APPENDIX B

Pilot Studies

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Acronyms/Abbreviations

gpm	gallon(s) per minute
ppb	part(s) per billion
Reclamation	Bureau of Reclamation
RO	reverse osmosis
Se	selenium
Westlands	Westlands Water District

Field investigations provide a critical source of information for the feasibility design and cost estimation of components that comprise full-scale drainage service. Pilot studies employ smaller-scale equipment in the field to test the actual systems to be designed and constructed. These pilot-scale systems are used to develop performance and cost information under field conditions. Analysis of this information permits extrapolation to the full-scale system and enables reliable designs and costs to be developed for implementation of drainage service.

Reclamation is currently planning, conducting, or monitoring several pilot studies in support of the San Luis Drainage Feature Re-evaluation. The following discussion provides a description of each activity, the data to be generated, next steps to integrate into the overall drainage plan, the potential impact, and the study schedule.

B1 REVERSE OSMOSIS TREATMENT

Uncertainty exists regarding the performance and cost of reverse osmosis (RO) treatment, because it is dependent upon calcium and other dissolved salt concentrations in the reused drainwater that vary across the San Joaquin Valley and requires modeling to predict future levels. The Bureau of Reclamation (Reclamation) is conducting RO pilot studies at two or more locations in the valley to test drainwaters having different concentrations of calcium.

B1.1 Reverse Osmosis Pilot Description

Reclamation is partnering with the Department of Water Resources and Red Rock Ranch, Inc., for a pilot test of RO treatment of reused drainwater in Westlands Water District (Westlands). Typically, the most challenging aspect of the RO pilot test is the development of pretreatment operations that modify certain qualities of the drainwater so that it does not foul the RO membranes. At a minimum, these operations normally include filtration and chemical addition. Once pretreatment requirements are determined and implemented, the drainwater is tested at a rate of about 6 gallons per minute (gpm) in the RO system in a continuous mode of operation for about 1,000 hours. A similar RO pilot test is underway with Panoche Drainage District. These two pilot tests will not employ pretreatment steps that remove calcium from the drainwater. Therefore, they will be operated to achieve only about 50 percent recovery of product water.

Reclamation is also collaborating with WaterTech Partners of Moraga, California, and PCI Membranes, Inc., for a pilot test of a unique pretreatment technology that removes calcium from the drainwater and enables higher recovery of product water from the RO treatment. The pretreatment utilizes tubular nanofiltration membranes to separate and remove calcium from the drainwater prior to RO treatment. Calcium sulfate is added to the drainwater, which acts as a seeding surface for additional precipitation of calcium sulfate within the tubular membranes, resulting in a net reduction of the calcium concentration and potentially higher recovery of desalted product water in the RO system.

B1.2 Reverse Osmosis Pilot Schedule and Results

The RO pilot test at Red Rock Ranch was conducted between May and August 2003. The RO pilot test at Panoche Drainage District was scheduled to run August to October 2004, and August to December 2005. The pilot test of tubular nanofiltration pretreatment will be conducted between September 2004 and March 2006.

The pilot tests provide information to determine pretreatment requirements, including filter media type, filter backwash cycles, and chemical dosage for pH control, coagulation, calcium removal, and antiscalant. RO data collection includes rejection characteristics (i.e., total dissolved solids, calcium, boron, and selenium [Se]), temperature, pressure, pH, flow rate, and conductivity of the incoming drainwater, the wastewater concentrate, and the desalted product water.

B1.3 Reverse Osmosis Pilot Impact to Drainage Plan

The properties of drainwater at Red Rock Ranch and Panoche Drainage District are representative of the expected range of variability across the San Joaquin Valley. Consequently, these two pilot tests should provide sufficient information to determine which drainwaters in the valley are amenable and economical to treat at the 50 percent level of product recovery. Pilot test data will be used to develop feasibility designs and cost estimates for full-scale RO treatment plants.

The information gained from the tubular nanofiltration pilot study will be used to determine whether the benefits of increased product water recovery (75 to 95 percent) exceed the added pretreatment expense for calcium removal. If the pilot study indicates that the calcium removal technology is both technically and economically viable, it will be incorporated into the current drainage plan for RO treatment of drainwater. The overall impact will be a greater recovery of treated drainwater that could be reused for irrigation of commercial crops. Also, a corresponding decrease of drainwater requiring Se treatment and disposal would occur.

B2 SELENIUM TREATMENT

During the past 15 years, numerous researchers have performed field studies of various technologies that remove Se from drainwater in the San Joaquin Valley. These studies provided sufficient information to reliably estimate the cost and performance of biotreatment as described in the Plan Formulation Report (Reclamation 2002).

Recently, however, Reclamation became aware of a new biotreatment technology that was patented and commercialized by Applied Biosciences, Inc., Salt Lake City, Utah. Treatment results at existing plants and from independent evaluations indicate greater Se removal and lower cost than the previously considered treatment technologies. Reclamation has contracted with Applied Biosciences (recently acquired by Zenon Environmental) to conduct a pilot study at Panoche Drainage District to determine the cost and performance of this technology to remove Se from agricultural drainwater. Their report, Pilot-Scale Evaluation of Biotreatment Technology, is included in this appendix as Attachment B-1.

B2.1 Selenium Treatment Pilot Description

The pilot system treats about 3 gpm of reused drainwater within bioreactor tanks that contain media inoculated with bacteria that are cultivated to metabolize Se. The media consists of granular activated carbon, which provides a large surface area for attachment of the bacteria and development of a biological film that reduces the dissolved Se to a solid form that is captured within the biomass. The treatment process is divided into two stages: nitrate reduction occurs in the first stage followed by Se reduction in the second stage. The reducing bacteria are sustained through daily additions of nutrient. Water samples are collected as needed to monitor the changes in nitrate and dissolved Se. Specialized laboratory analyses are used to characterize the Se species within the treated effluent and the biomass where Se is retained. The pilot study monitors many parameters that potentially affect the performance of the bioreactors, including flow rate, residence time within the reactors, drainwater temperature, pH, dissolved oxygen, and nutrient dosage. The Se bioreactor pilot tests are being conducted at Westlands and Panoche Drainage District.

B2.2 Selenium Treatment Pilot Schedule and Results

The Se pilot system began operation in May 2003 and has operated intermittently to the present; the pilot system will continue to operate indefinitely. The initial pilot results from 2003 demonstrated that Se was reduced from about 500 parts per billion (ppb) down to nondetect levels (i.e., 5 to 10 ppb) in the treated effluent. The pilot test has also encountered and identified numerous design and operational deficiencies that have impaired the performance of the bioreactors during the first half of 2004. Se concentrations in the treated effluent during this period have been variable but generally range between 15 and 100 ppb. Scientists and engineers are confident that these deficiencies are correctable and that sustained, stable operation at the initial level of performance will be achieved. Pilot test results during 2004 and 2005 are scheduled to be published in separate reports in May 2006.

B2.3 Selenium Treatment Pilot Impact to Drainage Plan

The pilot results will provide valuable information to assist in the full-scale design of treatment plants for the drainage plan, including the residence time within the bioreactors that is required for nitrate and Se reduction; the decrease in nitrate and dissolved Se concentrations; the composition and species of the reduced Se within the biomass; and the optimum type of bacteria, media, and nutrient additions. Additionally, the pilot results will provide data useful for assessing environmental impacts associated with Se in the drainage service plan.

B3 ENHANCED EVAPORATION

A variety of technologies have been developed whose purpose is to enhance or speed up the rate of natural solar evaporation. For the most part, these technologies consist of different mechanical methods of spraying water into the air, which increases the quantity of water-to-air interface across which evaporation occurs. The primary benefit of enhanced evaporation is the reduction of area required for conventional evaporation basins. The Department of Water Resources is currently conducting a pilot test of a spray technology for enhanced evaporation of drainwater in Westlands. Reclamation is monitoring their progress and evaluating the regulatory requirements for this option and may consider additional pilot tests if warranted. Additionally, Reclamation recently conducted a pilot test of a unique evaporation system that does not utilize sprayers to increase the evaporation rate, the SolarBee® pond circulator.

B3.1 Enhanced Evaporation Pilot Description

Reclamation conducted a pilot test of a SolarBee® pond circulator within storage ponds along the coast of the Salton Sea in Southern California. The SolarBee® utilizes a solar-powered pump to circulate water within a pond. Presumably, the rate of evaporation is enhanced by circulation of pondwater, which permits water heated at depth to rise to the pond surface, where it evaporates more quickly than cooler, stationary surface water.

Two lined test ponds were utilized for the pilot test: the pond circulator was installed in one pond and the other was used as a control pond for natural evaporation. Evaporation rates in both ponds were determined by monitoring the change in water volume and salinity within each. The pilot test evaluated performance on a daily and seasonal basis.

B3.2 Enhanced Evaporation Pilot Schedule and Results

The SolarBee® circulator was operated September–October 2003 and April–May 2004. A preliminary finding is that the circulator performs best in terms of enhancing evaporation during the nighttime when the evaporation increased by about a factor of 1.7. Another finding is that the circulator reduces algae growth by constant circulation and oxygenation of the pondwater. The test results will be evaluated and published as part of the feasibility report, which is scheduled to be completed in August 2006.

B3.3 Enhanced Evaporation Pilot Impact to Drainage Plan

Any increase in the natural evaporation rate would result in a proportional decrease in the aerial size of evaporation basins required for final disposal of drainwater in the San Joaquin Valley. The benefits of smaller evaporation basins (reduced environmental impacts and cost) will be compared to the additional expense of the enhanced evaporation system to determine whether the enhanced systems should be incorporated into the feasibility designs and cost estimates.

B4 BIOACCUMULATION

The objectives of the Se bioaccumulation pilot study were to:

- Set up a pilot-scale Se treatment and evaporation basins system to simulate the processes and conditions expected to occur in the full-scale system proposed by Reclamation.
- Measure Se speciation conditions within the treatment system, in the treatment system effluent, and throughout the evaporation basin system.
- Measure Se bioaccumulation in tissues of water column invertebrates and algae that are typical of saline evaporation basin conditions.
- Provide information on changes in Se speciation and bioavailability as water moved through the treatment system and evaporation basin system.
- Provide information to correlate Se concentrations in tissue of algae and invertebrate that inhabit evaporation basins with Se concentrations in the water column.

B4.1 Bioaccumulation Pilot Description

The effluent of the treatment system (described in Section B2.1) at Panoche Drainage District was allowed to flow into the evaporation basin facility. This facility consisted of three evaporation cells to be operated as an approximation of the full-scale system proposed by

Reclamation. The cells operated in series and the overall system was designed to have zero net discharge under typical evaporation and weather conditions. Proposed depths in each cell varied from approximately 3 to 5 feet, and the water-surface elevation in each cell was controlled by overflow spillways discharging to the next cell. The permanent water-surface elevation in the three cells decreased with each subsequent cell to allow for gravity flow between cells. A schematic of the pilot scale RO process, biotreatment system, and evaporation basin system is shown on Figure B-1.

During normal pilot system operation (after the initial filling phase), pond influent was regulated to provide constant inflow to all cells. The permanent pool in each cell was controlled by the overflow spillway elevations and will remain constant. After all three cells were filled, the required flow rate to the first cell was decreased to an average of 0.5 gpm, based on steady-state conditions. This rate was adjusted as necessary based on actual evaporation rates to maintain the cells at full capacity. Cells fed subsequent cells in an effort to match average evaporation rates. Due to the fact that downstream cells received effluent from upstream cells, the salinity was expected to increase from the first cell to the third cell.

B4.2 Bioaccumulation Pilot Schedule and Results

The approximate project schedule was as follows:

- Cells were prepared, filled, and seeded with invertebrates in November 2004.
- Se speciation and bioaccumulation were monitored between October 2004 and November 2005.
- Pilot study results were analyzed and incorporated into the Final EIS as Attachment B-2.

B4.3 Bioaccumulation Pilot Impact to Drainage Plan

The data from the Se bioaccumulation study will be used to identify appropriate parameters for the assessment of ecological risks due to Se, to calculate mitigation needs, and to assist in the understanding of the Se treatment process.

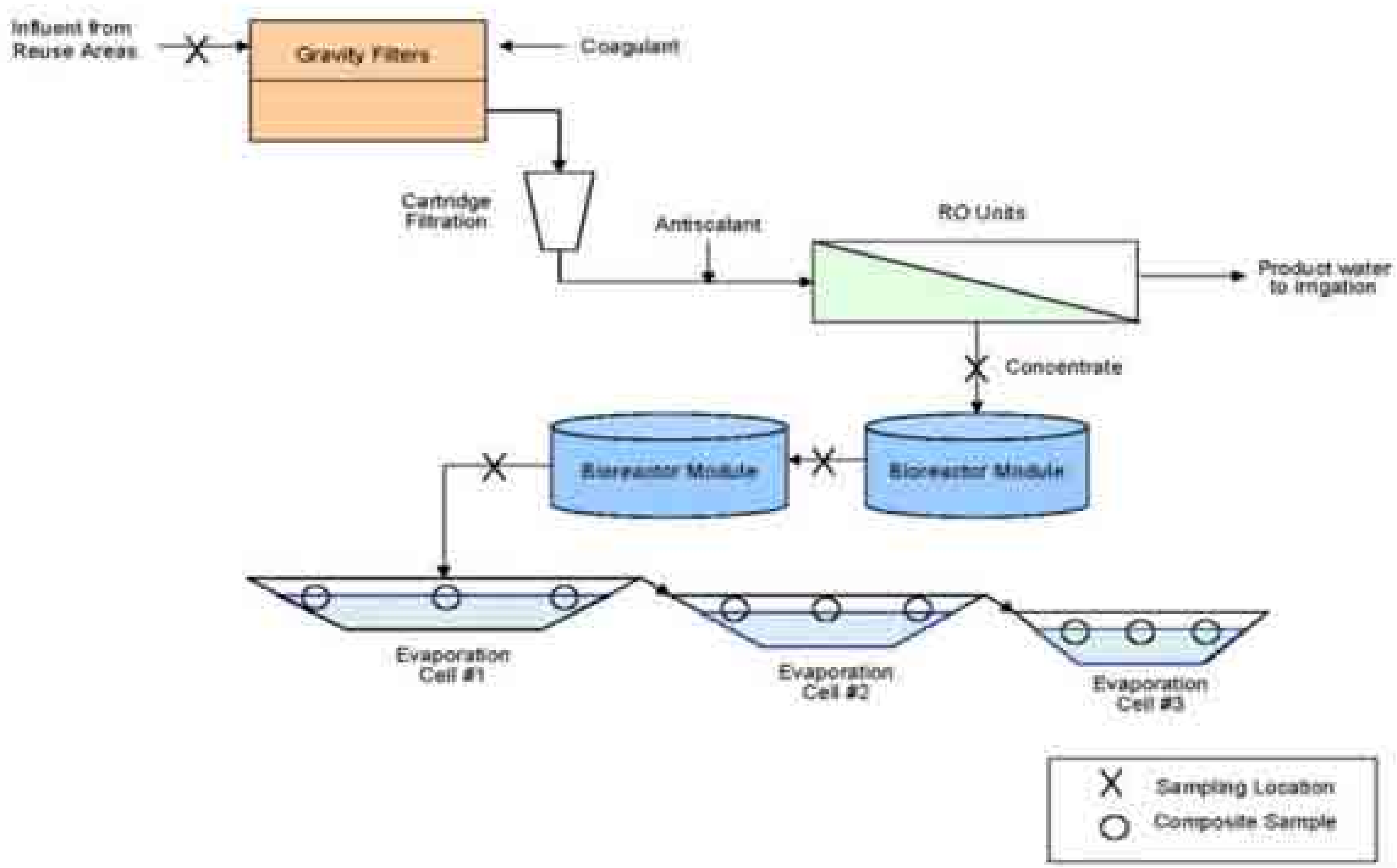


Figure B-1 Pilot Selenium Treatment, Reverse Osmosis, and Evaporation Basin System

B5 REFERENCES

Bureau of Reclamation. 2002. Plan Formulation Report. December.

Reemer, Harry. 2004. Team Leader, Special Technologies, Water Treatment Engineering and Research Group D8230. Bureau of Reclamation, Technical Services Center, Denver, CO. Personal communication with Terry Cooke, URS Oakland, June 2004.

ATTACHMENT B-1

Pilot-Scale Evaluation of Biotreatment Technology

Selenium and Nitrate Removal from Agricultural Drainage at Panoche Drainage District, Firebaugh, California

Pilot-Scale Evaluation of Biotreatment Technology

November 22, 2004

Prepared by:

applied biosciences

Applied Biosciences Corporation
P.O. Box 520518
Salt Lake City, UT 84152
(800) 280-7852
www.applied-biosciences.com

Bureau of Reclamation
Technical Service Center
Water Treatment Engineering and Research Group
P.O. Box 25007
Denver, Colorado 80225

ACRONYMS AND ABBREVIATIONS

DP-25	=	Panoche Drainage District Drainage Point Location Number 25
^{o}F	=	Degrees Fahrenheit
GPM	=	Gallons per Minute
gal/min	=	Gallons per Minute
hr	=	Hour
mg/l	=	milligrams per liter
µg/l	=	micrograms per liter
ND	=	Non-detect
R1	=	Bioreactor # 1
R2	=	Bioreactor # 2
R3	=	Bioreactor # 3
R4	=	Bioreactor # 4
Rctr	=	Reactor
RT	=	Retention Time

Introduction

Panoche Water and Drainage District located in the San Joaquin Valley near Firebaugh, California currently has drainage effluents containing elevated levels of selenium and nitrate. At present the U.S. Bureau of Reclamation is reviewing options for selenium and nitrate removal from these drainage waters.

Applied Biosciences conducted treatability studies on the drainage water which led to pilot scale studies. The studies were funded by the Bureau of Reclamation. After the completion of a successful treatability study, Applied Biosciences initiated a pilot-scale study to test the removal of selenium and nitrate from the District's drainage water. Results from the pilot scale testing will be used in the design and costing of a full scale system. The initial testing commenced on June 9, 2003 and stopped on October 13, 2003. This report serves as a summary of the results and conclusions of the pilot study during this period.

A secondary set of experiments were conducted during the pilot scale tests. The objective was to compare system performance using activated carbon to other microbial support materials. The results of these tests are presented in an appendix attached to this report.

Site Water Characteristics

The reactor influent originates from a well site designated as DP-25. Regular and frequent measurements found that selenium concentrations in DP-25 ranged between 160 µg/L and 1100µg/L and the nitrate concentrations (as NO_3) ranged between 250 mg/L and 420 mg/L, during the pilot study. Several other water quality constituents were measured infrequently in DP-25 and most likely did not cover the range of variation during the study period. The average values of these measurements are presented in Table 1; however, it is not known whether the measured values reflect the average values of these constituents. Standard plate count tests determined that native selenium reducers were not present.

Table 1 – Selected Water Quality Parameters Measured at Well DP-25[1]

Selenium	160 µg/L to 1100 µg/L (Avg. 430 mg/L)
Nitrate (as NO_3)	250 mg/L to 420 mg/L (Avg. 290 mg/L)
Bacteria (plate count)	1.4×10^6 CFU/mL
pH	7.7
Temperature	73 º F
Dissolved oxygen	4.5 mg/L
Reduction potential	-14 mV

[1] Selenium and nitrate concentrations were measured frequently throughout the study; all other constituents show the average value of only a few measurements and do not accurately reflect the actual average values during the test period.

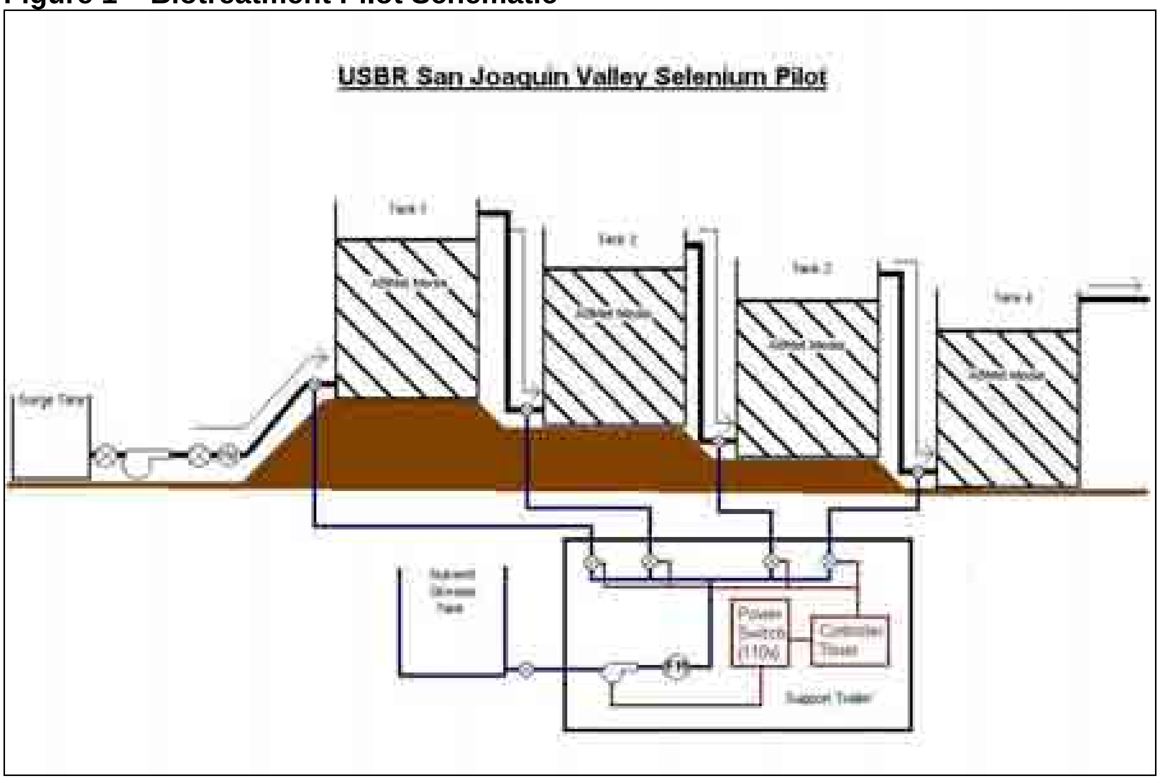
Materials and Method

Bioreactor Configuration

The equipment used in the pilot-scale testing consisted of four bioreactors in series, an automated nutrient delivery system, a surge tank, and a pump (Figure 1). The DP-25 well water flowed to a surge tank stored in a support trailer. A float valve allowed the surge tank to stay full at all times. Water was pumped from the surge tank into the first bioreactor. Flow rate was controlled by a diaphragm valve and flow meter.

The bioreactors consisted of four 1000 gallon tanks with lids fitted with a 1” PVC distribution system and 1/2” nozzles. The third reactor in series contained a second, larger distribution system designed to flush the reduced selenium from the system. A layer of washed gravel was added to each reactor to keep the distribution systems in place. To each reactor, 2750 pounds of granular activated carbon was added as a support material for the microbes. The bioreactor overflow was collected into an outlet header and then gravity fed into the distribution system of the next reactor. The final reactor discharged to a drainage ditch. All four reactors were positioned on an earthen berm to facilitate gravity flow (Figure 2). A nutrient feed line connected directly to the influent of each reactor allowed each reactor to be fed individually by an automated nutrient delivery system. The nutrient delivery system consisted of a 200 gallon nutrient tank, gear pump, flow meter, automated control valves and PLC control panel (pumps and instrumentation in trailer, Figure 3).

Figure 1 – Biotreatment Pilot Schematic



Microbial Inocula

Applied Biosciences arrived on site on June 3 with 300 gallons of selenium culture and 300 gallons of nitrate culture. Applied Biosciences personnel scaled each culture up to 800 gallons to inoculate the four bioreactors. After the reactors were inoculated, the influent flow was adjusted to approximately 0.3 gallons per minute, for a retention time of 19 hours per reactor. This flow rate was maintained to allow sufficient biomass to grow.

Figure 2 - Bioreactors on Earthen Berm

Figure 3 – 200 Gallon Nutrient Tank and Trailer

Sampling and Analysis

All samples were collected by Panoche Water District personnel. Each reactor was sampled three times per week and analyzed for total selenium and nitrate (as NO_3). The DP-25 sump was sampled once per week and analyzed for total selenium, nitrate (as NO_3), iron, magnesium, pH, phosphorus, and total organic carbon. Each sample was preserved in the appropriate acid preservative and stored on ice until pick-up and delivery to BSK Laboratories in Fresno, California.

RESULTS

Nitrate and selenium concentrations for the influent and the effluent for all reactors for the entire pilot study are presented in Table 2. The laboratory detection limit was given as 0.5 mg/L for nitrate and 5 µg/L for selenium. Some concentrations were measured below the detection limit but they are not reliable. Plots of nitrate and selenium concentrations for the influent and reactor effluent are presented in Figures 4 and 5 respectively. The retention time (RT) in the bioreactors was optimized by varying the flow rate of the water to the system. Three different flow rates were tested: one gallon/minute from June 20-July 2, two gallons/minute from July 16-July 30, and three gallons/minute from August 6 to October 17. The retention times for one, two and three gallons per minute were determined to be 6, 3 and 2 hours per reactor respectively. A discussion on bioreactor performance at the three flow rates is discussed in subsequent sections of this report.

Figures 4 and 5 show how a system change can have an impact on bioreactor performance. On August 19, Reactor 1 was taken offline when the earthen berm it rested on became unstable. Table 2 and Figure 4 show that prior to the removal of Reactor 1 on August 19, nitrate reduction to non-detect levels was possible with just the first two reactors (about 4 to 6 hour total retention time). When the system was restarted on August 26, Reactor 2 became the lead reactor, however effluent nitrate concentrations from this reactor spiked to 300 mg/l. Similarly, effluent nitrate concentrations in Reactors 3 and 4 also spiked. Applied Biosciences has speculated that the removal of Reactor 1 may have caused a system imbalance which required a few weeks for the system to reach equilibrium again. By late September, nitrate concentrations are seen to fall in both Reactors 2 and 3.

The impact of removing Reactor 1 on selenium reduction is presented in Figure 5. Prior to the removal of Reactor 1 on August 19, selenium reduction to non-detect levels was possible with two or three reactors (about 6+ hour total retention time). When Reactor 1 is taken offline on August 19, selenium concentration spikes are seen to occur in the effluent of Reactors 2, 3 and 4. By late September selenium concentrations in the reactors decrease as the system moves toward equilibrium. When the pilot was terminated on October 17, the effluent selenium concentration from the final reactor was found to be about 14 to 21 µg/l. Also shown in Figures 4 and 5 is the removal of Reactor 4 on September 19 due to plugging of its internal distribution system. Unlike Reactor 1, the removal of the final reactor in series has no impact on the performance of the bioreactors preceding it. Had Reactor 4 remained operational to the end of the pilot, the effluent selenium concentration from the biotreatment system would have been lower.

Table 2 – Selenium Biotreatment Pilot Data

Flow	Date	DP-25 Influent		Reactor 1		Reactor 2		Reactor 3		Reactor 4	
		Nitrate (mg/L)	Selenium (ug/L)	Nitrate (mg/L)	Selenium (ug/L)	Nitrate (mg/L)	Selenium (ug/L)	Nitrate (mg/L)	Selenium (ug/L)	Nitrate (mg/L)	Selenium (ug/L)
1 GPM (RT = 6 Hr/Reactor)	6/20/03			ND	15	ND	ND	ND	ND	ND	ND
	6/23/03			2		ND	ND	ND		ND	ND
	6/25/03	300	400	27	5.0	ND	ND	ND	ND	ND	ND
	6/27/03			ND	ND	ND	ND	ND	ND	ND	ND
	6/30/03			98	10	ND	ND	ND	ND	ND	ND
	7/2/03	310	480	94	23	ND	24	ND	ND	1.0	ND
2 GPM (RT = 3 Hr/Reactor)	7/16/03	300	480								
	7/21/03			150	170	ND	7.0	ND	4.0	ND	ND
	7/23/03	270	470	120	130	ND	4.0	ND	ND	ND	ND
	7/25/03			120	170	ND	2.0	ND	ND	ND	ND
	7/28/03			67	170	ND	4.0	ND	14	ND	ND
	7/30/03	310	530	100	190	ND	4.0	ND	ND	ND	ND
3 GPM (RT = 2 Hr/Reactor)	8/6/03	280	440	130	210	ND	23	ND	4.0	ND	ND
	8/7/03			96	140	ND	14	ND	ND	ND	ND
	8/8/03			85	170	ND	11	1.0	4.0	ND	ND
	8/11/03			94	240	ND	8.0	ND	7.0	ND	ND
	8/25/03			**Reactor 1 Offline**		1.0	430	2.0	ND	ND	ND
	9/12/03					310	560	110	30	3.0	7.0
	9/15/03					300	730	91	250	ND	45
	9/17/03	280	160			290	760	120	400	2.0	34
	9/19/03					350	760	220	530	120	100
	9/26/03					89	420	11	200	**Reactor 4 Offline**	
	9/29/03					180	470	2.0	100		
	10/1/03	420	1100			200	600	ND	52		
	10/3/03					240	500	ND	44		
	10/6/03					200	460	ND	21		
	10/8/03					180	480	ND	14		
	10/10/03	340	860			130	330	ND	16		
	10/17/03					68	370	1	21		

Notes: ND - Non Detect, GPM - Gallons Per Minute, RT - Retention Time, Nitrate given as (NO_3)

Figure 4 – Nitrate Data for duration 6/20 to 10/17/2003

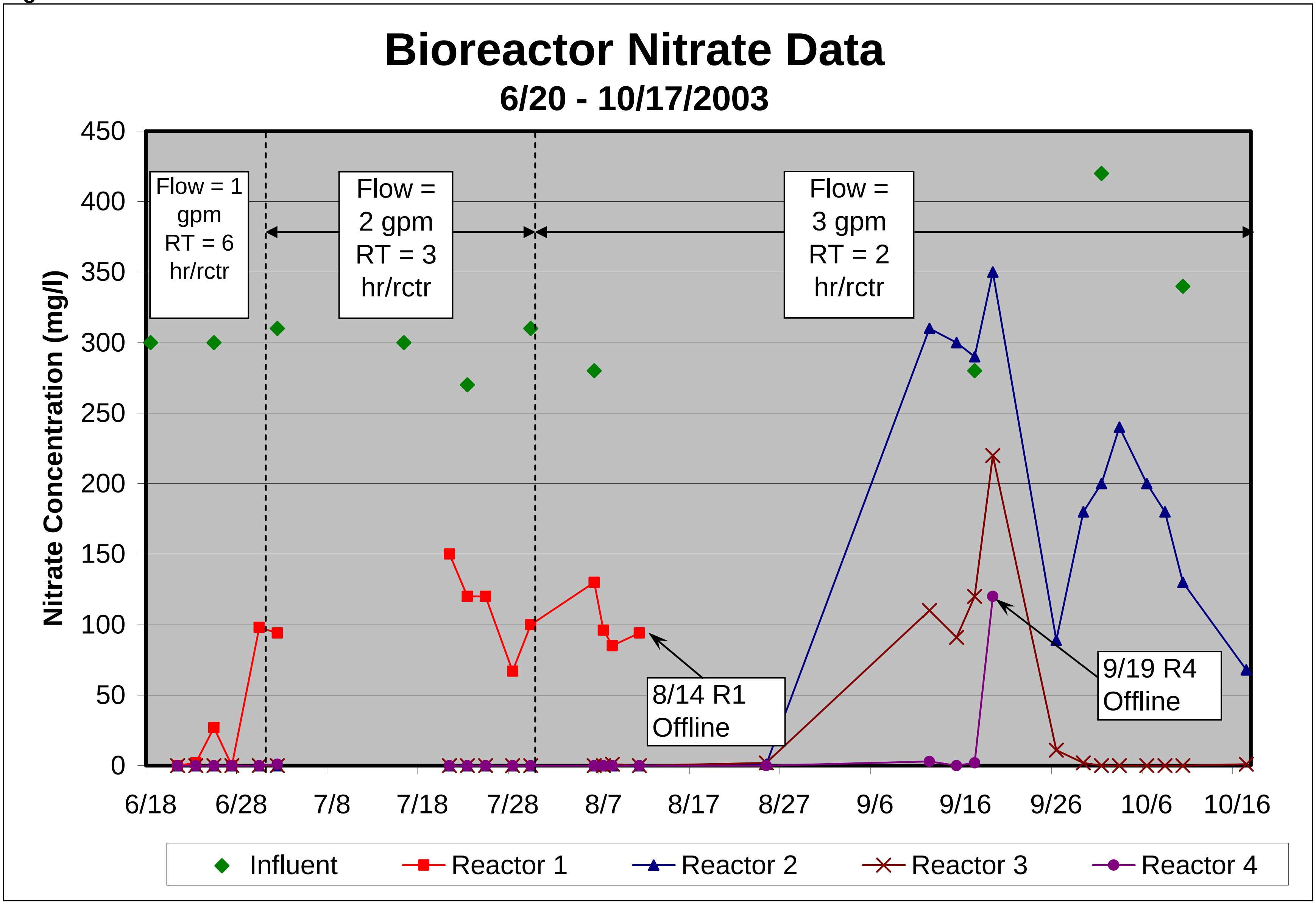
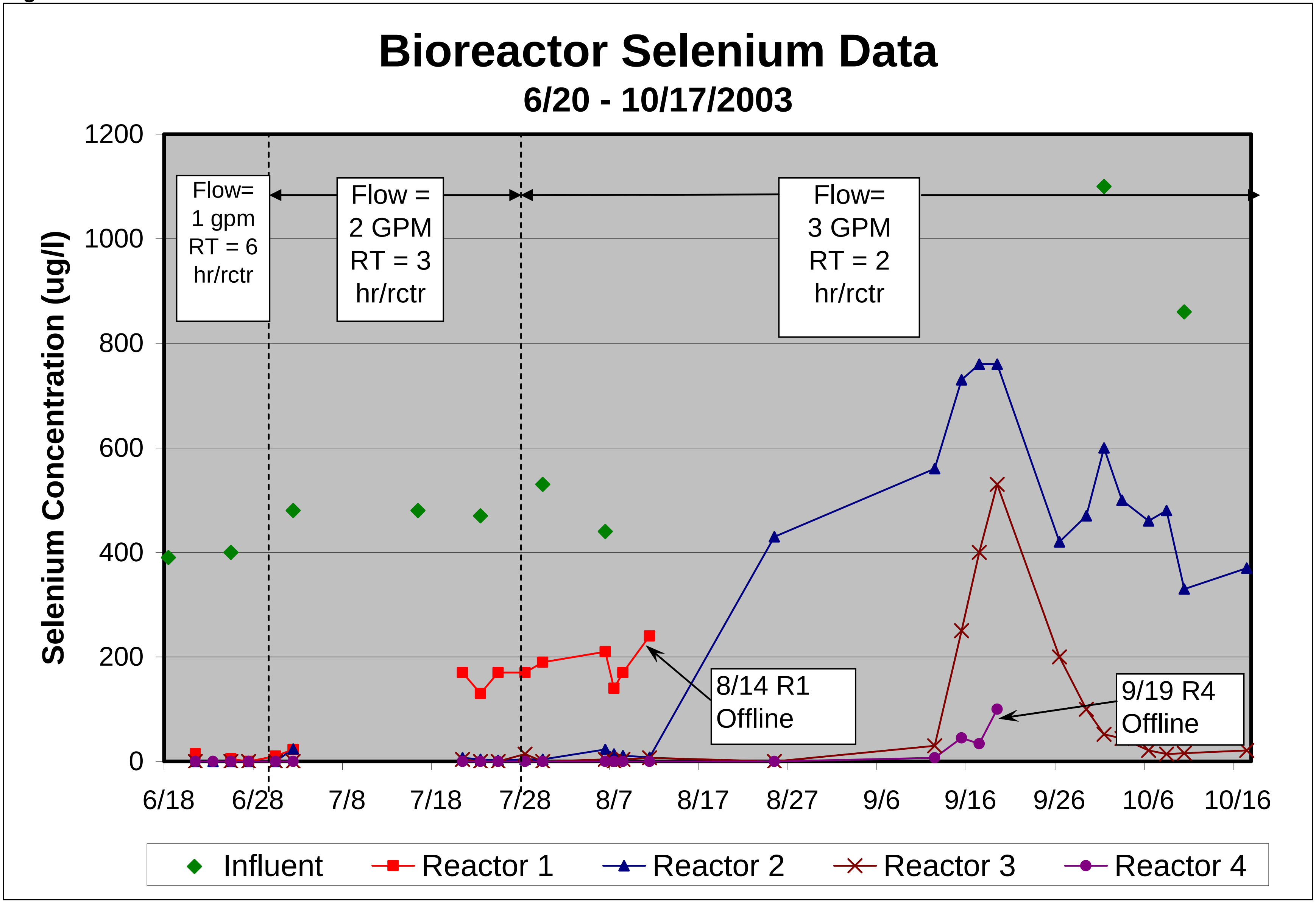


Figure 5 – Selenium Data for duration 6/20 to 10/17/2003



1 Gallon/min Flow rate

The reactors were started at 1 gallon/min flow rate, or 6 hour retention time in each reactor or 24 hours for the 4 reactor system. At this flow rate selenium and nitrate were reduced to levels below detection. In most cases, non-detectable concentrations were achieved by the second reactor at this flow rate. The entire system was fed about 2 gallons of nutrient per day. The bioreactors were operated at this level for about 30 days. Table 3 presents the influent and effluent concentrations of nitrate and selenium for a 1GPM flow rate.

Table 3 - System Effluent at 1GPM

Date Sampled	Reactor #1 Influent Nitrate (mg/L as NO_3)	Reactor #4 Effluent Nitrate (mg/L as NO_3)	Reactor #1 Influent Selenium (µg/L)	Reactor #4 Effluent Selenium (µg/L)
6/18/03	300		390	
6/20/03		Non Detect		Non Detect
6/23/03		Non Detect		Non Detect
6/25/03	300	Non Detect	400	Non Detect
6/27/03		Non Detect		Non Detect
6/30/03		Non Detect		Non Detect
7/2/03	310	1.0	480	Non Detect

Figures 6 and 7 show the nitrate and selenium concentration from each reactor for the one gallon per minute run.

After the first run, the reactors were shut down for repairs due to biomass plugging up the internal distribution system. In an effort to correct this problem, Applied Biosciences personnel enlarged the slots of the outlet headers for improved flow. The reactors were restarted on July 21.

2 Gallon/min Flow Rate

The reactors were restarted at 2 gallon/min flow rate. At this flow rate the retention time per reactor was 3 hours or 12 hours for the system. Nutrient was increased to 3 gallons per day to the system to account for the increased flow rate. The system again showed selenium removal to levels below detection by the third reactor. Results of the 2 gpm run are summarized in Table 4 and Figures 8 and 9.

Table 4 - System Effluent at 2 GPM

Date Sampled	Reactor #1 Influent Nitrate (mg/L as NO_3)	Reactor #4 Effluent Nitrate (mg/L as NO_3)	Reactor # 1 System Influent Selenium (µg/L)	Reactor #4 Effluent Selenium (µg/L)
7/16/03	300		480	
7/21/03		Non Detect		Non Detect
7/23/03	270	Non Detect	470	Non Detect
7/25/03		Non Detect		Non Detect
7/28/03		Non Detect		Non Detect
7/30/03	310	Non Detect	530	Non Detect

Figure 6 – Nitrate Concentration at 1 gallon per minute

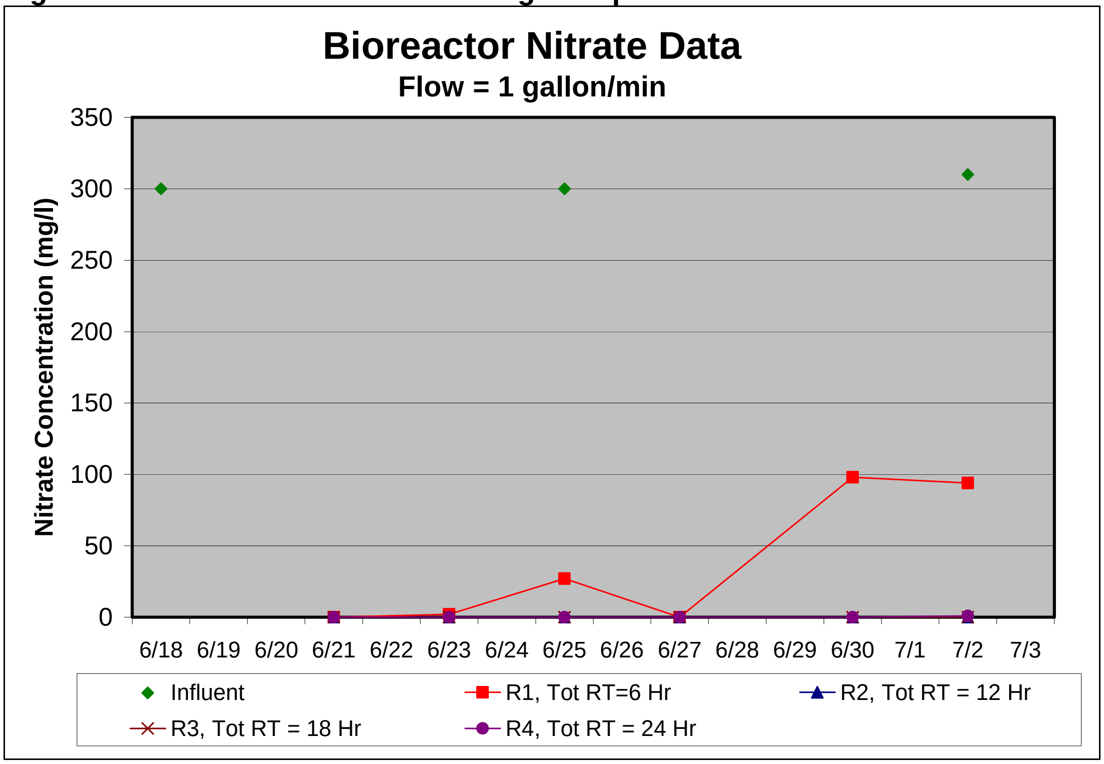


Figure 7 – Selenium Concentration at 1 gallon per minute

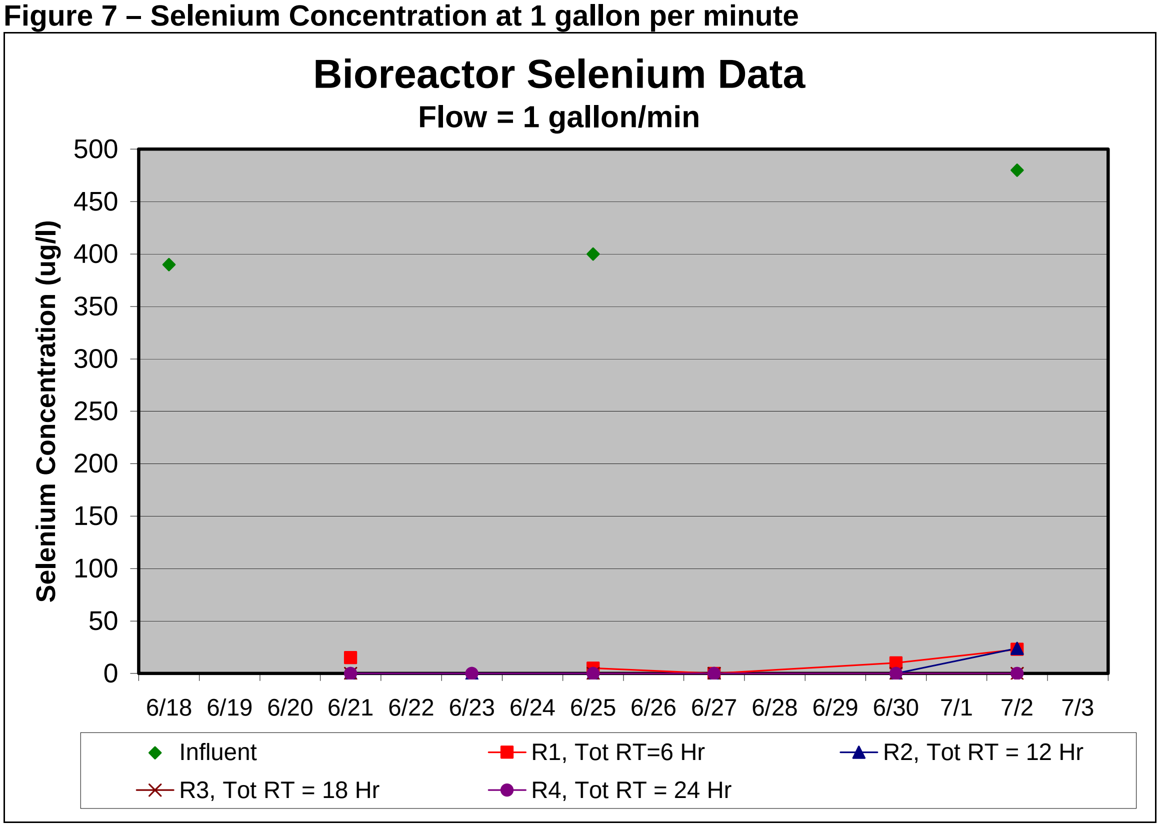


Figure 8 – Nitrate Concentration at 2 gallons per minute

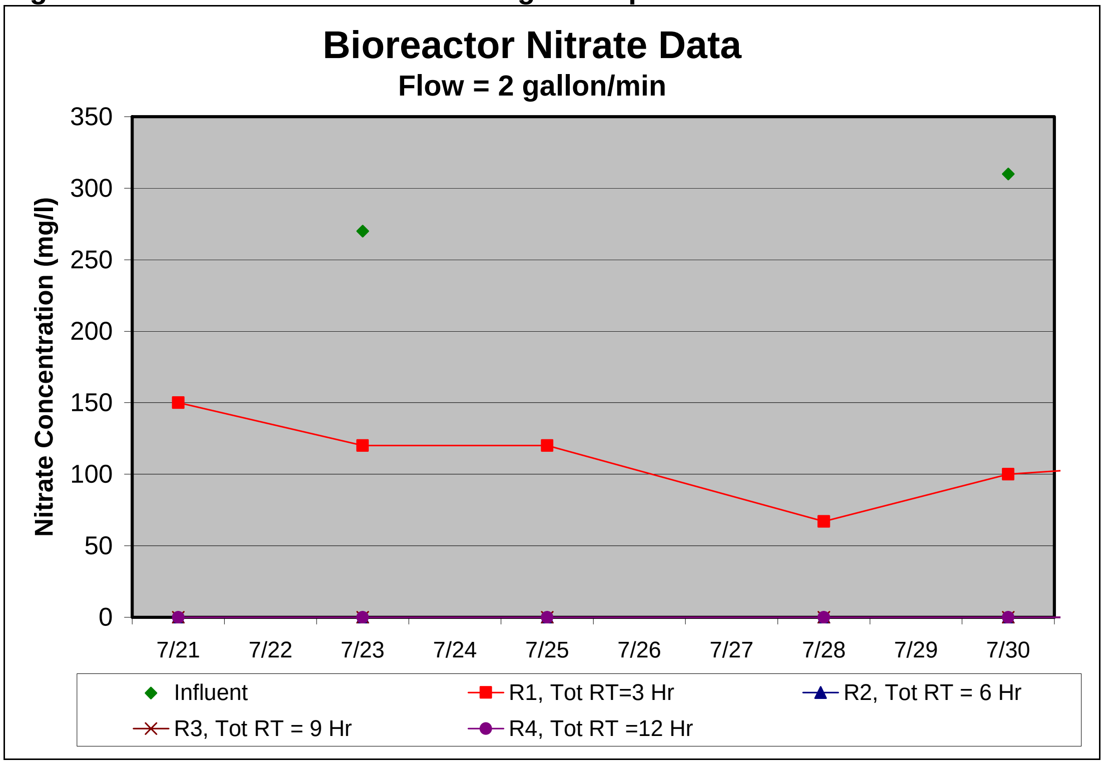
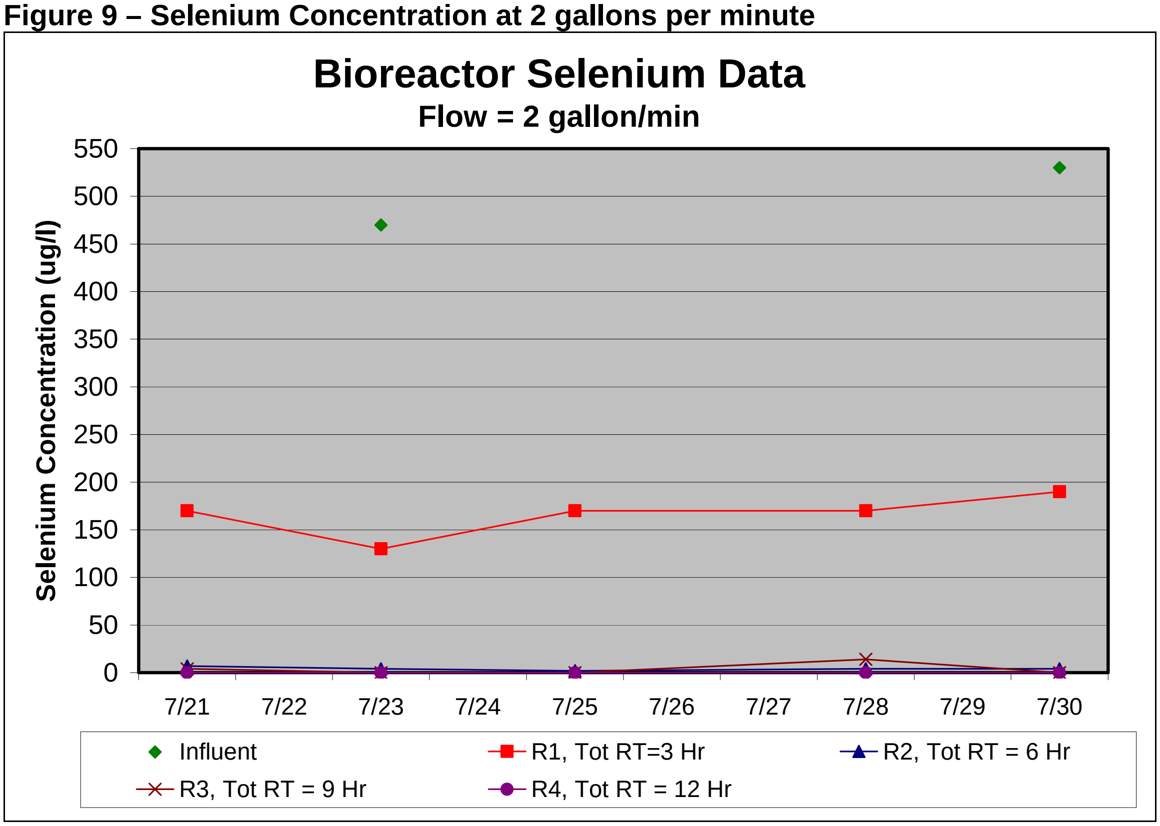


Figure 9 – Selenium Concentration at 2 gallons per minute



3 Gallon/min Flow Rate

On August 6, the reactors were started at 3 gallons per minute. At this flow rate the retention time was 2 hours per reactor or 8 hours for the entire system. Nutrient supplied to the system was adjusted to three feeding cycles per day at 1 gallon per feeding cycle. Results of the 3 gpm run are summarized in Table 5 and Figures 10 and 11.

