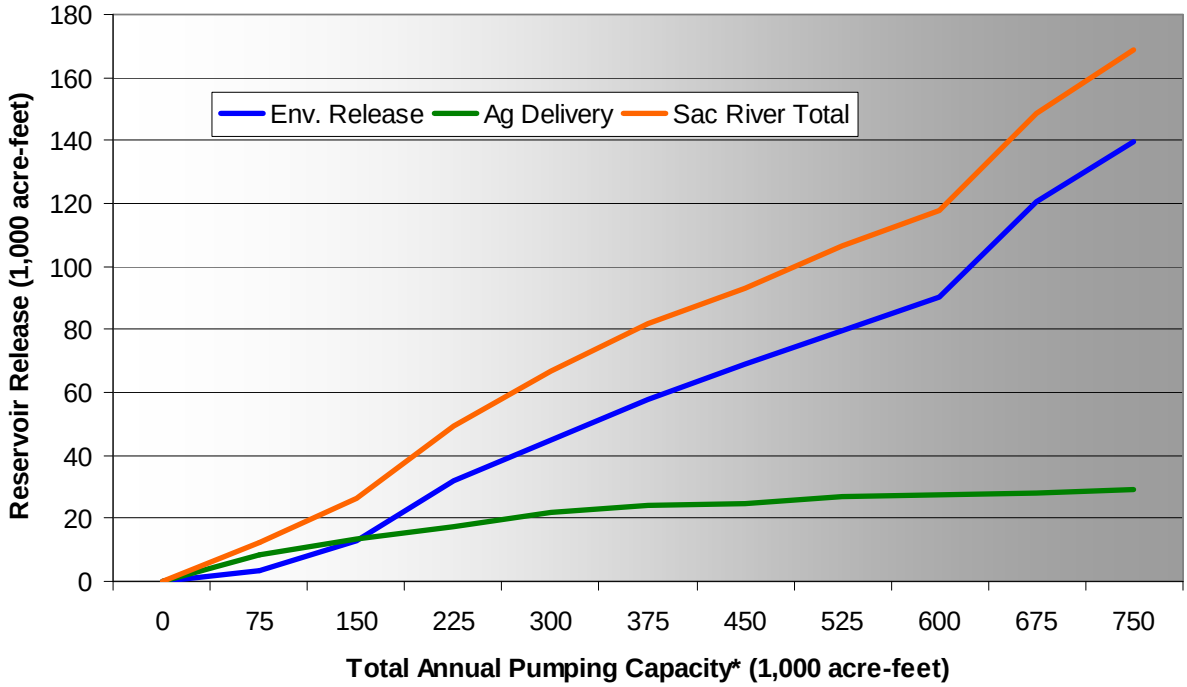
Figure 12-1 illustrates that projects between 75 and 150 TAF of pumping capacity have approximately the same marginal benefits when adding additional capacity. Figure 12-1 also illustrates that projects with 300 TAF may provide a good tradeoff at the upper end of the curve between pumping capacity and project benefits and that marginal benefits of increasing pumping capacity above 300 TAF are smaller than those realized by increasing from 150 to 300 TAF.

Project benefits presented on Figure 12-1 were compiled from reservoir releases to meet agricultural and environmental objectives. The model was set to first meet environmental objectives because of the all-or-nothing nature of those objectives. Figures 12-2 and 12-3 show the tradeoff between meeting agricultural and environmental objectives that occurs across a range of project pumping capacities.

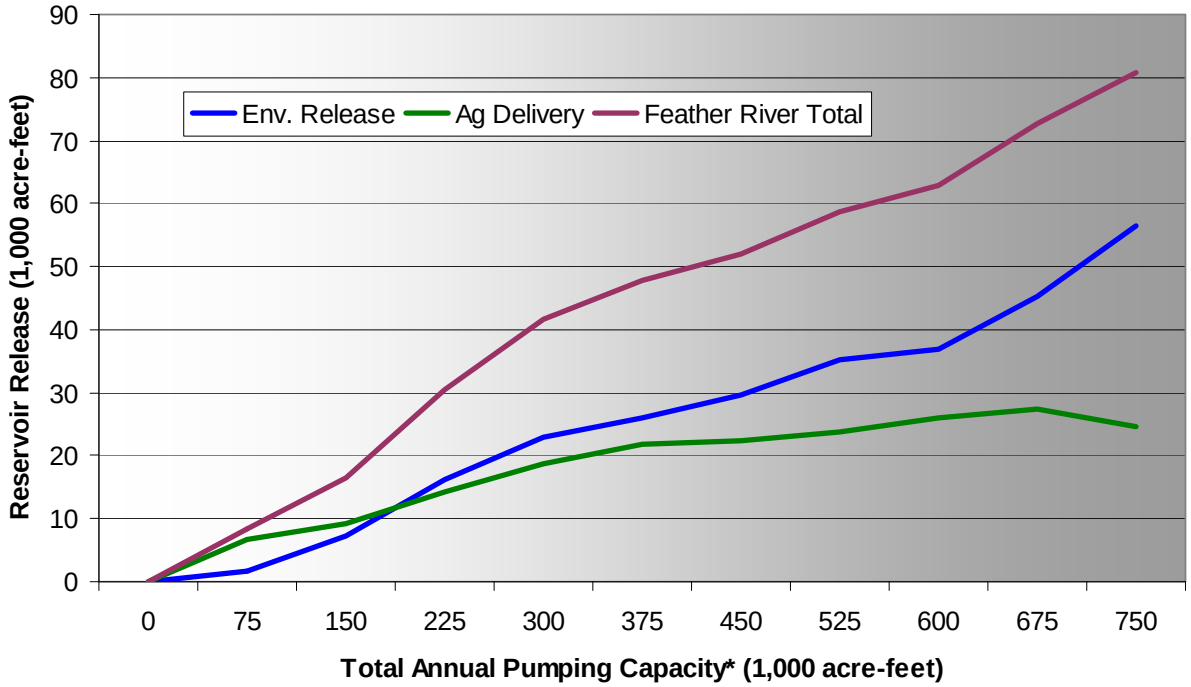


**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-2
SACRAMENTO RIVER AGRICULTURAL AND ENVIRONMENTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-2 provides additional detail on the split between project benefits for agricultural demand and environmental objectives on the Sacramento River. Projects with smaller pumping capacities do not provide as much water supply for environmental objectives. This occurs because water costs for meeting environmental objectives typically exceeds project assets for lower pumping capacity projects. The result is smaller pumping capacity projects supply a greater portion of total benefits to agricultural demands because agricultural objectives are not constrained by a minimum threshold. As pumping capacity, and therefore available project assets increase, a greater portion of total benefits are directed toward meeting environmental objectives. However, this does not necessarily come at the sake of meeting additional agricultural demand. A project with 300 TAF of pumping capacity is providing an average annual agricultural supply increase of approximately 20 TAF, and pumping capacity would need to be significantly increased to provide additional agricultural water supply, up to a maximum of approximately 30 TAF per year. Maximum agricultural benefit is also constrained by the restriction on project operations during Shasta critical years. In these years, there is significant unmet agricultural demand that conjunctive management projects cannot satisfy under assumptions made for this analysis.

Figure 12-3 shows same relationships between pumping capacity and agricultural, and environmental benefits presented for the Sacramento River on Figure 12-2 also exist on the Feather River.

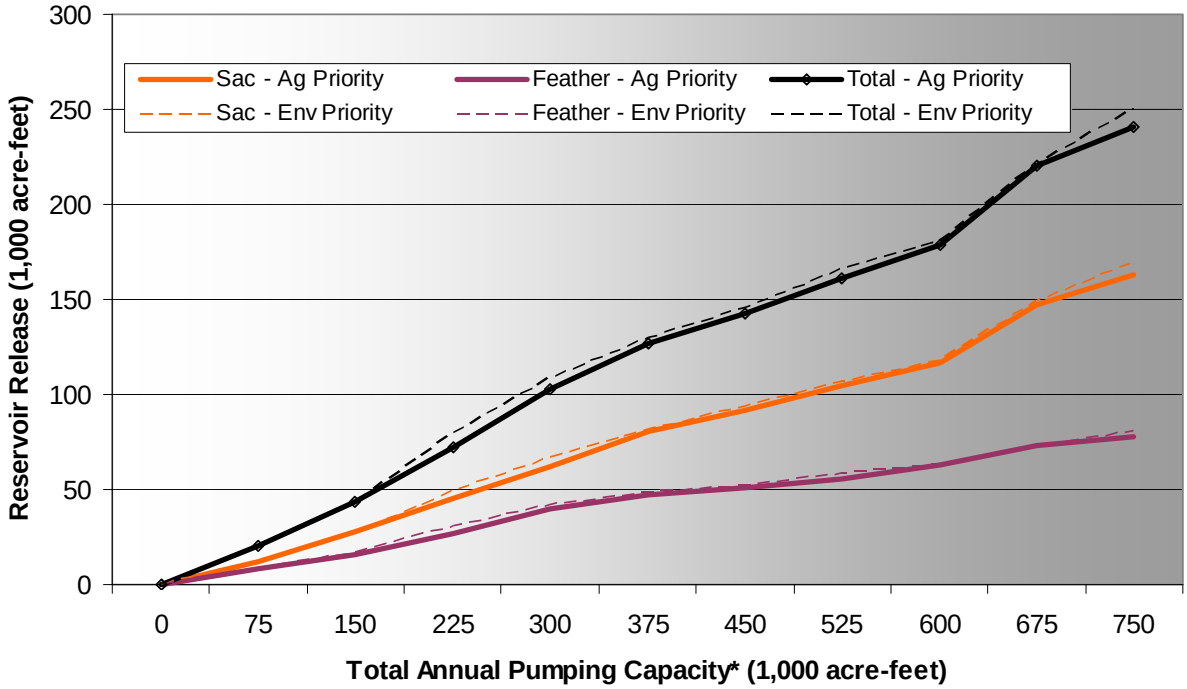


**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-3
FEATHER RIVER AGRICULTURAL AND ENVIRONMENTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

12.2 Prioritization of Objectives

The ability to direct additional water supply from conjunctive management toward meeting agricultural objectives first and environmental objectives second was also simulated. When environmental objectives are first priority, agricultural objectives are met more frequently for smaller capacity projects while environmental objectives are met more frequently for larger capacity projects. Figure 12-4 presents the same results as seen on Figure 12-1, with additional results that reflect when agricultural objectives are given first priority.



**Pumping capacity split 2:1 between GCID and Butte Basin*

FIGURE 12-4
TOTAL PROJECT BENEFITS FOR A RANGE OF PUMPING CAPACITIES WITH HIGHER PRIORITY TO AGRICULTURAL OBJECTIVES (AG PRIORITY) AND HIGHER PRIORITY TO ENVIRONMENTAL OBJECTIVES (ENV PRIORITY)
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-4 illustrates model results are insensitive to prioritization of objectives for lower pumping capacity projects. However, as pumping capacity increases and conjunctive management projects are able to meet additional environmental objectives, total project benefits decrease when meeting agricultural objectives first. Table 12-1 compares average annual benefits for each objective on each river system with different priorities and the number of environmental objectives met by conjunctive management projects.

TABLE 12-1
Comparison of Average Annual Benefits for 300 TAF Pumping Capacity Project with Different Prioritization of Objectives
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Sacramento River			Feather River		
	Env. First	**Ag First**	**Change**	**Env. First**	**Ag First**	**Change**
Ag Benefit (TAF)	22	26	+4	20	23	+3
Env Benefit (TAF)	45	36	-9	23	18	-5
Env Obj. Met (#)	57	50	-7	54	40	-14

Table 12-1 shows when prioritizing agricultural objectives first average annual agricultural benefits increase, but not by the same volume environmental benefits decrease. Therefore there is a reduction in the total project benefits when prioritizing agricultural benefits first, as illustrated on Figure 12-4.

12.3 Reservoir Drawdown Targets

A reservoir storage matrix is used in combination with project groundwater pumping capacity to determine project assets available to meet objectives each year. Results previously presented for Scenarios 1 through 4 assume a minimum end-of-September storage of 2,400 TAF for Shasta Reservoir and 1,500 TAF for Oroville Reservoir. Model sensitivity to these assumptions was evaluated to better understand risk to water supplies and cold water pool management in subsequent years.

Figure 12-5 illustrates effects of changes in minimum fall storage levels on end of September storage. A line at 1,900 TAF is shown because this is the minimum level specified in the biological opinion for winter run Chinook salmon and changes in storage below this level can have significant impacts on Reclamation's ability to manage cold water pool and meet existing temperature control criteria. Setting minimum fall storage levels less than 2,400 TAF can impact storage in subsequent years when storage goes below 1,900 TAF. Setting minimum storage levels above 2,400 TAF reduces project benefits.

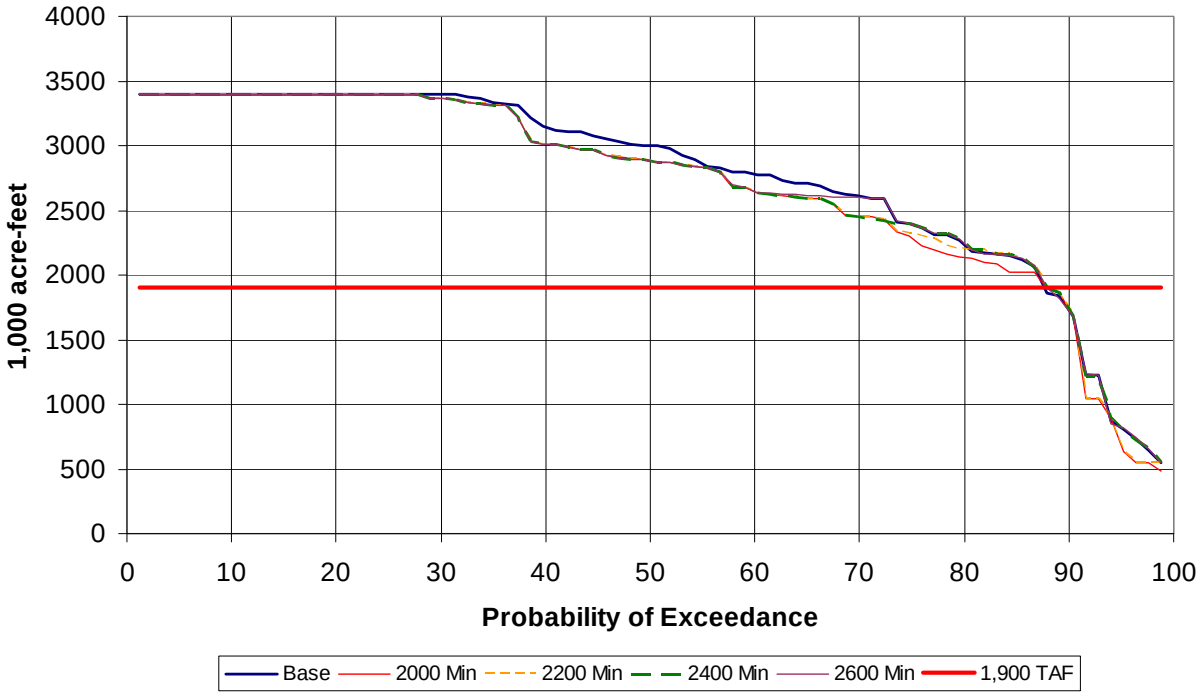


FIGURE 12-5
EXCEEDANCE PROBABILITY FOR END OF SEPTEMBER SHASTA STORAGE WITH SELECT MINIMUM STORAGE REQUIREMENTS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-6 illustrates similar results for Oroville Reservoir. There is no specified target for fall storage in Oroville, but it is understood that hydropower operations are affected when storage goes below 1,000 TAF. Results are less clear because of the smaller differences between base and project conditions; however, more aggressive operation of Oroville with a lower fall storage level may put operations in future years at risk. Therefore, 1,500 TAF was selected as a balance between achieving conjunctive management project benefits and operational risks.

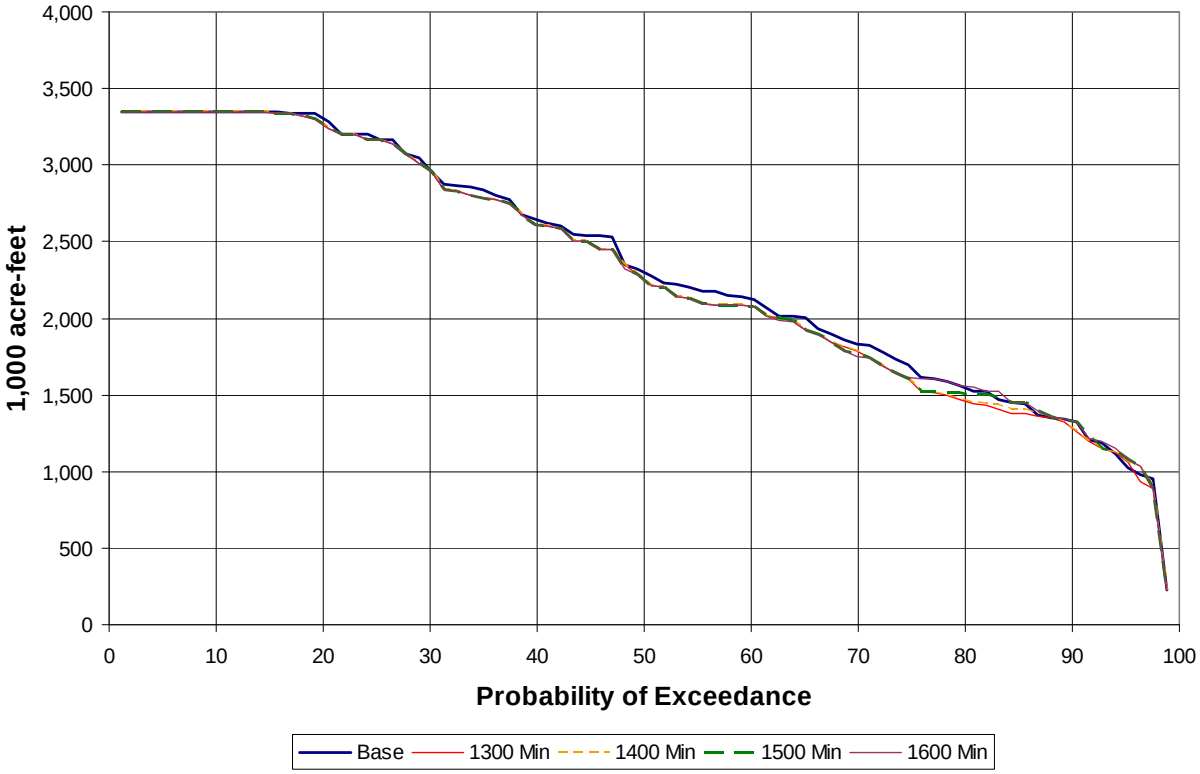


FIGURE 12-6
EXCEEDANCE PROBABILITY FOR SEPTEMBER OROVILLE STORAGE WITH SELECT MINIMUM STORAGE REQUIREMENTS
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

12.4 Environmental Objectives

Considerable uncertainty surrounds developing of environmental objectives; therefore, limited sensitivity analysis was performed to determine if changes in environmental objectives resulted in significant changes in project benefits. For example, if a 10 percent increase in flow targets specified for each objective resulted in no objectives being satisfied for a given scenario, the results from this scenario would be interpreted to contain significant uncertainty. Likewise, if project benefits are consistent across a range of environmental objectives, conjunctive management projects are likely to provide a level of environmental benefit, even if flow targets are slightly different than those simulated.

Figures 12-7 through 12-10 present simulation results of varying environmental targets (presented in Tables 9-1 through 9-5, by more or less than 10 percent. Figures 12-7 through 12-10 show the years that objectives are met, either in the base condition or through project release, and total number of years met. Results are aggregated for both river systems.

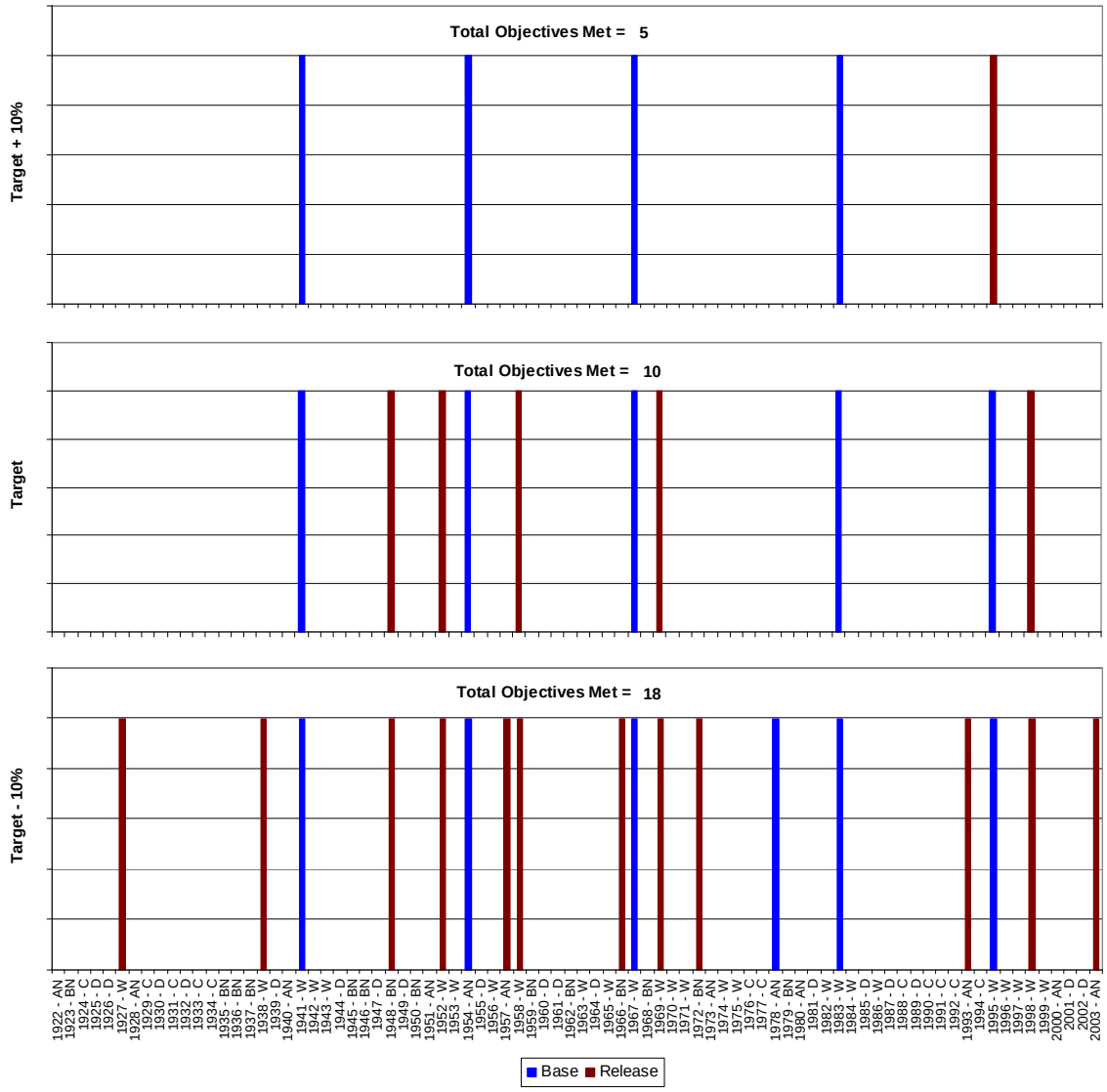


FIGURE 12-7
SENSITIVITY RESULTS FOR SPRING PULSE OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-7 shows that the larger water costs associated with meeting a larger spring pulse flow may decrease the ability of conjunctive management projects to satisfy the objective. Decreasing the flow target will increase the frequency of meeting the objective. The ability of conjunctive management projects to meet the spring pulse objective is sensitive to changes of more or less than 10 percent in the objective. Additionally, changes in the flow objective also change the frequency of meeting the objective with base operations.

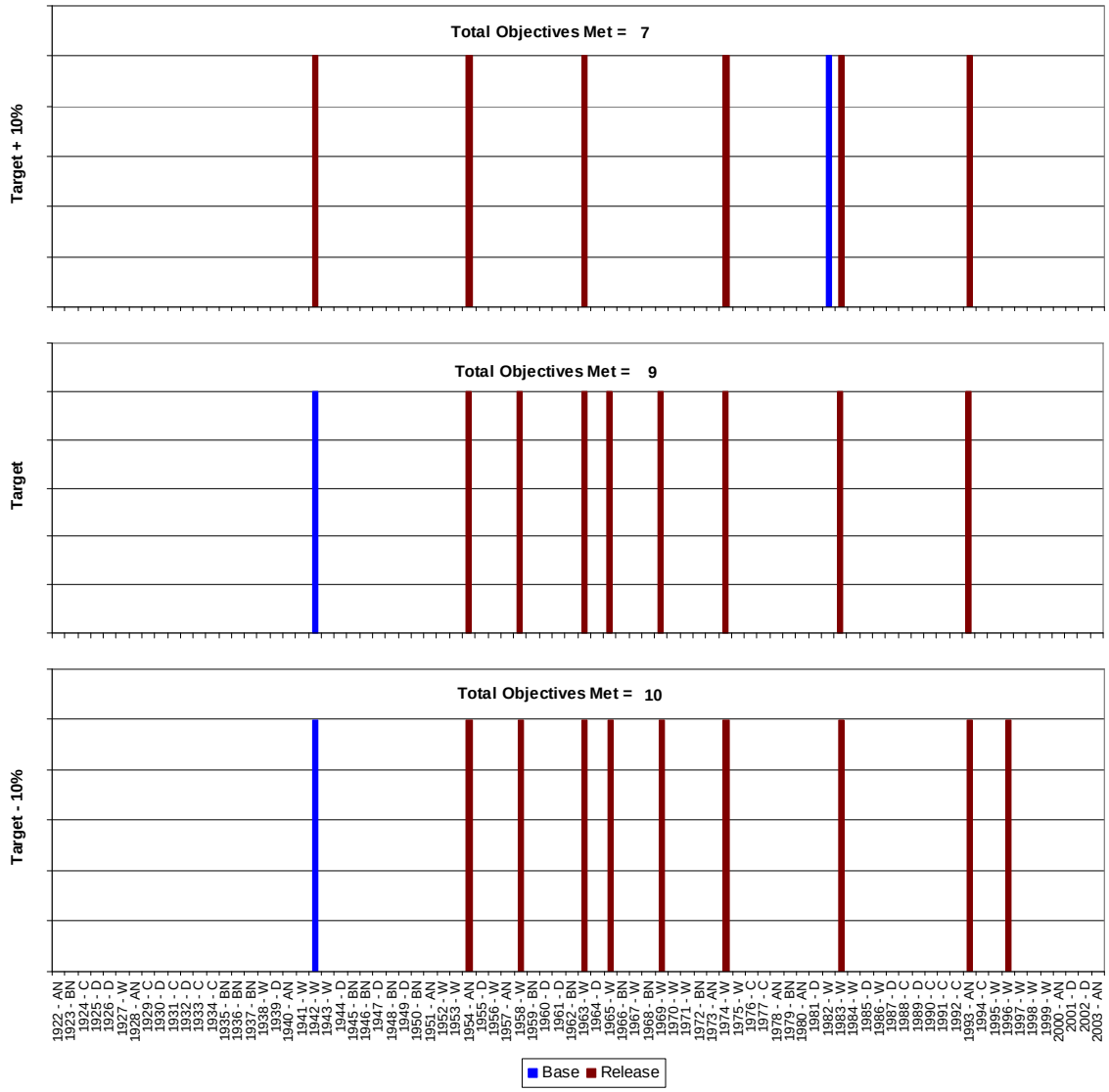


FIGURE 12-8
SENSITIVITY RESULTS FOR RIPARIAN RECRUITMENT OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION
MODELING REPORT

Figure 12-8 shows that riparian recruitment is less sensitive to changes in targets than the spring pulse objective. Changes in flow targets do not result in significant changes in the frequency of satisfying the objective.

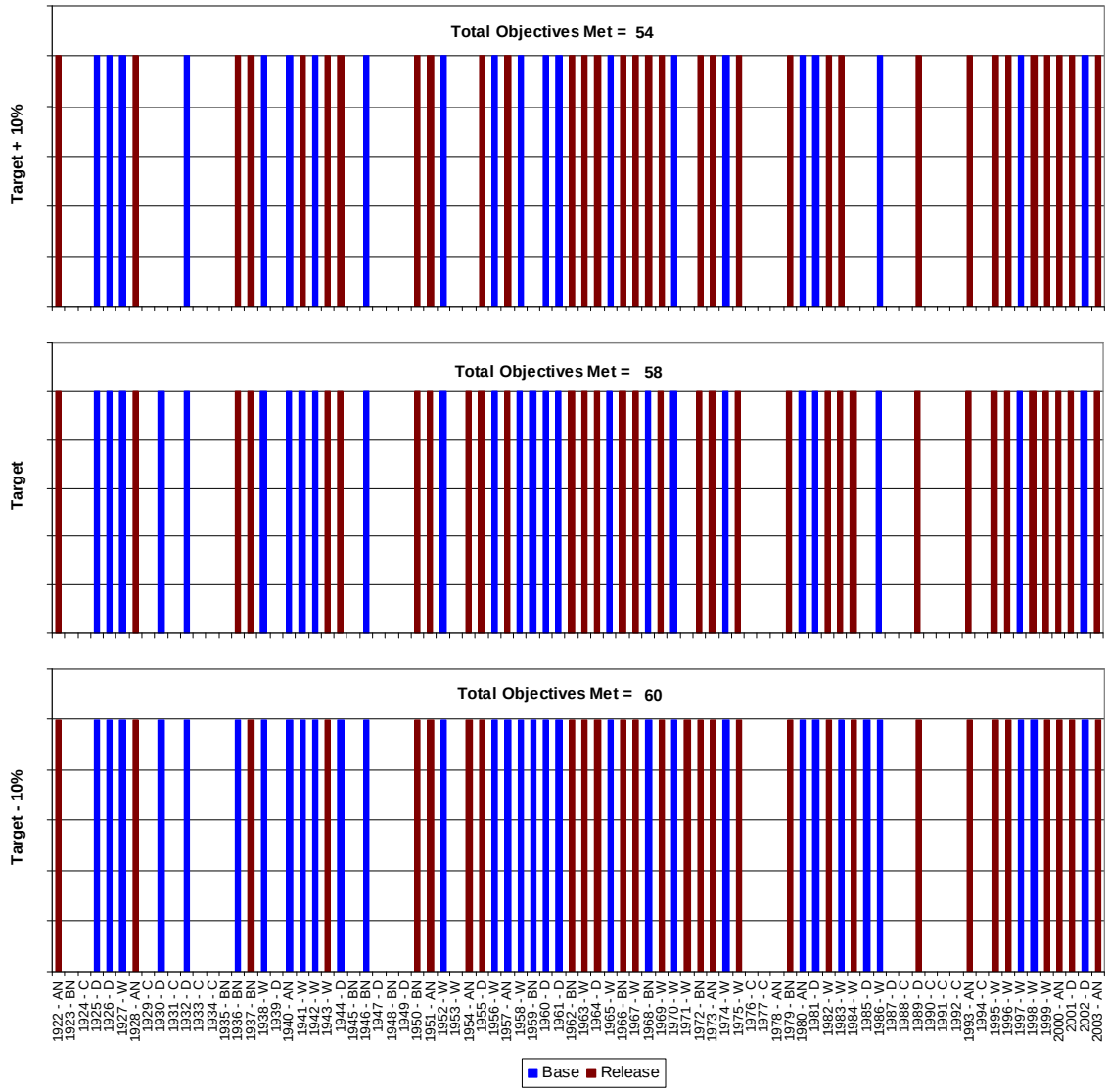


FIGURE 12-9
SENSITIVITY RESULTS FOR GEOMORPHIC OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-9 illustrates that the geomorphic objective is less sensitive to changes in targets than the spring pulse objective. Lower water cost of meeting a short duration objective results in being able to meet the objective, even when it is increased by 10 percent. Additionally, the objective is satisfied so frequently that reducing the flow target does not result in the objective being satisfied much more often.

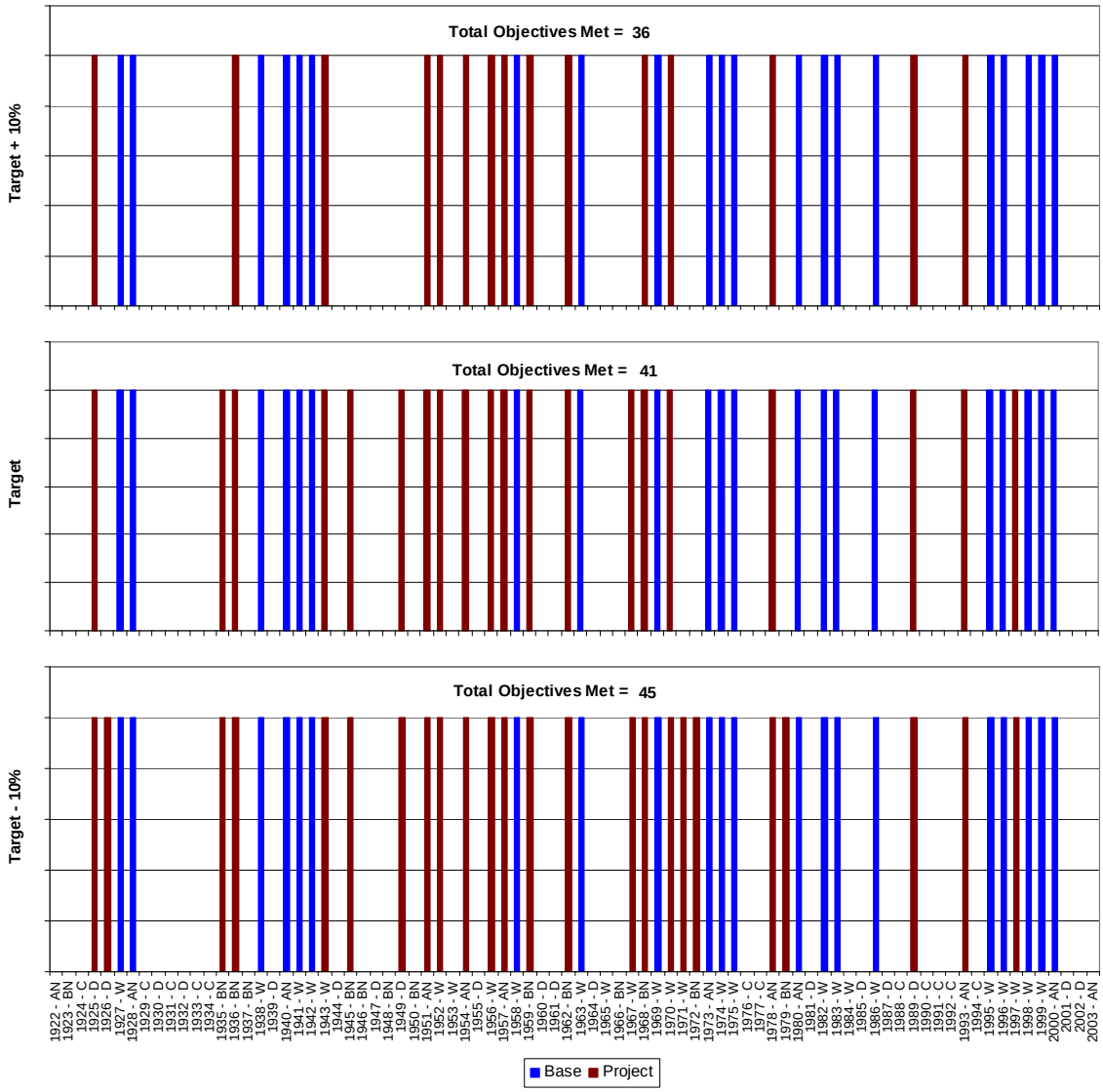


FIGURE 12-10
SENSITIVITY RESULTS FOR FLOOD PLAIN INUNDATION OBJECTIVE
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 12-10 illustrates that the flood plain inundation objective is also less sensitive to changes in the target than the spring pulse objective. Therefore, the conjunctive management project, including some form of weir modification, to allow inundation at lower river stages will allow the objective to be satisfied approximately 40 times if the flow target is within 10 percent of the target simulated in Scenarios 1 through 4.

SECTION 13

Systemwide Effects

This project focused operation of conjunctive management projects within the Sacramento Valley on developing water supply for uses within the Sacramento Valley. Developed water supply was split between environmental and agricultural objectives. However, water released to meet environmental objectives within the Sacramento Valley continues into the Sacramento-San Joaquin River Delta, where it may have additional environmental benefits or potentially be exported for delivery to CVP and SWP contractors south of the Delta.

13.1 Delta Salinity

Changes in Delta inflow, either increases from environmental releases or decreases when reservoirs or groundwater refill with surplus surface water, have the potential to change salinity conditions in the Delta. Formal simulation and analysis of expected changes is beyond the scope of modeling conducted to date. Generally, environmental releases will increase Delta inflow and improve salinity conditions, depending on how export operations respond to increased inflow. To the extent that environmental objectives can be met during drier periods those releases have potential to improve Delta salinity. Operations during wetter periods that either increased or decreased inflow may not result in large changes in Delta salinity. Overall, conjunctive management projects as described for this project will decrease average annual Delta inflow by the consumptive use of additional agricultural deliveries made possible by the project. Figures 13-1 and 13-2 present annual changes in inflow for Scenarios 1 and 2, respectively. Changes from Scenarios 3 and 4 are expected to be similar to those shown for Scenario 1.

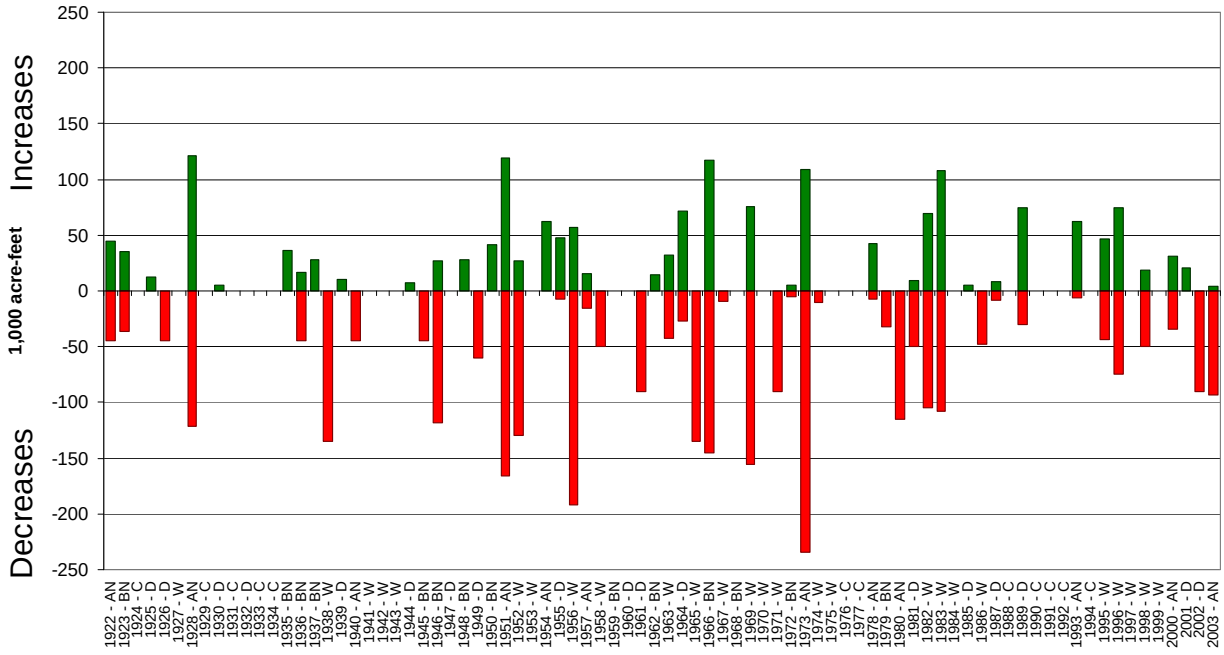


FIGURE 13-1
CHANGE IN ANNUAL DELTA INFLOW, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

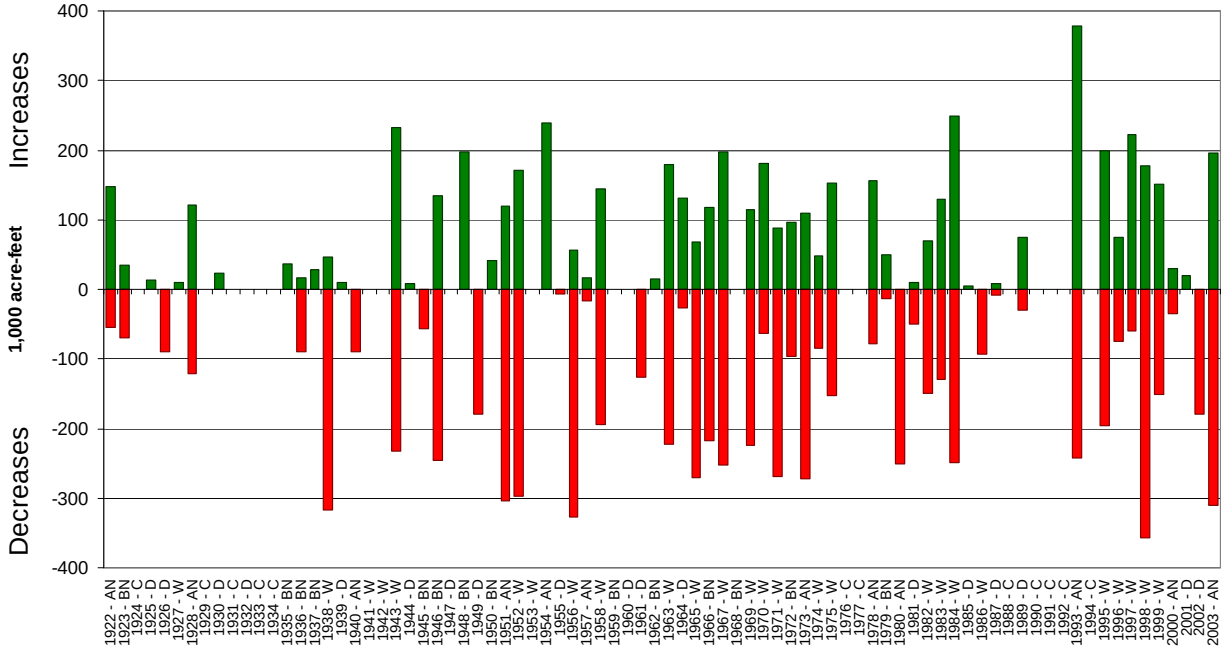


FIGURE 13-2
CHANGE IN ANNUAL DELTA INFLOW, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

13.2 South of Delta Water Supply

A preliminary analysis of the ability to export simulated environmental releases was made using the underlying CalSim II operations. This analysis considers the constraints imposed by D-1641 Delta flow and salinity standards, CVPIA b(2) restrictions, the Vernalis Adaptive Management Plan (2000), and export pumping capacity constraints. Analysis did not include pumping restrictions for protecting Delta smelt as proposed in the recent OCAP Biological Opinion (U.S. Fish and Wildlife Service, 2008). Export restrictions for protection of Delta smelt may significantly reduce ability to export environmental releases because smelt restrictions limit export operations during winter and spring months when environmental releases are made. Additionally, it was assumed that there is demand for any additional water that could be exported.

Figures 13-3 and 13-4 illustrate annual time series of total potential export of environmental releases made from Shasta and Oroville for Scenarios 1 and 2. Results for Scenarios 3 and 4 are essentially the same as for Scenario 1, because the timing and volume of environmental release does not change.

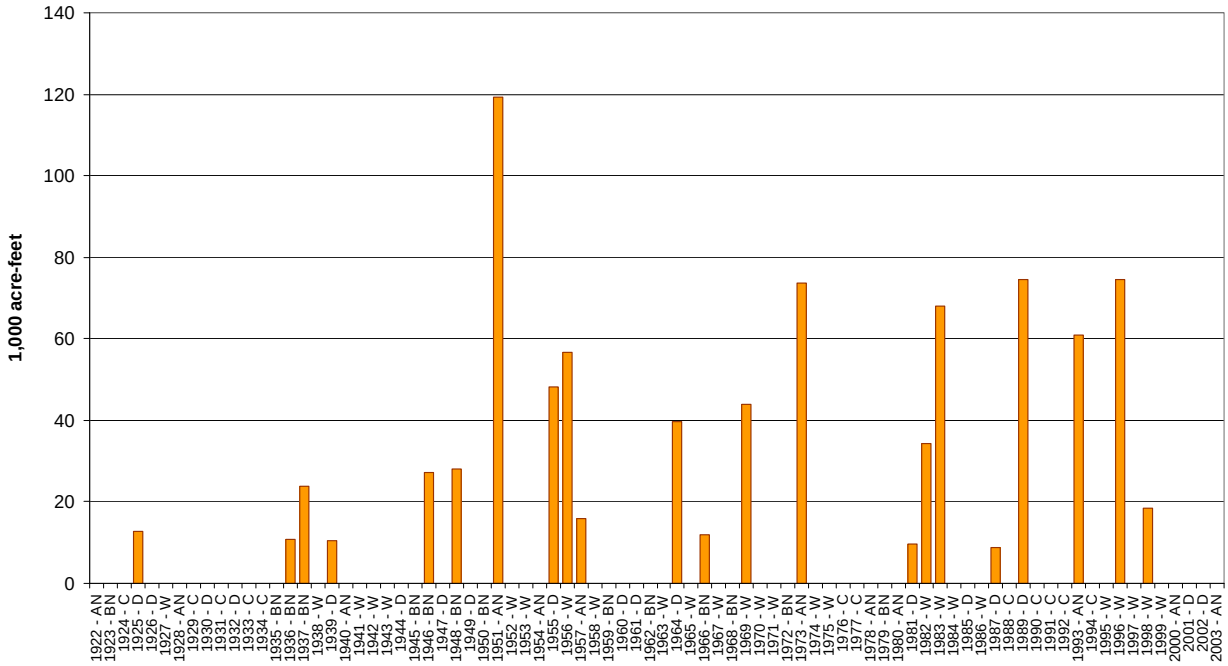


FIGURE 13-3
POTENTIAL EXPORT OF ENVIRONMENTAL RELEASES, SCENARIO 1
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 13-3 illustrates the volume and timing of additional export that may occur with conjunctive management projects. Average annual exports increase by approximately 11 of the 22 TAF from environmental releases on the Sacramento and Feather Rivers. The majority of additional exports occur when CVP and/or SWP San Luis Reservoir storage is full and

would therefore provide additional Section 215 water for CVP contractors and Article 21 water for SWP contractors.

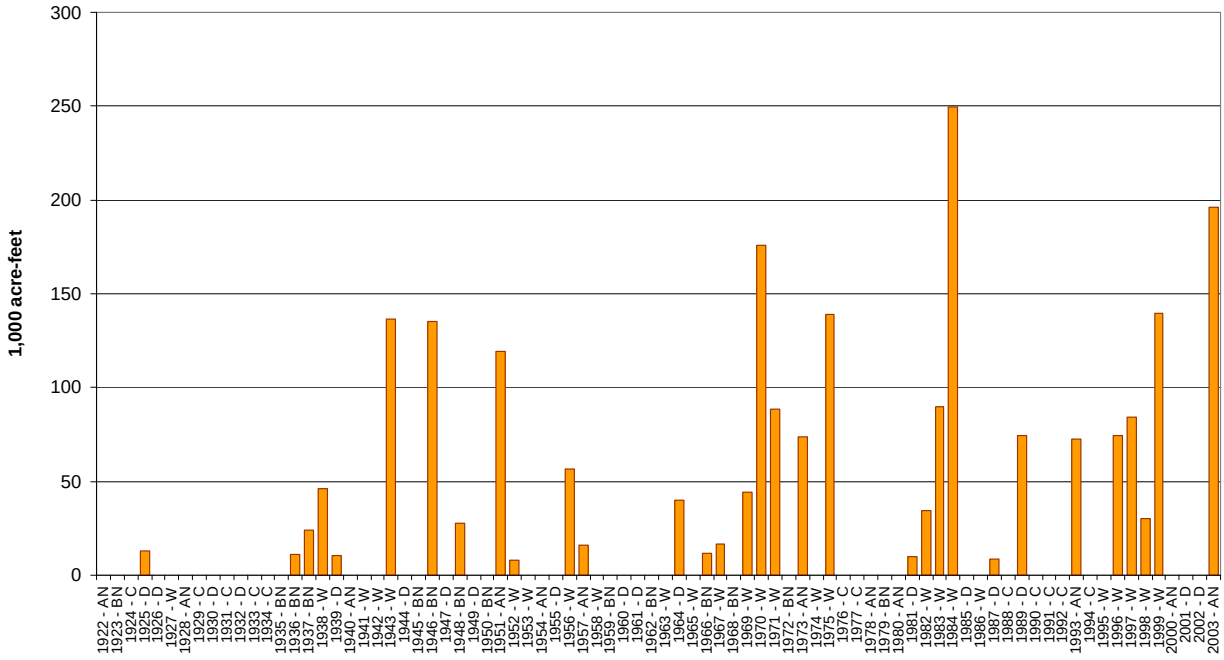


FIGURE 13-4
POTENTIAL EXPORT OF ENVIRONMENTAL RELEASES, SCENARIO 2
SACRAMENTO VALLEY CONJUNCTIVE WATER MANAGEMENT TECHNICAL INVESTIGATION MODELING REPORT

Figure 13-4 presents the same results for Scenario 2 with an average annual export of 28 of the 68 TAF of environmental releases. Exports with Scenario 2 may increase by up to 250 TAF in a given year. In these years with large increases, exports and may be limited by the ability to use or store the water south of the Delta.

13.3 Other Changes

Analysis conducted to date focused on operations on the main stem of the Sacramento and Feather Rivers, and CVP and SWP reservoirs on those rivers. In reality, the water system in California is operated as a whole and changes in one area, particularly large components of the system, such as Shasta and Oroville Reservoirs, will ripple into other areas. While not addressed in this report, it is understood that these changes would require additional analyses at a feasibility level.

SECTION 14

Model Limitations and Areas for Refinement

14.1 Groundwater Model

While SACFEM is a powerful tool designed specifically to evaluate effects of conjunctive water management pumping on surface water and groundwater resources, several areas for refinement remain. Due to constraints on available resources for this project, it was not possible to perform a rigorous transient calibration of the model to observed historic water level hydrographs across the valley. This effort would help improve the level of confidence that the model is accurately simulating transient patterns in groundwater levels seen historically. However, a preliminary assessment of the accuracy of SACFEM at matching a limited number of historic hydrographs was performed, and the model appears to generally replicate historically observed water levels quite well over the 22-year period of simulation (1982 through 2003).

Another area of potential refinement is to further evaluate behavior of smaller unregulated tributaries across the valley, specifically to better understand timing and magnitude of groundwater recharge that occurs from these surface water features. In the current analysis, it was assumed that unregulated streams were dry from June through October. While this assumption is reasonable, it is likely that behavior of these streams is more complex. Further, some of these tributary streams are used as conveyance facilities to deliver water within various water districts. This would result in streams being active over summer months, and potential sources of recharge to the groundwater system. An analysis of these stream characteristics could improve the accuracy of the simulation of recharge sources to the groundwater system, especially over the summer months.

Forecasts provided by modeling tools contain some degree of uncertainty, due to limitations of replicating a complex physical system with a more idealized mathematical representation of that system. Analyses described herein should be considered a planning level analysis that tests the general viability of conjunctive water management strategies presented, and provides a general estimate of benefits that may be realized by implementation of these projects. However, these evaluations will need to be significantly refined, both in specificity of infrastructure and operational protocols and response of the natural system to these operations, before a project of this type could be carried to the design phase.

14.2 Surface Water Model

Surface water modeling and analysis was conducted at a pre-feasibility, planning level and required numerous simplifying assumptions.

14.2.1 Forecast-based Operations

The surface water model uses perfect foresight in operating reservoirs and determining ability to meet environmental objectives. This results in an ideal operation of system

reservoirs and decisions to meet project objectives. In reality, project operators must rely on imperfect forecasts of water supply and demands when making daily decisions. In actual operations, there would be instances in which environmental objectives would be met or missed due to changing conditions that cannot be forecasted.

One method to address this uncertainty in future analyses would be to implement forecast-based decision logic that may help to illuminate some of the challenges in implementing environmental objectives in real-world operations. For example, because environmental objectives are specified for spring months, a forecast of the water year type (e.g., wet or above normal) is needed to estimate the flow target. In actual operations these forecasts will be uncertain and operations will need to respond to actual hydrology.

14.2.2 Temperature and Power Analyses

Conjunctive management operations as described and simulated for this report may have impacts on the ability to meet temperature control criteria, and the generation and use of CVP and SWP hydropower. For example, in some years, making releases for environmental objectives in spring may create challenges in meeting temperature control criteria in the fall, depending on how water is released from reservoirs. Additionally, large releases for certain objectives may be constrained by power plant capacities and may occur at times when power is less valuable. A better understanding of these constraints and simulation of resulting effects is necessary in future phases of the project.