Table 5 - System Effluent at 3 GPM

Date Sampled	Reactor # 1 Influent Nitrate (mg/L as NO_3)	Reactor #4 Effluent Nitrate (mg/L as NO_3)	Reactor #1 Influent Selenium (µg/L)	Reactor #4 Effluent Selenium (µg/L)
8/6/03	280	Non Detect	440	Non Detect
8/7/03		Non Detect		Non Detect
8/8/03		Non Detect		Non Detect
8/11/03		Non Detect		Non Detect
8/25/03		Non Detect		Non Detect

On August 14th all the reactors were shut down due to plugging problems. On August 19th Applied Biosciences personnel returned to the site to modify the system by adding a weir and sump pump at the top of each reactor for the purpose of forcing water into the next reactor in the series. Additionally, the first reactor in the series was drained and disconnected from the system because the reactor was starting to lean to one side due to erosion of the earthen berm.

The reactors were restarted on August 24. The modifications helped alleviate the plugging problems for about three weeks. On September 19 reactor 4 was shut down due to additional plugging problems. Figures 12 and 13 show the performance of the reactors for the period September 12 to the end of the pilot on October 17.

Around this same time the results of the DP-25 influent samples showed an increase in selenium values from 434 µg/L to levels as high as 1100 µg/L. Despite the increase in the selenium, the reactors were still able to remove 98% of the selenium in 4 hours retention time (see Figure 13).

Figure 10 – Nitrate Concentration at 3 gallons per minute

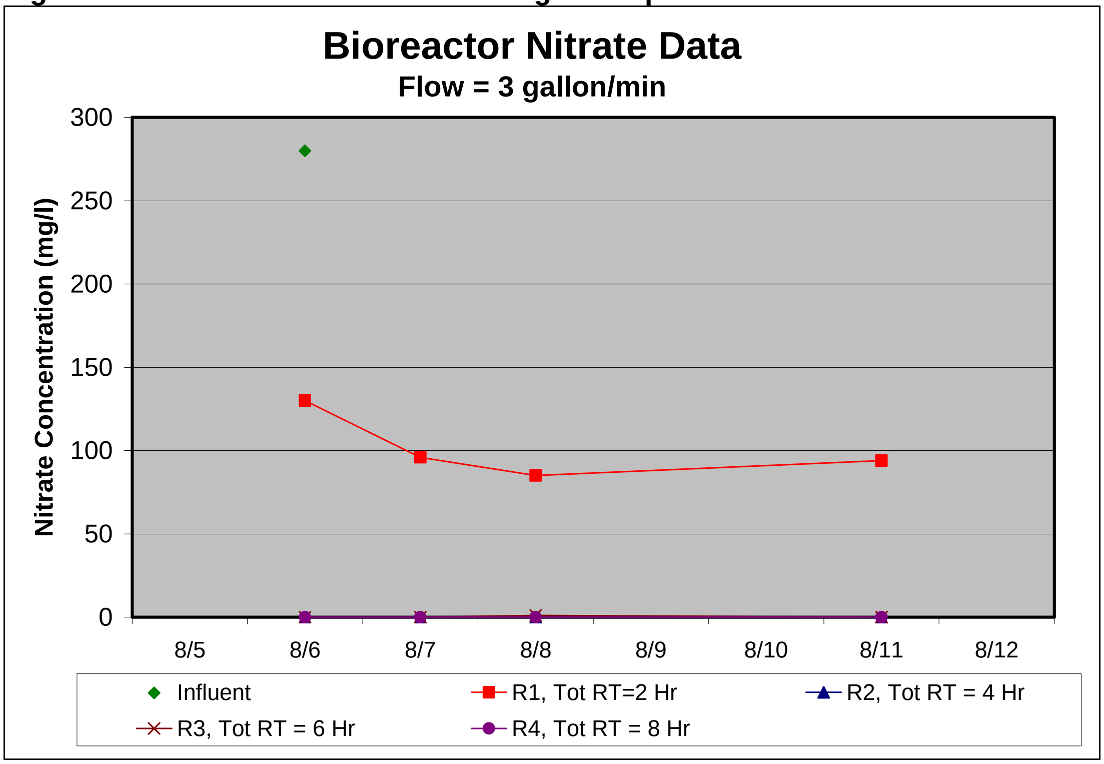


Figure 11 – Selenium Concentration at 3 gallons per minute

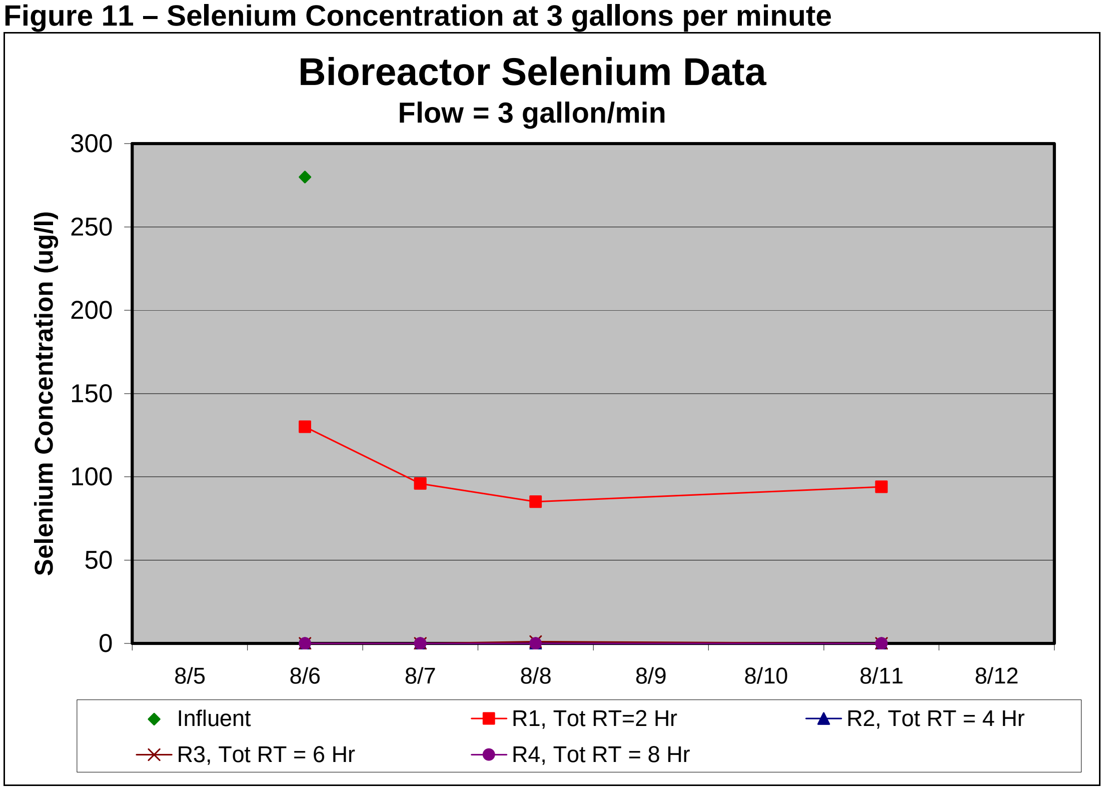


Figure 12 – Nitrate Concentration for 9/12 – 10/17/2003, Flow = 3 gallons per minute

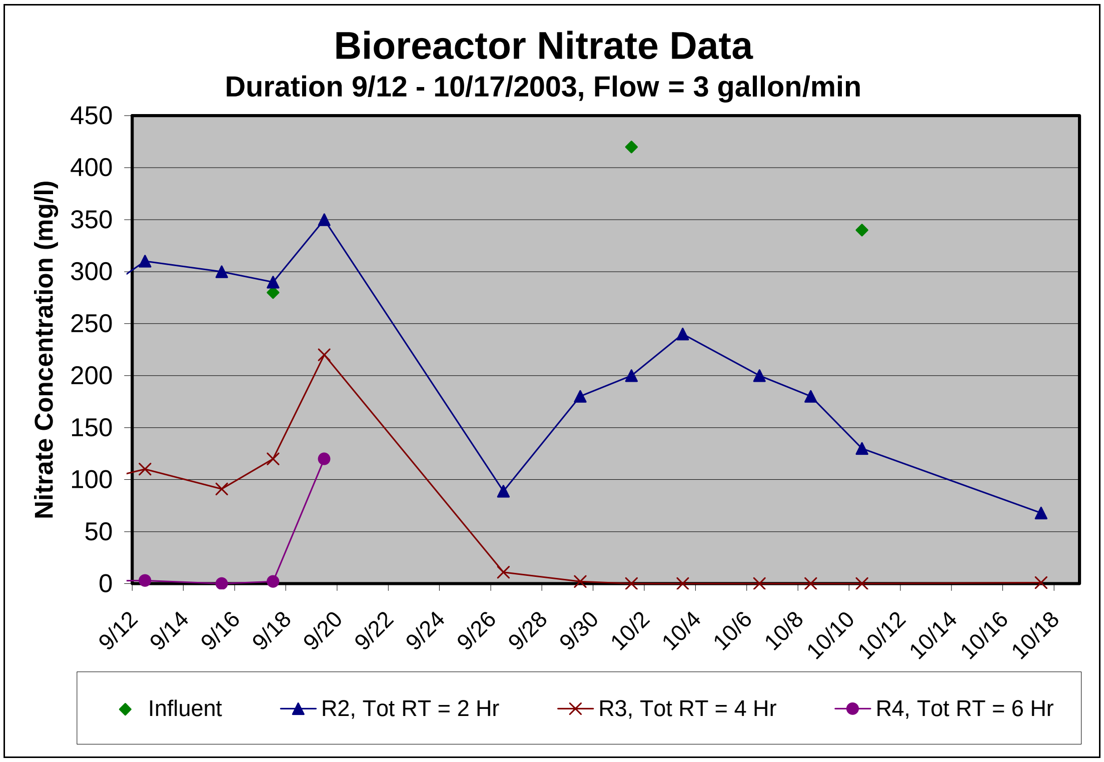
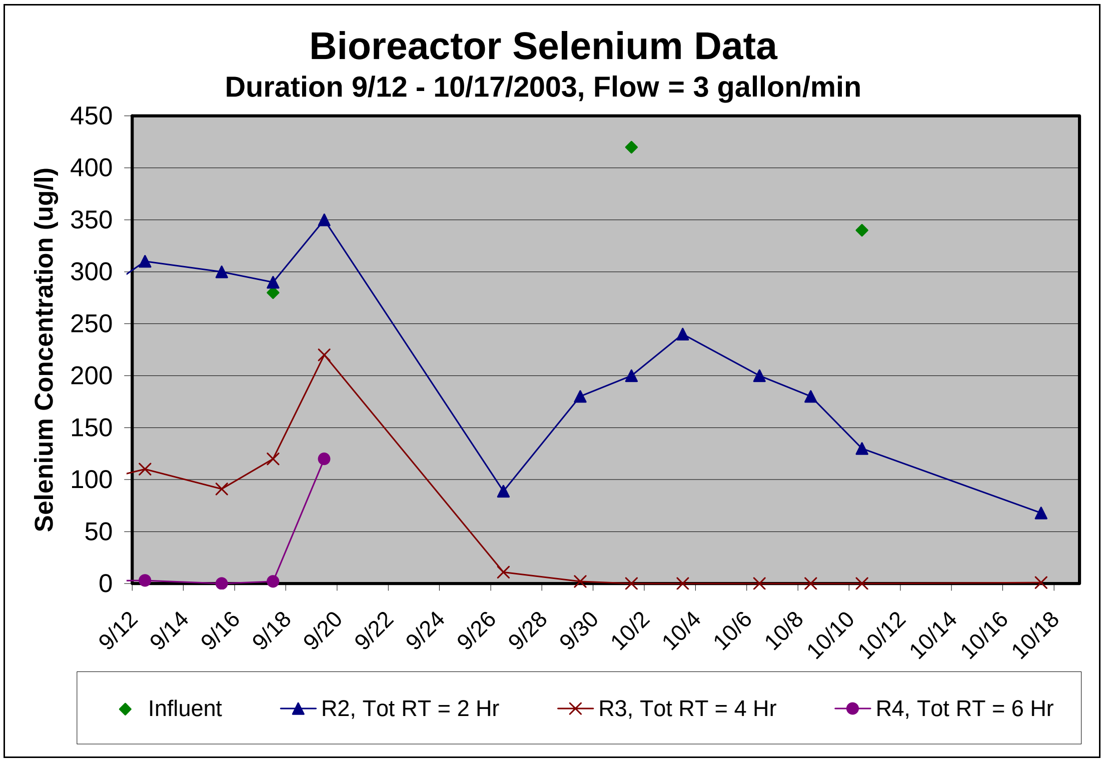


Figure 13 – Selenium Concentration for 9/12 – 10/17/2003, Flow = 3 gallons per minute



ORGANIC AND INORGANIC ANALYSIS OF SELENIUM

On August 21, two samples each of the feedwater and effluent from bioreactors 2, 3, and 4 were collected and sent to Frontier Geosciences Inc. of Seattle, WA for analysis of organic and inorganic selenium. The results of the sampling and analysis are given in Table 6.

Table 6 – Organic and Inorganic Selenium Analysis

Sample Location	Total Se (ug/l)	Inorganic Se (ug/l)	Organic Se (ug/l)
Feed	469	457	12.0
Feed	478	473	5.0
Reactor 2	6.83	4.33	2.5
Reactor 2	7.05	4.55	2.5
Reactor 3	1.61	1.16	0.45
Reactor 3	1.54	1.24	0.30
Reactor 4	0.932	0.405	0.527
Reactor 4	0.839	0.372	0.467

IMPACT OF RESIDENCE TIME ON BIOREACTOR PERFORMANCE

One of the primary factors influencing bioreactor performance is residence time. Figure 14 gives a plot of effluent nitrate concentration versus residence time. The plot was generated using data from all active nitrate reducing reactors (see Table 7). The period of record for the plot was June 20 to August 11, prior to Reactor 1 being taken offline. Nitrate readings collected after the decommissioning of Reactor 1 was not deemed applicable due to the disruption of equilibrium in the bioreactor system. Data points were obtained for total residence times of 12 hours, 8 hours, 6 hours, 4 hours, 3 hours and 2 hours. Influent nitrate concentrations were assigned a residence time of 0 hours. A best fit curve was drawn through the data points as shown in Figure 14. Several high nitrate values were found at the 6 hour retention time, however these points were deemed anomalous since the majority of the readings at this retention time were recorded as non-detect. The plot clearly shows that effluent nitrate concentration decreases as residence time increases. Effluent nitrate concentrations can be reduced to non-detect levels within a 6 hour retention time and perhaps as low as 4 hours.

The impact of residence time on effluent selenium concentration is provided in Table 8 and Figure 15. Similar to the nitrate analysis, the period of record for the selenium plot is from June 20 to August 11. Effluent selenium concentrations for all active selenium reducing reactors were included in this plot. Data points were obtained for total residence times of 12 hours, 8 hours, 6 hours, 4 hours, 3 hours, 2 hours and 0 hours (the influent). Figure 15 shows that effluent selenium concentrations can be reduced to non-detect levels within a 6 to 8 hour retention time.

The plots given in Figures 14 and 15 can be applied to the operation and also the design of full scale nitrate and selenium reducing biotreatment plants. In full scale plants, the number and volume of reactors will be invariable and residence time can be adjusted by varying the flow rate through the system. By decreasing the flow residence time will be increased, and increasing the flow will decrease the residence time. Residence time can also be adjusted during the plant design process when an established and invariable design flow is given. Designing larger volume reactors or increasing the number of reactors will increase the residence time of the system.

Impact of Nutrient Dosage on Bioreactor Performance

Nutrient dosage is based off empirical data. After reactor inoculation the system is fed a greater concentration of nutrient to insure formation of the desired biomass. This dosage is between 2.5 and 4 gallons of nutrient per 1000 gallons of water treated. Once formation of the biomass is achieved, nutrient dosage is reduced to 0.1 to 0.5 gallons per 1000 gallons of water treated during normal operations. Nutrient dosage is modified based on the following factors:

- Minimizing operating costs.
- Maintaining biofilm.
- Maximizing contaminant removal.
- Optimizing reducing conditions.

These factors are site specific, and are changed based on operating data.

Figure 14 – Impact of Residence Time on Nitrate Removal

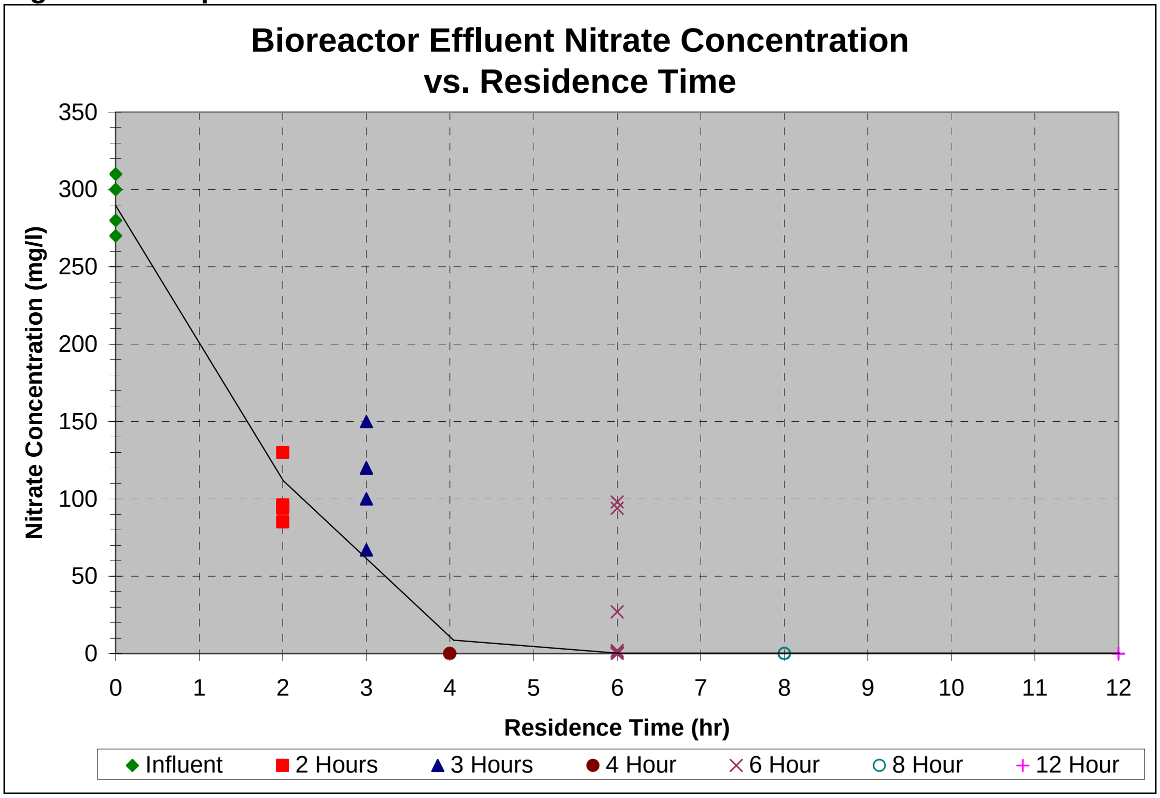


Figure 15 – Impact of Residence Time on Nitrate Removal

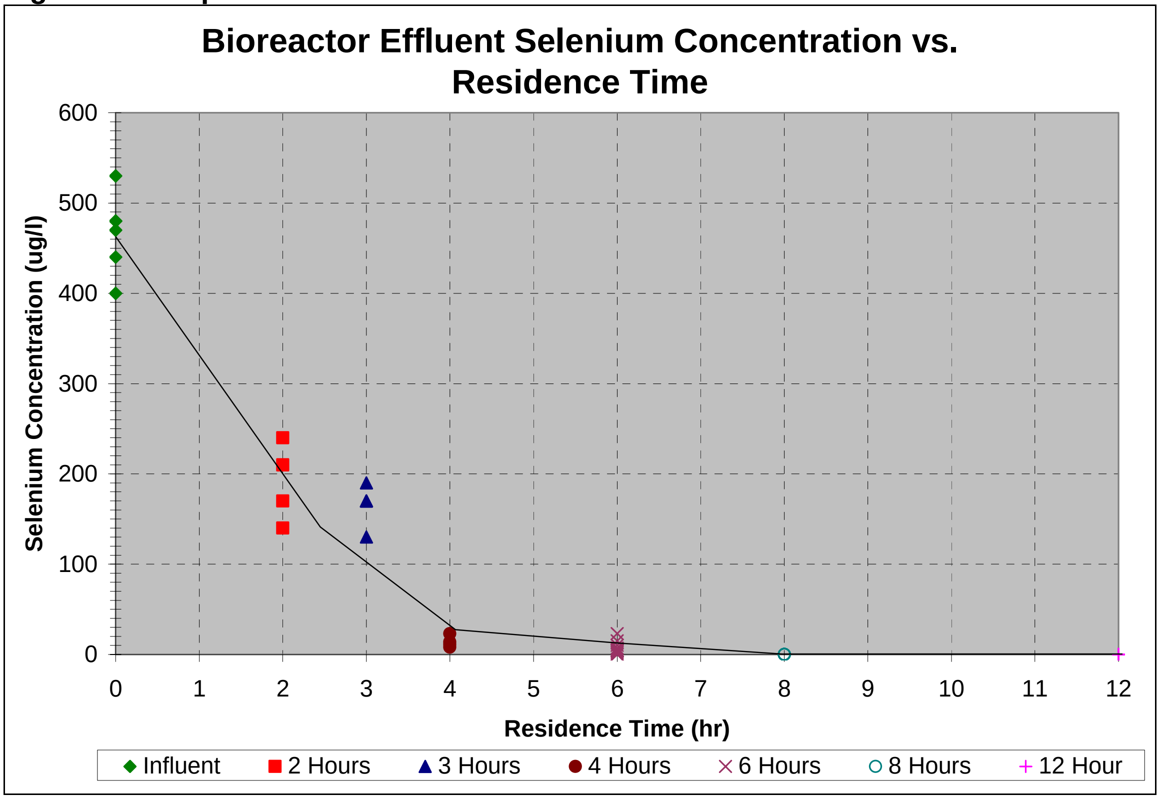


Table 7 – Residence Time and Nitrate Concentration

Residence Time (hr)	Date	Flow Rate (gpm)	Tank Number	Nitrate (mg/L as NO_3)
0	6/25/03		Influent	300
0	7/2/03		Influent	310
0	7/16/03		Influent	300
0	7/23/03		Influent	270
0	7/30/03		Influent	310
0	8/6/03		Influent	280
2	8/6/03	3	1	130
2	8/7/03	3	1	96
2	8/8/03	3	1	85
2	8/11/03	3	1	94
3	7/16/03	2	1	
3	7/21/03	2	1	150
3	7/23/03	2	1	120
3	7/25/03	2	1	120
3	7/28/03	2	1	67
3	7/30/03	2	1	100
4	8/6/03	3	2	ND
4	8/7/03	3	2	ND
4	8/8/03	3	2	ND
4	8/11/03	3	2	ND
6	6/20/03	1	1	ND
6	6/23/03	1	1	2
6	6/25/03	1	1	27.0
6	6/27/03	1	1	ND
6	6/30/03	1	1	98
6	7/2/03	1	1	94
6	7/16/03	2	2	
6	7/21/03	2	2	ND
6	7/23/03	2	2	ND
6	7/25/03	2	2	ND
6	7/28/03	2	2	ND
6	7/30/03	2	2	ND
6	8/6/03	3	3	ND
6	8/7/03	3	3	ND
6	8/8/03	3	3	1.0
6	8/11/03	3	3	ND
8	8/6/03	3	4	ND
8	8/7/03	3	4	ND
8	8/8/03	3	4	ND
8	8/11/03	3	4	ND
12	6/20/03	1	2	ND
12	6/23/03	1	2	ND
12	6/25/03	1	2	ND
12	6/27/03	1	2	ND
12	6/30/03	1	2	ND

Table 8 – Residence Time and Selenium Concentration

Residence Time (hr)	Date	Flow Rate (gpm)	Tank Number	Selenium (ug/L)
0	6/25/03		Influent	400
0	7/2/03		Influent	480
0	7/16/03		Influent	480
0	7/23/03		Influent	470
0	7/30/03		Influent	530
0	8/6/03		Influent	440
2	8/6/03	3	1	210
2	8/7/03	3	1	140
2	8/8/03	3	1	170
2	8/11/03	3	1	240
3	7/16/03	2	1	
3	7/21/03	2	1	170
3	7/23/03	2	1	130
3	7/25/03	2	1	170
3	7/28/03	2	1	170
3	7/30/03	2	1	190
4	8/6/03	3	2	23
4	8/7/03	3	2	14
4	8/8/03	3	2	11
4	8/11/03	3	2	8.0
6	6/20/03	1	1	15
6	6/23/03	1	1	
6	6/25/03	1	1	5.0
6	6/27/03	1	1	ND
6	6/30/03	1	1	10
6	7/2/03	1	1	23
6	7/16/03	2	2	
6	7/21/03	2	2	7.0
6	7/23/03	2	2	4.0
6	7/25/03	2	2	2.0
6	7/28/03	2	2	4.0
6	7/30/03	2	2	4.0
6	8/6/03	3	3	4.0
6	8/7/03	3	3	ND
6	8/8/03	3	3	4.0
6	8/11/03	3	3	7.0
8	8/6/03	3	4	ND
8	8/7/03	3	4	ND
8	8/8/03	3	4	ND
8	8/11/03	3	4	ND
12	6/20/03	1	2	ND
12	6/23/03	1	2	ND
12	6/25/03	1	2	ND
12	6/27/03	1	2	ND
12	6/30/03	1	2	ND

Conclusion

The pilot scale testing showed that Applied Biosciences ABMet® technology can successfully remove selenium and nitrate to below 5 µg/L and 5 mg/L, respectively, from the DP-25 drainage water. Effluent nitrate and selenium concentrations decrease as residence time increases. According to data collected during the pilot prior to the disconnection of Reactor 1, nitrate can be reduced to non-detect levels within a 4 to 6 hour retention time, and selenium can be reduced to non-detect levels within a 6 to 8 hour retention time. Changes in system configuration can have an impact on bioreactor performance. The removal of Reactor 1 from the system resulted in nitrate and selenium spikes in the effluent of the subsequent reactors. The data suggest that it may take several weeks for the treatment system to recover and reach equilibrium after a major system upset (e.g. the removal of Reactor 1).

Plugging encountered during the pilot scale test was likely caused by a combination of floating biomass and floating carbon that entered into the slotted effluent collection pipes. These pipes rested directly on top of the carbon media where they were susceptible to particle transport. It is believed that plugging can be avoided through an improved design of the hydraulic system to include suspending the effluent collection pipe above the media and utilizing a false-bottom plenum with nozzles below the media.

Acknowledgement

Field assistance for the operation of the pilot study was provided by staff from the Bureau of Reclamation, Applied Biosciences, Boyle Engineering, and Panoche Drainage District.

APPENDIX

MICROBIAL SUPPORT MEDIA EVALUATION

Introduction.

The purpose of this study is to evaluate selenium and nitrate removal with Applied Biosciences ABMet® microbes using various support media. The media types tested are; activated carbon, reactivated carbon, gravel, pumice, and a commercially available plastic bio-rings. The results of this test show that activated carbon media or reactivated carbon is the best choice for full scale implementation of Applied Biosciences ABMet® technologies.

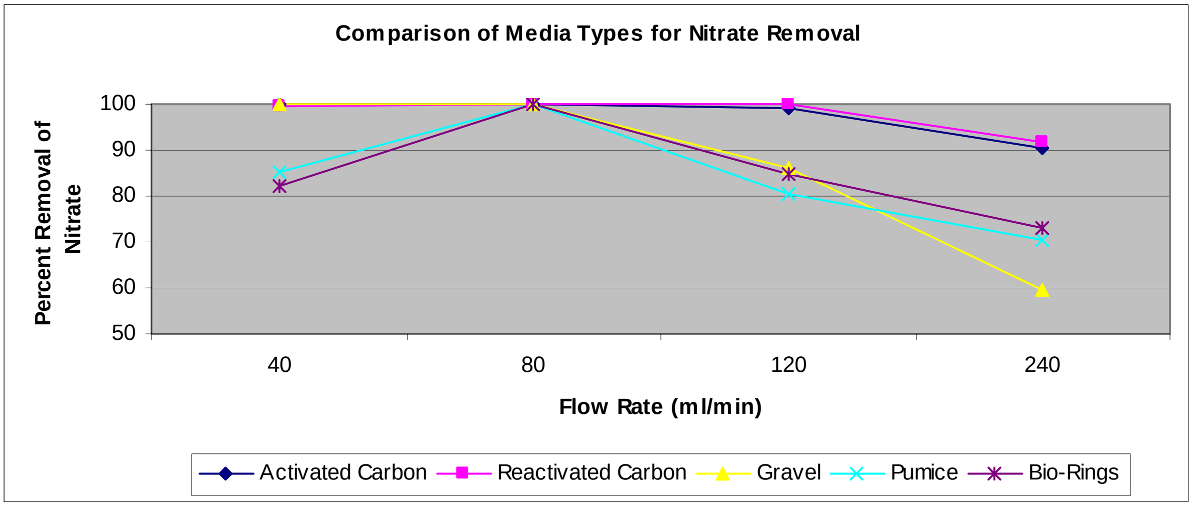
Material and Method

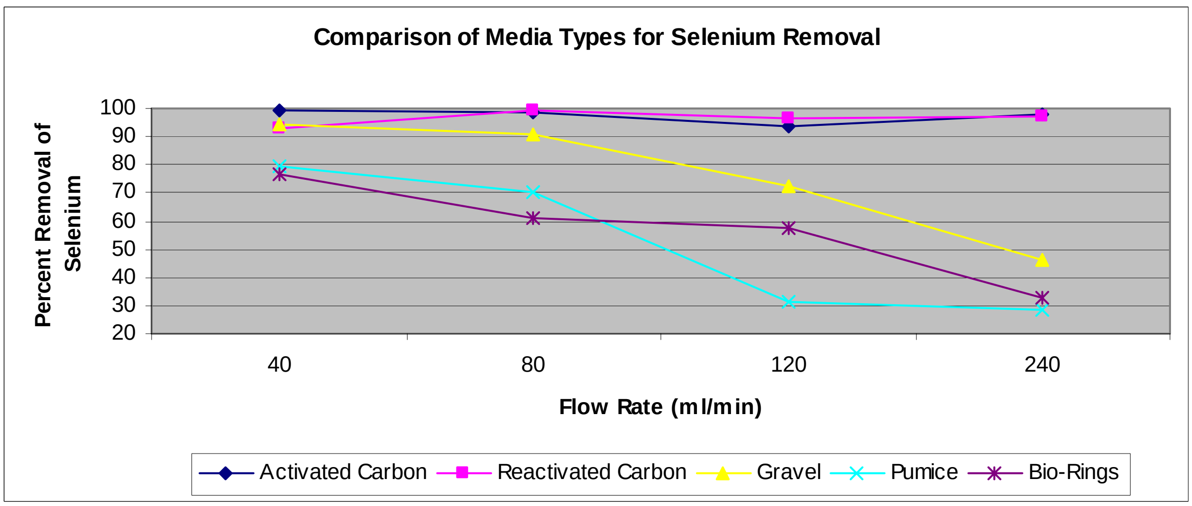
For this study Applied Biosciences personnel constructed five 30 gallon pilot scale reactors. Each reactor was plumbed with a water distribution system and automated nutrient delivery system. The reactors were filled to the same level with one of the five media types and inoculated with Applied Biosciences ABMet® microbes. The reactors were brought on site to Panoche Water and Drainage District's drainage well and connected to the well water.

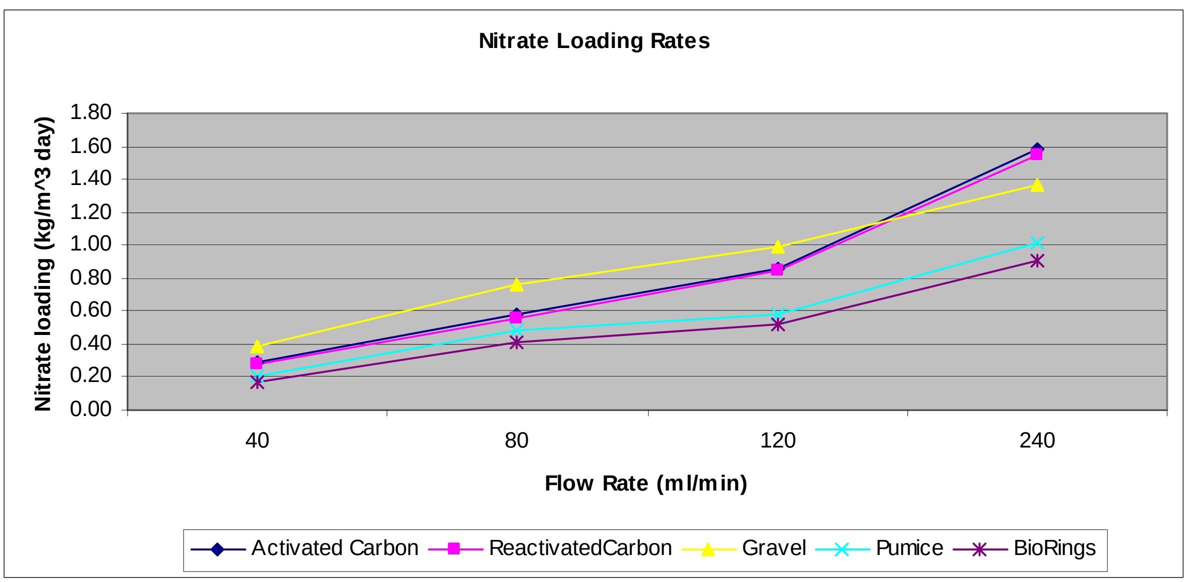
The system was tested at four flow rates over a period of six weeks. The reactor effluent was sampled three times per week and the supply was sampled once per week. All samples were collected by Panoche Water and Drainage District personnel and analyzed by BSK laboratories in Fresno California for nitrate and selenium.

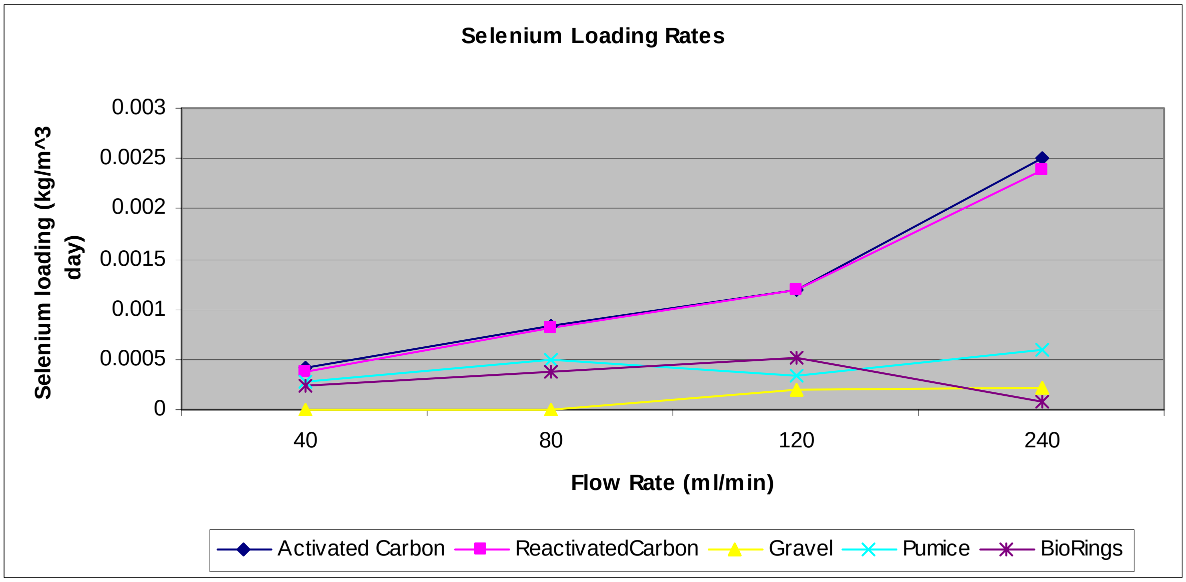
Results

Results of the study show that activated carbon and reactivated carbon worked significantly better that gravel, pumice and bio-rings. The average reactor nitrate influent was 293 mg/L and the average selenium influent was 429 µg/L. Results from the bioreactors were used to determine the percent removals, and loading rates for each support media at the four flow rates. The data is summarized in the following graphs.


Comparison of Media Types for Nitrate Removal
Percent Removal of Nitrate
100
90
80
70
60
50
40
80
120
240
Flow Rate (ml/min)
Activated Carbon
Reactivated Carbon
Gravel
Pumice
Bio-Rings


Comparison of Media Types for Selenium Removal
Percent Removal of Selenium
100
90
80
70
60
50
40
30
20
40
80
120
240
Flow Rate (ml/min)
Activated Carbon
Reactivated Carbon
Gravel
Pumice
Bio-Rings


Nitrate Loading Rates
Nitrate loading (kg/m^3 day)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
40
80
120
240
Flow Rate (ml/min)
Activated Carbon
ReactivatedCarbon
Gravel
Pumice
BioRings



Conclusion

Results of the media support study indicate that activated carbon and reactivated carbon are the best choices for full scale implementation of Applied Biosciences ABMet® technology. Activated carbon is normally used as the support media for Applied Biosciences' ABMet® process, because of its high ratio of surface area to volume. Since biological selenium reduction is a surface phenomenon, the high ratio enhances treatment efficiency. History of use must also consider of reactivated carbon because of the possibility of metals leaching from the matrix due to prior use. Any carbon that is used for Applied Biosciences ABMet® process must meet hardness and other specifications to ensure operational longevity of the system. Cost comparisons and specifications of both activated and reactivated carbon will be provided in the Feasibility Level Design Report for a full scale water treatment plant.

ATTACHMENT B-2

Selenium Speciation and Bioaccumulation Pilot Study

URS

Technical Memorandum

Date: February 21, 2006

To: Scott Irvine, Water Treatment Engineer, Bureau of Reclamation
Gerald Robbins, Project Manager, San Luis Drainage Feature Re-evaluation, Bureau of Reclamation
Mike Delamore, San Luis Drainage Program Manager, Bureau of Reclamation

From: Terry Cooke, Senior Project Manager

Subject: ***Final Results for Selenium Speciation and Bioaccumulation Study***
URS Project 18600809; Reclamation TO 04PE810545, Contract 01CS20210H

1.0 INTRODUCTION

This Technical Memorandum presents a data report of the results of the Pilot Selenium Bioaccumulation Study conducted by URS Corporation for the U.S. Bureau of Reclamation (Reclamation). This technical memorandum is the deliverable for scope of work for Task 8 under Task Order No. 04PE810545 issued for Contract No. 01CS20210H.