14.2.3 System Response

Analysis presented in this report focused on operation of only part of the CVP/SWP system. Shasta and Oroville Reservoirs and the Sacramento and Feather Rivers are part of a larger system that is operated in a coordinated manner. Simulation of only part of the system may underestimate benefits or impacts to other areas of the system. Preliminary analysis of systemwide effects based on how conjunctive management operations change, Delta inflows need to be refined and expanded to other areas of the system.

SECTION 15

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Vernalis Adaptive Management Plan as described and implemented in State Water Resources Control Board Revised Decision 1641, State Water Resources Control Board, March 15, 2000.

Appendix A
CalSim II Common Assumptions

APPENDIX A

CalSim II Common Assumptions

Table A-1 summarizes assumptions used in CalSim II simulation of CVP and SWP reservoirs used in the surface water model at the existing level of development (Existing Conditions Assumption).

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
Planning Horizon	2004[a]	2030[a]	Same
Demarcation Date	June 1, 2004[a]	Same	Same
Period of Simulation	82 years (1922 through 2003)	Same	Same
HYDROLOGY			
Level of Development	2005 level[b]	2030 level[c]	Same
Sacramento Valley (excluding American River)			
CVP	Land-use based, limited by contract amounts[d]	Same	Same
SWP (FRSA)	Land-use based, limited by contract amounts[e]	Same	Same
Non-Project	Land-use based	Same	Same
Federal Refuges	Recent historical Level 2 deliveries[f]	Firm Level 2 water needs[f]	Same
American River			
Water Rights	2004[g]	Sacramento Area Water Forum[g,h]	Same
CVP	2004[g]	Sacramento Area Water Forum (PCWA modified)[g,h]	Same
PCWA	No CVP contract water supply	35 TAF CVP contract supply diverted at the new American River PCWA Pump Station	Same
San Joaquin River[i]			
Friant Unit	Limited by contract amounts, based on current allocation policy	Same	Same
Lower Basin	Land-use based, based on district level	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
	operations and constraints		
Stanislaus River	Land-use based, based on New Melones Interim Operations Plan[j]	Same	Same
South of Delta (CVP/SWP Project Facilities)			
CVP	Demand based on contracts amounts[d]	Same	Same
CCWD	124 TAF CVP contract supply and water rights[k]	195 TAF CVP contract supply and water rights[k]	Same
SWP	Demand varies based pattern used for 2004 OCAP Today studies; Table A transfers that occurred in 2005 and 2006 are not included	Demand based on full Table A amounts[e,l]	Same
Article 56	Based on 2002-2006 contractor requests	Same	Same
Article 21	MWD demand up to 100 TAF/month from December to March, total of other demands up to 84 TAF per month in all months[e,l]	MWD demand unlimited but subject to capacity to convey and deliver; KCWA demand of up to 2,555 CFS; others same as existing	Same
Federal Refuges	Recent historical Level 2 deliveries[f]	Firm Level 2 water needs[f]	Same
FACILITIES			
Systemwide	Existing facilities[a]	Same	Same
Sacramento Valley			
Shasta Lake	Existing, 4,552-TAF capacity	Same	Same
Colusa Basin	Existing conveyance and storage facilities	Same	Same
Upper American River	PCWA American River pump station not	PCWA American River pump station	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
	included	included	
Lower Sacramento River	Freeport Regional Water Project not included	Freeport Regional Water Project included	Same
Delta Region			
SWP Banks Pumping Plant	6,680 cfs capacity[a]	Same	8,500 cfs capacity[a]
CVP C.W. Bill Jones Pumping Plant (Tracy PP)	More than 4,200 cfs diversions upstream of DMC constriction	4,600 cfs capacity in all months (allowed for by the Delta-Mendota Canal–California Aqueduct Intertie)	Same
Los Vaqueros Reservoir	Existing storage capacity, 100 TAF, (AIP not included)	Existing storage capacity, 100 TAF; AIP included[m]	Same
San Joaquin River			
Millerton Lake (Friant Dam)	Existing, 520 TAF capacity	Same	Same
South of Delta (CVP/SWP Project Facilities)			
South Bay Aqueduct Enlargement	None	430 cfs capacity from junction with California Aqueduct to Alameda County FC&WSD Zone 7 diversion point	Same
California Aqueduct East Branch Enlargement	None	None	Same
WATER MANAGEMENT ACTIONS (CALFED)			
Water Transfer Supplies (available long term program)			
Phase 8	None	Supplies up to 185 TAF per year from new groundwater substitution, with 60% going to SWP and 40% to CVP[n]	Same
Lower Yuba River Accord	Not included	Not included	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
REGULATORY STANDARDS			
Trinity River			
Minimum Flow Below Lewiston Dam	Trinity EIS Preferred Alternative (369-815 TAF per year)	Same	Same
Trinity Reservoir End-of-September Minimum Storage	Trinity EIS Preferred Alternative (600 TAF as able)	Same	Same
Clear Creek			
Minimum Flow Below Whiskeytown Dam	Downstream water rights, 1963 Reclamation Proposal to USFWS and NPS, and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Upper Sacramento River			
Shasta Lake End-of-September Minimum Storage	SWRCB WR 1993 Winter-run Biological Opinion (1900 TAF)	Same	Same
Minimum Flow Below Keswick Dam	Flows for SWRCB WR 90-5 and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Feather River			
Minimum Flow Below Thermalito Diversion Dam	1983 DWR, DFG Agreement (600 cfs)	Same	Same
Minimum Flow Below Thermalito Afterbay outlet	1983 DWR, DFG Agreement (750-1,700 cfs)	Same	Same
Yuba River			
Minimum Flow Below Daguerre Point Dam	Interim D-1644 Operations[o]	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
American River			
Minimum Flow Below Nimbus Dam	SWRCB D-893[p] (see accompanying Operations Criteria), and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Minimum Flow at H Street Bridge	SWRCB D-893	Same	Same
Lower Sacramento River			
Minimum Flow Near Rio Vista	SWRCB D-1641	Same	Same
Mokelumne River			
Minimum Flow Below Camanche Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (100-325 cfs)	Same	Same
Minimum Flow Below Woodbridge Div. Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (25-300 cfs)	Same	Same
Stanislaus River			
Minimum Flow Below Goodwin Dam	1987 USBR, CDFG agreement, and USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
Minimum Dissolved Oxygen	SWRCB D-1422	Same	Same
Merced River			
Minimum Flow Below Crocker-Huffman Diversion Dam	Davis-Grunsky (180-220 cfs, Nov-Mar), Cowell Agreement, and FERC 2179 (25-100 cfs)	Same	Same
Tuolumne River			
Minimum Flow at Lagrange Bridge	FERC 2299-024, 1995 (Settlement Agreement) (94-301 TAF per year)	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
San Joaquin River			
San Joaquin River Below Friant Dam/Mendota Pool	None	None	None
Maximum Salinity Near Vernalis	SWRCB D-1641	Same	Same
Minimum Flow Near Vernalis	SWRCB D-1641, and Vernalis Adaptive Management Plan per San Joaquin River Agreement	Same[q]	Same[s]
Sacramento River–San Joaquin River Delta			
Delta Outflow Index (Flow and Salinity)	SWRCB D-1641	Same	Same
Delta Cross Channel Gate Operation	SWRCB D-1641	Same	Same
Delta Exports	SWRCB D-1641, USFWS discretionary use of CVPIA 3406(b)(2)	Same	Same
OPERATIONS CRITERIA: RIVER-SPECIFIC			
Upper Sacramento River			
Flow Objective For Navigation (Wilkins Slough)	3,500-5,000 cfs based on CVP water supply condition	Same	Same
American River			
Folsom Dam Flood Control	Variable 400/670 flood control diagram (without outlet modifications)	Same	Same
Flow Below Nimbus Dam	Discretionary operations criteria corresponding to SWRCB D-893 required minimum flow	Same	Same
Sacramento Area Water Forum Mitigation Water	None	Up to 47 TAF in dry years	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
Feather River			
Flow at Mouth of Feather River (Above Verona)	Maintain DFG/DWR flow target of 2,800 cfs for Apr-Sep dependent on Oroville inflow and FRSA allocation	Same	Same
Stanislaus River			
Flow Below Goodwin Dam	1997 New Melones Interim Operations Plan	Same	Same
San Joaquin River			
Salinity at Vernalis	D1641	San Joaquin River Salinity Management Plan[r]	Same
OPERATIONS CRITERIA: SYSTEMWIDE			
CVP Water Allocation			
CVP Settlement and Exchange	100% (75% in Shasta critical years)	Same	Same
CVP Refuges	100% (75% in Shasta critical years)	Same	Same
CVP Agriculture	100%-0% based on supply (South-of-Delta allocations are reduced due to D-1641 and 3406(b)(2) allocation-related export restrictions)	Same	Same
CVP Municipal and Industrial	100%-50% based on supply (South-of-Delta allocations are reduced due to D-1641 and 3406(b)(2) allocation-related export restrictions)	Same	Same
SWP Water Allocation			
North of Delta (FRSA)	Contract specific	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
South of Delta (including North Bay Aqueduct)	Based on supply; equal prioritization between Ag and M&I based on Monterey Agreement	Same	Same
CVP-SWP Coordinated Operations			
Sharing of Responsibility for In-basin-Use	1986 Coordinated Operations Agreement (2/3 of the North Bay Aqueduct diversions are considered as Delta Export, 1/3 of the North Bay Aqueduct diversion is considered as in-basin-use)	1986 Coordinated Operations Agreement (FRWP EBMUD and 2/3 of the North Bay Aqueduct diversions are considered as Delta Export, 1/3 of the North Bay Aqueduct diversion is considered as in-basin-use)	Same
Sharing of Surplus Flows	1986 Coordinated Operations Agreement	Same	Same
Sharing of Restricted Export Capacity for Project-specific Priority Pumping	Equal sharing of export capacity under SWRCB D-1641; use of CVPIA 3406(b)(2) restricts only CVP exports	Same	Same
Dedicated CVP Conveyance at Banks	None	SWP to convey 50 TAF per year of Level 2 refuge water supplies at Banks Pumping Plant (July and August)	SWP to convey 100 TAF/yr of Level 2 refuge water supplies at Banks Pumping Plant (July and August)
North-of-Delta Accounting Adjustments	None	CVP to provide the SWP a maximum of 37.5 TAF per year of water to meet in-basin requirements through adjustments in 1986 Coordinated Operations Agreement accounting (released from Shasta Reservoir)	CVP to provide the SWP a maximum of 75 TAF per year of water to meet in-basin require-ments through adjustments in 1986 Coordinated Operations Agreement accounting (released from Shasta Reservoir)
Sharing of Export Capacity for Lesser Priority and Wheeling-related Pumping	Cross Valley Canal wheeling (max of 128 TAF/yr), CALFED ROD defined JPOD	Same	Same

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption
San Luis Low Point	San Luis Reservoir is allowed to operate to a minimum storage of 100 TAF	Same	Same
CVPIA 3406(b)(2)			
Policy Decision	Per May 2003 Dept. of Interior Decision:	Same	Same
Allocation	800 TAF, 700 TAF in 40-30-30 dry years, and 600 TAF in 40-30-30 critical years	Same	Same
CVPIA 3406(b)(2) (continued)			
Actions	1995 WQCP, Upstream fish flow objectives (Oct-Jan), VAMP (Apr 15-May 15) CVP export restriction, 3,000 cfs CVP export limit in May and June (D-1485 striped bass cont.), Post-VAMP (May 16-31) CVP export restriction, Ramping of CVP export (June), Upstream Releases (Feb-Sep)	Same	Same
Accounting adjustments	Per May 2003 Interior Decision, no limit on responsibility for non-discretionary D-1641 requirements with 500 TAF target, no reset with the storage metric and no offset with the release and export metrics, 200 TAF target on costs from Oct-Jan	Same	Same

[a]A detailed description of the assumptions selection criteria and policy basis used is included in the Policy section of this Common Assumptions: Common Model Package (CACMP) report.

[b]The Sacramento Valley hydrology used in the Existing Conditions CALSIM II model reflects nominal 2005 land-use assumptions. The nominal 2005 land-use was determined by interpolation between the 1995 and projected 2020 land-use assumptions associated with Bulletin 160-98. The San Joaquin Valley hydrology reflects 2005 land-use assumptions developed by Reclamation to support Reclamation studies.

[c]The Sacramento Valley hydrology used in the Future No-action CALSIM II model reflects 2020 land-use assumptions associated with Bulletin 160-98. The San

TABLE A-1
CALSIM II Inputs
Common Assumptions: Common Model Package (Version 8D)
Sacramento Valley Conjunctive Water Management Technical Investigation Modeling Report

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption

Joaquin Valley hydrology reflects draft 2030 land-use assumptions developed by Reclamation to support Reclamation studies.

[d]CVP contract amounts have been reviewed and updated according to existing and amended contracts as appropriate. Assumptions regarding CVP agricultural and municipal and industrial service contracts and Settlement Contract amounts are documented in Table 4 (North of Delta) and 6 (South of Delta) of Appendix B: CACMP Delivery Specifications.

[e]SWP contract amounts have been reviewed and updated as appropriate. Assumptions regarding SWP agricultural and M&I contract amounts are documented in Table 2 (North of Delta) and Table 3 (South of Delta) of Appendix B: CACMP Delivery Specifications.

[f]Water needs for federal refuges have been reviewed and updated as appropriate. Assumptions regarding firm Level 2 refuge water needs are documented in Table 4 (North of Delta) and 6 (South of Delta) of Appendix B: CACMP Delivery Specifications. As part of the Water Transfers technical memorandum (Appendix A: Characterization and Quantification), incremental Level 4 refuge water needs have been documented as part of the assumptions of future water transfers.

[g]Assumptions regarding American River water rights and CVP contracts are documented in Table 5 of Appendix B: CACMP Delivery Specifications.

[h]Sacramento Area Water Forum 2025 assumptions are defined in Sacramento Water Forum's EIR. PCWA CVP contract supply is modified to be diverted at the PCWA pump station. Assumptions regarding American River water rights and CVP contracts are documented in Table 4 of Appendix B: PFCMP Delivery Specifications.

[i]The new CALSIM II representation of the San Joaquin River has been included in this model package (CALSIM II San Joaquin River Model, Reclamation, 2005). Updates to the San Joaquin River representation have been included since the preliminary model release in August 2005. In addition, a dynamic groundwater simulation is currently being developed for San Joaquin River Valley, but is not yet implemented. Groundwater extraction/ recharge and stream-groundwater interaction are static assumptions and may not accurately reflect a response to simulated actions. These limitations should be considered in the analysis of results.

[j]The CACMP CALSIM II model representation for the Stanislaus River does not necessarily represent Reclamation's current or future operational policies.

[k]The Existing CVP contract is 140 TAF. The actual amount diverted is reduced due to supplies from the Los Vaqueros Project. The existing Los Vaqueros storage capacity is 100 TAF. Associated water rights for Delta excess flows are included.

[l]Table A and Article 21 deliveries into the San Francisco Bay Area Region–South and South Coast Region in the CACMP are a result of interaction between CALSIM II and LCPSIM. More information regarding LCPSIM is included in the following subsection of this document and the CALSIM-LCPSIM Integration technical memorandum (see Appendix C: Analytical Framework).

[m]The CCWD AIP is a new intake at Victoria Canal to operate as an alternate intake for Los Vaqueros Reservoir. This assumption is consistent with the future no-project condition defined by the Los Vaqueros Enlargement study team.

[n]This Phase 8 requirement is assumed to be met through Sacramento Valley Water Management Agreement Implementation.

	Existing Condition Assumption	Future No Action Condition Assumption	Supplemental Future Condition (#1) Assumption

[o]Interim D-1644 is assumed to be implemented.

[p]Sacramento Area Water Forum Lower American River Flow Management Standard is not included in the CACMP. Reclamation has agreed in principle to the Flow Management Standard, but flow specifications are not yet available for modeling purposes.

[q]It is assumed that either VAMP, a functional equivalent, or D-1641 requirements would be in place in 2030.

[r]The CACMP CALSIM II model representation for the San Joaquin River does not explicitly implement the CALFED Salinity Management Plan.

Notes:

PCWA	=	Placer County Water Agency	SWRCB	=	State Water Resources Control Board
DMC	=	Delta-Mendota Canal	DWR	=	Department of Water Resources
AIP	=	Alternate Intake Project	FERC	=	Federal Energy Regulatory Commission
TAF	=	thousand acre-feet	CDFG	=	California Department of Fish and Game
cfs	=	cubic feet per second	FRWB	=	
EIS	=	environmental impact statement	EBMUD	=	East Bay Municipal Utility District
Reclamation	=	Bureau of Reclamation	ROD	=	Record of Decision
USFWS	=	U.S. Fish and Wildlife Service	CALFED	=	Calfed Bay-Delta Program
NPS	=		JPOD	=	Joint Point of Diversion
CVPIA	=	Central Valley Project Improvement Act	WQCB	=	Water Quality Control Plan
SWP	=	State Water Project	VAMP	=	
CVP	=	Central Valley Project	CACMP	=	

Sources:

Vernalis Adaptive Management Plan as described and implemented in State Water Resources Control Board Revised Decision 1641, State Water Resources Control Board, March 15, 2000.

U.S. Fish and Wildlife Service. 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) at State Water Project (SWP). Memorandum from Regional Director, Fish and Wildlife Service, Region 8, Sacramento, California, to Operation Manager, Bureau of Reclamation, Central Valley Operations Office Sacramento, California. December 15. 310 pages plus 3 attachments.

Appendix C
Project Site Screening
Technical Memorandum

D R A F T T E C H N I C A L M E M O R A N D U M

DATE: October 18, 2007

TO: Sacramento Valley Conjunctive Management Project Team

FROM: NHI Technical Team

SUBJECT: DRAFT Candidate Site Screening Methodology

This memorandum is a draft summary of the methodology used to select sites for the Conjunctive Use IRWMP technical scenario development. The California Department of Water Resources and the U.S. Bureau of Reclamation (project donors) have awarded funds to Glenn Colusa Irrigation District and the Natural Heritage Institute to develop an Integrated Conjunctive Water Management Plan (ICWMP) for Northern California surface water and groundwater resources. A description of the criteria used to select sites for the Conjunctive Use IRWMP technical scenario development is summarized below. The evolution of knowledge for candidate sites considered is summarized for all technical meetings held between February 2007 and August 2007. Technical meeting notes and a draft technical memo developed by MBK are included as appendixes.

Objectives and Benefits

The three fundamental objectives driving the plan's development are:

- To improve local water supply reliability by enlarging the firm yield of the basin and enhancing water management flexibility.

- To enhance the ecosystems in the region's rivers. Healthy rivers are not just environmentally attractive, they also are central to ensuring reliable, sustainable water supplies. Water supply systems that work in concert with the environment are less likely to be encumbered by court orders, water rights hearings, and other restrictions that can have drastic effects on water supplies for farming and other economic uses.

- To allow for meeting water demands outside of the Sacramento River basin. The Sacramento River basin is already a source of much of the State's water supply. A plan that allows for well-managed and regulated water transfers is preferable to shortsighted decisions made when drought emergencies arise and water transfer revenues could help stabilize a challenged agricultural economy and provide regional economic benefits.

Methods

Conjunctive water management essentially involves the coordination of storage and withdrawal of water from surface reservoirs and groundwater aquifers to produce firm water supplies through wet and dry cycles. This general concept can be adapted in a variety of ways to increase operational flexibility both to enlarge the firm water supply and improve the environmental performance of the state and federal water projects. During the study, various reservoir reoperation scenarios will be developed and evaluated for Lakes Oroville and Shasta, the centerpieces of the State Water Project and Central Valley Projects, respectively. Additionally, the Stony Creek system will also be evaluated as another option for potential reservoir reoperation.

The region to be addressed in the integrated plan is comprised of all of the lands overlying the Lower Tuscan and interconnected groundwater formations within Butte, Glenn, Colusa and Tehama counties whose access to this groundwater could be hydrologically affected by development of the aquifer system at any location. The Sacramento Valley Conjunctive Management Technical Team (The team) began by looking for sites that fell into one of two conjunctive management operational modalities; Put-then-Take or Take-then-Put. A Put-then-Take modality involves storing surface water in a groundwater aquifer and extracting that water at a later date. This modality increases water storage space in reservoirs and increases the flexibility of water delivery quantity and timing. A Take-then-Put modality involves creating water storage space in the groundwater aquifer by extracting water that can later be refilled with surface water. Under this modality the groundwater banking operation would be given rights to surface water in storage that it can call at any time, whatever the hydrologic conditions, and require groundwater replenishment on a cycle that guarantees no interference with wells outside that water district. The goal of the site selection process was to identify at least one site for each operational modality that could be implemented through the State water project and one that could be implemented through the Central Valley project and which are sufficiently promising to warrant further analysis to develop specific operational conditions for conjunct management. The team developed screening criteria for each conjunctive management modality:

<u>Put-then-Take Screening Criteria</u>

1. Persistent or permanent cone(s) of depression with no seasonal recovery, (i.e. groundwater areas with available storage space) within

2. Dual use water districts that use both groundwater and surface water deliveries from the state or federal projects or within

3. Unincorporated groundwater usage areas adjacent to state or federal water districts so that the extension of the State Water Project (SWP) or Central Valley Project (CVP) into these areas is practical.

Take-then-Put Screening Criteria

1. Groundwater production areas within or adjacent to state of federal water districts areas, where groundwater extraction can be increased during drier than average years, and which are

2. A significant distance from surface water features of concern; rivers, wetlands, etc to avoid flow depletion effects, and where the dewatered aquifers

3. Can be actively recharged during wetter than average years from the state or federal reservoirs, without losing banked water, or which recover from annual infiltration.

Summary of technical meetings held on Feb 15th, 2007

At a project team meeting on February 15, 2007, nine preliminary sites were selected based on review of a Spring to Fall change groundwater contour map for 2006 made by DWR and the collective knowledge in the room regarding current operations. Five sites were selected as potential Put-then-Take sites, and four sites were selected as potential Take-then-Put sites.

a. Put-then-Take
   (1) Western Canal Water District
   (2) M & T Chico Ranch
   (3) Capay cone of depression
   (4) Cone of depression that is north of Richfield and west of Tehama
   (5) Yolo Zamora groundwater area
b. Take-then-Put
   (1) GCID—Stony Creek Fan partnership
   (2) Willow Creek Mutual Water District
   (3) Colusa County Water District
   (4) Olive Percy Davis Ranch

Summary of technical meeting held on June 19th, 2007 (See Appendix A)

For the June 19th, 2007 technical meeting MBK developed a brief description of each candidate site and how it might operate. This description was submitted to the project team in the form of a draft technical memorandum (Appendix B). For each site, current operations, current groundwater conditions, and the attributes of each water district were summarized in a table. These attributes included; general site information, operational concepts, aquifer characteristics, integration with surface water systems, infrastructure requirements, possible impacts and site screening criteria. There were several blanks in each attribute table, particularly for aquifer characteristics and potential impacts. These attributes required further research and development to be done during the full course of this study and would be used in future screening decisions. Based on each site's ability to meet the screening criteria they were either recommended to be retained for further

analysis or to be dropped from the study. A brief summary of the nine sites considered is summarized below.

Put-Then-Take

WESTERN CANAL WATER DISTRICT - DURHAM CONE
Western Canal Water District (WD) extends surface water (SW) delivery system into the area overlying Durham cone of depression and operates a groundwater (GW) bank with Oroville providing the source water. One operation scenario would be to expand conjunctive management operations within Western Canal to increase surface water deliveries in wet years and reduce SW deliveries in dry years. Some of the augmented supply might be delivered to the refuges just west of Western Canal (Sac River Wildlife Refuge, Upper Butte Creek state reserve).

Groundwater levels fluctuate seasonally in response to agricultural and municipal pumping. The maximum measured fluctuation in the Chico-Durham area in 2006 was approximately 30 ft with an average value of approximately 20 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Big Chico Creek and other local streams. This site has the ability to contribute to Feather River flows and integrate with Oroville operations. It was proposed that we retain this site for further analysis.

ORLAND-ARTOIS WATER DISTRICT
Orland-Artois WD, a CVP Ag Service contractor, receives additional surface water from the Tehama-Colusa (TC) or Glen Colusa (GC) Canals, or directly from Stony Creek. Additional surface water reduces groundwater demand in current cone of depression. Water is returned to the system with additional groundwater pumping in dry years instead of Orland-Artois WD taking all or a portion of their CVP contract. (Note, the original discussion focused on this project with M&T Chico Ranch, but M&T is on east side of river while current cone of depression is on west side of the river, so a more likely project partner would be Orland-Artois WD.)

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the southern portion of Orland-Artois WD area in 2006 was approximately 25 ft, but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from streams tributary to Willow Creek. This site has the ability to contribute to Sacramento River flows and integrate with CVP operations. It was recommended that we retain this site for further analysis.

CAPAY RANCHO WATER DISTRICT
Capay Rancho WD would operate a groundwater bank by receiving surface water in wet

years. Capay Rancho, a groundwater only district, is located over an existing cone of depression that may be utilized to store water. Methods for returning additional GW to the system in dry years are more complex, but may involve supplying water to areas in the TC Canal service area or GCID.

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Capay WD area in 2006 was approximately 50 ft with an average value of approximately 25 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Stony Creek and other local streams. Note that this is right next to the Sac river, therefore may be problems with gw/sw interactions. Because there was no perceived ability to contribute to Sacramento River flows and integrate with CVP operations it was recommended that we drop this site from the study.

CORNING CANAL SERVICE AREA

A portion of the Corning Canal Service Area overlies an existing cone of depression north of Richfield and west of Tehama. The overlying districts that could operate the groundwater bank include Elder Creek, El Camino ID, Tehama Ranch, and Thomes Creek. The Corning Canal runs though these districts and typically has unutilized capacity. CVP contractors along the Corning Canal include Proberta (3.5 TAF/yr), Thomes Creek (6.4 TAF/yr), and Corning (23 TAF/yr) WDs. These WDs have recently been pumping additional GW instead of taking CVP contract water due to the relative costs of CVP water to groundwater.

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Corning Canal Service Area in 2006 was in excess of 50 ft; but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Thomes Creek, Elder Creek, and other local streams draining the western foothills. This site has the ability to contribute to Sacramento River flows and integrate with Shasta operations and it was recommended that we retain this site for further analysis.

YOLO-ZAMORA WATER DISTRICT

The Yolo-Zamora WD overlies an existing cone of depression and relies on groundwater for irrigation. Surface water could be supplied by extending the Tehama Colusa Canal or constructing a canal from the Sacramento River. This has been studied in the past but rejected as prohibitively expensive as a substitute for groundwater for irrigation. Returning water to the system may be challenging.

Unable to evaluate due to lack of data from the Central District at this time. Awaiting receipt of groundwater level data from DWR. The option of extending the Colusa Canal would be economically impractical to distribute surface water in normal and non-normal

water years in addition it would be impractical to extract groundwater. There is currently no ability to contribute to Sacramento River flows and integrate with CVP operations it was recommended that this site be dropped from study.

Take-Then-Put

GLENN-COLUSA IRRIGATION DISTRICT - STONY CREEK FAN
Glenn-Colusa Irrigation District (GCID) could operate a groundwater bank in the Stony Creek Fan, banking CVP water in wet years and reducing CVP surface water deliveries in dry years. This operation may be similar to recent groundwater substitution transfers.

The northern portion of GCID represents an area known to have high aquifer transmissivity. The area is currently served by surface water. The area is underlain by the lower Tuscan Aquifer as well as shallower producing zones in the Tehama Formation. Groundwater levels in this area are shallow, generally less than 10 to 15 ft in the spring. Hydrographs suggest very little seasonal fluctuation in groundwater levels.

The southwestern portion of GCID is still relatively high, but less than that of the northern portion due to the proximity to the margin of the groundwater basin. Well yields in this area are more than sufficient to meet the demands of a take then put project. The area is currently served by surface water. Groundwater levels in this area are shallow, generally less than 5 to 15 ft in the spring. Hydrographs suggest extremely little seasonal fluctuation in groundwater levels. This sites ability to contribute to Sacramento River flows and integrate with CVP operations led to the recommendation that it be retained for further analysis.

WILLOW CREEK MUTUAL WATER DISTRICT
Willow Creek Mutual Water District (MWD) is a mixed groundwater and surface water district located between the GC Canal and the Sacramento River southeast of Willows. Willow Creek MWD is located in close proximity to the Sacramento National Wildlife Refuge. The District is small and does not have substantial agricultural areas. Groundwater characteristics were not evaluated due to proximity to the Sacramento National Wildlife Refuge. There is limited ability to contribute to Sacramento River flows and no clear way to integrate with CVP operations; therefore, it was recommended that it be dropped from the study.

COLUSA COUNTY WATER DISTRICT
Colusa County WD is a CVP Ag Service contractor that takes delivery from the southern reaches of the Tehama Colusa Canal. Some areas within the district are noted to receive both surface and GW. (Note, the original discussion included extracting the water from RD 108, but RD 108 is primarily supplied from surface water and borders the Sac River. I don’t know that this is reasonable or necessary, though water banked under Colusa County WD may flow to RD 108.)

Wells to the east of I-5 indicate relatively shallow depth to water (<5 to 40 ft below ground surface [bgs]) in the spring of 2006. Depth to water increases to the west, in excess of 100

feet below ground surface along the western boundary of the water district. Wells in the eastern portion of the water district generally have higher seasonal fluctuations (up to 20 ft). Wells in the western portion of the district show little to no seasonal fluctuation in groundwater levels. Hydrographs further suggest that there is no long-term trend in groundwater levels since 2000. Aquifer transmissivity in this area decreases due to proximity to the margin of the groundwater basin. This site's ability to contribute to Sacramento River flows and integrate with Shasta operations led to the recommendation that it be retained for further study.

OLIVE PERCY DAVIS RANCH

The Olive Percy Davis Ranch (Ranch) has a Sacramento River Settlement Contract for water from the Sacramento River and CVP. The Ranch is located along the west bank of the river, east of Williams. The ranch has mixed water sources to include surface and groundwater.

Hydrographs in this area indicate that groundwater in this area is extremely shallow (up to 5 ft bgs) with very little seasonal fluctuation. Proximity to the Sacramento River could affect the implementability of a take then put project due to concerns regarding impacts on surface water resources. The aquifer in this area will likely yield large quantities of water to wells. This site has the ability to contribute to Sacramento River flows and integrate with Shasta operations. It is close in proximity to the Sacramento River and raises concerns over SW-GW interaction. Overall, it was recommended that this site be retained for further analysis.

Summary of technical meeting held on July 30, 2007 (See Appendix C)

In an attempt to identify viable put then take project sites in the northern valley, CH2MHill evaluated groundwater elevation data from the period 1970 though present. The objective of this analysis was to determine whether areas exists in the valley where cones of depression in the water table persist year-round such that they represent favorable sites where water could potentially be stored in the aquifer for later use during dry periods. The first step in the analysis was to evaluate spring-fall difference maps to look for seasonal cones of depression. Several areas with seasonal cones of depression exist, specifically the Chico-Durham area, the Capay area, and the area around the Corning Canal among others. Once areas with seasonal depressions were identified, longer term historic water level hydrographs covering the period 1970 to present were constructed for key wells defining the seasonal depressions. The results of this analysis indicated that the cones of depression were really only seasonal features, with almost complete recovery over the winter recharge period. The only exception was in some locations during the 1976-1977 and 1988-1992 drought periods. Some persistent cones of depression were suggested during these droughts but groundwater levels recovered as soon as normal rainfall returned to the valley. Overall, this groundwater level analysis suggests that no obvious locations for successful Put-then-Take scenarios exist in the northern Sacramento Valley.

Appendix A: Meeting Notes

Lower Tuscan Integrated Conjunctive Water Management Plan

Technical Team Meeting
June 19, 2007

Summary Notes

Following are brief notes from a meeting of the Lower Tuscan Technical Team at MBK Engineers on June 19th, 2007. The purpose of the meeting was to review progress on selection and screening of prospective conjunctive use sites, development of analytical tools and development of environmental flow targets.

Attendees:
Thad Bettner/GCID
Greg Thomas/NHI
Carrie Monohan/NHI
John Cain/NHI
Peter Lawson/CH2M HILL
Walter Bourez/MBK
Lee Bergfeld/MBK
Grant Davids/Davids Engineering

Site Selection and Screening
Peter presented well hydrographs from the nine candidate conjunctive management sites previously selected. He explained that while there are areas in the Sacramento Valley that experience seasonal depression of groundwater levels, these areas generally recover each year due to recharge from surrounding aquifers, precipitation, applied irrigation water, stream leakage and other sources. Contrary to initial assumption, there appear to be no areas in the valley where groundwater levels do not recover fully, except possibly in the very driest years or multi-year series. Thus finding conjunctive management sites where year-to-year groundwater banking is accomplished through initial cycles of "put" followed by "take" does not look promising. Instead, we are left with formulations where the take cycle occurs first, and recharge occurs primarily from natural sources, potentially including increased leakage from surface streams, or reduction of groundwater accretion to streams, induced by the lowering of groundwater levels.

With this sharpened perspective, it appears that promising conjunctive management sites would be irrigated areas where:

1) Surface water supplies are reliable (meaning appreciable entitlement in dry years) and form a substantial portion or all of the total irrigation water supply.

2) Underlying groundwater aquifers are productive and economically developed

3) Interaction between groundwater and surface streams, especially the Sacramento River and Feather River does not exist or is highly damped.

Given these attributes, the basic operational scenario would be to pump groundwater and forego use of an equivalent amount of surface water. The surface water could be withdrawn from storage on a schedule designed to meet environmental needs, or other needs. Another option would be to reoperate surface reservoirs to draw them down further and, if they did not refill, rely on groundwater to fill the resulting shortage. Additional yield would be produced by groundwater refilling from natural recharge or surface reservoirs refilling from water that otherwise would be released for flood control purposes.

A significant concern is the extent to which groundwater pumping affects streamflow, and when the effects occur. Effects occurring during balanced conditions would need to be addressed.

We discussed the need to revisit selection of the candidate conjunctive management sites given the additional considerations defined above, and to better document the selection criteria and process. However, no decisions were made.

Model Development

MBK demonstrated the current version of the conjunctive operations spreadsheet model, clarifying that it is still a work in progress. The basic simulation approach is to use outputs from selected CALSIM runs and impose the conjunctive operation on the CALSIM simulated conditions. The basic functionality of the model is complete, and remaining work will focus on adding data integrity and hydrogeologic characterization of the candidate sites.

The model is set up so that each of the nine sites is represented. They can be evaluated independently or in combination, although rules will be needed to establish priorities among sites for combined runs. Independent runs will be made first, and then combined runs explored.

Environmental Flows

NHI has made substantial progress toward establishing environmental flow objectives for the Sacramento River, drawing substantially on ongoing efforts by others, notably The Nature Conservancy and Stillwater Sciences. The objectives address flows for Freemont Cottonwoods, sustaining geomorphic processes, and floodplain inundation. Recognizing that the environmental flow needs may far exceed the additional supplies and timing modifications possible through conjunctive management, next steps will focus on prioritization among the Sacramento River flow objectives, and developing similar objectives for the Feather.

It was acknowledged that the existing Delta export pumping schedules pose significant constraints to reduction of Sacramento River summer flows; however, analysis of modified export schedules (such as might be possible with an isolated facility and additional south of Delta storage) are far beyond the scope of the current investigation.

Action Items

1) **Peter** to check with DWR and validate that there are no areas within the Sacramento Valley with persistent cones of depression where put-then-take operation might work.
2) **Peter** will review the nine sites identified initially, and advise the group as to whether and how site selection should be revisited, considering today's discussion and what is learned from DWR (see #1 above).
3) **Grant** will provide water balance information to Lee for GCID, Orland-Artois, and the Orland Unit.

Next Meeting

1) Next meeting is scheduled for Monday, July 30, 9:00 am at MBK.
2) Peter and Grant will meet at CH2M HILL in Redding on July 19 to discuss site selection.

Appendix B:

D R A F T T E C H N I C A L M E M O R A N D U M

DATE: June 16, 2007

TO: Sacramento Valley Conjunctive Management Project Team

FROM: MBK and CH2M Hill Technical Team

SUBJECT: DRAFT Candidate Site Screening

This memorandum is a summary of nine potential project sites developed during a project team meeting at MBK Engineers on February 15, 2007. A brief description of how each site would operate and the current groundwater conditions is followed by a table listing site attributes relevant for conjunctive management and integration with the surface water system. The last section of each table summarizes the screening criteria used to rate the site to include ability to meet project objectives, volume of water that may be developed, and relative cost of developing the site. Information in the table was developed using existing data, tools, planning factors, and professional judgment to objectively evaluate all sites by consistent standards. The objective of this analysis is to screen the full list of sites and identify a maximum of six sites to carry forward in the study.

The tables are blank for several attributes, particularly for aquifer characteristics and potential impacts. These attributes will be researched and developed during the course of the study and used in future screening decisions. For example, aquifer characteristics will be determined during the next phase when water budgets are calculated for each project site. Aquifer characteristics and preliminary surface water modeling results will be used to further screen sites, and these sites may then be evaluated for possible impacts.

Western Canal Water District - Durham Cone

Project Operations

Western Canal Water District (WD) extends surface water (SW) delivery system into area

overlying Durham cone of depression and operates a groundwater (GW) bank with Oroville providing the source water. An alternative operation would be to expand conjunctive management operations within Western Canal to increase surface water deliveries in wet years and reduce SW deliveries in dry years.

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural and municipal pumping. The maximum measured fluctuation in the Chico-Durham area in 2006 was approximately 30 ft with an average value of approximately 20 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Big Chico Creek and other local streams.

Table 1: Western Canal-Durham Cone Site Attributes

General Site Information	
Project Location:	Western Canal WD and northeast of Western Canal WD near Durham
Current Water Source:	GW
Approximate Area:	? acres over Durham cone; Western Canal = 58,800 ag acres
Existing Project Contracts:	Western Canal – 145 TAF/yr Settlement, 150 TAF/yr Project
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Supply SW thru Western Canal to GW users
Return (dry years):	Pump additional GW in Western Canal to reduce SWP diversions from Feather River and Oroville
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	Seasonally depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Butte Creek
GW Quality:	Localized high Ca, NO3, and TDS in the Chico Area
Integration with SW System	
Existing:	Western Canal with SWP; Durham area is not integrated
With Project:	SWP
Reservoir:	Oroville
Infrastructure Requirements	
Supply Water:	Extend Western Canal canals to include lifts, distribution system in current GW only area
Return Water:	Additional wells in Western Canal
Possible Impacts	
Surface Water:	

Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Feather River flows and integrate with Oroville operations
Est. Water Developed:	Existing ag demands and contracts > 250 TAF/yr
Relative Cost:	Low in Western Canal only; high to include Durham area
Site Status:	**Retain for further analysis**

Orland-Artois Water District

Project Operations

Orland-Artois WD, a CVP Ag Service contractor, receives additional surface water from the Tehama-Colusa (TC) or Glen Colusa (GC) Canals, or directly from Stony Creek. Additional surface water reduces groundwater demand in current cone of depression. Water is returned to the system with additional groundwater pumping in dry years instead of Orland-Artois WD taking all or a portion of their CVP contract. (*Note, the original discussion focused on this project with M&T Chico Ranch, but M&T is on east side of river while current cone of depression is on west side of the river, so a more likely project partner would be Orland-Artois WD.)*

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the southern portion of Orland-Artois WD area in 2006 was approximately 25 ft, but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from streams tributary to Willow Creek.

Table 2: Orland-Artois WD Site Attributes

General Site Information	
Project Location:	Between TC and GC Canals south of Stony Creek
Current Water Source:	GW and mixed within Orland-Artois WD
Approximate Area:	? acres in cone; Orland Artois WD = 25,000 ag acres
Existing Project Contracts:	Orland-Artois WD – 53 TAF/yr CVP Ag service
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Additional SW thru TC Canal, Stony Creek, or uphill from GC Canal
Return (dry years):	Pump additional GW to reduce surface water diversions and back water into Shasta and/or Stony Creek System

Aquifer Characteristics	
GW Recharge Concept:	In-lieu and natural recharge from Stony Creek
Existing GW Levels:	Seasonally depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Stony Creek and Sacramento River
GW Quality:	High nitrates occur in Arbuckle, Knights Landing, and Willows. Localized areas have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP with Orland-Artois WD
With Project:	Possibly expand integration with CVP thru TC or GC canals
Reservoirs:	Shasta (Folsom) and/or Stony Creek system
Infrastructure Requirements	
Supply Water:	Distribution system, extend canals and possibly lift water from GC canal
Return Water:	Additional wells within Orland-Artois WD; minimal to return water to GC Canal
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Existing ag demands and contracts > 50 TAF/yr
Relative Cost:	Medium
Site Status:	**Retain for further analysis**

Capay Rancho Water District

Project Operations

Capay Rancho WD would operate a groundwater bank by receiving surface water in wet years. Capay Rancho, a groundwater only district, is located over an existing cone of depression that may be utilized to store water. Methods for returning additional GW to the system in dry years are more complex, but may involve supplying water to areas in the TC Canal service area or GCID.

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural pumping. The

maximum measured fluctuation in the Capay WD area in 2006 was approximately 50 ft with an average value of approximately 25 ft. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Stony Creek and other local streams.

Table 3: Capay Rancho WD Site Attributes

General Site Information	
Project Location:	Between TC Canal and Sacramento River, north of Stony Creek
Current Water Source:	GW
Approximate Area:	? acres overlying cone; Capay Rancho WD = 7,700 ag acres
Existing Project Contracts:	None
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Provide surface water thru TC Canal, Stony Creek, or pump up from Sacramento River or head of GC Canal
Return (dry years):	Pump additional GW, possibly into GC Canal to reduce surface water diversions and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu and natural recharge in Stony Creek
Existing GW Levels:	Seasonally depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Project borders Sacramento River, near Stony Creek
GW Quality:	The Corning Subbasin has locally high calcium.
Integration with SW System	
Existing:	None
With Project:	CVP thru TC or GC Canals
Reservoirs:	Shasta (Folsom) and/or Stony Creek system
Infrastructure Requirements	
Supply Water:	Distribution system to take surface water from nearby canals; possibly lift from Sacramento River, Stony Creek, or GC Canal
Return Water:	Conveyance to pump GW into GC or TC Canals?
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Currently no ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Small ag area (demands) and no existing contracts
Relative Cost:	Medium

Site Status:	**Drop from study**

Corning Canal Service Area

Project Operations

A portion of the Corning Canal Service Area overlies an existing cone of depression north of Richfield and west of Tehama. The overlying districts that could operate the groundwater bank include Elder Creek, El Camino ID, Tehama Ranch, and Thomes Creek. The Corning Canal runs though these districts and typically has unutilized capacity. CVP contractors along the Corning Canal include Proberta (3.5 TAF/yr), Thomes Creek (6.4 TAF/yr), and Corning (23 TAF/yr) WDs. These WDs have recently been pumping additional GW instead of taking CVP contract water due to the relative costs of CVP water to groundwater.

Current Groundwater Conditions

Groundwater levels fluctuate seasonally in response to agricultural pumping. The maximum measured fluctuation in the Corning Canal Service Area in 2006 was in excess of 50 ft; but appears to vary spatially due to localized pumping. Hydrographs from individual wells indicate that groundwater levels fully recover over the winter months. Additionally, hydrographs indicate no long-term declining trends in groundwater levels exist in this area. It is likely that the aquifer in this area receives recharge from Thomes Creek, Elder Creek, and other local streams draining the western foothills.

Table 4: Corning Canal Service Area Site Attributes

General Site Information	
Project Location:	Corning Canal service area
Current Water Source:	Mixed
Approximate Area:	? acres overlying cone of depression
Existing Project Contracts:	Corning Canal contracts total 32.9 TAF/yr
Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Supply SW thru Corning Canal and possibly TC Canal
Return (dry years):	Pump additional GW to reduce surface water diversions and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River and Thomes Creek
GW Quality:	Impairments in the Red Bluff Subbasin include high magnesium, TDS, calcium, ASAR, and phosphorus.

Integration with SW System	
Existing:	CVP Ag service contractors currently integrated
With Project:	Potential to integrate additional areas with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Minimal in Corning Canal area; significant in existing GW only areas
Return Water:	Additional wells and conveyance?
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with Shasta operations
Est. Water Developed:	Existing ag demands and contracts > 30 TAF/yr
Relative Cost:	Low Corning Canal area only; High to include other areas
Site Status:	**Retain for further analysis**

Yolo-Zamora Water District

Project Operations

The Yolo-Zamora WD overlies an existing cone of depression and relies on groundwater for irrigation. Surface water could be supplied by extending the Tehama Colusa Canal or constructing a canal from the Sacramento River. This has been studied in the past but rejected as too expensive as a substitute for groundwater for irrigation. Returning water to the system may be challenging.

Current Groundwater Conditions

Unable to evaluate due to lack of data from the Central District at this time. Awaiting receipt of groundwater level data from DWR.

Table 5: Yolo-Zamora WD Site Attributes

General Site Information	
Project Location:	Between southern end of Colusa Basin Drain (CBD) and north of Cache Creek
Current Water Source:	GW
Approximate Area:	? acres overlying cone; Yolo-Zamora WD = 19,000 ag acres
Existing Project Contracts:	None

Operational Concepts	
Type of Operation:	Put-then-take
Supply (wet years):	Surface water thru TC Canal or possibly from Colusa Basin Drain
Return (dry years):	Challenging to return water to system
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	Depressed
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River and Cache Creek
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	None
With Project:	Possibly with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Extend TC Canal or CBD; distribution system within Yolo-Zamora WD
Return Water:	Unknown
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Currently no ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Significant ag area (demands) but no existing contracts
Relative Cost:	High
Site Status:	**Drop from study**

Glenn-Colusa Irrigation District - Stony Creek Fan

Project Operations

Glenn-Colusa Irrigation District (GCID) could operate a groundwater bank in the Stony Creek Fan, banking CVP water in wet years and reducing CVP surface water deliveries in dry years. This operation may be similar to recent groundwater substitution transfers.

Current Groundwater Conditions

The northern portion of GCID represents an area known to have high aquifer transmissivity. The area is currently served by surface water. The area is underlain by the lower Tuscan Aquifer as well as shallower producing zones in the Tehama Formation. Groundwater levels in this area are shallow, generally less than 10 to 15 ft in the spring. Hydrographs suggest very little seasonal fluctuation in groundwater levels.

The southwestern portion of GCID is still relatively high, but less than that of the northern portion due to the proximity to the margin of the groundwater basin. Well yields in this area are more than sufficient to meet the demands of a take then put project. The area is currently served by surface water. Groundwater levels in this area are shallow, generally less than 5 to 15 ft in the spring. Hydrographs suggest extremely little seasonal fluctuation in groundwater levels.

Table 6: GCID-Stony Creek Fan Site Attributes

General Site Information	
Project Location:	Northern portion of GCID
Current Water Source:	Primarily surface water
Approximate Area:	Estimate area within GCID overlying Stony Creek Fan
Existing Project Contracts:	GCID - 825 TAF/yr Settlement Contract
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	In normal and wet years area takes existing surface water supply
Return (dry years):	Water returned to system by additional GW pumping to reduce surface water deliveries and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	Natural
Existing GW Levels:	Shallow and stable
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP thru GCID
With Project:	No change
Reservoirs:	Shasta (Folsom); potentially Stony Creek System
Infrastructure Requirements	
Supply Water:	None
Return Water:	Additional wells
Possible Impacts	
Surface Water:	

Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Existing ag demands and contracts > 800 TAF/yr
Relative Cost:	Low
Site Status:	**Retain for further analysis**

Willow Creek Mutual Water District

Project Operations

Willow Creek Mutual Water District (MWD) is a mixed groundwater and surface water district located between the GC Canal and the Sacramento River southeast of Willows. Willow Creek MWD is located in close proximity to the Sacramento National Wildlife Refuge. The District is small and does not have substantial agricultural areas.

Current Groundwater Conditions

Groundwater characteristics were not evaluated due to proximity to the Sacramento National Wildlife Refuge.

Table 7: Willow Creek MWD Site Attributes

General Site Information	
Project Location:	West of Willow Creek, east of Sacramento NWR and north of Delevan NWR
Current Water Source:	Mixed
Approximate Area:	Willow Creek MWD = 7,100 acres total, 2,900 ag
Existing Project Contracts:	None
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	
Return (dry years):	
Aquifer Characteristics	
GW Recharge Concept:	
Existing GW Levels:	Shallow and stable
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia,

	and phosphorus.
Integration with SW System	
Existing:	
With Project:	
Reservoirs:	
Infrastructure Requirements	
Supply Water:	
Return Water:	
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Currently no ability to contribute to Sacramento River flows and integrate with CVP operations
Est. Water Developed:	Small ag area (demands) and no existing contracts
Relative Cost:	Not evaluated
Site Status:	**Drop from study**

Colusa County Water District

Project Operations

Colusa County WD is a CVP Ag Service contractor that takes delivery from the southern reaches of the Tehama Colusa Canal. Some areas within the district are noted to receive both surface and GW. (*Note, the original discussion included extracting the water from RD 108, but RD 108 is primarily supplied from surface water and borders the Sac River. I don't know that this is reasonable or necessary, though water banked under Colusa County WD may flow to RD 108.)*

Current Groundwater Conditions

Wells to the east of I-5 indicate relatively shallow depth to water (<5 to 40 ft below ground surface [bgs]) in the spring of 2006. Depth to water increases to the west, in excess of 100 feet below ground surface along the western boundary of the water district. Wells in the eastern portion of the water district generally have higher seasonal fluctuations (up to 20 ft). Wells in the western portion of the district show little to no seasonal fluctuation in groundwater levels. Hydrographs further suggest that there is no long-term trend in groundwater levels since 2000. Aquifer transmissivity in this area decreases due to proximity to the margin of the groundwater basin.

Table 8: Colusa County WD Site Attributes

General Site Information

Project Location:	Southern reaches of TC Canal, west of RD 108
Current Water Source:	Mixed
Approximate Area:	Colusa County WD = 38,000 ag acres
Existing Project Contracts:	Colusa County WD - 68 TAF/yr
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	Supply additional surface water through TC Canal
Return (dry years):	Pump additional groundwater to reduce surface water deliveries and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	Stable since 2000. Depth increases from east-west (<5 ft bgs to >100 ft bgs).
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Local streams
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP
With Project:	Expanded integration with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Minimal
Return Water:	Minimal
Possible Impacts	
Surface Water:	
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with Shasta operations
Est. Water Developed:	Existing ag demands and contracts > 65 TAF/yr
Relative Cost:	Inexpensive
Site Status:	**Retain for further analysis**

Olive Percy Davis Ranch

Project Operations

The Olive Percy Davis Ranch (Ranch) has a Sacramento River Settlement Contract for water from the Sacramento River and CVP. The Ranch is located along the west bank of the river, east of Williams. The ranch has mixed water sources to include surface and groundwater.

Current Groundwater Conditions

Hydrographs in this area indicate that groundwater in this area is extremely shallow (up to 5 ft bgs) with very little seasonal fluctuation. Proximity to the Sacramento River could affect the implementability of a take then put project due to concerns regarding impacts on surface water resources. The aquifer in this area will likely yield large quantities of water to wells.

Table 9: Olive Percy Ranch Site Attributes

General Site Information	
Project Location:	Between town of Williams and Sacramento River
Current Water Source:	Mixed
Approximate Area:	Ranch = 6,900 ag acres (9,110 per contract)
Existing Project Contracts:	Ranch = 31.8 TAF/yr Settlement Contract
Operational Concepts	
Type of Operation:	Take-then-put
Supply (wet years):	Supply additional surface water from Sacramento River
Return (dry years):	Pump additional groundwater to reduce surface water deliveries and back water into Shasta
Aquifer Characteristics	
GW Recharge Concept:	In-lieu
Existing GW Levels:	
Storage Capacity:	
Loss Rates:	
Stream-GW Interaction:	Sacramento River
GW Quality:	Localized areas of the Colusa Subbasin have high manganese, fluoride, magnesium, sodium, iron, ASAR, chloride, TDS, ammonia, and phosphorus.
Integration with SW System	
Existing:	CVP
With Project:	Expanded integration with CVP
Reservoirs:	Shasta (Folsom)
Infrastructure Requirements	
Supply Water:	Potentially expand SW distribution system
Return Water:	Additional pumps?

Possible Impacts	
Surface Water:	Possible impacts to Sacramento River flows from increased GW pumping
Surrounding GW Levels:	
Subsidence:	
Sensitive Habitats:	
Site Screening Criteria	
Meets Project Objectives:	Ability to contribute to Sacramento River flows and integrate with Shasta operations; close proximity to Sacramento River raises concerns over SW-GW interaction and impacts
Est. Water Developed:	Existing ag demands and contracts > 30 TAF/yr
Relative Cost:	Inexpensive
Site Status:	**Retain for further analysis**

summary of site screening

A summary of the nine proposed sites and their respective status is provided in the following table.

Table 10: Summary of Site Status

Site Name	Status
Western Canal WD – Durham	**Retain**
Orland Artois WD	**Retain**
Capay Rancho WD	Drop
Corning Canal Service Area	**Retain**
Yolo-Zamora WD	Drop
GCID – Stony Creek Fan	**Retain**
Willow Creek MWD	Drop
Colusa County WD	**Retain**
Olive Percy Davis Ranch	**Retain**

The six sites that are retained will be carried forward for additional analysis to include calculation of water budgets, determination of aquifer characteristics, and preliminary surface water modeling.