The study involves investigation of the treatment and bioavailability of selenium (Se) in evaporation basins receiving agricultural drainage that has been treated to remove selenium using a biotreatment process (ABMet® process). Results are presented in two sections: Section 2 describes the biotreatment system study, and Section 3 describes the evaporation basin bioaccumulation study. Recommendations are presented in Section 4, and reference materials used to prepare this memorandum are listed in Section 5. Biology field reports are included in Appendix A.

2.0 BIOTREATMENT SYSTEM PERFORMANCE

This study was intended to supplement the main biotreatment system study being conducted by Reclamation by providing additional information on Se speciation in the biotreatment system. The report from Reclamation on the biotreatment system performance during the bioaccumulation study period reported herein is under development.

2.1 Biotreatment System Description

During the bioaccumulation study, two pilot-scale biotreatment systems (approximately 3 gallons per minute each) were operated by Reclamation. The systems were located at Red Rock Ranch (Red Rock), and Panoche Drainage District at sump DP-25 (Panoche). Each biotreatment system includes two bioreactors in series. Samples were collected of influent to the first bioreactor (INF), and of effluent from the first and second bioreactors (BIO1 and BIO2). Samples of the solid media (Granular Activated Carbon [GAC]) used to support growth of the microbial population within the reactors were also collected.

At the Panoche site, a Reverse Osmosis (RO) system was used to desalt the sump water prior to biotreatment, with the brine from the RO system replacing the sump water as influent to the first bioreactor. The feed to the RO system was also sampled (RO). The RO system was shut down periodically during the study for maintenance. During periods of RO shutdown, influent to the bioreactors was essentially filtered sump water. The RO and bioreactor systems were shut down on December 14, 2004, for repairs and reconfiguration. The bioreactor systems were back in startup mode during June 2005 and operational throughout the study with the exception of periodic maintenance.

2.2 Sampling Activities

Sampling activities for the bioreactors included collection of water and GAC in 2004 and water only in 2005.

2.2.1 Sampling Methods – Water

Sampling locations for the Panoche system are shown in Figure 2-1. Sampling points for the biotreatment systems were, in all cases, accessible by tap. Water samples were collected directly into clean polyethylene bottles provided by the analytical laboratory. Sample bottles were labeled, double bagged, recorded on a Chain-of-Custody form and shipped to the laboratory the same day.

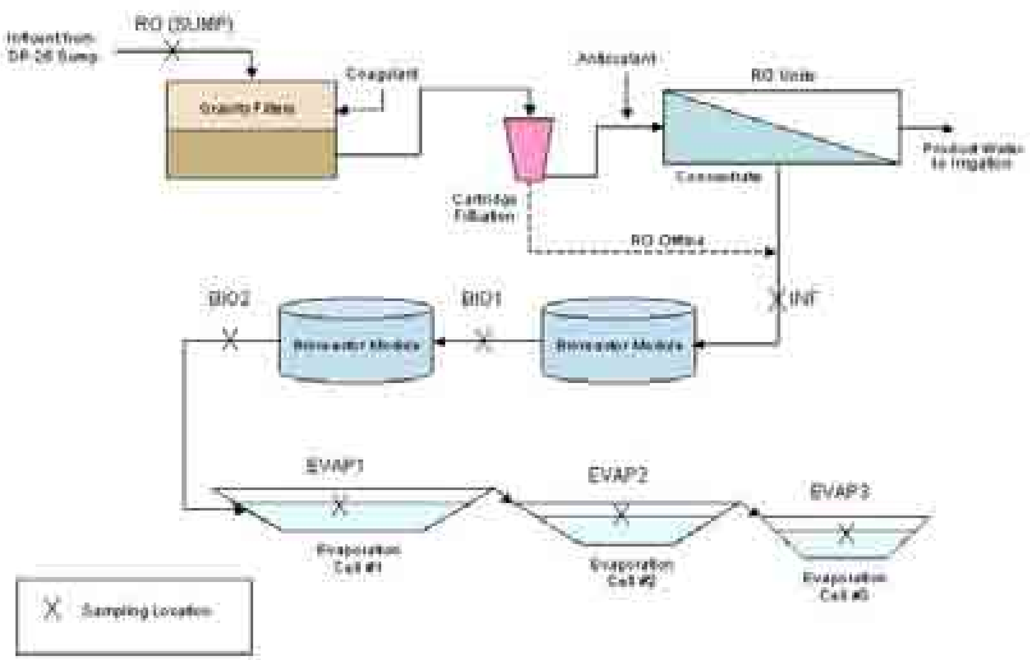


Figure 2-1. Panoche DP-25 Pilot System Sampling Locations

2.2.2 Sampling Methods – GAC

Composite samples were collected from the GAC canisters by inserting a sampling device at three depths (just below the surface, in the middle, and at the bottom) and combining the material collected in clean glass jars provided by the laboratory. Sample jars were labeled, double bagged, recorded on a Chain-of-Custody form and shipped to the laboratory the same day.

2.2.3 Field QC Samples

A duplicate sample was collected from one GAC canister. In addition, an equipment blank was collected on each field trip and either analyzed for both total and dissolved Se or total Se only.

2.3 Analytical Methods

2.3.1 2004 Analytical Methods

The analytical methods used are summarized in Table 1a. Total and dissolved Se were measured in all water samples. In addition, dissolved Se was speciated as selenite (Se IV), selenate (Se VI), and selenium cyanate (SeCN). The analysis of selenium cyanate was not requested but was reported by the laboratory because the method for selenite and selenate analysis (IC-ICP-MS) allows for simultaneous analysis of selenium cyanate and the laboratory instrumentation is normally calibrated to allow quantification of this compound, which is often found in petroleum refinery wastewater.

Organic+elemental Se was calculated as the difference between dissolved Se and the directly measured inorganic forms (Se IV, Se VI, and SeCN). Samples were also analyzed after passing though a C-18 column (non-polar resin) after adjustment to pH 1.5–2.0 to remove nonvolatile organic compounds after the procedure in Standard Methods SM 3500 G. This fraction was called "dissolved inorganic Se" but may also include some free selenium amino-acids that may not be removed by C-18. Se was quantified by ICP-DRC-MS, while the work plan calls for quantitation of Se by HG-AFS. The laboratory requested this change to address concerns with potential analytical interference. Chlorophyll a was also measured to provide an indication of algal growth.

The work plan also called for analysis of elemental Se, redox, and pH in GAC; however, the sample jars used did not allow collection of sufficient volume for all the analyses requested.

2.3.2 2005 Analytical Methods

The analytical methods used are summarized in Table 1b. Both an alkaline peroxide digestion and an HCL persulfate digestion were run on both the total and dissolved selenium fractions in July. The alkaline peroxide results are reported here. All total and dissolved Se aliquots were run with an alkaline peroxide digestion in August, September, October, and November of 2005. In July 2005, BOD and COD were added to the list of analytes.

2.4 2004 Study Results

2.4.1 Water Results

Water samples were collected from both the Red Rock and Panoche biotreatment systems in October and December 2004. Biotreatment system water results are summarized in Table 2a. The biotreatment systems were dismantled to allow reconfiguration after the second sampling.

Selenium Speciation in Sump Waters

Sump waters at Red Rock (RR-INF) contained between 925 micrograms per liter (µg/L) and 1,030 µg/L total Se. Dissolved Se results indicated Se was present primarily in dissolved forms. Dissolved inorganic Se concentrations (non-C-18 extractable) were similar to total and dissolved Se concentrations. Selenate was the major dissolved species present at Red Rock during both sampling rounds comprising 80 percent of the dissolved Se in the first round and 55 percent in the second sampling round. Selenite was a minor component of the dissolved fraction comprising less than 1 percent of the dissolved species during both sampling rounds. Dissolved organic+elemental Se comprised 15 percent of the dissolved Se during the first sampling round and was 40 percent of the dissolved Se during the second sampling round.

Total Se concentrations in Panoche sump waters (PAN-RO) varied considerably between the two sampling rounds, ranging from 695 µg/L during the first round and 171 µg/L during the second round. Greater than 95 percent of the Se was present as dissolved forms with selenate comprising between 73 percent and 81 percent of the dissolved Se. No selenite or SeCN was detected in sump waters from Panoche. Organic+elemental Se comprised between 15 percent and 24 percent of the dissolved species. Dissolved inorganic Se (non-C-18 extractable) was similar to dissolved Se concentrations.

Selenium Speciation in RO System

Only the October sampling was successful in obtaining samples for characterization of the RO system at Panoche. Salinity results for the RO and INF samples from the December sampling were similar, indicating brine was not successfully sampled, likely due to confusion as to the correct sample port location. It is recommended the sample ports for the entire system be labeled by the operators to avoid this problem in the future.

Total and dissolved Se concentrations in the brine effluent from the bioreactor (PAN-INF) in October were approximately double those in the influent to the system (PAN-RO) as would be expected for a 50 percent recovery single-pass RO system. Selenate concentrations in the brine increased by 250 percent compared to RO influent, while organic+elemental Se concentrations decreased in the brine, suggesting some conversion of organic and elemental Se to selenate may be occurring in the RO process.

Selenium in Bioreactors

Large reductions in both total and dissolved Se concentrations were found for the Red Rock and Panoche Biotreatment systems. Removals ranged between >94 percent and >99 percent for both systems, with effluent concentrations from the second bioreactor less than the detection limit (9.8 µg/L) during the December sampling. Higher concentrations of particulate Se were observed in October than in December. It is not clear if this is a result of operational differences or perhaps conditioning of the GAC during start-up.

Selenium speciation changed within the bioreactor systems with higher concentrations and proportions of selenite and organic+elemental Se found in the effluent from the first bioreactor as compared to the influent to the system and effluent from the second bioreactor. However, these species were largely removed in the second bioreactor. During the October sampling, Se species in the Panoche effluent included approximately equal amounts of selenite and organic+elemental Se as well as lesser amounts of SeCN. At the Red Rock reactor in October the effluent consisted primarily of selenate with lesser amounts of SeCN and elemental/organic Se. Selenium speciation in the effluent from the second bioreactor during the December sampling (when the systems were performing well) was composed mostly of organic+elemental Se with some apparent production of SeCN.

In some cases, the dissolved inorganic Se concentration measured was higher than the total Se concentration measured. The laboratory noted a large particulate component was sometimes present and the differences may have been due to sample heterogeneity. Better homogenization techniques in the laboratory prior to sub-sampling may reduce the occurrence of this anomaly.

In summary, the biotreatment systems removed large percentages of the total and dissolved Se. The treatment process results in higher proportions of reduced forms of Se in the effluent as compared to the influent, as would be expected for anaerobic reaction systems.

Salinity was only measured in the December sampling event. The Red Rock influent had higher salinity than the Panoche influent; however, effluent from both systems had similar salinities.

Chlorophyll a was not observed within either of the biotreatment systems.

2.4.2 GAC Results

GAC was collected from both the Red Rock and Panoche biotreatment systems in October 2004. Preliminary GAC results are summarized in Table 3. Comparison of total Se concentrations observed to the Title 22 California Code of Regulations Total Threshold Limit Concentration (TTLC) of 100 milligrams per kilogram (mg/kg) reveals that four of the five samples collected are higher than the TTLC.

2.5 2005 Study Results

2.5.1 Water Results

Water samples were collected from both the Red Rock and Panoche biotreatment systems in July, August, September, October, and November 2005. Biotreatment system water results are summarized in Table 2b.

Selenium Speciation in Sump Waters

Sump waters at Red Rock (RR-INF) contained between 937 µg/L and 1250 µg/L total Se. Dissolved Se results confirmed earlier findings and indicated Se was present primarily in dissolved forms. Dissolved inorganic Se concentrations (non-C-18 extractable) were similar to total and dissolved Se concentrations. Selenate continued to be the major dissolved species present at Red Rock throughout the 2005 sampling events and comprised between 75 percent and >99 percent of the dissolved Se in 2005. Selenite was a minor component of the dissolved fraction comprising up to 1 percent of the dissolved species during the 2005 sampling rounds. Dissolved organic+elemental Se comprised up to 25% of the dissolved Se in 2005.

Total Se concentrations in Panoche sump waters (PAN-INF) varied considerably from 375 µg/L in July 2005 up to 1820 µg/L in October 2005 and back to 335 µg/L in November 2005. Greater than 95% of the Se was present as dissolved forms with selenate comprising between 75 percent and 95 percent of the dissolved Se. No selenite or SeCN was detected in sump waters from Panoche. Organic+elemental Se comprised between 5 percent and 30 percent of the dissolved species in 2005. Dissolved inorganic Se (non-C-18 extractable) was similar to dissolved Se concentrations.

Selenium in Bioreactors

Large reductions in both total and dissolved Se concentrations were found for the Red Rock and Panoche biotreatment systems. Removals ranged between 95 percent and >99 percent at Red Rock for both total and dissolved Se and between 89 percent and >99 percent at Panoche for dissolved Se. Total Se removal at Panoche in November 2005 was only 50 percent, while the other sampling events ranged from 83 percent to >99 percent total Se removal. Particulate Se concentrations were calculated and vary substantially throughout the sampling period.

Se speciation generally changed within the Red Rock biotreatment system with higher concentrations and proportions of selenite and organic+elemental Se found in the effluent from the first bioreactor as compared to the influent to the system and the effluent from the second bioreactor. These species were largely removed in the second bioreactor. This trend holds true for selenite within the Panoche biotreatment system; however, organic+elemental Se was largely removed in the first bioreactor.

In summary, the biotreatment systems removed large percentages of the total and dissolved Se.

Salinity for the Red Rock biotreatment system was fairly consistent, ranging from 8.5 parts per thousand (ppt) to 10.2 ppt. Salinity for the Panoche biotreatment system was lower in July (5.4 ppt to 5.5 ppt) and November (5.4 ppt to 5.6 ppt) than in August, September, and October (13.3 ppt to 16.7 ppt in the influent).

3.0 EVAPORATION BASIN BIOACCUMULATION STUDY

Study methods and results for the evaporation basin bioaccumulation study are presented below. Included are sampling methods, analytical methods, and results for basin water and organisms in the basins (tissue).

3.1 Evaporation Basin System Description

The pilot evaporation basin system was constructed adjacent to DP-25 by Panoche Drainage District. URS provided conceptual design and drawings for use by Panoche in constructing the basins. An existing lined algal settling pond, previously used by LBL as a part of the algal-bacterial Se treatment system, was generously allowed to be re-configured for this study. The existing pond was pressure washed, bermed to avoid run-on, and used as Pond 1. Two new ponds were constructed, lined with plastic, and bermed to avoid run-on during wet weather. Pipes were placed between Ponds 1 and 2 and between Ponds 2 and 3 to allow sequential flow through the ponds. Inlet pipes to the ponds were opened at the bottom of the pond to avoid short circuiting across the surface of the ponds. A schematic of the system is shown in Figure 2-1.

Effluent from the bioreactor system began to fill the ponds in September 2004. It was anticipated it would take approximately 2 to 3 weeks to fill all three ponds. On September 22, 2004, water from LBL system lagoon inadvertently spilled into Pond 1. The water was removed and the ponds were pressure washed again. The ponds began refilling in October 2004. Effluent was supplied to the ponds from October until the treatment systems were shut down on December 14, 2004. Ponds received effluent through August 2005 after the biotreatment system reconfiguration. The ponds were full by the end of August 2005, and no additional effluent was added during the course of the study.

3.2 Sampling Methods

3.2.1 Sampling Methods – Water

Water samples were collected from the evaporation ponds with an HDPE beaker on a pole and transferred into clean polyethylene bottles provided by the laboratory. Sample bottles were labeled, double bagged, recorded on a Chain-of-Custody form and shipped to the laboratory the same day.

3.2.2 Sampling Methods – Tissue

Two collection methods were used for tissue samples. The water column was sampled for nektonic invertebrates using a net, and benthic invertebrates were collected using a bailer.

Nekton invertebrate samples were collected using a 0.5-millimeter mesh D-frame net. Water column samples were clean (i.e. no sediment and very minimal organic debris was in net) and organisms were individually removed from the net and placed in glass jars. The jars were provided by the laboratory. The first three collection sweeps from each pond were collected from a 20-foot-long transect parallel to the edge of the pond. Transect length was determined by measuring the maximum length possible without rounding any corners on the smallest pond. Invertebrates captured during the first three sweeps were identified and counted. After that, organisms were identified but not enumerated, to collect a total of 0.5 grams of invertebrates.

A plastic bailer was used to sample for benthic invertebrates. The bailer was lowered to the bottom of the pond and dragged up the liner to sample attached or benthic organisms. The sample was screened in a No. 35 Standard Test Sieve (500 micron mesh). Pondwater was used to wash the sample, and organisms were transferred from the sieve to a glass sample bottle or plastic bag.

Sample bottles were labeled, double bagged, recorded on a Chain-of-Custody form and shipped to the laboratory the same day.

3.2.3 Field Quality Control Samples

A duplicate sample was collected from one evaporation pond on each field trip. In addition, an equipment blank was collected on each field trip and either analyzed for both total and dissolved Se or total Se only.

Insufficient numbers of organisms were present to collect a full complement of three tissue samples per pond plus a quality assurance/quality control (QA/QC) sample.

3.3 Analytical Methods

The analytical methods used are summarized in Table 4. The analytical and speciation scheme was the same as discussed in Section 2.3.1. For the first three events, Se was quantified by ICP-DRC-MS, while both ICP-DRC-MS and HG-AFS were used in May. The HG-AFS results are reported for the May sampling event. HG-AFS was used in July, August, September, October, and November 2005. The work plan calls for quantitation of Se by HG-AFS. During the first three events the laboratory conducted ICP-DRC-MS because they felt interference was less likely as compared to the HG-AFS methods.

Both an alkaline peroxide digestion and an HCL persulfate digestion were run on both the total and dissolved Se fractions in July. The alkaline peroxide results are reported here. All total and dissolved Se aliquots were run with an alkaline peroxide digestion in August, September, October, and November 2005. In July 2005, BOD and COD were added to the list of analytes for water samples.

3.4 Evaporation Basin Results

3.4.1 Water Results

Water samples were collected from all three ponds in October and December 2004 and January, May, July, August, September, October, and November 2005. The results are summarized in Table 5.

Salinity

The salinity concentrations in the three ponds were similar for the December 2004 and January 2005 sampling events. In May 2005, salinity was lower in Ponds 2 and 3 than in Pond 1, which was physically isolated. Salinity generally increased from pond to pond throughout the summer; however, salinity in Pond 3 was lower than in Pond 2 in July and November.

Chlorophyll a

Very little chlorophyll a was observed in the ponds in October 2004. Samples were collected shortly after the ponds initially filled and algae had not yet colonized them. December concentrations of chlorophyll a increased and ranged from 200 to 250 milligrams per cubic meter (mg/m^3), while January concentrations were substantially lower. The weather was still comparatively fair in early December, whereas by the end of January winter had set in. Chlorophyll a concentrations in May were higher than January but not as high as in December. Chlorophyll a concentrations in July, August, September, and October were generally lower than those observed in May. Chlorophyll a concentrations in Ponds 1 and 2 for November 2005 exceeded those observed in December 2004. Pond 3 did not recover the chlorophyll a concentrations observed in 2004.

BOD and COD

In all cases, COD concentrations exceeded the corresponding BOD concentrations by an order of magnitude. Generally BOD and COD concentrations were lower in Pond 3 than in Pond 1.

Selenium

Total Se concentrations ranged from 3.11 to 21.1 µg/L in the three ponds. Average total Se concentrations were 9.8 µg/L, 13.2 µg/L, and 10.1 µg/L for Ponds 1, 2, and 3, respectively. Dissolved Se comprised between 46 percent and 100 percent of the total Se. Particulate Se concentrations ranged from 0.29 µg/L to 6.91 µg/L and showed no clear trend through the sampling period. Dissolved inorganic Se concentrations generally decreased in the ponds through the study. Dissolved organic+elemental Se concentrations were highest in all three ponds in December and generally comprised the majority of the dissolved Se throughout the study. Selenite was the second most prevalent form of Se and comprised up to 44 percent of the dissolved Se. SeCN concentrations were highest in

Pond 1 during the first sampling round, where it constituted the majority of the dissolved Se. Concentrations of SeCN decreased through the pond series in October and was only detected in Pond 1 in the December sampling. Selenate generally constituted a small percentage of the dissolved Se except during the May sampling of Pond 3, where it comprised 49 percent of the dissolved Se, and the August sampling of Pond 2, where it comprised 50 percent of the dissolved Se.

3.4.2 Tissue Results

Field Observations

The evaporation ponds were seeded with organisms collected from Cell 2 in the South Evaporation Basin series at Tulare Lake Drainage District (TLDD) located in Corcoran, California in November 2004. At that time samples were submitted to the laboratory to obtain baseline concentrations of Se.

Organisms were collected from the three treatment ponds in May, July, September, October and November 2005. Nektonic and benthic organisms were collected and submitted to the laboratory for analysis of total Se and percent moisture. Algae was not sampled because no discrete colonial, filamentous or algal mats were present. Aufwuchs (combination of algae, bacteria, and microorganisms) that floated up from the substrate was sampled in July. Sediment was collected for analysis during the July sampling event to determine Se concentration (as a potential source of Se for benthic invertebrates).

Table 6 contains a list of the organisms collected during each of the five sampling events and Table 7 lists the organisms in each sample sent to the laboratory. The dominant organism collected in each of the five events was waterboatmen (Corixidae). Corixidae, notonectids (backswimmers), chironomids (midges), *Tubifera* sp. (rat-tailed maggot), ephydridae (shore flies), anisoptera (dragonfly nymphs), dytiscidae (predaceous diving beetles, and nematodes (round worms) were also collected. Dragonflies and damselflies were observed laying eggs in Pond 1, and waterboatmen were reproducing successfully. The diversity of organisms has been consistently greater in Pond 2. The corixid population size increased during the year. Predaceous diving beetles (Dytiscids) were observed flying and diving into the ponds. This means Se content in their tissues is not necessarily from the ponds they were collected from. Both waterboatmen and backswimmers can also fly but were not observed doing so during the sampling events.

The number and diversity of organisms was affected by the intermittent flow to the system. Water was not flowing from Pond 1 to the other two ponds during the May or July sampling events due to shutdown of the bioreactors. When the flow was interrupted, evaporation decreased the water volume and increased the salinity. Water salinity data are presented in Table 8. The salinity ranged from 13 ppt to 45 ppt. The pondwater is highly brackish, and in July the salinity in Pond 2 exceeded the concentration of seawater. In July, the system appeared stressed. There were insufficient organisms in Ponds 1 and 3 to submit a neckton sample for analysis, and the organisms collected in Pond 2 were species adapted to poor water quality (shoreflies, brine flies, and midges).

Water color varied throughout the year. In September the water in Pond 1 was slightly green in color, whereas it was red-brown in Ponds 2 and 3. In October the Pond 1 water color was reddish and Ponds 2 and 3 had green-brown colored water. In November the Pond 1 water color was iron red-brown, Pond 2 was yellow-green, and Pond 3 was green-brown. These color shifts suggest differences in water chemistry among the ponds. The green color could indicate the presence of single-celled algae (see Chlorophyll under Section 3.4.1, above).

Biomass is defined as weight per unit area or volume. Since the water is not flowing, the water volume sampled can be estimated using the dimensions of the net opening and the length of water transect sampled as follows:

$$\text{Biomass } [g/m^3] = \frac{(\text{mass of biota [g]})}{[(0.39 \text{ sq. ft. net opening})(\text{linear distance [ft]})(0.02832\ m^3/ft^3]}$$

The type and weight of organisms collected for the biomass calculation for each of the sampling events is presented in Table 9. Biomass results depend on species collected, e.g., one dytiscid weighs more than one corixid. The biomass data interpretation needs to be qualified because the scale used during the May event had low accuracy for weights less than 1 gram. A new scale was used for the remaining sampling events. The biomass for Pond 1 in November is likely lower than it should be. It would have been closer to the Pond 3 reading if a different collection net had been used.

Summary of Observations

- Corixids are the dominant organism in the ponds.
- Seven other groups of organisms were present in varying abundance.
- The number of organisms increased during the year.
- The abundance and diversity of aquatic invertebrates is affected when water flow is interrupted and the pondwater level drops significantly. The evaporative loss increased salinities and likely affected water temperature and dissolved oxygen concentrations.
- Absent significant changes in pond ecology, it appears that insufficient algae will be available to sample in the ponds.
- The calcium sulfate scale attached to the liner and bottom of the ponds is abundant.

Laboratory Results

Table 10 presents the tissue results for Se and percent moisture. Selenium concentrations were reported on a wet-weight basis and converted to dry-weight using percent moisture measured from that sample or using an estimated percent moisture when a measurement was not available.

Se concentrations in nektonic organisms were higher in May as compared to the baseline concentrations measured from the Tulare System. Se in nektonic organisms in Ponds 2 and 3 were approximately twice the baseline concentrations. Se concentrations in Pond 1 nektonic organisms were five-fold higher than those measured in Ponds 2 and 3. It is not known why this pond was different from the other two ponds. Se concentrations in benthic midge larvae in Pond 2 were similar to nektonic organisms from the same pond.

Other than the May waterboatmen Se measurement of 15.8 mg/kg and three waterboatmen Se measurements of 10.8 mg/kg, 6.08 mg/kg, and 6.02 mg/kg in September, all other waterboatmen measurements ranged from 1.32 mg/kg to 3.82 mg/kg wet weight, which is similar to baseline measurements.

4.0 DISCUSSION

This study was undertaken due to the uncertainty associated with predictions of Se bioaccumulation in proposed evaporation basins. Monitoring reports available for existing evaporation basins are based on untreated effluent, which may have very different speciation compositions than the treated influent to the proposed evaporation basins. Even if the speciation of Se in the treated influent to the basins could be predicted with a reasonable amount of certainty, it is difficult to predict what will happen to the Se speciation when the water flows through the basin. Because speciation is dependent on various chemical and physical parameters that are characteristic of conditions in the evaporation basins, the speciation will eventually change if the residence time is long enough.

4.1.1 Historical Data on Se Bioaccumulation

Alaimo et al. (1994) measured Se speciation in four evaporation basins and found that it varied considerably. In the Westlake Farms basins (where the total Se concentration in water was 4.3 µg/L, the Se was measured as 100 percent selenate (the least bioavailable form). In contrast, the Se in the Bowman Farms evaporation basins was found to be 78 percent organic selenide (the most bioavailable form), even though the total Se concentration (10.8 µg/L) was in the same range of that in the Westlake Farms basin. Total Se concentrations in the Lost Hills Water District and Sumner Peck Ranch basins were substantially higher (320 and 679 µg/L, respectively). The Lost Hills basin contained selenate, selenite, and organic selenide, while only selenate and selenite were measured in the Sumner Peck Ranch basin water. These data demonstrate that no typical Se speciation distribution can be assumed for conditions in evaporation basins.

Amweg et al. (2003) investigated Se bioavailability and bioaccumulation in the effluent of a pilot-scale algal-bacterial Se reduction system similar to the treatment system proposed for the In-Valley Disposal Alternative. This study measured concentrations of organo-Se and selenate (combined analysis) and selenite in treatment effluent, as well as tissue concentrations in two species of invertebrates (*Lumbriculus variegatus* and *Helisoma* sp.).

It should be noted that these species are standard toxicity test organisms and are not representative of invertebrate species typically found in large numbers in evaporation basins. Using these data, bioconcentration factors (BCFs) were calculated. The BCF is defined as the ratio of the average Se concentration in bivalve tissue (dry weight) to the average dissolved Se concentration in water. Concentrations in aquatic invertebrates are estimated by multiplying the water concentration by the BCF:

$$C_{inv} \text{ (mg Se/kg tissue dry weight)} = C_w \text{ (mg/L)} \times \text{BCF (liters/kilogram)}$$

BCFs based on the Amweg et al. (2003) study results were calculated to be 603 for *Lumbriculus variegatus* and 618 for *Helisoma* sp. The Amweg study measured only total Se concentrations in water, not dissolved concentrations. However, because the treated effluent includes a filtration step, it is assumed that most of the total Se is present in the dissolved form.

Subsequent to completion of this study, the design of the treatment system was modified, and due to these modifications it is expected that bioavailability of Se in the final effluent will be lower than that measured by Amweg et al. In addition, Se bioaccumulation varies considerably among different invertebrate species, and BCFs calculated for *Lumbriculus variegatus* and *Helisoma* sp. may not be representative of BCFs for species more typically found in evaporation basins.

Fan et al. (2002) investigated Se bioavailability and bioaccumulation in agricultural drainwater and evaporation basins in the San Joaquin Valley. This study analyzed total Se concentrations in surface water, microphytes, macroinvertebrates, and fish. Water column macroinvertebrates primarily included brine shrimp (*Artemia franciscana franciscana*) and waterboatmen (Corixidae). Benthic macroinvertebrates primarily included midge larvae (Chironomidae) and brine fly larvae (Edaphae). Using these data, the average water-to-invertebrate BCF calculated for all samples in both evaporation basins was 1,565. However, the authors noted that Se concentrations in tissue did not correlate well with waterborne Se concentrations. (Use of BCFs to predict tissue concentrations assumes a linear relationship between Se concentrations in water and tissue.)

Ohlendorf (2003) reported that among the invertebrates sampled at Kesterson Reservoir, Se concentrations were highest in benthic species such as midge larvae (Chironomidae) and lowest in aquatic species such as waterboatmen (Corixidae). Se bioaccumulation factors for invertebrates samples at Kesterson ranged from 168 to 3,700, with a mean of 1,090 (Ohlendorf 2003). Most aquatic insects collected at Kesterson Reservoir in 1983, including damselfly nymphs (Zygoptera), dragonfly nymphs (Anisoptera), and midge larvae (Chironomidae), averaged more than 100 mg/kg Se. Waterboatmen contained lower concentrations (geometric mean of about 20 mg/kg). Se concentrations in water entering Kesterson Reservoir during 1983 to 1985 averaged about 300 µg/L Se. Waterborne Se concentrations generally decreased as water moved through a series of basins, but water in the downstream basins still contained 50 to 200 µg/L Se. BCFs were calculated by dividing the Se concentrations in biota by those in water samples collected at the same sites and times in 1983 (Ohlendorf 1989). Most biota at Kesterson Reservoir accumulated Se concentrations to levels more than 1,000 times the concentration in water and some more than 5,000 times (Ohlendorf and Hothem 1995).

The use of BCFs assumes a linear relationship between Se concentration in water and Se concentration in tissue. However, the true relationship is expected to be logarithmic, with the ratio of Se concentration in tissue to the Se concentration in water decreasing at higher concentrations. Therefore, a regression equation based on data collected at varying Se concentrations is expected to more accurately predict bioaccumulation. Also, because birds within the various categories described in Table 1 differ considerably with regard to foraging habitats and dietary composition, the Se bioaccumulation prediction for this evaluation has been broken down by different types of dietary components – plant matter, nektonic invertebrates, and benthic invertebrates.

4.1.2 Predictions of Se Bioaccumulation Used in the SLDFR EIS

Moore et al. (1990) compiled historical data on Se concentrations in water, plants, and invertebrates of evaporation basins in the San Joaquin Valley. These data were extracted from a wide variety of sources including scientific journals, technical reports, and lay publications published by public agencies, universities, private organizations, and individuals. These data, as well as the more recent data collected by Fan et al. (2002) (described above), were used in the EIS to develop regression equations to predict bioaccumulation for each of the dietary components (plant matter, nektonic invertebrates, and benthic invertebrates). Data for widgeongrass were used to represent Se uptake in plants, data for waterboatmen were used to represent Se uptake in nektonic invertebrates, and data for fly larvae (all available species) were used to represent Se uptake in benthic invertebrates. For nektonic and benthic invertebrates, the data set used to develop the regression equations was limited to Se concentrations in water that were no greater than 20 µg/L. Because the Se concentrations of water entering the evaporation basins are expected to be approximately 10 µg/L, data that were representative of these conditions were used for the regression equation. However, for vegetation, not enough data were available within this range to develop a regression equation with high confidence (the r^2 value was less than 0.25).

It should be noted that for this analysis, the raw data sets were not readily available and the mean Se concentrations for each study site were used. The regression was weighted by the sample sizes for the tissue samples from each site. As a result, it is likely that the r^2 values obtained are higher than would have been the case if the raw data had been used (variability would have been greater).

Historical data for widgeongrass from Moore et al. (1990) were used to represent Se uptake in plants. Initially, the data set was limited to Se concentrations in water that were no greater than 20 µg/L. However, not enough data were available within this range to develop a regression equation with high confidence (the r^2 value was less than 0.25). Therefore, a regression equation with the entire data set (all available concentrations) was developed:

$$\text{Veg [Se]} = 10^{\,1.8985 + 0.7350\,\text{Log}_{10}\,\text{Water [Se]}}$$

Where:

Veg [Se]	=	Vegetation tissue Se concentration in mg/kg dry weight
Water [Se]	=	Total recoverable waterborne Se concentration in milligrams per liter (mg/L)

Historical data for waterboatmen (Corixidae) from Moore et al. (1990) as well as more recent data collected by Fan et al. (2002) were used to represent Se uptake in nektonic invertebrates. Because the Se concentrations of water entering the evaporation basins are expected to be approximately 10 µg/L, data that were representative of these conditions (Se concentrations no greater than 20 µg/L in water) were used for the regression equation:

$$\text{Nektos [Se]} = 10^{\,2.0804 + 0.5711\,\text{Log}_{10}\,\text{Water [Se]}}$$

Where:

Nektos [Se]	=	Nektos tissue Se concentration in mg/kg dry weight
Water [Se]	=	Total recoverable waterborne Se concentration in mg/L

Historical data for fly larvae (all available species) from Moore et al. (1990) as well as the more recent data collected by Fan et al. (2002) were used to represent Se uptake in benthic invertebrates. Because the Se concentrations of water entering the evaporation basins are expected to be approximately 10 µg/L, data that were representative of these conditions (Se concentrations no greater than 20 µg/L in water) were used for the regression equation:

$$\text{Benthos [Se]} = 10^{\,2.8625 + 0.8345\,\text{Log}_{10}\,\text{Water [Se]}}$$

Where:

Benthos [Se]	=	Benthos tissue Se concentration in mg/kg dry weight
Water [Se]	=	Total recoverable waterborne Se concentration in mg/L

At a water concentration of 10 µg/L total Se, the predicted Se concentration in benthic invertebrate tissue would be 15.6 mg/kg.

4.1.3 Comparison of Predicted to Measured Se Bioaccumulation

Table 11 shows the predicted concentrations of Se in tissue based on the regression equations described above, as well as the associated measured concentrations.

For each tissue sampling event, the predicted Se concentration was calculated based on Se water concentrations for a period of 1 to 6 months prior to the tissue sampling event (depending on how often tissue was collected). It should be noted that in many cases, insufficient tissue biomass was available to allow for measurement of moisture content; therefore, dry weight Se concentrations were estimated for those samples based on assumed moisture content.

For the first pond tissue sampling event in May 2005, all of the measured Se tissue concentrations were substantially higher than the predicted Se tissue concentrations. It should be noted that most of these dry weight values were estimated due to lack of moisture content data. The results of the speciation analysis (see Table 5) for the first time period (between starting up and seeding the ponds in October 2004 and first tissue collection in May 2005) indicate that a high percentage of the Se was present as SeCN for the first couple of months, and as organic Se for the remaining months. The Se concentrations in nektonic invertebrates (primarily waterboatmen) in Pond 1 was especially high (the dry weight concentration was estimated for this sample).

For the second sampling event in July 2005, Se tissue concentration in nektonic invertebrates correlated very well with predicted concentrations, while the concentration in benthic invertebrates (primarily chironomids) collected from Pond 2 were lower than predicted (the dry weight concentration was estimated for this sample). It should be noted that no new effluent had been fed to the ponds for several months prior to sample collection, and the Se speciation regime changed substantially (less organic Se was present in July than in May).

For the third sampling event, which occurred in September 2005 after the ponds received effluent from the new system, Se tissue concentrations in nektonic invertebrates were predicted based not only on the Se concentrations measured in the pondwater, but also incorporated the Se concentration measured in effluent on a weekly basis. Se concentrations in effluent varied considerably during startup of the new system, and the highest concentration measured was 97.7 µg/L. Measured Se concentrations in nektonic invertebrates were substantially (2 to 17 times) higher than predicted concentrations.

For the fourth and fifth sampling events, which occurred in October 2005, measured Se concentrations in nektonic invertebrates were roughly 1 to 3 times higher than predicted concentrations. Measured Se concentrations in benthic invertebrates were lower than (about half) the concentration predicted.

While the organic form of Se in Ponds 1 and 2 increased in concentration during the periods when the system was receiving effluent, the concentration of organic Se in Pond 3 remained relatively constant throughout the entire period. Highest Se concentrations generally occurred in Pond 1, even though average Se concentrations in water were not generally higher than in the other ponds. This indicates that Se may be more bioavailable when it first comes out of the treatment system, but is less bioavailable once it reaches the other ponds. It should be noted, however, that the two highest Se tissue concentrations in Pond 1 were estimated based on assumed moisture content.

There was considerable variability in the Se tissue concentrations. Some of this variability may be due to the uncertainty incorporated by estimating dry weight concentrations based on assumed moisture content.

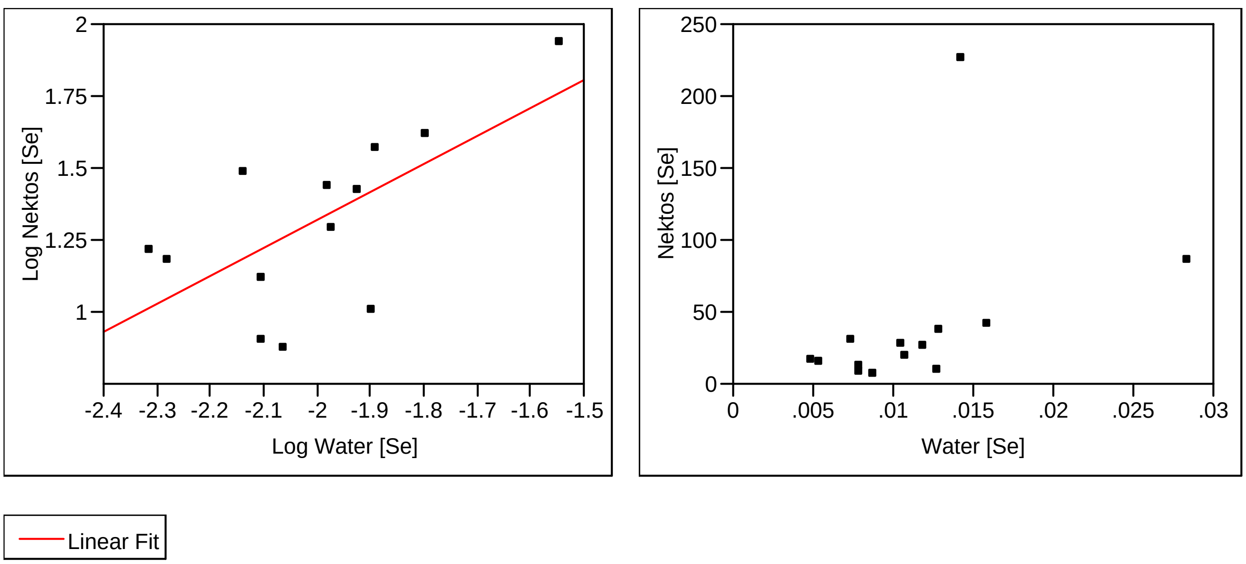
In order to determine how well Se tissue concentrations correlated with Se concentrations in water, tissue concentrations were plotted against the water concentrations and a regression was calculated using the same method as that used for historical data described in Section 4.1.2:

$$\text{Nektos [Se]} = 10^{3.2598612 + 0.9717492 \ \text{Log Water}_{10} \text{[Se]}}$$

Where:

Nektos [Se]	=	Nektos tissue Se concentration in mg/kg dry weight
Water [Se]	=	Total recoverable waterborne Se concentration in mg/L

Bivariate Fit of Log Nektos [Se] By Log Water [Se]



Linear Fit
Log Nektos [Se] = 3.2598612 + 0.9717492 Log Water [Se]

Summary of Fit

R^2	0.421511
R^2 Adj	0.368921
Root Mean Square Error	0.243002
Mean of Response	1.31229
Observations (or Sum Wgts)	13

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.4732870	0.473287	8.0151
Error	11	0.6495476	0.059050	Prob > F
C. Total	12	1.1228345		0.0163

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.2598612	0.691217	4.72	0.0006
Log Water [Se]	0.9717492	0.343243	2.83	0.0163

It should be noted that the equation above does not include the tissue concentration of 225.7 mg/kg that was estimated for the first sampling event. This estimated concentration was considered an outlier and was removed from the data set.

When the new regression equation above is used to calculate the Se tissue concentration for nektonic invertebrates assuming a Se water concentration of 10 µg/L, the resulting tissue concentration is 20.7 mg/kg, roughly twice the concentration calculated using the regression equation based on historical data (8.7 mg/kg). This indicates that the bioavailability of Se is likely to increase somewhat after biological treatment due to a higher proportion of organic Se than was reflected in the original dataset used to develop the regressions for the risk assessment. Reclamation is incorporating an oxidation treatment at the end of the biological treatment process that will likely reduce the bioavailability of biotreated drainwater. Adaptive monitoring and management will be used to determine the effectiveness of the biotreatment process in reducing Se accumulation in birds and to develop corrective action strategies as needed.