Appendix C:

Lower Tuscan Integrated Conjunctive Water Management Plan

Technical Team Meeting
July 30, 2007

Summary Notes

Following are brief notes from a meeting of the Lower Tuscan Technical Team at MBK Engineers on July 30, 2007. These are not intended as meeting minutes, rather as a summary of key points, decisions and action items. The primary purposes of the meeting were to: 1) resolve issues related to project site selection and 2) reach consensus on the technical approach for the groundwater analysis. Environmental flows for the Feather River were also discussed. The full meeting agenda is attached.

Attendees:
Thad Bettner/GCID
Carrie Monohan/NHI
John Cain/NHI
Peter Lawson/CH2M HILL
Walter Bourez/MBK
Lee Bergfeld/MBK
Grant Davids/Davids Engineering
Maurice Hall/DWR

1. Revisit Potential "Put-then-Take" Sites

Peter reviewed the rationale that had been used to identify particular geographic areas for investigation of put-then-take (P-T) conjunctive operations. While there are areas in the Valley where cones of depression develop seasonally, those cones generally refill each year by natural recharge and therefore do not offer opportunity for inter-annual storage as is needed for conjunctive operations. Additionally, to the extent that groundwater levels in these areas do not recover completely, this tends to occur in dry years when there would be little surface water available for recharge.

Groundwater hydrographs were reviewed for three areas where seasonal cones of depression occur:

- Chico-Durham
- Capay
- Corning

Some long-term downward decline in groundwater levels is evident in some wells, but there

are no persistent inter-annual cones of depression in these areas.

The Yolo-Zamora area was also discussed. Lee explained that while this area does have a local cone of depression that might be conducive to groundwater storage, there are two major shortcomings associated with this site. One is that it does not have an existing surface water supply to forego use of in dry years (and a new surface water supply would most likely be a CVP water service contract which would not provide a reliable dry year supply). The second is the need for extensive infrastructure improvements involving extension of the Tehama-Colusa Canal and construction of a completely new water distribution system.

The conclusion of the review was that there are no areas where a P-T strategy appears workable at this time on an appreciable scale. Therefore the investigation will proceed focusing on "take-then-put" (T-P) strategies, recognizing that natural recharge will play a significant role in refilling groundwater extracted for project purposes.

The degree of rigor and level of documentation needed in our screening process was discussed. It was agreed that our objective is not to conduct an exhaustive assessment of all possible conjunctive management sites in the Sac Valley, but to identify 2 or 3 most promising sites based on available information and professional judgment, and move ahead with characterization of those sites and development of our analytical tools. We also agreed that given the more detailed modeling approach we have adopted (see below), we should not conduct intermediate analyses of several sites (as originally planned) as a means of selecting the final 2 or 3.

The primary qualifications for candidate T-P sites (as discussed at our last meeting) are places where:

4) Surface water supplies are reliable (meaning appreciable entitlement in dry years) and form a substantial portion or all of the total irrigation water supply.

5) Underlying groundwater aquifers are productive and economically developed

6) Interaction between groundwater and surface streams, especially the Sacramento River and Feather River does not exist or is highly damped.

Additionally, sites that have potential to produce large quantities of groundwater are desirable.

The following three locales were discussed as having these basic attributes, and will receive primary attention as we move ahead with T-P analyses.

- Western Canal WD (potentially including the Chico-Dayton area)
- Stony Creek Fan-Northern GCID
- Central GCID

It was agreed that Carrie would spearhead documentation of our site screening and selection process. Our documentation needs to be clear that elimination of sites for our purposes at this time does not mean that those sites would not be attractive for other purposes or at other times.

2. Analytical Approaches and Tools

The ongoing Delta Vision process and its possible implications to our project were discussed at some length. It was acknowledged that it is as likely that future Delta operations will change, perhaps appreciably, as they are to remain the same. However, it was also acknowledged there is no reliable way to anticipate possible future Delta changes nor related changes to CVP and SWP reservoir operations. We agreed to continue the planned course of analysis within the context of existing Delta operating parameters. The tools and knowledge we are developing may be instructive for planning broader operational changes, but this is outside the scope of our current effort.

The three model improvement approaches formulated by CH2M HILL and MBK were discussed and a decision was made to pursue modifications to the existing superposition model (Option 3). This begins with MBK providing spatially distributed hydrologic time series to CH2M HILL for incorporation into the model. The model will be calibrated to historical groundwater levels.

The need to acknowledge and understand the nature of error and uncertainty in our analysis was discussed. Peter mentioned that sensitivity analyses could be conducted to assist in this process. We will need to track this and design appropriate analyses when we are further along.

Grant will review project budgets to identify where the necessary additional $40,000 can be found and review the necessary adjustments with GCID, NHI and DWR.

3. Environmental Flows

John and Carrie reiterated NHI's basic approach of seeking operational changes that move toward pre-project flow regimes. This approach, rather than a species-specific approach, is thought to be most effective and defensible. Hydrographs for the Feather River were discussed. (This discussion occurred in conjunction with discussion of Item 2.)

Specific rules and priorities by month are needed to incorporate the environmental flows into the analysis. John and Carrie will work on this next.

4. Schedule

Peter, Lee and Walter will establish milestones and develop a proposed schedule for completion of technical tasks to be reviewed by the Team.

5. Summary of Action Items

- Carrie will initiate draft documentation of our site screening and selection processes drawing on the assistance of other team members as needed. A draft will be distributed before our next meeting.
- Lee to transfer hydrologic data to Peter ASAP.
- Grant to review project budgets and initiate task order revisions to CH2M HILL and MBK, in coordination with GCID, NHI and DWR, ASAP.
- John and Carrie to coordinate with Walter in expressing environmental flows in a form conducive to modeling.
- Peter, Lee and Walter will establish milestones and develop a proposed schedule for completion of technical tasks to be reviewed by the Team, ASAP.

6. Next Meeting

The next meeting was set for September 13 at 10:00 a.m. at MBK

Appendix D
Estimating Ecologically Based Flow Targets for the
Sacramento and Feather Rivers

Estimating Ecologically Based Flow Targets for the Sacramento and Feather Rivers

THE NATURAL HERITAGE INSTITUTE

John Cain

Carrie Monohan

April 2008

PREFACE

This report was prepared as part of a collaborative investigation by the Glenn Colusa Irrigation District (GCID) and the Natural Heritage Institute (NHI) to explore opportunities to expand water supplies in the Sacramento Valley through conjunctive management of surface water and groundwater supplies. These expanded supplies could contribute toward achieving three primary objectives: (1) improve local in-basin water supply reliability for farms, cities, and the environment; (2) contribute to improvement of statewide water supply reliability; and (3) enhance ecosystems in the rivers in the Sacramento Valley. The investigation was funded by the California Department of Water Resources and Bureau of Reclamation.

The Scope of Work of the federal and state grants includes a task to define a range of environmental flows to restore in stream and riparian ecosystem processes to the maximum extent compatible with the protection of the interests of the riparian landowners in the floodplain improvements. Flows shall be defined for both the Sacramento River below Shasta and Keswick dams, and the Feather River below Oroville and Thermalito dams, in terms of magnitude, duration, frequency, seasonality and reach. This will be defined in a manner to avoid any uncompensated risks to affected landowners. The range may include various assumptions about levee setbacks in the floodplains. Flood-routing models will be used to estimate the potentially inundated area and system capacity to carry environmental flows.

This report was prepared by the NHI in partial fulfillment of the above-defined task. It postulates hypothetical environmental flow regimes for the Sacramento and Feather Rivers that are significantly different from those that presently exist. It is not yet known to what extent the flows can be achieved through conjunctive water management or, potentially, by other means that are outside the scope of this investigation, while other existing and future water demands are satisfied. Also, the risks that the recommended flows may pose to affected landowners are not addressed in the report, but will be addressed in subsequent work. NHI has prepared this report for the purposes of this planning investigation only. To the extent this report is used or referenced for other purposes, it will be subject to review, modification, and acceptance by the larger number of entities and stakeholders necessarily involved in crafting water management policies, projects and practices in the Sacramento Valley and downstream affected areas.

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1. EXECUTIVE SUMMARY

This study identifies an environmental flow regime for the Sacramento and the Feather Rivers in order to:

- Test the feasibility of reoperating terminal reservoirs in the Sacramento River Basin without diverting additional water away from agriculture,
- Develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River, and
- Use the environmental flow targets to inform and guide conjunctive use scenarios.

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

Our approach consists of five basic steps:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support achieve environmental objectives.
3. Compare and analyze existing and historical hydrology to understand natural hydrologic patterns and how they have been altered.
4. Identify obvious gaps between flows necessary to achieve objectives and existing flows.
5. Modify the existing hydrograph into an environmental flow hydrograph based on an understanding of natural hydrology and the flows necessary to achieve key objectives.

These five steps will ultimately need to be followed by an adaptive management research program to test and refine an improved environmental flow regime over time.

We designed the environmental hydrograph to achieve the following three types of objectives

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

- Riparian Habitat Sustainability: Recruitment and maintenance of Fremont Cottonwood.
- Chinook Salmon: Improved habitat, particularly rearing habitat, for all runs.

We relied on field data, modeling results, and studies , particularly the recent Nature Conservancy Study of the Sacramento River, to identify the minimum flows and critical thresholds to achieve each of our objectives. We then analyzed historical and existing hydrology to understand how the objectives may have been achieved under pre-dam conditions and to evaluate how existing hydrology may fall short of meeting those objectives.

A sharp reduction in the magnitude and duration of the late winter and early spring hydrograph and a corresponding reduction of inundated floodplain habitat is the most obvious and significant change in the hydrograph on both the Sacramento and Feather Rivers. The reduction in late winter and spring flows reduces the frequency of geomorphic and riparian flows and substantially reduces the extent and frequency of occurrence of inundated floodplain rearing habitat for salmonids. Restoring spring flows alone, however, will not be sufficient to dramatically increase the amount of floodplain habitat. Modifications of the levees and bypass system will also be necessary to enable high flows to inundate historical floodplains. We evaluate the amount of flow necessary to inundate the Yolo and Sutter Bypasses assuming modification of the weirs controlling flows into those bypasses in the interest of identifying water efficient strategies for creating large areas of inundated floodplain habitat.

The last chapter identifies an environmental flow regime for the Sacramento and Feather Rivers. An increase in late winter and early spring flow is the primary component of the environmental flow regime, but a corresponding reduction in summer base flows is also recommended. Reduced summer flows are primarily needed to free-up water needed to restore the spring hydrograph but may also provide ecological benefits by better approximating the natural hydrograph. Reducing summer base flows could, however, increase summer temperatures and harm salmonids including the endangered winter-run Chinook salmon. On the other hand, cool water temperatures in the upper Sacramento River are largely controlled by the volume of cold water storage behind Shasta Dam and the environmental flow regime identified here does not involve modifying coldwater pool management.

The summer temperature issue is one of several key uncertainties that must be addressed before any significant modifications to the flow regime can be refined and implemented for environmental purposes. Articulating a hypothetical environmental flow regime is the first step in identifying and addressing constraints and uncertainties associated with improving environmental flow regimes on regulated rivers. To that end, NHI welcomes comments and criticisms so that we can improve upon this report as we learn more about the rivers and the people who depend upon them for their livelihood.

2. INTRODUCTION

This study identifies environmental flow targets for the Sacramento River and the Feather River. The purpose of developing environmental flow targets is to:

- Test the feasibility of reoperating terminal reservoirs in the Sacramento River Basin without diverting additional water away from agriculture,
- Develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River, and
- Use the environmental flow targets to inform and guide conjunctive use scenarios.

Our thesis is that reservoirs operated today for a limited set of water supply and flood control objectives could be reoperated to achieve newly defined ecological objectives without compromising existing objectives. This opportunity was recognized by the authors of CALFED's Strategic Plan for Ecosystem Restoration:

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

Clearly defining this new set of ecological objectives and estimating the flows necessary to achieve them is the first step toward evaluating the feasibility of restoring these flows. The biological and physical processes that support natural riverine functions are complex and the task of defining environmental flow regimes is enormously difficult. For the purpose of defining an environmental flow regime and assessing the feasibility of attaining it, we have identified a simplified but broad set of water intensive ecological objectives that best capture the full range and magnitude of environmental flow requirements in the Sacramento Basin. These objectives include:

- Geomorphic Processes: sediment transport, channel geomorphology, floodplain inundation.
- Riparian vegetation: cottonwood recruitment and maintenance flows
- Chinook and Steelhead: stream temperatures and adequate flow for various life stages.

This study focuses on the magnitude and timing of flows necessary to replicate key ecological and geomorphic processes, and considers the flows necessary to provide suitable conditions for various life stages of Chinook salmon and steelhead. This study does not identify specific population targets for salmonid restoration, nor does it address important non-flow objectives such as habitat area required for restoration of target

species or augmentation of coarse sediment supplies necessary to restore full geomorphic structure and function. Rather this study focuses on magnitude, pattern, and quantity of water necessary to restore ecological functions assuming that adequate physical habitat exists or will be created to complement a suitable environmental flow regime. The rationale of this focus is to identify a hypothetical environmental flow regime for the purpose of evaluating whether it is possible to reestablish ecological and geomorphic flows on the rivers of the Sacramento Basin without reducing water supply deliveries to existing water users.

This report would not have been possible without the foundational analysis conducted by the Nature Conservancy and their consulting team, but it differs substantially from the Sacramento River Ecological Flows Study (SREFS) developed by the Nature Conservancy with funding from the CALFED Bay-Delta Program. The SREFS compiled information on the state of the Sacramento River ecosystem and developed a decision support tool to predict how changes in the flow regime of the Sacramento River might affect key attributes and species of the riverine ecosystem. The SREFS did not, however, attempt to develop an environmental flow prescription for the river and did not address ecological conditions or flow requirements for the Feather River. The SREFS decision support tool could be used to test and refine the flow regime developed for this report, but the SREFS did not and will not propose an environmental flow regime. We relied heavily on the information developed for the SREFS to generate the environmental flow regime described in this report.

Our study relies heavily on analysis of historical hydrology and the habitat it created to provide a reference point for identifying ecosystem restoration goals, but we recognize that it is not possible to restore historic conditions in highly altered systems such as the Sacramento River. Historical hydrologic analysis is useful for identifying patterns in the timing, magnitude, duration, and frequency of flows that may be important for maintaining native species, but it is less useful in developing specific flow prescriptions, because physical habitat has been so profoundly changed by dams and levees. We recognize that it is not possible to fully restore historical hydrology or habitat conditions in the Sacramento Valley, but ecosystem restoration will require reestablishment of a minimum threshold of both hydrologic and physical habitat conditions.

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

3. METHOD FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS FOR THE SACRAMENTO AND FEATHER RIVERS

We conducted a detailed literature review of various methods and approaches previously utilized to develop environmental flow recommendations, which is described in further detail in Appendix A. We have employed a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento River. This approach relies heavily on hydrological evaluations, previous studies, and expert opinion to estimate environmental flow requirements and develop a long-term adaptive management plan for implementing and refining an environmental flow regime over time. The results of the holistic approach provide a framework for increasing knowledge regarding the relationship between flow and environmental objectives and refining water management practices over time. The output of the holistic method envisioned here provides not only an estimate of environmental flow requirements, but more importantly, an explicit identification of key assumptions and uncertainties that need to be tested overtime to more accurately describe the flow requirements necessary to achieve environmental objectives.

We made two important assumptions in generally applying this method to the Sacramento River.

- Similarities in both the restoration objectives and the hydrologic, geomorphic, and ecological conditions on the Sacramento River will result in relatively similar prescriptions for environmental management flows. We believe this assumption is well supported by the environmental conditions and historical alteration of this river.

- The flow necessary to achieve restoration objectives may vary greatly depending on non-flow restoration actions such as improving spawning habitat, reconstructing degraded channel, removing levees to restore floodplain habitat, modifying and screening water diversions, reducing polluted run-off, managing ocean harvest, and other factors. In general, non-flow restoration actions will reduce the amount of water necessary to achieve restoration objectives.

The holistic approach applied in this study consists of the following 6-step process to identify an environmental flow regime:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.
3. Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.

4. Identify obvious gaps between objective flow requirements and existing flows.
5. Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.
6. Design an adaptive management program to further test and refine environmental flows.

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

Well-articulated target ecological conditions and desired species and communities are necessary for establishing environmental flows. Despite the correctly vogue concept of restoring ecosystem processes and avoiding species specific approaches, there is no getting around the fact that key species need specific hydrologic conditions at specific times. This analysis will include both aquatic and riparian communities and the flow parameters necessary to sustain these communities such as floodplain inundation, appropriate water temperature, or creation of structural habitat through geomorphic processes. These specific environmental objectives may vary by region, sub-basin, and reach of the river.

2) Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.

An environmental flow regime encompasses the adequate timing, magnitude, duration, and frequency of flows necessary to support target species and facilitate specific ecological processes encompassed in the stated environmental objectives. Where we understand the life cycle timing of various target species, it is relatively easy to identify the approximate timing and duration of flows necessary to support different life stages of target species. Estimating the required flow magnitude is far more difficult but can be informed by field data, results of numerical models, and general relationships described in the literature. Most short lived target species require adequate flows each year to reproduce, while longer lived species can sustain their populations with a lower frequency of flow conditions conducive to reproduction. For example, riparian forest species may only require recruitment flows every five to ten years to establish new seedlings.

Estimating the magnitude of flows necessary to support or optimize conditions for target species and processes is by far the most difficult element of the environmental hydrograph to approximate. Environmental engineers and biologists have developed relatively elaborate methods for determining ideal flow regimes such as physical habitat simulation (PHABSIM) and Instream Incremental Flow Methodology (IFIM) to identify optimum flow magnitudes based on known habitat preferences of target species, measured habitat conditions (velocity and depth) at various flows, and numerical models that predict habitat conditions at a range of flows. Numerical models that describe the width, depth, and velocity of the rivers at various discharges are useful for predicting river stage and temperature at various locations, factors that are important considerations

for habitat or facilitating geomorphic and hydrologic processes. As discussed above, these models tend to focus on the needs of specific species and can sometimes produce results that are inconsistent with both holistic ecological process restoration and common sense. Furthermore, these models are often not calibrated, particularly at higher flows relevant to riparian recruitment, geomorphic processes, and spring outmigration temperatures. Nevertheless, we utilized the results of these models as a guide combined with other information to develop our environmental flow management hypothesis.

Where possible, we relied on actual data and measurements to estimate the flows necessary to achieve suitable conditions to support biological, riparian, and geomorphic objectives for temperature, floodplain inundation, and bed mobilization. In particular, we relied on USGS temperature gauges to characterize the relationship between temperature and flow. Similarly, we relied on previous studies of the rivers to characterize flows necessary to mobilize bed material and inundate the floodplain.

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

Analyses of historical hydrologic data is useful for describing natural patterns and identifying potential links between hydrology and the requirements necessary to maintain species and precipitate key processes. An analysis of historical patterns can provide clues about the timing, magnitude, duration, and frequency of flows under which target species have evolved. Identification of major changes between historical and hydrologic patterns combined with the life history requirements of various species can help generate hypotheses about how flow regulation may be limiting target species. We will use the an analysis similar to the Index of Hydrologic Alteration approach (Richter et al. 1996) and the Hydrograph Component Analysis (HCA) (Trush et al. 2000) to evaluate changes in flow patterns. The analysis similar to the IHA provides a quick statistical overview of how several important hydrologic attributes have changed. The analysis similar to the Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. While valid and useful, the statistical analysis in the IHA method is not substitute for visually comparing and evaluating key components of the pre- and post-dam hydrographs. Similarly, visual comparisons of pre- and post-alteration hydrographs don't always reveal important changes identified by the IHA method.

4) Identify obvious gaps between objective flow requirements and existing flows.

An analysis of historical flow patterns combined with an approximation of the TMDF of flows necessary to achieve objectives compared with the regulated flow regime can help illustrate obvious gaps between regulated flows and flows that may be necessary to achieve environmental objectives. We will plot TMDF flow requirements developed in Step 2 as an annual hydrograph and compare it with average regulated and historical conditions.

5) Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key

hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.

This project identifies hypothetical restoration flow regimes but recognizes that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The purpose of developing the hypothetical flow regime is to develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River. However, the assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself.

6) Design an adaptive management program to further test and refine environmental flows.

To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of numerical modeling, pilot flow studies, model calibration, and long-term restoration implementation.

4. IDENTIFY ENVIRONMENTAL OBJECTIVES AND UNDERLYING CONCEPTUAL MODELS

4.1. Environmental Objectives

The geomorphic, riparian, and salmonid objectives considered in this report are summarized below. A more detailed description of the objectives, background information, and the underlying conceptual models is included in Appendix B.

Geomorphic Objectives

- Sediment Transport: bed mobilization and bed scour
- Channel Migration
- Floodplain Processes: inundation and fine sediment deposition

Riparian Objectives

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

Chinook Objectives

- Chinnook salmon: suitable flow conditions and temperatures for all life stages.
- Provide inundated floodplain habitat for rearing juveniles during the later winter and early spring.
- Maintain and recruit spawning habitat, but avoid scouring gravels while eggs or alevon are present

We purposely did not identify population targets for salmonids. The extent and magnitude of restoration actions depends on the size of the population fish managers are attempting to restore. More fish require presumably require more habitat particularly for spawning and rearing. Creating more habitat may require both physical changes in channel conditions and increased flows. .

Appendix B describes the underlying assumptions and rationale (conceptual model) for environmental flow requirements. It describes the science of how and why river flows are necessary to achieve the objectives listed above, and identifies some of the challenges associated with developing environmental flow prescriptions.

5. ENVIRONMENTAL FLOW THRESHOLDS AND REQUIREMENTS

5.1 Geomorphic Thresholds

Flow requirements broadly fall into two categories: threshold and targets. Thresholds are flow prescriptions that only achieve their objective if the threshold is reached or exceeded. For example, bed mobility flows must be high enough to mobilize the bed. If they are below the threshold, the bed does not mobilize and no progress toward the objective occurs. In actuality, however, bed mobilization may occur at different flows in different reaches making it difficult if not impossible to name a single threshold number. Targets are flow requirements that are desirable but not essential to achieve. Benefits still accrue when there is progress toward the target even though the target is not actually reached. For example, a flow release to meet a target of 5,000 cfs to achieve an optimal water temperature for twenty four hours a day will still provide temperature benefits even if the release only achieves 4,000 cfs and optimal water temperatures eighteen hours per day. At some point, however, there is a minimum threshold or minimum flow below which temperatures are lethal or flows are insufficient to support fish.

This paper focuses on thresholds for key ecological and geomorphic objectives that generally require high flow thresholds, but also identifies flow targets to sustain salmon. We have not attempted to define minimum flow thresholds for salmon, but rather have identified more generous targets based on historical base flow conditions. We identify the basis for these thresholds and targets in this section and compile them into a environmental hydrograph in the final chapter of this report.

For each threshold, we have estimated the magnitude, duration, frequency, and timing of flows necessary to achieve a desired outcome and have organized table X and the following text accordingly.

5.1.1. Bed Mobilization:

Magnitude: There is limited information regarding the magnitude of flows required to initiate bed mobilization on the Sacramento River, but less information regarding flows necessary to precipitate full-scale bed mobilization. Under natural conditions the gravel bedded reaches of the Sacramento River were theoretically mobilized by peak flows exceeding the 1.5 to 2 year recurrence interval of the annual instantaneous peak (Leopold et al 1964), which is approximately 80,000 cfs to 120,000 cfs. For comparison, the post dam Q1.5 and 2.0 recurrence interval flow is approximately 65,000 and 80,000 cfs respectively. The Department of Water Resources estimated that the threshold for spawning gravel mobilization immediately below Keswick Dam was 50,000 cfs (CDWR 1981), but this is considered to be a minimum because it was based on observations of gravel that was artificially deposited below the dam *(Stillwater,*

2006).[1] DWR added 13,300 yd^3 of gravel below Keswick Dam in 1978 and 1979, and estimated that 85% of it was eroded by high flows of 36,000 and 50,000 cfs during the winter of 1980 (CDWR 1981). Latter, Koll Buer of the USBR measured mobility and transport downstream of Keswick with "flower box" samplers – boxes placed into the channel bed before a high flow event. Buer's measurements indicate that gravel transport begins at 24,000 cfs but did not provide information about when larger gravels and the entire bed begin to mobilize. The coarser riffles downstream of Keswick (small boulders and large cobbles) are probably armored due to years of erosion from sediment free water released from Shasta Dam. These armored riffles appear not to change and thus probably remain immobile even at flows exceeding 100,000 cfs (K. Buer, personal communication in Kondolf, 2000).

There are not empirical studies or observations regarding bed mobility on the Feather River. Historical flow data is the only information available to estimate the discharge necessary to mobilize the bed on the Feather River. The 1.5 to 2 year recurrence interval of the annual instantaneous peak prior to the construction of Oroville Dam was 33,000 to 50,000 cfs respectively.

Frequency: Relatively frequent bed mobilization is necessary to prevent vegetation establishment and encroachment on gravel bars. Willows can become well established and resistant to scour in three to four years (cite). Therefore, bed mobilization flows are necessary at a greater frequency then every three to four years to prevent vegetation establishment.

Duration: The duration of peak flows may vary depending on the objective. A short duration may be enough to clean gravels on a spawning riffle while a longer duration flow may be necessary to maintain overall transport of gravels. Because coarse sediment inputs are limited by the upstream dam and riffles already show signs of armoring, long duration peak flows may actually degrade riffles. For this reason and to both reduce flood hazards and economize water, a short duration bed mobilization flow of approximately 12 hours at the recommended peak flow and then ramping down thereafter consistent with historical patterns may be optimal.

Timing: Ideally, bed mobility flows should occur after fall run fry have emerged from the gravel and before swallows begin nesting on stream banks in late march. We therefore recommend a 30 day target window between February 20 and March 20.

[1] These gravels may have mobilized at lower flows because of their unnatural position relative to the high flows or because they were not integrated into the gravel/cobble matrix of the natural bed

5.1.2 Bed Scour

Less is known about the bed scour process, flows exceeding the natural 5–10 year recurrence interval are probably necessary to precipitate bed scour (Trush et al. 2000). The pre-dam Q5 and Q10 recurrence interval on the Sacramento are 150,000 and 200,000 cfs respectively. During the post dam era, flows of 150,000 cfs or more occurred roughly once every 10 years. On the Feather River, the pre-dam Q5 and Q10 were 104,000 and 144,000 respectively. Flows of this magnitude have only occurred twice in the forty years since Oroville Dam was constructed. Because of the lack of information regarding bed scour and the probable flooding impacts of these flows, it is exceptionally difficult to develop and achieve a bed scour flow recommendation.

5.1.3 Bank Erosion and Channel Migration

Magnitude

Stillwater reports that there is general disagreement on the exact magnitude of flow to initiate substantial bank erosion, but claims there is growing evidence that flows between 20,000 and 25,000 cfs will erode some banks while flows above 50,000 to 60,000 cfs are likely to cause widespread bank erosion (Stillwater, 2007). Meander migration modeling analysis for the Sacramento River assumed that 15,000 cfs was the lower threshold for meander migration (Larsen, 2007). Total bank erosion and channel migration, however, is dependent on both the duration and magnitude of flows, which together produce a cumulative streampower in any given year. Analysis of cross section surveys (Buer, 1994a) over more than ten years shows that rates of bank erosion are closely correlated with cumulative annual stream power (Larsen, et al., unpublished in Stillwater, 2006). Bank erosion.

On the Feather River, there is very little information regarding flows necessary to initiate bank erosion and channel migration. The pre-dam Q1.5 on the Feather River (35,000 cfs) is approximately forty four percent of the pre-dam Q 1.5 on the Sacramento River (80,000) cfs. If channel migration flows on the Feather were similarly proportioned channel migration flows on the Sacramento (50,000 – 60,000 cfs), then one could expect significant and wide spread bank erosion on the Feather River at flows between 20,000 and 25,000 cfs. Instantaneous peak flows of this magnitude reoccur every 2.5 years on average, and large areas of channel revetment along the Feather River indicate that the unprotected bank is subject to erosion under the current flow regime.

Duration

The stream power relationship between magnitude and duration make it difficult to identify a specific threshold. Without modeling analysis, it is difficult to assess whether two weeks at 30,000 cfs could result in as much bank erosion as two days at 60,000 cfs.

Frequency

Bank erosion and channel migration are important for maintaining general riparian habitat, nesting habitat for bank swallows, and turbidity for juvenile fish cover. We are uncertain how often migration and erosion should occur but suspect that some bank erosion every year is a reasonable target. Slight but annual bank erosion may be

beneficial for maintaining optimal bank swallow habitat. More significant and annual erosion events may be necessary for producing turbid water conditions. Moderate but less frequent bank erosion, every (2-4) years, may be adequate for generating new riparian habitat.

Timing
Erosive flows during the bank swallow nesting period, which generally begins in late March, can actually disrupt bank swallows. Therefore, it may be most beneficial to bank swallows to achieve bank erosion objectives prior to late march.

5.1.4 Floodplain Inundation and Rearing Habitat Flows

The occurrence of inundated floodplain habitat has been substantially altered by both levees and dams. Dams have reduced the frequency of high flows sufficient to inundate floodplains, while levees have prevented high flows, even very high flows, from inundating floodplains particularly in the lower reaches of the river below Colusa. It is not reasonable to reestablish inundated floodplains by overtopping levees, because it would require extremely, even unnaturally, high flows and would cause widespread flood damage.

Adequate duration of flooding in the designated flood bypasses generally occurs in the wet years and sometimes in normal wet years creating excellent conditions for salmon and splittail. But overtopping the weirs and flooding the bypasses in normal dry and dry years would require prohibitive amounts of water to achieve in normal dry and dry years. For efficiency sake, it is probably only realistic to achieve prolonged (30-60 days) floodplain inundation in normal dry and dry years by notching (or removing) the upstream weirs to allow a small amount of water to pass (3,000-5,000 cfs) and installing inflatable weirs in the low flow channels of the bypasses to back-up water.

Strategically breaching levees and flood control weirs to inundate flood bypasses and other undeveloped land is a much more prudent and achievable approach for creating inundated habitat. Although there may be many places to create inundated flood plain habitat with strategic levee modifications, we have focused on identifying flows that would create inundated habitat in the Yolo and Sutter Bypasses if modifications are made to the weirs that control flow onto the bypass. The area of inundation under a given flow is determined by topography and drainage. We assume changes in the topography and drainage of the bypasses (i.e. berms or inflatable wiers) to maximize the area of inundation at lower flows and minimize the potential for stranding. While it might be possible to create large areas of habitat at low flows, more flows may be necessary to optimize temperatures on the flood plain and conveyance of nutrients from the floodplain to the Delta.

Magnitude
We evaluated two questions associated with magnitude: the magnitude of flow necessary in the Sacramento or Feather Rivers necessary to inundate the bypasses and the magnitude of flow in the bypasses necessary to create large areas of suitable floodplain

habitat. It may be possible to inundate large areas of the bypass with relatively little flow by installing flow barriers in the bypass to back-up water onto the floodplain. While this may be suitable for creating large areas of inundation, it might not create the right residence time and temperature for optimal habitat. Habitat characteristics such as velocity, depth, temperature, residence time, primary productivity are negatively correlated with flow, while Diptera, an important food resource, was positively correlated with flow (Sommer et al, 2004).

According to DWR modeling analysis, large areas of the bypass become inundated with as little as 5,000 cfs flowing through the bypass (figure 5.1) (Harrell, B., 2008). Flows in excess of 25,000 cfs in the Sacramento River, however, may be necessary before it is possible to get 5,000 cfs down the bypass.

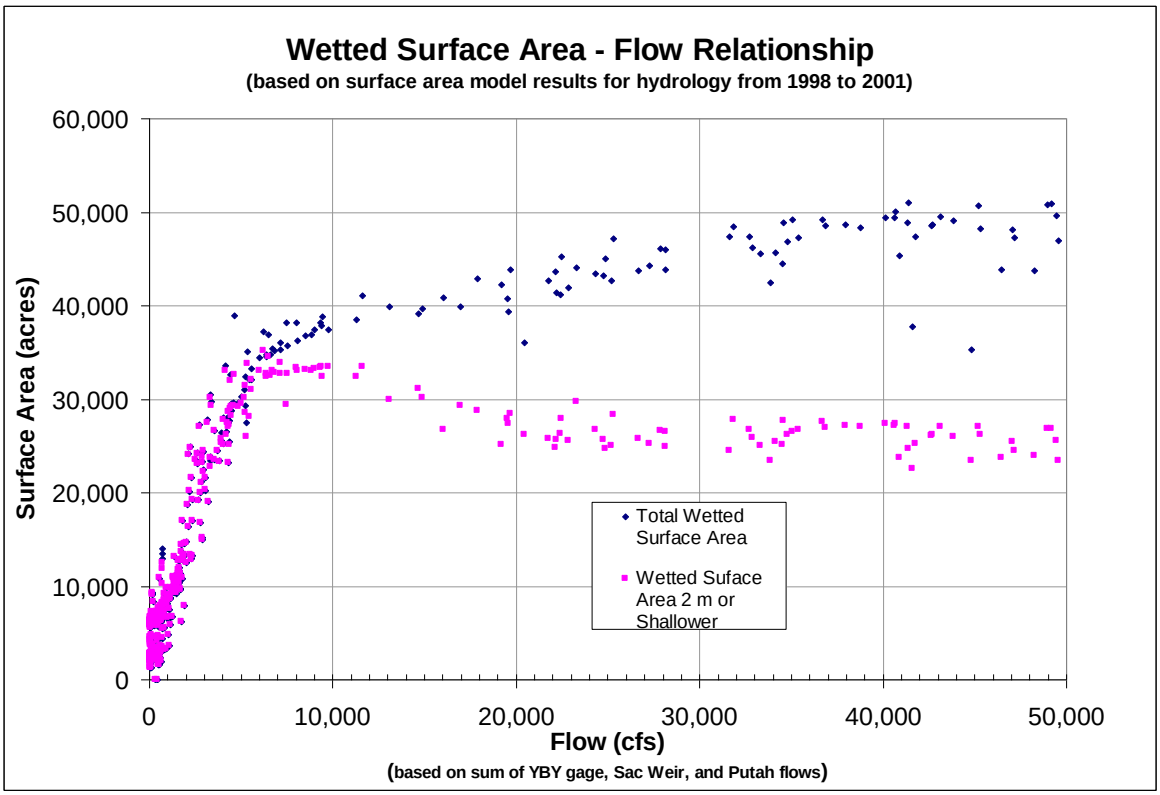


Figure 5.1: Wetter surface area-flow relationship for flows in the Yolo bypass (cite)

To estimate the amount of flow necessary to inundate the Sutter and Yolo Bypasses, we referred to USGS topographic maps to determine ground elevations at Tisdale and Freemont weirs which currently control flows onto the bypass, and then used stage discharge relationships for nearby gauges to estimate the amount of flow necessary to achieve a stage equal to the ground elevation at the weir – an overbank flow assuming the weir did not exist or was operable (table 5.1). The overbank flow, however, is not enough to push substantial amount of water down the bypasses. We therefore assumed that a minimum of 5,000 to 10,000 cfs above the overbank flow was necessary to create substantial inundated floodplain in the bypass.

Table 5.2 identifies flow recommendations for various year types at four key sites: Tisdale Weir, Freemont Weir, and Verona Gauge on the Sacramento River and Nicolaus Gauge on the Feather River. Tisdale Weir spills into the Sutter Bypass and then flows back into the Sacramento River near Freemont Weir. The sum of Freemont and Nicolaus should equal Verona. Note, however, that table 5.1 flows at Verona are lower then the sum of Freemont and Nicolaus. This is because large amounts of the Sutter Bypass (ground elevation of 25 feet) will flood with backwater from the Sacramento at flows above 27,000 cfs at Freemont Weir. In other words, if Freemont or Verona is greater then 30,000 cfs, then large amounts of the Sutter Bypass are flooded irregardless of flows in the Feather River or at Tisdale Weir.

Table 5.1: Overbank flows in the Yolo or Sutter Bypass assuming levees or weirs along the Sacramento and Feather Rivers are breached or removed

Gauge or Weir	Ground Elevation	Overbank Flow	Notes
Nicolaus Gauge (Feather)	30	10,500	
Freemont Weir	25	27,000	Approximate based on Verona Gauge
Freemont with Excavation	13	15,000	Invert of the Toe Drain
Tisdale Weir	40	25,000	Approximate
Sacramento Wier (I Street Bridge)	15	49,000	
Sac Weir with Excavation	10	31,000	Sac Weir with excavation
Right Bank at Verona	25	42,000	Remove right bank levee

Table 5.2: Recommended flows to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types.

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Duration and Timing

Provide floodplain inundation flows for 30 – 60 days between February 15 and April 30 into Sutter and Yolo Bypasses to provide rearing habitat for salmon and splittail and spawning habitat for splittail. Where possible, time releases to coincide with and extend duration of high releases on the Yuba and Sacramento.

Frequency

Ideally, it would be possible to inundate the bypass in every year to enhance foodweb productivity and improve rearing habitat for every year class of salmon. It may be

possible to do this while economizing on water by inundating relatively small areas in dry years and very large areas in wet years with no inundation in critical dry years.

5.2 Riparian Flow Requirements

A sequence of hydrologic, geomorphic, and biologic phenomena is necessary to recruit cottonwood seedlings to the riparian forest. Under natural flow regimes, moderate 5- to 10-year flood events precipitate channel migration and the creation of point bars suitable for cottonwood seedling establishment (McBain and Trush 2000, Trush et al. 2000). Analysis of hydrologic data, dendrochronologic data, historic channel mapping, and aerial photography riparian recruitment appears to occur approximately once per decade in the post-regulation period (Roberts, 2003). But recruitment may now be limited to larger, less frequent events due to greater hydrologic modification in recent years. Recruitment did result from the recent large flood events of 1983-1986, and 1995-1997, (Roberts, 2003) but willows dominate while cottonwood recruitment is spatially limited.

In order to maintain or re-establish woody riparian vegetation using a process-based restoration approach, managed flows need to mimic natural hydrographs in the following key ways (Stillwater, 2007):

- High flow peaks, which should mimic to some degree the characteristics of peak flows associated with winter peak rain events in the unimpaired hydrograph are necessary to control vegetation encroachment by herbaceous and weedy species and prepare seedbeds prior to seedling recruitment flows in wet years (scouring or encroachment prevention flows) and seedbed preparation flows.
- High spring snow-melt peak flows with relatively gradual recession rates during wet years to moisten the seedbeds and induce seed germination on geomorphic surfaces suitable for long-term establishment (recruitment flows for seedling initiation).
- Summer and fall base flows are needed to ensure that new seedling cohorts and older cohorts of saplings and mature trees have adequate soil moisture for summer growth and survival during the annual dry season (seedling establishment and maintenance flows).

In regulated rivers it may also be necessary to limit unnaturally high summer flows. Summer base flows higher than spring flows may give a competitive advantage to non-native species that reproduce by seed during the summer months. Establishment of non-natives could impede later recruitment of natives such as cottonwood (cite).

5.2.4 Site Preparation

Large flows scour away herbaceous plants and/or deposit fine sediments on floodplains, preparing new seed beds for pioneer riparian species (Mahoney and Rood 1998). The magnitude of flows necessary to scour or deposit seed beds is presumably much larger then the amount of water necessary to inundate these sites. For this analysis, we assume that flows sufficient to mobilize the bed (80-100k cfs on the Sacramento and 35,000-50,000 on the Feather) are sufficient and that seedling establishment flows will only occur in wetter years after bed mobilization generally occurs.

5.2.5 Seedling establishment:

In order to assure long-term survival, seedlings must become established in a zone that is high enough on the bars and banks to avoid scour from peak flows, but low enough to avoid desiccation during low flows in summer and fall. Rood and Mahoney (2000) developed a recruitment box model that placed this zone at 2.5 to 4 feet above mean low (MLW) water for the St. Mary River in Alberta Canada. Roberts (2003) calibrated the recruitment box model on the Sacramento placing the recruitment zone at 3-6 feet above MLW and developed a stage discharge relationship at three representative sites to determine that recruitment zone is inundated at flows between 23,000 and 30,000 cfs. Roberts recruitment zone, however, is based on the artificially high summer flows in the Sacramento River. Under natural summer flow conditions the recruitment zone, and flows necessary to inundate it, may be somewhat lower.

Little to no information exists regarding seedling establishment elevation for the Feather River. Furthermore, it is difficult to identify a suitable recruitment zone at some distance from the mean low water, because mean low water levels in the summer are two to three times higher then pre-dam, natural levels. The stage discharge relationship for the Feather River at Nicolaus combined with topographic maps indicate that the Feather River overflows its banks at Nicolaus at approximately 12,500 cfs. The banks further upstream are higher and can convey more flow before overtopping. Since cottonwoods generally become established on the banks and gravel bars of alluvial rivers, it is reasonable to assume that the recruitment zone is below the stage of the bankfull discharge. The seedling establishment flow on the Sacramento (23,000 – 30,000 cfs) is twenty seven to thirty seven percent of the bankfull discharge (Q1.5 to Q2) on the Sacramento. Assuming a similar proportional relationship on the Feather River, flows in the range of 9,500 to 18,000 would be suitable for seedling establishment. Analysis of historical flow data (section seven of this report) indicate that flows in this range were common during April and May when germination is most likely to occur.

Post-germination decline of river stage, which is presumed to control adjacent groundwater levels, should not exceed approximately one inch per day (Mahoney and Rood 1998, Busch et al. 1992). This is the rate at which seedling root growth (0.16–0.47 inches/day; Reichenbacher 1984, Horton et al. 1960) can maintain contact with the capillary fringe of a receding water table in a sandy substrate. Cottonwood root growth and seedling establishment rates are higher in these soils than in coarser textured soils, which are more porous (Kocsis et al. 1991). In reaches with gravelly substrates, slower draw-down rates are necessary to support seedling establishment.

Information necessary to design a gentle recession limb is limited. Stage discharge data from gauging stations may not be representative of Cotonwood recruitment sites, because they are generally sited at geomorphically stable and simple sites while cottonwood recruitment often occurs on complex and dynamic sites. Kondolf and Stillwater (Kondolf, 2007) measured stage discharge relationships at several representative gravel bars along the Sacramento River and determined that stage drops 0.1 meter (.34 feet) per 1000 cfs at flows ranging from 7,000 to 15,000 cfs, but cautioned against extrapolating

this relationship to flows outside the observed range. Within this range, however, a discharge decline of 250 cfs per day would yield a stage decline of one inch per day.

To estimate a suitable recession rate flow schedule, we assumed that cottonwood seedlings would become established six feet above the mean low water and then calculated that it would take 72 days to drop river stage six feet at a rate of one inch per day. On this basis, we recommend a 72 day recession period from the establishment flow to the summer base flow. The actual recession flow required may vary substantially depending where seedlings become established relative to the mean summer flows.

5.2.6 Recruitment stage:

After the second year, growth rates level. Despite extensive root development during this stage, cottonwoods are still somewhat susceptible to drought stress. Yearly flows must be sufficient to maintain groundwater levels within 10 to 20 feet of ground surface elevations (JSA and MEI 2002). Groundwater extraction and reduced flows can reduce groundwater levels and induce drought stress in cottonwood saplings (Jones & Stokes 1998. Acute draw down and corresponding drought stress is primarily a problem in arid river ecosystems and will probably not be a problem on the Sacramento River where summer flows are artificially high.

5.3 Chinook Flow Requirements

Adult Upstream Migration

If salmon migration is motivated by major storms, early freshets or pulses after the first rain, and most of the large flows from storm events are trapped behind dams, reservoir operators can simulate pulse events by releasing water from the reservoir. However, "There is [a] concern that pulse flow releases in mid October to attract salmon may cause the fish to enter the rivers earlier than normal, which may expose them to high water temperatures when the pulse flows cease." (CMARP). Therefore, if flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for migrating adults and subsequent spawning.

Spawning

In order to provide quality areas of spawning habitat, adequate flows need to be released from dams into the tributaries during the spawning period. Due to channel alteration from gravel mining, artificial gravel habitat construction and enhancement may be necessary. Over the long run, periodic high flows are necessary to mobilize gravels and flush-out fine sediments. However, large peak flow events that occur in channels that have been excessively incised and leveed cause excessive gravel mobilization, which can disrupt spawning and cause egg mortality (CMARP). Therefore, these flows should be released after mid-February so they reduce mortality to incubating salmon eggs (McBain and Trush, 2000). Increased flows may also be needed to decrease water temperatures in late October and early November to prompt earlier spawning, expand the area with suitable temperatures for spawning and incubation, to increase egg viability, and to reduce the probability of superimposition of redds. If flows are increased during this

mid-fall period, it is important to continue to maintain adequate flows for spawning and to prevent dewatering of redds.

Egg Development and Emergence

Dewatering of redds is a known mortality factor effecting development of alevins. (Becker et al., 1982, 1983 in Healey, 1991). Dewatering of redds can be minimized below dams by careful flow regulation.

Adequate base flows during the incubation and emergence period combined with periodic flushing flows outside the period should reduce the mortality factor of eggs and alevins. Instream flows, at or above spawning flows, should be maintained throughout the incubation and emergence period to avoid dewatering redds. Siltation and capping from fine sediments could be minimized with small reservoir releases timed to coincide with rainfall induced local run-off. These releases would help convey fine sediments out of the spawning reach.

Rearing and Outmigration

We hypothesize that increasing rearing habitat will improve growth rates and successful smolt outmgration and may also reduce mortality from diversions and predation, because larger fish are less vulnerable to these sources of mortality. Based on robust results from research in the Yolo Bypass, it appears providing seasonally inundated floodplain habitat is perhaps the best way to ensure adequate growth before outmigration to the Delta and Ocean. If nothing else, providing seasonally inundated floodplain habitat will provide better habitat for the young that migrate or are washed out of the gravel bedded reaches early. We describe the flow regimes necessary to create inundated floodplain in section 6.3 above.

In addition to inundated floodplain habitat, seasonally inundated off-channel habitats may also provide valuable rearing habitats for juvenile salmon. Kondolf and Stillwater (Kondolf, 2007) determined that secondary scour channels on gravel bars along the upper Sacramento River become inundated and connected to the mainstem at flows above 12,500 cfs. They also determined that these same secondary channels become disconnected and desiccated at flows below 8,500 cfs. To assist juvenile rearing, it may therefore be advantageous to maintain flows between 8,500 and 12,500 cfs or greater during winter and spring when fish are rearing. To prevent establishment of non-native, resident predator fish populations that thrive in shallow or warm water habitats, however, it may be beneficial to maintain flows below 8,500 cfs during the summer months. Preventing inundation and connectivity of the off-channel habitats during summer months could also reduce temperatures by significantly reducing wetted perimeter and surface area. Lower temperatures should favor native fish over exotic fish populations.

6. EVALUATION OF EXISTING AND HISTORIC FLOW REGIMES

To identify specific hydrograph component alterations between historical and current conditions which may limit the attainment of environmental objectives an analysis of existing and historical hydrologic patterns was conducted using daily flow data from USGS gages at multiple locations on the Sacramento and Feather Rivers. We used two approaches to compare existing and historical hydrologic patterns, a statistical approach similar to IHA whereby specific hydrograph components were graphed using box plots for different year types and a visual approach similar to HCA whereby median hydrographs for historical and current conditions were compared.

We evaluated pre- and post-project hydrology using statistical methods similar to IHA and HCA methods to generate hypotheses regarding the causal links between historical hydrograph components and ecological conditions relevant to our restoration objectives. The Index of Hydrologic Alteration (IHA) method (Richter et al. 1996) provides a statistical overview of how several important hydrologic attributes change between historical and regulated conditions. The Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. Instead of using a formal IHA and HCA analysis the fundamental principals of these methods were used to conduct an analysis based on first principles.

To conduct this analysis USGS daily discharge data was organized into water year types based on the Sacramento Four Rivers Index. The water year data was divided into pre project or post project data sets. The project id defined by the construction of a dam in the headwaters of the river under consideration. For the Sacramento River the project is Shasta Dam which was constructed in 1945. For the Feather River the project is defined by Oroville Reservoir which was constructed in 1968. Hydrograph components for each water year were compared for pre and post project periods using box plots. This statistical approach was coupled with a visual comparison of the pre and post project median flows hydrographs. The pre project period was further defined by the 25th and 75th percentile hydrographs. The 25th and 75th percentile captured the natural range of variability around the median hydrograph during the pre project period for each year type. When the current hydrograph was outside of this acceptable range of variability then a significant discrepancy between the historic and current flow regimes could be identified.

The hydrograph components that were considered for the statistical analysis were: 1) summer baseflow, 2) winter peaks, 3) winter baseflows and 4) spring peaks(Figure 5). A useful way to describe streamflow hydrology and relate it to geomorphic, riparian, and biological ecosystem components is by quantifying these hydrograph components. Kondolf et. al. 2000 described these four primary components of the annual hydrograph in the following way:

(1) Summer base flows extending from July through Spetember/October

(2) Large magnitude, short duration winter floods during December through April

(3) Sustained high winter base flows intermittent between high flow events

(4) Spring snowmelt flood and recession limb of long duration, but typically moderate magnitude

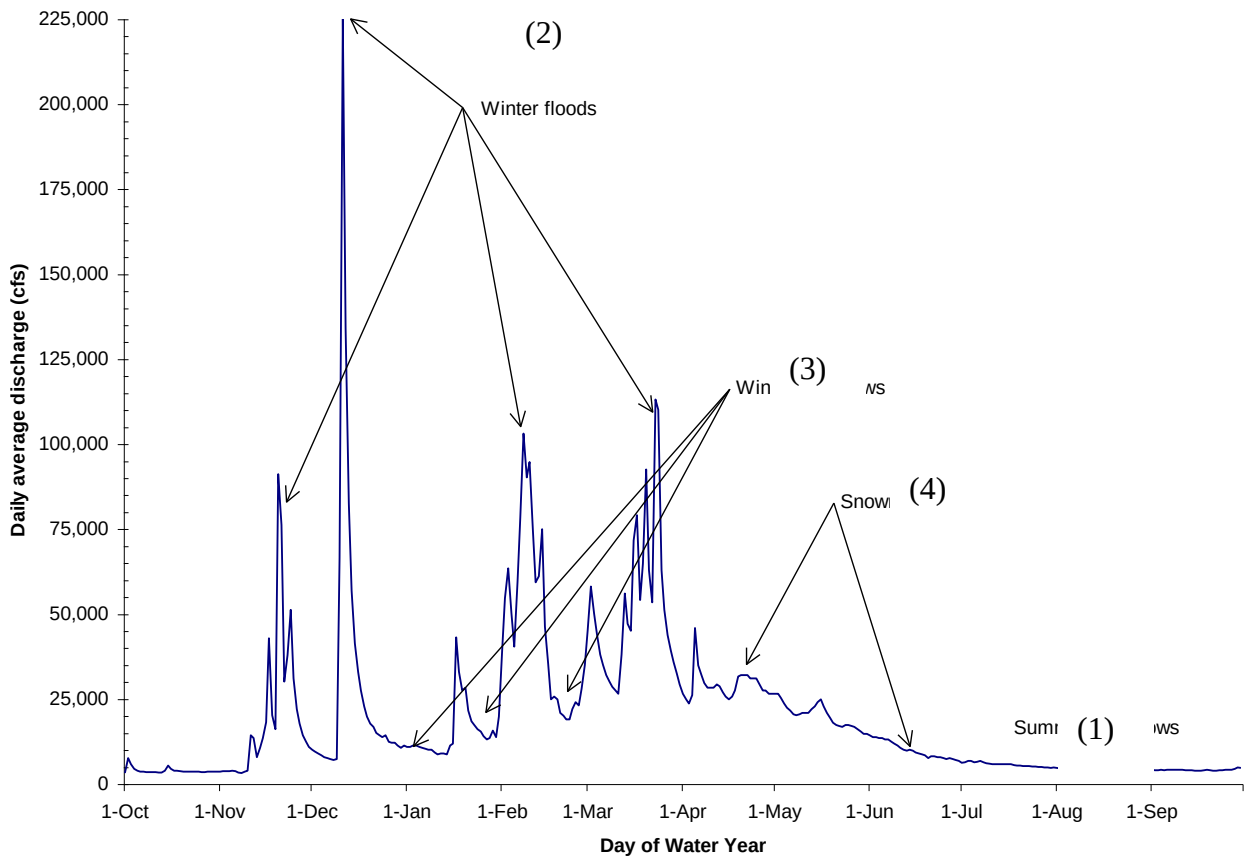


Figure 6.1: Sacramento River hydrograph components illustrated in the 1938 hydrograph for the Sacramento River above Bend Bridge, near Red Bluff gauging station. Modified from Kondolf et al. 2000.

a. Methods

Data Source

We analyzed hydrologic data for periods before and after dams were constructed on the Sacramento and Feather Rivers. Table 4 shows the gauges analyzed their period of record, and the pre and post-dam analysis periods. We divided data into five year types based on the Sacramento Basin Index: wet, above normal, below normal, dry, and critical.