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TABLES

Table 1a. Biotreatment System Analytical Methods for Water and GAC Samples in 2004

Matrix	Analyte	Method
Water	Selenium, total	Oxidative digestion followed by ICP-DRC-MS
	Selenium, dissolved	Filtered, oxidative digestion followed by ICP-DRC-MS
	"Inorganic" Selenium, dissolved	Filtered, pH adjusted to 1.5-2.0, passed through C-18, oxidative digestion followed by ICP-DRC-MS
	Selenite and Selenate	IC-ICP-MS
	Chlorophyll a	SM 10200H
	Conductivity	FGS-079
GAC	Selenium, total	Oxidative digestion followed by ICP-DRC-MS
	Selenium, TCLP	TCLP extraction followed by ICP-DRC-MS
	Selenium, STLC	STLC extraction followed by ICP-DRC-MS

Table 1b. Biotreatment System Analytical Methods for Water Samples in 2005

Matrix	Analyte	Method
Water	Selenium, total	Alkaline peroxide digestion followed by ICP-DRC-MS
	Selenium, dissolved	Filtered, aklaline peroxide digestion followed by ICP-DRC-MS
	"Inorganic" Selenium, dissolved	Filtered, pH adjusted to 1.5-2.0, passed through C-18, oxidative digestion followed by ICP-DRC-MS
	Selenite and Selenate	IC-ICP-MS
	Chlorophyll a	SM 10200H
	Conductivity	FGS-079
	BOD	EPA 405.1
	COD	EPA 410.4

URS

Table 2. Summary of Biotreatment System Water Sample Results for Selected Analytes

Sample ID	Sampling Date	A Total Se [µg/L] measured	B Dissolved Se [µg/L] measured	Particulate Se [µg/L] calculated A-B	C Dissolved Inorganic Se [µg/L] measured	D Dissolved Se(IV) [µg/L] measured	E Dissolved Se(VI) [µg/L] measured	F Dissolved SeCN [µg/L] measured	Elemental + Organic Se [µg/L] calculated B (or C)-D-E-F	Conductivity [µS/cm]	Chlorophyll a [mg/m3]	BOD [mg/L]	COD [mg/L]
RR-INF-1004	10/22/2004	945	925	20	947	6.7	770	<2.3	146	na	<5	na	na
RR-BIO1-1004	10/22/2004	296	63.2	233	1040	231	668	<1.2	139.8	na	<5	na	na
RR-BIO2-1004	10/22/2004	29.2	9.6	19.6	55.1	1.51	30.3	12.5	10.8	na	<5	na	na
% removal	(INF-BIO2/INF)	97%	99%	2%	94%	77%	96%	-443%	93%				
RR-INF-1204	12/9/2004	1030	1020	10	1142	4.1	567	<1.3	447.6	8.3	<5	na	na
RR-BIO1-1204	12/9/2004	384	362	22	397	202	<0.83	<0.65	158.52	8.2	<5	na	na
RR-BIO2-1204	12/9/2004	<9.8	<9.8	nc	11.4	<0.50	<0.41	2.16	8.33	8.2	<5	na	na
% removal	(INF-BIO2/INF)	99%	99%	nc	99%	88%	100%	-66%	98%				
RR-INF-0705	7/28/2005	974	947	27	999	9.67	783	<1.1	205.2	10.2	na	na	na
RR-BIO1-0705	7/28/2005	443	294	149	576	302	8.23	1.23	264.5	10.1	na	na	na
RR-BIO2-0705	7/28/2005	22.7	1.93	20.77	2.48	0.482	<0.037	0.62	1.3	9.8	na	na	na
% removal	(INF-BIO2/INF)	98%	100%	23%	100%	95%	100%	44%	-22%				
RR-INF-0805	8/30/2005	937	922	15	915	7.09	820	<1.4	86.5	9.6	na	na	na
RR-BIO1-0805	8/30/2005	892	881	11	1020	8.73	916	<1.4	93.9	9.5	na	na	na
RR-BIO2-0805	8/30/2005	3.53	2.40	1.13	2.53	0.383	0.97	0.91	0.3	8.5	na	na	na
% removal	(INF-BIO2/INF)	100%	100%	92%	100%	95%	100%	35%	100%				
RR-INF-0905	9/29/2005	1020	1010	10	922	7	1020	<0.42	-105.4	9	na	<6	78.4
RR-BIO1-0905	9/29/2005	16.5	9.38	7.12	2.88	1.62	3.24	<0.42	-2.4	9.2	na	29	175
RR-BIO2-0905	9/29/2005	17.4	7.26	10.14	3.27	0.182	<0.15	0.89	2.0	9.3	na	<375	372
% removal	(INF-BIO2/INF)	98%	99%	-1%	100%	97%	100%	-112%	102%				

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Table 2. Summary of Biotreatment System Water Sample Results for Selected Analytes

Sample ID	Sampling Date	A Total Se [µg/L] measured	B Dissolved Se [µg/L] measured	Particulate Se [µg/L] calculated A-B	C Dissolved Inorganic Se [µg/L] measured	D Dissolved Se(IV) [µg/L] measured	E Dissolved Se(VI) [µg/L] measured	F Dissolved SeCN [µg/L] measured	Elemental + Organic Se [µg/L] calculated B (or C)-D-E-F	Conductivity [µS/cm]	Chlorophyll a [mg/m3]	BOD [mg/L]	COD [mg/L]
RR-INF-1005	10/26/2005	1250	1240	10	1120	1.57	939	<0.70	298.7	8.8	na	12	84.6
RR-BIO1-1005	10/26/2005	205	75.7	129.3	26.9	4.47	<0.48	10.5	60.3	8.8	na	887	2860
RR-BIO2-1005	10/26/2005	61.5	14.6	46.9	7.09	2.43	3.46	4.39	4.3	9.2	na	568	2510
% removal	(INF-BIO2/INF)	95%	99%	-369%	99%	-55%	100%	-527%	99%				
RR-INF-1105	11/30/2005	1000	947	53	995	4.29	921	<0.14	21.6	8.4	na	2	55.0
RR-BIO1-1105	11/30/2005	972	960	12.0	936	156	695	<0.14	108.9	8.4	na	32	bb
RR-BIO2-1105	11/30/2005	484	345	139.0	297	168	56.9	3.33	116.8	8.4	na	10	80
% removal	(INF-BIO2/INF)	52%	64%	-162%	70%	-3816%	94%	-2279%	-441%				
PAN-RO-1004	10/22/2004	695	677	18	703	<3.6	499	<2.3	172.1	na	<5	na	na
PAN-INF-1004	10/22/2004	1530	1350	180	1380	<3.6	1270	<2.3	74.1	na	<5	na	na
PAN-BIO1-1004	10/22/2004	1220	973	247	1080	219	631	<2.3	120.7	na	<5	na	na
PAN-BIO2-1004	10/22/2004	53.7	46.2	7.5	35.7	18.6	<0.78	2.36	24.46	na	<5	na	na
% removal	(INF-BIO2/INF)	96%	97%	96%	97%	-417%	100%	-3%	67%				
PAN-RO-1204	12/9/2004	174	176	-2	184	<2.0	144	<1.3	28.7	4.3	<5	na	na
PAN-INF-1204	12/9/2004	171	173	-2	187	<2.0	137	<1.3	32.7	4.2	<5	na	na
PAN-BIO1-1204	12/9/2004	214	213	1	235	<2.0	61.3	<1.3	148.4	7.9	<5	na	na
PAN-BIO2-1204	12/9/2004	<9.8	<9.8	nc	26.4	<0.50	0.44	20.1	5.4	7.9	<5	na	na
% removal	(INF-BIO2/INF)	94%	94%	nc	86%	nc	100%	-1446%	84%				
PAN-INF-0705	7/28/2005	375	365	10	377	<0.55	292	<2.1	82.4	5.5	na	na	na
PAN-BIO1-0705	7/28/2005	16.0	14.7	1.3	26.0	6.93	2.98	2.22	13.9	5.4	na	na	na
PAN-BIO2-0705	7/28/2005	8.88	2.77	6.11	4.27	0.708	0.682	0.43	2.5	5.5	na	na	na
% removal	(INF-BIO2/INF)	98%	99%	39%	99%	-29%	100%	80%	97%				

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Table 2. Summary of Biotreatment System Water Sample Results for Selected Analytes

Sample ID	Sampling Date	A Total Se [µg/L] measured	B Dissolved Se [µg/L] measured	Particulate Se [µg/L] calculated A-B	C Dissolved Inorganic Se [µg/L] measured	D Dissolved Se(IV) [µg/L] measured	E Dissolved Se(VI) [µg/L] measured	F Dissolved SeCN [µg/L] measured	Elemental + Organic Se [µg/L] calculated B (or C)-D-E-F	Conductivity [µS/cm]	Chlorophyll a [mg/m3]	BOD [mg/L]	COD [mg/L]
PAN-INF-0805	8/30/2005	1170	1200	-30	1270	<0.23	921	<1.4	347.4	15.0	na	<9	57.1
PAN-BIO1-0805	8/30/2005	159	87.3	71.7	46.6	3.87	11.0	9.61	22.1	14.8	na	620	1310
PAN-BIO2-0805	8/30/2005	2.81	1.65	1.16	1.68	<0.028	<0.17	1.20	0.3	14.2	na	36	214
% removal	(INF-BIO2/INF)	100%	100%	-104%	100%	88%	100%	14%	100%				
PAN-INF-0905	9/29/2005	1650	1570	80	1550	<0.22	1420	<0.42	129.36	16.7	na	<2	73.4
PAN-BIO1-0905	9/29/2005	592	597	-5	569	200	337	0.85	31.2	11.2	na	109	244
PAN-BIO2-0905	9/29/2005	25.0	11.6	13.4	8.90	1.39	0.25	2.14	5.1	10.7	na	20	141
% removal	(INF-BIO2/INF)	98%	99%	83%	99%	-532%	100%	-410%	96%				
PAN-INF-1005	10/26/2005	1820	1840	-20	1550	<1.2	1730	<3.5	105.3	13.3	na	<1	34.7
PAN-BIO1-1005	10/26/2005	1770	1736	34	1510	160	1640	<1.8	-65.8	13.2	na	<12	106
PAN-BIO2-1005	10/26/2005	310	200	110	183	79	129	2.50	-10.7	13.3	na	13	272
% removal	(INF-BIO2/INF)	83%	89%	650%	88%	-6500%	93%	29%	110%				
PAN-INF-1105	11/30/2005	335	322	13	328	<0.27	291	<0.14	30.6	5.4	na	11	68.9
PAN-BIO1-1105	11/30/2005	291	258	33	280	44.5	174	<0.067	39.6	5.5	na	43	67.2
PAN-BIO2-1105	11/30/2005	166	13.2	153	7.49	6.12	<0.077	3.63	3.5	5.6	na	124	186
% removal	(INF-BIO2/INF)	50%	96%	-1075%	98%	-2167%	100%	-2493%	88%				

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Table 3. Bioreactor Granular Activated Carbon Results (preliminary results)

Sample ID	Description	Sampling Date	Total Se [mg/Kg wet wt.]	TCLP Se [ug/L]	STLC Se [ug/L]
RR-GAC1-1004	Red Rock Bioreactor 1	10/22/2004	631	60.6	12.8
RR-GAC2-1004	Red Rock Bioreactor 2	10/22/2004	182	2.72	2.18
PAN-GAC1-1004(AVG)	Panoche Bioreactor 1	10/22/2004	286	33.3	14.1
PAN-GAC2-1004	Panoche Bioreactor 2	10/22/2004	93.1	96.9	7.21

Table 4. Evaporation Pond Analytical Methods for Water and Tissue Samples

Matrix	Dates	Analyte	Method
Water	October 2004, December 2004, January 2005	Selenium, total	Oxidative digestion followed by ICP-DRC-MS
		Selenium, dissolved	Filtered, oxidative digestion followed by ICP-DRC-MS
		"Inorganic" Selenium, dissolved	Filtered, pH adjusted to 1.5-2.0, passed through C-18, oxidative digestion followed by ICP-DRC-MS
		Selenite and Selenate	IC-ICP-MS
		Chlorophyll a	SM 10200H
		Conductivity	FGS-079
Water	May 2005	Selenium, total	Oxidative digestion followed by HG-AFS
		Selenium, dissolved	Filtered, oxidative digestion followed by HG-AFS
		"Inorganic" Selenium, dissolved	Filtered, pH adjusted to 1.5-2.0, passed through C-18, oxidative digestion followed by HG-AFS
		Selenite and Selenate	IC-ICP-MS
		Chlorophyll a	SM 10200H
		Conductivity	FGS-079
Water	July, August, September, November 2005	Selenium, total	Alkaline peroxide digestion followed by HG-AFS
		Selenium, dissolved	Filtered, alkaline peroxide digestion followed by HG-AFS
		"Inorganic" Selenium, dissolved	Filtered, pH adjusted to 1.5-2.0, passed through C-18, oxidative digestion followed by HG-AFS
		Selenite and Selenate	IC-ICP-MS
		Chlorophyll a	SM 10200H
		Conductivity	FGS-079
		BOD	EPA 405.1
		COD	EPA 410.4
Tissue	September 2004	Selenium, total	Oxidative digestion followed by ICP-MS
		Percent moisture	Gravitational
Tissue	May 2005	Selenium, total	Oxidative digestion followed by HG-AFS
		Percent moisture	Gravitational

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Table 5. Summary of Evaporation Pond Results for Selected Analytes

Sample ID	Pond	Sampling Date	A Total Se [µg/L] measured	B Dissolved Se [µg/L] measured DSe	Particulate Se [µg/L] calculated A-B PSe	C Dissolved Inorganic Se [µg/L] measured ISe	D Dissolved Se(IV) [µg/L] measured SeIV	E Dissolved Se(VI) [µg/L] measured SeVI	F Dissolved SeCN [µg/L] measured SeCN	Elemental + Organic Se [µg/L] calculated B (or C)-D-E-F Se-II+0	Conductivity [µS/cm]	Chlorophyll a [mg/m3]	BOD [mg/L]	COD [mg/L]
PAN-EVAP1-1004(AVG)	Pond 1	10/22/2004	21.1	19.5	1.6	17.9	2.65	2.15	15	-0.3	na	6.4	na	na
PAN-EVAP1-1204	Pond 1	12/9/2004	<9.8	<9.8	nc	17.4	<0.50	1.39	3.68	11.8	8.8	200	na	na
PAN-EVAP1-0105	Pond 1	1/31/2005	11.3	9.1	2.2	8.75	2.62	1.06	<0.25 UJ	5.2	7.6	32	na	na
PAN-EVAP1-0505	Pond 1	5/12/2005	14	10.7	3.3	5.76	2.78	0.064	na	7.9	8.8	140	na	na
PAN-EVAP1-0705	Pond 1	7/28/2005	3.11	2.82	0.29	2.28	0.777	<0.037	<0.27	2.0	10.8	19	na	na
PAN-EVAP1-0805	Pond 1	8/30/2005	14.5	8.94	5.56	4.53	1.02	1.34	<0.18	6.6	11.5	110	30	360
PAN-EVAP1-0905	Pond 1	9/29/2005	5.27	4.29	0.98	0.445	0.38	0.26	<0.10	3.7	14.0	72	24	209
PAN-EVAP1-1005(AVG)	Pond 1	10/26/2005	5.13	3.58	1.55	1.46	0.31	0.35	<0.18	2.9	16.2	100.5	96	618.5
PAN-EVAP1-1105	Pond 1	11/30/2005	4.38	3.88	0.50	2.04	0.27	<0.077	<0.033	3.5	17.4	510	70	430
PAN-EVAP2-1004	Pond 2	10/22/2004	20.3	22	-1.7	12	2.14	1.39	5.85	12.6	na	<5	na	na
PAN-EVAP2-1204	Pond 2	12/9/2004	13.4	<9.8	3.6	19.8	3.43	1.82	<0.32	14.2	9.2	250	na	na
PAN-EVAP2-0105	Pond 2	1/31/2005	10.7	9.67	1.0	10.4	3.7	1.06	<0.25 UJ	4.7	7.5	9.6	na	na
PAN-EVAP2-0505(AVG)	Pond 2	5/12/2005	18.85	15.5	3.4	9.77	6.8	1.73	na	7.0	7.15	66.5	na	na
PAN-EVAP2-0705(AVG)	Pond 2	7/28/2005	12.95	6.04	6.91	5.09	0.82	0.039	<0.27	5.2	33.3	155	na	na
PAN-EVAP2-0805	Pond 2	8/30/2005	11.1	10.6	0.5	8.83	1.70	5.25	<0.18	3.7	11.8	34	12	280
PAN-EVAP2-0905	Pond 2	9/29/2005	10.7	10.2	0.5	7.96	2.29	0.98	<0.10	6.9	16.2	32	14	231
PAN-EVAP2-1005	Pond 2	10/26/2005	10.1	8.72	1.38	5.14	2.16	0.90	<0.18	5.7	20.3	77	16	608
PAN-EVAP2-1105(AVG)	Pond 2	11/30/2005	11.12	8.43	2.69	5.28	1.57	<0.077	<0.033	6.8	23.05	265	51	391.5
PAN-EVAP3-1004	Pond 3	10/22/2004	8.7	7.5	1.2	9.06	3.12	<0.78	0.96	4.2	na	<5	na	na
PAN-EVAP3-1204(AVG)	Pond 3	12/9/2004	12.9	<9.8	3.1	13.6	4.69	<0.41	<0.32	8.2	8.6	215	na	na
PAN-EVAP3-0105(AVG)	Pond 3	1/31/2005	10.6	10.0	0.5	10.2	2.8	0.7	<0.25 UJ	6.3	7.4	24	na	na
PAN-EVAP3-0505	Pond 3	5/12/2005	18.9	14.1	4.8	10	1.79	6.91	na	5.4	6.8	130	na	na
PAN-EVAP3-0705	Pond 3	7/28/2005	6.23	5.12	1.11	2.45	0.258	0.467	<0.27	4.4	18.1	31	na	na
PAN-EVAP3-0805(AVG)	Pond 3	8/30/2005	9.74	9.19	0.55	6.12	1.93	1.37	<0.18	5.9	13.8	44.5	14	321
PAN-EVAP3-0905	Pond 3	9/29/2005	8.15	7.43	0.72	0.182	0.46	0.50	<0.10	6.5	16.9	50	14	314
PAN-EVAP3-1005	Pond 3	10/26/2005	7.48	6.76	0.72	3.91	1.47	0.66	<0.18	4.6	19.3	72	16	486
PAN-EVAP3-1105	Pond 3	11/30/2005	8.21	7.12	1.09	2.44	1.29	<0.077	<0.033	5.8	20.8	81	28	363

na - not analyzed
nc - not calculable

Table 6. Aquatic Invertebrates Collected from Treatment Ponds, 2005 Collection Dates

Scientifiic Name	Common Name	Pond 1	Pond 2	Pond 3
Corixidae	Waterboatman	5/12, 7/28, 9/30, 10/26, 11/30	5/12, 7/28, 9/30, 10/26, 11/30	5/12, 7/28, 9/30, 10/26, 11/30
Notonectid	Backswimmer	5/12	5/12, 9/30	9/30
Chironomid	Midge		5/12, 7/28, 9/30, 10/26, 11/30	11/30
Tubifera sp.	Rat-tailed maggot		7/28, 9/30	
Ephydridae	Shore flies		7/28, 9/30, 10/26, 11/30	9/30
Anisoptera	Dragonfly (nymph)		9/30	
Dytiscidae	Predaceous diving beetle (adult)	5/12	5/12	5/12
Nematodes	Round worms		7/28	

Table 7. Sample Contents

		5/12/05	7/28/05	9/30/05	10/26/05	11/30/05
Pond 1	Sample 1	Corixidae, 1 Dytiscidae	Aufwuchs	Corixidae (small amount of organic debris)	Corixidae	Corixidae
	Sample 2		Aufwuchs	Corixidae	Corixidae	Corixidae
	Sample 3		Aufwuchs		Corixidae	Corixidae
Pond 2	Sample 1	Corixidae, Notonectid, Chironomid, Tendipedid	Ephydridae, chironomids, *Tubifera sp.*	Anisoptera, chironomid, Ephydridae, Corixid, *Tubifera sp.*	Corixidae	Corixidae
	Sample 2	Chironomids[1]	Sediment		Corixidae	Corixidae
	Sample 3		Sediment		Corixidae	Corixidae
	Sample 4		Sediment		Chironomids, Ephydridae[2]	Corixidae[2]
	Sample 5					Chironomids[1]
	Sample 6					Ephydridae[1]
Pond 3	Sample 1	Corixidae, 1 Dytiscid, 1 Notonectid	Aufwuchs	Mostly Corixidae	Corixidae	Corixidae
	Sample 2		Aufwuchs	Mostly Corixidae	Corixidae	Corixidae
	Sample 3		Aufwuchs		Corixidae	Chironomids[1]

[1]Benthic sampling
[2]Pond 2 replicate sampling

Table 8. Pond Salinity

	5/12/05	7/28/05	9/30/05	10/26/05	11/30/05
Pond 1	No data	13 ppt	17 ppt	24 ppt	25 ppt
Pond 2	No data	45 ppt	21 ppt	30 ppt	34 ppt
Pond 3	No data	25 ppt	23 ppt	28 ppt	30 ppt

Table 9. Water Column Biomass

Date	Pond 1		Pond 2		Pond 3	
	Total number of organisms	**Invertebrate Biomass**	**Total number of organisms**	**Invertebrate Biomass**	**Total number of organisms**	**Invertebrate Biomass**
5/12/05	36 Corixidae	0.45 g / m^3 water	7 Corixidae	<0.15 g / m^3 water	7 Corixidae, 1 Dytiscid	0.45 g / m^3 water
7/28/05	11 Corixidae	<0.75 g / m^3 water	5 *Tubifera*	4.98 g / m^3 water	No invertebrates observed	
9/30/05	178 Corixidae	0.56 g / m^3 water	2 Notonectids, 71 Corixidae, 3 Ephydridae	0.14 g/ m^3 water	39 Corixidae, 2 Ephydridae, 1 Notonectid	0.18 g / m^3 water
10/26/05	94 Corixidae	0.66 g / m^3 water	314 Corixidae	1.53 g / m^3 water	141 Corixidae	0.75 g / m^3 water
11/30/05	No Count	0.08 g / m^3 water	No Count	3.16 g / m^3 water	No Count	14.52 g / m^3 water

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Table 10. Tissue Results

Sample ID	Organism Type	Sampling Date	Total Se [mg/Kg wet wt.]	Percent Moisture [%]	Total Se [mg/Kg dry wt.]
Sample 1-TLDD seed organisms	Water Boatmen	11/9/2004	1.56	93.3	23.3
Sample 2-TLDD seed organisms	Water Boatmen	11/9/2004	1.73	92.9	24.4
Sample 3-TLDD seed organisms	Water Boatmen	11/9/2004	1.45	92.8	20.1
Pond 1 Sample 1 (nektonic)	Water Boatmen + others	5/12/2005	15.8	na	225.7
Pond 2 Sample 1 (nektonic)	Water Boatmen + others	5/12/2005	3.24	na	46.3
Pond 2 Sample 2 (benthic)	Chironomids	5/12/2005	8.04	80.6	41.4
Pond 3 Sample 1 (nektonic)	Water Boatmen + others	5/12/2005	2.62	na	37.4
Pond 1-2 AUF	Aufwuchs	7/28/2005	0.374	93.8	6.0
Pond 1-3 AUF	Aufwuchs	7/28/2005	0.522	94.2	9.0
Pond 2-1 BEN	Benthic	7/28/2005	0.880	na	4.5
Pond 2-2 SED	Sediment	7/28/2005	1.03	67.1	3.1
Pond 2-4 SED	Sediment	7/28/2005	0.970	68.4	3.1
Pond 2-BRANCHES	Branches	7/28/2005	0.987	na	nc
Pond 3-2 AUF	Aufwuchs	7/28/2005	0.806	92.7	11
Pond 3-3 AUF	Aufwuchs	7/28/2005	0.646	93.1	9.4
Pond 1 #1	Water boatmen & small amount of organic debris	9/30/2005	6.08	na	86.9
Pond 1 #2	water boatmen	9/30/2005	6.02	na	86.0
Pond 2	mixture of water boatmen, dragonfly nymphs, shore fly larva	9/30/2005	4.86	81.6	26.4
Pond 3 #1	mostly water boatmen	9/30/2005	3.82	80.5	19.6
Pond 3 #2	mostly water boatmen	9/30/2005	10.8	73.8	41.2
Pond 1 #1	water boatmen	10/26/2005	2.48	80.1	12.5
Pond 1 #2	water boatmen	10/26/2005	3.61	76.9	15.6
Pond 1 #3	water boatmen	10/26/2005	3.89	78.9	18.4
Pond 1 #4 (field rep for QA/QC)	water boatmen	10/26/2005	2.83	79.6	13.9
Pond 2 #1	water boatmen	10/26/2005	3.58	84.6	23.2
Pond 2 #2	water boatmen	10/26/2005	3.03	84.6	19.7
Pond 2 #3	water boatmen	10/26/2005	2.24	87.6	18.1
Pond 2 #4	*Chironomids* and *Ephydridae*	10/26/2005	1.93	96	48.3
Pond 3 #1	water boatmen	10/26/2005	2.11	84.7	13.8
Pond 3 #2	water boatmen	10/26/2005	1.97	85.9	14.0
Pond 3 #3	water boatmen	10/26/2005	1.47	87.1	11.4
Pond 1a	waterboatmen	11/30/2005	3.16	85.8	22.2
Pond 1b	waterboatmen	11/30/2005	2.24	84.7	14.7
Pond 1c	waterboatmen	11/30/2005	2.33	81.6	12.6
Pond 2a	waterboatmen	11/30/2005	3.50	81.3	18.7
Pond 2b	waterboatmen	11/30/2005	3.59	83.3	21.5
Pond 2c	waterboatmen	11/30/2005	3.11	84.3	19.8
Pond 2d	Chironomids	11/30/2005	0.87	na	4.5
Pond 2e	Ephydrid pupae	11/30/2005	0.82	93.1	11.8
Pond 4a (blind field rep from pond 2)	waterboatmen	11/30/2005	2.75	85.1	18.4
Pond 3a	waterboatmen	11/30/2005	1.79	81.7	9.76
Pond 3b	waterboatmen	11/30/2005	1.32	82.8	7.65
Pond 3c	waterboatmen	11/30/2005	1.44	83.6	8.79
Pond 3d	Chironomids	11/30/2005	0.48	92.0	5.97

na - not analyzed
nc - not calculated

Note - Dry weight was calculated using an estimate of percent moisture where percent moisture was not available.

Table 11. Selenium Concentrations in Water versus Tissue

5/12/2005

Pond	Total Se in Water (ug/L)					Predicted Tissue Concentration (mg/kg Se dry weight)		Actual Tissue Concentration (mg/kg Se dry weight)	
	10/22/2004	12/9/2004	1/31/2005	5/12/2005	Average	Benthic Invertebrates	Nektonic Invertebrates	Benthic Invertebrates	Nektonic Invertebrates
1	21.1	9.8	11.3	14	14.1	20.7	10.5		225.7
2	20.3	13.4	10.7	18.85	15.8	22.9	11.3	46.3	41.4
3	8.7	12.9	10.6	18.9	12.8	19.2	10.0		37.4

7/28/2005

Pond	Total Se in Water (ug/L)					Predicted Tissue Concentration (mg/kg Se dry weight)		Actual Tissue Concentration (mg/kg Se dry weight)	
	5/12/2005	7/28/2005			Average	Benthic Invertebrates	Nektonic Invertebrates	Benthic Invertebrates	Nektonic Invertebrates
1	14	3.11			8.6	13.7	7.9		7.5
2	18.85	12.95			15.9	23.0	11.3	4.5	
3	18.9	6.23			12.6	18.9	9.9		10.2

9/30/2005

Pond	Total Se in Water (ug/L)							Predicted Tissue Concentration (mg/kg Se dry weight)		Actual Tissue Concentration (mg/kg Se dry weight)	
	7/28/2005	8/2/2005	8/9/2005	8/16/2005	8/23/2005	9/29/2005	Average	Benthic Invertebrates	Nektonic Invertebrates	Benthic Invertebrates	Nektonic Invertebrates
1	3.11	23	97.7	21.8	18.7	5.27	28.3	37.2	15.7		86.4
2	12.95					10.7	11.8	18.0	9.5		26.4
3	6.23					8.15	7.2	11.9	7.2		30.4

10/26/2005

Pond	Total Se in Water (ug/L)					Predicted Tissue Concentration (mg/kg Se dry weight)		Actual Tissue Concentration (mg/kg Se dry weight)	
	9/29/2005	10/26/2005			Average	Benthic Invertebrates	Nektonic Invertebrates	Benthic Invertebrates	Nektonic Invertebrates
1	5.27	5.13			5.2	9.0	6.0		15.1
2	10.7	10.1			10.4	16.1	8.9		27.3
3	8.15	7.48			7.8	12.7	7.5		13.1

11/30/2005

Pond	Total Se in Water (ug/L)					Predicted Tissue Concentration (mg/kg Se dry weight)		Actual Tissue Concentration (mg/kg Se dry weight)	
	10/26/2005	11/30/2005			Average	Benthic Invertebrates	Nektonic Invertebrates	Benthic Invertebrates	Nektonic Invertebrates
1	5.13	4.38			4.8	8.4	5.7		16.5
2	10.1	11.12			10.6	16.4	9.0	8.15	19.6
3	7.48	8.21			7.8	12.8	7.6		8.0

Appendix A
Biology Field Reports

URS

Date: November 18, 2004

To: Selenium Bioaccumulation Study project file (18600809)

From: Francesca Demgen

Subject: ***Pilot Project Inoculation with Aquatic Invertebrates***

On November 9, 2004 Francesca Demgen and Kevin Fisher drove to the Tulare Lake Drainage District (TLDD) located in Corcoran, California. We were escorted by Larry Davis (TLDD staff) to Cell 2 in the South Evaporation Basin series of ponds. Aquatic invertebrates from the shallow water column (less than three feet deep) were collected using nets. The dominant aquatic macroinvertebrate in the large open water pond (i.e. no emergent vegetation) was water boatmen (Corixidae). A very small proportion of the aquatic macroinvertebrate community was comprised of backswimmers (Notonectidae) and exuviae (empty cases of aquatic insects). Fish (probably *Gambusia affinis*)were present in the pond, also in very small numbers relative to the waterboatmen population. These later 3 organism types were removed from the samples to be submitted to the laboratory, but not from the material for pond inoculation. Pond surface water salinity was 20 parts per thousand, measured using a refractometer.

Three composite samples of greater than or equal to 5 grams each were placed in separate glass jars and the jars were sealed in plastic bags. The samples were shipped on November 19, 2004 to Frontier Geosciences in Seattle, Washington and no preservatives were used. A chain of custody sheet accompanied the samples and indicated that total selenium and percent moisture were to be analyzed.

The sample to be transferred to the Panoche site pilot project ponds was transported in a cooler, in Cell 2 ambient water plus ice. An air bubbler was used to aerate the sample. The entire sample was placed in the first pilot project pond.

Prior to introducing the inoculant, the pond water column and liner surface were sampled to identify pre-existing aquatic macroinvertebrates. Water boatmen were present in the pond. Qualitative observations, based in the number of individuals retrieved in the net, suggest that the population density was small as compared to the population in Cell 2 at TLDD.

Recommendation

The population in the pilot project basins needs time to increase. Rapid population growth will not occur over the winter due to the colder weather. It is recommended that samples of invertebrates not be collected (i.e. removed) from the pond during the winter months to allow the population to expand come spring, so that there are sufficient organisms available for sampling next summer.

URS

Date: May 24, 2005

To: Terry Cooke

From: Francesca Demgen

Subject: ***Selenium Pilot Study Invertebrate Sampling***

A field site visit was conducted on May 12, 2005 to the selenium pilot study ponds located in Firebaugh, California.

Methods

Two sample collection methods were used. The water column was sampled for nektonic invertebrates using a net and the benthic invertebrate sample was collected using a bailer.

Nekton Invertebrate Collection: Samples were collected using a 0.5 millimeter mesh D-frame net. Water column samples were clean (i.e. no sediment and very minimal organic debris was in net) and organisms were individually removed from the net and placed in glass jars. The jars were provided by the laboratory. The first 3 collection sweeps from each pond were collected from a twenty foot long transect parallel to the edge of the pond. Transect length was determined by measuring the maximum length possible without rounding any corners on the smallest pond. Invertebrates captured during the first 3 sweeps were identified and counted. After that organisms were identified but not enumerated, to collect a total of 0.5 grams of invertebrates.

Benthic Invertebrate Collection: A plastic bailer was used to check for benthic invertebrates. It was lowered to the bottom of the pond and dragged up the liner to try and sample attached or benthic organisms. The sample was screened in a No. 35 Standard Test Sieve (500 micron mesh). Pond water was used to wash the sample and chironomids were transferred from the sieve to a glass sample bottle.

Sample bottles were labeled, double bagged, recorded on a Chain of Custody form and shipped to the laboratory the same day.

Results, Observations, Recommendations

Table 1 contains a list of the organisms collected and submitted to the laboratory for analysis of total selenium and percent moisture. Algae was not sampled because there was no colonial, filamentous or algal mats present. Benthic invertebrates were only present in pond 2.

Pond 1 was the only pond with significant reproduction of water boatmen (Corixids). Water was not flowing from pond 1 to the other 2 ponds. This is affecting abundance and distribution of water boatmen in the other ponds. The predaecous diving beetles (Dytiscids) were observed flying and diving into the ponds. This means any selenium content in their tissues is not necessarily from the ponds they were collected from. Both water boatmen and backswimmers (Notonectids) can also fly but were not observed doing so during the sampling event). Pond 2 has soil on the bottom that provides habitat for midge larvae (Chironomids and other Tendipedids). The soil should be analyzed to determine selenium concentration.

Only 1 sample of nekton was collected and submitted from each pond because I still have concerns about depleting the population. Since reproduction appears to only be occuring in pond 1 and there is no flow between pond 1 and the others, this is even more of a concern. There were times when a 20 foot long net sweep retrieved no organisms and the maximum number was 16 organisms. There needs to be a higher abundance of organisms present to collect a full complement of 3 samples per pond plus a QA/QC sample.

Table 1 Aquatic Invertebrates Collected and Submitted for Selenium Analysis (May 12, 2005)

Pond and Sample Number	Sweep #1	Sweep #2	Sweep #3	Sample Composition
Pond 1 sample 1	2 adult Corixids 5 nymph Corixids	8 adult Corixids 8 nymph Corixids	7 adult Corixids 6 nymph Corixids	All Corixids plus 1 Dytiscid
Pond 2 sample 1	No organisms	1 adult Corixid 1 nymph Corixid	5 adult Corixids	Predominantly adult Corixids plus: 2 nymph Corixid 1 Notonectid 2 Dytiscid 7-8 Chironomid 1 Tendipedid
Pond 2 sample 2	Benthic sample, sweeps not measured	Benthic sample, sweeps not measured	Benthic sample, sweeps not measured	All Chironomids
Pond 3 sample 1	1 adult Corixid	3 adult Corixid 1 Dytiscid	3 adult Corixid	All adult Corixids plus: 1 Dytiscid 1 Notonectid

Biomass is defined as weight per unit area or volume. Since the water is not flowing the water volume sampled can be estimated using the dimensions of the net opening and the length of water transect sampled as follows: (0.39 square feet net opening) X (60 linear feet of water sampled) = 23.4 cubic feet of water sampled. Total gallons = (23.4 cubic feet) X (7.48 gallons per cubic foot). Biomass is presented in Table 2.

Table 2 Nekton Biomass (May 12, 2005)

Pond	Number and Types of Organisms in 3 Sweeps	Biomass (grams per 175 gallons of water)
Pond 1	36 corixids	0.3 g
Pond 2	7 corixids	<0.1 g
Pond 3	7 corixids & 1 dytiscid	0.3 g

Biomass results depend on species collected, e.g. 1 dytiscid weighs more than 1 corixid. Samples from ponds 1 and 3 had about the same weight but different compositions.

URS

Date: July 28, 2005

To: Terry Cooke

From: Francesca Demgen

Subject: ***Selenium Pilot Study Invertebrate Sampling***

A field site visit was conducted on July 28, 2005 to the selenium pilot study ponds located in Firebaugh, California.

Methods

Two sample collection methods were used. The water column was sampled for nektonic invertebrates using a net and the benthic invertebrate sample was collected using a bailer.

Nekton Invertebrate Collection: Samples were collected using a 0.5 millimeter mesh D-frame net. Water column samples were clean (i.e. no sediment and very minimal organic debris was in net) and organisms were individually removed from the net and placed in glass jars. The jars were provided by the laboratory. The first 3 collection sweeps from each pond were collected from a twenty foot long transect parallel to the edge of the pond. Transect length was determined by measuring the maximum length possible without rounding any corners on the smallest pond. Invertebrates captured during the first 3 sweeps were identified and counted. After that organisms were identified but not enumerated, to collect a total of up to 0.5 grams of invertebrates.

Benthic Invertebrate Collection: A plastic bailer was used to check for benthic invertebrates. It was lowered to the bottom of the pond and dragged up the liner to try and sample attached or benthic organisms. The sample was screened in a No. 35 Standard Test Sieve (500 micron mesh). Pond water was used to wash the sample and chironomids were transferred from the sieve to a glass sample bottle.

Aufwuchs Collection: Aufwuchs is a combination of algae, bacteria and microorganisms that was floating on the pond surface and was collected with the bailer.

Sample bottles were labeled, double bagged, recorded on a Chain of Custody form and shipped to the laboratory the same day.

Results, Observations, Recommendations

Water levels were low during this sampling event. Pond 2 had only approximately 6 inches of water (water surface was 5 feet below the top of bank (TOB)). Water surface was 3.5 ft below TOB in pond 1 and 5 ft. below TOB in pond 3. Water salinity was 13 parts per thousand (ppt) in pond 1, 45 ppt in pond 2 and 25 ppt in pond 3. There were insufficient numbers of invertebrates present in ponds 1 and 3 to submit nekton samples for laboratory analysis. Aufwuchs was collected from ponds 1 and 3 and submitted for analysis. Dragonflies and damselflies were laying eggs in pond 1. A dried radish plant was placed in pond 2 to add surface area for egg laying.

Table 1 Aquatic Invertebrates Collected and Submitted for Selenium Analysis (July 28, 2005)

Pond and Sample Number	Sweep #1	Sweep #2	Sweep #3	Sample Composition
Pond 1 sample 1	3 adult Corixids	4 adult Corixids	4adult Corixids	Sample not submitted
Pond 2 sample 1	5 rattail maggots	Shorefly larvae	3 chironomids	5 rattail maggots, shore fly larvae, 3 midge larvae
Pond 3 sample 1	No invertebrates	No invertebrates	No invertebrates	Sample not submitted

Biomass is defined as weight per unit area or volume. Since the water is not flowing the water volume sampled can be estimated using the dimensions of the net opening and the length of water transect sampled as follows:

Biomass in g/m^3= (mass of biota in grams) / [(0.39 sq. ft. net opening) X (linear distance in ft) X (0.02832 m^3/ft^3]

Biomass is presented in Table 2.

Table 2 Nekton Biomass (May 12, 2005)

Pond	Number and Types of Organisms in 3 Sweeps	Biomass (grams per cubic meter of water)
Pond 1	11 corixids	<0.75 g/m^3
Pond 2	5 rattail maggots, shore fly larvae, 3 midge larvae	4.98 g/m^3
Pond 3	No invertebrates observed	

Summary

Lack of water likely negatively affected the population of aquatic invertebrates in the ponds.

URS

Date: October 3, 2005

To: Terry Cooke

From: Francesca Demgen

Subject: ***Selenium Pilot Study Invertebrate Sampling***

A field site visit was conducted on September 30, 2005 to the selenium pilot study ponds located in Firebaugh, California.

Methods

Two sample collection methods were used. The water column was sampled for nektonic invertebrates using 2 styles of net, a small dip net and a larger D-frame net and the benthic invertebrate sample was collected using a bailer. Use of the smaller dip net facilitated collection of invertebrates from the pond sides.

Nekton Invertebrate Collection: Samples were collected using a 0.5 millimeter mesh D-frame net. Water column samples were clean (i.e. no sediment and very minimal organic debris was in net) and organisms were individually removed from the net and placed in glass or plastic jars. The jars were provided by the laboratory. The first 3 sweeps from each pond were collected from 43 foot (ponds 1 & 3) and 33 foot (pond 2) long transect parallel to the edge of the pond. The transect length was increased from the first 2 sampling trips to try and capture more organisms to improve the biomass estimate precision. Invertebrates captured during the first 3 sweeps were identified and counted. After that organisms were identified but not enumerated, to collect a total of approximately 1 gram of invertebrates per sample.

Benthic Invertebrate Collection: A plastic bailer was used to collect benthic sediments. It was lowered to the bottom of the pond and dragged up the liner to try and sample attached or benthic organisms. The sample was screened in a No. 35 Standard Test Sieve (500 micron mesh). Pond water was used to wash the sample and organisms were transferred from the sieve to a glass sample bottle. Only pond 2 contained benthic substrate within reach. The substrate was black in color and had an anaerobic odor.

Water salinity was recorded using a refractometer.

Sample bottles were labeled, double bagged, recorded on a Chain of Custody form and shipped to the laboratory the following day.

Results, Observations, Recommendations

Table 1 contains a list of the organisms collected during each of the 3 sampling events. The dominant organism collected in each of the 3 events was water boatmen (Corixids). Table 2 lists the contents of the samples submitted to the laboratory for analysis of total selenium and percent moisture. Benthic sediments and invertebrates were only present in pond 2. Algae was not sampled because there was no colonial, filamentous or algal mats present, however floating mats of aufwuchs were present during the July 28 sampling event. Aufwuchs samples were collected and submitted for analysis. The pond water surface level was very low in July: 3.5 feet below top of

bank in Pond 1 and 5 feet below top of bank in Ponds 2 and 3. By September the ponds were closer to full, water level was ~ 1 foot below top of bank.
In September the water in Pond 1 was slightly green in color, whereas it was red-brown in ponds 2 and 3. The diversity of organisms has been consistently greater in Pond 2.

Table 1 Aquatic invertebrates collected from treatment ponds, 2005 collection dates

Scientific Name	Common Name	Pond 1	Pond 2	Pond 3
Corixid	Water boatman	5/12, 7/28, 9/30	5/12, 7/28, 9/30	5/12, 7/28, 9/30
Notonectid	Backswimmer	5/12	5/12, 9/30	9/30
Chironomid	Midge		5/12, 7/28, 9/30	
Tubifera sp.	Rat-tailed maggot		7/28, 9/30	
Ephydridae	Shore flies		7/28, 9/30	9/30
Anisoptera	Dragonfly (nymph)		9/30	
Dytiscidae	Predaceous diving beetle (adult)	5/12	5/12	5/12
Nematodes	Round worms		7/28	

Table 2 Sample Contents

		5/12/5	7/28/5	9/30/5
Pond 1	Sample 1	Corixids 1 Dytiscidae	Aufwuchs	Corixids (small amount of organic debris)
	Sample 2		Aufwuchs	Corixids
	Sample 3		Aufwuchs	
Pond 2	Sample 1	Mixture of all species	Mixture of all species	Mixture of all organisms
	Sample 2	Chironomids	Sediment	
	Sample 3		Sediment	
	Sample 4		Sediment	
Pond 3	Sample 1	Corixids 1 Dytiscid 1 Notonectid	Aufwuchs	Mostly Corixids
	Sample 2		Aufwuchs	Mostly Corixids
	Sample 3		Aufwuchs	

Water salinity was tested in July and September and is presented in Table 3. The salinity in Pond 2 was double in July (45 ppt) compared with September (21ppt).

Table 3 Pond Salinity

	5/12/5	7/28/5	9/30/5
Pond 1	No data	13 ppt	17 ppt
Pond 2	No data	45 ppt	21 ppt
Pond 3	No data	25 ppt	23 ppt

Biomass is defined as weight per unit area or volume. Since the water is not flowing the water volume sampled can be estimated using the dimensions of the net opening and the length of water transect sampled as follows:

For Ponds 1 and 3 in the September sampling event:
(0.39 ft^2 net opening) X (129 linear feet of water sampled) = 50.31 ft^3 of water sampled.
(50.31 ft^3) X (7.48 gallons per ft^3) = 376 total gallons sampled

For Pond 2 in the September sampling event:
(0.39 ft^2 net opening) X (99 linear feet of water sampled) = 38.61 ft^3 of water sampled.
(38.61 ft^3) X (7.48 gallons per ft^3) = 289 total gallons sampled

The type and weight of organisms collected for the biomass calculation for each of the three sampling events is presented in Table 4. Biomass results depend on species collected, e.g. 1 dytiscid weighs more than 1 corixid. Table 5 contains the biomass adjsuted to per 100 gallons of water for comparative purposes.

Table 4 Water Column Biomass

	5/12/2 Total number of organisms	**5/12/5 Invertebrate Biomass**	**7/28/5 Total number of organisms**	**7/28/5 Invertebrate Biomass**	**9/30/5 Total number of organisms**	**9/30/5 Invertebrate Biomass**
Pond 1	36 Corixids	0.3 g / 175 gal water	11 Corixids	<0.5 g / 175 gal water	178 Corixids	0.8 g /376 gal water
Pond 2	7 Corixids	<0.1 g / 175 gal water	5 *Tubifera*	3.3 g / 175 gal water	2 Notonectids, 71 Corixids, 3 Ephydridae	0.2 g / 289 gal water
Pond 3	7 Corixids, 1 Dytiscid	0.3 g / 175 gal water	No invertebrates observed		39 Corixids, 2 Ephydridae, 1 Notonectid	0.2 g/ 376 gal water

Table 5 Water Column Biomass adjusted to per 100 gallons

	5/12/5	**7/28/5**	**9/30/5**
Pond 1	0.17 g	0.28 g	0.21 g
Pond 2	<0.05 g	1.89 g	0.07 g
Pond 3	0.17 g	No data	0.05 g

Summary of Observations

The number of organisms is increasing, however the abundance and diversity of aquatic invertebrates is affected when the water flow is terminated and the pond water level drops significantly. The evaporative loss increased salinity in Pond 2 and likely affected water temperature and dissolved oxygen concentrations.

Absent significant changes in pond ecology, it appears that there will not be algae available to sample in the ponds. The aufwuchs mats are a combination of algae, bacteria, and other microbes. The mats float up off the bottom under certain conditions, likely as a result of gas production.

The calcium sulfate scale attached to the liner and bottom of the ponds is abundant.

It takes a significant amount of time to collect the invertebrate samples because fo the number of organisms present and because nearly every organism is individually handled. During future sampling events it may be useful to have 2 biologists on site to collect the samples in a timeframe that allows same day shipping.

URS

Date: October 26, 2005

To: Terry Cooke

From: Francesca Demgen

Subject: Selenium Pilot Study Invertebrate Sampling

A field site visit was conducted on October 26, 2005 to the selenium pilot study ponds located in Firebaugh, California.

Methods

Two sample collection methods were used. The water column was sampled for nektonic invertebrates using a net and the benthic invertebrate sample was collected using a bailer.

Nekton Invertebrate Collection: Samples were collected using a 0.5 millimeter mesh D-frame net. Water column samples were clean (i.e. no sediment and very minimal organic debris was in net) and organisms were individually removed from the net and placed in glass jars. The jars were provided by the laboratory. The first 3 collection sweeps from each pond were collected from a twenty foot long transect parallel to the edge of the pond. Transect length was determined by measuring the maximum length possible without rounding any corners on the smallest pond. Invertebrates captured during the first 3 sweeps were identified, counted and used to calculate biomass. Biomass is defined as weight per unit area or volume. Since the water is not flowing the water volume sampled can be estimated using the dimensions of the net opening and the length of water transect sampled as follows:

Biomass in g/m^3= (mass of biota in grams) / [(0.39 sq. ft. net opening) X (linear distance in ft) X (0.02832 m^3/ft^3]

After that organisms were identified but not enumerated, to collect a total of up to 0.5 grams of invertebrates for each sample. The objective was to collect 3 replicates per pond per sample type: nekton, benthos, others (such as aufwuchs or algae). In addition, a blind field replicate was submitted to the laboratory when sufficient sample volume was available.

Benthic Invertebrate Collection: A plastic bailer was used to check for benthic invertebrates. It was lowered to the bottom of the pond and dragged up the liner to try and sample attached or benthic organisms. The sample was screened in a No. 35 Standard Test Sieve (500 micron mesh). Pond water was used to wash the sample and chironomids were transferred from the sieve to a glass sample bottle.

Aufwuchs Collection: Aufwuchs is a combination of algae, bacteria and microorganisms that was floating on the pond surface and was collected with the bailer.

Salinity was measured using a Spartan A366 ATC Refractometer.

Sample bottles were labeled, double bagged, recorded on a Chain of Custody form and shipped to the laboratory the same day.

Results, Observations, Recommendations

Pond 1: 4 nekton samples were submitted for selenium analysis. They were comprised of 100% corixids, mostly adults. The biomass sample of 94 corixids was from a total of 50 feet. The sediments were anaerobic had a slime layer and contained no benthic macroinvertebrates. The pond 1 water was reddish in color and had 24 ppt of salinity. The water level was 2 ft below top of bank (TOB).

Pond 2: 3 nekton samples comprised of corixids were submitted for analysis. One benthic sample comprised of midge and shore fly larvae was submitted for analysis. The biomass sample was comprised of 314 corixids (80% adults and 20% larvae) and was collected over 49 feet. The water color was green brown and it had a salinity of 30 ppt. The water level was 1.4 feet below TOB.

Pond 3: 3 nekton samples comprised of corixids were collected and submitted for analysis. The biomass sample was collected from 47 feet of water column and contained 141 corixids, some very small individuals. The water color was green brown. The water level was 1.1 feet below TOB.

There was no macroalgae or aufwuchs.

The ponds were more full and the corixid population had grown significantly.

URS

Date: November 30, 2005

To: Terry Cooke

From: Francesca Demgen

Subject: Selenium Pilot Study Invertebrate Sampling

A field site visit was conducted on November 30, 2005 to the selenium pilot study ponds located in Firebaugh, California.

Methods

Two sample collection methods were used. The water column was sampled for nektonic invertebrates using a net and the benthic invertebrate sample was collected using a bailer.

Nekton Invertebrate Collection: Samples were collected using a 0.5 millimeter mesh D-frame net. Water column samples were clean (i.e. no sediment and very minimal organic debris was in net) and organisms were individually removed from the net and placed in glass jars. The jars were provided by the laboratory. The first 3 collection sweeps from each pond were collected from a twenty foot long transect parallel to the edge of the pond. Transect length was determined by measuring the maximum length possible without rounding any corners on the smallest pond. Invertebrates captured during the first 3 sweeps were identified, counted and used to calculate biomass. Biomass is defined as weight per unit area or volume. Since the water is not flowing the water volume sampled can be estimated using the dimensions of the net opening and the length of water transect sampled as follows:

Biomass in g/m^3= (mass of biota in grams) / [(0.39 sq. ft. net opening) X (linear distance in ft) X (0.02832 m^3/ft^3]

After that organisms were identified but not enumerated, to collect a total of up to 0.5 grams of invertebrates for each sample. The objective was to collect 3 replicates per pond per sample type: nekton, benthos, others (such as aufwuchs or algae). In addition, a blind field replicate was submitted to the laboratory when sufficient sample volume was available.

Benthic Invertebrate Collection: A plastic bailer was used to check for benthic invertebrates. It was lowered to the bottom of the pond and dragged up the liner to try and sample attached or benthic organisms. The sample was screened in a No. 35 Standard Test Sieve (500 micron mesh). Pond water was used to wash the sample and chironomids were transferred from the sieve to a glass sample bottle.

Aufwuchs Collection: Aufwuchs is a combination of algae, bacteria and microorganisms that was floating on the pond surface and was collected with the bailer.

Salinity was measured using a Spartan A366 ATC Refractometer.

Sample bottles were labeled, double bagged, recorded on a Chain of Custody form and shipped to the laboratory the same day.

URS

Results, Observations, Recommendations

Pond 1: 3 nekton samples were submitted for selenium analysis. They were comprised of 100% corixids, mostly adults. The weight of corixids from a 20 ft long haul was 0.048 grams. The sediments were anaerobic and contained no benthic macroinvertebrates. The pond 1 water was iron red brown in color and had 25 ppt of salinity. The water level was 1 ft. 10 in. ft below top of bank (TOB).

Pond 2: 3 nekton samples comprised of corixids were submitted for analysis. A blind field replicate was also collected. Two benthic sample comprised of (1) midge larvae and (1) shore fly pupa were submitted for analysis. The 1.152 gram mass of corixids and was collected over 20 feet. The water color was yellow green and it had a salinity of 34 ppt. The water level was 1.6 feet below TOB.

Pond 3: 3 nekton samples comprised of corixids were collected and submitted for analysis. The corixid mass of 2.726 grams was collected from 20 feet of water column. One benthic sample comprised of chironomids was collected. The water color was green brown. The water level was 1.6 feet below TOB and the salinity was 30 ppt.

There was no macroalgae or aufwuchs. No water was flowing between the ponds and the pond sediments were anaerobic.

The ponds were more full and the corixid population had grown significantly.

APPENDIX C

Drainwater Quantity and Quality

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Acronyms

AF	acre-foot or acre-feet
B	boron
cfs	cubic feet per second
CVPIA	Central Valley Project Improvement Act (Title XXXIV of Public Law 102-575)
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
µg/L	microgram(s) per liter
mg/L	milligram(s) per liter
Mo	molybdenum
PFR	Plan Formulation Report
Reclamation	Bureau of Reclamation
RO	reverse osmosis
Se	selenium
TDS	total dissolved solids
Westlands	Westlands Water District

C1 DRAINAGE QUANTITY

C1.1 SUMMARY OF DRAINAGE AREA

C1.1.1 Areas Needing Drainage

This section provides an overview of the areas needing drainage for which the water quantity analysis was performed. The areas needing drainage service by the end of the 50-year planning horizon were estimated from previous projections and information collected as part of the Plan Formulation Report (PFR). How these estimates were derived is explained in more detail below. Table C1-1 summarizes the areas needing drainage service for both the Northerly Area and Westlands Water District (Westlands), resulting in a drainage service area of 379,000 acres for the entire study area.

Table C1-1
Area Needing Drainage Service by 2050

District	Area (acres)
Westlands North	102,000
Westlands Central	104,000
Westlands South	92,000
Subtotal (Westlands Water District)	298,000
Northern San Luis Unit Districts	45,000
Northerly Area Outside of San Luis Unit	36,000
Subtotal (Northerly Area)	81,000
Total	**379,000**

The previous projections for Westlands are shown in Table C1-2.

Table C1-2
Past Projections of Area Needing Drainage Service
in the Westlands Water District

Projection	Area (acres)
Johnston (1993)	
Westlands North	64,000
Westlands Central	79,000
Westlands South	48,000
Total	**191,000**
Busch (1994)	
Westlands North	102,000
Westlands Central	104,000

**Table C1-2 (concluded)
Past Projections of Area Needing Drainage Service
in the Westlands Water District**

Projection	Area (acres)
Westlands South	92,000
Total	**298,000**
Preliminary Alternatives Report (Reclamation 2001a)	
Westlands North	75,000
Westlands Central	75,000
Westlands South	75,000
Subtotal (Westlands Water District)	225,000
San Luis Unit Districts	35,600
Total	**260,600**

The Johnston (1993) numbers in Table C1-2 were developed based on the area of land with a shallow water table of 5 feet or less in April, the area where the salinity of the shallow groundwater is 12 deciSiemens per meter, and the general soil characteristics (soil salinity, soil permeability, and soil depth). These factors were analyzed and a judgment was made as to the area requiring drainage. The Busch (1994) area was developed using groundwater elevations, soil classification maps, monitoring well hydrographs, and the geohydrology responses of monitoring wells, and based on these factors, a projection was made as to the areas requiring drainage at present and in the future. The Preliminary Alternatives Report numbers were based on the Bureau of Reclamation's unpublished *Draft Environmental Impact Statement* (Reclamation 1984). This document considered depth to water, salt accumulation in the soil, and applied water.

The depth to water that is required for arability of land and salinity control is normally taken to be about 7 feet. The area with depth to water of 10 feet or less within Westlands in April 2001 was approximately 270,000 acres. In addition, in April 2002 Kerry Arroues, Supervisory Soil Scientist, Natural Resource Conservation Service, indicated that from a soils characteristic standpoint, the area needing drainage service to maintain arability in Westlands is close to 300,000 acres. The physical characteristics in Westlands might prevent the area from increasing significantly beyond 300,000 acres in the future (Arroues, pers. comm., 2002).

Comparing and evaluating this information with the previous projections, Reclamation determined that the Busch (1994) projection more accurately estimated the current and future drainage needs in the San Luis Unit. Therefore, the area of drainage-impaired lands in Westlands was identified in the 2002 PFR as 298,000 acres. This value was reduced to 253,900 acres in the 2004 addendum to the PFR based on the 44,100 acres of land recently placed in retirement. However, for this Environmental Impact Statement (EIS) the area that will ultimately need service within Westlands is considered to be about 298,000 acres.

Lands in the Northerly Area have been drained and, therefore, have had drainage service for many years. Currently, approximately 48,000 acres within the Northerly Area have drainage systems installed. Conversations with landowners within this area were used as a basis to predict that by 2050, 81,000 acres will need drainage service. These areas are shown in Table C1-3.

Table C1-3
Current Projections of Area Needing Drainage Service:
Northerly Area

District	**Area (acres)**
Broadview Water District*	10,000
Camp 13 Drainage District	6,000
Charleston Drainage District*	3,000
Firebaugh Canal Water District	24,000
Pacheco Water District*	5,000
Panoche Water District*	27,000
Panoche Drainage District not in Panoche Water District	6,000
Total	**81,000**
Total in San Luis Unit**	**45,000**

* Districts within the San Luis Unit.
** Total acreage in the San Luis Unit within the Northerly Area.

C1.1.2 Current and Future Drainage Systems

The disposal alternatives design is based on the drainage flow generated by those areas with drainage systems installed by the end of the 50-year planning period within the drainage-impaired lands. Reclamation determined that 53,000 acres currently have drainage systems installed in the study area. Table C1-4 shows areas with drainage systems installed by 2002.

Table C1-4
Drainage Systems Installed, 2002

District	**Area (acres)**
Westlands North	5,000
Westlands Central	0
Westlands South	0
Subtotal (Westlands Water District)	5,000
Northern San Luis Unit Districts	30,000
Northerly Area Outside of San Luis Unit	18,000
Subtotal (Northerly Area)	48,000
Total	**53,000**

It is reasonable to expect that not all of the areas in the drainage service area within the Northerly Area and within Westlands would have on-farm drainage systems installed as a result of the project. Some farmers would elect not to install drains based on specific site conditions and economic considerations. Therefore, Reclamation estimated that two-thirds of the area in the drainage service area would actually have subsurface drainage systems installed. Modeling of the drainwater flows and water table elevations indicates that arability is maintained with this condition (URS 2002).

C1.1.3 Factors Affecting Drainage Quantity And Quality

Reclamation evaluated three factors affecting drainage quantity and quality:

- Which lands would ultimately need drainage to maintain arability of the soil
- The rate at which water would need to be drained off the fields to maintain arability of the soil
- What reasonable on-farm and in-district drainwater reduction actions could be implemented

Section C2 details the modeling assumptions made and results obtained to determine the quantity and quality of drainwater for the Out-of-Valley and In-Valley Disposal Alternatives. Several determinations were made in assessing drainwater reduction actions:

- Reclamation determined that regional drainwater reuse facilities would be a cost-effective measure for reducing the volume of drainwater for subsequent treatment and disposal and should be included in all alternatives.
- Reclamation identified the drainwater reduction measures for which the cost of reducing an acre-foot of drainwater would be less than the cost of collecting, reusing, treating, managing, and disposing of that acre-foot of drainwater. The three drainwater reduction measures found to be cost-effective in the 2002 PFR were drainwater recycling, shallow groundwater management, and seepage reduction. See the PFR, Section 3.2 and Appendix A for additional information on the analysis of cost effectiveness. In the PFR Addendum, Reclamation determined that in addition to the three drainwater reduction measures, improvements in irrigation efficiencies (reductions in deep percolation to shallow groundwater) would also be cost effective. See Section 3.3 of the PFR Addendum for the cost analysis.
- In addition, it was determined that the storage capacity of the groundwater aquifer beneath the reuse facilities could be used to regulate the seasonal variations in drainwater flows.
- Farmers and water districts would have flexibility to select other measures to reduce drainwater if they determine these measures to be more cost-effective.

Reclamation developed drainage quantities and flow rates in the PFR (Reclamation 2002). However, these drainage flows had to be further adjusted in March 2003 to incorporate land retirement actions from December 2002. The revised drainage quantities and flow rates accounted for the 34,100 acres either retired from production or with no drainage service as part of the Sumner Peck Ranch et al. settlement (December 2002), in addition to the planned 7,000 acres to be retired under Reclamation's Central Valley Project Improvement Act (CVPIA) land retirement program, and the 3,006 acres retired in 2002 under the Britz settlement. See Section 2.3.3 for a discussion of land retirement assumptions for the No Action and action alternatives. Table 2.3-1 shows the land retirement assumptions for Existing Conditions and No Action. Table 2.13-1 shows the land retirement acreage for the action alternatives.

Table C1-5 shows the drainwater reduction and the resulting drainwater quantity. The difference in drainage output between the In-Valley and Out-of-Valley Disposal Alternatives is due to the differences in land retirement and project features for the different alternatives. More detail on drainwater reductions and quantity is given in Sections C1.1.4 and C1.1.4.1.

Table C1-5
Drainwater Flow and Reduction

	In-Valley Disposal (AF/year)	In-Valley/ Groundwater Quality Land Retirement (AF/year)	In-Valley/ Water Needs Land Retirement (AF/year)	In-Valley Drainage-Impaired Area Land Retirement (AF/year)	Out-of-Valley (Ocean and Delta) (AF/year)
Drainage Flow without Reduction	96,578	85,305	62,807	36,440	97,023
Drainage Flow with Drainwater Reduction Activities (drainwater recycling, shallow groundwater management, and seepage reduction)	69,645	61,036	45,287	26,830	69,957
Drainage Flow with Drainwater Reduction and Regional Reuse Facilities	21,116	18,458	13,730	8,100	20,988
Average Design Flow with Drainwater Reduction and Regional Reuse Facilities	29.2 cfs	25.6 cfs	19.0 cfs	11.2 cfs	29.1 cfs

AF = acre-feet
cfs = cubic feet per second
Note: Drainage values were taken from Table 2.13-1. Differences from drainage totals shown in Tables C1-6 to C1-10 are within an acceptable level of error.

C1.1.4 Drainwater Reduction Measures and Drainage Quantity

Drainwater reduction measures are intended to reduce the drainwater flow for disposal, and these measures may be applicable on farm or regionally. The following drainwater reduction measures were identified and evaluated during development of the PFR (Section 3.2 and Appendix A):

1. **Drainwater Recycling.** Reapplying drainwater and mixing it with freshwater for crop irrigation. This option can be undertaken by an individual farm or on a districtwide basis. This option reduces the amount of drainwater after it leaves the subsurface drainage systems and before disposal.
2. **Shallow Groundwater Management.** Controlling the discharges and water depths from subsurface tile drainage systems so that a portion of irrigation deep percolation is retained in the soil and is available to contribute to crop evapotranspiration. This option reduces the amount of deep percolation that becomes drainwater.
3. **Seepage Reduction.** Lining or piping of existing unlined irrigation conveyance and distribution facilities to reduce seepage losses. This option tends to reduce recharge to the

shallow aquifer, thereby reducing the quantity and/or postponing the need for artificial drainage.

4. **Shallow Groundwater Pumping.** Pumping groundwater from aquifers that overlie more impermeable layers. This option tends to lower shallow water tables and reduce the quantity and/or postpone the need for artificial drainage in affected areas.
5. **On-Farm Irrigation Systems and Management.** Improving the uniformity and timing of irrigation to reduce deep percolation. Also referred to as "improved irrigation management", this option tends to reduce the quantity and/or postpone the need for artificial drainage in affected areas by reducing recharge to the shallow aquifer.
6. **Annual Fallowing.** Similar to land retirement (changing from irrigated to nonirrigated land uses over the long term so that irrigation deep percolation and the need for drainage is totally eliminated on selected lands) but implemented on an annual basis by willing parties. This option would reduce the irrigated acreage and, therefore, the deep percolation under the fallowed land. This option would tend to reduce recharge to the shallow aquifer, thereby reducing the quantity of and/or delaying the need for artificial drainage. Water that would have been used on these lands would be reallocated within the appropriate district.
7. **Reuse/Drainwater Management.** Using drainwater as an irrigation supply for salt-tolerant crops. The lands would need to be drained. This option would reduce the volume of drainwater requiring disposal. This option could be implemented by the individual farm or on a regional basis. Furthermore, the reuse facility may be used as an underground regulating reservoir to control the flow of reused drainwater to subsequent features.

Concerning the recirculation systems within the Grassland Drainage Area operate differently in each district. In Panoche Drainage District, Pacheco Water District, and Charleston Drainage District, the drainage recirculation criteria are based on total dissolved solids (TDS) level in the mixed water. For Panoche Drainage District, this level is 600 and 800 milligrams per liter (mg/L) in Pacheco Water District and Charleston Drainage District. These levels are less than what is reported as the threshold of yield reduction for the crops typically grown in the region (Western Fertilizer Handbook, pp. 42-49). No complaints of adverse effects have been reported. Firebaugh Canal Water District recirculates drainage by discharging sumps directly into the water supply system. In many cases no other possible point of discharge exists and the district is forced to incorporate this water into its irrigation supply. It should be noted that the salinity of applied water is not the only factor, and soil salinity can also impact crop yield. For drainage recirculation to be used successfully, a certain amount of leaching is required.

Options 2 and 5 are on-farm drainwater reduction measures, Options 3 and 6 are regional drainwater reduction measures, and Options 1 and 7 are post-drain measures.

Reclamation evaluated the effect of each drainwater reduction measure on the drainage quantity and the cost of implementation to determine the most cost-effective combination of drainwater reduction measures for each disposal alternative. In the 2002 PFR, Tables A-1 through A-6 in Appendix A show this cost and flow analysis. The estimated reduction in drainwater flow for each of the drainwater reduction options is shown in Table A-1. All drainwater reduction measures have been shown as if they were fully implemented for each of the drainage subareas. Although drainwater reduction was estimated for each subarea individually, the selection of the most cost-effective combination of drainwater reduction measures looked at the entire study area.

Based on the analysis presented above, Reclamation found three on-farm drainwater reduction measures (source control) to be cost-effective in the 2002 PFR: drainwater recycling, shallow groundwater management, and seepage reduction. These measures continue to be used to estimate drainage production but have been supplemented with irrigation efficiency improvements and land retirement. The following sections describe these additional analyses.

C1.1.4.1 Drainage Rates

Drainage rates for Westlands and the Northerly Area were derived using a variety of modeling and analytical tools. The annual field drainage rates used are 0.35 AF/tiled acre for Westlands and 0.42 AF/tiled acre for the Northerly Area. After application of source control measures (shallow groundwater management, drainwater recycling, and seepage reductions) and adding in uncontrolled seepage in the Northerly Area, the corresponding drainage rates to the reuse facilities are 0.25 AF/tiled acre for Westlands and 0.54 AF/tiled acre for the Northerly Area. After reuse, the drainage rates for treatment and disposal decrease to 0.134 AF/tiled acre for Westlands and 0.164 AF/tiled acre for the Northerly Area.

The drainage rates above reflect reductions in deep percolation (or improvements in irrigation efficiency) applied on all lands in the drainage study area except for the drainage-impaired land in Westlands. Further analysis of deep percolation rates is discussed in Section 3.3.10.3 of the PFR Addendum.

The rate at which water will need to be drained off the fields to maintain arability of the soil has been estimated using two methods: field studies and regional groundwater modeling. The following sections discuss the development of the drainage rates using both of these approaches. Results from both approaches were considered in the selection of the final drainage rates and quantities for reuse and disposal for the four In-Valley Disposal Alternatives (with and without land retirement). Drainage flows from the field estimates were higher than those from the groundwater modeling efforts and were used to develop rates for Westlands. Expected drainage rates for the Northerly Area were based on a variety of factors including monitoring data from the Grassland Area Farmers and Grassland Bypass Project, regional groundwater modeling results, and professional judgment by the Technical Team members.

The Technical Team consisted of a variety of knowledgeable people from URS Corporation, HydroFocus, Western Resource Economics, Summers Engineering, Westlands Water District, California Department of Water Resources at Fresno, and Reclamation's South Central California Area Office, Mid-Pacific Regional Office, and Denver Technical Service Center. The Technical Team was utilized to discuss, and agree upon, several issues relating to the irrigation and drainage components of this project.

<u>**Field Estimates for Drained Lands**</u>

The drainage collector system that will be used to carry drainwater to the reuse areas needs to be sized properly. Reclamation's approach to the sizing criteria was to calculate an expected future peak daily drain discharge and use that discharge as the pipeline design criterion. Computing a future daily peak drainage discharge required estimating the amount of drainwater produced by on-farm subsurface drains. Many miles of surface and subsurface drains exist within the

Northerly Area, so the estimated future flows are considered to be similar to the present day flows with some adjustments for control of seepage losses. The estimated future on-farm drainflows in Westlands required additional assumptions and estimates of what the future irrigated agriculture operations might become.

Assumptions regarding what the future irrigated agriculture might become are very important to the estimated return flows from the on-farm drains. Issues as simple as ‘What crops are going to be grown?’ have a significant effect on drainage return flow quantity and quality. Several discussions and telephone conference calls with the Technical Team have been required to arrive at a set of reasonable assumptions that provide the basis for the drain return flow that can be used both for collector pipe sizing and reuse area sizing, and finally treatment plant and evaporation basin sizing.

The approach used by Reclamation for the collector size criteria relied upon the soil and water setting with an estimate of the expected drainage from irrigated agriculture. The soils data of the area (Westlands) are fairly detailed, and the water supply for irrigation is well defined. The primary unknown parts of this effort are the types of crops grown; the mix of crops and how many acres of each; the irrigation application efficiency; and the influences of other items such as seepage, water table flow from other areas, and influence of well pumping. Estimates of the crops and crop mix, and the expected irrigation efficiency have been completed; however, the contribution of seepage, water table flow, and well pumping have been evaluated by the regional groundwater model analysis discussed later in this section under “Groundwater Model Estimates.”

The crop mix has been developed to reflect a mix of alfalfa, cotton, sugar beets, small grains, tomatoes, and vegetables. Various planting and harvesting dates that are common to Westlands have been used. The computation of various water delivery times to replenish the soil moisture depletion from the actively growing crops is also involved. The on-farm drains have been assumed to be constructed at a depth and spacing that provides for proper water table control for the crop and irrigation sequence that produces the most water table recharge. The crop with the most water table recharge is cotton, so the return flows for the collector system design are based on the drain spacing for cotton. However, less than 100 percent of the area is planted in cotton. When the other crops in the cropping pattern are grown, the drainage return flows are computed using drains that have been spaced for the cotton crop.

Reclamation’s investigations into drainwater volume are focused on field studies for the sizing of drainwater reuse areas in Westlands subareas (outside of the Northerly Area). They serve as a check for estimates produced from the groundwater model. Appendix C of the PFR Addendum, Drainwater Reuse, provides a comprehensive discussion of the sizing of the reuse areas. Figure C2-1 illustrates the Westlands and Northerly drainage service areas and potential reuse sites (A through Z).

Results of Reclamation’s investigations for drainage volume for the In-Valley Disposal Alternatives are incorporated into Table C1-6 with inflow into the reuse areas. The drainage volume from the commercially irrigated lands is reduced by implementing source control measures (Source Control Memorandum [URS 2002]). Two specific source control measures have been included in these calculations: shallow groundwater use by crops, and recycling of drainwater back into the irrigation water supply. The source reductions are estimated on an AF/irrigated acre basis, and are applied before the drainwater reaches the reuse area. After source reduction, a total of 40,185 AF/year of drainwater would flow to the 15 Westlands reuse areas, a rate of production of 0.25 AF/drained acre. A total of 29,460 AF/year of drainwater would flow to the Northerly Reuse Area (Area Z) from the Northerly Area.

Drainwater reduction values and drainage flow were adjusted from those values reported in the *Source Control Memorandum* (URS 2002) to account for the lands retired under Reclamation's CVPIA land retirement program, the Britz settlement, and the Sumner Peck Ranch et al. settlement (December 2002), as well as lands taken out of production for facilities as part of the alternative implementation.

Discharge from reuse areas would be combined and pumped to treatment plants for all of the In-Valley Disposal Alternatives (with and without land retirement). The average annual discharge from the reuse areas is the supply for the reverse osmosis (RO) treatment process. For the In-Valley Disposal Alternative, this discharge is estimated at 12,260 AF/year for the Westlands North, Westlands Central, and Westlands South reuse areas with groundwater management and recycling drainwater reduction measures, and 8,856 AF/year for the Northerly Reuse Area with groundwater management, drainwater recycling, and seepage reduction measures (Tables C1-7 through C1-10). A similar analysis was performed for the other action alternatives. Total drainwater reductions and drainage rates before and after reuse are compared for all the Action alternatives in Table 2.13-1.

Table C1-6
Drainwater Inflow to Westlands and Northerly Reuse Areas

Reuse Area	Commercially Irrigated Gross Acres[1]	Commercially Irrigated Tiled Acres[2]	Annual Drain Volume (AF/yr)[3]	Source Reductions		Reuse Inflow (AF/yr)
				Groundwater Management (AF/yr)[4]	Recycling (AF/yr)[4]	
A	7,035	4,690	1,642	-136	-352	1,154
B	26,440	17,627	6,169	-512	-1,322	4,335
C	24,294	16,196	5,669	-470	-1,215	3,984
D	37,633	25,089	8,781	-728	-1,882	6,171
E	9,828	6,552	2,293	-190	-491	1,612
F	8,622	5,748	2,012	-167	-431	1,414
G	36,378	24,252	8,488	-704	-1,819	5,965
H	28,001	18,667	6,534	-542	-1,400	4,592
I	5,070	3,380	1,183	-98	-254	831
J	6,920	4,613	1,615	-134	-346	1,135
K	6,660	4,440	1,554	-129	-333	1,092
L	11,460	7,640	2,674	-222	-573	1,879
M	20,730	13,820	4,837	-401	-1,037	3,399
N	10,880	7,253	2,539	-211	-544	1,784
O	6,080	4,053	1,419	-118	-304	997
$Z_{(exist)}$[5]	75,490	48,490	35,683	-651	-4,700	27,222
$Z_{(new)}$[6]	5,510	5,510	2,397	-159	0	2,238
All Areas	327,031	218,020	95,489	-5,572	-17,003	69,804

Source: Addendum to PFR, Appendix C, Table C-4.
Notes:
[1]Acreages area approximate based on collection area and will change after completion of the feasibility design. Some rounding up to full quarter sections is included.
[2]Based on an estimated two-thirds of the Gross Area.
[3]Based on annual drainage production rate of 0.35 AF per tiled acre for Westlands, monitoring data for the existing drained portion of the Northerly Area, and 0.42 AF per tiled acre for the future drained Northerly Area.
[4]Estimated annual reduction is prorated to collection size of each reuse area.
[5]This is the portion of the Northerly Area that currently has drainage collection.
[6]This portion of the Northerly Area would have new collectors installed as part of the project.

Table C1-7
Discharge from Westlands North Reuse Area

Area	Area (acres)	Annual Outflow (AF)	Average Outflow (AF/day)
I	231	249	0.68
J	315	340	0.93
K	303	328	0.9
L	522	564	1.54
M	882	1,020	2.79
N	463	535	1.47
O	277	299	0.82
Totals	**2,994**	**3,335**	**9.14**

Average Annual Discharge Rate: 4.61 cfs

Table C1-8
Discharge from Westlands Central Reuse Area

Area	Area (acres)	Annual Outflow (AF)	Average Outflow (AF/day)
D	1,500	1,851	5.07
E	392	483	1.32
F	344	424	1.16
G	1,710	1,847	5.06
H	1,192	1,377	3.77
Totals	**5,138**	**5,983**	**16.4**

Average Annual Discharge Rate: 8.26 cfs

Table C1-9
Discharge from Westlands South Reuse Area

Area	Area (acres)	Annual Outflow (AF)	Average Outflow (AF/day)
A	320	346	0.95
B	1,205	1,301	3.56
C	1,107	1,195	3.27
Totals	**2,631**	**2,842**	**7.79**

Average Annual Discharge Rate: 3.93 cfs

Table C1-10
Discharge from Northerly Reuse Area

Area	Area (acres)	Annual Outflow (AF)	Average Outflow (AF/day)
Existing Reuse Area Z	4,303	4,647	12.7
New Reuse Area Z	3,897	4,209	11.5
Totals	**8,200**	**8,856**	**24.2**

Average Annual Discharge Rate: 12.2 cfs

Groundwater Model Estimates

A transient, three-dimensional, regional groundwater-flow model was used to simulate changes in western San Joaquin Valley groundwater storage and water table depths under different water and land use scenarios. The USGS developed the model for the San Joaquin Valley Drainage Program (Belitz et al. 1993). HydroFocus, Inc. (1998) evaluated model-projected groundwater levels and drainflow during the period 1989–97. They updated boundary conditions, recharge, and pumpage data and concluded model results are acceptable to evaluate long-term changes in water-table depth.

The groundwater model simulates hydrologic conditions in both the upper semiconfined and lower confined aquifer systems. It is spatially discretized into more than 550 square-mile model cells (shown on Figure 4-2 of the Addendum to the PFR), and represents about 212,500 acres of the approximately 604,000-acre Westlands Water District, and about 81,500 acres of the 97,400-acre Northerly Area.

Model Assumptions

The model utilizes mean annual recharge and pumpage data to project long-term annual changes in groundwater storage and water table depth. The model simulates water table recharge and groundwater pumpage within nine water budget subareas (shown on Figure 4-3 of the Addendum to the PFR). Most of the subareas correspond with individual water districts; however, Westlands is subdivided into three subareas based on depth to the water table (10 feet below land surface or less, 10 to 20 feet below land surface, and greater than 20 feet below land surface). Specified recharge and pumping rates are reported in Appendix B of the Addendum to the PFR, Table B-1, and relevant data sources and assumptions are summarized below:

- For current conditions, annual district-wide recharge rates were estimated using information from Table 5 (Fraction of Deep Percolation by Irrigation Method) from the Source Control Memorandum (URS 2002). In Westlands, the spatial distribution of water table recharge was weighted based on the recharge distribution reported by Belitz et al. (1993).
- Groundwater is a water supply within Westlands, but not within the Northerly Area. In Westlands, simulated annual groundwater pumping is maintained constant at 175,000 AF/year, which is equal to the average private supply reported in Westlands' Water Needs Assessment (Reclamation 2003b).

Several assumptions were made to simplify model input data set development and construction. These assumptions relax some of the approaches employed for previous analyses of the In-

Valley Disposal Alternative. Most of these simplifications are common to all the scenarios assessed for the land retirement analysis. The key simplifications are summarized below:

- Drainage system installation and land retirement were implemented instantaneously rather than phased in gradually over a 5-year period.
- Water table recharge beneath reuse facilities and evaporation basins was not included.
- Seepage control measures in the Northerly Area were not included. Seepage control measures reduce water table recharge in the Northerly Area by 4,200 AF/year.
- New drainage systems planned for the Northerly Area (3,007 acres) were not included.
- All new drainage systems are conventional in design; however, 25 percent of the new drainage systems planned for Westlands and 10 percent of the new drainage systems planned for the Northerly Area are assumed to be designed to manage shallow groundwater (for example, using closer drain lateral spacing and shallower drain lateral depths).

Drainflow Estimates

Drainflow is the net result of water table recharge, evaporative losses from the shallow water table, and natural drainage (vertical downward movement of groundwater past the drain laterals); regional processes (water table recharge and pumping) influence the underlying distribution of hydraulic head and the resulting natural drainage.

Beginning in 2005, new subsurface drainage systems are assumed in the model to be installed in all areas of Westland's drainage-impaired area having a simulated water table within 7.5 feet of land surface. After 2005, drainage systems will gradually be installed within the remaining drainage-impaired area when the simulated water table reaches a depth of 7.5 feet or less.

Simulated drainflows were adjusted to account for processes not directly simulated by the regional groundwater flow model including:

- Scaling the model drainflow to account for drainage-impaired areas not within the model domain. This resulted in multiplying the Northerly Area simulated drainflow by a factor of 1.12 and Westlands simulated drainflow by a factor of 2.71.
- Adjusting the annual drainflow estimates to account for temporal variability not explicitly represented by the model. The model utilizes annual stress periods to estimate average annual drainflow, but relatively greater volumes of drainwater are produced during and immediately following irrigation than are expected from annual drainflow conditions (Deverel and Fio 1991; Fio and Deverel 1991). The scaled simulated annual drainflows for the Northerly Area and Westlands were multiplied by 1.5 to account for temporal processes based on comparisons with measured and modeled drainflow in the Northerly Area.

- Simulated drainflow from the Northerly drainage-impaired area was increased by 15,400 AF/year to account for uncontrolled discharges[1] into the drainage systems (URS 2002).

Total annual drainflow estimated for the In-Valley Disposal Alternative for the Northerly Area and Westlands are 35,200 AF/year and 40,562 AF/year, respectively, corresponding to a drainflow of 0.55 AF/tiled acre in the Northerly Area and 0.24 AF/tiled acre in Westlands.

C1.1.4.2 Drainwater Reduction Measures

Reclamation found three on-farm drainwater reduction measures (source control) to be cost-effective in the 2002 PFR: drainwater recycling, shallow groundwater management, and seepage reduction. These measures continue to be used to estimate drainage production but have been supplemented with irrigation efficiency improvements and land retirement.

Land Retirement

The hydrologic effects due to mandatory retirement of various land areas were investigated in the PFR Addendum. A transient, three-dimensional, regional groundwater-flow model was used to simulate changes in western San Joaquin Valley groundwater storage and water table depths under different water and land use scenarios. Various amounts of lands were retired in the model in 2005, and the annual changes in groundwater storage, water table depths, and resulting drainflows were simulated.

As a result of land retirement, irrigation ceases on the retired lands and, consequently, groundwater pumpage and surface-water deliveries are discontinued. The simulated pumping rate beneath retired lands also becomes zero, but the pumping rate beneath active lands was increased to maintain a constant pumping rate of 175,000 AF/year within Westlands. A relationship was developed between the fraction of drainage-impaired land that was retired and the simulated drainflow and area requiring drainage systems in the remaining farmed area. The results of these relationships are shown on Figures 4-4 and 4-5 of the Addendum to the PFR. The results of the land retirement drainflow analysis for Westlands are shown in Table C1-11. The results indicate the scaled annual drainflow rate per tiled area is similar for all alternatives, ranging from 0.24 to 0.26 AF/tiled acre, with the exception of the scenario that retires all drainage-impaired areas, which resulted in no drainflow. For the Northerly Area, only one land retirement scenario was modeled (retirement of Broadview Water District). However, the model indicated land retirement in Westlands did have a small effect on drainflow rates in the Northerly Area. The resulting drainage flow rates in the Northerly Area are 0.47 to 0.55 AF/tiled acre/year.

[1] "Uncontrolled discharges" refer to discharges in the Northerly Area associated with the relatively deep, unlined open-channel collection systems. The collection systems add yield in addition to what comes out of the subsurface drains. The additional yield may include aqueduct seepage, underground flows from the Coast Ranges, and upslope activities, as well as shallow groundwater seepage directly into the unlined channel, tailwater inflows, discharge from ricefields, and other flows originating within the Northerly Area – uncontrolled discharge is any channel flow in addition to metered sump flow. Uncontrolled discharge was estimated by the difference between observed discharge to the San Joaquin River (by way of the Grasslands Bypass Project) and measured sump discharge in the Northerly Area. Under existing and drainage project conditions, these discharges are controlled and managed. In contrast, under No Action conditions these discharges can continue but are no longer managed after the Bypass Project expires. These assumptions and the potential effects are similar to those made as part of the Grasslands Bypass Project EIS/EIR.

Table C1-11
Simulated 2050 Drainflow for Different Levels of Land Retirement – Current Recharge

	Retired (Westlands)		2050 Westlands Drainflow (AF/yr)		2050 Westlands Collector System Area (acres)		2050 Drainflow (AF/tiled acre)	
Scenario	**Acres**	**Fraction of Drainage-Impaired Area Irrigated**	**Model**	**Scaled**	**Model**	**Scaled**	**Westlands**	**Northerly Area***
In-Valley	57,141	0.81	9,989	40,562	62,083	168,066	0.24	0.55
Groundwater Quality	88,578	0.70	8,573	34,811	52,147	141,169	0.25	0.55
Water Needs	185,000	0.38	4,441	18,035	25,116	67,993	0.26	0.53
Drainage-Impaired Area	298,238	0.00	0	0	0	0	0.00	0.47

*Northerly Area drainflow rate does not include the approximately 15,400 AF of uncontrolled discharge. The total drainflow volume is, therefore, equal to the drainflow rate multiplied by 48,000 acres tiled plus the uncontrolled discharge.

Irrigation Efficiency

A similar analysis was also performed to determine how improvements to irrigation efficiency would change drainflow rates. For this analysis, water table recharge rates used in the model were reduced to simulate improved irrigation efficiencies. Similar to the previous analysis, relationships were developed between the fraction of land in the drainage-impaired area remaining in production and the predicted drainage rates for two additional levels of water recharge. Results of the modeling are shown in Tables C1-12 and C1-13. See also Sections 3.3.4 and 3.3.10.3 of the Addendum to the PFR for further discussion of analysis of deep percolation rates.

Table C1-12
Simulated 2050 Drainflow – Moderate Recharge Reduction

	Retired (Westlands)		2050 Westlands Drainflow (AF/yr)		2050 Westlands Collector System Area (acres)		2050 Drainflow (AF/tiled acre)	
Scenario	**Acres**	**Fraction of DIA Irrigated**	**Model**	**Scaled**	**Model**	**Scaled**	**Westlands**	**Northerly Area***
In-Valley	57,141	0.81	5,085	20,647	41,276	111,739	0.18	0.42
Groundwater Quality	88,578	0.70	4,353	17,676	25,053	94,893	0.19	0.42
Water Needs	185,000	0.38	2,237	9,085	17,540	47,482	0.19	0.40
Drainage-Impaired Area	298,238	0.00	0	0	0	0	0.00	0.36

*Northerly Area drainflow rate does not include the approximately 14,000 AF of uncontrolled discharge. The total drainflow volume is, therefore, equal to the drainflow rate multiplied by 48,000 plus the uncontrolled discharge. Drainflow reduction due to recharge reductions in Northerly Area lands located outside of the San Luis Unit (i.e., Firebaugh Water Budget Subarea in Table A-2 of the Addendum to the PFR) were estimated using model results for simulated recharge reductions in lands located within the San Luis Unit land (i.e., the Panoche and San Luis Water Budget Subareas in Table A-2 of the Addendum to the PFR).

Table C1-13
Simulated 2050 Drainflow – Maximum Recharge Reduction

Scenario	Retired (Westlands)		2050 Westlands Drainflow (AF/yr)		2050 Westlands Collector System Area (acres)		2050 Drainflow (AF/tiled acre)	
	Acres	Fraction of DIA Irrigated	Model	Scaled	Model	Scaled	Westlands	Northerly Area*
In-Valley	57,141	0.81	3,218	13,067	30,836	83,476	0.16	0.29
Groundwater Quality	88,578	0.70	2,718	11,038	26,053	70,529	0.16	0.29
Water Needs	185,000	0.38	1,335	5,422	12,809	34,675	0.16	0.28
Drainage-Impaired Area	298,238	0.00	0	0	0	0	0.00	0.25

*Northerly Area drainflow rate does not include the approximately 12,600 AF of uncontrolled discharge. The total drainflow volume is, therefore, equal to the drainflow rate multiplied by 48,000 plus the uncontrolled discharge. Drainflow reduction due to recharge reductions in Northerly Area lands located outside of the San Luis Unit (i.e., Firebaugh Water Budget Subarea in Table A-2 of the Addendum to the PFR) were estimated using model results for simulated recharge reductions in lands located within the San Luis Unit land (i.e., the Panoche and San Luis Water Budget Subareas in Table A-2 of the Addendum to the PFR).

These results were used to develop a cost/benefit analysis for land retirement and improvements in irrigation efficiencies (Section 3.3 of the PFR Addendum).

Other On-Farm Measures

Drainage reduction from other regional and on-farm source control measures was previously analyzed in the PFR. The drainage reduction (source control) measures identified as cost effective in the PFR included seepage reduction, regional recycling, and shallow groundwater management. The on-farm, in-district drainwater reduction actions are not components of the drainage service alternatives to be implemented by Reclamation. Rather, they represent the assumptions Reclamation has made regarding the conditions of the area to be served and the reasonable actions that could be implemented by districts within the area to be served in order to estimate a reasonable drainage quantity and quality for the future once drainage service is provided. Although drainwater reduction actions other than the ones selected have been proposed in the Westside Regional Drainage Plan and could be implemented to reduce drainage flows (e.g., shallow groundwater pumping), it was determined that they were either not cost effective compared to the disposal facilities, or it was not reasonable to assume that they would be implemented due to the uncertainty regarding the effectiveness of the action. Shallow groundwater pumping shows promise for reducing drainflows. However, additional information is needed to demonstrate its practical feasibility, including the potential uses for the pumped groundwater.

For this analysis, drainwater reduction from regional recycling and shallow groundwater management were scaled from the estimates in the PFR, based on the size of the drainage collector area for the different land retirement alternatives. The benefit of lining water supply canals in the Northerly Area for seepage reduction was shown as a reduction of 3,200 AF/year in the Unit and 4,200 AF/year in the entire Northerly Area.

To estimate the current cost-effectiveness of these source control measures, the updated drainage treatment and disposal costs for each AF of drainwater treated were compared to costs per AF of drainwater avoided due to the on-farm and regional source control measures. The previously selected source control measures were determined to be cost-effective, given the new information on cost for treatment and disposal (Table C1-14). The annual savings per AF varies from $38 for drainwater recycling up to $154 for seepage reduction.

Table C1-14
Cost-Effectiveness Analysis of Drainwater Reduction Measures

Project Feature	Net Drainage Delivered to Reuse Areas (AF)	Estimated Capital Cost ($)	Estimated Operation/ Maintenance/ Replacement Cost ($)	Total Annual Equivalent Costs ($)
Alternative Costs with Source Reduction Measures				
Drainwater Recycling	59,805	553,492,000	14,255,000	
Shallow Groundwater Management	59,805	553,492,000	14,255,000	
Seepage Reduction	59,805	553,492,000	14,255,000	
Alternative Costs without Source Reduction Measures				
Drainwater Recycling	70,573	551,004,000	14,812,000	
Shallow Groundwater Management	64,875	567,639,000	14,081,000	
Seepage Reduction	63,005	555,315,000	14,638,000	
Difference Attributable to Source Reduction				
Drainwater Recycling	(10,768)	$2,488,000	($557,000)	
Shallow Groundwater Management	(5,071)	(14,147,000)	174,000	
Seepage Reduction	(3,200)	(1,823,000)	(383,000)	
Annual Equivalent Cost of Source Reduction				
Drainwater Recycling		$149,649	($557,000)	($407,351)
Shallow Groundwater Management		(850,920)	174,000	(676,920)
Seepage Reduction		(109,651)	(3893,000)	(492,651)
Annual Savings per AF of Source Reduction				
Drainwater Recycling		($14)	$52	$38
Shallow Groundwater Management		$168	($34)	$133
Seepage Reduction		$34	$120	$154

Interest Rate 5.6250%
Project Life (years) 50

C1.1.5 Drainage System Buildup

A projection is needed for the buildup of installation of drainage systems. It is unlikely that wholesale installation of new systems would occur within Westlands when drainage service is provided. The cost is considerable to install the systems, and a farmer would need to be able to justify the capital outlay. Once drainage service is available, the existing area in Westlands North with drains currently installed would connect immediately. Within the first 10 years approximately 30 percent of the drains would be installed. Installation of the remaining 70 percent of the drains would proceed over the next 40 years as a linear increase. For the Grassland Drainage Area a linear buildup from the current acreage drained to final build-out by the end of the project was assumed.

Drains would not discharge water to the reuse facilities until construction of disposal facilities were within 2 years of completion. This restriction will ensure that reuse facilities remain agriculturally viable and function as intended. Previous experience in the existing Northerly Area reuse area has shown operation of reuse facilities without disposal is possible for 2 years. The starting dates for drainage service in each subarea are based on the project schedule and reflect the year that reuse areas would be completed but no more than 2 years prior to completion of disposal facilities.

C2 DRAINWATER QUALITY

C2.1 PURPOSE AND SUMMARY

Revised estimates of drainwater quantity and quality from farmed lands and reuse areas were developed to enable calculation of discharge water quality for each disposal alternative. The revised estimates are used in this EIS to evaluate effects on surface- and groundwater resources.

The groundwater quality map developed by Swain (1990) was updated to allow estimation of mean concentrations and uncertainty in drainwater quality by drainage subarea and for reuse areas within the subareas. Because the previous groundwater quality maps provided only a concentration range for different regions, a specific mean concentration for a given region could not reliably be estimated. This specific mean concentration is required to allow evaluation of the effects of retiring lands and using specific lands for reuse facilities.