Period of Analysis	River	Description	USGS Gage Number	Period of Record
Pre Shasta	Sacramento River	Bend Bridge	11377100	1906-1944
Post Shasta	Sacramento River	Bend Bridge	11377100	1945-2006
Pre Shasta	Sacramento River	Verona	11425500	1929-1944
Post Shasta	Sacramento River	Verona	11425500	1945-2006
Pre New Bullards Bar	Yuba River	Marysville	11421000	1944-1969
Post New Bullards Bar	Yuba River	Marysville	11421000	1970-2006
Pre Oroville	Feather River	Oroville	11407000	1906-1967
Post Oroville	Feather River	Oroville	11407000	1968-2006
Post Oroville	Feather River	Thermalito AfterBay	11406920	1968-2006

Table 6.1: USGS gauges used for hydrologic analysis, the period of analysis, location, description and the period of record.

Hydrographs

For each year type we compared post-dam median flows to pre-dam median flows. Median flows bounded by the 25th and 75th percentiles represent the natural range of variability during the pre-dam period for each water year type. Hydrographs provide a visual tool to identify portions of the current hydrograph that are outside of the historic range of variability. When the current hydrograph is outside of the natural range of variability we would expect the greatest potential loss of environmental flow benefits.

Box Plots

Box plots were used to statistically compare hydrograph components including summer baseflows, winter floods, winter baseflows, and spring peak flows. The lower edge of the boxes represent the 25th percentile and the upper end represents the 75th percentile, with the whiskers at the maximum and minimum values. The various components of the hydrograph were computed as follows.

- **Summer baseflows** were computed as average August discharge. Summer baseflows begin following the spring snowmelt recession in July and August and last through autumn when the first rainfall events occur.
- **Winter floods** were computed as the maximum daily average discharge over the course of the entire water year.
- **Winter baseflows** were computed as the median flow for February and March.
- **Spring peak flows** were computed as peak flows in April and June.

Flood Frequency Analysis

We conducted the food frequency analysis for a range of reoccurrence intervals for pre and post project periods using the peak instantaneous flow records at USGS. The flood frequency analysis enables further quantification of storm events and their geomorphic potential.

b. Results

The analysis utilized 100 years of daily flow data from the Bend Bridge gage near Red Bluff on the Sacramento River (11377100). This gage was selected for the analysis because it has a long period of record 1906-2006, and best characterizes flow conditions where salmon concentrate. The Bend Bridge gage is at the upstream end of what is considered the most valuable habitat in the Sacramento River. However, flows at Bend Bridge are not fully representative of downstream conditions, particularly in the irrigation season because irrigation diversions operate downstream. Four major diversions are listed below:

- The Glenn-Colusa Irrigation District (GCID) diversion, located just upstream of Hamilton City at RM 206, began diverting summer flows for irrigation around the turn of the century, and has a diversion capacity of about 3,000 cfs.
- The Anderson-Cottonwood Irrigation District (ACID) diversion, located on the north side of the City of Redding downstream of Shasta Dam, began diverting for irrigation during the summer months, around 1917.
- The Red Bluff diversion and Tehama-Colusa Canal at Red Bluff was built in 1964, and diverts during the summer months for irrigation.
- The Trinity River Division of the Central Valley Project was completed in 1963, and typically diverted over 1,000,000 acre-ft/yr of Trinity River flows into the Sacramento River basin just below Shasta Dam between 1963 and 2000. Due to new flow requirements for the Trinity River, substantially less flow is now diverted into the Sacramento River.

The hydrograph at Bend Bridge reflects operations at Shasta Reservoir in timing and magnitude, but it is only by looking at the hydrograph from a downstream gage that we can evaluate the impacts of diversions operations and the degree of hydrograph recovery from tributary inputs. It is for this reason that we used the eighty year record, from 1926-2006) daily discharge data at the USGS gage at Verona (11425500). Major tributary inputs to the Sacramento below Bend Bridge include Mill Creek, Deer Creek and the Feather River. The Feather River flow regime exhibits similar characteristics to the Sacarmento below Red Buff because of the operation of Oroville Dam. The major tributary to the Feather is the Yuba River which also displays similar characteristics due to the operation of Bullards Bar. For this reason a hydrograph comparison for the Feather (11407000, 11406920) and Yuba River (11421000) was also conducted.

5.2.1 Sacramento River at Bend Bridge

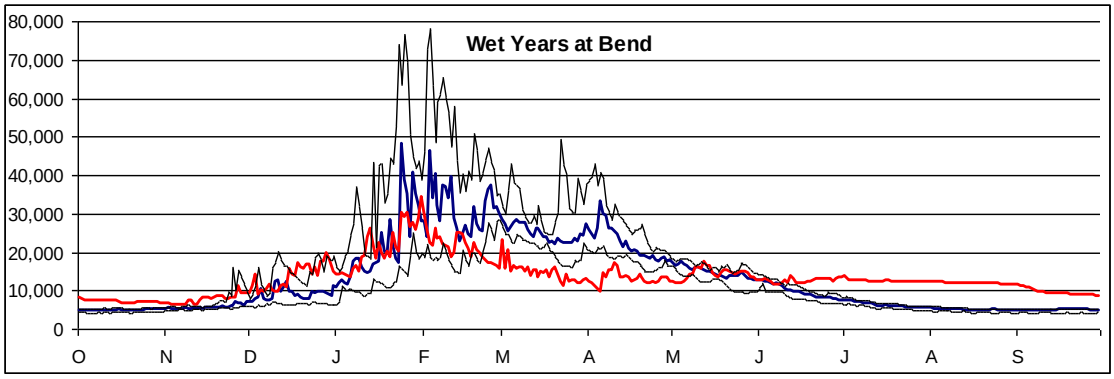
Hydrologic Changes
The hydrographs and box plots for pre and post Shasta at Bend Bridge (Figures 6 and 7) illustrate significant differences in all hydrograph components.

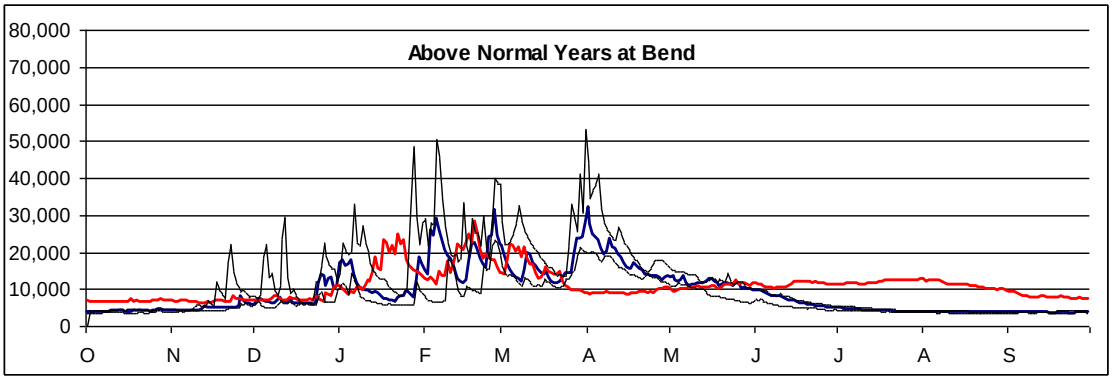
- Summer base flows are significantly higher post Shasta for all water year types. The average summer base flow pre-Shasta was 3,000-4,000 cfs which is significantly less than the current average of 10,000-12,000 cfs. These artificially high summer flows are driven by summer water supply demands for agriculture and power.

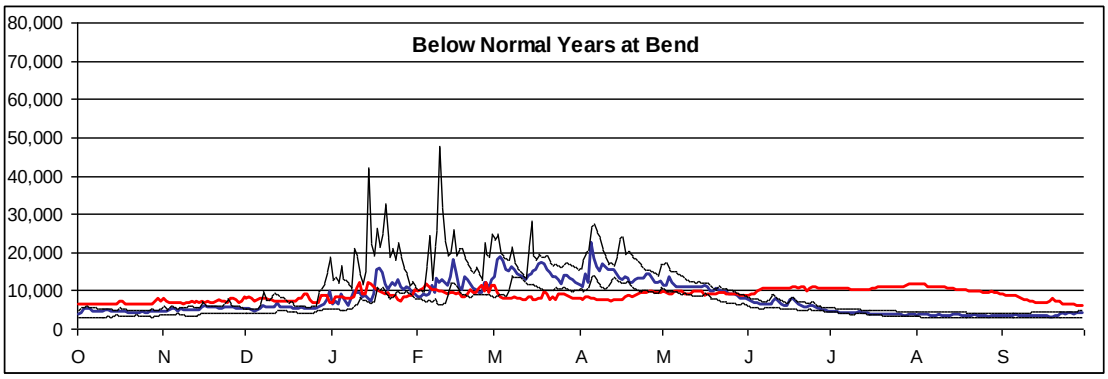
- Spring peak flow events are significantly reduced in the post Shasta era for below normal, above normal and wet year types and there is a truncated spring and early summer recession limb, particularly in wet years. The reduction in spring peak flows hampers cottonwood recruitment, seed establishment and germination.

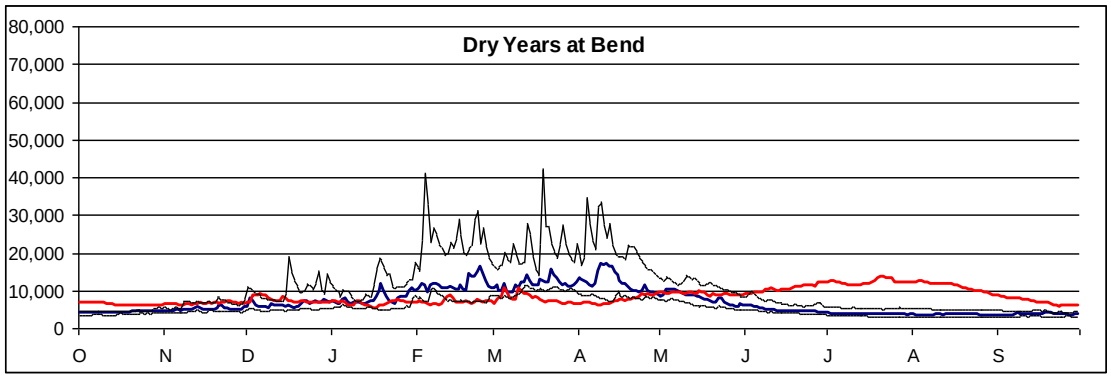
- Winter peak flows are significantly reduced in the post Shasta era. The magnitude and duration of winter peak flows are responsible for channel forming flows. Channel forming flows effect cottonwood recruitment and off channel habitat formation critical to Chinook Salmon rearing and survival.

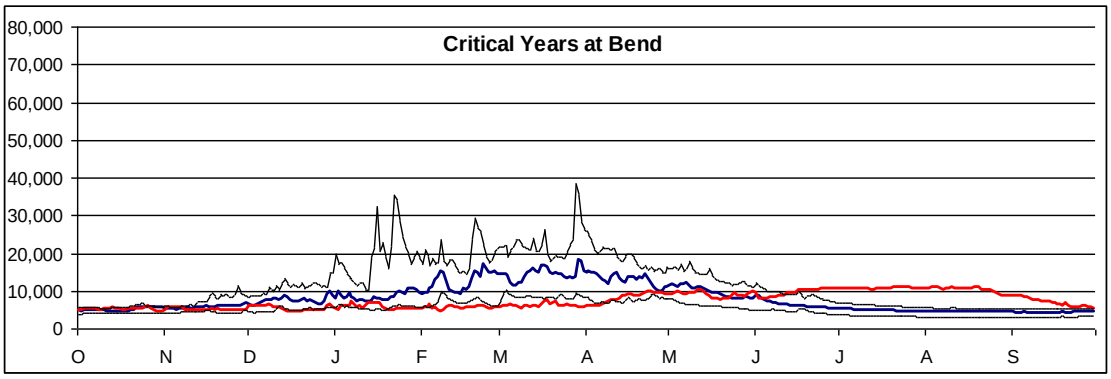
- In addition to significantly altered hydrograph components there is also a general decline in hydrologic variability in the post Shasta era.











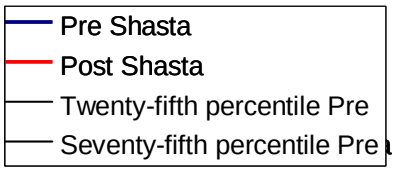


Figure 6.2: Bend Bridge median hydrographs : Historical data was used to construct hydrographs for five water year types at Bend Bridge (USGS Gage 11377100). The median hydrographs pre and post Shasta represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) See the table of the number of water year types below.

Water Year Type	Pre Shasta (1906-1944)	Post Shasta (1945-2006)
W	13	22
AN	5	10
BN	7	11
D	8	12
C	6	7
Total	39	62

Figure 6.3: Sacramento River Box Plots at Bend Bridge. Box plots display the median and the range of variability for each hydrograph component. Summer baseflows are represented by the average August discharge for each water year type. Winter floods are represented by the maximum daily average discharge for each water year type. Winter base flows are represented by the median discharge in February and March for each water year type. Spring peak flows are represented by peak average daily discharge value in April-June for each water year type. The top of the box plot is the 75th percentile and the bottom of the box is the 25th percentile. The 25th percentile means that 75% of the data is above this point. The wiskers represent the maximum and minimum values. The dark line inside the box is the median value, or 50th percentile. When the boxes do not over lap then there is a very highly significant difference between the data sets.

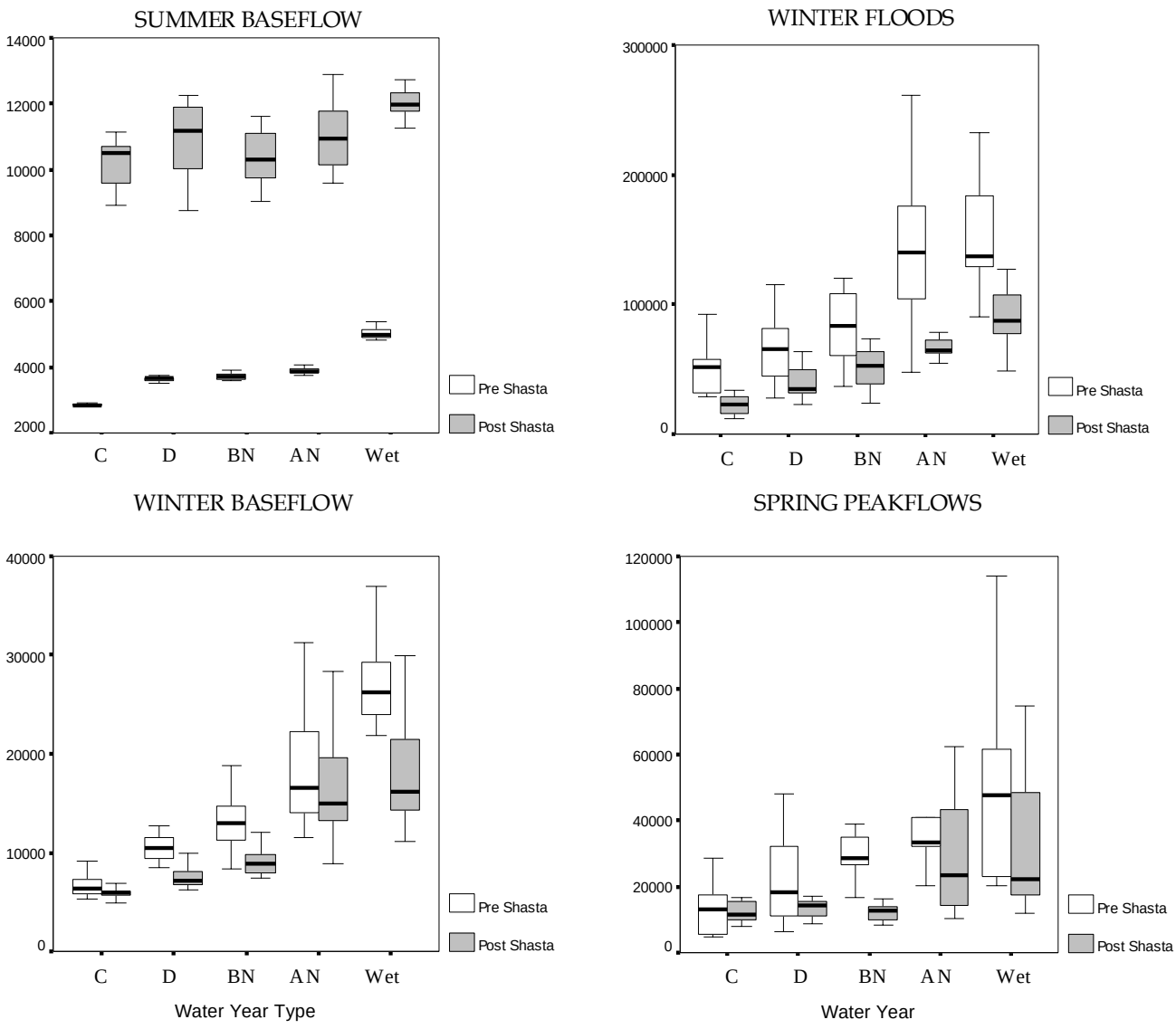


Figure 6.4: Flood frequency analysis at Bend Bridge Pre and Post-Shasta. The flood frequency analysis displays the magnitude of flows expected to occur in a 1.5, 2, 2.5, 5, 10, 20….year flood. The two year flood event in the pre Shasta era is ~100,000 cfs. Bed mobility is expected at the 1.5 year flood (Q1.5) or 82,795cfs.

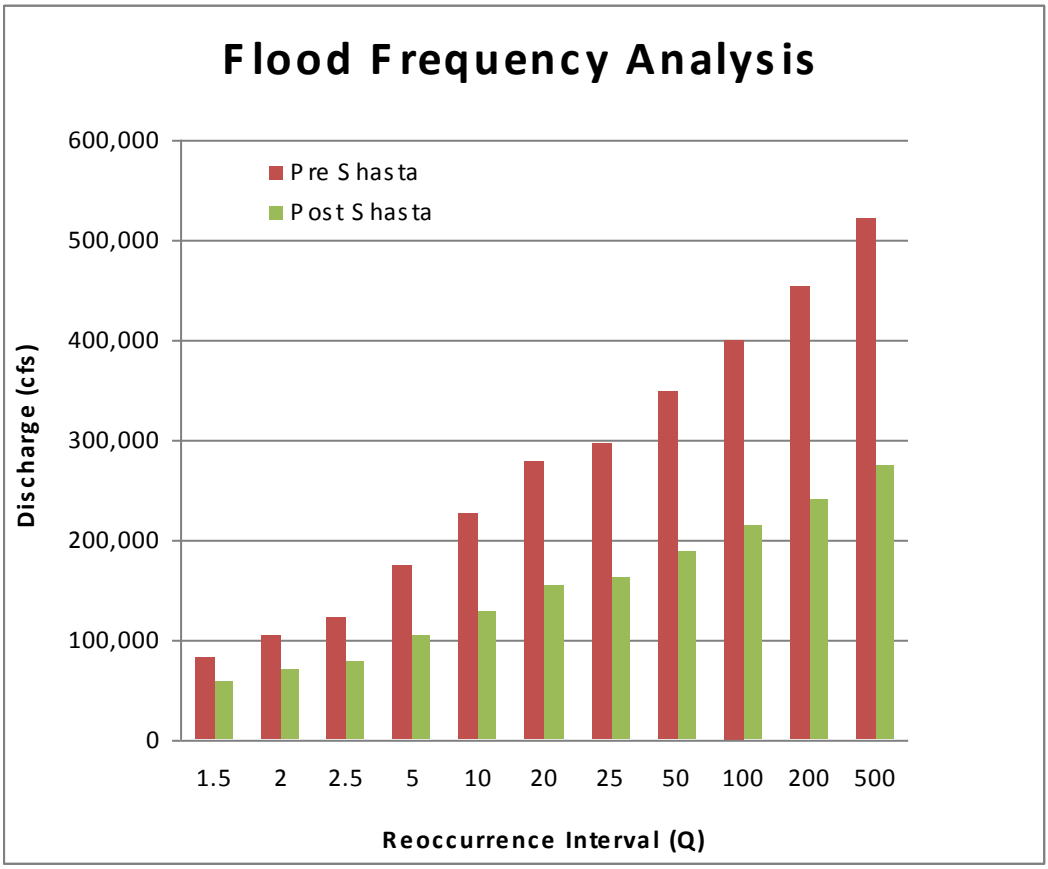


Table 6.2: Sacramento River Flood Frequency

Recurrence Interval (years)	Post 1939 (cfs)	Pre 1939 (cfs)
1.5	65,000	87,000
2	78,000	105,000
2.5	87,000	120,000
5	120,000	160,000
10	153,000	225,000
20	160,000	285,000
50	190,000	350,000
100	210,000	400,000

Table 6.3: Summary of Geomorphic Flow Thresholds				
Sacramento River	**Pre-Dam ($Q_{1.5}$)**	**Bed Mobility ($Q_{1.5}$)**	**Channel Scour and Migration (Q_{10})**	**Floodplain Inundation (Q_{1})**
Flows at Bend	82,795	82,795	226,476	52,087

6.2.1 Feather and Yuba Rivers

Introduction

Oroville Dam and Reservoir on the Feather River were completed in 1968 and have a storage capacity of 3.5 million acre feet (maf). It is managed for water supply, hydropower, and flood control. The average annual yield of the upstream Feather River basin at Oroville is about 4.2 maf. Due to several diversions in the upper watershed, average annual inflow into Oroville Reservoir is approximately 4.0 maf, but varies annually depending on precipitation. From 1979 to 1999, annual inflows ranged from a minimum of 1.7 maf to as high as 10 maf . Most of the water released from the dam, except during flood spills, is routed through the Thermalito diversion pool and afterbay and therefore bypass a 7 mile stretch below the dam known as the low flow channel. A minimum flow of 700-800 cfs is released into the low flow channel to maintain habitat for salmonids.

We evaluated change in hydrology that resulted from construction and operation of Oroville Dam. We compared pre and post dam hydrology at the USGS gauge below Oroville. In order to account for the water in the post-dam period that is discharged into the Thermalito diversion pool and bypasses the Oroville gauge, we summed daily values from the Thermalito (11406920) and Oroville (11407000) gauges to calculate the average daily flow for the river below the low flow channel.

Minimum instream flows below Thermalito Afterbay range from 1,000 cfs in the late spring and summer to 1,200 -1,700 cfs during the fall winter months. Minimum flows for the low flow channel are between 700 and 800 cfs all year. Minimum flows are slightly higher during the fall and winter to provide flow for spawning and incubating salmonids. Minimum flows in the summer are necessary to maintain cool temperatures for over summering juveniles and adult salmonids.

Most irrigation releases are made directly into irrigation canals, so relatively little water is conveyed to irrigators via the Feather River channel. Most irrigation water is released from Oroville Reservoir into Thermolito Diversion Pool, Forebay, and Afterbay where it is subsequently diverted into irrigation canals. Thus, it is possible to substantially meet summer irrigation demands without conveying water through the Feather River Channel.

The Feather River is joined downstream by a major tributary, the Yuba River. The hydrology of the Yuba River was modified early in the 19th century, but the first big storage reservoir, Bullards Bar, was not constructed until 1968. As a result, the hydrology of both the Yuba and Feather River were substantially altered at the same time by large reservoirs constructed in the late 1960s.

Hydrologic Changes

The construction and operation of Oroville dam and reservoir have significantly altered the hydrograph of the Feather River downstream of Oroville. Figures 10 and 11 depict the hydrologic patterns during different year types before and after 1968 when Oroville

Dam was completed. Figure 12 and Table 6 show changes in peak flow magnitude and duration. The most significant changes to the hydrograph are:

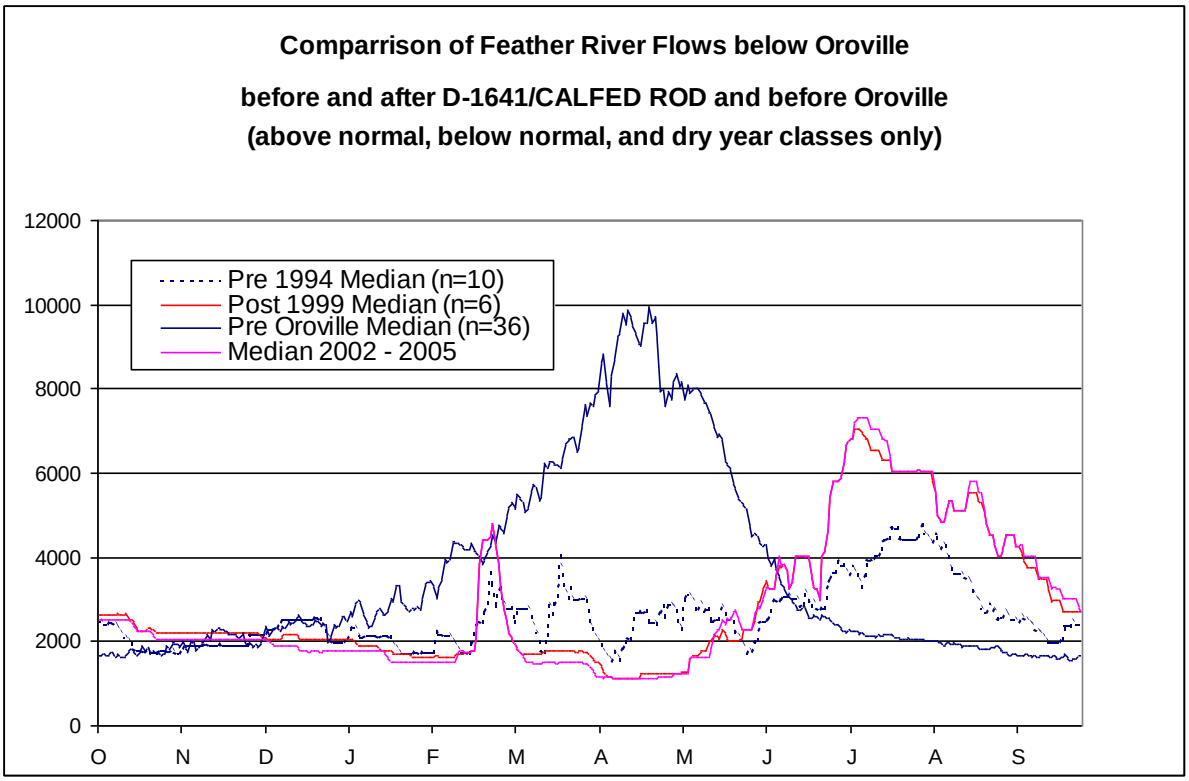
- Very significant reductions in spring flows during all year types, particularly during April and May. Storage of spring run-off and snow melt behind Oroville Dam has virtually eliminated any spring flows above a base flow of approximately 2,000 cfs.
- Increases in summer flows by 150-200% in all year types during July, August, and September.
- Reduction in the frequency and magnitude of peak flows, such as Q1.5[2] or channel forming flow by an order of magnitude. Substantially less reduction in the magnitude of the 5 year recurrence interval event (Table 6)
- Reduction in the frequency of short duration fall and winter flow pulses.

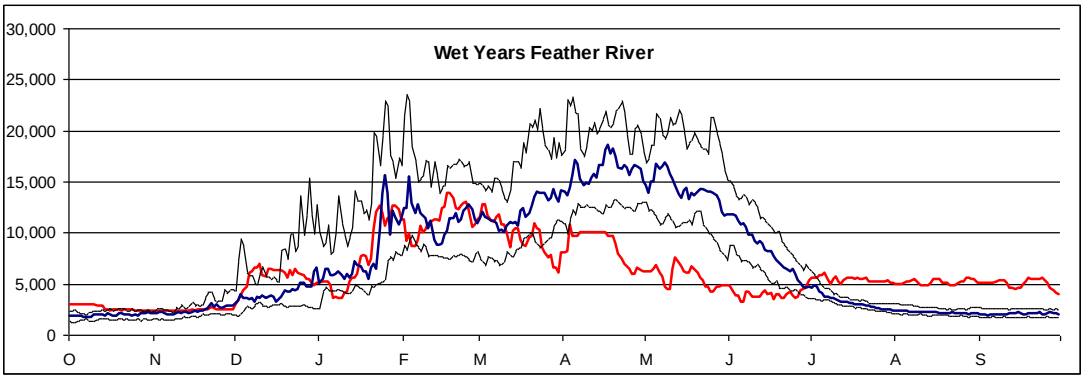
These hydrograph modifications are a result of Oroville Reservoir's water supply, flood management, and hydropower operations. Oroville Reservoir captures high flows in the winter and spring for use during the summer months. Stored water is released to meet minimum instream flows, irrigation demand in the Feather River region between April 1 and October 31, generate hydropower primarily in the summer, and meet water quality and export water demands in the Delta. Large volumes of stored water are periodically released during the winter months to create reservoir space for flood management purposes.

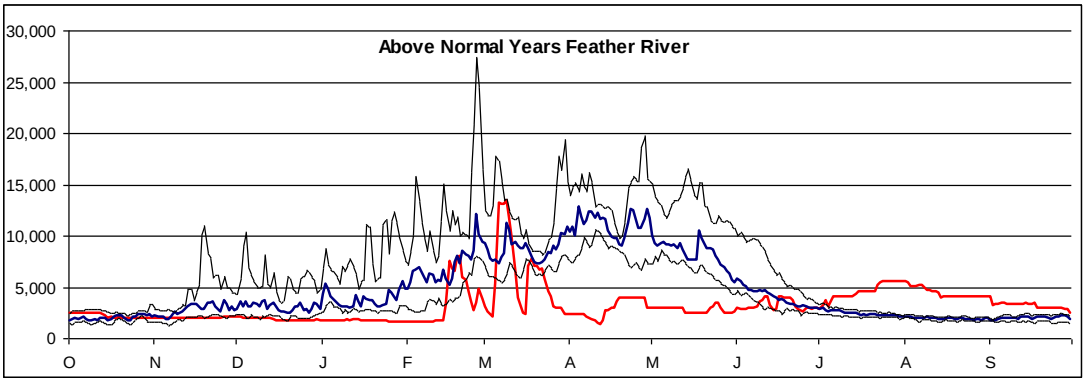
Most of the increases in summer flow in the Feather River channel are the result of Oroville releases to meet water quality and export demands in the Delta. As a unit of the State Water Project, Oroville is specifically operated to meet water quality and export demands in the Delta. An analysis of pre-1995 and post 1995 hydrology shows that Feather River flows changed significantly after the 1995 Water Quality Control Plan tightened restrictions on the timing of Delta diversions. After implementation of the plan, spring flow in the Feather River has been further diminished while summer flow has been further increased.

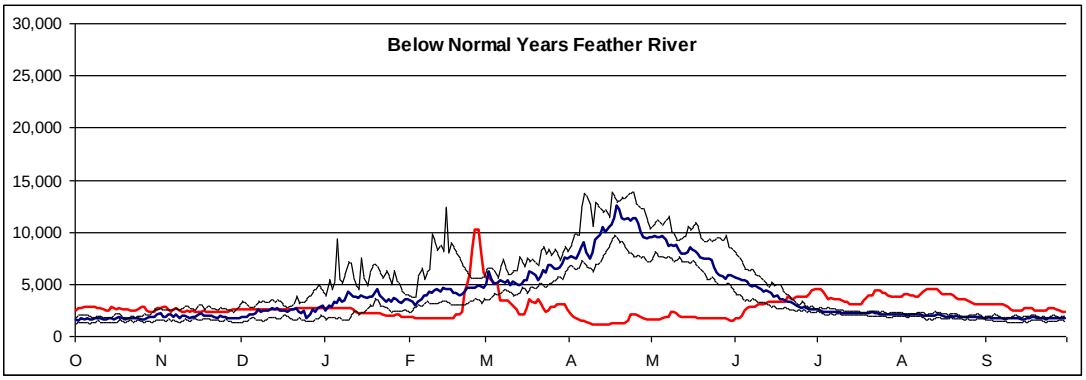
[2] The instantaneous peak annual flow with a recurrence interval of 1.5 years.

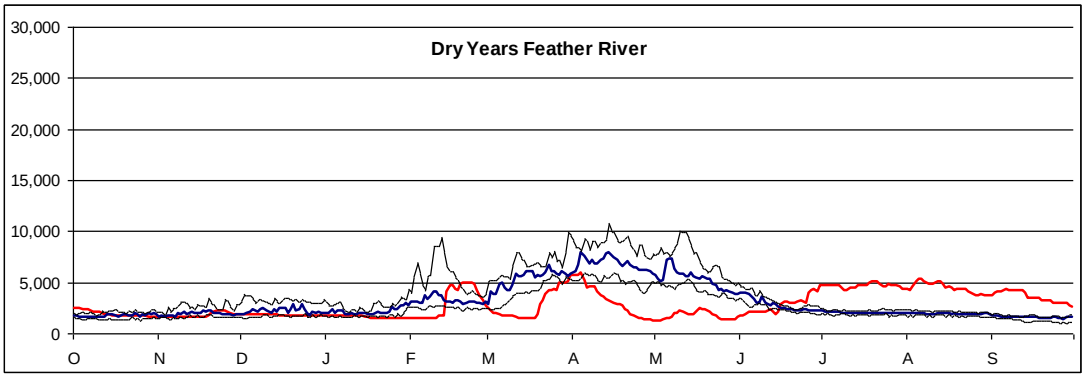
Figure 6.5: Influence of Sacramento-San Joaquin Delta Regulations on Feather River Hydrograph. The blue line of pre Oroville median flows represents the most natural hydrograph. In 1995 the Water Quality Control Plan tightened restrictions on the timing of Delta diversions. The pre 1994 hydrograph compared to the post 1999 illustrates how the hydrograph shifted spring flows to summer releases to meet Delta requirements.

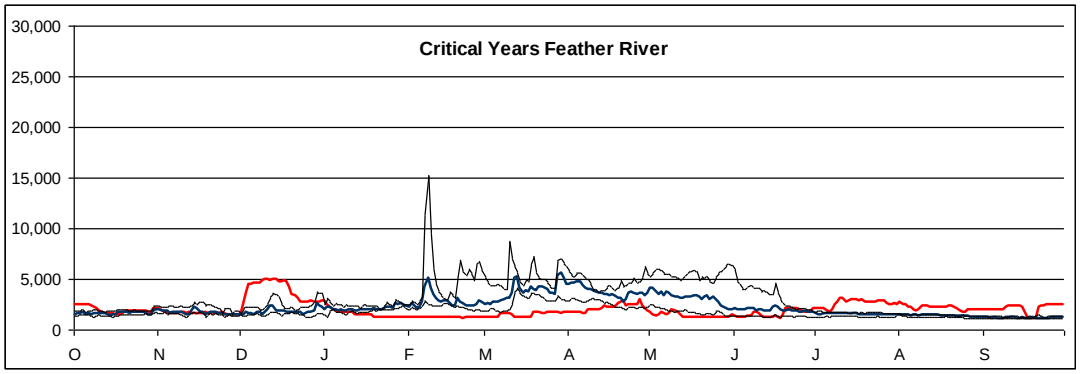












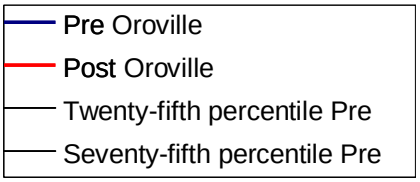


Figure 6.6: Feather River median hydrographs : Historical data was used to construct hydrographs for five water year types on the Feather River (USGS Gage11407000 and 11406920). The median hydrographs pre and post Oroville represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) The hydrographs post Oroville (1968-2006) are the sum of the Oroville (11407000) and Thermolito Afterbay gages (11406920). See the table of the number of water year types below.

Water Year Type	Pre Oroville (1906-1967)	Post Oroville (1968-2006)
W	20	15
AN	8	7
BN	14	4
D	14	6
C	6	7
Total	**62**	**39**

Figure 6.7: Feather River box plots for Oroville gauge. Box plots display the median and the range of variability for each hydrograph component. Summer baseflows are represented by the average August discharge for each water year type. Winter floods are represented by the maximum daily average discharge for each water year type. Winter base flows are represented by the median discharge in February and March for each water year type. Spring peak flows are represented by peak average daily discharge value in April-June for each water year type. The top of the box plot is the 75th percentile and the bottom of the box is the 25th percentile. The 25th percentile means that 75% of the data is above this point. The wiskers represent the maximum and minimum values. The dark line inside the box is the median value, or 50th percentile. When the boxes do not over lap then there is
a very highly significant difference between the data sets.

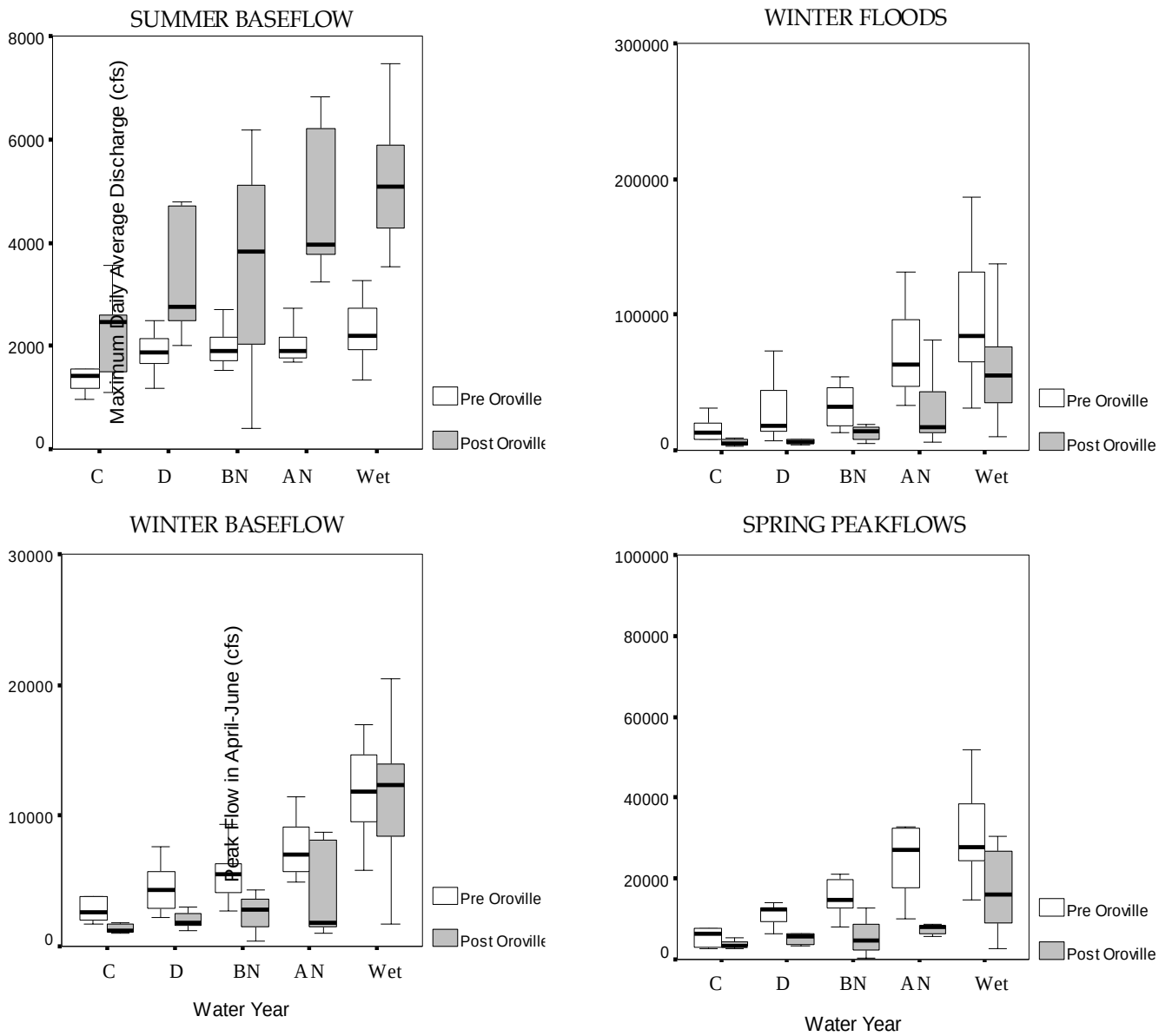


Figure 6.8: Flood Frequency Analysis for Feather River Flood frequency analysis at Bend Bridge Pre and Post-Shasta. The flood frequency analysis displays the magnitude of flows expected to occur in a 1.5, 2, 2.5, 5, 10, 20….year flood. The two year flood event in the pre Shasta era is ~50,000 cfs. Bed mobility is expected at the 1.5 year flood (Q1.5) or 33,224cfs.

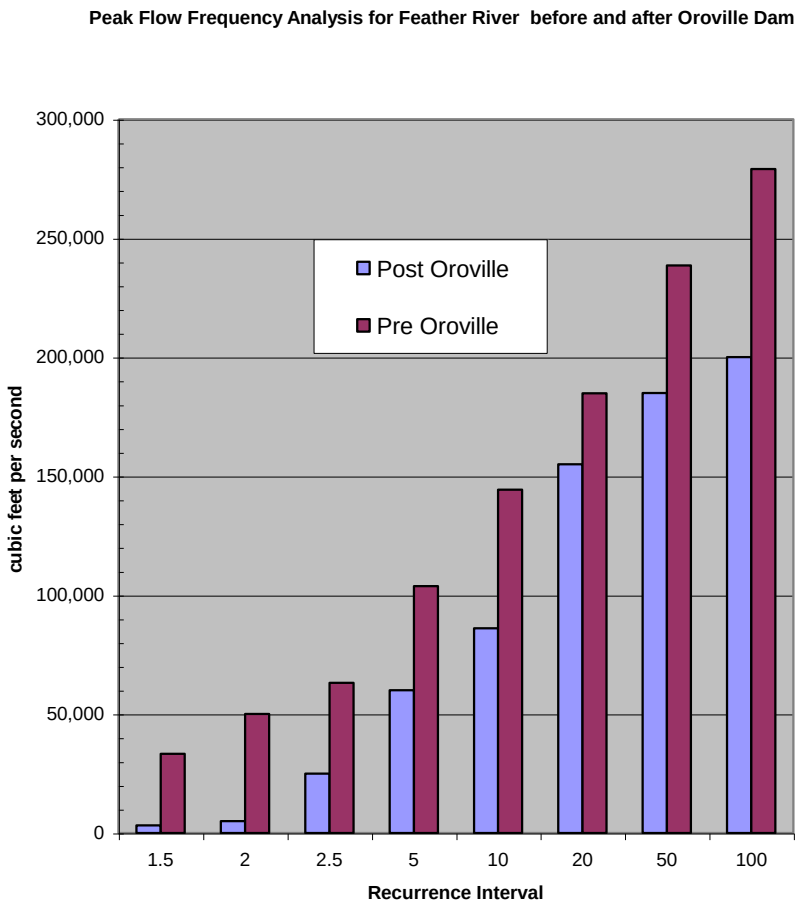
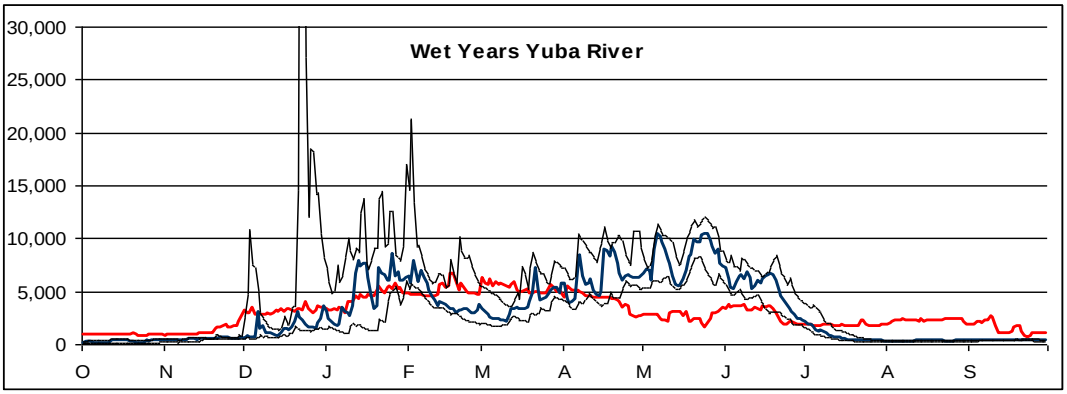
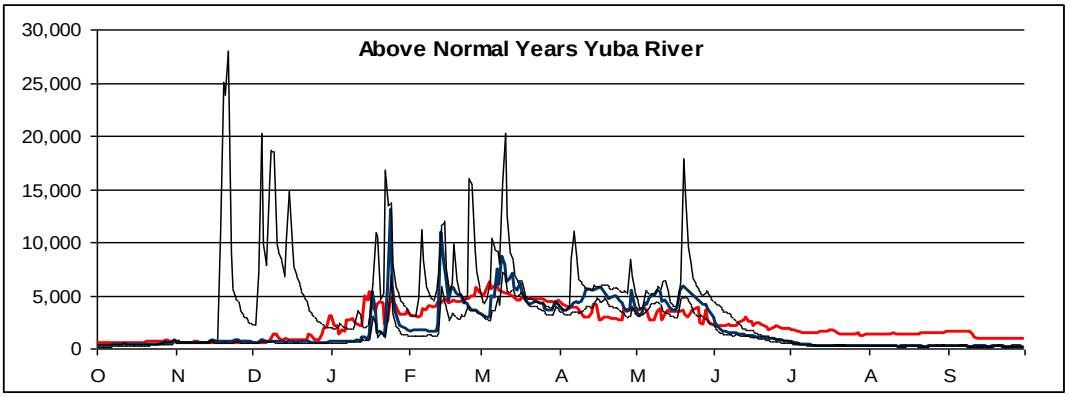
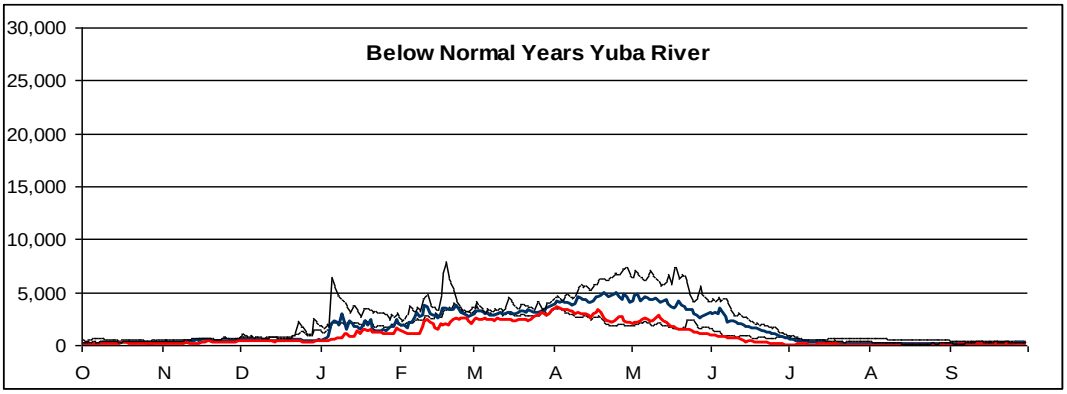


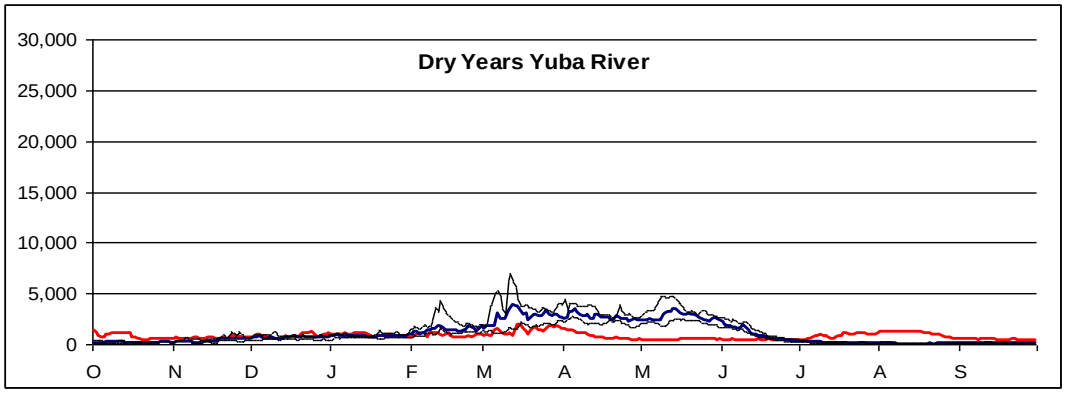
Table 6.4: Feather River Flood Frequency

Recurrence Interval (years)	Post 1968 (cfs)	Pre 1968 (cfs)
1.5	3,170	33,224
2	5,000	50,065
2.5	25,000	63,128
5	60,000	103,704
10	86,000	144,281
20	155,000	184,858
50	185,000	238,498
100	200,000	279,075









Pre New Bullards Bar
Post New Bullards Bar
Twenty-fifth percentile Pre
Seventy-fifth percentile Pre

Figure 6.9: Yuba median hydrographs : Historical data was used to construct hydrographs for different water year types for the Yuba (USGS Gage 11421000). The median hydrographs pre and post New Bullards Bar represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.)There is no median hydrograph for the Critical Year type because there were no critical years between 1944 and 1969. See the table of the number of water year types below.

Water Year Type	Pre New Bullards Bar (1944-1969)	Post New Bullards Bar (1970-2006)
W	7	13
AN	3	7
BN	8	3
D	7	6
C	0	7
Total	**25**	**36**

6.3 Sacramento River at Verona

Analysis of the Sacramento and Feather Rivers at gauges near the large dams only tells part of the story. The Verona gauge is downstream of the confluence of the Sacramento and Feather River, and measures run-off from numerous large tributaries not measured by the gauges at Oroville and Bend Bridge. Several of these tributaries do not have large storage reservoirs and thus continue to exhibit relatively natural hydrographs. Figure 14 shows the hydrographs from Mill and Deer Creek which are characterized by large, gently receding spring flows. As a group, these less regulated tributaries tend to dampen the effect of Shasta, Oroville, and New Bullards Bar, but only to a limited extent.

Figures 16 shows hydrologic patterns for four periods: before Shasta, after Shasta but before Oroville Dam, after Oroville Dam, and after the implementation of the 1995 water quality control plan that established stringent limits on the timing of water exports from the Delta. The hydrology from all four periods shows a clear and consistent trend: progressively less spring flow and continuously increasing summer time flows. The decrease in spring flows and increase in summer flows is particularly striking after 2000 when the water quality control plan was in full effect in the Delta. Due to stringent export restrictions in the spring, the state water project, which operates Oroville Reservoir and controls the Harvey O'Banks pumping plant in the Delta, has apparently shifted operations to minimize spring time releases from Shasta and favor summer time releases so that it can deliver water to the Delta when pumping restrictions are less severe.

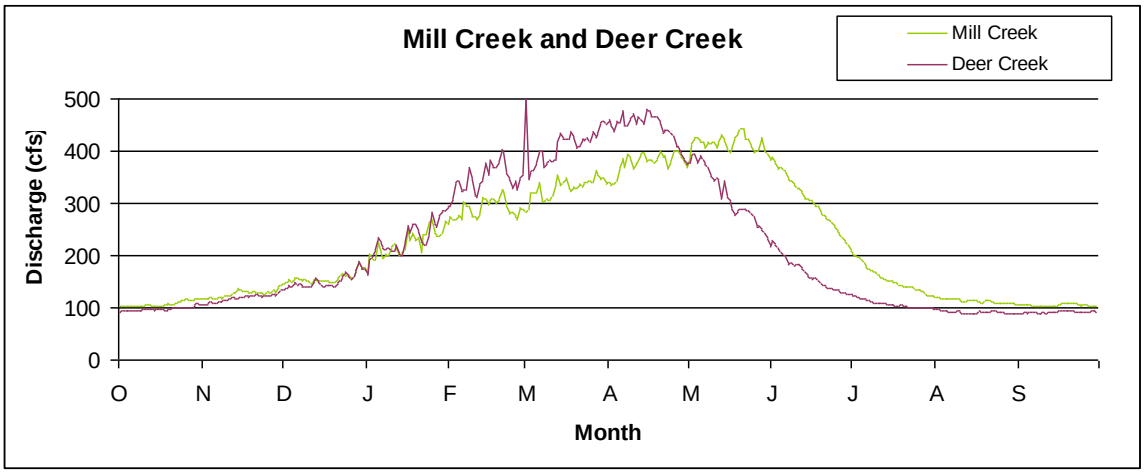


Figure 6.10: Median hydrographs for Mill and Deer Creek.