Updated groundwater quality maps (contained in Section 6.1) were produced through geostatistical techniques (block kriging) of mean or median concentrations measured in shallow groundwater wells using data collected in the 1980s. Results from the 2002 groundwater sampling showed no consistent changes in groundwater quality relative to 1980s results. Maps were produced for TDS, selenium (Se), boron (B), and molybdenum (Mo). These estimated groundwater concentrations were compared to water quality measured in sumps during the same time period to determine if a consistent bias was present in the predicted concentrations. No bias was apparent from the comparison allowing the use of the predicted groundwater concentrations as an estimate of drainwater concentration. Block kriging was then used to estimate average concentrations for each 5,000- by 5,000-meter grid cell in the drainage-impaired area. Results from the block kriging were used to calculate mean concentrations for each subarea and for reuse areas. Estimates of the hydraulic conductivity of each 1-mile grid cell in the area covered by the Belitz groundwater model (Westlands North and most of the Northerly Area) were used to scale the estimated mean concentration to account for differences in drainage yield. Standard error from the block kriging was used to estimate the upper 95th percentile confidence limit of the means and the scaled means for each subarea (calculated as mean + (2 x standard error)).

Predictions for farmed lands in the Northerly Area were compared to measured values in sumps to provide a further check on the analysis. The concentrations in shallow groundwater for the farmed and reuse areas were used with the predicted flow rates and project components (reuse, Se treatment, RO treatment) for each disposal alternative to develop a flow-weighted concentration for each disposal alternative.

C2.2 DATA SOURCES

The primary data source for this analysis was Reclamation’s groundwater quality database. These data were obtained as GIS ArcInfo files from David Hansen (gw1990). The database included samples of shallow groundwater, sumps, and evaporation basin inlets collected between 1950 and 1990. The majority of the data were collected between 1984 and 1989. For each location a mean or median concentration was reported or calculated. The mean or median concentration from sumps and evaporation basins were excluded from the groundwater dataset and kriging analysis. The detection limit was substituted for any nondetected values (generally a small number of the samples). Data from the drainage sumps were used to validate the predicted groundwater concentrations and check for drainage-related effects.

C2.3 DEVELOPMENT OF SUBAREA DELINEATIONS

The subareas used to calculate average water quality are shown on Figures C2-1 (In-Valley Disposal Alternative) C2-2 (In-Valley/Groundwater Quality Land Retirement Alternative), C2-3 (In-Valley/Water Needs Land Retirement Alternative), and C2-4 (Out-of-Valley Disposal Alternatives). The process used to develop these subareas is described below. Subareas include farmed lands (shown as service areas) and reuse areas for all action alternatives, and evaporation basins for the In-Valley Disposal Alternative only.

C2.3.1 Exclusion of Retired Lands

Retired land areas were removed from each drainage subarea for each disposal alternative. The number of acres removed for each Action alternative is shown in Table 2.13-1. Figures C2-1, C2-2, C2-3 and C2-4 show the location of the retired lands within the service areas. Lands were removed based on the current Reclamation retirement programs including the Sumner Peck and Britz settlement agreements (see Section 2.3.3). Additional lands were identified as retired based on Se concentrations in shallow groundwater (See PFR Addendum, Section 3). Future lands identified in Reclamation’s CVPIA land retirement program or needed to achieve the total retirement goal for the In-Valley/Water Needs Land Retirement Alternative were assumed to be randomly distributed in the drainage-impacted area and to not affect the quality of water from the subarea. Table 2.13-1 shows the retired lands acreage for each alternative that was excluded from the water quality analysis.

C2.3.2 Reuse Areas

Existing and potential future reuse areas were delineated based on preliminary reconnaissance performed by Reclamation and then these acreages were removed from drainage-impaired areas. The mapped reuse areas are larger than the areas required for drainage service but are assumed to be representative of potential reuse areas for water quality estimation purposes. Figures C2-1 through C2-4 show the locations of the reuse areas.

C2.4 EXPLORATORY DATA ANALYSIS OF WELL DATA

Exploratory data analysis was performed on the well data to determine general statistics (mean, median, standard deviation, and coefficient of variation) and to test if the distributions were normal. While predictions using kriging do not require normally distributed data, the estimation of kriging errors is sensitive to the distribution. Summary statistics for each subarea and lands outside the study area are shown in Tables C2-1 through C2-4.

Table C2-1
Total Dissolved Solids Concentrations General Statistics

TDS	N	mean	median	min	max	std dev	p-value* Arith	p-value* Nat. Log
Outside	920	3600	920	43	92000	7900	0	0
Northerly Area	68	9600	5500	910	38000	8800	0.0001	0.0038
Westlands North	84	9300	7200	330	57000	9800	0	0.0383
Westlands Central	28	3700	2900	390	16000	3500	0.0001	0.2115
Westlands South	19	10000	4500	590	110000	24000	0.0001	0.1944

Table C2-2
Selenium Concentrations General Statistics

Se	N	mean	median	min	max	std dev	p-value* Arith	p-value* Nat. Log
Outside	530	31	1	1	4100	210	0	0
Northerly Area	59	1000	110	1	7300	1900	0	0.0214
Westlands North	77	700	160	1	3500	940	0	0.0001
Westlands Central	19	27	25	1	100	25	0.0082	0.004
Westlands South	18	12	2	1	92	22	0.0001	0.0097

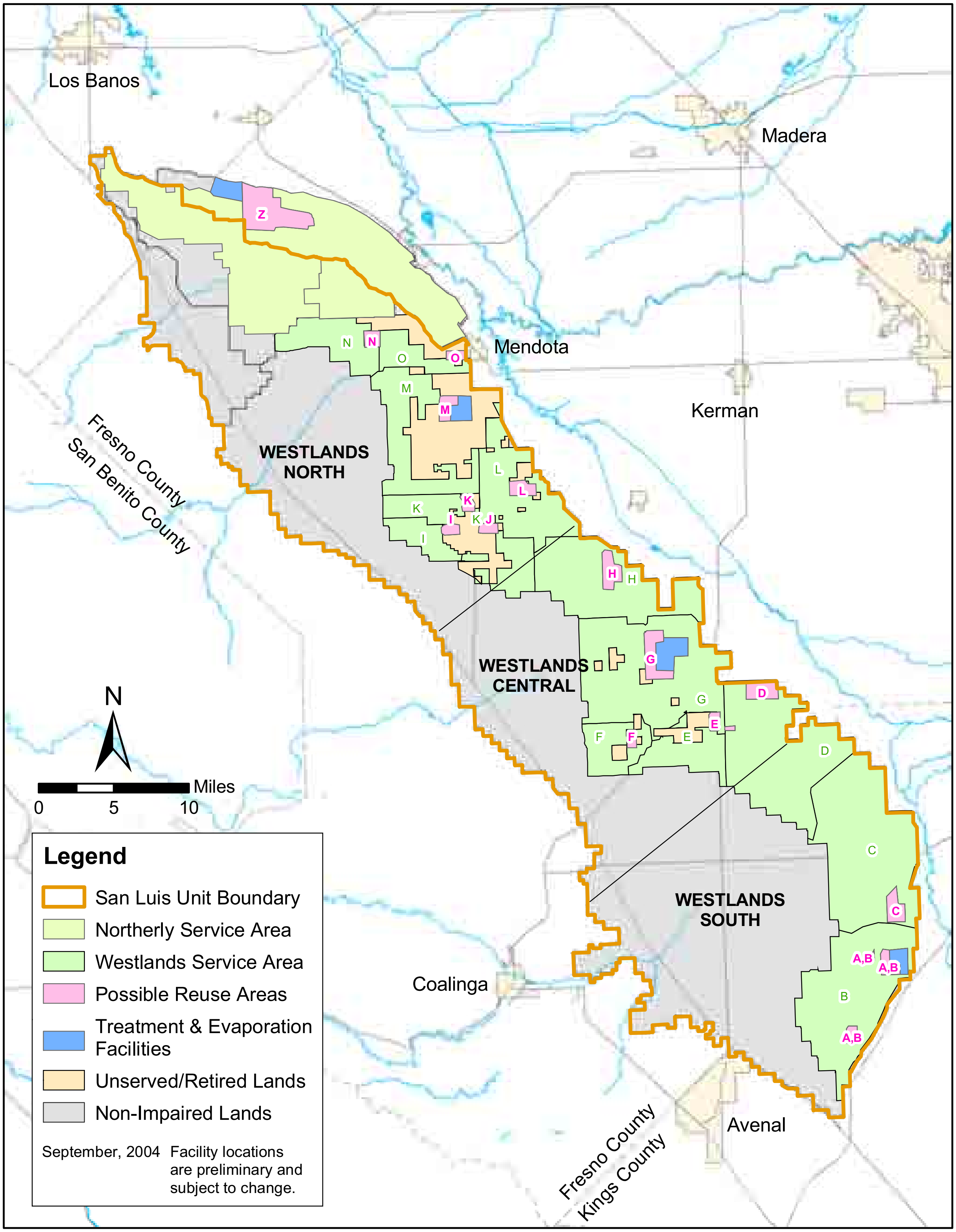
Table C2-3
Molybdenum Concentrations General Statistics

Molybdenum	N	mean	median	min	max	std dev	p-value* Arith	p-value* Nat. Log
Outside	410	54	6	1	1900	200	0	0
Northerly Area	65	37	10	1	430	76	0	0.0002
Westlands North	79	170	38	1	4000	540	0	0.0318
Westlands Central	19	67	22	5	760	170	0.0001	0.0721
Westlands South	15	130	82	2	510	160	0.0006	0.5633

Table C2-4
Boron Concentrations General Statistics

Boron	N	mean	median	min	max	std dev	p-value* Arith	p-value* Nat. Log
Outside	870	2300	610	10	73000	6300	0	0.0261
Northerly Area	62	20000	10000	2000	83000	22000	0.0001	0.0003
Westlands North	82	15000	10000	320	120000	19000	0	0.0312
Westlands Central	25	3300	2000	220	16000	3600	0.0001	0.7008
Westlands South	16	5300	3400	640	18000	5300	0.0031	0.724

*Shapiro-Wilk W test. If the p-value reported is less than .05 (or some other alpha), then you conclude that the distribution is not normal.



San Luis Drainage Feature Re-evaluation	Drainage and Reuse Areas, In-Valley Disposal Alternative	Figure C2-1
17324004		

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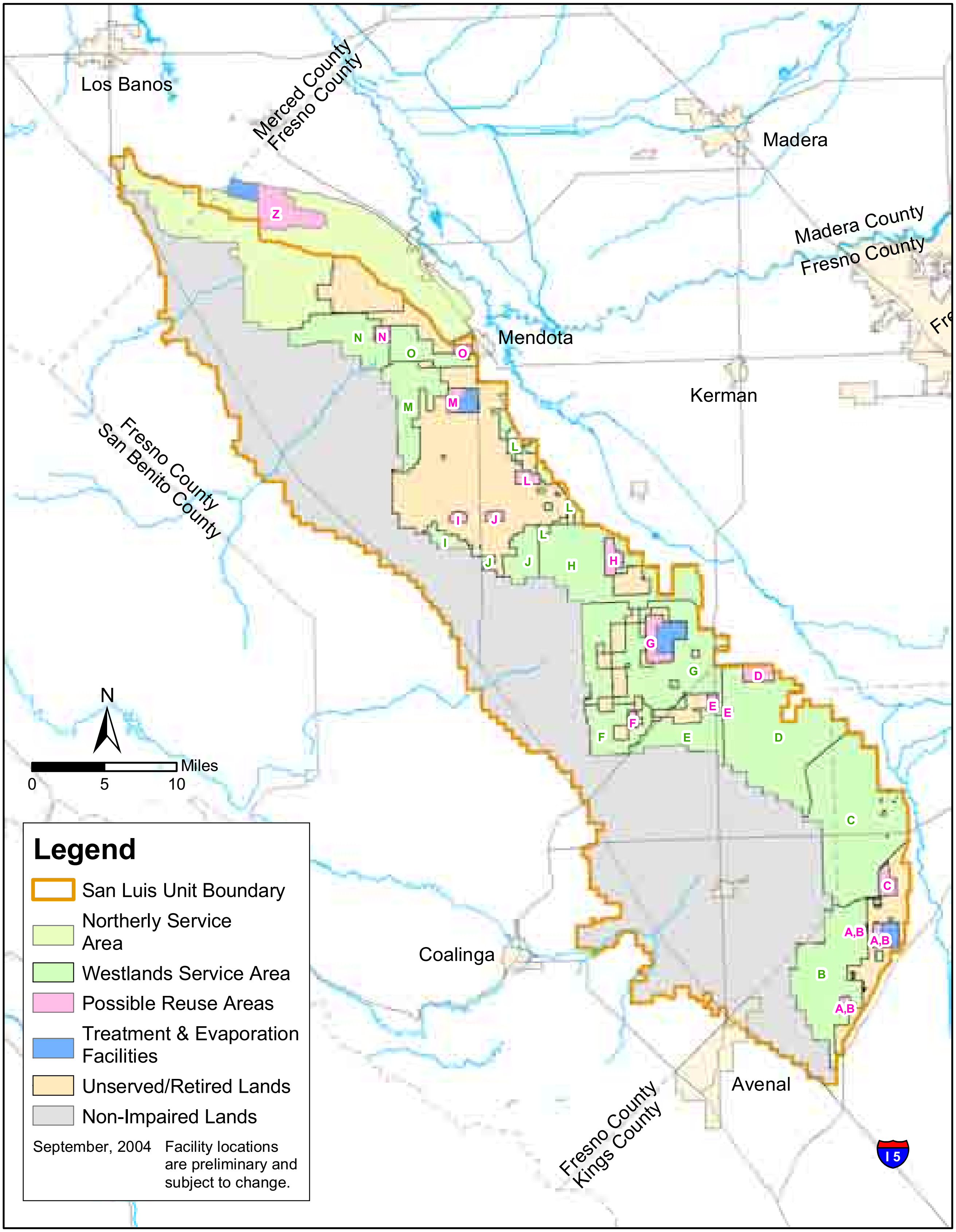

San Luis Drainage Feature Re-evaluation	Drainage and Reuse Areas, In-Valley/Groundwater Quality Land Retirement Alternative	Figure C2-2
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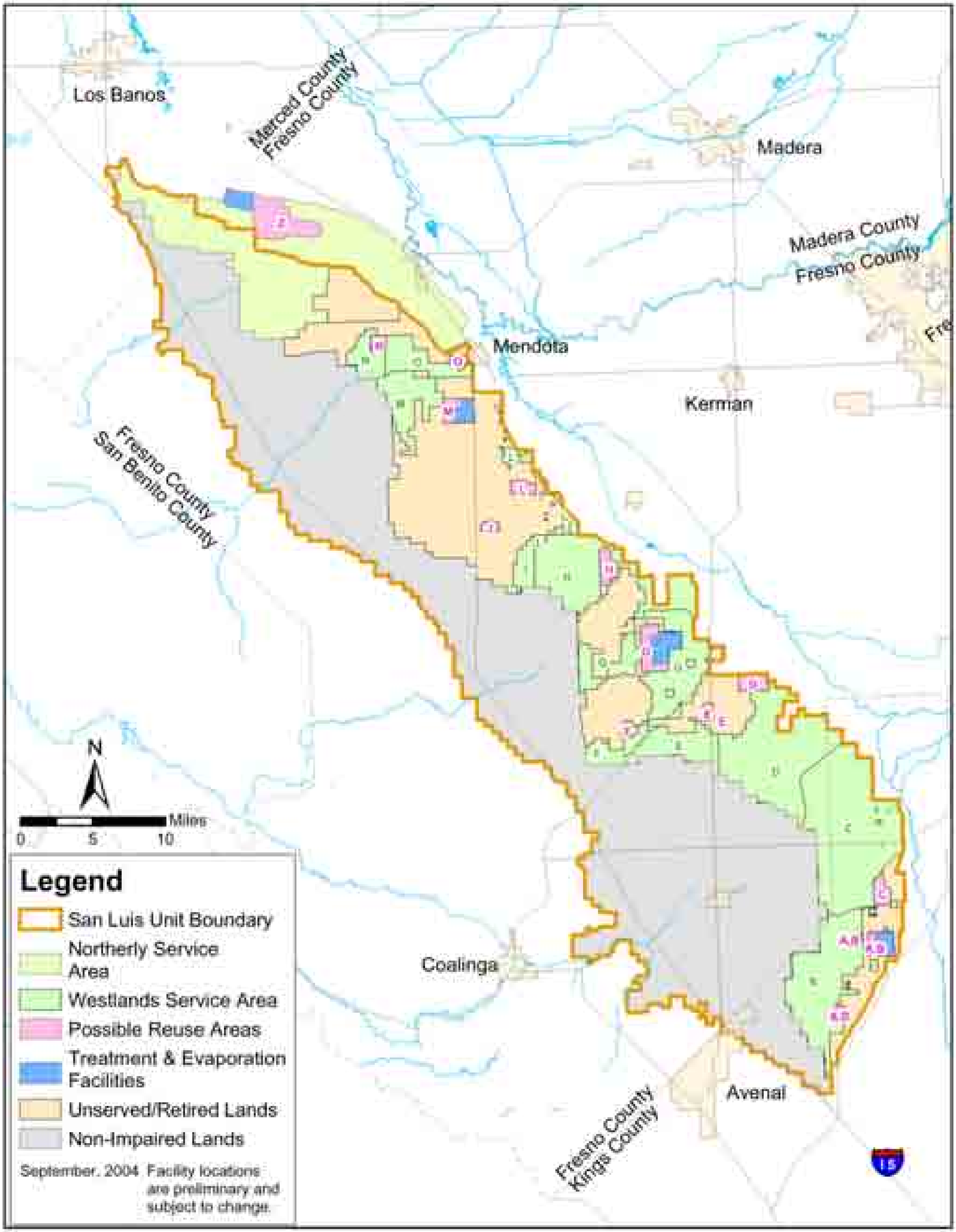

San Luis Drainage Feature Re-evaluation	Drainage and Reuse Areas, In-Valley/Water Needs Land Retirement Alternative	Figure C2-3
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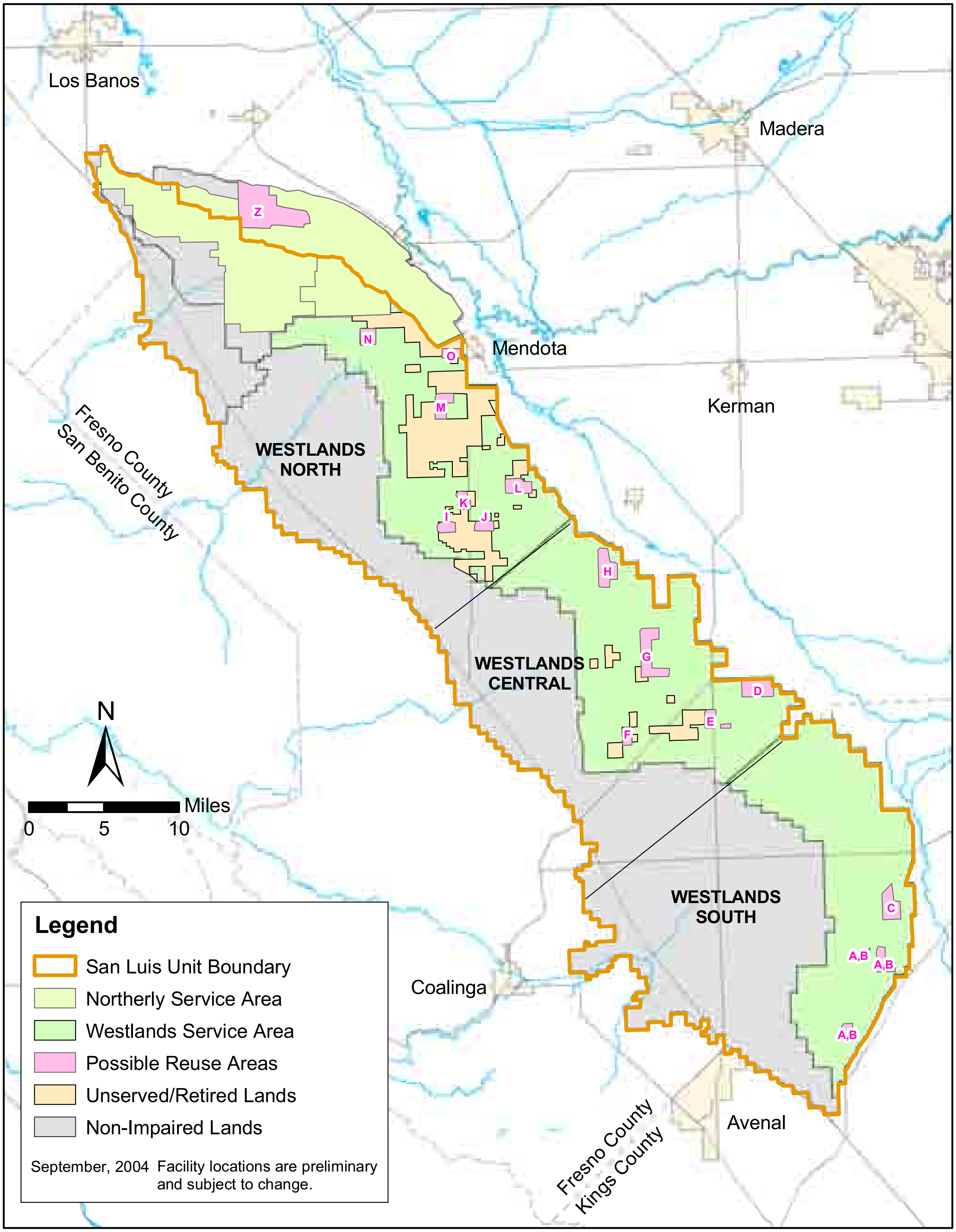

San Luis Drainage Feature Re-evaluation	Drainage and Reuse Areas, Out-of-Valley Disposal Alternatives	Figure C2-4
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Each dataset was tested for normality or log-normality using Shapiro Wilks test. None of the constituents were normally distributed and generally contained high values that skewed the distribution. The constituents were approximated with a log-normal distribution; therefore, the natural logs of the values were used.

C2.5 KRIGING

ArcGIS Geostatistical Analyst software was used to perform the geostatistical modeling. Kriging was used to generate a 2-dimensional groundwater quality surface for each constituent. Kriging is a technique that uses the spatial autocorrelation of the individual sample points to develop a mathematical weighting technique to predict values for unknown locations based on the location and values of nearby measured values. Kriging was selected as the geostatistical method because it allows calculation of an estimated error in the predicted values. The steps involved in kriging include exploratory data analysis, data transformation, development of the semivariagram model, defining the search radius, outputting the estimated values, model validation, and estimating the error in the predicted values or area averages.

C2.5.1 Semivariagram Modeling

Semivariagram modeling explores the overall spatial autocorrelation of the measured points by use of a function that relates semivariance (or dissimilarity) of data points to the distance that separates them. The semivariagram shows the difference-squared of the values between each pair of points at different distances, and determines the best fit for a model that will pass through the points in the semivariagram. Table C2-5 shows the semiveriagram model parameters used to develop the kriged surface in the geostatistical analyst software.

Table C2-5
Semivariagram Model Parameters

Parameters*	Constituents			
	TDS	**Se**	**Boron**	**Molybdenum**
Semivariagram Model	Circular	Spherical	Circular	Circular
Anisotropy	Yes	No	Yes	No
Major Range (m)	25000	15000	28000	11500
Minor Range (m)	15000	NA	15000	NA
Direction (degrees)	324.7	NA	135	NA
Partial Sill	1.5	3	2.15	2.2
Nugget	0.425	1.23	0.515	0.73

*Parameters used in kriging functions of Geostatistical Analyst Software

C2.5.2 Block Kriging

The purpose of block kriging was to develop estimates of average concentrations for each region of interest (drainage in each subarea, reuse areas) while minimizing the standard error. To perform the block kriging, the semivariagram surface was sampled by a 5,000- by 5,000-meter grid surface. This grid cell size was chosen to resolve the boundaries of the larger subareas, as well as providing a sampling size similar to the smallest subarea of interest (evaporation basins).

This provided a grid of concentrations and predicted errors for each 5,000-square-meter grid cell. Average values were calculated for each subarea from these grid values. Because the kriged surface was developed in natural log space, statistical relationships and mathematical transformation were used to convert the predicted values and standard errors to arithmetic space. In addition, because the subareas are irregular boundaries and not square areas, a grid subsampling procedure was used in ArcGIS to improve the accuracy of the estimates. The block kriging procedure was used to obtain zonal statistics of Se, TDS, Mo, and B concentrations for each subarea.

A detailed description ArcGIS Geostatistical Analyst block kriging procedure used to calculate predicted concentrations, errors, and zonal statistics for each subarea is presented in Section C2.5.3.

The following relationships were used to calculate the zonal statistics and convert the kriged log values into arithmetic values.

The predicted arithmetic value for each grid cell (M_n) is:

$$M_n = e^{\left(x_n + 0.5[\sigma_n]^2\right)} \tag{C-1}$$

Where:

x_n = predicted (kriged) concentration, in natural-log space, of each grid cell

σ_n = standard error of kriged predicted value extracted from the geostatistical analyst software, in natural-log space, for grid cell n

To account for differences in hydraulic conductivity in different grid cells, which will result in different amounts of drainwater production, the predicted arithmetic values were scaled by ratio of the hydraulic conductivity in the grid cell to the mean hydraulic conductivity for the subarea using the following relationship:

$$[\text{Mscaled}]_n = [\text{M}]_n \left(\frac{K_n}{K\_mean} \right) \tag{C-2}$$

Where:

K_n = the hydraulic conductivity of a respective cell

K_mean = the average hydraulic conductivity of the respective subarea

The zonal average for n grid cells in a given area is:

$$\text{Mean} = \frac{\sum M_n}{n} \tag{C-3}$$

Where:

Mean = zonal mean (or scaled mean) of grid matrix n

M_n = the predicted arithmetic concentration (or scaled concentration) within a grid cell

n = the number of cells in the subarea

To calculate the standard errors associated with the predicted zonal means and convert them to arithmetic space the following relationships were used:

$$C_n = \sqrt{e^{(\sigma_n)^2 - 1}} \qquad \text{(C-4)}$$

Where:

C_n = coefficient of variation of predicted arithmetic value for grid cell n

σ_n = standard error of kriged predicted value extracted from the geostatistical analyst software, in natural-log space, for grid cell n

The standard error for each grid cell (S_n) was calculated as:

$$S_n = [C_n][M_n] \qquad \text{(C-5)}$$

Where :

S_n = standard error for each grid cell

M_n = predicted arithmetic mean (or scaled mean) concentration for grid cell n from Equation C-1 or C-2

C_n = coefficient of variation of predicted arithmetic value for grid cell n from Equation C-4

Mean standard error for a given subarea is found by taking the average of the standard error for each grid cell contained within the subarea similar to Equation C-3.

$$\text{Mean Standard Error for subarea} = \frac{\sum S_n}{n} \qquad \text{(C-6)}$$

To improve the confidence and provide a conservative estimate of the mean values for the subsequent environmental analysis the upper 95 percent confidence limit of the mean values was calculated from the subarea mean (and scaled mean) and mean standard errors using the following relationship:

> 95th upper confidence limit of Mean (or scaled mean) = Subarea Mean (or subarea scaled mean) × 2 × Mean Standard Error for subarea

The following section describes the process used to implement this procedure in ArcGIS using the Geostatistical Analyst Software.

C2.5.3 Geostatistical Analyst Procedure Definitions

$Pred\_5000_n$ = mean predicted natural-log values for each grid cell in 5000- by 5000-meter grid space

$Pred\_250_n$ = mean predicted natural-log values for each grid cell in 250- by 250-meter grid space

Err_5000_n = natural-log kriging error in 5000- by 5000-meter grid space

$Pred\_100_n$ = cell means from $Pred\_5000_n$ resampled to fit 100- by 100-meter grid space

$Pred\_mean\_5000_n$	=	predicted zonal mean statistics fit into 5000- by 5000-meter grid space
$Pred\_mean\_100_n$	=	predicted zonal mean statistics fit into 100- by 100-meter grid space (n refers to the grid cell number)
C	=	Coefficient of Variation of arithmetic values matrix
M	=	predicted arithmetic value matrix
Mscaled	=	predicted arithmetic values scaled by hydraulic conductivity matrix
S	=	standard error of predicted arithmetic values
S	=	[C]*[M]

1. The kriging surface of predicted concentrations was divided into 5000- by 5000-meter grid cells. The kriging surface was sampled to obtain a matrix of 20 x 20 points within each 5000- by 5000-meter grid cell, and an average value for each grid cell was calculated and termed $Pred\_5000_n$. The same was also done on 250- by 250-meter grid cell spacing, with the kriging surface sampled at 2 by 2. The 250- by 250-meter grid cells were termed $Pred\_250_n$.

   The Standard Error of the predicted kriging surface was sampled to obtain a matrix of 20 by 20 points for each 5000- by 5000-meter grid cell. The average Standard Error for each grid cell was calculated. These values are termed Err_5000_n.

2. To better fit the values into the actual shape of each subarea, the 5,000 m^2 grid cells, $Pred\_5000_n$, were then divided into smaller, 100- by 100-meter cells, each of which took the same value as the mean for the 5000- by 5000-meter cell in which the smaller cell is located. These values are termed $Pred\_100_n$.

3. The predicted mean concentration for each subarea's productive/drained lands, reuse areas, and evaporation basins were calculated by averaging the grid cells, $Pred\_100_n$, within each area to obtain the zonal statistics.

   Zonal statistics derived from averaging $Pred\_100_n$ cells were compared to zonal statistics for the same area that were derived from averaging the $Pred\_250_n$ cells. Means were very similar.

4. Zonal statistics values, derived from the $Pred\_mean\_100_n$ grid cells, were put into a 100- by 100-meter grid, to fit the shape of the areas including drainage lands, reuse areas, and evaporation basins, which comprise the In-Valley and Out-of-Valley Disposal Alternatives.

5. Zonal statistic mean values for each 100- by 100-meter cell were converted from natural-log to arithmetic values by the following formula:

   $$M_n = e^{\left((Pred\_mean\_100\,n) + 0.5(Err\_5000\,n)^2\right)}$$

   A grid, M, was made up of the values M_n.

6. The Coefficient of Variation was calculated for each 100 m^2 cell by the following formula:

   $$C_n = e^{\left((Err\_5000\,n)^2 - 1\right)}$$

   A grid, C, was made up of the values C_n.

7. The Standard Deviation was calculated by multiplying grid M by grid C.

$$S = [C][M]$$

A grid, S, was made up of these values.

8. The scaled values of the arithmetic means were calculated with the following formula

$$[\text{Mscaled}]_n = [M]_n \left(\frac{K_n}{K\_mean} \right)$$

Where K_n is the hydraulic conductivity of a respective cell from the Belitz model and K_mean is the mean of the hydraulic conductivity for a respective subarea.

A matrix, Mscaled, was made up of the scaled values.

9. Zonal statistics were calculated from grid M, S, C, Mscaled.

C2.5.4 Validation of Predicted Concentrations

Predicted versus measured concentrations are shown in Table C2-6.

Table C2-6
Comparison of Measured and Predicted Water Quality for Northerly Area

		Observed	Geostatistical Modeling				
Constituent	**Units**	**Flow Weighted Mean Measured in Sumps***	**Mean**	**Std error**	**95% UCL Mean**	**Scaled Mean**	**95% UCL Scaled Mean**
Se	µg/L	132	43	38	118	44	119
TDS	mg/L	4000	3529	2387	8302	3516	8290
Boron	µg/L	9100	5078	3829	12736	5088	12745

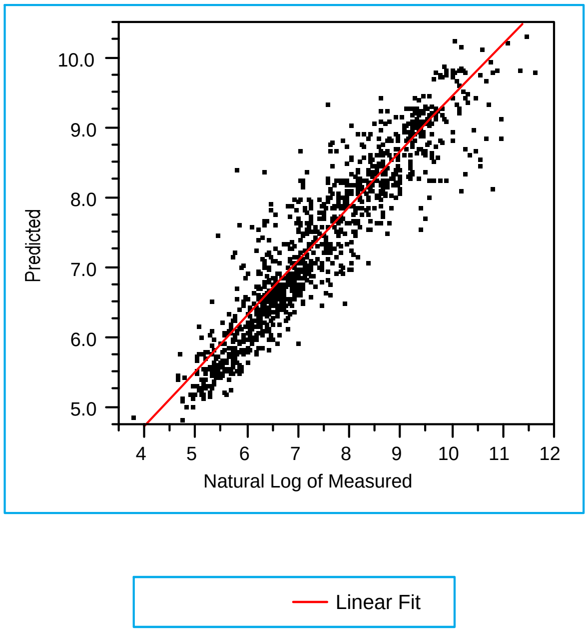
µg/L = micrograms per liter

*Taken from actual sump readings for Camp 13 and Charleston Drainage Districts and Firebaugh Canal and Pacheco Water Districts, Water Year 1999. Broadview Water District data not available.

Source: Summers Engineering 2003.

The predicted point values from the kriging model were compared to well data. Figures C2-5 through C2-8 show results of the regression analysis for the comparisons between the predicted and measured values for each constituent. For all constituents the results showed strong correspondence with the measured values. Results for Se show an under prediction of very high values (greater than 9), although the general fit is good.

Figure C2-5 Total Dissolved Solids Predicted By Natural Log of Measured Concentrations



Linear Fit

Predicted = 1.59683 + 0.78224 Natural Log of Measured Concentrations

Summary of Fit

RSquare	0.864601
RSquare Adj	0.86448
Root Mean Square Error	0.441291
Mean of Response	7.35132
Observations (or Sum Wgts)	1116

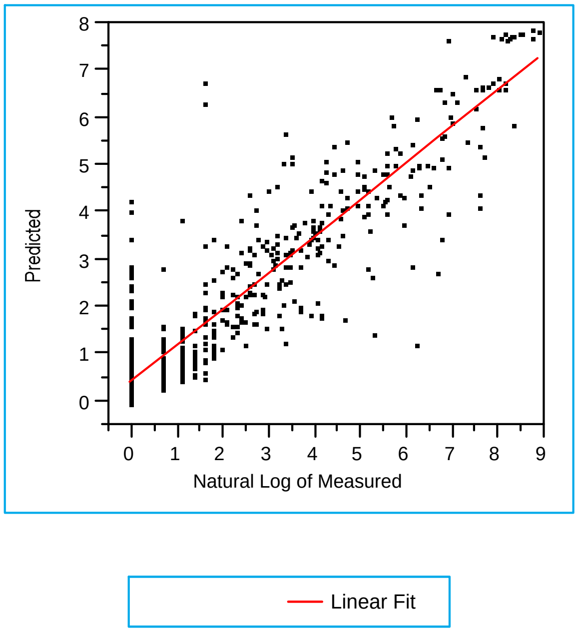
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1385.2796	1385.28	7113.553
Error	1114	216.9382	0.19	Prob>F
C Total	1115	1602.2178		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t
Intercept	1.5968284	0.069495	22.98	<.0001
Natural Log of Measured	0.7822376	0.009275	84.34	0.0000

Figure C2-6 Selenium Predicted By Natural Log of Measured Concentrations



Linear Fit

Predicted = 0.39757 + 0.77114 Natural Log of Measured Concentrations

Summary of Fit

RSquare	0.839277
RSquare Adj	0.839048
Root Mean Square Error	0.785872
Mean of Response	1.759245
Observations (or Sum Wgts)	703

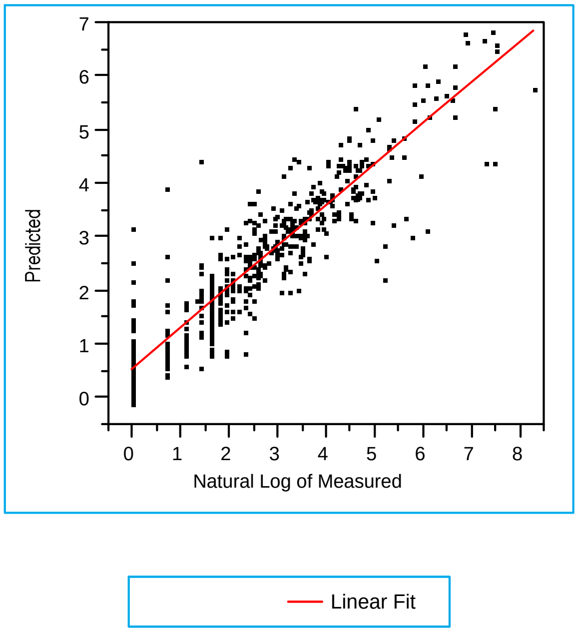
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2260.7353	2260.74	3660.545
Error	701	432.9343	0.62	Prob>F
C Total	702	2693.6696		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.3975655	0.037216	10.68	<.0001
Natural Log of Measured	0.7711449	0.012746	60.50	<.0001

Figure C2-7 Molybdenum Predicted By Natural Log of Measured Concentrations



Linear Fit

Predicted = 0.55129 + 0.76163 Natural Log of Measured Concentrations

Summary of Fit

RSquare	0.845696
RSquare Adj	0.845433
Root Mean Square Error	0.586152
Mean of Response	2.33246
Observations (or Sum Wgts)	588

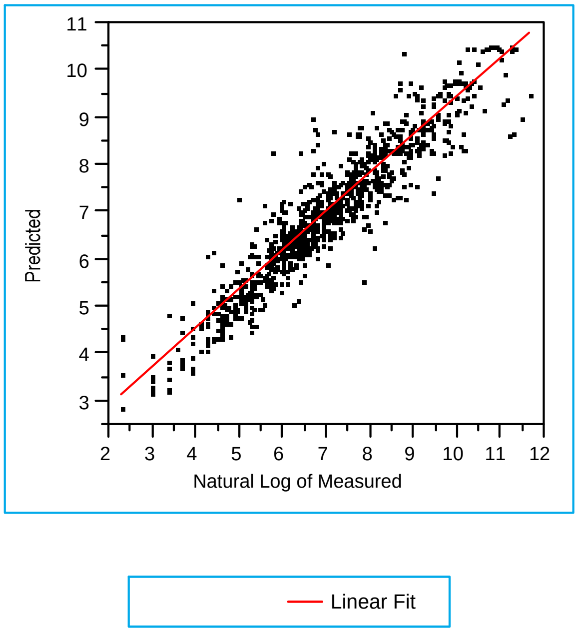
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1103.4619	1103.46	3211.71
Error	586	201.3347	0.34	Prob>F
C Total	587	1304.7966		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.5512905	0.03965	13.90	<.0001
Natural Log of Measured	0.761628	0.013439	56.67	<.0001

Figure C2-8 Boron Predicted By Natural Log of Measured Concentrations



Linear Fit

Predicted = 1.26643 + 0.81669 Natural Log of Measured Concentrations

Summary of Fit

RSquare	0.884777
RSquare Adj	0.884668
Root Mean Square Error	0.498302
Mean of Response	6.938321
Observations (or Sum Wgts)	1059

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2015.3595	2015.36	8116.487
Error	1057	262.4578	0.25	Prob>F
C Total	1058	2277.8172		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.2664325	0.064792	19.55	<.0001
Natural Log of Measured	0.8166946	0.009065	90.09	0.0000

C2.5.4.1 Hydraulic Conductivity Normalization Procedure

Not all lands contribute the same amount of water to subsurface drains due to differences in hydraulic conductivity of the soils. Results for the subarea averages were weighted based on the hydraulic conductivity used in the topsoil layer of the Belitz model to reflect the lower water yields of areas with low conductivity. The weighting was done for each subarea by applying a scaling factor to each.

An estimate for each subarea of the average hydraulic conductivity, K_mean, and the hydraulic conductivity for each grid cell, K_n, were obtained from the Britz model and were used to scale the water quality parameter with the following formula:

$$[\text{Se\_scaled}]_n = [\text{Se}]_n \left(\frac{K_n}{\text{K\_mean}} \right)$$

Where $[\text{Se\_scaled}]_n$ is the scaled Se concentration for a given cell, and $[\text{Se}]_n$ is the predicted unscaled Se concentration for the cell. This scaling operation was performed on the predicted concentrations of TDS, Se, Mo, and B. The scaled concentrations are used in determining drainwater quality from farmed lands and reuse areas to enable calculation of discharge water quality for each disposal alternative.

C2.6 RESULTS

Concentrations for constituents other than TDS, Se, B, and Mo have been estimated from TDS concentrations for all three Westlands subareas by adjustment with a scaling factor. The scaling factor for each constituent in each subarea was calculated as a ratio of the TDS concentration from the geostatistical analysis for each subarea to the respective constituent monitored in the Westlands North area. Table C2-7 is a summary of water quality in each subarea. This analysis does not include water from the Delta-Mendota Canal Drain, which is not expected to have a significant effect on drainwater quality due to the small flow rate compared to the other project drainflows.

Table C2-7
Drainwater Quality from Farm Lands for the In-Valley Disposal Alternative and the Out-of-Valley Disposal Alternatives

Constituent	Units	Report of Waste Discharge Westlands North [1]	Westlands North Best Available Data[2,3]	Westlands Central[2]	Westlands South[2]	Northerly Area[4]	San Luis Unit Flow-Weighted Average[5]
Sodium	mg/L	2,190	1,721	1,324	1,620	595	1,141
Potassium	mg/L	7	7	6	7	9.2	8
Calcium	mg/L	555	436	336	411	286	343
Magnesium	mg/L	270	201	155	189	93	143
Hardness	mg/L	2,498	1,918	1,476	1,806	1,097	1,445
Alkalinity	mg/L	195	196	151	185	170	171
Sulfate	mg/L	4,650	3,734	2,873	3,516	1,500	2,559

Table C2-7 (concluded)
Drainwater Quality from Farm Lands for the In-Valley Disposal Alternative and the Out-of-Valley Disposal Alternatives

Constituent	Units	Report of Waste Discharge Westlands North [1]	Westlands North Best Available Data[2,3]	Westlands Central[2]	Westlands South[2]	Northerly Area[4]	San Luis Unit Flow-Weighted Average[5]
Chloride	mg/L	155	1,009	777	950	546	748
Nitrate (NO_3)	mg/L	213	235	181	221	44	141
Nitrate (N)	mg/L	48	53	41	50	9.94	32
Ammonia	mg/L	0.01	0	0.01	0.01	1	0.4
Silica	mg/L	37	37	29	35	NA	32
Bicarbonate	mg/L	NA	225	173	212	173	187
Carbonate	mg/L	NA	NA	NA	NA	3.6	3.6
Bromide	mg/L	1.6	1.6	1.2	1.5	2.2	1.7
TDS	mg/L	9,850	9,253	7,119	8,712	4,000	6,454
TSS	mg/L	10	10	8	9	NA	9
TOC	mg/L	9.5	9.5	7	9	10	9
COD	mg/L	30	30	23	28	NA	26
BOD	mg/L	3	3	2	3	NA	3
Temp	C	18	18	NA	NA	NA	18
pH	SU	8.2	7.70	7.70	7.70	8.2	7.9
Boron	µg/L	15,000	9,800	6,724	7,666	9,100	8,314
Se	µg/L	230	101	56	19	132	88
Strontium	µg/L	6,400	6,432	4,949	6,057	NA	5,618
Iron	µg/L	150	151	116	142	NA	132
Molybdenum	µg/L	93	87	109	219	34	91
Aluminum	µg/L	NA	NA	NA	NA	NA	NA
Arsenic	µg/L	0	3	2	3	8.2	5
Cadmium	µg/L	1	1	1	1	NA	1
Chromium	µg/L	20	32	25	30	5.9	19
Copper	µg/L	10	10	8	9	3.4	7
Lead	µg/L	1	1	1	1	4.8	2
Manganese	µg/L	10	10	8	9	2	6
Mercury	µg/L	0.1	0.1	0.1	0.1	0.2	0.1
Nickel	µg/L	20	20	15	19	5.3	13
Silver	µg/L	1	1	1	1	NA	1
Zinc	µg/L	10	10	8	9	2.4	6

NA=Data is not available or detection limit is not available

1 CH2MHILL 1985.

2 Westlands North, South, and Central data are estimated by scaling geostatistical analysis by a ratio of TDS concentrations from the kriging analysis to the measured concentrations of each constituent in each subarea. Best Available North data is also comprised of older CH2MHILL data and additional (1986-96) data from Westlands Water District, where available.

3 Concentrations of lead, copper, and mercury were reported to be less than the detection limits.

4 Northerly Area concentrations from flow-weighted average of measured sumps for TDS, B, Se, and Mo concentrations from kriging analysis; other data from Grassland Bypass EIS/EIR (Reclamation 2001b), and other data (personal communication with Joe McGahan).

5 Drainage rates for each subarea are based on Tables C1-7 through C1-10.

Flow-weighted averages are based on final flow rates for subareas shown in Section C1. Areas are not included in the average when data are not available

The water quality of the perched groundwater under the reuse areas is expected to gradually change due to the perched aquifer being replaced by the applied drainwater percolating past the root zone. The quality of the discharged drainwater would then become that of the applied drainwater concentrated by the fraction leached (assuming that the salt, B, and Se mass is conserved).

Estimates of TDS, Se, and B concentrations from reuse area discharges were calculated based on an estimated 73 percent water usage volume by reuse facility crops. It was assumed that all constituents are conserved. These calculations and current groundwater concentration under the potential locations for the reuse facilities were then averaged to account for dilution of drainage from the facility with shallow groundwater before discharge into reuse facility drains. This average resulted in calculated estimated discharge concentrations for Westlands (and its subareas) and the Northerly Area. Current data for all other constituents were then scaled by the ratio of calculated estimated TDS concentration to current TDS concentration.

Table C2-7a summarizes additional existing water quality data on subsurface drainage from the drainage area. These data were collected as a part of the Grassland Bypass Project EIS/EIR (Reclamation 2001b). Samples were collected from the Grassland Bypass Project discharge from the San Luis Drain into Mud Slough (Station B) and represents the quality of water that would be discharged into the Northerly Reuse Area. The fate of the organic compounds is difficult to judge following discharge into the reuse area because many compounds tend to sorb to soil due to their hydrophobic nature. As such, the concentrations would represent a maximum possible concentration in the discharge from the reuse areas to the ocean.

Table C2-7a
Drainwater Quality for Other Constituents – 1997 San Luis Drain Site B Sampling

	Sample 1	Sample 2		Sample 1	Sample 2
Selenium	69.9	69.7	**Organochlorine Pesticides (μg/L) cont.**		
Molybdenum	49	49	Endosulfan I	<0.050	<0.050
Standard Minerals (mg/L)			Endosulfan II	<0.10	<0.10
Alkalinity as $CaC0_3$	200	200	Endosulfan sulfate	<0.10	<0.10
Bicarbonate as $CaC0_3$	200	200	Endrin	<0.10	<0.10
Cardonate as $CaC0_3$	<1.0	<1.0	Endrin aldehyde	<0.10	<0.10
Hydroxide as $CaC0_3$	<1.0	<1.0	Heptachlor	<0.050	<0.050
Calcium	340	330	Heptachlor epoxide	<0.050	<0.050
Chloride	660	680	Kepone	<0.10	<0.10
Hardness as $CaC0_3$	1,300	1,300	Methoxychlor	<0.50	<0.50
Boron	8.6	8.4	Mirex	<0.10	<0.10
Potassium	6.0	5.7	Toxaphene	<1.0	<1.0
Methylene Blue Active Substances	<0.50	<0.50	**Polychlorinated Biphenyls (μg/L)**		
Magnesium	110	110	Aroclor 1016	<0.50	<0.50
Sodium	830	870	Aroclor 1221	<0.50	<0.50
Nitrate (as N)	14	13	Aroclor 1232	<0.50	<0.50
pH	8.2	7.0	Aroclor 1242	<0.50	<0.50
Specific Conductance (umhos/cm)	4,800	4,800	Aroclor 1248	<0.50	<0.50
Sulfate	1700	1600	Aroclor 1254	<0.50	<0.50
Ammonia	<0.10	0.10	Aroclor 1260	<0.50	<0.50
Orthophosphate	<0.050	<0.050	**Organophosphorus Pesticides (μg/L)**		
Total Dissolved Solids	3,900	3,900	Dichlorvos	<1.0	<1.0
Trace Elements (μg/L)			Demeton	<1.0	<1.0
Arsenic	8.0	8.4	Ethoprop	<1.0	<1.0
Chromium	3.6	3.7	Naled	<2.0	<2.0
Copper	17	19	Phorate	<1.0	<1.0
Mercury	<0.20	<0.20	Diazinon	<1.0	<1.0
Nickel	11	10	Disulfoton	<1.0	<1.0
Lead	<2.0	<2.0	Ronnel	<1.0	<1.0
Zinc	10	13	Methyl parathion	<1.0	<1.0
Hexavalent Chromium	<10	<10	Chlorpyrifos	<1.0	<1.0
N-Methylcarbamates (μg/L)			Trichloronate	<1.0	<1.0
Aldicarb	<0.10	<0.10	Merphos	<1.0	<1.0
Aldicarb sulfone	<0.10	<0.10	Prothiophos	<1.0	<1.0
Baygon	<0.10	<0.10	Bolstar	<1.0	<1.0
Carbaryl	<0.10	<0.10	Mevinphos	<1.0	<1.0
Carbofuran	<0.10	<0.10	Fenthion	<1.0	<1.0
3-Hydroxycarbofuran	<1.0	<1.0	Malathion	<1.0	<1.0
Methiocarb	<0.10	<0.10	Stirophos	<1.0	<1.0
Dioxacarb (Elocron)	<0.10	<0.10	Fensulfothion	<1.0	<1.0
Promecarb (Carbamult)	<0.10	<0.10	Coumaphos	<2.0	<2.0
Methomyl	9.7	15	Gution	<1.0	<1.0
Organochlorine Pesticides (μg/L)			**Chlorinated Acid Herbicides (μg/L)**		
Aldrin	<0.050	<0.050	2,4,5-T	<0.50	<0.50
alpha BHC	<0.050	<0.050	2, 4-D	<1.0	<1.0
beta BHC	<0.050	<0.050	2, 4-DB	<2.0	<2.0
delta-BHC	<0.050	<0.050	Dalapon	<2.0	<2.0
Lindane	<0.050	<0.050	Dicamba	<1.0	<1.0
Chlordane	<0.50	<0.50	Dichloroprop	<2.0	<2.0
4, 4'-DDD	<0.10	<0.10	Dinoseb	<1.0	<1.0
4,4'-DDE	<0.10	<0.10	MCPA	<250	<250
4, 4'-DDT	<0.10	<0.10	MCPP	<250	<250
Dieldrin	<0.10	<0.10	Silvex (2, 4, 5-TP)	<0.20	<0.20

Source: Reclamation 2001b

Table C2-8 summarizes the estimated post-reuse concentrations for the San Luis Unit. It should be noted that these concentrations will not occur until final buildout of drainage service and many years of reuse facility operation, and that initial discharge quality would be dependent on the final selection of reuse facility locations.

Table C2-8
Drainwater Quality After Reuse for the In-Valley Disposal Alternative and the Out-of-Valley Disposal Alternatives

Constituent	Unit	North Westlands[1]	Central Westlands[1]	South Westlands[1]	Northerly Area[1]	San Luis Unit Flow Weighted Average
Sodium	mg/L	4,463	3,086	4,747	2,231	3,211
Potassium	mg/L	19	13	20	35	24
Calcium	mg/L	1,132	783	1,204	1,073	1,015
Magnesium	mg/L	522	361	555	349	410
Hardness	mg/L	4,975	3,440	5,291	4,550	4,395
Alkalinity	mg/L	508	352	541	638	517
Sulfate	mg/L	9,685	6,697	10,302	5,625	7,278
Chloride	mg/L	2,618	1,810	2,785	2,048	2,176
Nitrate (NO_3)	mg/L	609	421	648	165	383
Nitrate (N)	mg/L	137	95	146	37	86
Ammonia	mg/L	0.03	0.02	0.03	4	1
Silica	mg/L	96	67	103	NA	83
Bicarbonate	mg/L	585	404	622	649	562
Carbonate	mg/L	NA	NA	NA	14	14
Bromide	mg/L	4	3	4	8	5
TDS[2]	mg/L	24,000	16,596	25,528	12,285	17,381
TSS	mg/L	26	18	28	NA	23
TOC	mg/L	10	7	9	10	9
COD	mg/L	30	23	28	NA	26
BOD	mg/L	8	5	8	NA	7
Temp	C	18.1	NA	NA	NA	18.1
pH	SU	7.7	7.7	7.7	8.2	7.9
Boron[2]	µg/L	22,140	15,613	16,781	25,759	20,872
Se[2]	µg/L	270	130	56	293	207
Strontium	µg/L	16,684	11,537	17,747	NA	14,400
Iron	µg/L	391	270	416	NA	338
Molybdenum[2]	µg/L	150	335	343	85	207
Aluminum	µg/L	NA	NA	NA	NA	NA
Arsenic	µg/L	8	5	8	31	16
Cadmium	µg/L	3	2	3	NA	2
Chromium	µg/L	84	58	89	22	52
Copper	µg/L	26	18	28	13	19

Table C2-8 (concluded)
Drainwater Quality After Reuse for the In-Valley Disposal Alternative and the Out-of-Valley Disposal Alternatives

Constituent	Unit	North Westlands[1]	Central Westlands[1]	South Westlands[1]	Northerly Area[1]	San Luis Unit Flow Weighted Average
Lead	µg/L	3	2	3	18	8
Manganese	µg/L	26	18	28	8	17
Mercury	µg/L	0.3	0.2	0.3	0.8	0.4
Nickel	µg/L	52	36	55	20	35
Silver	µg/L	3	2	3	NA	2
Zinc	µg/L	26	18	28	9	17

NA=Data is not available or detection limit is not available

[1] Westlands North, South, and Central data are estimated by scaling geostatistical analysis TDS concentrations to the measured concentrations of each constituent in each subarea, accounting for 73 percent water usage by reuse crops and averaged with current concentrations to account for dilution.

[2] Data from geostatistical analysis, accounting for 73 percent water usage by reuse crops and averaged with current concentrations to account for dilution.

C2.6.1 Zonal Statistics

Tables C2-9 through C2-12 show the groundwater quality zonal statistics for the In-Valley Disposal Alternative and the Out-of-Valley Disposal Alternatives for each area. Zonal statistics for Se in Drainage Areas are also shown for the In-Valley/Groundwater Quality Land Retirement Alternative and the In-Valley/Water Needs Land Retirement Alternative in Tables C2-13 and C2-14.

Table C2-9
Predicted Total Dissolved Solids Zonal Statistics, In-Valley Disposal Alternative and Out-of-Valley Disposal Alternatives

Name	Mean (mg/L)	Std Error	95% UCL Mean (mg/L)	Scaled Mean (mg/L)	Std Error	95% UCL Scaled Mean (mg/L)
Retired Land	4,481	2,980	10,440	6,212	4,127	14,466
Northerly Drainage Area	3,521	2,380	8,281	3,453	2,319	8,091
Drainage Area B	3,489	2,397	8,282	3,489	2,397	8,284
Drainage Area C	3,917	2,641	9,198	3,923	2,648	9,218
Drainage Area D	2,046	1,362	4,769	2,045	1,361	4,767
Drainage Area E	2,193	1,437	5,068	2,193	1,437	5,067
Drainage Area F	3,483	2,339	8,160	3,483	2,339	8,161
Drainage Area G	3,759	2,556	8,870	3,760	2,557	8,873
Drainage Area H	3,260	2,265	7,789	3,272	2,268	7,807
Drainage Area I	6,165	4,288	14,742	3,974	2,799	9,571
Drainage Area J	3,931	2,608	9,146	6,108	4,040	14,188

Table C2-9 (concluded)
Predicted Total Dissolved Solids Zonal Statistics, In-Valley Disposal Alternative and Out-of-Valley Disposal Alternatives

Name	Mean (mg/L)	Std Error	95% UCL Mean (mg/L)	Scaled Mean (mg/L)	Std Error	95% UCL Scaled Mean (mg/L)
Drainage Area K	5,669	3,820	13,308	2,452	1,644	5,739
Drainage Area L	4,727	3,113	10,954	4,338	2,872	10,082
Drainage Area M	3,636	2,369	8,374	4,400	2,864	10,128
Drainage Area N	2,591	1,786	6,162	2,284	1,533	5,350
Drainage Area O	3,218	2,186	7,590	3,000	2,011	7,021
Northerly Reuse Area	5,813	4,038	13,889	6,096	4,295	14,686
Reuse Area B	6,753	4,520	15,794	6,757	4,525	15,807
Reuse Area C	3,541	2,344	8,230	3,543	2,347	8,237
Reuse Area D	1,799	1,205	4,208	1,791	1,191	4,173
Reuse Area E	3,256	2,176	7,607	3,256	2,176	7,607
Reuse Area F	2,641	1,756	6,153	2,641	1,756	6,153
Reuse Area G	3,852	2,671	9,195	3,861	2,683	9,226
Reuse Area H	3,603	2,407	8,417	3,603	2,406	8,416
Reuse Area I	5,537	3,759	13,054	2,553	1,733	6,019
Reuse Area J	4,611	3,074	10,759	8,674	5,783	20,239
Reuse Area K	6,154	4,083	14,320	3,035	2,019	7,073
Reuse Area L	5,092	3,272	11,635	1,883	1,242	4,366
Reuse Area M	6,147	4,064	14,275	13,678	9,042	31,763
Reuse Area N	2,586	1,764	6,115	2,799	1,910	6,620
Reuse Area O	2,196	1,470	5,135	3,629	2,445	8,519
Northerly Area Evaporation Basin[1]	7,488	5,163	17,813	NA	NA	NA
Westlands North Evaporation Basin [1]	6,360	4,205	14,770	NA	NA	NA
Westlands Central Evaporation Basin [1]	6,601	4,431	15,463	NA	NA	NA
Westlands South Evaporation Basin [1]	3,809	2,593	8,995	NA	NA	NA

[1]Evaporation basins are not included in the Out-of-Valley Disposal Alternatives.

Table C2-10
Predicted Selenium Zonal Statistics, In-Valley Disposal Alternative and Out-of-Valley Disposal Alternatives

Name	Mean (µg/L)	Std Error	95% UCL Mean (µg/L)	Scaled Mean (µg/L)	Std Error	95% UCL Scaled Mean (µg/L)
Retired Land	36	29	93	49	38	125
Northerly Drainage Area	43	37	117	43	39	121
Drainage Area B	8	8	23	8	8	23
Drainage Area C	5	4	13	5	4	13
Drainage Area D	14	12	38	14	12	38
Drainage Area E	10	8	26	10	8	26
Drainage Area F	25	21	66	25	21	66
Drainage Area G	25	23	71	25	23	71
Drainage Area H	19	22	63	19	21	61
Drainage Area I	100	94	288	63	58	180
Drainage Area J	48	37	123	74	58	189
Drainage Area K	122	94	310	51	39	129
Drainage Area L	42	33	108	38	31	99
Drainage Area M	30	23	76	36	26	89
Drainage Area N	30	29	88	25	22	68
Drainage Area O	7	6	19	6	6	18
Northerly Reuse Area	45	42	129	46	42	131
Reuse Area B	11	9	29	11	9	29
Reuse Area C	3	2	8	3	2	8
Reuse Area D	19	17	53	19	17	52
Reuse Area E	19	15	50	19	15	50
Reuse Area F	25	21	67	25	21	67
Reuse Area G	21	22	66	22	23	67
Reuse Area H	20	21	61	20	20	61
Reuse Area I	132	113	357	61	52	165
Reuse Area J	89	69	226	167	129	425
Reuse Area K	311	237	786	153	117	386
Reuse Area L	87	64	216	32	24	81
Reuse Area M	23	18	58	51	39	129
Reuse Area N	19	16	52	20	18	56
Reuse Area O	5	4	12	8	7	21
Northerly Area Evaporation Basin [1]	23	25	73	NA	NA	NA
Westlands North Evaporation Basin [1]	14	11	37	NA	NA	NA
Westlands Central Evaporation Basin [1]	5	4	13	NA	NA	NA
Westlands South Evaporation Basin [1]	21	22	65	NA	NA	NA

[1]Evaporation basins are not included in the Out-of-Valley Disposal Alternatives.

Table C2-11
Predicted Boron Zonal Statistics, In-Valley Disposal Alternative and Out-of-Valley Disposal Alternatives

Name	Mean (µg/L)	Std Error	95% UCL Mean (µg/L)	Scaled Mean (µg/L)	Std Error	95% UCL Scaled Mean (µg/L)
Retired Land	4,472	3,317	11,105	6,069	4,522	15,114
Northerly Drainage Area	4,985	3,750	12,486	4,915	3,690	12,295
Drainage Area B	2,256	1,801	5,858	2,256	1,802	5,861
Drainage Area C	3,890	2,931	9,753	3,901	2,948	9,796
Drainage Area D	2,422	1,776	5,975	2,422	1,776	5,973
Drainage Area E	2,021	1,465	4,951	2,019	1,462	4,943
Drainage Area F	3,969	3,027	10,023	3,969	3,027	10,023
Drainage Area G	3,034	2,376	7,786	3,034	2,376	7,786
Drainage Area H	2,173	1,788	5,750	2,178	1,786	5,750
Drainage Area I	4,883	3,808	12,499	3,145	2,479	8,104
Drainage Area J	2,613	1,911	6,434	4,058	2,959	9,975
Drainage Area K	5,334	3,978	13,289	2,295	1,691	5,676
Drainage Area L	5,316	3,867	13,049	4,881	3,569	12,018
Drainage Area M	3,955	2,821	9,596	4,766	3,379	11,523
Drainage Area N	3,388	2,619	8,626	2,970	2,215	7,401
Drainage Area O	3,160	2,450	8,060	2,846	2,106	7,059
Northerly Reuse Area	9,471	7,560	24,591	9,906	7,986	25,878
Reuse Area B	3,596	2,790	9,175	3,598	2,792	9,182
Reuse Area C	4,179	3,101	10,382	4,180	3,102	10,383
Reuse Area D	2,114	1,584	5,282	2,109	1,573	5,254
Reuse Area E	2,494	1,829	6,151	2,494	1,829	6,151
Reuse Area F	2,122	1,665	5,451	2,122	1,665	5,451
Reuse Area G	2,716	2,182	7,079	2,727	2,199	7,126
Reuse Area H	2,493	1,927	6,347	2,490	1,922	6,334
Reuse Area I	6,463	5,110	16,682	2,987	2,366	7,719
Reuse Area J	4,103	2,914	9,932	7,702	5,458	18,617
Reuse Area K	6,081	4,524	15,129	2,994	2,229	7,453
Reuse Area L	6,395	4,450	15,295	2,375	1,700	5,775
Reuse Area M	5,833	4,354	14,541	13,008	9,732	32,471
Reuse Area N	3,623	2,838	9,299	3,907	3,049	10,005
Reuse Area O	2,926	2,239	7,404	4,793	3,659	12,111
Northerly Area Evaporation Basin [1]	6,747	5,313	17,372	NA	NA	NA
Westlands North Evaporation Basin [1]	6,807	5,170	17,146	NA	NA	NA
Westlands Central Evaporation Basin [1]	5,934	4,567	15,067	NA	NA	NA
Westlands South Evaporation Basin [1]	2,750	2,186	7,122	NA	NA	NA

[1]Evaporation basins are not included in the Out-of-Valley Disposal Alternatives.

Table C2-12
Predicted Molybdenum Zonal Statistics, In-Valley Disposal Alternative and Out-of-Valley Disposal Alternatives

Name	Mean (µg/L)	Std Error	95% UCL Mean (µg/L)	Scaled Mean (µg/L)	Std Error	95% UCL Scaled Mean (µg/L)
Retired Land	33	24	82	48	36	120
Northerly Drainage Area	13	10	34	13	10	34
Drainage Area B	91	79	249	91	79	249
Drainage Area C	73	55	183	73	56	184
Drainage Area D	29	24	77	29	24	77
Drainage Area E	20	14	48	20	14	48
Drainage Area F	14	11	35	14	11	35
Drainage Area G	30	25	79	30	25	79
Drainage Area H	79	77	233	78	75	229
Drainage Area I	10	8	27	6	5	17
Drainage Area J	36	26	88	55	40	135
Drainage Area K	17	12	42	7	5	17
Drainage Area L	77	57	190	71	52	175
Drainage Area M	18	12	43	21	15	51
Drainage Area N	20	18	56	17	14	44
Drainage Area O	22	17	56	20	16	53
Northerly Reuse Area	23	19	61	23	20	62
Reuse Area B	160	137	434	160	137	434
Reuse Area C	116	84	285	116	84	285
Reuse Area D	33	27	88	33	27	88
Reuse Area E	26	19	64	26	19	64
Reuse Area F	28	21	69	28	21	69
Reuse Area G	48	45	138	48	46	140
Reuse Area H	148	133	414	147	132	412
Reuse Area I	27	21	68	12	10	31
Reuse Area J	46	33	113	87	63	212
Reuse Area K	52	37	126	25	18	62
Reuse Area L	119	83	286	44	31	107
Reuse Area M	41	29	100	91	66	222
Reuse Area N	27	21	68	29	23	74
Reuse Area O	16	12	40	27	20	67
Northerly Area Evaporation Basin[1]	12	12	36	NA	NA	NA
Westlands North Evaporation Basin[1]	38	28	95	NA	NA	NA
Westlands Central Evaporation Basin[1]	206	159	524	NA	NA	NA
Westlands South Evaporation Basin[1]	49	45	140	NA	NA	NA

[1]Evaporation basins are not included in the Out-of-Valley Disposal Alternatives.

Table C2-13
Predicted Selenium Zonal Statistics, In-Valley/ Groundwater Quality
Land Retirement Alternative

Name	Mean (µg/L)	Std Error	95% UCL Mean (µg/L)	Scaled Mean (µg/L)	Std Error	95% UCL Scaled Mean (µg/L)
Northerly Drainage Area	43	37	117	43	39	121
Drainage Area B	8	8	25	9	8	25
Drainage Area C	5	4	13	5	4	13
Drainage Area D	14	12	38	14	12	38
Drainage Area E	10	8	26	10	8	26
Drainage Area F	24	20	65	24	20	65
Drainage Area G	25	23	70	25	22	69
Drainage Area H	19	21	62	19	21	61
Drainage Area I	100	94	290	78	71	220
Drainage Area J	41	32	104	55	43	141
Drainage Area K	NA	NA	NA	NA	NA	NA
Drainage Area L	17	14	45	23	19	60
Drainage Area M	12	9	31	14	10	35
Drainage Area N	29	29	88	21	21	64
Drainage Area O	7	6	19	5	5	14

Note: Reuse and evaporation basin areas not shown are assumed to be similar to In-Valley Disposal Alternative

Table C2-14
Predicted Selenium Zonal Statistics, In-Valley/Water Needs Land Retirement Alternative

Name	Mean (µg/L)	Std Error	95% UCL Mean (µg/L)	Scaled Mean (µg/L)	Std Error	95% UCL Scaled Mean (µg/L)
Northerly Drainage Area	43	37	117	43	39	121
Drainage Area B	8	8	25	8	8	24
Drainage Area C	5	4	13	5	4	13
Drainage Area D	11	10	32	11	10	32
Drainage Area E	10	7	25	10	7	25
Drainage Area F	18	14	46	18	14	46
Drainage Area G	22	21	63	22	21	63
Drainage Area H	18	21	59	18	21	59
Drainage Area I	NA	NA	NA	NA	NA	NA
Drainage Area J	35	30	95	44	37	118
Drainage Area K	NA	NA	NA	NA	NA	NA
Drainage Area L	17	15	46	22	20	62
Drainage Area M	10	7.5	25	9	7	23
Drainage Area N	16	14	44	20	17	54
Drainage Area O	7	6.2	19	5	4	14

Note: Reuse and evaporation basin areas not shown are assumed to be similar to In-Valley Disposal Alternative

C2.6.2 In-Valley Disposal Alternative Water Quality Results

Table C2-15 shows the predicted concentration of shallow groundwater for farmed lands (after removal of retired lands, reuse areas, and evaporation basins) in each drainage subarea. Results for farmed lands in the three Westlands subareas were developed from the 95th percentile upper confidence limit of the scaled mean concentration estimated using kriging described above. Scaled mean concentrations were generally one-half of the upper 95th percentile values. Results for the shallow groundwater in farmed lands from the Northerly Area were from flow weighted average sump concentrations measured in the Northerly Area in 1999 for TDS, B, and Se. Because the values from the Northerly Area are measured values with lower uncertainty than the predicted values, the average rather than the 95th percentile upper confidence limits of the average values were used. Because no measured data were available, results for Mo were from the 95th percentile upper confidence limit of the scaled mean concentration estimated using kriging described above.

Table C2-15
Drainage Area Groundwater Quality[1]

Drainage Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area[2]	130	4,000	9,100	34
Westlands North	100	9,200	9,800	87
Westlands Central	55	7,100	6,700	109
Westlands South	18	8,700	7,700	219

1 Calculated as 95th percent upper confidence limit of average concentration using kriged groundwater well data.

2 Northerly Area drained area groundwater for Se, TDS, and B based on average 1999 sump monitoring data from Panoche, Pacheco, and Charleston Drainage Districts.

Table C2-16 shows the predicted average initial groundwater quality for the reuse areas. These values are the concentration in shallow groundwater predicted from the kriging analysis prior to applying drainwater.

Table C2-16
Reuse Area Initial Groundwater Quality*

Reuse Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	140	14,700	25,900	70
Westlands North	154	13,550	15,000	150
Westlands Central	62	7,250	6,250	200
Westlands South	19	12,200	10,000	400

*Calculated as 95th percent upper confidence limit of average concentration using kriged groundwater well data.

Table C2-17 shows the theoretical highest concentration in shallow groundwater under the reuse area after application of drainwater for many years. These values were calculated from the predicted drainwater quality by assuming all constituents were conserved in the drainwater but the volume of water was reduced by 73 percent due to reuse area crop use and evaporation.

Table C2-17
Reuse Area Theoretical Final Groundwater Quality*

Reuse Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	490	15,000	34,000	130
Westlands North	370	34,000	38,000	250
Westlands Central	220	26,000	25,000	320
Westlands South	57	28,000	28,000	660

*Calculated as drainage area groundwater/0.27 leaching factor, assuming constituents are conserved.

In practice, the quality of the water removed from the reuse areas changes over time and will be a mixture of initial groundwater and the theoretical groundwater quality. To reflect this process, Table C2-18 presents the average of initial groundwater and theoretical groundwater quality as an estimate of the final quality of drainage that is expected out of the reuse facilities.

Table C2-18
Reuse Area Likely Final Groundwater Quality*

Reuse Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	320	15,000	30,000	100
Westlands North	270	24,000	26,000	250
Westlands Central	140	17,000	16,000	300
Westlands South	45	22,500	20,000	600

*Calculated as average of initial and theoretical final reuse area quality (Tables C2-16 and C2-17)

Table C2-19 shows the initial concentration in shallow groundwater under the potential evaporation basin areas identified by Reclamation. These concentrations are based on the kriging analysis prior to applying drainwater to the ponds.

Table C2-19
Evaporation Basin Area Initial Groundwater Quality*

Evaporation Basin	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	73	18,000	17,500	40
Westlands North	37	15,000	17,500	100
Westlands Central	13	15,500	15,500	530
Westlands South	65	9,000	7,500	140

*Calculated as 95th percent upper confidence limit of average concentration using kriged groundwater well data.

Table C2-20 shows the effect of RO treatment on water quality. Concentrations were increased by a factor of two for Se, TDS, and Mo based on the use of single pass RO. Boron concentrations in RO brine were 40 percent of the reuse area concentrations based on previous performance of RO systems operated in Panoche Drainage District and elsewhere. RO is estimated to result in 80 percent of B passing through to the product water, with 20 percent remaining with the brine. The 20 percent concentration is contained within half the volume of water resulting in concentrations that are 40 percent of the starting concentration. Table C2-20a shows the initial estimate of product water quality from the RO system. This water would be reclaimed as supply for irrigation users. Note to meet agricultural water quality goals for boron (700 µg/L) the product water would require blending with CVP irrigation supply water at a ratio of 20 parts supply water to one part product water. Other water uses may not require as extensive blending.

Table C2-20
Initial Brine Effluent from Reverse Osmosis Treatment

Reuse Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	280	29,400	10,360	140
Westlands North	310	27,100	6,000	300
Westlands Central	120	14,500	2,500	400
Westlands South	40	24,400	4,000	800

Table C2-20a
Initial Product Water from Reverse Osmosis Treatment

Treatment Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	1.4	300	15,600	1.4
Westlands North	1.5	280	9,000	2.7
Westlands Central	0.6	150	3,800	3.6
Westlands South	0.2	250	5,900	7.3

Table C2-21 shows the expected initial concentrations after Se treatment, prior to long-term irrigation with drainwater. Se concentrations are estimated to be less than 10 µg/L based on observed performance in testing at Panoche and Westlands.

Table C2-21
Initial Effluent from Selenium Treatment to Evaporation Basins

Treatment Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	10	29,400	10,400	140
Westlands North	10	27,100	6,000	300
Westlands Central	10	14,500	2,500	370
Westlands South	10	24,400	4,000	740

Tables C2-22, C2-22a, and C2-23 show a similar analysis for the final water quality that is expected for each disposal location. These predictions use the best estimate of the final groundwater quality under the reuse areas after long-term irrigation with drainwater (Table C2-18) as the basis for the estimates rather than the initial water quality currently under reuse areas. Based on previous modeling conducted by Western Resource Economics in the PFR, the time needed to reach final water quality from the reuse areas is estimated to be approximately 20 to 25 years.

Table C2-22
Final Brine Effluent from Reverse Osmosis Treatment

Reuse Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	640	30,000	12,000	200
Westlands North	540	48,100	10,000	500
Westlands Central	275	34,000	6,000	600
Westlands South	90	45,000	8,000	1,200

Table C2-22a
Final Product Water from Reverse Osmosis Treatment

Treatment Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	3.2	300	18,000	2
Westlands North	2.7	450	14,500	4
Westlands Central	1.4	340	9,400	6
Westlands South	0.5	460	11,900	12

Table C2-23
Final Effluent from Selenium Treatment to Evaporation Basins

Treatment Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	10	30,000	12,000	200
Westlands North	10	48,100	10,000	500
Westlands Central	10	34,000	6,000	600
Westlands South	10	45,000	8,000	1,200

C2.6.3 Water Quality Results for Land Retirement Alternatives

The In-Valley/Groundwater Quality Land Retirement Alternative and the In-Valley/Water Needs Land Retirement Alternative are partial land retirement alternatives that retire farmed lands with the highest Se concentration in shallow groundwater. Drainwater quality predictions were developed for these alternatives by removing the lands from the collector system and recalculating the zonal statistics for the remaining lands in production.

Results of the Se analysis are shown in Table C2-24 for the In-Valley Disposal Alternative, In-Valley/Groundwater Quality Land Retirement Alternative, and the In-Valley/Water Needs Land Retirement Alternative. Se concentrations entering the treatment system in the Northerly Area remain the same as for the In-Valley Disposal Alternative (shown in Tables C2-20 and C2-22) because the land being retired in the Northerly Drainage Area (Broadview Water District) does not currently drain to the Grassland Bypass Project, which provided the monitoring data that is the basis for the water quality estimates.

Table C2-24
Initial and Final Selenium Concentrations Entering Selenium Treatment System for In-Valley and Land Retirement Alternatives

Alternative	In-Valley		Groundwater Quality Land Retirement[1]		Water Needs Land Retirement[2]	
Disposal Location	Initial	Final	Initial	Final	Initial	Final
Westlands North Evaporation Basin	308	543	263	380	242	142
Westlands Central Evaporation Basin	124	275	125	276	123	124
Westlands South Evaporation Basin	38	90	36	97	36	48

[1]Lands with Se concentrations in shallow groundwater greater than 50 ppb are retired.
[2]Lands with Se concentrations in shallow groundwater greater than 20 ppb are retired.

The table shows the initial and final Se concentrations in drainwater after reuse and RO but prior to Se treatment. Initial Se concentrations are driven by the initial quality of groundwater under the reuse areas and are independent of the lands retired, except when a reuse area is no longer needed. Compared to the In-Valley Disposal Alternative, final Se concentrations into the Westlands North Se treatment system are predicted to decrease by 30 and 74 percent for the Groundwater Quality and Water Needs Land Retirement Alternatives, respectively. For the Groundwater Quality Land Retirement Alternative no decreases in Se concentration into the Westlands Central and South treatment systems are predicted because the retired lands are contained only within the Westlands North subarea. For the Water Needs Land Retirement Alternative, Se concentrations into the Westland Central and South treatment systems are predicted to decrease by 55 and 47 percent, respectively, compared to the In-Valley Disposal and Groundwater Quality Land Retirement Alternatives.

In addition to lowering the total flow to be treated and disposed, retiring lands with high Se in shallow groundwater and lowering the Se concentrations entering the Se treatment system may decrease the cost of the system. However, no performance data are presently available for drainwater at lower concentrations to determine the potential cost savings of retiring lands with high Se concentrations.

C2.6.4 Out-Of-Valley Disposal Alternatives (Delta and Ocean)

For the Out-of-Valley Disposal Alternatives, the predicted concentration of shallow groundwater for farmed lands (after removal of retired lands and reuse areas) in each drainage subarea is the same as for the In-Valley Disposal Alternative shown in Table C2-15. Section 2.6.2 describes the methodology for calculating the drainage area groundwater quality as well as the initial and final groundwater quality of the reuse areas. The results for the Out-of-Valley Disposal Alternatives are the same as those shown for the In-Valley Disposal Alternative in Tables C2-16 through C2-19.

Table C2-25 shows the predicted initial water quality for each subarea and for all subareas combined for the Delta Disposal Alternatives after reuse and Se treatment. Se concentrations are estimated to be less than 10 µg/L based on observed performance in testing at Panoche and Westlands.

Table C2-25
Initial Effluent from Selenium Treatment – Delta Disposal Alternatives

Treatment Area	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	10	14,700	25,900	70
Westlands North	10	15,500	16,900	140
Westlands Central	10	7,200	6,200	180
Westlands South	9	12,700	9,700	380
Combined Out-of-Valley	10	12,500	16,700	160

Table C2-26 shows the predicted initial water quality for each disposal alternative. The two Delta Disposal Alternatives (Chipps Island and Carquinez Strait) receive water from the combined Se treatment system effluent. The Ocean Disposal Alternative receives water from the combined Out-of-Valley reuse areas without Se treatment.

Table C2-26
Initial Effluent Flow and Quality for Out-of-Valley Alternatives

Disposal Alternative	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Delta (Chipps and Carquinez)	10	12,500	16,700	160
Point Estero	110	12,500	16,700	160

Tables C2-27 and C2-28 show a similar analysis for the final water quality that is expected for each disposal alternative. These predictions use the estimate of the final water quality under the reuse areas after long-term irrigation with drainwater (Table C2-18) as the basis for the estimates rather than the initial water quality currently under reuse areas. Based on previous modeling conducted by Western Resource Economics in the PFR, the time needed to reach final water quality from the reuse areas is estimated to be approximately 20 to 25 years.

Table C2-27
Final Effluent from Selenium Treatment - Delta Disposal Alternatives

Treatment Area	Flow (cfs)	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Northerly Area	12.2	10	15,000	30,000	100
Westlands North	4.6	10	25,000	27,000	210
Westlands Central	8.3	10	17,000	16,000	290
Westlands South	3.9	10	23,000	19,000	600
Combined Out-of-Valley	29	10	19,000	25,000	240

Table C2-28
Final Effluent Flow and Quality for Out-of-Valley Disposal Alternatives

Disposal Alternative	Flow (cfs)	Se (µg/L)	TDS (mg/L)	B (µg/L)	Mo (µg/L)
Delta (Chipps and Carquinez)	29	10	19,000	25,000	240
Point Estero	29	220	19,000	25,000	240

C2.6.5 Uncertainty Analysis

Assumptions were made when using the results of the predictions of shallow groundwater quality using the kriging technique. The use of the 95th percentile upper confidence limit of the predicted mean concentrations serves to elevate the predicted concentration for each disposal alternative over what would be derived using the predicted mean concentration. The 95th percentile was chosen as a conservative (high) estimate of the water quality to reflect the uncertainty in the data and the kriging process.

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APPENDIX D

Water Quality Modeling

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Acronyms

AD	MIKE 21 advection-dispersion module
AF	acre-foot or acre-feet
CCWD	Contra Costa Water District
CDFG	California Department of Fish and Game
cfs	cubic feet per second
CVP	Central Valley Project
CVPIA	Central Valley Project Implementation Act
CVRWQCB	Central Valley Regional Water Quality Control Board
Delta	Sacramento-San Joaquin River Delta
DWR	California Department of Water Resources
EC	electrical conductivity
EIS	Environmental Impact Statement
EWA	Environmental Water Account
FDM	Fischer-Delta Model
GDA	Grassland Drainage Area
HD	MIKE 21 hydrodynamic module
kg	kilogram(s)
L/kg	liter(s) per kilogram
L/mg	liter(s) per milligram
ME	MIKE 21 heavy metals module
µg/L	microgram(s) per liter
µs/cm	microSiemens(s) per centimeter
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
ppb	part(s) per billion
ppm	part(s) per million
Re-evaluation	San Luis Drainage Feature Re-evaluation
Reclamation	Bureau of Reclamation
RMS	root-mean-squared
RMP	Regional Monitoring Program for Trace Substances
Se	selenium

Service	U.S. Fish and Wildlife Service
State Board	State Water Resources Control Board
SWP	State Water Project
TDS	total dissolved solids
TOC	total organic carbon
TMDL	total maximum daily load
USGS	U.S. Geological Survey
VAMP	Vernalis Adaptive Management Plan

D1 FISCHER-DELTA FAR-FIELD MODELING

D1.1 Introduction

This section describes a numerical simulation study that was conducted to estimate the distribution of salt, selenium (Se), total organic carbon (TOC), and bromide concentrations within the Sacramento-San Joaquin River Delta (Delta) that would result from a steady discharge of agricultural drainwater at Chipps Island. The discharge was presumed to have a flow rate of 29.1 cubic feet per second (cfs) with a total dissolved solids (TDS) concentration of 19,000 parts per million (ppm), representing a discharge of 15.7 kilograms per second of salt. The 29.1-cfs discharge represents average annual flow conditions; higher peak flows are not expected over the course of the year. Therefore, 29.1 cfs represents a worst-case scenario. The concentrations of Se, TOC, and bromide in the discharge are assumed to be 10 micrograms per liter (µg/L or parts per billion [ppb]), 8.5 ppm, and 5.2 ppm, respectively.

D1.2 Modeling Approach

The addition of 29.1 cfs of flow to the Delta at Chipps Island provides a negligible increase in the total estuary flow at that location so that the actual drainage flow rate is insignificant in relation to natural Delta flows. The modeling assumes that the discharge will be uniformly mixed across the river by a multiport diffuser, enabling a far-field analysis to be carried out on the basis that the discharge is completely mixed with the Delta flow at the point of discharge. TDS concentrations are reported in parts per million of TDS, with no reference to the various constituents in the salt mixture other than Se and bromide.

To provide a realistic simulation of the likely impact of the proposed Chipps Island discharge, a 35-year simulation was prepared using the actual Delta flows, exports, and hydrology for the period 1956–1991. For these simulations the Fischer-Delta Model (FDM) Version 8.2 was used with San Francisco Bay replaced by a downstream boundary condition at Carquinez Strait. This model has been widely used to simulate the operation of the Delta, and the State Water Resources Control Board (State Board) has accepted the model output in several permit hearings.

In the 35-year simulations 15.7 kilograms per second of salt was added at a constant flow rate into the Delta at Chipps Island and the TDS increments at Suisun Bay, Rock Slough, Martinez, and Clifton Court Forebay were tracked for the 35-year period. Simulation results are shown in Section 5.2.9.4 of this Environmental Impact Statement (EIS) on Figure 5.2-3, which presents the temporal distribution of the mean TDS increment that is predicted to occur at Suisun Bay and at the Contra Costa Water District (CCWD) export point at Rock Slough. The predicted TDS increments at Martinez and Clifton Court Forebay are shown on Figure 5.2-4. As shown in both figures, the maximum impact of the simulated agricultural discharge is predicted to have occurred in the 1977 drought period, the driest period on record.

In a similar way the predicted concentration increments for Se, TOC, and bromide were computed as time series for the period 1956 through 1991. The results of these computations are shown on Figures 5.2-5 through 5.2-10. Table D1-1 summarizes predicted maximum concentration increments at the four Delta locations. Maximum modeled monthly concentration increments occurred during the 1977 drought period. Concentrations would be proportionately reduced (or increased) if the discharge or inflow concentration is reduced (or increased).

Table D1-1
Maximum Monthly Concentration Increments

Delta Location	TDS (ppm)	Selenium (ppb)	TOC (ppm)	Bromide (ppm)
Suisun Bay, Channel 19	75.2	0.04	0.034	0.021
Rock Slough, CCWD Intake	17.9	0.01	0.008	0.005
Martinez	57.9	0.03	0.026	0.016
Clifton Court Forebay	13.6	0.01	0.006	0.004

Source: Flow Science FDM modeling, 2004.

With the results of the simulations available as a time series, it is possible to determine the frequency with which specified TDS (or other constituent) levels would be attained at each of the sampling locations. These results provide the probability of a given salinity (or other constituent) level being exceeded in any month of the year, or during any randomly selected year.

The TDS exceedance probabilities computed from the analysis are presented on Figures 5.2-11, 5.2-12, and 5.2-13 for Suisun Bay, Rock Slough, and Clifton Court Forebay, respectively. These data show that based on the 30-year sequence of flows, the increase in TDS (salinity) at Suisun Bay could be expected to exceed 30 ppm with an approximate probability of 58 percent, and exceed 60 ppm with an approximate probability of 11 percent. For the CCWD intake at Rock Slough, the simulation data show that a 5 ppm TDS increment will be exceeded approximately 26 percent of the time. For the CCWD intake at Rock Slough, the computed TDS concentration increment never exceeded 20 ppm. At Clifton Court Forebay, the computed salinity increment exceeded 10 ppm less than 4 percent of the time.

The simulation data also allow computation of monthly mean increments in TDS (or other constituents) at the three locations considered. For example, Figure 5.2-14 shows the 22-year mean monthly TDS at Pittsburg together with the predicted mean monthly increment in TDS at nearby Suisun Bay from a discharge at Chipps Island of 29.1 cfs at 19,000 ppm TDS. Similar data are shown for the CCWD intake at Rock Slough and Clifton Court Forebay for each month of the year on Figures 5.2-15 and 5.2-16, respectively.

D2 CALSIM II MODELING STUDIES

This section describes the CALSIM II modeling studies developed to approximate future changes in flow and salinity in the San Joaquin River due to the proposed San Luis Drainage Project. The San Luis Drainage Feature Re-evaluation EIS is being prepared to evaluate future agricultural drainage service to the San Luis Unit. Each of the alternatives considered in the EIS includes project elements that will reduce the quantity of drainwater returning to the San Joaquin River, particularly from the Grasslands Drainage Area (GDA).

The GDA, located at the northern end of the San Luis Unit, is responsible for approximately 30,000 acre-feet (AF) per year of agricultural drainage that is discharged into the San Luis Drain. The Drain collects agricultural runoff from several areas in the valley and conveys drainwater to the San Joaquin River. The current average electrical conductivity (EC) for the GDA drainwater is approximately 4,200 microSiemens per centimeter (µS/cm), which represents a total salt load of nearly 120,000 tons of salt each year. CALSIM II modeling scenarios were developed to evaluate changes in the San Joaquin River flow and salinity based on removal of GDA drainwater flows into the river. As discussed in Section D2.3, the drainage from the GDA totaled 41,000 AF/year for the modeled scenarios under existing conditions because it was assured that the GDA would be allowed to discharge Se loads up to the load values that were in place in 2001. This results in an annual salt load of approximately 170,000 tons leaving the GDA under existing conditions.

D2.1 Overview of CALSIM II Studies

Three CALSIM II modeling studies were developed to help approximate the changes in the San Joaquin River in response to changes in drainwater quantity and quality. Studies were developed using the best available CALSIM II models, hydrologic inputs, and assumptions and provide maximum consistency with the studies developed for the Operations Criteria and Plan Endangered Species Act consultation. One set of studies represent existing level of development and demands (2001 level of development) and the other set approximates future conditions (2030 level of development).

D2.1.1 Existing Level Studies

The existing level of development studies included in this report are listed below:

- **Study 1B.** Study 1B represents the conditions that would be anticipated in the future, at current levels of development, infrastructure, and regulations. In this study, the Bureau of Reclamation (Reclamation) assumed that drainage flows from the GDA would be at the maximum allowable under the 2001 Se load limits.
- **Study 1C.** Study 1C represents existing conditions in the absence of GDA drain flows entering the San Joaquin River. This study, when compared to Study 1B, allows an assessment of the project impacts on San Joaquin River flow and salinity.

D2.1.2 Future Level Studies

The future level of development studies included in this report is listed below:

- **Study 2A.** Study 2A represents the conditions that would be anticipated in the future at 2030 level of development (population and land use) in the absence of San Luis drainage service.

D2.2 Study Methodology and Assumptions

Each of the studies described above is simulated using the revised CALSIM II representation of the San Joaquin Valley hydrologic system and associated water quality. The revised CALSIM II representation of the San Joaquin Valley has been reviewed by Reclamation, has undergone a public and peer review process, and is considered an improvement over the previous CALSIM II representations. The limitations associated with the assumptions and model capabilities are discussed in a subsequent section of this report.

CALSIM II is a computer model that simulates much of the water resources systems and their operations in California's Central Valley and Sacramento-San Joaquin Delta region. The focus of CALSIM II representation is primarily on the Central Valley Project and State Water Project systems (CVP-SWP). The model was developed jointly by the California Department of Water Resources (DWR) and Reclamation. Its purpose is to provide quantitative hydrologic information related to scenario-based CVP-SWP operations and assumptions related to climate, water demands, and regulatory environment. As the official planning model of both agencies, CALSIM II is used extensively to support a variety of studies describing comparative effects of alternative scenarios varying by infrastructure, operational rules, regulations, water demands, and/or climate.