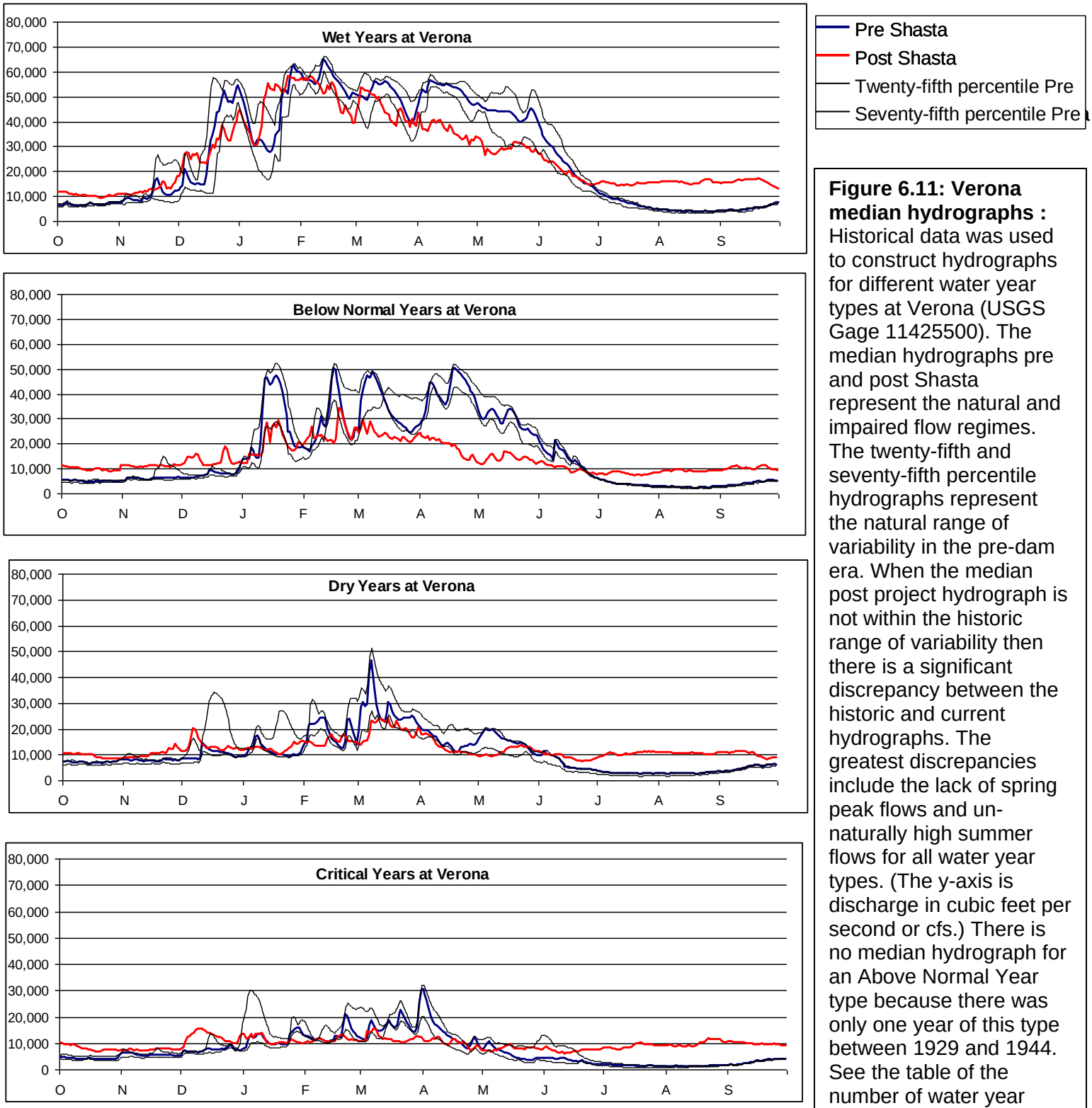


Figure 6.11: Verona median hydrographs : Historical data was used to construct hydrographs for different water year types at Verona (USGS Gage 11425500). The median hydrographs pre and post Shasta represent the natural and impaired flow regimes. The twenty-fifth and seventy-fifth percentile hydrographs represent the natural range of variability in the pre-dam era. When the median post project hydrograph is not within the historic range of variability then there is a significant discrepancy between the historic and current hydrographs. The greatest discrepancies include the lack of spring peak flows and un-naturally high summer flows for all water year types. (The y-axis is discharge in cubic feet per second or cfs.) There is no median hydrograph for an Above Normal Year type because there was only one year of this type between 1929 and 1944. See the table of the number of water year types below.

Water Year Type	Pre Shasta (1929-1944)	Post Shasta (1945-2006)
W	4	22
AN	1	10
BN	3	11
D	4	12
C	3	7
Total	**15**	**62**

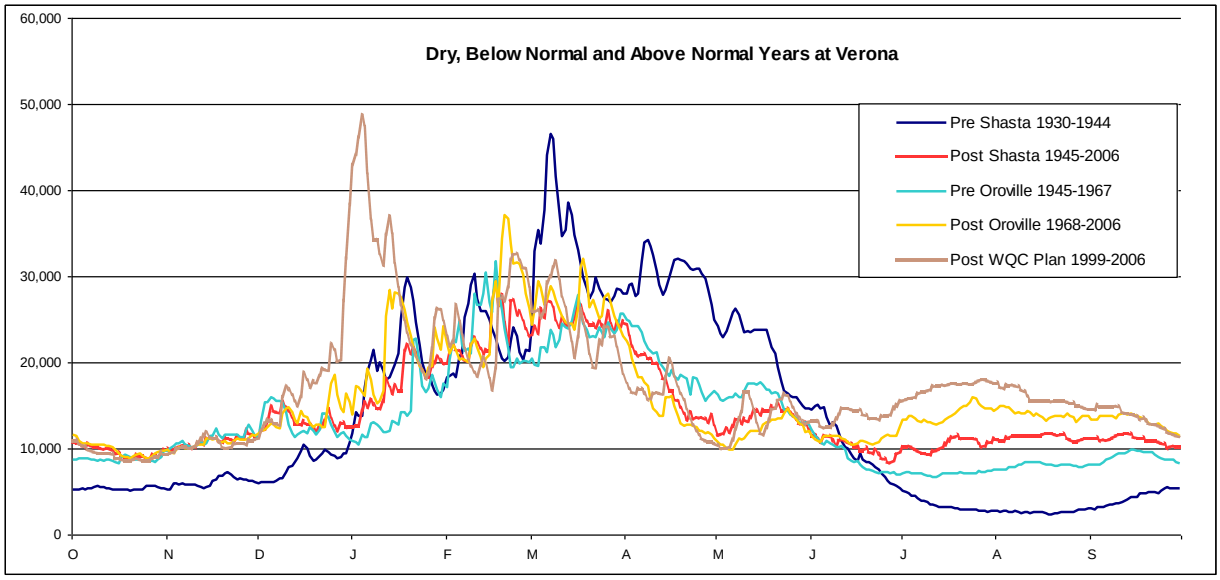


Figure 6.12: Median hydrographs for different time periods indicate a progression towards increased summer flows and decreased spring peaks. The increased regulation of the Sacramento and Feather Rivers with Shasta in 1945, Oroville in 1968 and the implementation of the Water Quality Control Plan in 1999 all had the effect of releasing increased flows during the summer when demands are high and as a consequence eliminated spring peak flows.

Summary of Results

From the hydrograph comparisons of current hydrographs to pre project, or natural hydrographs, a consistent trend immerges for all sites. This trend is the result of reservoir operations where by water is stored until periods of peak demand arise. In the Sacramento River basin peak demands occur in the summer months which means that reservoirs hold water through the spring, eliminating peak spring flows and augmenting summer base flows well above pre project levels. In this way reservoirs alter the timing and magnitude of the spring and summer hydrographs. In addition the presence large reservoirs in the headwaters dampen winter floods in all but the wettest of years. Loss of these geomorphic and riparian flows impacts riparian vegetation and Chinook Salmon habitat.

7.0 IDENTIFY OBVIOUS GAPS BETWEEN OBJECTIVES FLOW REQUIREMENTS AND EXISTING FLOWS

7.1 Gaps in Riparian Vegetation Objectives

Bed Mobilization

The frequency and size of large flows capable of mobilizing the bed have been reduced, but large flows occur in more than half of the years on the Sacramento River. The size of the Q1.5 has been reduced by twenty fiver percent. The pre-dam Q1.5 of 87,000 cfs now has a recurrence interval of every 2.5 years instead of every 1.5 years. While this is a significant reduction, it is a relatively small reduction in comparison to hydrologic alteration on other rivers such as the Feather or San Joaquin Rivers. The abundance of active riffles in the Sacramento River meander belt suggests that the river still periodically mobilizes its bed. Lack of bed mobility in the upper reach below Keswick Dam may be more a result of armoring due to coarse sediment trapping upstream then it is a result of reduced flows.

On the Feather River, the frequency and magnitude of peak flows has been reduced more substantially. The historical instantaneous Q1.5 – 2 has of 33,000 – 50,000 has been reduced by an order of magnitude to 3,000 – 5,000 cfs. The Q2.5, however, is 25,000 cfs. Under the post dam regime, several 4-5 years can pass without exceeding a bed mobilizing flow. This enable riparian vegetation to become established on gravel bars leading to long term stabilization and degradation of the channel.

Bed Scour

The frequency of very large, bed scouring events has been reduced substantially. The pre-dam Q5 of 160,000 cfs now has a twenty-year recurrence interval rather then a five-year recurrence interval. Similarly, the pre-dam ten-year flow now has a one hundred year recurrence interval. The physical processes and ecological function of these large events is not well understood. It is possible that smaller flows substantially scour the bed, rearrange the channel, and form new channel habitat. If so, the reduction in very large flows may not be as important. On the other hand, these very large events may be very important for creating and maintaining important habitats such as oxbow lakes and other off-channel habitats.

Bank Erosion and Channel Migration

We did not conduct an assessment of changes in stream power, but figure 5.2 illustrates that the occurrence of flows exceeding 15,000 or 20,000 cfs in dry, critical dry, and below normal years has been reduce substantially. Larson (2007) identified 15,000 cfs as the lower threshold for bank migration. Median flows frequently reached 15,000 cfs in these drier year types during the pre-dam period, but in the post-dam period median flows

seldom rise above 10,000 cfs. During the wettest forty percent of years, wet and normal wet years, median flows frequently exceed 20,000 cfs and thus maintain some level of bank erosion and channel migration processes. Reduction in the frequency and duration of erosive events may have substantial impacts on the colonization and succession of riparian habitat over time. It definitely has habitat implications for bank swallow, a listed species that nests on recently eroded stream banks. Reduced bank erosion almost certainly lowers the suspended sediment levels and could therefore have significant impacts on instream fish habitat for juvenile salmon or Delta smelt that appear to prefer or concentrate in turbid waters (citation?). Although the reduction in the frequency or duration of bank erosion events may have significantly ecological impacts, it may be less important then the widespread presence of bank revetments along the Sacramento Rivers (Larson, 2007).

Inundated Floodplain and off-channel habitat during late winter and spring

The lack of prolonged flows of sufficient magnitude to inundate floodplain and off-channel habitats during the late winter and early spring months is perhaps the most significant ecological change to the Sacramento and Feather Rivers. Large, prolonged flows still occur in wet and normal wet years, but they are largely disconnected from the floodplains due to levees that prevent inundation of the vast historic floodplain of the lower Sacramento River. Large areas of the Sutter and Yolo Bypass become inundated in wet and normal wet years, but little or no floodplains become inundated for any length of time in the drier sixty percent of the years. This is a result of both levees and flow alteration, but flow alteration alone is sufficient to preclude floodplain inundation in the drier years.

Loss of shallow water habitats in secondary channels and floodplains not only reduces the amount of rearing habitat, it also may reduce foodweb productivity in the spring months when juvenile fish are rearing and moving downstream to the Delta. Increase connectivity between shallow water habitats and open water can substantially increase aquatic productivity in estuaries (Cloern, 2008).

Inundated off-channel habitat such as high flow channels can also provide rearing habitat for salmon (Peterson and Reid, 1984), but regulated spring flows are generally insufficient to inundate these habitats for prolonged periods (30-60) days. A recent study of these habitats in the Sacramento River determined that a large proportion of secondary channels between Red Bluff and Colusa become fully connected to the river at flows above 12,000 cfs (Kondolf, 2007). Regulated flows seldom exceed 10,000 cfs in the drier year types (dry and below normal) during late winter and spring when salmon are most likely to require spawning habitat. Even in normal wet years, median April flows are generally below 10,000 cfs.

7.2 Gaps in Riparian Vegetation Objectives

Peak spring flows are conspicuously absent under current conditions. On both the Sacramento and Feather River, median summer flows are significantly greater then median spring flows in all but wet years. As a result, any seeds that might germinate during the cottonwood seed release period in April and May are at risk of mortality from prolonged inundation throughout the summer months. If seeds to become established, they are less likely to grow deep roots during their first growing season due to high groundwater levels and therefore may be more vulnerable to desiccation mortality when water levels do drop.

In addition to the overall decapitation of the spring hydrograph, rapid flow declines during the spring months create a hostile environment for establishment of Fremont cottonwoods. Changes in the rate of the spring snowmelt recession are not obvious from the composite hydrographs depicted in figure 6 because they are of average spring flows over several years. The recession rate is more directly controlled by reservoir release operations in specific wet and above normal years. Our evaluation of hydrographs for individual years indicates that the recession rates are often characterized by abrupt changes in flow during the seed germination period on both the Sacramento and Feather rivers as illustrated in figures 6.1 and 6.2. Abrupt changes in reservoir releases during germination and initial seedling establishment period can limit recruitment by abruptly desiccating recently germinated seedlings before their roots reach the water table or by scouring and inundating newly established seedlings with high summer flows shortly after germination.

Even in wet years, median flows do not reach the documented threshold of 23,000 cfs on the Sacramento necessary to recruit riparian vegetation in a zone that is not vulnerable to subsequent channel scour. Similarly, the Feather River only reaches the assumed threshold of 8,000 -10,000 in median wet years. While it is true that the median numbers depicted in figure 6 obscure the variability that actually occurs in various years, figure 6 clearly illustrates how dramatically the critical spring and summer hydrograph has been altered in non-wet years. Even in wet years, the hydrographs are often not suitable due to the rapid fluctuation in flows (figures 6.1 and 6.2).

Figure 7.1: Annual hydrograph for Sacramento River at Bend Bridge illustrating abrupt flow decline in mid April during cottonwood germination period.

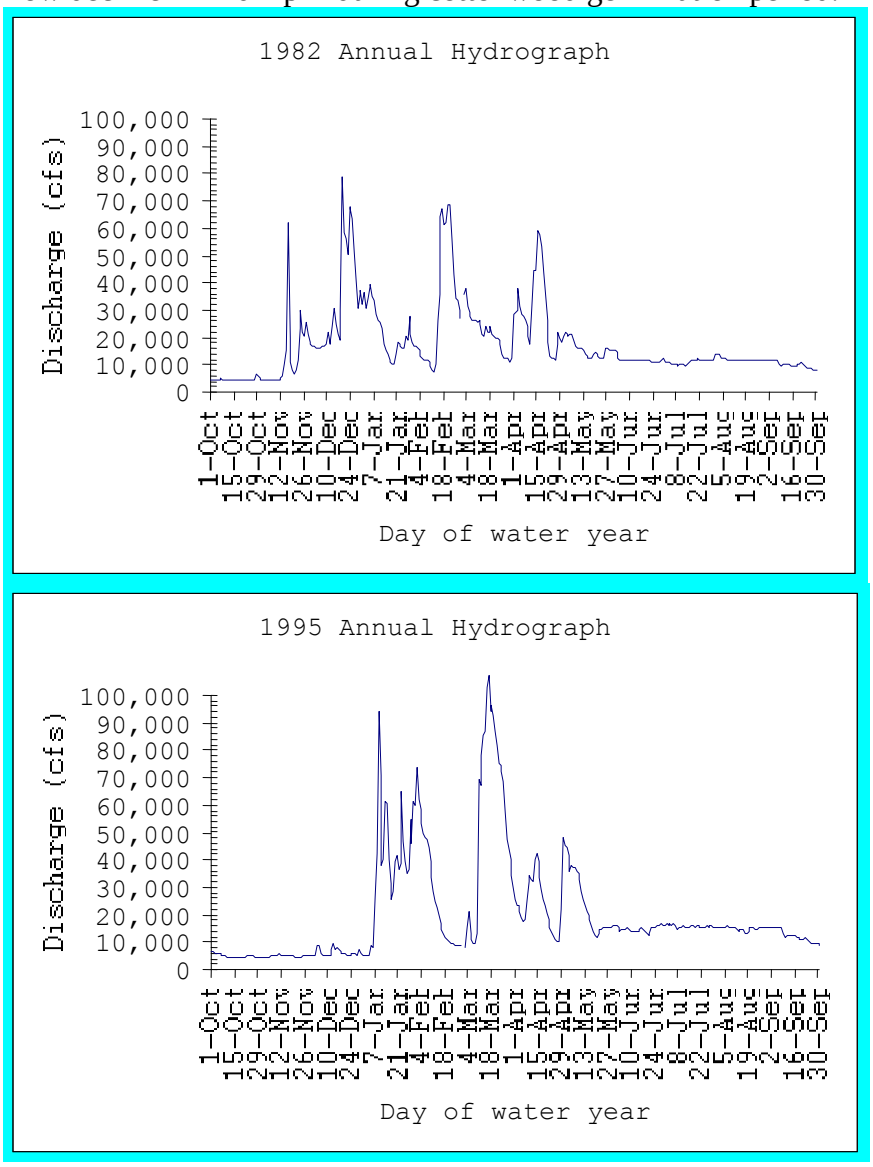
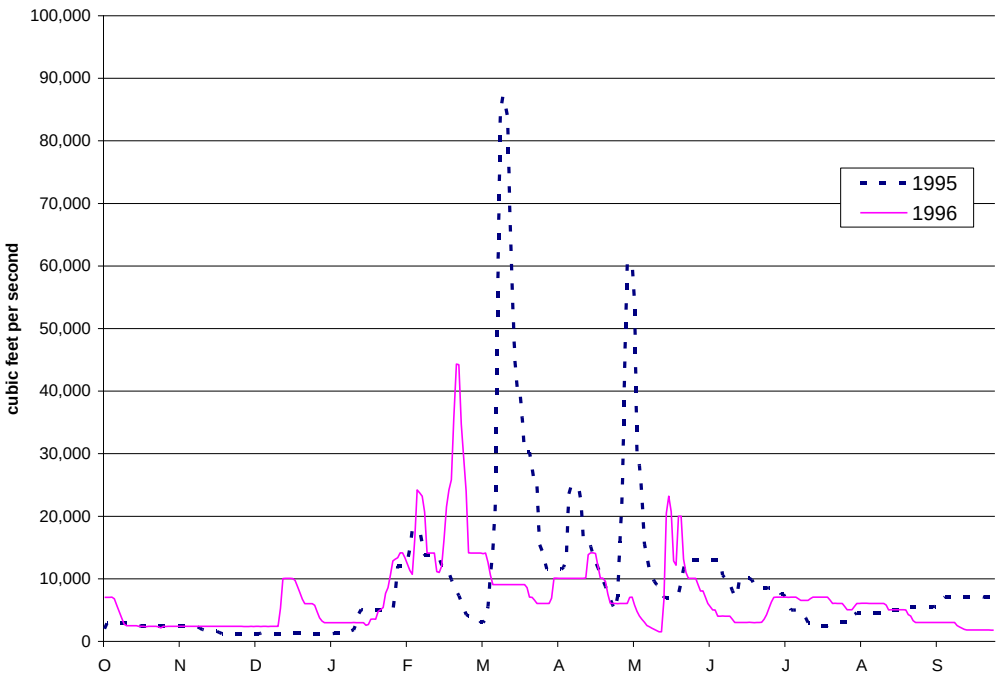


Figure 7.2: Annual hydrograph for Feather River at (sum of Oroville and Thermolito gauges) illustrating abrupt flow decline in mid April during cottonwood germination period.



7.3 Gaps in Chinook Salmon Objectives

Spring Pulse

Elimination of high winter and spring flows has substantially reduced the amount of rearing habitat on inundated floodplains and in off-channel habitats. A close examination of flow patterns indicate that later winter and early spring flows are increasingly the lowest flows of the entire year on both the upper Sacramento and Feather River. Under natural conditions, the highest prolonged flows of the year consistently occurred in the late winter and spring. This "spring rise" in flows inundated gravel bars, secondary channels and associated backwaters, and floodplains during the larger events.

Late winter and early spring flows at Bend Bridge on the Sacramento are about fifty to sixty five percent of what they were historically. A recent study of off-channel habitats on the upper Sacramento River (Kondolf and Stillwater, 2007) identified 12,500 cfs as an important threshold for inundating side channel habitats. On the Sacramento River, median spring flows at Bend Bridge seldom fell below 12,000 cfs between February and April prior to Shasta Dam. In the post dam era, median flows are consistently below 10,000 cfs in all but the wettest years. Meanwhile, summer flows which were historically

below 5,000 cfs are now consistently above 10,000 cfs. The shift from spring to summer has become even more pronounced in recent years as dam operators have shifted operations to meet water quality and water supply demands for the Sacramento-San Joaquin Delta.

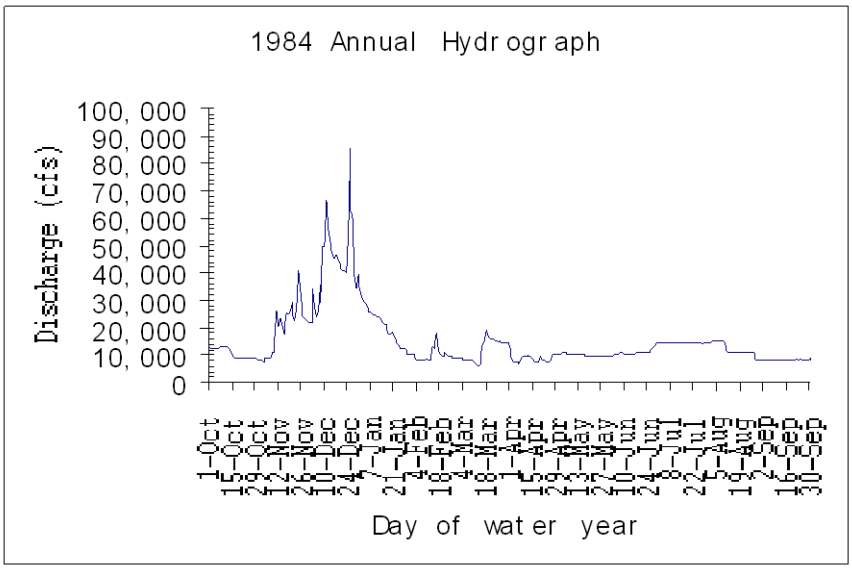
The pattern of reduced spring flows is even more pronounced on the Feather River where median spring flows are fifteen to thirty percent of what they were historically in most year types. The only exception is wet years when they are approximately fifty percent of the historical median. But even in these wetter years, the spring flows are characterized by abruptly fluctuating flood flows as illustrated in figure 6.2, rather then the prolonged spring pulse that characterized historic flows.

Fluctuating Flow Events

The median flow analysis presented in the previous chapter is not well suited for evaluating the frequency of abrupt flow changes, because the composite hydrographs depicted in figure 6 do not reveal individual flow events, which may harm salmon populations. The recent Nature Conservancy study of the Sacramento River (Stillwater, 2007, 2008 appendix F) hypothesized that abrupt increases or decreases in flows in the Sacramento may impact salmon and other species by scouring or dewatering reds, stranding fish, or eroding bank swallow nesting sites. Our cursory analysis of annual hydrographs, illustrated in figures x and xx, indicate that abrupt fluctuations in flow do occur in some years. The timing of these fluctuations may be a significant problem for fish in individual years. Large, rapid fluctuations in the winter or spring could strand juvenile salmon on floodplains or was juveniles downstream to poor habitat. Large reservoir releases in the fall, followed by declines to a significantly lower stage during the remainder of the winter, as illustrated in figure 6.3, could result in dewatering and stranding of redds. Large fall releases are usually limited to periods following very wet years when reservoir levels are high and need to be reduced prior to the rainy season for flood control purposes.

It is clear that large fluctuations in flow occurred under natural conditions on both the Feather and Sacramento Rivers. It is unclear how and whether individuals and populations of these salmon survived these events. Did very high flows that scoured the bed result in reproductive failure? How often did this occur? It is likely that today's regulated flow regime fluctuates in the present day riverine conditions is more likely to harm salmon then fluctuating flows under historical conditions. Under historical flow conditions, high peak flows are often followed by subsequent peaks that might enable stranded fish to reenter the river. More habitat complexity under historical conditions increased the probability that salmon could spawn or take refuge in areas safe from the potential negative effects of high flows. In today's environment, large peaks are often abruptly ended only to be followed by weeks of low flows. Levees and channelization have cut-off important refuge and foraging habitat that fish might have otherwise used during high flows.

Figure 7.3: 1984 annual hydrograph from the Sacramento illustrating high flow falls that could result in salmon redd stranding and reproductive failure.



Base Flows

Base flows in the Sacramento and Feather Rivers have been increased in most months except the spring, as previously discussed. Increased base flows during the summer and fall probably lower water temperatures and improve fish passage conditions. It is unclear whether unnaturally high base flows in the summer and fall have any deleterious impacts on fish such as harboring exotic species.

8 ENVIRONMENTAL FLOW REGIME RECOMENDATION

This chapter identifies flow recommendations for the Sacramento River based on the objectives and flow thresholds identified in chapters three and four, and the analyses of natural and regulated hydrology presented in chapters five and six.

Although this study identifies hypothetical restoration flow regimes for the Sacramento and Feather Rivers, we recognize that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program. The hypothetical flow regime that we have developed and identified is imperfect, but it serves as a reasonable starting point for evaluating the feasibility of reoperating reservoirs without impacts on existing reservoir functions.

The assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself. To cost effectively achieve restoration, managers will ultimately need to test these assumptions and address the uncertainties through a program of modeling, pilot flow studies, model calibration, and long-term restoration implementation. In the text below, we have explicitly identified some of these uncertainties so that they can be further evaluated.

8.1 Summary Recommendation

The key component of the environmental flow proposal for both the Sacramento and Feather Rivers is to restore higher flows during the late winter and spring. This period was once characterized by sustained, high flows. Under regulated conditions, however, spring flows are nearly half their historic volume and substantially below summer flows. We recommend restoring a stable spring base flow that is sufficient to inundate secondary channels, as well as, a spring pulse flow to inundated floodplains, particularly the Yolo and Sutter Bypasses.

A second key objective of the flow regime is to ensure adequate flows for the geomorphic and riparian processes that are necessary to sustain riverine and riparian habitat. We recommend short duration, high magnitude flows during the late winter to increase the frequency of hydrologic events that will mobilize the river bed or erode river banks. During late winter and early spring, we recommend prolonged duration moderately high flows to create inundated floodplain habitat for salmon. During the spring of wet and normal years, we recommend moderate duration, high flow evernts in wet and normal wet years to facilitate recruitment of Fremont cottonwoods and other riparian vegetation.

Restoring higher flows in the spring will necessarily reduce flows during other times of the year We propose reducing summer base flows to enhance spring flow, but realize that this could reduce suitable habitat for winter-run salmon during the summer months. We are not proposing any changes in the cold water pool management regime, which currently assures cold water releases from Shasta Reservoir. We recommend against

diverting additional water away from the winter months, because we believe that existing winter flood events are necessary to create and maintain riverine and riparian habitat.

8.2 Sacramento River

Summary recommendations for Sacramento River base flows, key ecological flows, and a flow schedule are presented in tables 7.1 – 7.3. Illustrative flow recommendation hydrographs for each year type are presented in figure 7.2.

Table 8.1: Sacramento Environmental Flow Targets for Bend Bridge and Verona

	Critical	Dry	Below Normal	Above Normal	Wet	Location
Bed Mobilization		35,000	65,000	85,000	105,000	Bend
Floodplain Inundation			25,000	35,000	45,000	Verona
Riparian Establishment Flow				23,000	37,000	Bend
Bed Scour	No Recommendation					
Channel Migration						

Table 8.2: Sacramento River Base Flow Target Summary for Bend Bridge

	Critical	Dry	Normal Dry	Normal Wet	Wet
Fall base flow	5,250	5,250	5,250	5,250	5,250
Winter base flow	4,500	6,000	6,500	7,000	8,000
Spring base flow	10,000	12,000	12,500	14,000	14,000
Summer Base	8,000	8,000	8,000	8,000	8,000
Summer Base at Colusa	4,000	4,000	4,000	4,000	4,000

Table 8.3: General Timing and Duration of Sacramento Environmental Flow Targets

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Geomorphic					2/15 -3/15							
Floodplain Inundation					Only 45 Days							
Riparian Establishment Flow												
Riparian Recession Limb												
Spring Rise												
Fall Base Flow												
Winter Base Flow												
Spring Base Flow												
Summer Base Flow												

8.2.1 Fall Base Flows

We propose stepping flows down from a stable summer base flow (see below) in late September in the upper river (between Keswick and Red Bluff). Under both natural and regulated conditions, flows in early fall are the lowest flows of the year. The primary purpose of lowering fall base flows closer to their historic levels is to economize on water and shift the saved water to the spring months when it is more important. The secondary purpose is to provide stable base flows for spring and fall-run spawning salmon and suitable rearing conditions for winter-run 5,500 cfs release from Keswick is about 1,000 – 1,500 cfs below existing fall base flows, but should be adequate for spawning habitat. The fall base flows must be stable to avoid dewatering or redds that may occur when flows are substantially dropped from the norm. Lower base flows in October could also potentially improve rearing habitat for winter run by creating slightly warmer fall water temperatures and thus an increased food supply.

Below Keswick	5,500
Below Red Bluff Diversion	5,250
Below GCID Diversion	5,000
Below Colusa	4,750

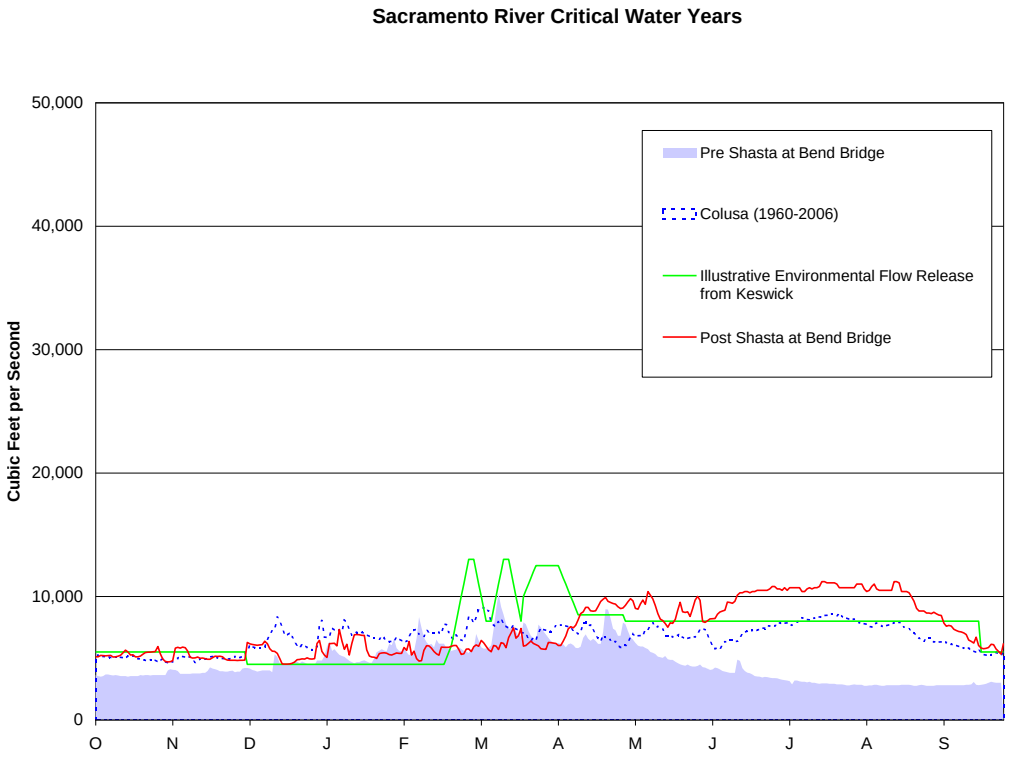
Key Uncertainties

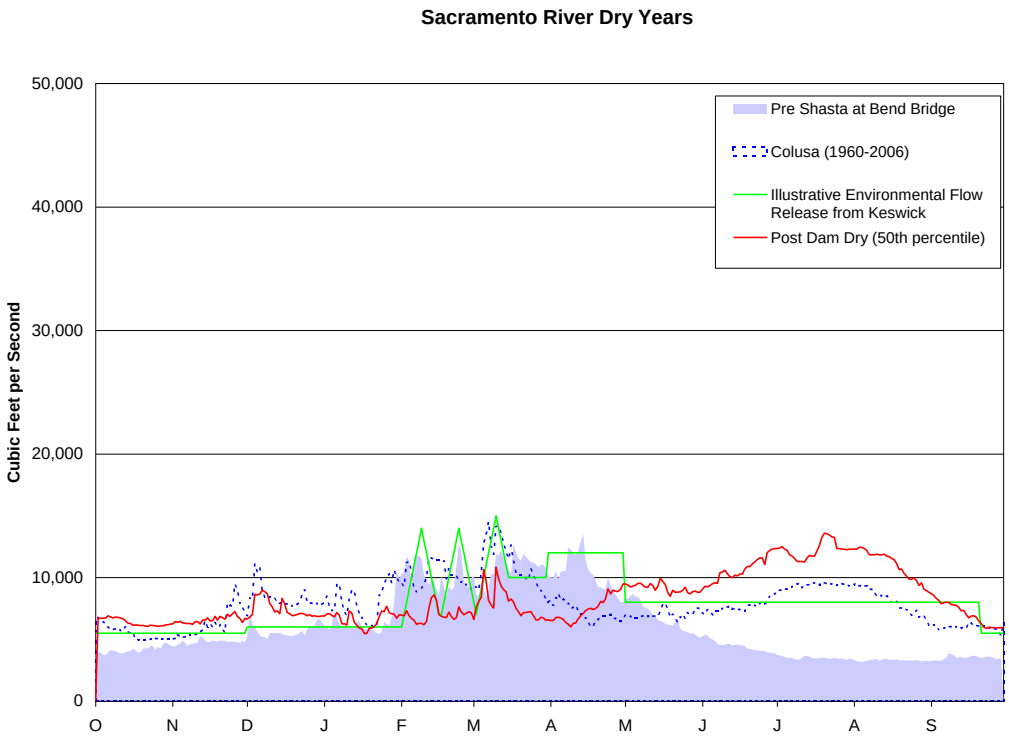
- Are proposed fall base flows sufficient for area of spawning habitat?
- Will lowering fall base flows provide warmer, slower velocity habitat for rearing winter run juveniles, and will this improve their growth and survival?
- Will reduce fall base flows cause adverse impacts in the Delta ecosystem?

8.2.2 Fall Pulse Flow

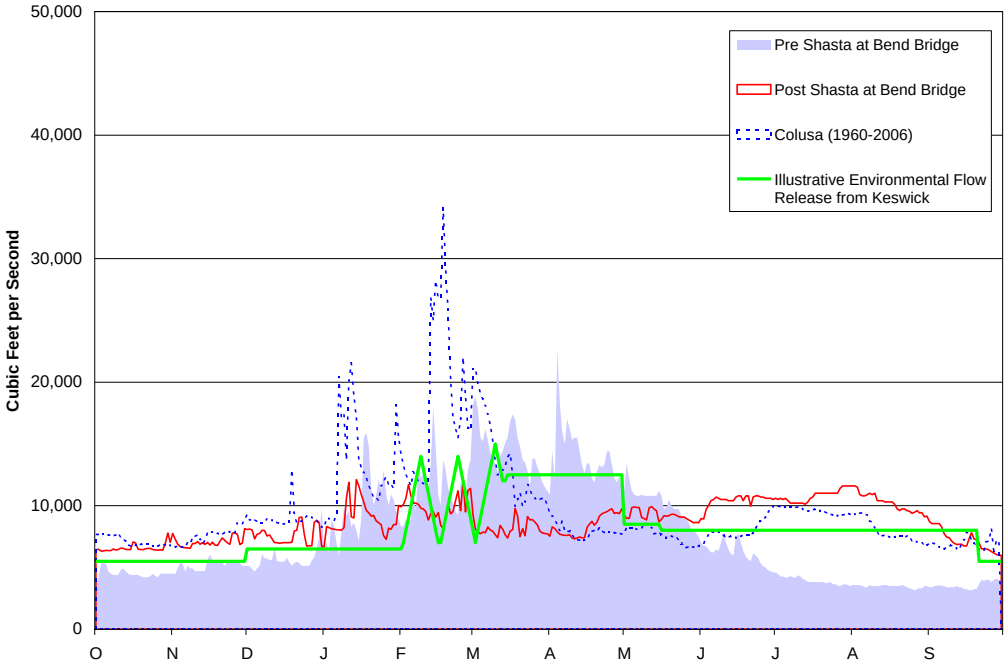
We considered a pulse flow to improve rearing conditions for juvenile salmon in the fall but did not include it in figure 7.2. The purpose of the fall pulse flow would be to improve food supply and rearing conditions for the winter run salmon and is loosely

Figure 8.2: Illustrative environmental hydrographs for five year types on the Sacramento River relative to existing regulated hydrograph and pre-Shasta hydrograph.

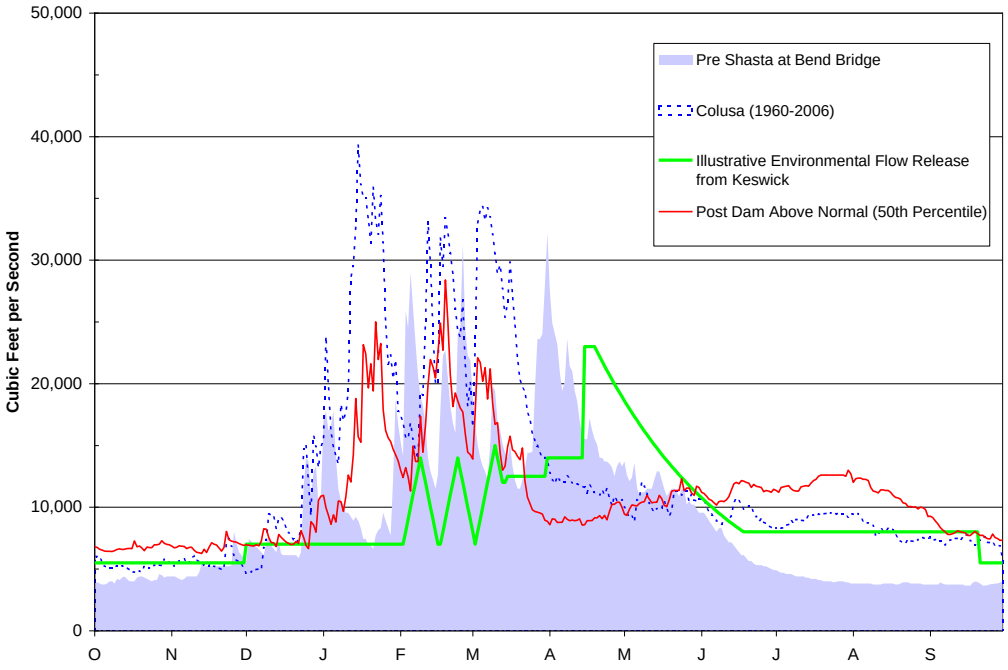


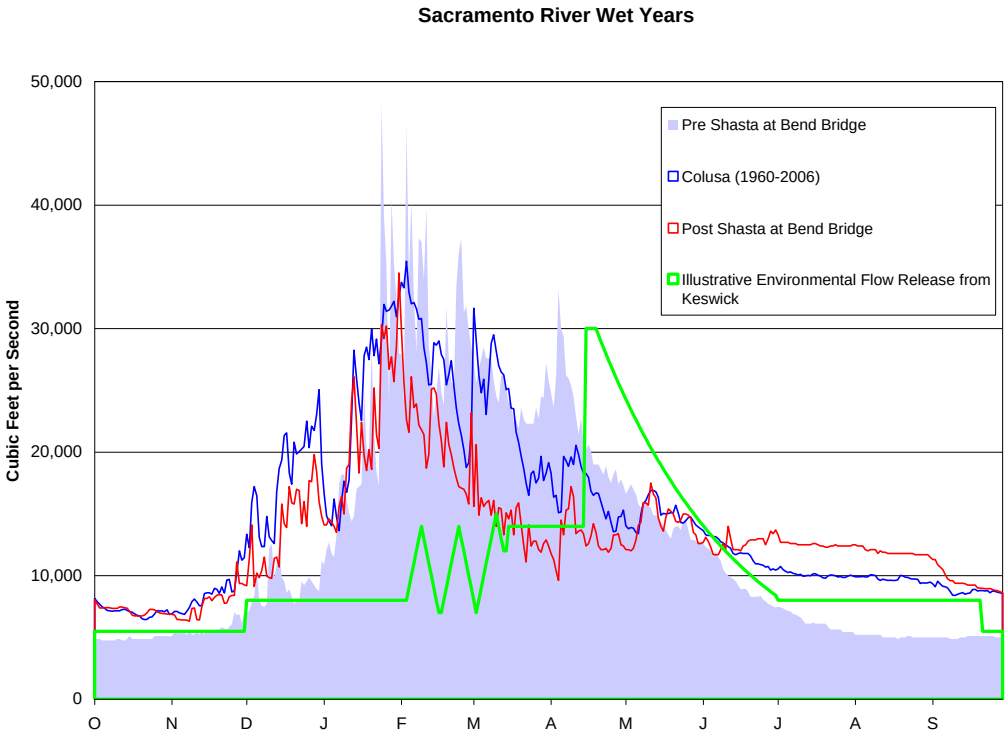


Sacramento River Below Normal Years



Sacramento River Above Normal Years

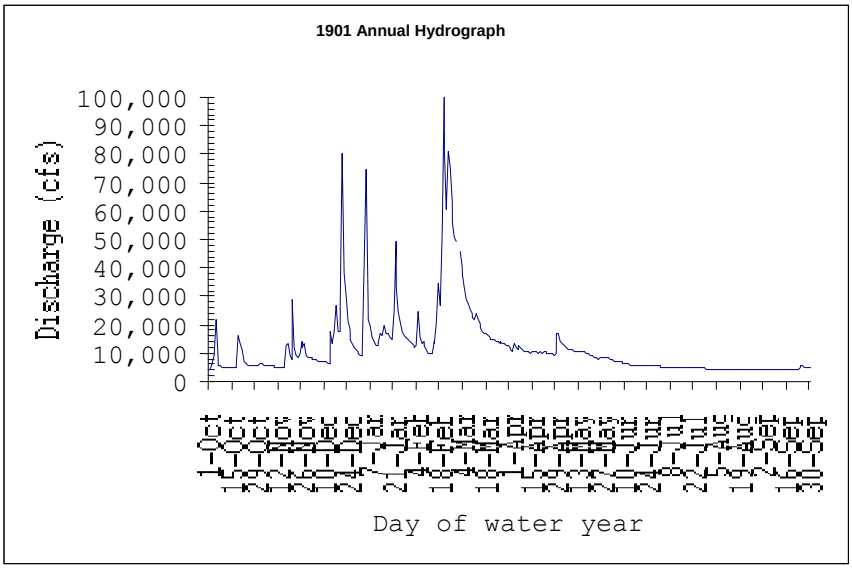



Sacramento River Wet Years
Cubic Feet per Second
50,000
40,000
30,000
20,000
10,000
0
O
N
D
J
F
M
A
M
J
J
A
S
Pre Shasta at Bend Bridge
Colusa (1960-2006)
Post Shasta at Bend Bridge
Illustrative Environmental Flow Release from Keswick

based on recommendations of the recently published Sacramento River Environmental Flows Report (Stillwater, 2007; ESSA Technologies, 2008). Rather then releasing a long duration rearing flow as proposed by Stillwater, it may be more economical to release two or three short duration pulses (3-5 days) of 12,000 cfs in late September and early October to inundate secondary channels and channel margins. The initial pulses would inundate the side channels and then be lowered to allow high residence times in the side channels. Each pulse would be followed by a subsequent pulse to flush food resources into the main channel and prevent fish stranding.

The main potential problem with a fall pulse flow would be to enable salmon, particularly spring run, to spawn on areas that would subsequently be dewatered. If the pulses are short enough, this problem may be limited. But the shorter the pulses will provide less potential for rearing habitat and food supply. Early fall pulse flows were rare under natural conditions, but they did occur occasionally as illustrated by the 1901 hydrograph (figure 7.1). Under regulated conditions, the winter run are confined to the mainstem river. The fall pulse, although largely unnatural, is designed to improve rearing conditions for them before cool winter months when food resources will presumably be less abundant.

Figure 8.1: 1901 hydrograph at Bend Bridge illustrating the rare, but natural occurrence of early fall pulse flows.



Key Uncertainties

- Will fall pulse flows for a few days result in dewatered reds once the pulse subsides?
- How long do secondary channel habitats need to be inundated in order to provide prolonged and substantial food supply benefits in the main channel?

8.2.3 Winter Base Flows

The purpose of the winter base flows is to provide stable conditions for incubating salmonids and reduce flashy regulated hydrology that can result when run-off from unregulated tributaries, primarily on the west side, is not modulated by less flashy natural hydrology from the larger, regulated watersheds. We recommend base flows of between 4,500 cfs in critical dry years and 8,000 cfs in wet years (table 7.4), which is similar to both existing regulated conditions and pre-dam historical conditions.

The winter base flows are a minimum base flow and are designed to occur in combination with unregulated run-off and flood control releases. Figure 7.2 shows the winter base flows as a straight line, but it is just a base flow that supports larger, unregulated peak flows. As a result, actual flows at Bend Bridge will be far more variable then depicted in figure 7.2.

Table 8.4: Winter base flow release from Keswick

	Critical	Dry	Normal Dry	Normal Wet	Wet
Winter base flow	4,500	6,000	6,500	7,000	8,000

Fairly substantial winter base flows combined with run-off events from less regulated tributaries will increase the frequency of inundation of channel margins and secondary channels that may serve as important rearing habitat.

8.2.4 Winter and Spring Peak Flows

The geomorphic flow targets discussed below may require additional releases from Shasta but are not explicitly included in figure 7.2 because they are short duration flow events that would be constructed upon unregulated run-off peaks. Smaller magnitude winter and spring peaks for fish rearing discussed below should be sufficient, particularly if reshaped, to achieve geomorphic targets below Red Bluff when combined with unregulated run-off.

Bed Mobilization
We recommend increasing the frequency of channel migration and bed mobilization flows during dry and below normal years for the reasons discussed in Appendix B. On the basis of thresholds discussed in chapter six, we recommend measures to achieve bed mobilization flows in most years (table 7.5). Based on the analysis of flow thresholds presented in chapter five, 35,000 cfs in dry years should be enough to initiate bed mobilization, at least locally, but it is probably not enough to precipitate widespread bed mobilization. The recommended peak flows in wetter years should be sufficient to precipitate significant bed mobilization in below normal, above normal, and wet years.

Table 8.5: Bed mobilization flow targets for Sacramento River between Keswick and Bend Bridge during different year types.

	Critical	Dry	Below Normal	Above Normal	Wet
Bed Mobilization		35,000	65,000	85,000	105,000

Some fish biologists have expressed concerns that high flow, even relative modest high flowss, could scour redds and thereby harm salmonid reproduction (ESSA, 2008; Stillwater, 2007). Based on our flow threshold analysis (chapter 5), we doubt that flows below 25,000 cfs will substantially mobilize the bed or scour redds. Much higher flows will significantly mobilize the bed, but the biological impact is not well documented and dependent on timing.

The ideal timing for bed mobilization is in early March after most salmon fry have emerged from the gravel and before bank swallow initiate nesting on cut banks. We expect that most mobilization events will result largely from unregulated run-off that humans are unable to control. While it seem logical that scouring flows would impair salmon reproduction, the natural hydrograph was characterized by multiple bed mobilization events in most years, raising the question of whether high, scouring flows actually limit salmonid reproduction. Under natural conditions, however, young fish would have had abundant floodplain and backwater habitat that is now scarce due to levees and reduced channel complexity.

Bed Scour

Information regarding the bed scour process and the magnitude of flow necessary to scour the bed is limited. While we recognize the potential importance of bed scour processes, we have not recommended any measures to precipitate bed scour due to the high level of uncertainty and the sheer magnitude of flow that may be necessary. We do, however, expect some bed scour to occur during the larges flow events once every ten years or more.

Channel Migration

Bank erosion and channel migration is a natural process that shapes the river ecosystem and provides habitats for riverine species. Bank swallows nest in recently eroded cut banks. Coarse and fine materials eroded from cut banks create substrates for growth of riparian vegetation and spawning salmon respectively. Turbid water resulting from bank erosion can provide important cover habitat for juvenile fish that would otherwise be very vulnerable to predation.

Some degree of bank erosion and channel migration will occur at the bed mobilization flows identified above and the spring pulse flows described below. Flows sufficient to erode unprotected banks already occurs and will continue to occur in wet and above normal years due to unregulated flows irregardless of a flow prescription. Furthermore, removal of bank revetment may be a more cost water efficient measure to facilitate natural channel migration then intentional flow releases. For all of these reasons, we

have not developed a specific flow recommendation for bank erosion and channel migration at this time.

Key Uncertainties:

- How much does the bed need to be mobilized? Is it sufficient to barely move the gravel and cobble substrate on the surface of the bed, or is it necessary to achieve full scale mobilization.
- What duration of peak flow is necessary to adequately mobilize the bed?
- How much does or could natural rates of bank erosion contribute to the overall turbidity and sediment load of the Sacramento River.

8.2.5 Spring Base Flow

The purpose of the spring base flow is to substantially increase rearing habitat along channel margins and within high flow channels for 45 to 120 days. Under natural conditions, spring flows (March and April) were consistently the highest, prolonged flow of the water year and resulted in widespread inundation of flood plain habitats. Under existing conditions, spring flows are substantially reduced, and a system of levees prevents widespread floodplain inundations.

We propose base flows to inundate secondary channels for rearing habitat during the spring months (table x). According to a recent study, a large number of secondary channels become fully connected to the channel at flows above 12,000 cfs (Kondolf, 2007). In critical dry years, flows would average 10,000 for thirty days after March 15, but small pulses greater then 12,000 cfs would increase connectivity with rearing habitat. In wetter years, larger flows would presumably create more rearing habitat and connectivity for longer periods of time.

Figure 8.6: Spring Pulse Flows at Bend Bridge

	3/15 - 3/31	4/1 - 4/14	4/15 - 4/30	4/30 - 5/14	5/1 - 5/14	5/15 - 5/31	6/15 - 6/30
Critical	10,000	10,000	8,500				
Dry	10,000	12,000	12,000	8,500			
Below Normal	12,500	12,500	12,500	8,500			
Above Normal	12,500	14,000	14,000	14,000	8,500		
Wet	14,000	14,000	14,000	14,000	14,000	8,500	

Key Uncertainties:

- Do flows in excess of what is necessary to inundate high flow channels create better rearing habitat and more food then flows barely sufficient to inundate these habitats?
- What is the optimal flow and residence time to create ideal rearing habitat conditions (food supply, temperature, and depth) in the secondary channels.

- Is the secondary channel habitat significant enough to substantially improve rearing conditions relative to the rearing habitat in the channel.

8.2.6 Floodplain Inundation Flows

The purpose of the floodplain inundation flows is to inundate floodplains in the Sutter and Yolo flood bypasses for rearing habitat and food web productivity. The flow objective is to create substantial inundated floodplain habitat for 30-60 days between February 15 and April 15 in most year types. To economize on the amount of water necessary to inundate these bypasses, we propose modifying the Tisdale and Fremont weirs to created inundated flood plain habitat more frequently and for a longer duration. Based on the floodplain process analysis in chapter 5, we developed a schedule of flood flow targets for various year types to create good conditions for floodplain rearing and foodweb productivity in nearly all year types (table 7.7).

The floodplain inundation flows are not explicitly included in figure 7.2. The winter and spring pulse flows described above combined with unregulated run-off at Colusa and environmental flows from the Feather and Yuba should be sufficient to achieve the table 7.7 targets.

Table 8.7: Recommended average monthly flows at Verona and Nicolaus on the Feather to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types (30-60 days).

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Key Uncertainties:

- What magnitude of flow is necessary in the Sacramento and Feather Rivers to move water across the bypasses assuming a modified weir structure?
- What is the optimal timing and flow to create optimal habitat conditions on the bypasses (depth, velocity, temperature, residence time) and food web productivity for the estuary?

8.2.7 Spring Snowmelt Recession Limb

The purpose of the spring, snowmelt recession is to periodically provide conditions for recruitment of Fremont cottonwoods, a keystone species in the riparian ecosystem. As discussed in appendix A and chapter 5, recruitment of cottonwoods requires a high spring flow followed by a gradual decline in order to enable cottonwoods set roots into the groundwater on higher surfaces that are relatively immune from scour during subsequent winter floods. An earlier analyses (TNC, 2003) determined that a range of 23,000 cfs to 37,000 cfs inundates the appropriate seedbed for establishment of cottonwood.

Cottonwood trees need not be recruited in all years to ensure a sustained riparian forest ecosystem.

We recommend recruitment flows of 23,000 in above normal years and 37,000 cfs (or somewhere in that general range) in wet years for 4-7 days between mid April and mid May followed by a gradual recession for 8-10 weeks. This flow regime should enable seeds released in mid spring to germinate on relatively high surfaces and then gradually extend roots to the permanent water table before the subsequent growing season.

8.2.8 Summer Base Flow June 15 to September 15

We have designed summer base flows between Keswick and Red Bluff to economically provide suitable conditions for winter run, spring run, and steelhead that spend a temperature sensitive portion of their life cycle between Keswick Dam and Red Bluff diversion Dam (table 7.8). Under natural conditions, these fish would have migrated upstream of Keswick and Shasta, but there mainstem habitat is now limited to the cold tail water provided by reservoir releases. Current base flows are artificially high to deliver water to Sacramento Valley irrigation districts and the Delta. Ideally, these unnaturally high flows could be shifted to the early spring to restore a prolonged spring pulse flow for rearing habitat and aquatic productivity, but providing a more natural flow regime (3,000 to 5,000 cfs) could result in lethal water temperatures for incubating winter run-eggs. Furthermore, flows of only 3,000-5,000 cfs would not provide sufficient water for both diversion into the north valley canals and base flows all the way downstream to the Delta. Therefore, we have proposed an intermediate level summer base that falls at the mid-range between historic base flows and existing base flows between Keswick and Red Bluff.

Table 8.8: Summer base recommendation at various points on the Sacramento River for all year types.

Below Keswick	8,000
Below Red Bluff Diversion	6,000
Below GCID Diversion	4,500
Below Colusa	4,000

Below Red Bluff and the GCID diversions, we have proposed substantially reduced summer base flows in order to shift more flow to the early spring months without disrupting the cold water pool management regime. The primary purpose is to provide better habitat conditions in the spring, but restoring a more natural summer base flow may have environmental benefits in its own right. Summer base flows substantially below the 8,000 cfs needed to inundate off-channel backwaters will create more natural summer conditions and thus may discourage invasive plant and animal species that may out compete natives under the existing artificial summer base flow regime. Seasonally desiccated off-channel habitats may be more productive then perennially inundated wetlands and less likely to harbor exotics predators such as bull frogs and bass. Lower

summer water levels may be less beneficial to late germinating invasive vegetation such as tamarisk that can out compete native cottonwoods.

Key Uncertainties:

1. Assuming no changes to the cold water pool management, what flow is necessary to maintain sufficient water temperatures for over summering life stages of winter-run, spring-run, late fall-run and steelhead?
2. Will low flows and corresponding higher temperatures increase populations of non-native warm water fish that prey upon or compete with native species?
3. Will summer base flows be sufficient between Red Bluff and GCID to maintain water temperature conditions suitable for juvenile salmonids or adult migrating salmonids?
4. Will more "natural" conditions provide better habitat and feeding conditions for native species?

8.3 Feather River

Summary recommendations for Sacramento River base flows, key ecological flows, and a flow schedule are presented in tables 7.1 – 7.3. Illustrative flow recommendation hydrographs for each year type are presented in figure 7.2.

Table 8.9: Feather River Environmental Flow Targets for Bend Bridge and Verona

	Critical	Dry	Below Normal	Above Normal	Wet	Location
Bed Mobilization		10,000	20,000	55,000	50,000	Bend
Floodplain Inundation		6,000	8,000	10,000	12,000	Verona
Riparian Establishment Flow				10,000	12,000	Bend
Bed Scour	No Recommendation					
Channel Migration						

Table 8.10: Feather River Minimum Base Flow Targets for Oroville

	Critical	Dry	Normal Dry	Normal Wet	Wet
Fall base flow	1,250	1,250	1,300	1,600	1,750
Winter base flow	1,500	1,700	1,850	2,750	3,500
Spring base flow	2,000	2,700	3,200	6,500	8,000
Spring rise	2,750	5,500	8,000	10,000	12,500
Summer Base	1,300	1,700	2,000	2,000	2,000

Table 8.11: Feather River Environmental Flow Targets (Timing and Duration)												
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
Geomorphic									Optimal 2/15 -3/15*			
Floodplain Inundation					Only 45 Days							
Riparian Establishment Flow												
Riparian Recession Limb												
Spring Rise												
Fall Base Flow												
Winter Base Flow												
Spring Base Flow												
Summer Base Flow												

8.3.1 Fall Base Flows

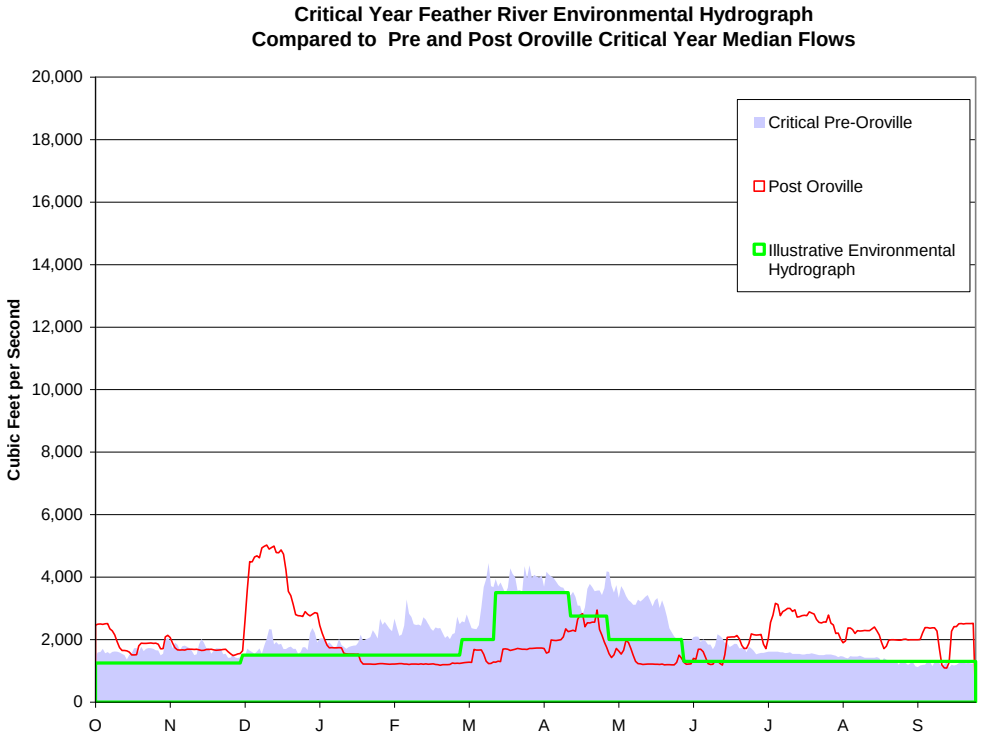
We propose stepping flows down from a stable summer base flow (see below) in late September (table 7.10) to fall spawning flows specified by the recent Oroville relicensing proceeding. The new minimum instream flows below Thermalito Afterbay range from 1,000 cfs in the late spring and summer to 1,200 -1,700 cfs during the fall winter months. Under both natural and regulated conditions, flows in early fall are the lowest flows of the year. The primary purpose of lowering base flows in the fall closer to their historic and regulatory minimum levels is to economize on water and shift the saved water to the spring months when it is more important. The secondary purpose is to provide stable base flows for spring and fall-run spawning and potentially to trigger spring-run spawning. The fall base flows must be stable to avoid dewatering or redds that may occur when flows are substantially dropped from the norm.

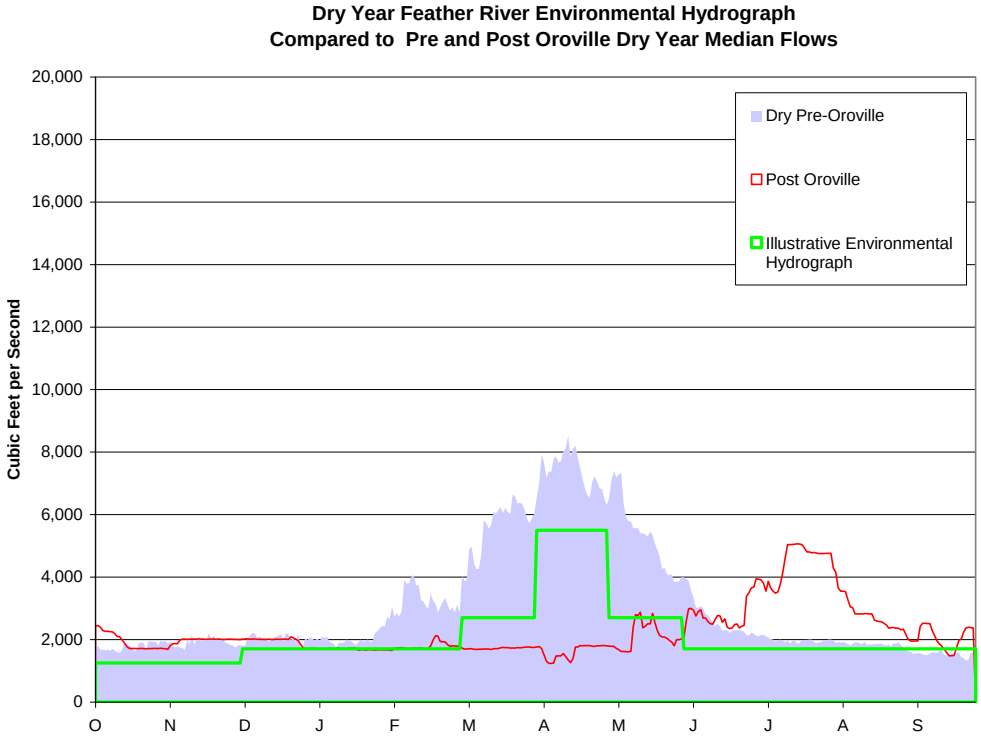
Key Uncertainties

- Are proposed fall base flows sufficient for area of spawning habitat?

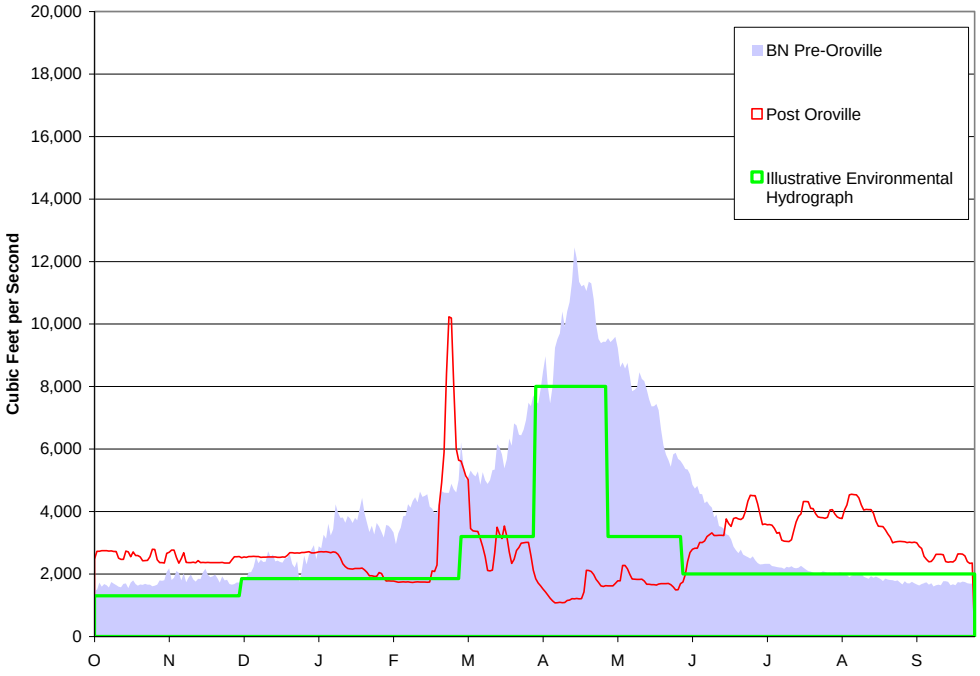
Will reduce fall base flows cause adverse impacts in the Delta ecosystem?

Figure 8.3: Illustrative environmental hydrographs for five year types on the Feather River relative to pre and post Oroville hydrographs.

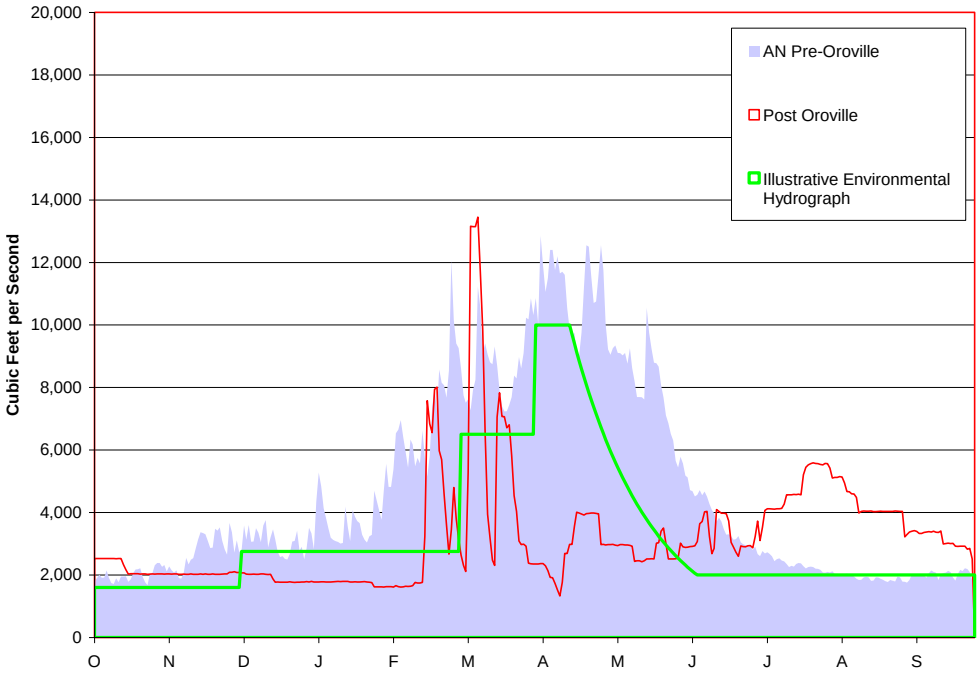


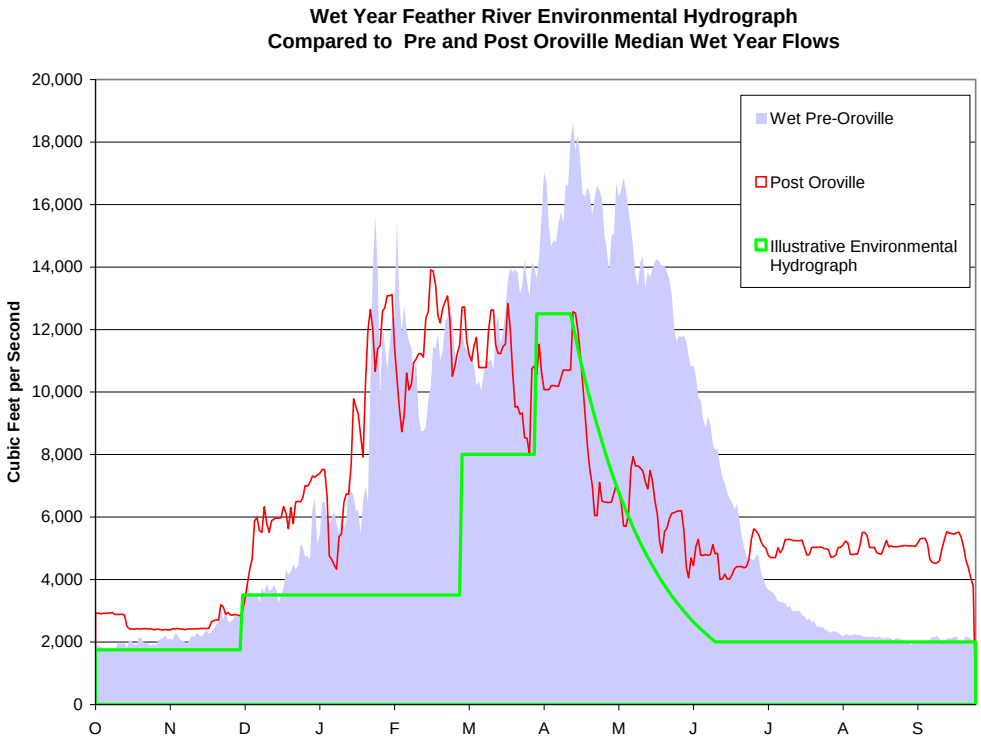


Below Normal Year Feather River Environmental Hydrograph
Compared to Pre and Post Below Normal Oroville Median Flows



Above Normal Year Feather River Environmental Hydrograph
Compared to Pre and Post Oroville Above Normal Median Flows





8.3.2 Winter Base Flows

The purpose of the winter base flows is to provide stable conditions for incubating salmonids and reduce flashy regulated hydrology that can result when run-off from unregulated tributaries, particularly the South Fork Yuba, is not modulated by less flashy natural hydrology from the larger, regulated watersheds. We recommend base flows of between 1,500 cfs in critical dry years and 3,500 cfs in wet years (table 7.10), which is similar to both existing regulated conditions and pre-dam historical conditions.

The winter base flows are a minimum base flow and are designed to occur in combination with unregulated run-off and flood control releases. Figure 7.3 shows the winter base flows as a straight line, but it is just a base flow that supports larger, unregulated peak flows. As a result, actual flows below the confluence with the Yuba will be far more variable then depicted in figure 7.3.
Fairly substantial winter base flows combined with run-off events from less regulated tributaries will increase the frequency of inundation of channel margins and secondary channels that may serve as important rearing habitat.

8.3.4 Winter and Spring Peak Flows

The geomorphic flow targets discussed below may require additional releases from Shasta but are not explicitly included in figure 7.3 because they are short duration flow

events that would be constructed upon the spring rise or ordinary flood control releases. Smaller magnitude spring pulse flows for fish rearing discussed below should be sufficient, particularly if reshaped, to achieve geomorphic targets.

Bed Mobilization
We recommend increasing the frequency of channel migration and bed mobilization flows during dry and below normal years for the reasons discussed in Appendix B. On the basis of thresholds discussed in chapter six, we recommend measures to achieve bed mobilization flows in most years (table 7.5). Based on the analysis of flow thresholds presented in chapter five, 35,000 cfs in dry years should be enough to initiate bed mobilization, at least locally, but it is probably not enough to precipitate widespread bed mobilization. The recommended peak flows in wetter years should be sufficient to precipitate significant bed mobilization in below normal, above normal, and wet years.

Table 8.12: Bed mobilization flow targets for Feather River below Oroville

	Critical	Dry	Below Normal	Above Normal	Wet
Bed Mobilization		10,000	25,000	35,000	50,000

Some fish biologists have expressed concerns that high flow, even relative modest high flowss, could scour redds and thereby harm salmonid reproduction on the Sacramento River (ESSA, 2008; Stillwater, 2007). Because are bed mobilization flows for the Feather River are based on statistical estimates rather then empirical evidence of bed mobility, the potential for red scour is a big uncertainty, but we doubt it will occur at 25,000 cfs or less and the greater magnitude flows prescribed for above normal and wet are likely to happen from flood control releases regardless of our flow recommendations.

The ideal timing for bed mobilization after late February when most salmon fry have emerged from the gravel. We expect that most mobilization events will result largely from unregulated run-off that humans are unable to control. While it seem logical that scouring flows would impair salmon reproduction, the natural hydrograph was characterized by multiple bed mobilization events in most years, raising the question of whether high, scouring flows actually limit salmonid reproduction. Under natural conditions, however, young fish would have had abundant floodplain and backwater habitat that is now scarce due to levees and reduced channel complexity.

Bed Scour
Information regarding the bed scour process and the magnitude of flow necessary to scour the bed is limited. While we recognize the potential importance of bed scour processes, we have not recommended any measures to precipitate bed scour due to the high level of uncertainty and the sheer magnitude of flow that may be necessary. We do, however, expect some bed scour to occur during the larges flow events once every ten years or more.

Channel Migration
Bank erosion and channel migration is a natural process that shapes the river ecosystem and provides habitats for riverine species. Bank swallows nest in recently eroded cut banks. Coarse and fine materials eroded from cut banks create substrates for growth of riparian vegetation and spawning salmon respectively. Turbid water resulting from bank erosion can provide important cover habitat for juvenile fish that would otherwise be very vulnerable to predation.

Some degree of bank erosion and channel migration will occur at the bed mobilization flows identified above and the spring pulse flows described below. Flows sufficient to erode unprotected banks already occurs and will continue to occur in wet and above normal years due to unregulated flows irregardless of a flow prescription. Furthermore, removal of bank revetment may be a more cost water efficient measure to facilitate natural channel migration then intentional flow releases. For all of these reasons, we have not developed a specific flow recommendation for bank erosion and channel migration at this time.

Key Uncertainties:

- How much does the bed need to be mobilized? Is it sufficient to barely move the gravel and cobble substrate on the surface of the bed, or is it necessary to achieve full scale mobilization.
- What duration of peak flow is necessary to adequately mobilize the bed?
- How much does or could natural rates of bank erosion contribute to the overall turbidity and sediment load of the Sacramento River.

8.3.5 Spring Base Flow

The purpose of the spring base flow is to substantially increase rearing habitat along channel margins and within high flow channels for 45 to 120 days. Under natural conditions, spring flows (March and April) were consistently the highest, prolonged flow of the water year and resulted in widespread inundation of flood plain habitats. Under existing conditions, spring flows are substantially reduced, and a system of levees prevents widespread floodplain inundations.

On the Feather River, we do not have good information regarding the flows necessary to inundate back-water channels. As a result we developed spring flow targets based on historical hydrology and an assessment of the flows necessary to inundate the Sutter Bypass (table 7.13). Wetter year spring flow pulses begin later in the spring and last longer, while dryer year targets economize on water early to get salmon out of the river before temperatures could become a problem in the lower Sacramento.

Figure 8.13: Spring Pulse Flows below Oroville

	3/1-3/14	**3/14-3/30**	**4/1-4/14**	**4//14 - 4/30**	**5/1 - 5/14**	**5/15 – 5/31**
Critical	2,000	3,500	3,500	2,000		
Dry	2,700	2,700	5,500	5,500	2,700	
Below Normal	3,200	3,200	8,000	8,000	3,200	
Above Normal	6,500	6,500	10,000	10,000	5,000	3,000
Wet	8,000	12,500	12,500	11,000	6,000	4,000

Key Uncertainties:

- Do flows in excess of what is necessary to inundate high flow channels create better rearing habitat and more food then flows barely sufficient to inundate these habitats?
- What is the optimal flow and residence time to create ideal rearing habitat conditions (food supply, temperature, and depth) in the secondary channels.
- Is the secondary channel habitat significant enough to substantially improve rearing conditions relative to the rearing habitat in the channel.

8.3.6 Floodplain Inundation Flows

The purpose of the floodplain inundation flows is to inundate floodplains in the Sutter and Yolo flood bypasses for rearing habitat and food web productivity. The flow objective is to create substantial inundated floodplain habitat for 30-60 days between February 15 and April 15 in most year types. To economize on the amount of water necessary to inundate these bypasses, we propose modifying the Tisdale and Fremont weirs to created inundated flood plain habitat more frequently and for a longer duration. Based on the floodplain process analysis in chapter 5, we developed a schedule of flood flow targets for various year types to create good conditions for floodplain rearing and foodweb productivity in nearly all year types (table 7.7).

The floodplain inundation flows are not explicitly included in figure 7.3. The spring pulse flows described above combined with unregulated run-off from the Sacramento and Yuba Rivers will be sufficient to achieve the table 7.7 targets.

Table 8.14: Recommended average monthly flows at Verona and Nicolaus on the Feather to create inundated floodplain habitat in the Yolo and Sutter Bypasses for various year types (30-60 days).

	Year Type				
	C	D	BN	AN	W
Nicolaus (Feather)			12,000	15,000	20,000
Freemont Wier		25,000	30,000	37,500	45,000
Tisdale Weir		25,000	30,000	35,000	40,000
Verona		25,000	35,000	45,000	55,000

Key Uncertainties:

- What magnitude of flow is necessary in the Sacramento and Feather Rivers to move water across the bypasses assuming a modified weir structure?
- What is the optimal timing and flow to create optimal habitat conditions on the bypasses (depth, velocity, temperature, residence time) and food web productivity for the estuary?

8.3.7 Spring Snowmelt Recession Limb

The purpose of the spring, snowmelt recession is to periodically provide conditions for recruitment of Fremont cottonwoods, a keystone species in the riparian ecosystem. As discussed in appendix A and chapter 5, recruitment of cottonwoods requires a high spring flow followed by a gradual decline in order to enable cottonwoods set roots into the groundwater on higher surfaces that are relatively immune from scour during subsequent winter floods. Since we did not have estimates of flows suitable for riparian recruitment on the Feather River, we estimated a seedling establishment flow target based on the Sacramento riparian recruitment target. We simply scaled down the Sacramento target based on the ratio of the seedling establishment flow to the Q1.5. The seedling establishment flow on the Sacramento (23,000 – 30,000 cfs) is twenty seven to thirty seven percent of the bankfull discharge (Q1.5 to Q2) on the Sacramento. Assuming a similar proportional relationship on the Feather River, flows in the range of 9,500 to 18,000 would be suitable for seedling establishment.

We recommend seedling establishment flows of 10,000 in above normal years and 12,500 cfsin wet years for 4-7 days between mid April and mid May followed by a gradual recession for 8-10 weeks. This flow regime should enable seeds released in mid spring to germinate on relatively high surfaces and then gradually extend roots to the permanent water table before the subsequent growing season.

8.3.8 Summer Base Flow June 15 to September 15

The purpose of the summer base flow is to provide suitable temperature and rearing conditions for over summering salmonids, both juvenile and adult spring-run and steelhead. We propose base flow targets ranging from 1,300 in critical dry years to 2,000 cfs in above normal and wet years. These flows are very similar to natural summer base flows and are higher then the minimum existing minimum flows established during the recent relicensing proceedings. Existing minimum regulatory flows are 1,000 cfs in the summer. Existing actual flows are far higher then are recommendation.

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APPENDIX A

LITERATURE REVIEW OF ENVIRONMENTAL FLOW METHODS

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LITERATURE REVIEW OF ENVIRONMENTAL FLOW METHODOLOGIES

Over the past five decades, the development and application of environmental flow methodologies (EFMs) has rapidly progressed, as a means to help sustain or restore natural aquatic functions and ecosystems in the face of increasing demands for limited water resources. EFMs are science-based processes for assessing and/or recommending instream flows for regulated rivers. Their purpose may be as general as maintaining a healthy riverine ecosystem or as specific as enhancing the survival of targeted aquatic species. The growing prominence of EFMs in river management planning reflects a trend towards more sustainable use of the world's freshwater resources and a shift in focus from water quality to water *quantity* as a major factor in the degradation of rivers (O'Keeffe 2000).

In a comprehensive study of environmental flow methodologies, Tharme (2000) documented the existence of more than 200 EFMs, recorded worldwide. These included various modifications and hybrids of some commonly applied methods, site-specific approaches with limited applications, and procedures that are no longer in use. In actuality there are only a few dozen EFMs that are still widely applied. They can be divided into four major categories: 1) hydrological, 2) hydraulic rating, 3) habitat simulation, and 4) holistic methodologies (Tharme 2000). An overview of each of these categories is provided below, along with general strengths, weaknesses, and associated trends.

1.1. Hydrological Methods

Hydrological methodologies make up the largest proportion (30%) of environmental flow methodologies developed (Tharme, 2000). Hydrological methods are usually simple office procedures that recommend a proportion of a river's historical unregulated or naturalized flow regime as the minimum flow to maintain a fishery or other aquatic features. Recommended flows may be given on a monthly, seasonal, or annual basis. For example, the Tennant (Montana) method suggests 20% of mean annual flow (MAF) during the wet season and 40% MAF during the dry season to maintain "good" river conditions. Because of their simplicity and low resolution, Tennant and other hydrological methods are most appropriate for early reconnaissance-level project planning, to provide relatively quick and inexpensive estimates of flows to allocate for environmental purposes. Although biological factors are not explicitly considered in these methods, most were developed with some general biological basis (Caissie and El-Jabi 1995). In addition, hydrological methods assume that a minimum flow within the historic flow range for a river will sustain some proportion of native aquatic biota because the species survived such conditions in the past (Jowett 1997).

Hydrological methods have the primary advantages of being simple, straightforward, and relatively inexpensive to apply. Most require only historical flow records for a site, with little or no additional fieldwork. The simplicity of these methods, however, is also their greatest weakness. Because they do not incorporate site-specific habitat data, their

ecological validity is often questionable (King et al. 2000). For example, these methods are frequently applied without regard to artificial changes in channel conditions (due to flow regulation or man-made structures) that may influence the ecological impact of recommended flows. EFMs in this category also should not be applied to river systems that do not approximate in size and type the reference river systems on which they were developed. Many hydrological methods do not address ecologically important intra- and interannual variations in flows. And unlike other methods, hydrologically based EFMs usually cannot be used to compare alternative flow regimes. Finally, for some river systems it may be difficult to obtain the unregulated or naturalized flow data necessary to calculate recommended flows.

Despite their many limitations, Tharme (2000) suggested that hydrological methods will continue to be the EFMs of choice for the foreseeable future. However, we can expect to see progress in their development towards more ecologically defensible and sophisticated methodologies. The Range of Variability Approach (RVA) is one such recently developed EFM that is considered to represent a significant advance over earlier hydrological methods. Unlike other EFMs in its category, the RVA captures the complex intra- and interannual variability of natural flow regimes over multiple temporal scales, incorporates a large number of ecologically based hydrologic indices in its analysis, and utilizes an adaptive management program for monitoring and refinement (Richter et al. 1996, 1997). Since its inception, the RVA has attracted considerable interest among river scientists and managers as a new class of ecologically grounded hydrologically based environmental flow methodologies (King et al. 2000).

1.2. Hydraulic Rating Methods

Hydraulic rating methodologies comprise 11% of the global total of EFMs. They differ from purely hydrology-based methods in that they incorporate site-specific information on hydraulic parameters, such as wetted perimeter or maximum depth, as measured across riffles or other limiting river cross sections. These parameters are used as surrogates for the habitat available for target biota such as fish or macroinvertebrate communities. Hydraulic rating methods assess changes in the habitat surrogates in response to changes in discharge. Recommended flows are commonly set at a breakpoint in the parameter-discharge curve, interpreted as the flow below which habitat decreases rapidly with a decrease in flow and above which habitat increases slowly with an increase in flow (Loar et al. 1986).

Although they require some fieldwork and data analysis, hydraulic rating methods enable a relatively quick and simple assessment of flows for maintaining habitat of target biota. They are considered more advanced and biologically relevant than hydrological methods. Their inclusion of site-specific field measurements better adapts them to different river systems. Hydraulic rating methods, however, are based on a number of simplistic assumptions that often cannot be verified. Key among these is that the chosen hydraulic variable(s) can be used to determine the flow requirements of the target species. In addition, the validity of results is highly dependent on appropriate sampling of critical river cross sections and proper identification of a breakpoint in the parameter-discharge curve. The latter is frequently complicated by the existence of multiple breakpoints or

the lack of any defined breakpoint in the curve. And like most hydrological methods, EFMs in this category generally do not address ecologically important intra- and interannual variations in flows.

In the past decade there have been few advances in the development or application of hydraulic rating methodologies. Instead, this category of EFMs seems to have been superceded by the more advanced habitat simulation methodologies for which they are precursors. The Wetted Perimeter Approach, the best-known EFM in this category, is still widely applied in North America and globally (Reiser 1989, King et al. 2000). However, it is likely that many other hydraulic rating methods will gradually fall into obsolescence as the science of EFMs advances in alternate directions (Tharme 2000).

1.3. Habitat Simulation Methods

Habitat simulation methodologies (28%) rank second only to hydrological methods in proportion of total EFMs. This group of flow methodologies includes the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), which is the most widely used EFM in North America and the world (Reiser 1989, Tharme 2000). IFIM and many other habitat simulation methods comprise systems of highly sophisticated computer modeling techniques that integrate site-specific hydraulic and hydrologic data with species specific habitat preference data (in the form of habitat suitability curves). Computer outputs are usually in the form of habitat usability-flow discharge curves for the various factors of interest, e.g., different life stages of one or two fish species. Practitioners evaluate these curves and determine flow regimes based on the levels of protection (habitat usability) desired for each factor of interest. Because there is considerable potential for conflicting habitat requirements in this final step, it is necessary to have clear management objectives and a good understanding of the stream ecosystem when using IFIM and other habitat simulation methods to develop flow regimes.

Habitat simulation methods are flexible and adaptable. They incorporate site-specific and species specific information, so can be tailored for particular conditions and management goals. They can be used to analyze flow-related trade offs among multiple species and life stages. They may be modified to recommend flows for riparian vegetation, sediment flushing, recreation, and any number of other instream purposes. They are capable of addressing ecologically important intra- and interannual variations in flows for target species. Habitat simulation methods are also often perceived as scientifically objective and legally defensible; thus, they may be suitable for allocating instream flows in highly controversial situations (Estes 1996).

The focus of habitat simulation methods on specific target species and/or instream uses raises the risk that other essential components of the stream ecosystem may be overlooked (Prewitt & Carlson 1980). On the other hand, when these methods are used to address multiple management objectives for a river system, there are no set procedures for resolving conflicting flow requirements. The flexibility that habitat simulation methods provide make them among the most difficult EFMs to apply and interpret. Another important consideration, especially for developing countries, is that habitat

simulation methods are often time-consuming, costly, and require considerable technical and scientific expertise for proper application. Modeling applications can be run without sufficient understanding of input and output processes; therefore, there is high potential for misuse by improperly trained persons. Other important sources of error or bias for modeling outputs include selection of representative cross sections for collecting hydraulic data, and construction of species-specific habitat suitability curves. Finally, a commonly cited criticism of PHABSIM, the modeling system used with IFIM, is the seeming lack of relation between fish and habitat usability estimates produced by the models (Orth and Maughan 1982).

Habitat simulation models, though the subject of much criticism, are still highly regarded by many river scientists. Current trends in their development are more advanced modeling techniques, multi-dimensional graphics, and integration of GIS display platforms.

1.4. Holistic Methods

These methods are relatively new to the science of environmental flow management. They were first documented by Tharme (1996) and currently make up 7.7% of total EFMs (Tharme 2002). Holistic approaches rely largely on multidisciplinary expert panels to recommend instream flows (Tharme 2000). They represent a significant departure from earlier environmental flow methods, in that their recommendations are almost wholly subjective. However, more advanced holistic methods, such as the Building Block Methodology (BBM), may utilize several of the analytical tools described for other EFMs to assist in the decision-making process (Tharme 2000). An early step in the BBM and some other holistic methods is identification of the magnitude, timing, duration, and frequency of important flow events for various ecosystem components and functions. The decision-making process for integrating these flow events may include a number of activities, including workshops, site visits, and limited data collection and analysis. The final output of the consensus process is a recommended flow regime to meet various specific management objectives.

Most holistic methods are relatively quick and inexpensive to apply. They have limited requirements for technical expertise and hydrologic data. And with appropriate interdisciplinary representation, these methods can comprehensively address all major components of the riverine ecosystem, including geomorphological, riparian, biological, water quality, social and other elements. Holistic methods can recommend flows at a variety of temporal scales. They are site-specific and allow for assessment of whole stretches of river rather than extrapolation from sample cross sections. The major weakness of holistic methods is the subjectivity of their approach, which may open their findings to controversy and criticism.

Holistic methods are still very much in the infancy of their development. Most of these methods have their roots in South Africa and Australia. Few have been applied outside of these countries of origin. Application of holistic methods for environmental flow management is expected to grow rapidly over the next decade, as EFMs become better established as river management tools in developing countries. Holistic methods are well

suited for use in these countries, where data, finances, and technical expertise are frequently limited.

2. METHOD FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS FOR THE SACRAMENTO AND FEATHER RIVERS

We have employed a version of the holistic approach practiced in South Africa and Australia (King et. al. 2000) to identify an environmental flow regime for the Sacramento River. This approach relies heavily on hydrological evaluations, previous studies, and expert opinion to estimate environmental flow requirements and develop a long-term adaptive management plan for implementing and refining an environmental flow regime over time. The results of the holistic approach provide a framework for increasing knowledge regarding the relationship between flow and environmental objectives and refining water management practices over time. The output of the holistic method envisioned here provides not only an estimate of environmental flow requirements, but more importantly, an explicit identification of key assumptions and uncertainties that need to be tested overtime to more accurately describe the flow requirements necessary to achieve environmental objectives.

We made two important assumptions in generally applying this method to the Sacramento River.

- Similarities in both the restoration objectives and the hydrologic, geomorphic, and ecological conditions on the Sacramento River will result in relatively similar prescriptions for environmental management flows. We believe this assumption is well supported by the environmental conditions and historical alteration of this river.

- The flow necessary to achieve restoration objectives may vary greatly depending on non-flow restoration actions such as improving spawning habitat, reconstructing degraded channel, removing levees to restore floodplain habitat, modifying and screening water diversions, reducing polluted run-off, managing ocean harvest, and other factors. In general, non-flow restoration actions will reduce the amount of water necessary to achieve restoration objectives.

The holistic approach applied in this study consists of the following 6-step process to identify an environmental flow regime:

1. Identify specific environmental objectives (i.e,. target species, aquatic and riparian communities, and desired ecological conditions that are flow dependent).
2. Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.
3. Compare existing vs. historical hydrology to understand natural hydrologic patterns and how they have been altered.
4. Identify obvious gaps between objective flow requirements and existing flows.

5. Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.
6. Design an adaptive management program to further test and refine environmental flows.

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

Well-articulated target ecological conditions and desired species and communities are necessary for establishing environmental flows. Despite the correctly vogue concept of restoring ecosystem processes and avoiding species specific approaches, there is no getting around the fact that key species need specific hydrologic conditions at specific times. This analysis will include both aquatic and riparian communities and the flow parameters necessary to sustain these communities such as floodplain inundation, appropriate water temperature, or creation of structural habitat through geomorphic processes. These specific environmental objectives may vary by region, sub-basin, and reach of the river.

2) Approximate the timing, magnitude, frequency, and duration (TMDF) of flows necessary to support target species, communities and desired ecological processes.

An environmental flow regime encompasses the adequate timing, magnitude, duration, and frequency of flows necessary to support target species and facilitate specific ecological processes encompassed in the stated environmental objectives. Where we understand the life cycle timing of various target species, it is relatively easy to identify the approximate timing and duration of flows necessary to support different life stages of target species. Estimating the required flow magnitude is far more difficult but can be informed by field data, results of numerical models, and general relationships described in the literature. Most short lived target species require adequate flows each year to reproduce, while longer lived species can sustain their populations with a lower frequency of flow conditions conducive to reproduction. For example, riparian forest species may only require recruitment flows every five to ten years to establish new seedlings.

Estimating the magnitude of flows necessary to support or optimize conditions for target species and processes is by far the most difficult element of the environmental hydrograph to approximate. Environmental engineers and biologists have developed relatively elaborate methods for determining ideal flow regimes such as physical habitat simulation (PHABSIM) and Instream Incremental Flow Methodology (IFIM) to identify optimum flow magnitudes based on known habitat preferences of target species, measured habitat conditions (velocity and depth) at various flows, and numerical models that predict habitat conditions at a range of flows. Numerical models that describe the width, depth, and velocity of the rivers at various discharges are useful for predicting river stage and temperature at various locations, factors that are important considerations for habitat or facilitating geomorphic and hydrologic processes. As discussed above,

these models tend to focus on the needs of specific species and can sometimes produce results that are inconsistent with both holistic ecological process restoration and common sense. Furthermore, these models are often not calibrated, particularly at higher flows relevant to riparian recruitment, geomorphic processes, and spring outmigration temperatures. Nevertheless, we utilized the results of these models as a guide combined with other information to develop our environmental flow management hypothesis.

Where possible, we relied on actual data and measurements to estimate the flows necessary to achieve suitable conditions to support biological, riparian, and geomorphic objectives for temperature, floodplain inundation, and bed mobilization. In particular, we relied on USGS temperature gauges to characterize the relationship between temperature and flow. Similarly, we relied on previous studies of the rivers to characterize flows necessary to mobilize bed material and inundate the floodplain.

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

Analyses of historical hydrologic data is useful for describing natural patterns and identifying potential links between hydrology and the requirements necessary to maintain species and precipitate key processes. An analysis of historical patterns can provide clues about the timing, magnitude, duration, and frequency of flows under which target species have evolved. Identification of major changes between historical and hydrologic patterns combined with the life history requirements of various species can help generate hypotheses about how flow regulation may be limiting target species. We will use the an analysis similar to the Index of Hydrologic Alteration approach (Richter et al. 1996) and the Hydrograph Component Analysis (HCA) (Trush et al. 2000) to evaluate changes in flow patterns. The analysis similar to the IHA provides a quick statistical overview of how several important hydrologic attributes have changed. The analysis similar to the Hydrograph Component Analysis (HCA) method developed by McBain and Trush provides a detailed graphical analysis of historical and existing hydrologic conditions. While valid and useful, the statistical analysis in the IHA method is not substitute for visually comparing and evaluating key components of the pre- and post-dam hydrographs. Similarly, visual comparisons of pre- and post-alteration hydrographs don't always reveal important changes identified by the IHA method.

4) Identify obvious gaps between objective flow requirements and existing flows.

An analysis of historical flow patterns combined with an approximation of the TMDF of flows necessary to achieve objectives compared with the regulated flow regime can help illustrate obvious gaps between regulated flows and flows that may be necessary to achieve environmental objectives. We will plot TMDF flow requirements developed in Step 2 as an annual hydrograph and compare it with average regulated and historical conditions.

5) Develop an environmental flow hydrograph to achieve ecological objectives based upon a clear understanding of historical and existing hydrologic patterns, and identify key hypotheses and uncertainties regarding the relationship between flow patterns and environmental objectives.

This project identifies hypothetical restoration flow regimes but recognizes that the most reliable method for developing a restoration flow regime is through a long-term adaptive management program including a series of trials that test the effectiveness of various flow prescriptions. The purpose of developing the hypothetical flow regime is to develop a comprehensive hypothesis regarding the range of flows that may be necessary to restore ecological processes to the Sacramento River. However, the assumptions and uncertainties associated with the hypothetical flow regime are as important as the flow regime itself.

6) Design an adaptive management program to further test and refine environmental flows.

To cost effectively achieve restoration, managers will ultimately need to test these assumptions and limit the uncertainties through an adaptive management program consisting of a combination of numerical modeling, pilot flow studies, model calibration, and long-term restoration implementation.

APPENDIX B

CONCEPTUAL MODELS

FOR

GEOMORPHIC PROCESSES, FREMONT COTTONWOODS,

AND CHINOOK SALMON

APPENDIX B: CONCEPTUAL MODELS

Geomorphic Conceptual Model

1.0 Geomorphic Conceptual Model

Geomorphic processes are generally initiated at threshold flow levels. Bed mobilization and floodplain inundation do not occur until flows reach a threshold level sufficient to flow over bank or create sheer stresses necessary to mobilize gravel. Theoretically, no benefit occurs unless the threshold flow is achieved. No amount of flows less than the threshold will initiate bed mobilization or floodplain inundation, but in reality the actual threshold flow varies spatially from reach to reach. Research from several gravel bedded river systems indicates that a flow with a natural (unregulated) recurrence interval of every 1.5 years is generally needed to mobilize the bed and initiate over bank flows (Leopold et al. 1964). In reality, however, the threshold flows necessary to initiate geomorphic processes naturally vary from reach to reach depending on channel dimensions, slope, and the size of bed material. In general, sand bedded reaches mobilize at lower flows than gravel bedded reaches with larger particle sizes. Similarly, low gradient reaches flood at lower discharges than steeper reaches, particularly where large woody debris is allowed to accumulate.

Human modifications of the channels from their natural state have changed the relationship between flows and geomorphic processes and have therefore complicated the already difficult task of determining the flows necessary for precipitating various geomorphic processes. Gravel and channel restoration projects have changed and could continue to change the particle size of gravels and the channel dimensions and will thus further change the relationship between flow and geomorphic processes. More importantly, there is no single bed mobility threshold for any reach of the Sacramento River or any other river channel due to spatial vaiabilty in particle size and channel form (Kondolf et al, 2000; Wilcock, 1996).

There are varying degrees of bed mobilization, further complicating the definition of mobility and its distinction with bed scour. For this study, we attempted to estimate the flows necessary to mobilize and scour the bed. Bed mobility and bed scour are two different processes that occur at different flow thresholds. We use the term bed mobility to refer to mobilization of the surface of the channel bed. Bed scour is the process of scouring the bed deeper than its coarse surface layer. Incipient bed mobility is the threshold at which bed material begins to mobilize and occurs when the ratio of the critical sheer stress to the D_{50} equals 1. Incipient mobility can cause small movement of gravel across the top of the riffle without general mobilization of the riffle surface. Relatively frequent (every 1–2 years) incipient motion of gravels on a riffle may be adequate for certain objectives such as flushing fines from the gravels, but is probably not sufficient for certain geomorphic objectives such as restoring sediment transport or maintaining a dynamic, alternating bar sequence (Trush et al. 2000). General bed mobility mobilizes the entire riffle surface and occurs when the ratio of critical sheer

stress to particle size D_{50} exceeds 1.3. General bed mobility may be necessary for restoring basic alluvial functions such as transporting coarse sediment from one riffle to the next.

Lastly, there is relatively little information regarding the flows necessary to perform various geomorphic objectives. Geomorphic processes associated with these objectives occur at very high flows, when field measurement is difficult. Hydraulic models and equations have been applied on the Sacramento to provide insight into the flows necessary to mobilize the bed and banks and inundate the floodplain, but in many cases these models have not been adequately calibrated at high flows or do not accurately describe the actual hydraulics at specific cross sections (Kondolf, 2000). Empirical observations are generally more reliable, but are often limited to specific study sites. In this study, we have relied on previously reported field measurements, modeling analysis, and general principles from the literature to roughly estimate the magnitude of flows necessary to initiate geomorphic processes.

For all of the reasons discussed above, it is not possible to estimate future flow levels necessary to initiate geomorphic processes across an entire river, but for the purposes of this study, a rough estimate will be sufficient to evaluate the feasibility of reoperating reservoir releases for the purpose of achieving geomorphic objectives. In this study, we have focused on the flows necessary to mobilize the gravel bedded reaches, because they are more relevant to salmon restoration and because they will also result in mobilization of the sand bedded reaches. For floodplain inundation, we have focused on the lowland floodplains because they can be inundated at lower flows with demonstrated fisheries benefits.

The geomorphic conceptual model in its most succinct form is that high flows exert sheer stress on and transport sediment over the many structural components of a river channel and floodplain (bed, banks, other exposed surfaces) causing them to change, erode, migrate, and otherwise respond in a qualitatively predictable manner.

The geomorphic conceptual model described below is based on inputs and outputs. Inputs into the model are in three categories: flow, topography, and sediment. The outputs of the model are physical functions that in turn support habitat and biotic responses in the river system.

The Sacramento River requires a variety of high flows ($Q_{1.5} – Q_{10}$) to clean sediment, rejuvenate alternate bar sequences, prepare the floodplain for vegetation recruitment, and drive channel migration. Each one of these functions supports a biotic or habitat response described previously in this chapter.

Figure 1 illustrates the relationships between flow, sediment, and topographic inputs, and ensuing geomorphic processes. The model has been simplified to focus primarily on restoration objectives of this project and the inputs we propose to modify to achieve these restoration objectives (outlined in bold).

Inputs

The driving inputs in the conceptual model fall into three categories: flow, topography, and sediment. In reality, the conceptual model is at least partly cyclic, where the outputs are also inputs into successive cycles.

Flow Inputs

Flow inputs can be divided into three broad categories: regulated runoff, unregulated runoff, and groundwater inputs. Regulated runoff refers to flow releases from reservoirs over which humans exert some control. This is of particular importance to this conceptual model because it is the input we propose to modify. Unregulated runoff refers to flow inputs on streams and rivers over which humans do not exert much control. As the distance between any point on a river and an upstream dam or diversion increases, so too does the influence of unregulated runoff. More tributaries enter the river and the unregulated drainage area increases downstream from the dam or diversion.

Groundwater refers to any inputs from subsurface flows. These are not, in fact, entirely independent of regulated or unregulated runoff. Interaction of high flows with floodplain surfaces, flow durations, and flow frequencies impact the quantity and timing of groundwater inputs. Similarly, groundwater inputs impact base flow levels in both regulated and unregulated systems. For the sake of simplicity and focus, groundwater is considered an independent input.

Topographic Inputs

The shape of the river channel and floodplain, the location of the levees, the amount and type of vegetation in the channel and on the floodplain, and other structural characteristics comprise the topographical inputs of the conceptual model. They determine the distribution and velocity of any given flow quantity. For example, if one hundred acre-feet of water enter into a river, the water will pass much more quickly and smoothly if the river channel resembles a pipe - smooth and straight. If the channel is small, the water may spill onto the floodplain. If the channel is flat and wide, the water may travel very slowly. If the channel is full of vegetation, it may impede the flow of water or concentrate it between walls of vegetation.

Upstream Sediment Inputs

Upstream sediment inputs refer to silts, sands, cobbles, gravels or boulders transported in the river system. The quantity and quality of upstream sediment input create the building blocks for depositional processes. Because dams capture most upstream sediment, in regulated rivers sediment inputs are mostly from unregulated tributaries and storage in banks and bars below the reservoir.

Flow Outputs

Regulated flow, unregulated flow, and groundwater establish the amount of water in a river system. The topographic features determine the surface over which the water flows, and how it flows over that surface. Together, they determine the discharge, stage, and velocity of the flows (producing sheer stress). Combined with the frequency of these

flows, and the upstream sediment inputs, they drive various geomorphic processes in river systems (described below).

Process Responses

Gravel Bed Mobilization

Gravel bed mobilization refers to the entrainment of D50[1] gravels. This generally occurs in alluvial rivers during the historic annual or biannual floods or roughly the $Q_{1.5}$ flow or Q_2. The mobilization of the gravels "cleans" them by removing accumulated silt, algae and other fine particulates (Stillwater Sciences, 2001).

Floodplain Inundation

Floodplain inundation is a hydrogeomorphic process that serves important ecological functions. Floodplain inundation provides temporary access to floodplain habitat for aquatic species, recruits nutrients from the floodplain into the river, and helps to recharge groundwater levels in riparian zones. Inundated floodplains provide important spawning and rearing habitat for numerous species. Sacramento splittail are largely dependent on inundated floodplains for successful spawning and rearing. Juvenile salmon grow two to three times as fast on floodplains compared to channels. Due to large surface area, the volume of area in the photo zone, and relatively warm temperatures during cool winter and early spring months, floodplains generate larges amounts of phytoplankton and zooplankton during the critical spring months.

Determining the flow necessary to inundate floodplains is complicated by the fact that different types of rivers and river reaches overflow their banks at different flows. Floodplain inundation in gravel bedded streams generally occurs during flows at or above the historic biannual flood (Q_2) (Stillwater Sciences, 2001). However, floodplain inundation on lowland Rivers such as the lower Sacramento and Feather Rivers occurr far more often, creating extensive flood basins that were inundated for weeks or months in all but the driest years (Bay Institute, 1998). Even under post dam hydrology, many of these basins, such as the Yolo Bypass, would flood for weeks or days at flows far below the bankfull discharge.

It is not realistic to restore floodplain inundation to the historic flood basins of the Sacramento Valley. It would simply be too disruptive to the water supply and economic functions of the Sacramento River and its historical floodplains. It is, however, more realistic to intentionally inundate the system of flood bypasses designed to safely accommodate flood flows in the Sacramento River. The magnitude of flows necessary to inundate bypasses, as well as the frequency of bypass inundation is controlled by weirs at the upstream end of each bypass. Water does not enter the bypass and create inundated habitat until the river stage is high enough to overtop the weir. A study sponsored by the US Army Corps of Engineers, however, demonstrated that it is possible to inundate the bypasses at greater frequency and lower flows by intentionally notching the weirs (NHI, 2002). For the purposes of this study, we have assumed that you could inundate

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[1] D refers to the length of the intermediate axis of gravels in a gravel bed. The D50 refers to the gravels in the 50th percentile size class, relative to the other gravels in the bed.

floodplains in flood bypass areas using this method at multiple weirs in the Sacramento Valley.

Bed Scour and Deposition
Bed scour and deposition refer to the removal of sediment and the corresponding replacement of sediment that occurs during storm events. The bed scour and deposition process discourages the river channel from being "fossilized" by riparian encroachment, maintaining it in a dynamic alluvial state. It is a greater level of mobilization than simply gravel bed mobilization, in that the bed degrades during the ascending limb of the hydrograph and aggrades on the receding limb of the hydrograph. Q_5 to Q_{10} floods generally provide the necessary shear stress to scour beds and redeposit with little net change in channel elevation (Trush et al. 2000)

Floodplain Sediment Scour and Deposition
Floodplain sediment scour requires greater sheer stress than simply inundation and generally occurs during flows equivalent to the historic Q_{10}. By exerting sheer stress, scour prepares floodplain surfaces for recruitment of riparian vegetation by removing existing vegetation, depositing clean sand and transporting new seed across the floodplain. Depositional processes also require higher flows to transport sediment away from the channel onto the floodplain. As flows increase, they spill across the floodplain, velocities slow, and the river deposits its sediments. Most floodplain sediments are the result of this process (Leopold et al., 1964). Deposition on the floodplain further reshapes and prepares the surfaces for recruitment.

Channel Migration
Channel migration is a function of stream energy and substrate strength. By eroding, channel migration recruits gravels and large woody debris into the system and directly and indirectly creates habitat complexity in the channel and floodplain. By depositing, channel migration prepares surfaces for pioneer species allowing for a diversity of riparian habitats. The process of channel migration is responsible backwater areas, sloughs, oxbow lakes, and secondary or abandoned channels (Bay Institute, 1998).

Channel migration requires the greatest amount of stream energy and generally requires large flows for a prolonged period, which can require very large volumes of water. Flows larger than the bank full discharge may be necessary to cause major channel migration or channel avulsion, but gradual channel migration may occur each year at some bends with flows well below the bank full discharge.

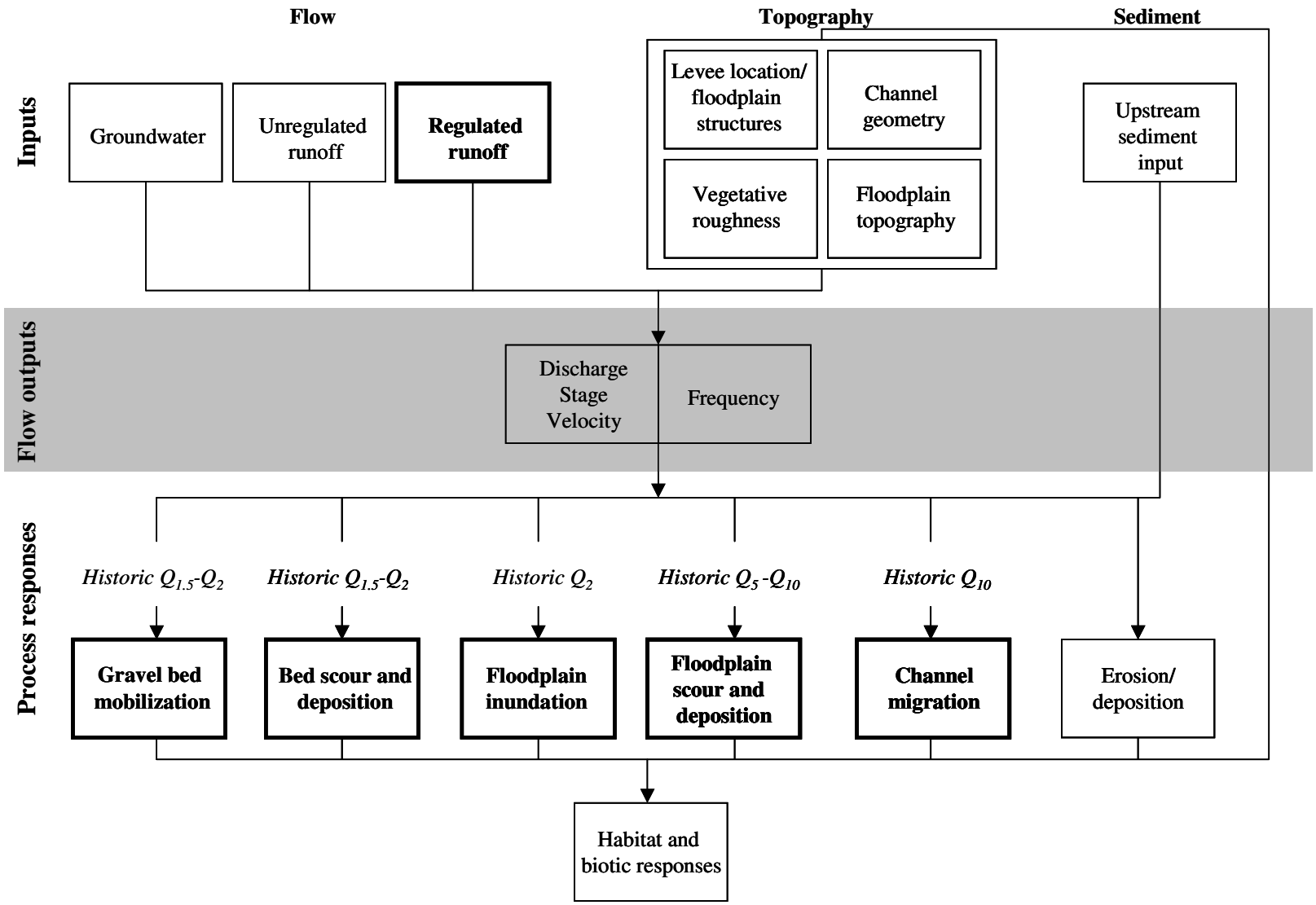

Figure 1. Geomorphic Conceptual Model. The figure above illustrates the relationships between flow, sediment, and topographic inputs, and ensuing geomorphic processes. The model has been simplified to focus primarily on restoration objectives of this project and the inputs we propose to modify to achieve these restoration objectives (outlined in bold).

Appendix C: Cottonwood Conceptual Model

4.2 Cottonwood Conceptual Model

Critical life history stages of cottonwoods and other pioneer riparian species in the Sacramento River basin are tightly linked with the hydrologic and geomorphic processes described in the previous conceptual model. Floodplain scour/deposition, channel migration, channel avulsion, and erosion/deposition processes generate new sites for cottonwood seedling establishment. Floodplain inundation provides moist substrates to sustain seedlings through their first growing season. Gravel and sand bed mobilization and bed scour/deposition help define a minimum elevation for cottonwood recruitment. Over time, these processes play a key role in determining the distribution, extent, and age structure of cottonwood communities in the Sacramento River basin. In turn, as cottonwoods mature, they have the potential to impact sediment deposition processes, channel stability, and channel dynamics. Both geomorphic processes and riparian habitat structure are important determinants of abundance and distribution of aquatic species such as chinook salmon, as described in the next section.

Land use activities and managed flow operations have greatly reduced the extent and integrity of riparian forests, particularly cottonwood forests, in the Sacramento Basin. Most existing cottonwood stands in the basin are mature, exhibiting older age structure than typical under natural conditions (McBain and Trush 2000, Stillwater Sciences 2002a, Jones & Stokes 1998). The absence of sapling cohorts in many reaches of the basin suggests that natural recruitment processes are not occurring under current conditions (McBain and Trush 2000, Jones & Stokes 1998, Stillwater Sciences 2002a). Without younger age classes, senescent trees cannot be replaced as they die, potentially leading to further substantial loss of this once dominant riparian vegetation community.

This conceptual model describes the ecological flows and geomorphic processes that drive establishment and recruitment of cottonwoods under natural conditions (Figure 2). The model identifies factors that currently limit cottonwood recruitment in the Sacramento Basin and opportunities for restoring this process through modification of flows and/or channel-floodplain geomorphology. Because channel attributes may differ widely among rivers and reaches of the Sacramento Basin, flow characteristics for restoration are described qualitatively in this model, with respect to channel and floodplain elevations.

Various species of cottonwoods share the characteristics discussed below. Any discussion specific to the Fremont cottonwood *(Populus fremontii),* the predominant species of the Central Valley (Stillwater Sciences 2002a, 2002b, 2006: McBain and Trush 2000), is noted as such.

4.2.1 Site Preparation

The creation of barren nursery sites through erosional and depositional processes is the first step in cottonwood seedling recruitment. Because cottonwood seeds contain very little endosperm, seedlings require full sunlight to produce photosynthates for growth and development; thus, cottonwood seedlings compete poorly on vegetated sites (Fenner et al. 1984). Under natural flow regimes, moderate 5- to 10-year flood events precipitate channel migration and the creation of point bars suitable for cottonwood seedling establishment (McBain and Trush 2000, Trush et

al. 2000). Large flows scour away herbaceous plants and/or deposit fine sediments on floodplains, preparing new seed beds for pioneer riparian species (Mahoney and Rood 1998). In addition to point bars and floodplains, cottonwood forests may occur in high flow scour channels, oxbows, and other off-channel backwaters that receive scouring and sediment deposition (Stillwater Sciences 2002a).

Over the past century, continued agricultural and urban encroachment into riparian zones have greatly decreased the landscape area upon which cottonwood recruitment can occur (Stillwater, 2006; McBain and Trush 2000, Jones & Stokes 1998). In addition, flow regulation has reduced the intensity and frequency of winter and spring flood flows. The lower flows have led to a moderate reduction in the high-energy processes that, in less regulated river systems, create new seedbeds for recruitment—channel migration, point bar accretion, bed scour, and floodplain inundation. Levees and bank stabilization practices have reduced floodplain width and channel migration, in addition to isolating riparian backwaters (Stillwater, 2006). In addition, the loss of upstream sediment supply may have resulted in channel incision, requiring greater discharges for flows to inundate adjacent floodplains (TNC, 2003). The cumulative result of these processes has been a significant reduction in favorable germination sites for cottonwood seedlings.

There are several options for human intervention to increase availability of suitable recruitment sites for cottonwoods. Flood operations can be modified in wet years to allow shorter duration, but higher winter or spring peak flows sufficient to inundate floodplains and mobilize channel sediments (Jones & Stokes 1998). Reservoirs can be operated to release flows that mimic the 5- to 10-year flood events historically associated with cottonwood recruitment. Mechanical approaches include lowering floodplain surfaces for greater inundation frequency at current low flows, setting back or breaching levees to increase floodplain area, restoring the river's connection with abandoned side channels and backwaters, and artificially clearing floodplain sites to reduce plant competition.

Reductions in peak flows can lead to vegetation encroachment of more aggressive native riparian species into the formerly active river channel, further limiting cottonwood recruitment (Jones & Stokes 1998). Under natural hydrologic conditions, surfaces at the edge of low-flow channels were high-scour zones that generally prohibited the establishment of riparian vegetation. Under regulated conditions where the frequency of scouring flows has decreased significantly, vegetation —primarily alders and willows and forbes— can encroach along channel margins that were previously characterized by shifting and exposed gravel or sand bars (Stillwater Sciences 2002a, McBain and Trush 2000, FWUA and NRDC 2002). Vegetation encroachment can ultimately result in simplified and confined river channels resistant to fluvial geomorphic processes (e.g., channel migration) that create barren seedbeds for cottonwood recruitment. This does not appear to be a problem on the Sacramento River due to relatively frequent high flow events, but vegetation studies do indicate that recruitment is currently dominated by willows (TNC, 2003) to the potential detriment of cottonwoods. Therefore, maintaining the proper frequency and magnitude of high flows is necessary for maintaining habitats where cottonwoods are likely to become established and dominant.

4.2.2 Seedling Establishment

Establishment describes the process of seed release, germination, and growth through the end of the first year. This stage in the life cycle of cottonwoods is marked by high mortality rates, in both natural and regulated river systems (Mahoney and Rood 1998).

Most studies on Fremont cottonwood recruitment have focused on establishment of new stands through seed release, rather than vegetative sprouts. In the Sacramento Basin, mature female Fremont cottonwoods release hundreds of thousands to millions of seeds between April and June. Timing and duration of seed release are influenced by photoperiod and temperature, with maximal seed release generally occurring over a three-week period (FWUA and NRDC 2002, Stillwater Sciences 2002a). Seeds are dispersed by wind and water. They may travel up to a couple miles away, but more often they are deposited within a several hundred feet of the parent tree (Braatne et al. 1996). Dry Fremont cottonwood seeds are viable for one to three weeks (Horton et al. 1960). Once they are wet, their viability decreases to a few days (Braatne et al. 1996). Thus, for riparian restoration purposes it is important to understand the mechanisms that influence cottonwood seed release and dispersal, to ensure that timing of spring (snow-melt) pulse flows coincides with cottonwood seed dispersal. The spring pulse flows provide the moist nursery sites necessary for immediate germination of seeds (Mahoney and Rood 1998).

Cottonwoods germinate within 24–48 hours of landing on bare, moist substrates such as silt, sand, or gravel (John Stella, Stillwater Sciences, pers. com., 8 April 2003). For one to three weeks after germination, the upper layer of substrate must maintain moisture as the seedlings' root systems grow. Post-germination decline of river stage, which is presumed to control adjacent groundwater levels (JSA and MEI 2002), should not exceed approximately one inch per day (Mahoney and Rood 1998, Busch et al. 1992). This is the rate at which seedling root growth (0.16–0.47 inches/day; Reichenbacher 1984, Horton et al. 1960) can maintain contact with the capillary fringe of a receding water table in a sandy substrate. Cottonwood root growth and seedling establishment rates are higher in these soils than in coarser textured soils, which are more porous (Kocsis et al. 1991). In reaches with gravelly substrates, slower draw-down rates are necessary to support seedling establishment.

Mahoney and Rood (1998) describe the temporal and spatial window of opportunity for cottonwood seedling establishment as a "recruitment box", defined by timing of spring pulse ("establishment") flows/seed release and by seedling elevation relative to river stage. Optimal timing of seed release for successful establishment is during the gradually declining limb of a spring pulse flow. Optimal elevation relative to river stage is set at the upper end by the seedling's ability to maintain contact with the declining water table, and at the lower end by scouring and inundation flow levels in the first year, especially during the first winter.

The vast majority of cottonwood seedlings in this life stage die of drought stress because root growth is unable to keep pace with the decline in the water table (Mahoney and Rood 1998). Regulated ramp-down rates after spring pulse flows are often steep, in order to conserve water for human uses (Stillwater Sciences 2002b). Alternatively, decreased spring flows in regulated systems may cause seedlings to initiate at elevations too low to protect seedlings from flooding and scouring flows later in the growing season or during the winter (Mahoney and Rood 1998). In some rivers overwinter mortality of cottonwood seedlings is particularly high because flow

regulation has reduced spring peak flows relative to winter peak flows (Stillwater Sciences 2002a).

High seedling mortality rates suggest that opportunities for improving cottonwood recruitment may be greatest in this life stage. In the first year of life, drought stress can be minimized by managing flood release flows for slow ramp-down rates after 5- to 10-year flood releases. Since reservoir spills often occur in wet years, reduced ramp-down rates may be accomplished by reshaping existing flood release flows without reducing water supply deliveries.

Artificial floodplain irrigation, either through flooding or a drip system, can also relieve summer drought stress for newly initiated seedlings. Agricultural irrigation close to the channel during the dry season would achieve similar gains in groundwater level. Grazing and trampling of seedlings by livestock can be minimized through grazing management practices or by building exclosures to protect cottonwood nurseries. To reduce winter mortality due to scouring and inundation, establishment flows can be discharged in spring rather than winter.

4.2.3 Vegetative Reproduction

In addition to seed dispersal and seedling establishment, vegetative reproduction is a potentially significant but commonly overlooked method for cottonwood recruitment along newly formed or previously established floodplains and point bars. Fremont cottonwoods can reproduce clonally through sprouting of buried broken or detached branches, or through development of suckers from shallow roots. This little-studied phenomenon has been alluded to in the riparian literature, and reported anecdotally and in unpublished studies (Tu 2000; Mike Roberts, TNC, pers. com., 27 February 2003). Additional insight into the process can be gained from studies of vegetative reproduction in other cottonwood species (Rood et al. 1994, Reed 1995).

Vegetative reproduction may be particularly important for sustaining Fremont cottonwood populations in altered hydrologic systems such as the Sacramento Basin. Tu (2000) reported that three years after the floods of 1996 established a new sandbar along the lower Cosumnes River, successful Fremont cottonwood recruits from vegetative branches outnumbered those from seeds by almost six to one. This is especially notable in light of the fact that the original 1996 cohort studied included 7,898 Fremont cottonwood seedlings compared to only 36 vegetative branches. Thus, the greater number of surviving 3-year-old recruits from vegetative branches compared to seedlings was due to their considerably higher survival rates rather than initial predominance. Most of the seedlings in this study died in their first year post-germination as a result of desiccation. Tu (2000) surmised that vegetative branches were better able to survive the critical first year by virtue of their greater nutrient storage, higher competitive ability for light, and greater proximity to declining water tables (most were partially buried in the soil).

In many parts of the Sacramento Basin, it is possible that the loss of natural recruitment processes under current conditions has increased the importance of vegetative propagation relative to seed propagation for sustaining cottonwood populations. An intervention opportunity based on natural vegetative reproduction is to plant cuttings collected from local cottonwood populations. Although this option would be time and labor intensive, cottonwoods have been successfully re-established by this method in Clear Creek and on the Sacramento and Merced Rivers (Mike Harris, USFWS, pers. com., 26 February 2003; John Stella, Stillwater Sciences,

pers. com., 8 April 2003). Once a small number of individuals are successfully recruited to a new site, expansion of the population may subsequently occur via sprouting, suckering, or seed dispersal. Due to the uncertainties of seed dispersal timing, availability of flows, and high cost of flows (unless part of flood release flows), a dual strategy of vegetative reproduction and improved flow management may be the most cost effective option for improving rates of cottonwood recruitment in the Sacramento Basin.

4.2.4 Recruitment

The recruitment phase occurs from the end of the first year to sexual maturity, at five to ten years of age for Fremont cottonwoods (Reichenbacher 1984). Flow-related mortality is relatively low during this period because a plant has generally developed a sufficient root and shoot system to survive seasonal conditions of drought and flooding. Growth rates are very high in the second year, by the end of which roots may be almost ten feet deep (Ware and Penfound 1949). After the second year, growth rates level. Despite extensive root development during this stage, cottonwoods are still somewhat susceptible to drought stress. Thus, yearly flows must be sufficient to maintain groundwater levels within 10 to 20 feet of ground surface elevations (JSA and MEI 2002).

Groundwater extraction and reduced flows can reduce groundwater levels and induce drought stress in cottonwood saplings (Jones & Stokes 1998). In regulated river systems, low frequency of scouring flows may also allow exotics such as eucalyptus, tamarisk, and giant reed to establish and outcompete early successional native species such as cottonwood (Jones & Stokes 1998, McBain and Trush 2000). Relatively low flow-related mortality during this stage diminishes the importance of flow management opportunities. However, mortality due to herbivory (e.g., beavers, voles, mice) may be significant during this phase (John Stella, Stillwater Sciences, pers. com., 8 April 2003). Density-dependent mortality (self-thinning) may also occur if initial seedling density is high.

4.2.5 Maturity & Senescence

Maturity begins with the first flowering of a sexually mature adult. Senescence begins when reproductive capacity declines. Field studies indicate that a large proportion of existing cottonwood stands in the Sacramento Basin comprise mature and senescing individuals (McBain and Trush 2000, Stillwater Sciences 2002a, Jones & Stokes 1998). As these cottonwoods die (lifespan >130 years; Shanfield 1983), they are unlikely to be replaced by new generations of cottonwoods. Although cottonwood seedlings are readily germinating on the Sacramento River, most cohorts are not surviving to reproductive maturity, for the reasons outlined above. In addition, urban and agricultural conversion of mature cottonwood forests in the Sacramento Basin further reduces seed sources and threatens future prospects for this once-abundant riparian habitat (McBain and Trush 2000, Jones & Stokes 1998, Stillwater Sciences 2002a).

Cottonwood Conceptual Model

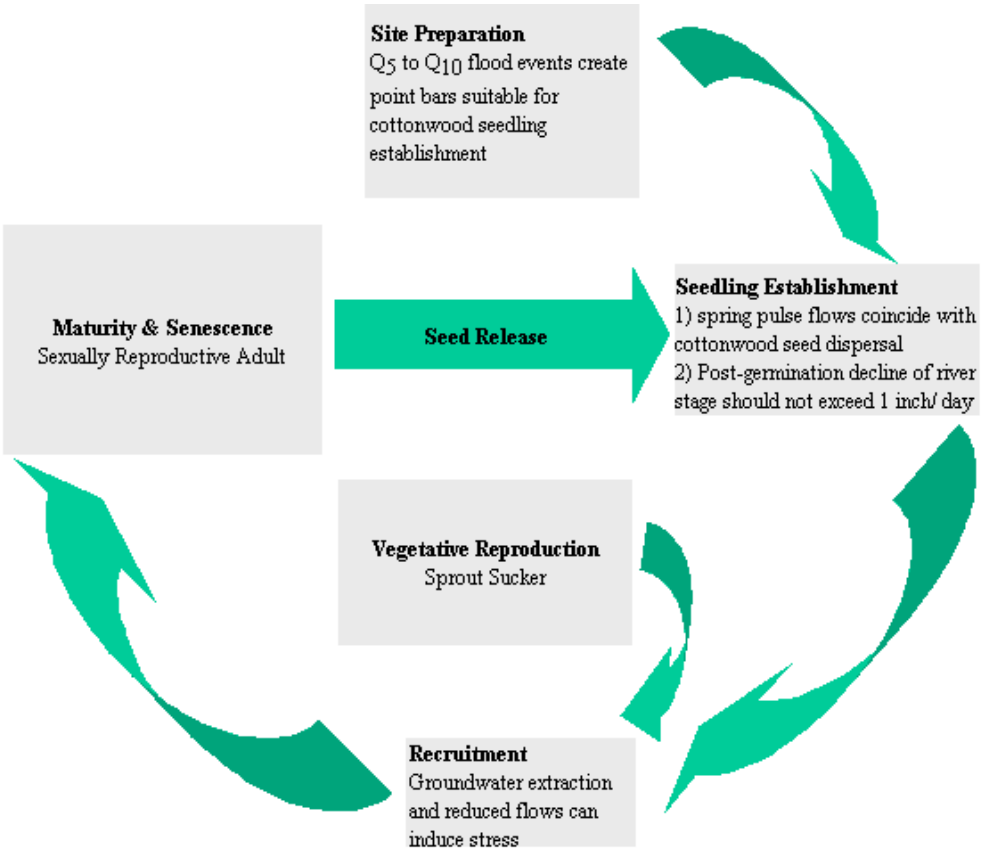

Figure 2. Cottonwood Conceptual Model for Sacramento Basin highlights characteristics of the flow regime that effect different life stages.

Chinook Salmon Conceptual Model

This conceptual model focuses on the flow related factors that affect populations of Chinook in the Sacramento and Feather Rivers. There are many non-flow factors that affect salmon populations, but we have only focused on the flow related factors for the purpose of developing an environmental flow regime. The model addresses flow-related factors for four runs of Chinook salmon and steelhead by life stage.

There are four distinct runs of Chinook salmon in the Sacramento River, the fall-run, the late fall-run, winter-run and spring-run. The different runs of Chinook differ in the timing of their life history. In general each run is named for the time that it begins migrating back to its natal stream. Table 1 shows that each run has the same life stages, but different runs move through the life-cycle at different times of the year and often employ different life stage strategies. For example, fall-run salmon are sometimes referred to as ocean type because they generally migrate to the ocean before their first year, while spring run generally spend a full year in the stream before migrating. Differences in timing and life history strategies mean that different runs can be vulnerable to different stressors. For example, winter run eggs incubate over the summer months and are therefore limited by summer water temperatures, while fall run eggs are much less likely to endure temperature stress since they incubate during the relatively cool winter months. The Chinook Conceptual Model lists the limiting factors that may impact the success of each life stage, the degree to which the limiting factor is relevant may depend on the particular run of Chinook which is being considered.

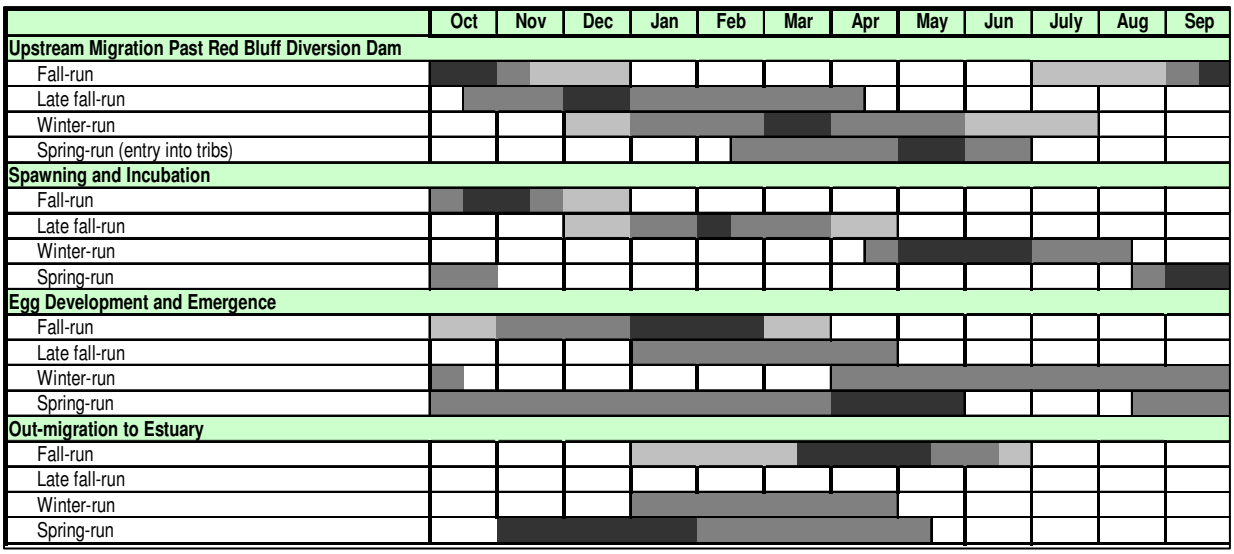

Table 1: Salmon life history table. The timing and duration of the life history stage for each of the salmon runs; These are the periods of time that are most critical to the success of a particular life stage.

	Period of light activity
	Period of acitivity
	Period of peak activity

Table 2: Chinook Salmon (CHS) Thermal Tolerances. All lethal temperature data is presented as incipient upper lethal temperatures (IULT), which is a better indicator of natural conditions because experimental designs use a slower rate of change (1oC/d). (Modified from Moyle 2005, information largely from McCullough 1999.)

	Sub-Optimal	Optimal	Sub-Optimal	Lethal	Notes
Adult Migration	<10°C	10-20°C	20-21°C	21-24°C	Migration usually stops when temps climb above 21ºC. Under most conditions fish observed moving at high temps are probably moving to refugia.
Adult Holding	<10°C	10-16°C	16-21°C	10-20°C	Fish in Butte Creek experience heavy mortality above 21°C but will survive temperatures as high as 23.5°C for short periods of time. In some holding areas fish have been observed in temperatures of 20ºC for over 50 days during the summer.
Adult Spawning	<13°C	13-16°C	16-19°C	10-20°C	Egg viability may be reduced at higher temperatures
Egg Incubation	<19°C	9-13°C	13-17°C	10-20oC	This is the most temperature sensitive phase of life cycle American River CHS experience 100% mortality in temperatures greater than 16.7°C; Sacramento River fall-run CHS mortality exceeded 82% in temperatures greater than 13.9°C
Juvenile Rearing	<13°C	13-20°C	20-24°C	10-20oC	Past exposure (acclimation temperatures) has a large effect on tolerance. Fish with high acclimation temps may survive at 28-29ºC for short periods of time. When food is abundant, fish that live under conditions between 16 and 24ºC may grow very rapidly.
Smoltification	<10°C	10-19°C	19-24°C	10-20oC	Smolts may survive and grow at suboptimal temps but are primarily avoiding predators

Temperature is one of the key factors that can limit salmon population numbers, but different life-stages display widely different temperature tolerances (Table 2). In general, salmon are most vulnerable to temperature stress in the egg life stage and least vulnerable in the juvenile life stage. Winter run are acutely sensitive to temperature, because their eggs are present during the summer months. Thus, different runs are effected differently by temperature stress due to the differences in run timing.

4.2.6 Life in the Ocean

All four runs of Chinook salmon spend approximately 1 to 5 years in the ocean before returning to spawn in their natal stream (Moyle, 2002), though historically, most Chinook salmon returning to the Sacramento River are approximately 4 years old (Clark 1929, in USFWS 1995).

Mortality of salmon in the ocean is based on natural and non-natural factors. Natural stressors include predation by other species, and ocean conditions, such as nutrient flow patterns (CMARP and CALFED Appendix C). The non-natural mortality factor affecting salmon is harvest. From 1967 to 1991, 60-80% of total salmon production was harvested (CMARP).

Changes in river management will do little to decrease natural mortality of salmon in the ocean. This study is not considering restoration of Chinook populations by limiting ocean harvest of salmon at this time. However, it is important to emphasize that large-scale harvesting of salmon in the ocean may be severely limiting salmon populations. If we could manage ocean stocks to increase the number of older fish, it may be possible to increase the ecosystem resilience against drought.

4.2.7 Adult Upstream Migration

Adult salmon migration can be limited by high temperatures and low dissolved oxygen. In the Sacramento River where flows are severely limited, adult salmon migration are delayed or disrupted by low flows and poor water quality. In particular, low levels of dissolved oxygen (DO) during summer and early fall at the Stockton Deep Water Ship Channel and high levels of ammonia from the Stockton wastewater plant in October cause poor water quality to delay adult Chinook migration up the lower San Joaquin, which causes an increase in poaching, lower egg and sperm viability and greater threats to outmigrating juveniles (Hallock et al, 1970 in CMARP). Fish migration does not appear to be limited by existing flow conditions, but reduced flows combined with polluted or warm water agricultural discharges could create problems for migrating fish.

Fall-Run
Adult fall-run Chinook salmon migrate into the Sacramento River and its tributaries from June through December (Yoshiyama, et al. 1998) Migration Peaks in September and October and spawning by mature adults begins shortly thereafter. Cool water releases in the Sacramento and Feather rivers are unnaturally high in late-summer and fall due to hypolimnetic discharge from

Shasta Reservoir (Stillwater, 2006). Increased summer and fall discharge, therefore may improve water quality and temperature conditions for migrating fall-run salmon. High ambient temperatures during late summer and early fall combined with warm or polluted agricultural drain water could become a problem for migrating salmon at lower stream flows (Domagalski, et al.). By mid October, however, water and ambient temperatures are cool enough for migrating salmon (Figure 4).

High water temperatures can prevent upstream migration, and can cause physiological damage and exhaustion (CALFED C-9). Temperatures above 70°F (21.1°C) prevented the upstream migration of adult Chinook salmon from the Delta to the Sacramento River, but the Chinook began migrating into the lower Sacramento as water temperatures fell from 72°F-66°F (22°C-18.9°C) (Hallock 1970 in USFWS, 1995). Temperatures ranging between 50°F and 67°F were found to be suitable for upstream migration of fall-run Chinook (Bell, 1986; Bell, 1973 in USFWS, 1995; and Bell, 1991 in Oroville). Although water temperatures below 38°F are reported to decreases adult survival (Hinze 1959 in USFWS, 1995), temperatures this low are not likely to occur in the Sacramento Basin tributaries.

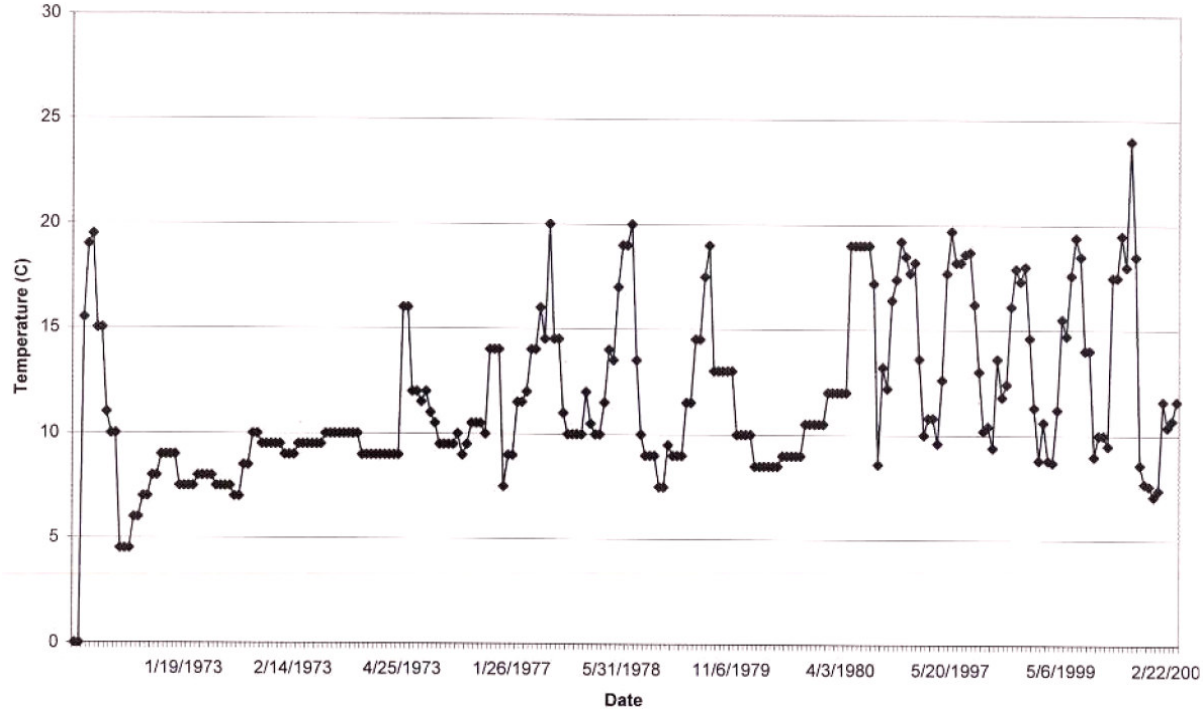

Figure 3: Temperature data collected on the Sacramento River downstream of Wilkins Slough (RM 118) between 1973 and 2000 at the Wilkins Slough gaging station (#11390500). Modified from Figure 4.2-7 in the Sacramento River Ecological Flows Study State of the System Public Review Draft.

A more natural flow regime in the late summer and fall could delay or impede the migration of fall-run salmon. Observations from the San Joaquin Basin where fall flows are lower and warmer suggest that the peak of the fall-run migration would shift to October and November. This may not reduce the overall population of fall-run salmon spawners, but it could create problems for recruitment by delaying emergence until the later spring months. Based on experience from the San Joaquin River (Stillwater, 2003) fall-run that emerge latter may have difficulty migrating out of the Sacramento and Feather Rivers before temperatures begin to rise in the late spring.

Increasing instream flows in the early fall in the Sacramento basin could improve conditions for migrating adult fall-run Chinook by reducing straying, improving water quality, improving passage barriers, decreasing water temperatures and decreasing the delay in migration. If salmon migration is motivated by major storms, early freshets or pulses after the first rain, and most of the large flows from storm events are trapped behind dams, reservoir operators can simulate pulse events by releasing water from the reservoir. However, "There is [a] concern that pulse flow releases in mid October to attract salmon may cause the fish to enter the rivers earlier than normal, which may expose them to high water temperatures when the pulse flows cease." (CMARP). Therefore, if flows are increased during this mid-fall period, it is important to continue to maintain adequate flows for migrating adults and subsequent spawning.

Late-Fall Run

Adult late fall-run Chinook salmon migrate up the Sacramento River between mid-October and mid April, with peak migration occurring in December (Vogel and Marine, 1991). Water temperature and flow conditions within the natural range of variability will be suitable for late fall-run since water temperatures are within optimal levels.

Winter-Run

Adult winter-run Chinook salmon enter San Francisco Bay from November through June (Van Woert 1958, Hallowck et al. 1957 in NMFS 1997). Migration past Red Bluff Diversion Dam begins in mid-December and can continue into early August but the majority of winter run adults migrate past Red Bluff Diversion Dam between January and May with a peak in mid-March (Hallock and Fisher, 1985). Current RBDD operations facilitate upstream passage of winter-run adults by raising gates between September 15 and May 15.

Lower fall and winter flows are unlikely to create temperature adverse to winter-run migration, but lower spring flows could conceivably become a problem in drier years if spring flows are further reduced. Similarly, increased spring flows could be beneficial particularly for the latter part of the migration, but there is no evidence that the current adult migration is stressed by low flows or high temperatures.

Spring-Run

Although spring-run were probably the most abundant run historically in the Sacramento River (Mills and Fischer, 1994), most spring-run fish currently spawn in three tributaries: Deer, Mill, and Butte Creeks. Mainstem habitat was mostly blocked by Shasta Dam, but some spring-run still spawn below the dam, although they have apparently hybridized to some extent with the fall-run (Stillwater, 2006).

Adult spring-run enter the Sacramento-San Joaquin Delta beginning in January, entering their natal spawning streams from March to July (Myers et al. 1998). Adult spring-run migrate upstream to spawn in different tributaries at somewhat different times, suggesting some degree of life-stage flexibility. Butte Creek fish migrate up beginning in February and peaking March and April when flows peak in that stream. Adults from Deer and Mill Creek begin migration in March and peak in May, concluding in June.

Increased spring flows in the Sacramento during the late spring may provide some small benefits for migrating salmon in drier years, but there is no evidence that the adults are currently under stress during their migration. Increased flows in the Sacramento in drier years will not benefit conditions in the tributaries where most spring-run salmon migrate.

4.2.8 Spawning, Egg Incubation, and Emergence

Different runs spawn throughout the year and construct their redds in gravels that are typically 6 inches (15 cm) or less in diameter (Flosi et al., 1998). High water temperatures (greater than 56F) due to low reservoir storage, high air temperatures and low flow releases could decrease available spawning habitat and affect sperm and egg viability. High temperatures cause spawners to concentrate in the upper reaches where water temperatures are lower, which increases the rate of superimpostion of redds (CMARP). “Mature females subjected to prolonged exposure to water temperatures above 60F have poor survival rates and produce less viable eggs” (USFWS, 1995) and water temperatures below 38F also can result in lower egg viability (Hinze 1959 in USFWS, 1995).

In order to provide quality areas of spawning habitat, adequate flows need to be released from dams into the tributaries during the spawning period. Over the long run, periodic high flows are necessary to mobilize gravels and flush-out fine sediments. However, large peak flow events that occur in channels that have been excessively incised and leveed cause excessive gravel mobilization, which can disrupt spawning and cause egg mortality (CMARP). Therefore, these flows should be released during periods when most fry have already emerged from the gravels so they reduce mortality to incubating salmon eggs (McBain and Trush, 2000).

Eggs usually incubate in the gravel for approximately 6 1-64 days before hatching (Healey 1991) and it takes about 70 days for fry to emerge from the gravel (USFWS 1998 in SP Cramer, 2000). This is consistent with EA Engineering’s findings, (1991 in CMARP) which found that eggs incubate for 40-60 days and remain in the gravel for 45-90 days. When fry first emerge from the gravel they are known as alevins and have an attached yolk sac that they depend on for food and nourishment.

The development of eggs into fry appears to be a difficult time for Chinook (Healey, 1991). High water temperatures, fine sediment capping, dewatered redds, poor quality gravel, and low substrate flow may contribute to the high mortality rate during egg and alevin development. High water temperatures (greater than 56F), due to low reservoir storage, high air temperatures and low flow releases (CMARP, Loudermilk 1996) may cause egg mortality and decrease the incubation period when eggs are in the gravel (EA Engineering 1993 in CMARP). The late-fall

and winter period of incubation combined with hypolimnetic discharge from the reservoirs generally maintains adequate water temperatures.

Low substrate flow through spawning gravels is known as an important cause of mortality in egg and alevin development. "Adequate water percolation through the spawning gravel is essential for egg and alevin survival. There is no doubt that percolation is affected by siltation and that siltation in spawning beds can cause high mortality" (Shaw and Maga 1943, Wickett 1954, and Shelton and Pollock 1966 in Healey 1991). Fine sediment capping occurs when redds become covered with fine silt (fines) due to small storm events that transport and deposit fines downstream. Shaw and Maga (1943) observed that siltation resulted in greatest mortality when it affected eggs in their early incubation stage (in Healey, 1991). Although common in steep coastal watersheds, fine sediment capping is relatively rare in the Sacramento basin due to sediment trapping in upstream reservoirs and the general lack of unregulated tributaries upstream of spawning areas.

Dewatering of redds is a known mortality factor effecting development of alevins. (Becker et al., 1982, 1983 in Healey, 1991). Dewatering of redds can be minimized below dams by careful flow regulation. Contaminated groundwater caused by seepage from agricultural or urban areas causes an increase in water temperature and reduces dissolved oxygen within spawning gravel, which may be harmful to incubating salmon eggs (CMARP).

Adequate base flows during the incubation and emergence period combined with periodic flushing flows outside the period should reduce the mortality factor of eggs and alevins. Instream flows, at or above spawning flows, should be maintained throughout the incubation and emergence period to avoid dewatering redds. Siltation and capping from fine sediments could be minimized with small reservoir releases timed to coincide with rainfall induced local run-off. These releases would help convey fine sediments out of the spawning reach.

Fall-Run, Late-Fall, and Spring Run

The mature adults spawn shortly after arriving at their spawning grounds between September and December. In the Sacramento and its tributaries, incubation and alevin development occurs from October through March (CMARP). Flow or temperature conditions are unlikely to be a problem except when Shasta Reservoir levels are drawn down. High water temperatures is probably not an important factor affecting fall, late fall and spring- run Chinook in the Sacramento Basin because incubation occurs between September and April when water temperatures do not rise above 14°C (57.2°F).

Winter-Run

Temperature stress induced by lower flows or lower reservoir levels in the summer, could be a significant problem for winter-run Chinook that incubate during the summer months. Temperatures in the winter-run spawning reach below Keswick Dam are largely controlled by the cold water pool in Shasta Reservoir and the Shasta temperature control device constructed in the 1990's to manage cold water pool releases for the benefit of salmon. Currently, however, summer time flows are unnaturally high. Substantially reducing summer time flows, may result in elevated temperatures to the extent that it substantially increases travel time for cool water releases to reach the downstream end of the spawning reach, resulting in more time for the water

to warm. However, stream temperatures will be controlled by a combination of cold water pool management in the reservoir j(reservoir level) and releases from that cold water pool (instream flows).

It is unclear how much, and at what point reduced flows in summer will increase temperature and how much that will negatively impact winter run. If substantially reducing flows creates negative impacts the endangered winter run irregardless of cold water pool management, then managers will be forced to maintain artificially high summer flows during winter run at incubation at the expense of increasing flows during other parts of the year for other species and other life-stages.

4.2.9 Juvenile Development and Rearing

Growth and rearing of juveniles is crucial to ensure that they grow fast enough to smolt before the onset of high temperature stresses common in the late spring. Smolts are typically >70-80mm and are able to survive in saltwater. Larger juveniles have a better chance of succeeding and surviving to the smoltification phase. "The rate of downstream migration of Chinook fingerlings appears to be both time and size dependent and may also be related to river discharge and the location of the Chinook in the river…Larger Chinook traveled downstream faster, and the rate of migration increased with the season" (Healey 1991). Growth is also important for avoiding other sources of stress and mortality such as lack of food, entrainment, predation, and disease. Larger fish are better able to compete for larger prey and avoid entrainment and predation. Larger juveniles have a competitive advantage over smaller fish in selecting prime positions in rearing areas (Fausch 1984 in Myrick and Cech), which can increase feeding rates (Alanara and Brannas 1997 in Myrick and Cech 2001). Larger fish also have more energy stores to withstand stresses imposed by disease.

There is great uncertainty about the suitability of the Delta for juvenile rearing and growth relative to rearing conditions farther upstream in the spawning reaches. The CALFED Strategic Plan for Ecosystem Restoration identified this question as one of the major uncertainties constraining the restoration planning process in the Bay-Delta watershed. Although Chinook salmon use other estuaries for rearing, most research and previous management actions on salmon in the Delta assume that juveniles suffer very high mortality in the Delta and has thus focused on moving smolt through the Delta as quickly as possible. Moyle (2002) found that "juveniles from other runs apparently do not spend as much time in the estuary, but pass through fairly rapidly on their way to sea. Whether or not this rapid passage is a recent phenomenon as the result of drastic changes in estuarine habitat or is the historical pattern is not clear".

Fry appear to develop and grow in the tributaries, on inundated floodplains and in the Delta at different times until they become smolts and are large enough to migrate to the Ocean. There is strong evidence that juveniles rearing on inundated floodplains in the Yolo Bypass, a lowland transition zone between the spawning reaches and the Delta, had significantly higher growth rates than juveniles reared in the mainstem of the Sacramento River (Sommer et al. 2001). Sommer et al. (in preparation) attributed the higher growth rates to the increased area of suitable habitat, increased temperatures and increased food resources. Sommer et al. (2001) found that drift insects (primarily chironomids) were an order of magnitude more abundant in the Yolo

Bypass than the adjacent Sacramento River channel during 1998 and 1999 flood events. Seasonally inundated floodplains are also relatively free of exotic predators. "In the Central Valley during high flow periods, these fish historically moved into the floodplain, where they could rear for several months." (Moyle, 2002). Today, however, most of the rivers in the Sacramento Basin have been cut off from their floodplains, decreasing the available habitat for juveniles to develop and grow.

Less is known about the value of inundated floodplains relative to the gravel bedded reaches of the tributaries, which produce abundant food resources from macro-invertebrate production. Numerous studies indicate that gravel bedded reaches are more productive than sand and clay bottomed reaches that characterize the lower Sacramento. The increased food resources in the gravel bedded spawning reaches may be somewhat offset by the constant cold water, hypolimnetic releases from the dams, which may dampen growth. Channel incision, degraded riparian vegetation and degraded streambed complexity have been found to reduce the supply of organic detritus that invertebrates depend on for food, which may limit growth and survival of juvenile salmon that depend on invertebrates (Allan 1995 in CMARP). Incised channels in the Sacramento basin have cut off the rivers from their floodplains, which further limit access to food supplies (CMARP). These incised channels combined with high flows can result in fry and juveniles being washed down stream into less productive lowland reaches with high predator populations. Despite lower macroinvertebrate production, warmer water temperatures in the low-lying rivers and in the Delta may result in higher growth rates similar to observations from the Yolo bypass. Healey (1991) found that fry grow more rapidly in the Sacramento-San Joaquin estuary than in the rivers. However, others report that "fry that rear in the upper rivers experience a higher survival to smolting than fry that rear in the delta" (Kjelson et al. 1982, Brown 1986 in Healey, 1991).

Temperature has a major impact on growth. High water temperatures were found to stimulate smoltification and growth (Kreeger and McNeil 1992 in CMARP and SP Cramer, 2000 and Castleberry et al., 1991 in Myrick and Cech, 2001). Myrick and Cech (2001) conducted an extensive review of temperature effects on growth of juvenile Chinook in the Central Valley (Table 3.6). Although they found conflicting results, generally temperatures in the 60-66°F (15-19°C) range lead to high juvenile growth rates. When juveniles are rearing in February and March, temperatures in the tributaries are relatively low, cooler than temperatures needed for optimal growth. SP Cramer (2000) found that "higher water years result in cooler river temperatures [in the spring], which in turn can slow growth rates…However, Cramer et al. (1985) concluded from a variety of growth measurements that warmer temperatures, rather than lower flows, were driving growth of juvenile Chinook" (SP Cramer 2000). Higher growth rates may be a factor of slightly higher temperatures on the floodplains and in the Delta during this early spring period.

Table 3. Effects of temperature on growth of Juvenile Chinook in the Central Valley (Myrick and Cech, 2001 and Moyle, 2002)

Source	**Location**	**Maximum Growth**
Moyle (2002 referencing Marine)		55-64°F (13-18°C)
Rich (1987)	Nimbus State Fish Hatchery on American River	56-60°F (13-15°C)
Marine (1997)	Coleman National Fish Hatchery on Sacramento River	63-68°F (17-20°C)
Cech and Myrick (1999)	Nimbus State Fish Hatchery on American River	66°F (19°C)

Water temperatures greater than 77°F (25°C) were found to be lethal to juveniles in the Central Valley when exposed to these high temperatures for a long period of time, but they could withstand brief periods of high temperatures up to 84.2°F (29°C) (Myrick and Cech, 2001).

Although the mid water trawl surveys at Chipps Island measure smolt outmigration from the Delta (Baker et al. 1995), there are no measurements that identify where these outmigrating fish reared. Without this information it is impossible to estimate the relative importance to the population of fry reared in the Delta and on lower river floodplains compared with fry that rear in the tributaries before outmigrating. It is fairly clear, however, that the majority of juveniles migrate to the lower river and Delta soon after emergence. Therefore, we hypothesize that improving rearing conditions in the lower river and the Delta should increase overall escapement. Present management seems to focus on the quality of rearing habitat in the tributaries, but if the majority of young are moving out of the tributaries, it seems prudent to improve conditions for them as well. In order to understand where to focus limited resources where they will have the most impact on successful rearing, we need better information on the relative success of fish rearing in the lower river and Delta relative to fish rearing in the gravel bedded reaches of the tributaries.

Entrainment in water diversion facilities and predation, particularly from non-native bass, are also a major problem for salmon during the juvenile life stage. "Predators are commonly implicated as the principal agent of mortality among fry and fingerlings of chinook…[and] other fish are generally considered to be the most important predators of juvenile salmon" (Healey, 1991). Entrainment and predation are less related to flow then morality associated with high temperatures during the outmigration period. Juvenile growth rates probably affects mortality from predation and entrainment because smaller juveniles are more susceptible to mortality. Juvenile growth rates may also affect ultimate survival because faster growing juveniles and smolts migrate out of the system earlier in the spring before temperature becomes a major source of mortality and because larger juveniles travel downstream faster (Healey 1991, CMARP).

Contaminated agricultural and urban runoff may also increase outmigrating juvenile salmon's susceptibility to disease, such as *Ceratomyxa*, which causes a high mortality rate in Chinook and flourishes in organic sediments and possibly in mine pits (CMARP p 19 and 20).

We hypothesize that improving juvenile growth rates will improve the rates of successful smolt outmgration and may also reduce mortality from diversions and predation. Based on robust

results from research in the Yolo Bypass, it appears providing seasonally inundated floodplain habitat is perhaps the best way to ensure adequate growth before outmigration to the Delta and Ocean. If nothing else, providing seasonally inundated floodplain habitat will provide better habitat for the young that migrate or are washed out of the gravel bedded reaches early.

Increased flows during the rearing period combined with floodplain restoration should help increase overall growth rates and potentially decrease predation. Increased flows during this period should also dilute poor water quality. Increased flow may also decrease negative effects on salmon from contaminants and disease. Agricultural return flow from the west side of the San Joaquin did not cause any detrimental effects on growth and survival of hatchery-born Chinook salmon when the return flows were diluted by 50% or more with water from the San Joaquin (Saiki et al., 1992, from CMARP p 19).

Fall-Run

Fall-run Chinook usually emerge from the gravel as fry between January and March. Large portions of fry are immediately dispersed downstream to the lower rivers and the Delta, while some fry remain in the tributaries to rear (Kjelson et al. 1982 in Healey 1991, Moyle, 2002, and SP Cramer, 2000). SP Cramer (2000) found that peak migration of fry on the Stanislaus was associated with an increase in daily average flows. Different studies have found that fry and smolts are more abundant in the Sacramento-San Joaquin Delta at different times, depending on how long they remain in the upstream tributaries, before migrating to the ocean. "Most rearing occurs in freshwater habitats in the upper delta area, and the fry do not move into brackish water until they smoltify" (Kjelson et al., 1981, 1982 in Healey, 1991).

Higher flows during January through March d are more likely to result in inundated flood-plain or channel margin habitat ideal for rearing.

Late Fall-Run

Due to their late emergence in April and May, late-fall run are not able to migrate downstream before summer temperatures in the lower river become lethal. Rather most escapement probably results from juveniles that rear and over summer in the upper river. Increasing late spring and early summer may improve conditions for those fish that attempt to migrate out in the late spring and early summer as juveniles. Very large flows, however, would be necessary to create suitable temperature conditions in the lower river.

Winter-Run

Winter-run fry emerge from the spawning gravels from mid-June through mid-October (NMFS 1997). Because winter-run salmon spawning is concentrated upstream in the reaches below Keswick Dam, the entire Sacramento River serves as a nursery area for juvenile winter-run Chinook as they migrate downstream. Downstream movement of juveniles typically begins in August soon after fry emerge from redds. Rotary screw traps at RBDD usually record peaks in the abundance of winter-run salmon fry in September and October. However, following these initial pulses of fry, winter-run juveniles steadily stream past RBDD through March (Kimmerer and Brown, in prep.). Most juvenile winter-run Chinook reach the Delta between January and April, when they pose a conflict with Delta pumping operations designed to increase South of Delta storage during winter months when conflicts with protections for Delta smelt are reduced.

Higher flows during the out migration period for winter run are likely to result in inundated flood-plain or channel margin habitat ideal for rearing. More food will reduce mortality to the extent food is limiting and faster growing fish will have higher survival against gape limited predators or through the smoltification process.

Spring-Run

The rearing and outmigration patterns exhibited by spring-run Chinook salmon are highly variable, with fish rearing anywhere from 3 to 15 months before outmigrating to the ocean (Fisher 1994). Variation in length of juvenile residence may be observed both within and among streams (e.g., Butte versus Mill creeks, USFWS 1995, as cited in Yoshiyama et al. 1998). Some may disperse downstream soon after emergence as fry in March and April, with others smolting after several months of rearing, and still others remaining to oversummer and emigrate as yearlings (USFWS 1995, as cited in Yoshiyama et al. 1998). Scale analysis indicates that most returning adults have emigrated as subyearlings (Myers et al. 1998). Calkins et al. (1940, as cited in Myers
et al. 1998) conducted an analysis of scales of returning adults and estimated that greater than 90% had emigrated as subyearlings, at about 3.5 in (88 mm).

Spring-run that migrate early in their first year could benefit substantially from inundated floodplain habitat and channel margins that higher flows could provide. The excerpt below drafted by Stillwater (2003) clearly explains the phenomena:

> "As stream-type salmon, a fraction of spring-run juveniles may spend a summer rearing in natal streams before emigrating to the ocean. After emergence, spring-run juveniles display agonistic behavior, establishing and defending territories. This behavior means that summer rearing habitat can be quickly saturated, even if escapements are low, because of the area required to support each juvenile. Spring-run that migrate downstream as fry often represent those individuals displaced as a result of rearing habitat saturation in upstream reaches. Because these fry are forced to migrate downstream at a small size < 1.6 m (40 mm), they are vulnerable to predation, such that the fry component may not contribute significantly to future escapements. However, recent research conducted on the Butte Creek population of spring-run salmon suggest that successful rearing by spring-run fry in the Sutter Bypass may be stimulating the recent increase in escapements. Generally, the Deer and Mill creek populations spring-run do not seem to have the same success in fry rearing. To improve fry rearing potential for the Deer and Mill Creek populations, we recommend the creation of a dedicated floodplain/bypass area along the mainstem Sacramento River downstream of Deer and Mill creeks. A bypass in the vicinity of Deer and Mill creeks would provide rearing habitat to fry and juveniles outmigrating to the main stem from these important spawning tributaries for remaining wild-type spring-run Chinook. Such a bypass should be constructed to provide high-quality rearing habitat at relatively low flows, so that the habitat is available for a large portion of every winter, even during drier years.

4.2.10 Smolt Outmigration

As mentioned in the previous section, after fry emerge from the gravel the majority disperse downstream, especially during increases in flows or after storm events. Whether young fish migrate out of the tributaries soon after emergence or whether they rear in the tributaries, they eventually undergo smoltification and make their physiological transition to salt water. Several factors trigger smoltification, including changing hormone concentrations, increasing photoperiod, increasing temperature, and increasing body size (Myrick and Cech, 2001). While most of these factors cannot be influenced by changing management actions in the tributaries or the Delta and are not discussed in this report, temperature and body size are affected by flow and can be influenced by reservoir reoperation.

Smolts require lower temperatures than rearing juveniles. While higher temperatures in the 60-66°F (15-19°C) range can optimize growth of juveniles and better prepare them for smoltification earlier, lower temperatures are more optimal during the smoltification process. A comprehensive study by Myrick and Cech (2001) found that Chinook have a better chance of surviving in the Ocean if they undergo smoltification at lower temperatures, ranging from 50-63.5°F (10-17.5 °C). Warmer temperatures in the February –March period (which occur on floodplains) stimulate growth of juveniles so they are larger before they undergo smolification and therefore larger when they enter the Ocean (Myrick and Cech, 2001). Larger juveniles are also able to smolify before harmful high late spring temperatures set in. Cooler temperatures are necessary in the smolt outmigration period of April – June. The need for warmer temperatures in the early spring and cooler temperatures in late spring reflects the historical hydrograph, where large, cold snowmelt flows dominated the Sacramento Basin later in the spring.

Body size is an important function of the success of outmigrating smolts and the development to smoltification (Dlarke and Shelbourn 1985; Johnssson and Clarke 1988 in Myrick and Cech, 2001). It is important that Chinook reach an appropriate size for smolting before they arrive in saltwater. Relatively warm temperatures can be beneficial for growth provided adequate food supply. Increases inundated floodplain habitat provides the type of habitat that allow juveniles to grow larger before smoltification (Sommer et al, 1991).

High water temperatures, low flows and entrainment may cause increased mortality rates in outmigrating smolts and affect growth of juvenile Chinook. High water temperatures, particularly in May and June may pose the largest threat to juveniles that remain in the tributaries and in the Delta later in the spring. Baker et al (1995) found that 50% of Chinook smolt that migrate through the Delta die when temperatures reach 72-75°F (22-24°C) McCullough (1999 in Moyle) found that few fish can survive temperatures greater than 75.2°F (24°C) even for short periods of time.

Prolonged periods of high flows from January through June, especially from late February through mid-April, will reduce temperatures and help flush out outmigrating juveniles and smolt (CMARP). There are several programs underway and several measures that could be taken to improve juvenile outmigration and survival. Increased flows during outmigration improve juvenile/smolt survival in the Sacramento basin tributaries and Delta. Studies have shown that

survival of fry and smolts passing through the Sacramento-San Joaquin River delta were highly correlated with discharge of the Sacramento River (Healey, 1991 and USFWS, 1998 in SP Cramer). Studies from the Stanislaus River shows that Smolt survival was high (about 78%) when releases from were increased in late April in 1986 and 1988, but were low (28%) when releases were lower in April 1989. A substantial increase in migrating juvenile was measured when flows were increased in the Stanislaus River for seven days in April 1995 (SP Cramer 1995 in CMARP).

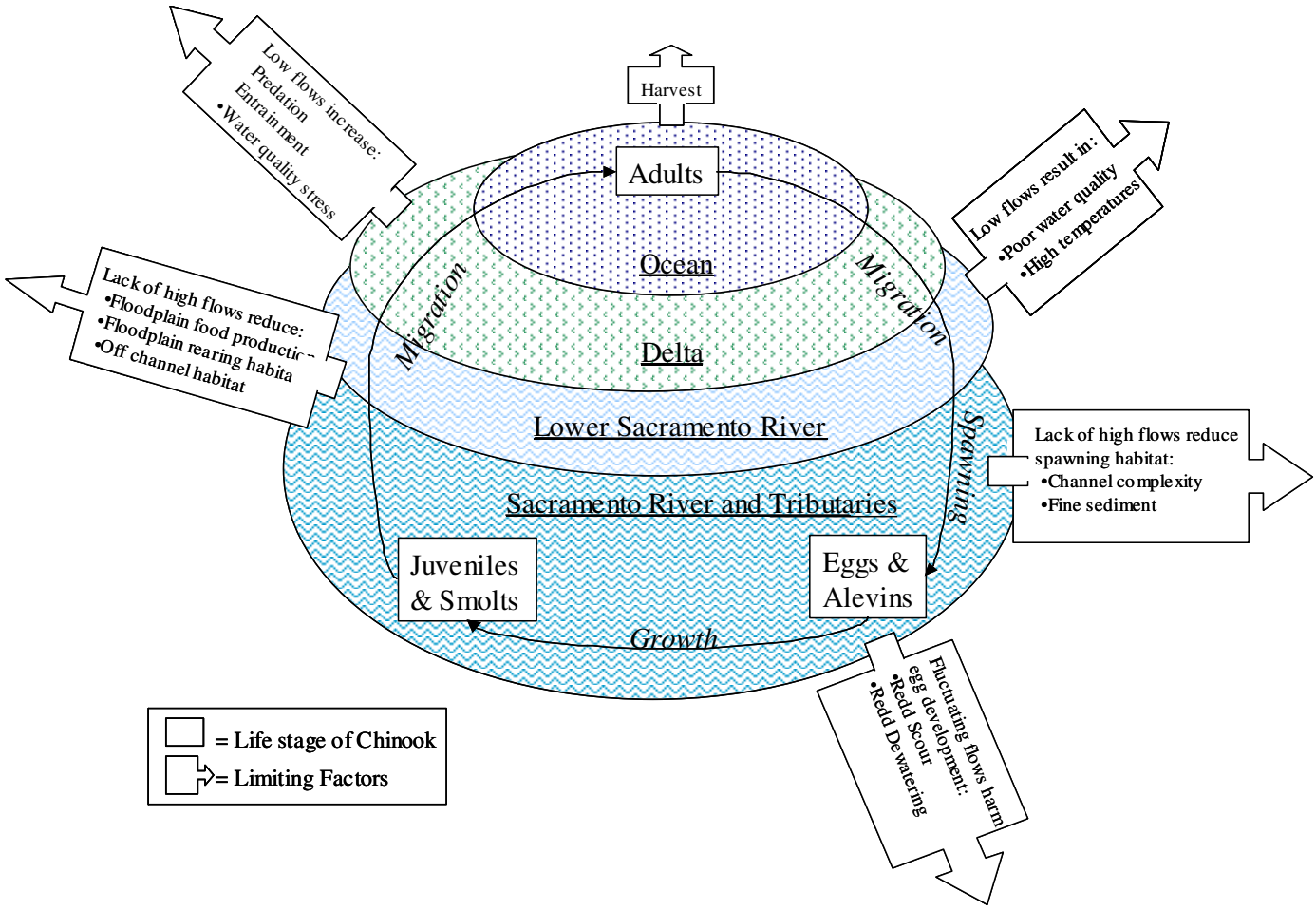

Figure 4: This conceptual model for Chinook salmon illustrates the life cycle of the Chinook in the Sacramento River, factors that increase Chinook mortality during their life cycle, and how restoration can improve the conditions of these fish.

Appendix E
Estimates of Project Costs
Technical Memorandum

DAVIDS
ENGINEERING, INC
Specialists in Ag Water Management

Technical Memorandum

TO: File

FROM: Davids Engineering, Inc.

DATE: October 4, 2011

SUBJECT: Estimation of Sacramento Valley Conjunctive Water Management Program Costs

Background and Objectives

The objective of this effort was to estimate implementation costs for Sacramento Valley Conjunctive Water Management Program. The cost estimates were developed based on an evaluation of capital, operations, maintenance, and mitigation costs associated with program. All costs were estimated in 2010 dollars.

The following pumping scenarios were evaluated:

- 300 TAF Summer Pumping, New Well Field
- 300 TAF Summer Pumping, Existing Well Field
- 150 TAF Summer Pumping, New Well Field
- 150 TAF Summer Pumping, Existing Well Field
- 150 TAF Fall Pumping, New Well Field
- 150 TAF Fall Pumping, Existing Well Field
- 150 TAF Summer and Fall Pumping, New Well Field
- 150 TAF Summer and Fall Pumping, Existing Well Field

This brief technical memorandum describes the estimation of implementation costs.

Summary of Program Implementation Cost Items

Capital, operations and maintenance, and mitigation cost items associated with the Program are summarized in Table 1. For each cost item, the nature of the cost is described, along with the basis upon which the associated cost was estimated.

Global Cost Parameters

The following cost parameters were assumed for the cost estimates:

- Contingency applied to all cost items: 20%
- Engineering and project management as a percentage of up-front capital costs: 12%
- Percent of normal maintenance required for Program wells in non-pumping years: 20%
    - Assumes that maintenance requirements are less in years the Program wells are not operated.
- PG&E energy rate paid for project pumping: $0.22/kWh

Table 1. Capital, O&M, and Mitigation Cost Items Associated with Sacramento Valley Conjunctive Water Management Program.

Cost Category	Cost Item	Item Description	Basis/Comment
Capital	Construct and equip shallow irrigation well	Construct new, typical ~450 foot deep irrigation production well in regional aquifer. Purchase land, electrical line extension, install well pad, pump, electrical motor and controls, discharge piping and connection to open canal, security enclosure.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Construct and equip deep irrigation well	Construct new, typical ~1,400 foot deep irrigation production well in deep aquifer. Purchase land, electrical line extension, install well pad, pump, electrical motor and controls, discharge piping and connection to open canal, security enclosure.	Recent SCF bids to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Rehabilitate existing shallow irrigation well (inspect and reinstall)	Remove existing pump and motor; perform downhole video and qualification assessment; reinstall existing pump and motor; discharge piping and connection to open canal, security enclosure. In some cases, well may require rehabilitation (acid wash) and/or upgrade of electrical. Also, conversion from Diesel to electric and electrical line extension may be required.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Rehabilitate existing shallow irrigation well (inspect and rebuild)	Remove existing pump and motor; perform downhole video and qualification assessment; rebuild existing pump and motor, upgrade electric controls; discharge piping and connection to open canal, security enclosure. In some cases, well may require rehabilitation (acid wash) and/or upgrade of electrical. Also, conversion from Diesel to electric and electrical line extension may be required.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Rehabilitate existing shallow irrigation well (inspect and replace)	Remove existing pump and motor; perform downhole video and qualification assessment; replace existing pump and motor; discharge piping and connection to open canal, security enclosure. In some cases, well may require rehabilitation (acid wash) and/or upgrade of electrical. Also, conversion from Diesel to electric and electrical line extension may be required.	Well driller interview/discussion to estimate unit costs. Estimate quantities based on available well surveys and project pumping requirements.
Capital	Purchase and install SCADA equipment at production or monitoring well site	Furnish and install RTU, sensors, enclosure, radio, antenna, complete, installed.	Estimate unit costs based on data from ITRC. Estimate quantities based on number of project and monitoring wells required.
Capital	Construct dedicated monitoring well	Contruct new, typical 1,200-foot triple completion, dedicated monitoring well	Estimate unit costs based on input from DWR and well driller. Estimate quantites based on required number of project wells.
O&M	Electrical energy costs for project pumping	PG&E energy costs associated with project pumping.	Estimate unit costs based on PG&E rates, estimated lift from GW model and typical flow rates, OPPE from CIT APEP. Estimate quantities from SW model.

Table 1 (Continued). Capital, O&M, and Mitigation Cost Items Associated with Sacramento Valley Conjunctive Water Management Program.

Cost Category	Cost Item	Item Description	Basis/Comment
O&M	Water level monitoring, feedback and realtime management	During and following years of project pumping, conduct water level monitoring, operate and maintain GW model, manage pumping in real time to minimize or avoid impacts, confer with appropriate authorities, prepare periodic reports of project operations.	Estimate staffing requirements and costs for individual tasks during pumping and non-pumping years based on professional judgement.
O&M	Project operations	Operations forecasting and scheduling according to program objectives and operating rules.	Estimate staffing requirements and costs for individual tasks during pumping and non-pumping years based on professional judgement.
Mitigation	Construct domestic well	Replacement of domestic wells with yield impacted by project pumping.	Estimate unit costs based on well driller information. Estimate quantities based on analysis of yield impacted wells using GW model results from 1987 to 2003.
Mitigation	Payments for incremental agricultural pumping costs	Reimbursement for energy costs associated with increased lift caused by interference drawdown from the project.	Estimate unit costs based on PG&E rates, estimated lift from GW model and typical flow rates, OPPE from CIT APEP. Estimate quantities from GW/SW model.
Mitigation	Payments for incremental domestic pumping costs	Reimbursement for energy costs associated with increased lift caused by interference drawdown from the project.	Estimate unit costs based on PG&E rates, estimated lift from GW model and typical flow rates, OPPE from CIT APEP. Estimate quantities from spatially distributed Census data and USGS per capita water use rates.
Mitigation	Administration, outreach, complaint response and dispute resolution, mitigation operations, and legal counsel.	Provide administration of monitoring and mitigation, conduct public outreach regarding observed impacts, handle impacts complaints/disputes. Provide legal support.	Estimate staffing requirements and costs for individual tasks during pumping and non-pumping years based on professional judgement.

Domestic Well Replacement Quantities and Costs

Domestic Well Replacement Quantities

The number of domestic wells requiring replacement was estimated for each pumping scenario based on the analysis of peak drawdown relative to screened interval length for domestic wells in the project area with available screen length data, described elsewhere. The number of wells impacted was scaled up based on the total number of domestic, industrial, public, stock, and other potentially wells in the study area, as reported by DWR. The estimated number of wells requiring replacement is summarized in the table below.

Pumping Scenario	Well Field	Impacted Wells[1] Min	Max	Average
300K Summer	New	63	172	118
	Existing	167	310	238
150K Summer	New	7	29	18
	Existing	99	189	144
150K Fall	New	7	32	19
	Existing	92	196	144
150K Summer and Fall	New	9	27	18
	Existing	69	142	105

1. Estimates of probable range of impacts based on analysis of peak interference drawdown relative to screened interval length for domestic wells in the project area with available screen length data. The number of wells impacted was scaled up based on the total number of domestic, industrial, public, stock, and other potentially impacted wells within the study area.

Unit Cost for Domestic Well Replacement

The unit cost of replacement for domestic wells was estimated to be $18,200, as summarized below. Based on an amortization rate of 3%, the annualized cost per well replaced was estimated to be $1,580.

Cost Item	Capital	Life (yr)	Amort. Rate	Annual Capital
Construction of New Domestic Well	$10,000	30	3%	$ 510
Installation of pump/motor/tank	$2,500	10	3%	$ 293
Abandon Old Domestic Well	$1,500	30	3%	$ 77
SUBTOTAL	$14,000			$880
Engineering and Project Management	$1,400		(10%)	$140
Contingencies	$2,800		(20%)	$560
TOTALS	$18,200			$1,580

NOTE: It is assumed that domestic wells replaced by the program will be maintained at the expense of the well owner.

Total Cost of Domestic Well Replacement

Combining the estimated quantity of domestic wells requiring replacement with the estimated unit cost of well replacement, the total cost of domestic well replacement was calculated and is summarized below.

Pumping Scenario	Well Field	Total Capital Min	Max	Average	Annual Capital Min	Max	Average
300K Summer	New	$1,151,660	$3,137,280	$2,144,470	$99,966	$272,322	$186,144
	Existing	$3,037,999	$5,639,161	$4,338,580	$263,705	$489,491	$376,598
150K Summer	New	$119,137	$536,117	$327,627	$10,341	$46,536	$28,439
	Existing	$1,806,914	$3,435,123	$2,621,018	$156,844	$298,176	$227,510
150K Fall	New	$119,137	$575,830	$347,484	$10,341	$49,983	$30,162
	Existing	$1,667,921	$3,574,116	$2,621,018	$144,779	$310,241	$227,510
150K Summer and Fall	New	$158,850	$496,405	$327,627	$13,788	$43,089	$28,439
	Existing	$1,250,941	$2,581,306	$1,916,123	$108,584	$224,063	$166,323

Project Well Construction and Rehabilitation Costs

Quantity of Project Wells Required

The number of project wells required was estimated based on estimates of the number and distribution of existing production wells in the study area, typical production well capacities in the study area, peak monthly pumping volumes for each pumping scenario, and assumptions regarding downtime for project wells. Estimated well capacities are summarized below.

Average Flow Rate per Well (gpm)[1]

	GCID	WCWD	Richvale
Existing Wells	2800	2400	2400
New Shallow Wells[2]	2800	2400	2400
New Deep Wells[2]	2800	2400	2400

1. GCID and WCWD average flow rates estimated based on average values from well surveys in each district. Richvale ID flow rate assumed to be similar to WCWD.
2. New wells assumed to have flow rates similar to existing wells.

Maximum monthly pumping volumes by scenario, estimated based on the reservoir operations model, are summarized below.

Maximum Monthly Pumping Volume (ac-ft)

Pumping Scenario	GCID	WCWD[3]	Richvale[3]
300K Summer	50,000	12,500	12,500
150K Summer	25,000	6,250	6,250
150K Fall	40,000	10,000	10,000
150K Summer and Fall	15,000	3,750	3,750

3. Equal pumping volumes assumed for WCWD and Richvale ID

The quantities of simultaneously operated project wells required to meet peak pumping requirements for each pumping scenario are summarized below.

Number of Simultaneously Operated Wells Required to Satisfy Project Pumping Requirements[4]

Pumping Scenario	Well Field	GCID	WCWD	Richvale
300K Summer	New	133	39	39
	Existing	133	39	39
150K Summer	New	66	19	19
	Existing	66	19	19
150K Fall	New	106	31	31
	Existing	106	31	31
150K Summer and Fall	New	40	12	12
	Existing	40	12	12

4. Assume pumps will operate every day, 24 hours per day at peak.

Due to periodic maintenance and other unknowns, it is likely that some project wells will be inoperable at times. As a result, the number of additional project wells required to ensure sufficient pumping capacity during peak production was estimated as described below.

Additional Wells Required to Allow for Downtime

Contingency for maintenance/repair of existing wells during peak pumping:	5%
Contingency for strategic shutdown of project wells to avoid yield impacts to domestic wells:	10%
TOTAL CONTINGENCY:	15%

Total Number of Project Wells Required to Satisfy Project Pumping Requirements

Pumping Scenario	Well Field	GCID	WCWD	Richvale
300K Summer	New	153	45	45
	Existing	153	45	45
150K Summer	New	76	22	22
	Existing	76	22	22
150K Fall	New	122	36	36
	Existing	122	36	36
150K Summer and Fall	New	46	13	13
	Existing	46	13	13

Quantity of Additional Production Wells Needed for Existing Well Field Scenarios

Even under the existing well field scenarios, additional production wells are needed to meet peak pumping demands in some areas.

Only a portion of existing wells are likely to enter the program due to lack of grower willingness, well condition, or other issues. As a result, the number of existing wells entering the program will be less than the total number of existing wells.

The estimated number of existing production wells in each area, the number of existing wells expected to enter the program, and the corresponding number of additional production wells required for the existing well field scenarios are summarized on the following page.

Existing Wells Potentially Available to Support Project Pumping

	GCID[5]	WCWD[6]	Richvale[7]
Existing Irrigation Wells	155	131	77

5. Estimated as number of wells listed in GCID well survey.
6. Estimated as number of wells listed in WCWD well survey, multiplied by 50%. It appears some wells listed may be domestic or abandoned.
7. Estimated based on number of wells in WCWD assuming equal number of wells per section.

Existing Wells Ultimately Included in Program

Existing wells not suitable for project due to nonideal location, owner unwillingness, or well unsuitable: 67%

	Existing Wells Entering Program		
Pumping Scenario	GCID	WCWD	Richvale
300K Summer	51	43	25
150K Summer	51	22	22
150K Fall	51	36	25
150K Summer and Fall	46	13	13

Additional New Shallow Irrigation Wells Needed for Existing Well Field Pumping Scenarios

Pumping Scenario	GCID	WCWD	Richvale
300K Summer	102	2	20
150K Summer	25	-	-
150K Fall	71	-	11
150K Summer and Fall	-	-	-

Existing Well Rehabilitation Quantities

Existing wells entering the Program will need inspection and in many cases rehabilitation. Estimates of the quantity of wells entering the program requiring rehabilitation are summarized below for each of the existing well field pumping scenarios.

Number of Existing Wells Requiring Upgrades or Repairs

Proportion of existing wells requiring down hole inspection:	100%	
Proportion of existing wells requiring rehabilitation:	30%	
Proportion of existing wells requiring well seal:	20%	(based on GCID well survey number of wells with no seal)
Proportion of existing wells requiring reinstallation of existing pump and motor:	50%	
Proportion of existing wells requiring rebuild of existing pump and motor:	30%	
Proportion of existing wells requiring replacement of pump and motor:	20%	
Proportion of existing wells requiring Diesel --> Electric conversion:	80%	

	Downhole Inspection			Well Rehabilitation			Construct Well Seal		
Pumping Scenario	GCID	WCWD	Richvale	GCID	WCWD	Richvale	GCID	WCWD	Richvale
300K Summer	51	43	25	15	13	8	10	9	5
150K Summer	51	22	22	15	7	7	10	4	4
150K Fall	51	36	25	15	11	8	10	7	5
150K Summer and Fall	46	13	13	14	4	4	9	3	3

	Reinstall Pump and Motor			Rebuild Pump and Motor			Replace Pump and Motor		
Pumping Scenario	GCID	WCWD	Richvale	GCID	WCWD	Richvale	GCID	WCWD	Richvale
300K Summer	26	22	13	15	13	8	10	9	5
150K Summer	26	11	11	15	7	7	10	4	4
150K Fall	26	18	13	15	11	8	10	7	5
150K Summer and Fall	23	7	7	14	4	4	9	3	3

	Diesel --> Electric Conversion		
Pumping Scenario	GCID	WCWD	Richvale
300K Summer	81	1	16
150K Summer	20	-	-
150K Fall	57	-	8
150K Summer and Fall	-	-	-

Unit Costs for Well Construction, Rehabilitation, Operation, and Maintenance

Unit costs for well construction and rehabilitation were estimated based on discussion with well drillers and based on recent well costs for test wells.

The estimated unit cost for construction, operation, and maintenance of a new deep project well is summarized on Page 9.

The estimated unit cost for construction, operation, and maintenance of a new shallow project well is summarized on Page 10.

The estimated cost for purchase, operation, and maintenance of an existing production well is summarized on Page 11.

It is anticipated that existing Diesel wells would be converted to electrical power upon entering the program. The estimated cost for conversion of existing Diesel wells to electrical drive is summarized on Page 12.

Estimated unit costs for well rehabilitation are summarized on Page 13.

It is anticipated that project wells will be equipped with SCADA to support monitoring of well operation, water level, and pumped volume. Estimated unit costs for SCADA are summarized on Page 14.

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Estimated Cost to Construct, Maintain, and Operate New Irrigation Well (Lower Aquifer)

General Characteristics

Depth:	1200 ft	Estimated Specific Capacity:	50	gpm/ft	Total Dynamic Head:	138	ft
Diameter:	16 in	Estimated OPPE:	65%		Water Horsepower:	87	HP
Discharge:	2500 gpm	Estimated Static Water Level:	80	ft	Input Horsepower:	134	HP
		Estimated Friction Losses and Discharge Head:	8	ft			

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250 per ft	1200	$ 300,000	60	$ 10,840	1%	$ 3,000	
Construct pad, install pump, electrical motor and controls, discharge piping	$ 100,000 ea	1	$ 100,000	30	$ 5,102	3%	$ 3,000	
Connection to distribution system (18" buried PVC)	$ 80 per ft	350	$ 28,000	50	$ 1,088	1%	$ 280	
Land purchase	$ 40,000 per ac	0.25	$ 10,000	100	$ 316		$ -	
Electrical service, 3-phase	$ 105,600 per mi	0.25	$ 26,400	50	$ 1,026		$ -	
Transformer and Power Drop	$ 12,500 ea	1	$ 12,500	30	$ 638		$ -	
Vandalism enclosure	$ 3,800 ea	0	$ -	20	$ -		$ -	(included in scada cost)
SUBTOTALS			$ 476,900		$ 19,010		$ 6,280	
Engineering and Project Management	(12%)		$ 57,228		$ 2,281			
Contingencies	(20%)		$ 95,380		$ 3,802		$ 1,256	
TOTALS			$ 629,508		$ 25,094		$ 7,536	

Operations Cost

Total Dynamic Head:	138	kwh per ac-ft:	217	Pumping energy cost:	$48 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

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Estimated Cost to Construct, Maintain, and Operate New Irrigation Well (Regional Aquifer)

General Characteristics

Depth:	450 ft	Estimated Specific Capacity:	30 gpm/ft	Total Dynamic Head:	171 ft
Diameter:	16 in	Estimated OPPE:	65%	Water Horsepower:	108 HP
Discharge:	2500 gpm	Estimated Static Water Level:	80 ft	Input Horsepower:	166 HP
		Estimated Friction Losses and Discharge Head:	8 ft		

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250 per ft	450	$ 112,500	60	$ 4,065	1%	$ 1,125	
Construct pad, install pump, electrical motor and controls, discharge piping	$ 100,000 ea	1	$ 100,000	30	$ 5,102	3%	$ 3,000	
Connection to distribution system (18" buried PVC)	$ 80 per ft	350	$ 28,000	50	$ 1,088	1%	$ 280	
Land purchase	$ 40,000 per ac	0.25	$ 10,000	100	$ 316		$ -	
Electrical service, 3-phase	$ 105,600 per mi	0.25	$ 26,400	50	$ 1,026		$ -	
Transformer and Power Drop	$ 12,500 ea	1	$ 12,500	30	$ 638		$ -	
Vandalism enclosure	$ 3,800 ea	0	$ -	20	$ -		$ -	(included in SCADA cost)
SUBTOTALS			$ 289,400		$ 12,235		$ 4,405	
Engineering and Project Management	(12%)		$ 34,728		$ 1,468			
Contingencies	(20%)		$ 57,880		$ 2,447		$ 881	
TOTALS			$ 382,008		$ 16,151		$ 5,286	

Operations Cost

Total Dynamic Head:	171	kwh per ac-ft:	270	Pumping energy cost:	$59 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

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Estimated Cost to Purchase, Maintain, and Operate Existing Irrigation well

General Characteristics

Depth:	450 ft	Estimated Specific Capacity:	30	gpm/ft	Total Dynamic Head:	171	ft
Diameter:	16 in	Estimated OPPE:	65%		Water Horsepower:	108	HP
Discharge:	2500 gpm	Estimated Static Water Level:	80	ft	Input Horsepower:	166	HP
		Estimated Friction Losses and Discharge Head:	8	ft			

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250 per ft	450	$ 112,500	60	$ 4,065	1%	$ 1,125	
Construct pad, install pump, electrical motor and controls, discharge piping	$ 100,000 ea	0.5	$ 50,000	30	$ 2,551	3%	$ 1,500	(motor, pad, panels not purchased with wel
Connection to distribution system (18" buried PVC)	$ 80 per ft	350	$ 28,000	50	$ 1,088	1%	$ 280	
Land purchase	$ 40,000 per ac	0.25	$ 10,000	100	$ 316		$ -	
Electrical service, 3-phase	$ 105,600 per mi	0	$ -	50	$ -		$ -	(not purchased with well)
Transformer and Power Drop	$ 12,500 ea	0	$ -	30	$ -		$ -	(not purchased with well)
Vandalism enclosure	$ 3,800 ea	0	$ -	20	$ -		$ -	(included in SCADA cost)
SUBTOTALS			$ 200,500		$ 8,021		$ 2,905	
Engineering and Project Management	(12%)		$ 24,060		$ 962			
Contingencies	(20%)		$ 40,100		$ 1,604		$ 581	
TOTALS			$ 264,660		$ 10,587		$ 3,486	

PURCHASE COST (ASSUME 1/2 COST OF NEW WELL DUE TO WEAR ON COMPONENTS) $ 132,330

Operations Cost

Total Dynamic Head:	171	kwh per ac-ft:	270	Pumping energy cost:	$59 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

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Estimated Cost to Convert Diesel to Electric Irrigation Well

General Characteristics

Depth:	450 ft	Estimated Specific Capacity:	30	gpm/ft	Total Dynamic Head:	171	ft
Diameter:	16 in	Estimated OPPE:	65%		Water Horsepower:	108	HP
Discharge:	2500 gpm	Estimated Static Water Level:	80	ft	Input Horsepower:	166	HP
		Estimated Friction Losses and Discharge Head:	8	ft			

Construction and Maintenance Cost

Discount Rate: 3%

Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Well drilling, testing, and completion	$ 250 per ft	0	$ -	60	$ -	1%	$ -	(included in purchase cost)
Construct pad, install pump, electrical motor and controls, discharge piping **(pad, motor, and controls only)**	$ 100,000 ea	0.5	$ 50,000	30	$ 2,551	3%	$ 1,500	(pad, motor, and controls only)
Connection to distribution system (18" buried PVC)	$ 80 per ft	0	$ -	50	$ -	1%	$ -	(included in purchase cost)
Land purchase	$ 40,000 per ac	0	$ -	100	$ -		$ -	(included in purchase cost)
Electrical service, 3-phase	$ 105,600 per mi	0.25	$ 26,400	50	$ 1,026		$ -	
Transformer and Power Drop	$ 12,500 ea	1	$ 12,500	30	$ 638		$ -	
Vandalism enclosure	$ 3,800 ea	0	$ -	20	$ -		$ -	(included in SCADA cost)
SUBTOTALS			$ 88,900		$ 4,215		$ 1,500	
Engineering and Project Management	(12%)		$ 10,668		$ 506			
Contingencies	(20%)		$ 17,780		$ 843		$ 300	
TOTALS			$ 117,348		$ 5,563		$ 1,800	

Operations Cost

Total Dynamic Head:	171	kwh per ac-ft:	270	Pumping energy cost:	$59 per ac-ft
OPPE:	65%	Electrical rate:	$0.22 per kwh		

Estimated Costs for Rehabilitation of Existing Wells

Discount Rate: 3%

Cost Item	Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.	
Downhole Inspection	$ 3,000 ea	1	$ 3,000	25	$ 120			(includes pump and motor removal)
Well Rehabilitation	$ 5,000 ea	1	$ 5,000	25	$ 200			(rehab screen, acid wash and brush)
Construct Well Seal	$ 5,000 ea	1	$ 5,000	25	$ 200			
Reinstall Pump and Motor	$ 3,000 ea	1	$ 3,000	25	$ 120			
Rebuild Pump and Motor	$ 15,000 ea	1	$ 15,000	25	$ 600			
Replace Pump and Motor	$ 60,000 ea	1	$ 60,000	25	$ 2,400			

These represent upfront costs of bringing existing wells into the program. Cost associated with ongoing well maintenance have been estimated separately for newly constructed wells and will also apply to rehabilitated wells once brought in to program.

Estimated Cost to Equip Production Well with SCADA

Construction and Maintenance Cost

Discount Rate: 3%

Item		Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.
RTU, monitoring only		$ 12,500 ea	1	$ 12,500	15	$ 1,047	10%	$ 1,250
Antenna, mast, and cable		$ 3,000 ea	1	$ 3,000	15	$ 251	10%	$ 300
Vandalism enclosure		$ 3,800 ea	1	$ 3,800	25	$ 218	2%	$ 76
Water level sensor		$ 2,000 ea	1	$ 2,000	15	$ 168	10%	$ 200
Panametrics flow meter		$ 8,100 ea	1	$ 8,100	15	$ 679	10%	$ 810
SUBTOTALS				$ 29,400		$ 2,363		$ 2,636
Engineering and Project Management	(12%)			$ 3,528		$ 284		
Contingencies	(20%)			$ 5,880		$ 473		$ 527
TOTALS				$ 38,808		$ 3,119		$ 3,163

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In addition to production wells, it is anticipated that monitoring wells will be installed as part of the project to support monitoring of water level impacts and mitigation activities. The estimated unit cost for construction and maintenance of a triple-completion monitoring well is summarized on Page 16, along with the estimated unit cost to equip the well with SCADA and to maintain the SCADA system.

Estimated Cost to Construct and Maintain Dedicated Monitoring Well

General Characteristics

Max Depth: 1400 ft
Completions: triple

Construction and Maintenance Cost

Discount Rate: 3%

Item		Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.
Triple completion monitoring well		$ 100,000 ea	1	$ 100,000	50	$ 3,887	1%	$ 1,000
SUBTOTALS				$ 100,000		$ 3,887		$ 1,000
Engineering and Project Management	(12%)			$ 12,000		$ 466		
Contingencies	(20%)			$ 20,000		$ 777		$ 200
TOTALS				$ 132,000		$ 5,130		$ 1,200

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Estimated Cost to Equip Monitoring Well with SCADA

Construction and Maintenance Cost

Discount Rate: 3%

Item		Unit Cost	Qty	Total	Life (yr)	Annual	Maint. %	Ann. Maint.
RTU, monitoring only		$ 12,500 ea	1	$ 12,500	15	$ 1,047	10%	$ 1,250
Antenna, mast, and cable		$ 3,000 ea	1	$ 3,000	15	$ 251	10%	$ 300
Vandalism enclosure		$ 3,800 ea	1	$ 3,800	25	$ 218	2%	$ 76
Water level sensor		$ 2,000 ea	3	$ 6,000	15	$ 503	10%	$ 600
Panametrics flow meter		$ 8,100 ea	0	$ -	15	$ -	10%	$ -
SUBTOTALS				$ 25,300		$ 2,019		$ 2,226
Engineering and Project Management	(12%)			$ 3,036		$ 242		
Contingencies	(20%)			$ 5,060		$ 404		$ 445
TOTALS				$ 33,396		$ 2,665		$ 2,671

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Total Costs for Well Construction, Rehabilitation, and Maintenance

Total capital costs for well construction or purchase for each pumping scenario are summarized below for each pumping scenario.

	300 TAF Summer Pumping, New Well Field					300 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	243	ea	$629,508	$152,970,444	$ 6,097,745	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	123	ea	$382,008	$47,016,781	$ 1,987,795
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	120	ea[1]	$117,378	$14,076,252	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	120	ea	$132,330	$15,869,278	$ 1,269,641
Construct Triple-Completion Monitoring Well[2]	24	ea	$132,000	$ 3,207,600	$ 124,665	24	ea	$132,000	$ 3,207,600	$ 124,665
Equip Production and Monitoring Wells with SCADA	267	ea	$ 38,316	$ 10,241,867	$ 822,612	267	ea	$ 26,450	$ 7,069,978	$ 822,612
TOTALS				$166,419,911	$ 7,045,022				$87,239,889	$ 4,204,712

	150 TAF Summer Pumping, New Well Field					150 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	120	ea	$629,508	$ 75,540,960	$ 3,011,232	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	25	ea	$382,008	$ 9,492,899	$ 401,345
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	95	ea[1]	$117,378	$11,168,555	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	95	ea	$132,330	$12,591,200	$ 1,007,374
Construct Triple-Completion Monitoring Well[2]	12	ea	$132,000	$ 1,584,000	$ 61,563	12	ea	$132,000	$ 1,584,000	$ 61,563
Equip Production and Monitoring Wells with SCADA	132	ea	$ 38,316	$ 5,057,712	$ 406,228	132	ea	$ 22,266	$ 2,939,106	$ 406,228
TOTALS				$ 82,182,672	$ 3,479,023				$37,775,759	$ 1,876,510

	150 TAF Fall Pumping, New Well Field					150 TAF Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	194	ea	$629,508	$122,124,552	$ 4,868,159	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	81	ea	$382,008	$31,110,732	$ 1,315,313
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	113	ea[1]	$117,378	$13,212,113	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	113	ea	$132,330	$14,895,065	$ 1,191,698
Construct Triple-Completion Monitoring Well[2]	19	ea	$132,000	$ 2,560,800	$ 99,527	19	ea	$132,000	$ 2,560,800	$ 99,527
Equip Production and Monitoring Wells with SCADA	213	ea	$ 38,316	$ 8,176,634	$ 656,735	213	ea	$ 25,085	$ 5,353,092	$ 656,735
TOTALS				$132,861,986	$ 5,624,421				$67,131,801	$ 3,263,272

	150 TAF Summer & Fall Pumping, New Well Field					150 TAF Summer & Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Construct and Equip Deep Irrigation Well	72	ea	$629,508	$ 45,324,576	$ 1,806,739	0	ea	$629,508	$ -	$ -
Construct and Equip Shallow Irrigation Well	0	ea	$382,008	$ -	$ -	0	ea	$382,008	$ -	$ -
Rehabilitate Existing Shallow Irrigation Well	0	ea[1]	$117,378	$ -	$ -	72	ea[1]	$117,378	$ 8,451,245	$ -
Purchase Existing Irrigation Well	0	ea	$132,330	$ -	$ -	72	ea	$132,330	$ 9,527,760	$ 762,280
Construct Triple-Completion Monitoring Well[2]	7	ea	$132,000	$ 950,400	$ 36,938	7	ea	$132,000	$ 950,400	$ 36,938
Equip Production and Monitoring Wells with SCADA	79	ea	$ 38,316	$ 3,034,627	$ 243,737	79	ea	$ 20,070	$ 1,589,567	$ 243,737
TOTALS				$ 49,309,603	$ 2,087,414				$20,518,971	$ 1,042,954

1. Quantity and unit costs are calculated by the proportion of wells requiring each rehabilitation activity (well rehabilitation, pump and motor rebuild, etc.).
2. It has been assumed that one monitoring well will be constructed for each 10 project wells, on average.

Annual maintenance costs for project wells, including monitoring wells and SCADA are summarized on Page 19 for each pumping scenario.

	300 TAF Summer Pumping, New Well Field					300 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	243	ea	$ 7,536	$ 1,831,248	$ 1,831,248	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	243	ea	$ 5,286	$ 1,284,498	$ 1,284,498
Monitoring Well Maintenance[3]	24	ea	$ 1,200	$ 29,160	$ 29,160	24	ea	$ 1,200	$ 29,160	$ 29,160
SCADA Maintenance[3]	267	ea	$ 3,119	$ 833,577	$ 833,577	267	ea	$ 3,119	$ 833,577	$ 833,577
TOTALS					$ 2,693,985					$ 2,147,235

	150 TAF Summer Pumping, New Well Field					150 TAF Summer Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	120	ea	$ 7,536	$ 904,320	$ 904,320	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	120	ea	$ 5,286	$ 634,320	$ 634,320
Monitoring Well Maintenance[3]	12	ea	$ 1,200	$ 14,400	$ 14,400	12	ea	$ 1,200	$ 14,400	$ 14,400
SCADA Maintenance[3]	132	ea	$ 3,119	$ 411,643	$ 411,643	132	ea	$ 3,119	$ 411,643	$ 411,643
TOTALS					$ 1,330,363					$ 1,060,363

	150 TAF Fall Pumping, New Well Field					150 TAF Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	194	ea	$ 7,536	$ 1,461,984	$ 1,461,984	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	194	ea	$ 5,286	$ 1,025,484	$ 1,025,484
Monitoring Well Maintenance[3]	19	ea	$ 1,200	$ 23,280	$ 23,280	19	ea	$ 1,200	$ 23,280	$ 23,280
SCADA Maintenance[3]	213	ea	$ 3,119	$ 665,490	$ 665,490	213	ea	$ 3,119	$ 665,490	$ 665,490
TOTALS					$ 2,150,754					$ 1,714,254

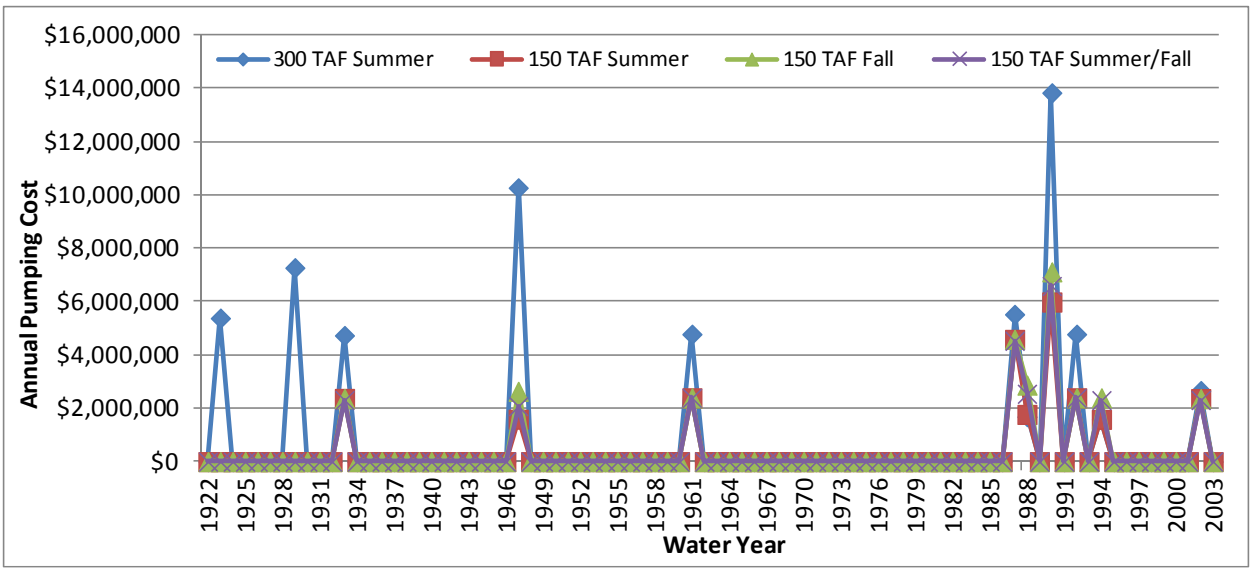
	150 TAF Summer & Fall Pumping, New Well Field					150 TAF Summer & Fall Pumping, Existing Well Field				
	Qty	Unit	Unit Cost	Total Cost	Annualized Cost	Qty	Unit	Unit Cost	Total Cost	Annualized Cost
Deep Well Maintenance[3]	72	ea	$ 7,536	$ 542,592	$ 542,592	0	ea	$ 7,536	$ -	$ -
Shallow Well Maintenance[3]	0	ea	$ 5,286	$ -	$ -	72	ea	$ 5,286	$ 380,592	$ 380,592
Monitoring Well Maintenance[3]	7	ea	$ 1,200	$ 8,640	$ 8,640	7	ea	$ 1,200	$ 8,640	$ 8,640
SCADA Maintenance[3]	79	ea	$ 3,119	$ 246,986	$ 246,986	79	ea	$ 3,119	$ 246,986	$ 246,986
TOTALS					$ 798,218					$ 636,218

3. Maintenance costs represent annual amounts estimated as a percent of initial capital cost.

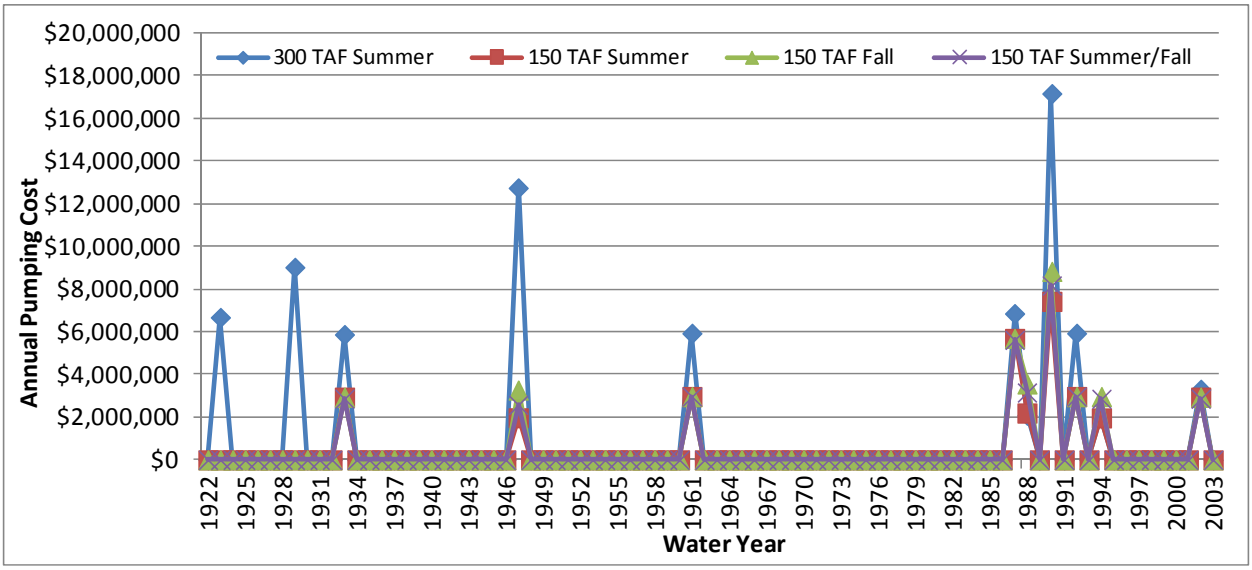
Annual Pumping Costs

Annual pumping costs were calculated based on pumped volumes and estimated cost per acre-foot pumped for shallow and deep production wells. Total pumping costs for the full study period are summarized in the table below. The time series of annual pumping costs for new well field pumping scenarios is shown in the following figure.

Pumping Scenario	Well Field	Pumping Costs	
		Total (full study period)	Average (years with pumping)
300 TAF Summer	New	$ 30,060,829	$ 5,010,138
	Existing	$ 37,321,899	$ 6,220,316
150 TAF Summer	New	$ 18,672,745	$ 3,112,124
	Existing	$ 23,183,070	$ 3,863,845
150 TAF Fall	New	$ 21,708,314	$ 3,618,052
	Existing	$ 26,951,868	$ 4,491,978
150 TAF Summer/Fall	New	$ 20,657,963	$ 3,442,994
	Existing	$ 25,647,809	$ 4,274,635



The time series of annual pumping costs for existing well field pumping scenarios is shown in the following figure.



As indicated, pumping costs tend to be greater for the existing well field scenarios as compared to the new well field scenarios. This is due to the lower aquifer having a greater specific capacity, which results in less pumping drawdown and required lift as compared to pumping from the shallow regional aquifer.

Project Operations Costs

The cost of operating the project was estimated based on the estimated level of effort required to operate the project and estimated salaries and overhead for project operators. Estimated operation costs for years with and without pumping are provided on the following page.

Estimated cost for project operations. Responsibilities include forecasting and scheduling project pumping according to program objectives and operating rules; coordination with USBR, DWR, and other agencies; and overall project management.

Estimated Time Required in Pumping Years

	Summer	Fall	Summer & Fall	
Pumping Duration (months):	6	5	9	(2 months added to account for ramp up/down)
Working Days per Month:	22			
Estimated Time Requirement (hr/day) During Pumping:	2	(25%)		
Estimated Time Requirement (hr/week) During Non-Pumping Period:	2			

	Summer	Fall	Summer & Fall
Total Hours Required per Year:	313	278	452
	15%	14%	22%
Base Salary:	$120,000		
Multiplier:	2.5		

	Summer	Fall	Summer & Fall
Total Cost (Pumping Years):	$ 45,966	$ 40,854	$ 66,401

Estimated Time Required in Non-Pumping Years

Estimated Time Requirement (hr/week) During Non-Pumping Period:	2

	Summer	Fall	Summer & Fall
Total Hours Required per Year:	104	104	104
	5%	5%	5%
Base Salary:	$120,000		
Multiplier:	2.5		

Project Monitoring Costs

Monitoring costs were estimated based on the estimated level of effort required for monitoring of water levels, groundwater modeling, managing pump operation to minimize or avoid impacts, and providing coordination and reporting, along with estimated salaries and overhead for project operators. Estimated monitoring costs for years with and without pumping are provided below.

Estimated cost for water level monitoring, feedback, and real-time program management. Responsibilities include conducting monitoring, operating and maintaining GW model, managing pump operation in real time to minimize or avoid impacts, conferring with appropriate authorities, and preparing periodic reports of project operations.

Estimated Time Required in Pumping Years

	Summer	Fall	Summer & Fall	
Monitoring Duration (months):	12	12	12	(assumes full year of monitoring in any year of operation)
Working Days per Month:	22			

Task	Position	Salary	Multiplier	Hourly	Hours per Week Required: Pumping Period	Hours per Week Required: Non-Pumping Period
Water Level Monitoring	Eng. Tech	$60,000	2.5	$72.12	20	10
Data Quality Control	Eng. Tech	$60,000	2.5	$72.12	10	5
Monitor Pump Operation	Eng. Tech	$60,000	2.5	$72.12	10	0
Analysis of Monitoring Data	Engineer	$90,000	2.5	$108.17	20	4
Real Time Strategic Operation Decisions	Engineer	$90,000	2.5	$108.17	10	0
Confer with Appropriate Authorities	Engineer	$90,000	2.5	$108.17	2	0
Preparation of Monitoring and Operations Reports	Engineer	$90,000	2.5	$108.17	2	2

	Monthly Cost	
Position	Pumping Period	Non-Pumping Period
Engineering Technician	$12,500	$4,688
Engineer	$15,938	$2,813
TOTALS	$28,438	$7,500

	Annual Cost		
Position	Summer	Fall	S & F
Engineering Technician	$150,000	$150,000	$150,000
Engineer	$191,250	$191,250	$191,250
TOTALS	$341,250	$341,250	$341,250

Estimated Time Required in Non-Pumping Years

Task	Position	Salary	Multiplier	Hourly	Hours per Week
Water Level Monitoring	Eng. Tech	$60,000	2.5	$72.12	10
Data Quality Control	Eng. Tech	$60,000	2.5	$72.12	5
Monitor Pump Operation	Eng. Tech	$60,000	2.5	$72.12	0
Analysis of Monitoring Data	Engineer	$90,000	2.5	$108.17	4
Real Time Strategic Operation Decisions	Engineer	$90,000	2.5	$108.17	0
Confer with Appropriate Authorities	Engineer	$90,000	2.5	$108.17	0.5
Preparation of Monitoring and Operations Reports	Engineer	$90,000	2.5	$108.17	1

Position	Annual Cost
Engineering Technician	$56,250
Engineer	$30,938
TOTALS	$87,188

Annual GW Model Update

Task	Consultant Rate ($/hr)	Hours	Total
GW Model Update (incorporate new data, calibrate, operate, report)	$200	160	$32,000

Project Administrative and Legal Costs

Costs for administration of mitigation aspects of the program, including legal costs, were estimated based on the estimated level of effort required in pumping and non-pumping years, combined with estimated salaries and overhead for program administrators and legal staff. Estimated administrative and legal costs are summarized below.

Estimated cost for administration of mitigation aspects of the program. Costs will be incurred in greater amounts in pumping years, but residual effects of pumping will lead to a need for mitigation in non-pumping years as well.

Estimated Time Required in Pumping Years

	Summer	Fall	Summer & Fall
Mitigation Duration (months)	12	12	12

Working Days per Month: 22

Task	Position	Equiv. Salary	Multiplier	Hourly	Hours per Week Required: Pumping Period	Hours per Week Required: Non-Pumping Period
Interface with Monitoring Team; Review Data	Manager	$120,000	2.5	$144.23	2	2
Conduct Outreach Regarding Observed Impacts	Manager	$120,000	2.5	$144.23	2	2
Handle Disputes Over Impacts	Manager	$120,000	2.5	$144.23	4	4
Legal Support	Attorney	$250,000	2.5	$300.48	5	5

Position	Monthly Cost: Pumping Period	Monthly Cost: Non-Pumping Period
Manager	$5,000	$5,000
Attorney	$6,510	$6,510
TOTALS	$11,510	$11,510

Position	Annual Cost: Summer	Annual Cost: Fall	Annual Cost: S & F
Manager	$60,000	$60,000	$60,000
Attorney	$78,125	$78,125	$78,125
TOTALS	$138,125	$138,125	$138,125

Estimated Time Required in Non-Pumping Years

Task	Position	Salary	Multiplier	Hourly	Hours per Week
Interface with Monitoring Team; Review Data	Manager	$120,000	2.5	$144.23	1
Conduct Outreach Regarding Observed Impacts	Manager	$120,000	2.5	$144.23	1
Handle Disputes Over Impacts	Manager	$120,000	2.5	$144.23	1
Legal Support	Attorney	$250,000	2.5	$300.48	1

Position	Annual Cost
Manager	$22,500
Attorney	$15,625
TOTALS	$38,125