At present, however, a fully integrated CALSIM II model of the entire Central Valley system for existing and future levels of development *including* the revised San Joaquin representation does not exist. For the purposes of the analysis of the San Luis Drainage Feature Re-Evaluation, the studies were developed by using the best available CALSIM II water planning models of the San Joaquin System and the Sacramento Valley/Sacramento-San Joaquin Delta system, respectively. One version of the CALSIM II model (termed CALSIM II-SAC/DELTA in this report) was used to provide the best representation of the Sacramento Valley and Delta operations including CVP and SWP reservoir operations and exports (except New Melones). The second version of the CALSIM II model (termed CALSIM II-SJR in this report) was used to provide the best representation of the San Joaquin system including tributary reservoir operations (including New Melones), San Joaquin water districts operations, and agricultural drain flows. The CALSIM II-SJR was simulated using the CVP delivery allocations and Delta conditions derived from the CALSIM II-SAC/DELTA model. The models, when simulated in sequence, provide a reasonable representation of the entire Central Valley water system for comparative analysis of drainage effects.

The CALSIM II models are used to simulate a 73-year period approximating future conditions under assumptions of future levels of development and historic climate conditions. Tables D-1 and D-2 outline the hydrologic and operational assumptions included in the San Luis Drainage Feature Re-Evaluation modeling analyses. Greater detail regarding the general model representation of the Central Valley water resources system and quantitative methods are described in DWR (2002), Draper et al. (2004), and Reclamation (2005). The modifications implemented in the model to represent each of the drainage reduction scenarios are described in the following sections along with summary results.

Table D2-1
CALSIM II Sacramento River and Delta Model Assumptions

	Existing Conditions	Future No Action and Alternative Scenarios
Period of Simulation	**73 years (1922-1994)**	Same
HYDROLOGY		
Level of Development (Land Use)	2001 Level, DWR Bulletin 160-98[a]	2020 Level, DWR Bulletin 160-98 (except San Joaquin River, see Table D2-2
Demands		
North of Delta (except American River)		
CVP	Land Use based, Limited by Full Contract	Same
SWP (FRSA)	Land Use based, Limited by Full Contract	Same
Nonproject	Land Use based	Same
CVP Refuges	Firm Level 2[b]	Same
American River Basin		
Water Rights	2001[c]	2020[d]
CVP	2001[c]	2020[d]
San Joaquin River Basin		
See Table D2-2.		
South of Delta		
CVP	Full Contract	Same
CCWD	124,000 AF/year[e]	Same
SWP (w/ North Bay Aqueduct)	3.0-4.1 million AF/year	Same
SWP Article 21 Demand	MWDSC up to 50,000 AF/month, Dec-Mar, others up to 84,000 AF/month	Same
FACILITIES		
Freeport Regional Water Project	None	Implementation per Freeport Regional Water Project Environmental Impact Report
Banks Pumping Capacity	6,680 cfs	8,500 cfs (with implementation of South Delta Improvement Program)
Tracy Pumping Capacity	4,200 cfs + deliveries upstream of Delta-Mendota Canal constriction	4,600 cfs (with implementation of CA-Delta-Mendota Canal Intertie)
Trinity River		
Minimum Flow below Lewiston Dam	Trinity EIS Preferred Alternative (368,600-815,000 AF/year)	Same
Trinity Reservoir End-of-September Minimum Storage	Trinity export-to-inflows Preferred Alternative (600,000 AF as able)	Same
Clear Creek		
Minimum Flow below Whiskeytown Dam	Downstream water rights, 1963 Reclamation Proposal to Service and National Park Service, and Service use of CVPIA 3406(b)(2) water	Same

Table D2-1 (continued)
CALSIM II Sacramento River and Delta Model Assumptions

	Existing Conditions	Future No Action and Alternative Scenarios
Period of Simulation	**73 years (1922-1994)**	Same
Upper Sacramento River		
Shasta Lake End-of-September Minimum Storage	State Board WR 1993 Winter-Run Biological Opinion (1.9 Million AF)	Same
Minimum Flow below Keswick Dam	Flows for State Board WR 90-5 and 1993 Winter-Run Biological Opinion temperature control, and Service use of CVPIA 3406(b)(2) water	Same
Feather River		
Minimum Flow below Thermalito Diversion Dam	1983 DWR, CDFG Agreement (600 cfs)	Same
Minimum Flow below Thermalito Afterbay outlet	1983 DWR, CDFG Agreement (1,000–1,700 cfs)	Same
American River		
Minimum Flow below Nimbus Dam	State Board D-893 (see accompanying Operations Criteria), and Service use of CVPIA 3406(b)(2) water	Same
Minimum Flow at H Street Bridge	State Board D-893	Same
Lower Sacramento River		
Minimum Flow near Rio Vista	State Board D-1641	Same
Mokelumne River		
Minimum Flow below Camanche Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (100–325 cfs)	Same
Minimum Flow below Woodbridge Diversion Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (25–300 cfs)	Same
Stanislaus River		
Minimum Flow below Goodwin Dam	1987 Reclamation, CDFG agreement, and Service use of CVPIA 3406(b)(2) water	Same
Minimum Dissolved Oxygen	State Board D-1422	Same
Merced River		
Minimum Flow below Crocker-Huffman Diversion Dam	Davis-Grunsky (180–220 cfs, Nov–Mar), and Cowell Agreement	Same
Minimum Flow at Shaffer Bridge	FERC 2179 (25–100 cfs)	Same
Tuolumne River		
Minimum Flow at Lagrange Bridge	FERC 2299-024, 1995 (Settlement Agreement 94,000–301,000 AF/year)	Same

Table D2-1 (continued)
CALSIM II Sacramento River and Delta Model Assumptions

Period of Simulation	Existing Conditions 73 years (1922-1994)	Future No Action and Alternative Scenarios Same
San Joaquin River		
Maximum Salinity near Vernalis	State Board D-1641	Same
Minimum Flow near Vernalis	State Board D-1641, and VAMP per San Joaquin River Agreement	Same
Sacramento River-San Joaquin River Delta		
Delta Outflow Index (Flow and Salinity)	State Board D-1641	Same
Delta Cross Channel Gate Operation	State Board D-1641	Same
Delta Exports	State Board D-1641, Service use of CVPIA 3406(b)(2) water, and CALFED Fisheries Agencies use of EWA assets	Same
Subsystem		
Upper Sacramento River		
Flow Objective for Navigation (Wilkins Slough)	3,250–5,000 cfs based on Lake Shasta storage condition	Same
American River		
Folsom Dam Flood Control	Sacramento Area Flood Control Agency, Interim-Reoperation of Folsom Dam, Variable 400/670 (without outlet modifications)	Same
Feather River		
Flow at Mouth	Maintain the CDFG/DWR flow target above Verona or 2,800 cfs for Apr–Sep dependent on Oroville inflow and FRSA allocation	Same
Stanislaus River		
Flow below Goodwin Dam	1997 New Melones Interim Operations Plan	Same
San Joaquin River		
Flow near Vernalis	San Joaquin River Agreement in support of the VAMP	Same
System-wide		
CVP Water Allocation		
CVP Settlement and Exchange	100% (75% in Shasta Critical years)	Same
CVP Refuges	100% (75% in Shasta Critical years)	Same
CVP Agriculture	100% - 0% based on supply	Same
CVP Municipal & Industrial	100% - 50% based on supply	Same

Table D2-1 (continued)
CALSIM II Sacramento River and Delta Model Assumptions

Period of Simulation	**Existing Conditions** **73 years (1922-1994)**	**Future No Action and Alternative Scenarios** **Same**
SWP Water Allocation		
North of Delta (FRSA)	Contract specific	Same
South of Delta	Based on supply; Monterey Agreement	Same
CVP/SWP Coordinated Operations		
Sharing of Responsibility for In-Basin-Use	1986 Coordinated Operations Agreement	Same
Sharing of Surplus Flows	1986 Coordinated Operations Agreement	Same
Sharing of Restricted Export Capacity	Equal sharing of export capacity under State Board D-1641; use of CVPIA 3406(b)(2) only restricts CVP exports; EWA use restricts CVP and/or SWP exports as directed by CALFED Fisheries Agencies	Same
Transfers		
Dry Year Program	None	Same
Phase 8	None	Same
Water Forum Analyses Water Transfers /Mitigation Water	None	Same
MWDSC/CVP Settlement Contractors	None	Same
CVP/SWP Integration		
Dedicated Conveyance at Banks	None	SWP to convey 100,000 AF of Level 2 refuge water each year at Banks Pumping Plant.
NOD Accounting Adjustments	None	CVP to provide the SWP a max of 75,000 AF of water to meet in-basin requirements through adjustments in Coordinated Operations Agreement accounting.
CVPIA 3406(b)(2)	Dept of Interior 2003 Decision	Same
Allocation	800,000 AF/year, 700,000 AF/year in 40-30-30 Dry Years, and 600,000 AF/year in 40-30-30 Critical Years	Same
Actions	1995 Water Quality Control Plan, Fish flow objectives (Oct-Jan), VAMP (Apr 15- May 16) CVP export restriction, 3,000 cfs CVP export limit in May and June (D1485 Striped Bass continuation), Post (May 16-31) VAMP CVP export restriction, Ramping of CVP export (Jun), Upstream Releases (Feb-Sep)	Same

Table D2-1 (concluded)
CALSIM II Sacramento River and Delta Model Assumptions

Period of Simulation	Existing Conditions	Future No Action and Alternative Scenarios
	73 years (1922-1994)	Same
Accounting Adjustments	Per May 2003 Interior Decision, no limit on responsibility for D1641 requirements no Reset with the Storage metric and no Offset with the Release and Export metrics.	Same
CALFED Environmental Water Account	Modeled	Same
Actions	Dec-Feb reduce total exports by 50,000 AF/month relative to total exports without EWA; VAMP (Apr 15- May 16) export restriction on SWP; Post (May 16-31) VAMP export restriction on SWP and potentially on CVP if B2 Post-VAMP action is not taken; Ramping of exports (Jun).	Same
Assets	Fixed Water Purchases 250,000 AF/year, 230,000 AF/year in 40-30-30 dry years, and 210,000 AF/year in 40-30-30 critical years. The purchases range from 0 AF in Wet Years to approximately 153,000 AF in Critical Years NOD, and 57,000 AF in Critical Years to 250,000 AF in Wet Years SOD. Variable assets include the following: use of 50% Joint Point of Diversion export capacity, acquisition of 50% of any CVPIA 3406(b)(2) releases pumped by SWP, flexing of Delta Export/Inflow Ratio (post-processed from CALSIM II results), dedicated 500 cfs pumping capacity at Banks in Jul – Sep.	Same
Debt restrictions	Delivery debt paid back in full upon assessment; Storage debt paid back over time based on asset/action priorities; SOD and NOD debt carryover is allowed; SOD debt carryover is explicitly managed or spilled; NOD debt carryover must be spilled; SOD and NOD asset carryover is allowed.	Same

CDFG = California Department of Fish and Game
CVPIA = Central Valley Project Implementation Act
EWA = Environmental Water Account
FERC = Federal Energy Regulatory Commission
FRSA = Feather River Service Area
MWDSC = Metropolitan Water District of Southern California
NOD = North of Delta
SOD = South of Delta
Service = U.S. Fish and Wildlife Service
VAMP = Vernalis Adaptive Management Program

Notes:

[a] 2001 Level of Development defined by linearly interpolated values from the 1995 Level of Development and 2020 Level of Development from DWR Bulletin 160-98.

[b] It is assumed that Level 4 supplies are obtained through water transfers and are not part of the basic operating demands in CALSIM.

[c] Sacramento Water Forum 1998 Level Demands defined in Sacramento Water Forum's Environmental Impact Report with a few updated entries.

[d] Sacramento Water Forum 2025 Level Demands defined in Sacramento Water Forum's Environmental Impact Report.

[e] Delta diversions include operations of Los Vaqueros Reservoir.

Table D2-2
CALSIM-II San Joaquin River Basin Model Assumptions

	Existing Conditions	Future No Action and Alternative Scenarios
Period of Simulation	73 water years (1922-1994)	Same
San Joaquin Basin Hydrology		
Level of Development (Land Use)	2001 Level, DWR Bulletin 160-98[a]	2020 Level, DWR Bulletin 160-98 Sacramento Basin, 2030 Level San Joaquin River Basin Ag. DWR, 2020 Level Urban San Joaquin River
San Joaquin River Basin		
Friant Unit	Land Use based, operated based on current allocation policy	Same
Lower Basin	Land Use based, operated based on district constraints	Same
Stanislaus River Basin	New Melones Interim Operations Plan	Same
Water Supply Source Shift		
Modesto Irrigation District	Urban area demands met by groundwater and surface water	Surface-water delivery is increased 30,000 AF to meet urban demand
South San Joaquin Irrigation District	Urban area demands met by groundwater and surface water	Surface-water delivery is increased to 44,000 AF to meet urban demand
Merced Irrigation District	Ag. demands dependant on surface and groundwater	Decrease minimum groundwater pumping by 20,000 AF.
Turlock Irrigation District	Ag. demands dependant on surface and groundwater	Decrease minimum groundwater pumping by 10,000 AF
South of Delta		
CVP	Full Contract	Same
CVP Refuges	Firm Level 2	Same
Facilities		
SWP Banks Pumping Plant	6,680 cfs, can increase up to 8,500 cfs Dec 15-Mar 15	8,500 cfs year-round (500 cfs reserved for EWA Jul, Aug, Sep)
CVP Tracy Pumping Plant	4,200 cfs plus diversions upstream of Delta-Mendota Canal constriction	4,600 cfs (allowed by the Delta-Mendota Canal/CA Intertie)
San Luis Drain	Discharge into Grasslands Bypass	No discharge into Grassland Bypass

Table D2-2 (concluded)
CALSIM-II San Joaquin River Basin Model Assumptions

	Existing Conditions	Future No Action and Alternative Scenarios
Period of Simulation	**73 water years (1922-1994)**	**Same**
Regulatory Standards		
Stanislaus River		
Minimum Flow below Goodwin Dam	1987 Reclamation, CDFG agreement, and Service discretionary use of CVPIA 3406(b)(2)	Same
Minimum Dissolved Oxygen	State Board D-1422	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
Tuolumne River		
Minimum Flow at Lagrange Bridge	FERC 2299-024, 1995 (Settlement Agreement) (94,000–301,000 AF/year)	Same
San Joaquin River		
Maximum Salinity near Vernalis	State Board D-1641	Same
Minimum Flow near Vernalis	State Board D-1641, and VAMP per San Joaquin River Agreement	Same[b]
Total Maximum Daily Loads		
Selenium TMDL	GDA drainage flows limited by 2001 Se load values	GDA drainage flows limited by Se TMDL
Salt and Boron TMDLs	None	GDA drainage flows limited by salt and BORON TMDLs
Dissolved Oxygen TMDL	None	None
Operations Criteria		
Stanislaus River		
Flow below Goodwin Dam	1997 New Melones Interim Operations Plan	Same

TMDL = total maximum daily load

Notes:

[a] 2001 Level of Development defined by linearly interpolated values from the 1995 Level of Development and 2020 Level of Development from DWR Bulletin 160-98

[b] It is assumed that either VAMP, a functional equivalent, or D1641 requirements would be in place in 2020.

D2.3 2001 Level of Development Studies 1B and 1C

D2.3.1 Study 1B

Study 1B is the requested CALSIM II study to represent existing conditions for the EIS. In this study, GDA drainage flows are limited to those allowable under 2001 Se load values. The GDA discharge flows and EC assumed in this study are shown in Table D2-3.

Table D2-3
Grasslands Drainage Area Discharge and EC Values Used in Study 1B

Month	EC of GDA Discharge (µS/cm)	Discharge from GDA when Limited by 2001 Se Load Values* (Thousand AF)
Oct	3,879	2.936
Nov	3,782	2.809
Dec	4,219	2.596
Jan	4,020	3.056
Feb	4,245	3.988
Mar	5,080	4.059
Apr	5,090	3.007
May	4,488	3.404
Jun	4,276	3.740
Jul	3,870	4.356
Aug	3,500	4.415
Sep	4,060	2.681
Annual Average or Total	**4,209**	**41.0**

*Assumes that monthly loads may be greater than historical. Applies to all water year types.

D2.3.2 Study 1C

Study 1C represents existing (2001) conditions without GDA drainage flows to the San Luis Drain. The flows and salt loads from the GDA to the San Joaquin River are assumed to be zero in this study. Comparison of this study to Study 1B allows for an assessment of the relative change in river flows and salinity due to the removal of San Luis drainage service.

D2.3.2.1 Changes in San Joaquin River Flow and Salinity

The changes in San Joaquin River flow and EC due to the reduction in GDA drainage to the San Joaquin River (Study 1C minus Study 1B) are summarized on Figures D2-1 and D2-2. These figures show the average monthly change in flow and EC on the San Joaquin River from Lander Avenue to Vernalis. The change at Lander Avenue, however, is zero as the GDA drainage flows are downstream of this location.

The reduction in flow in the San Joaquin River upstream of the Stanislaus River is approximately 41,000 AF/year and approximately 43,000 AF/year downstream of the Stanislaus River. New Melones releases are reduced by an average of approximately 2,000 AF/year, primarily due to improved water quality at Vernalis and a reduced need for dilution flows from the Stanislaus River. The change in San Joaquin River flows follows the same pattern as the reduction in drainage discharge from the GDA. GDA drainage flows, assumed in Study 1B, are relatively constant, but with slight increases in February-March and July-August. The San Joaquin River flow reductions are of the same magnitude as the reduction in drainage flows, except where a change in New Melones operations was triggered either due to reduced water quality releases (i.e., February and March) or a change in flood control operations (i.e., December). The minor changes to New Melones operations are discussed in the subsequent section.

Changes in monthly average San Joaquin River salinity are presented on Figure D2-2. The relatively large reduction in San Joaquin River EC simulated downstream of Mud and Salt sloughs represents the reduction in salt load from the GDA. The reduction in river EC, however, is attenuated downstream as the tributary river flows and other return flows cause dilution along the river. The average reduction in EC in the river downstream of Mud and Salt sloughs is approximately 305 µS/cm, but represents an approximately 50 µS/cm EC reduction at Vernalis.

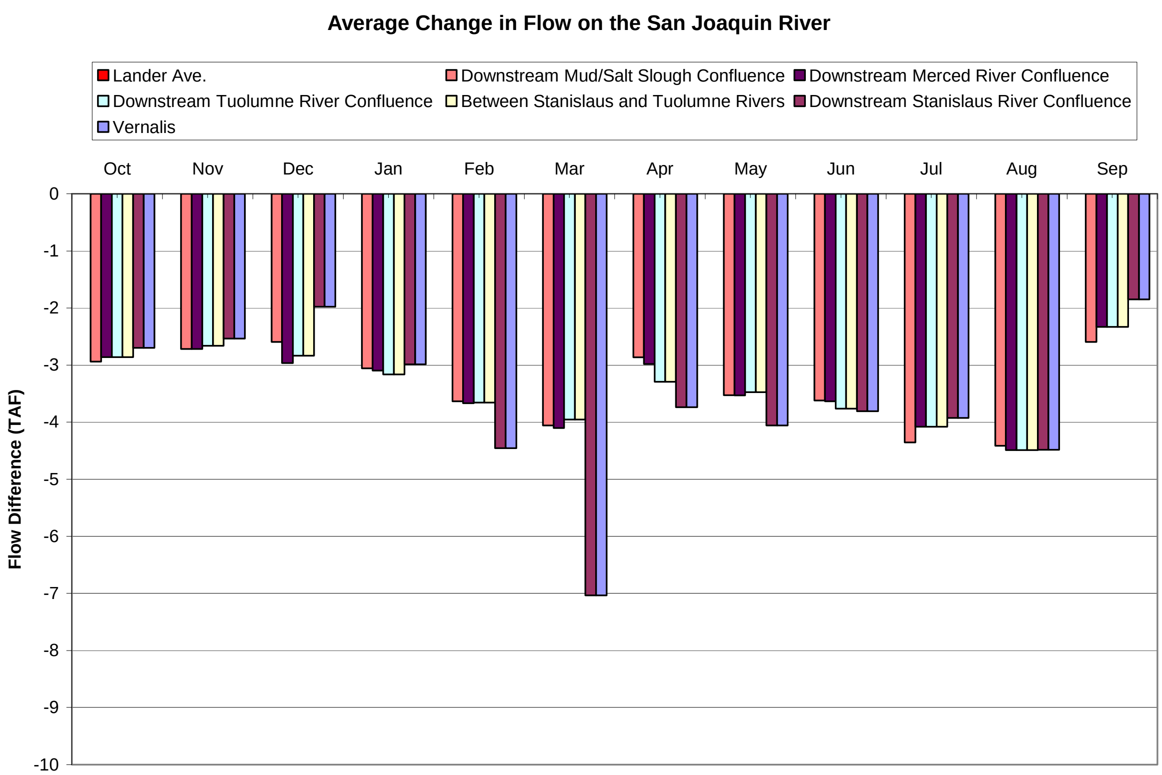

Figure D2-1 Flow Changes on the San Joaquin River under Study 1C Conditions

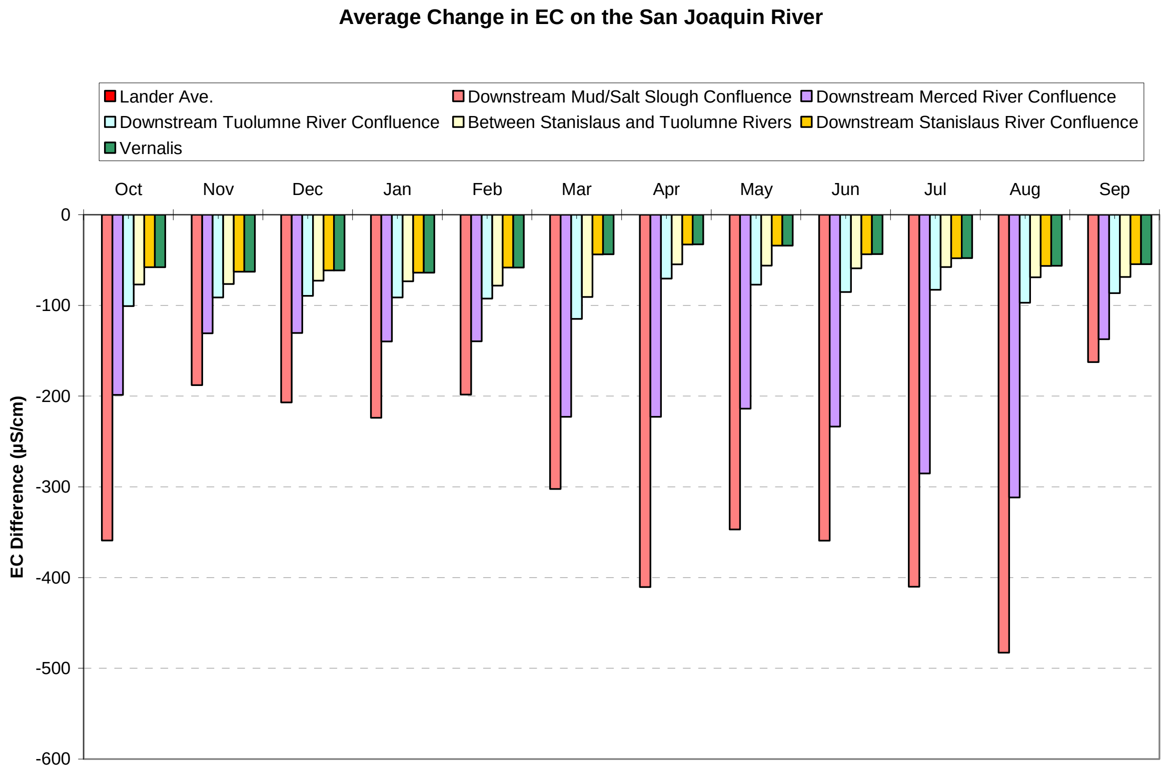

Figure D2-2 Electrical Conductivity Changes in the San Joaquin River under Study 1C Conditions

Figures D2-3 through D2-7 show the simulated monthly flows and EC for Studies 1B and 1C at locations along the San Joaquin River from Mud and Salt sloughs to Vernalis. The river flows are shown on the left vertical axis and the EC values are shown on the right vertical axis. The monthly differences between Studies 1B and 1C are also shown on these figures.

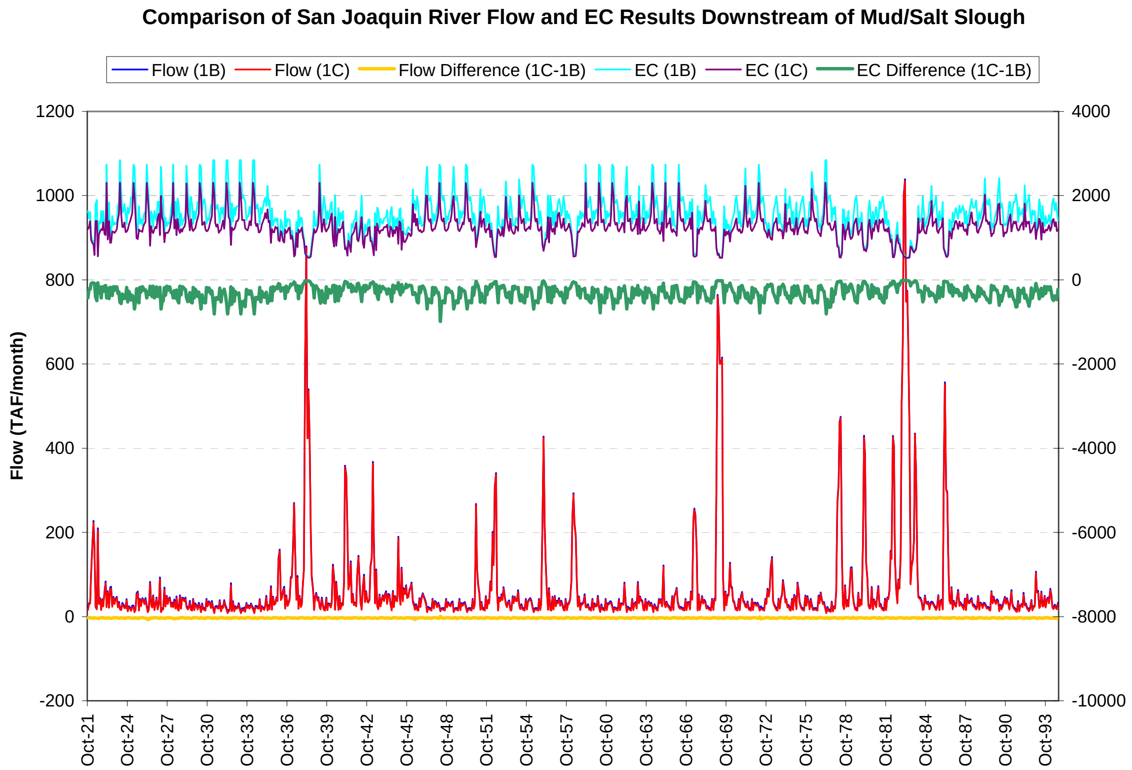

Figure D2-3 Flow and Electrical Conductivity Comparison Between Studies 1B and 1C for the San Joaquin River Downstream of the Mud/Salt Slough Confluence

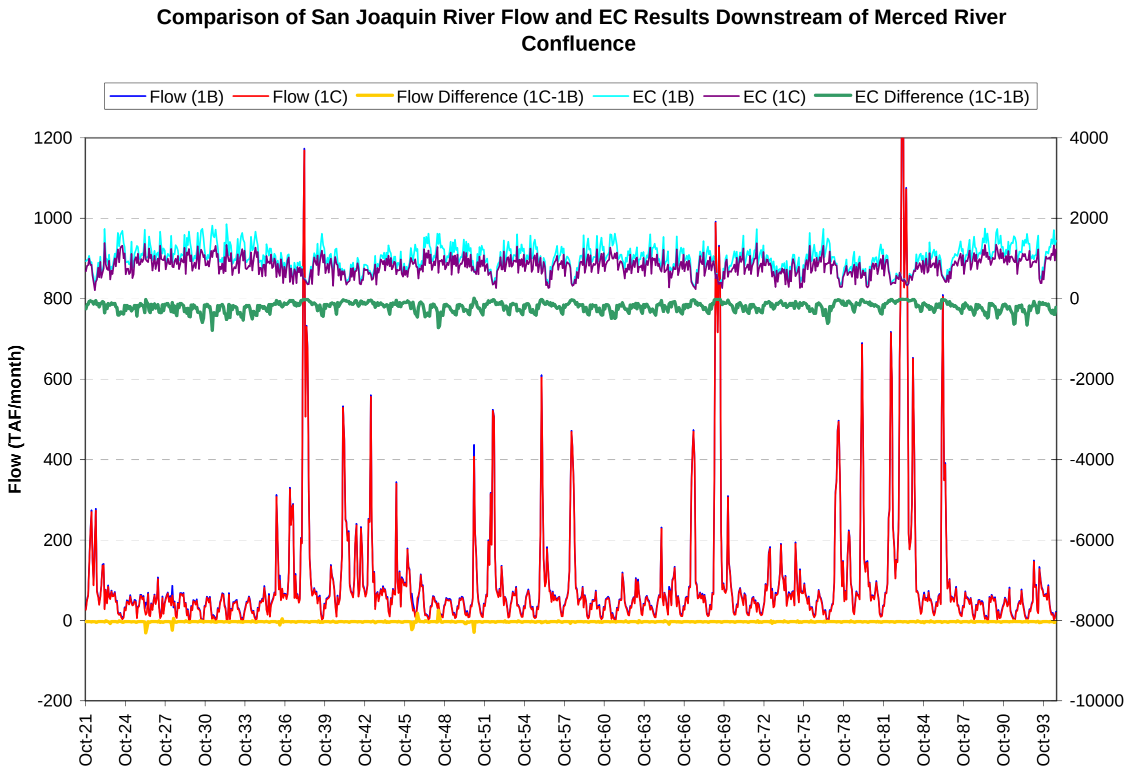

Figure D2-4 Flow and Electrical Conductivity Comparison Between Studies 1B and 1C for the San Joaquin River Downstream of the Merced River Confluence

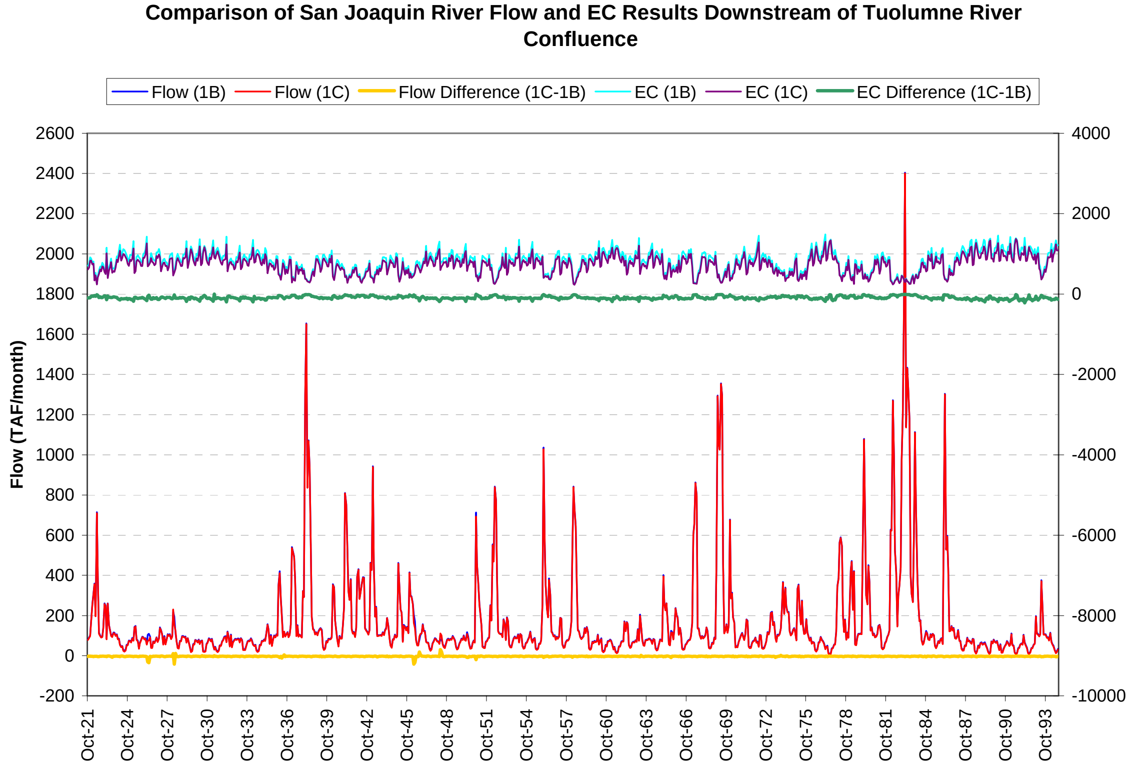

Figure D2-5 Flow and Electrical Conductivity Comparison Between Studies 1B and 1C for the San Joaquin River Downstream of the Tuolumne River Confluence

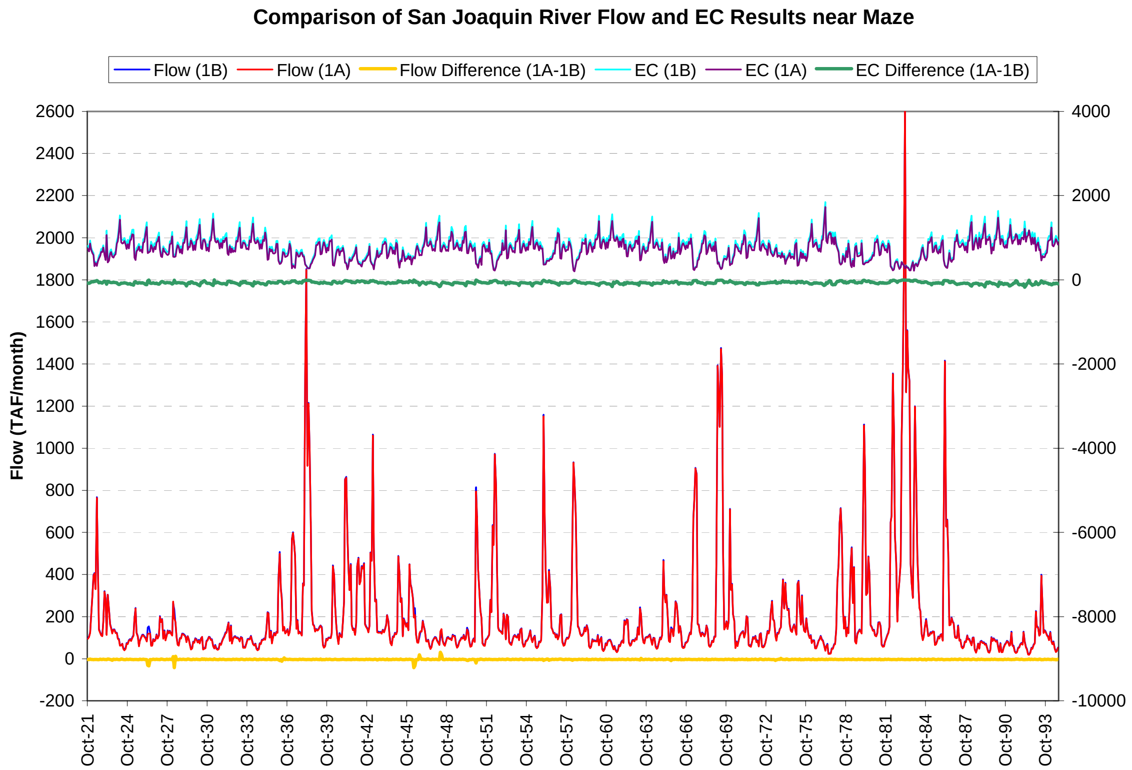

Figure D2-6 Flow and Electrical Conductivity Comparison Between Studies 1B and 1C for the San Joaquin River Near Maze

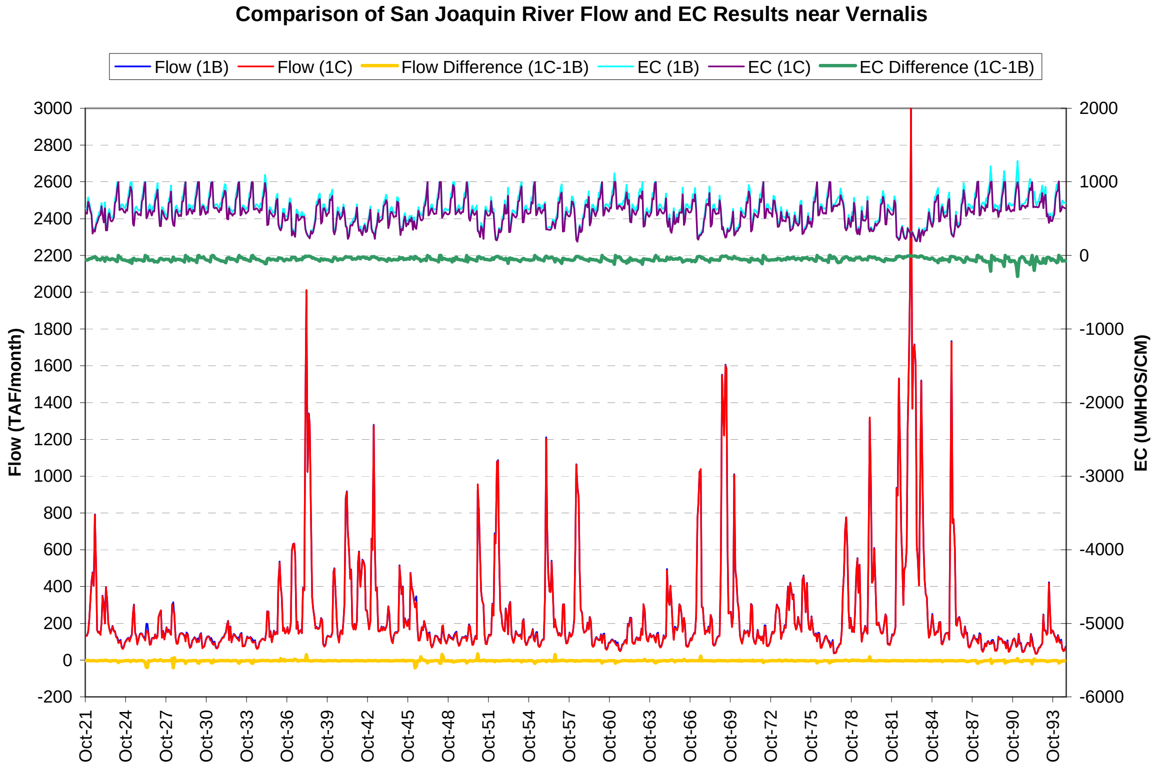

Figure D2-7 Flow and Electrical Conductivity Comparison Between Studies 1B and 1C for the San Joaquin River Near Vernalis

D2.3.2.2 Changes in New Melones Reservoir Operations

The reduction in drainage discharge from the GDA causes relatively minor changes in operations at New Melones Reservoir. As discussed previously, the improved water quality at Vernalis under Study 1C reduces the required quantity of water quality release from New Melones Reservoir. The average annual reduction in New Melones water quality releases is approximately 12,000 AF/year. The monthly pattern of the water quality release changes is shown on Figure D2-8. These reductions in New Melones required releases allow for small increases in New Melones Reservoir storage as shown on Figure D2-9. The average end of September storage is increased by approximately 25,000 AF/year. The increases in storage allow for higher allocations to CVP contractors on the Stanislaus River (increase of less than 2,000 AF/year) and greater releases for San Joaquin River dissolved oxygen goals (increase of less than 2,000 AF/year), but also cause slight increases in New Melones flood control releases (increases of less than 2,000 AF/year). The monthly average change in total New Melones releases is shown on Figure D2-10.

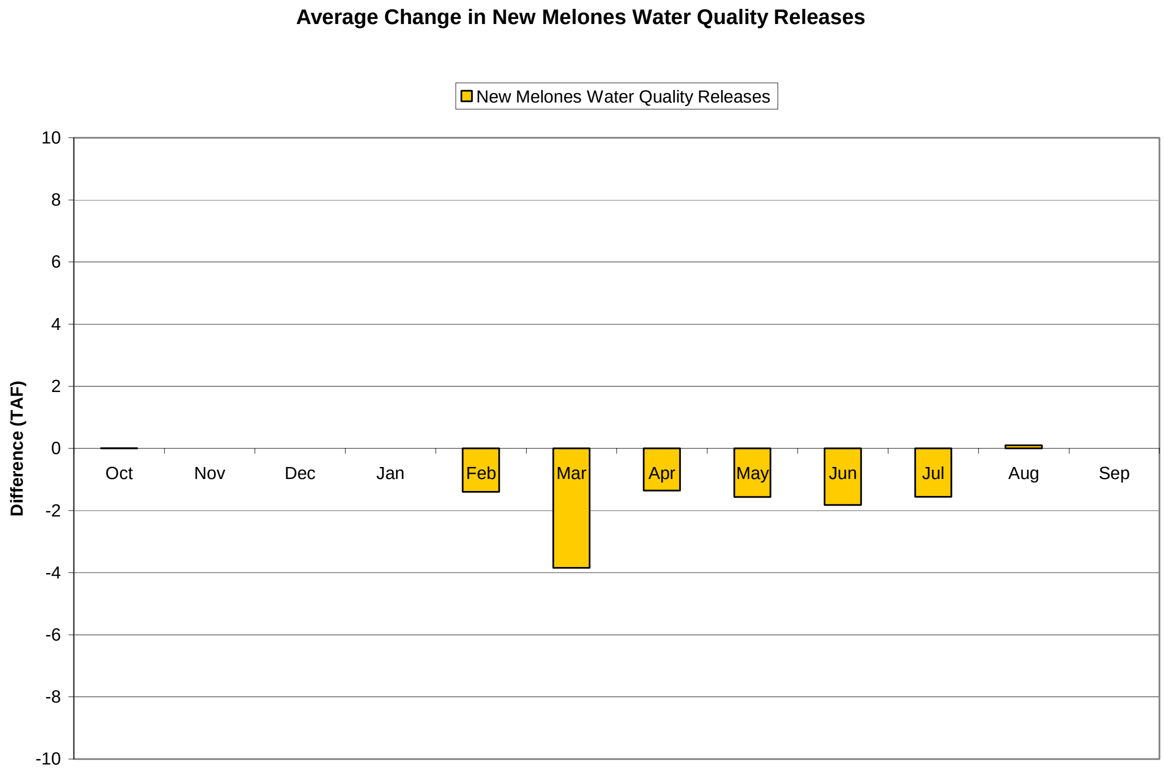

Figure D2-8 Average Monthly Change in New Melones Reservoir Releases for Vernalis Salinity Requirements

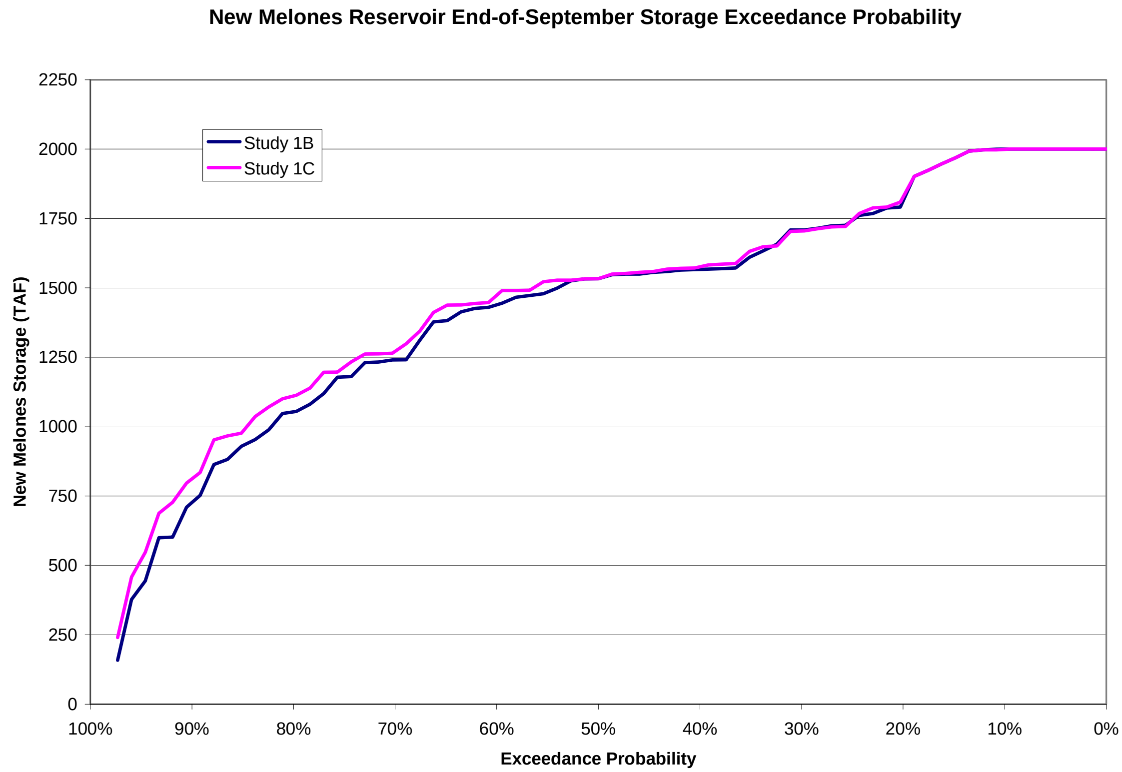

Figure D2-9 Exceedance Probability of the New Melones Reservoir End-of-September Storage

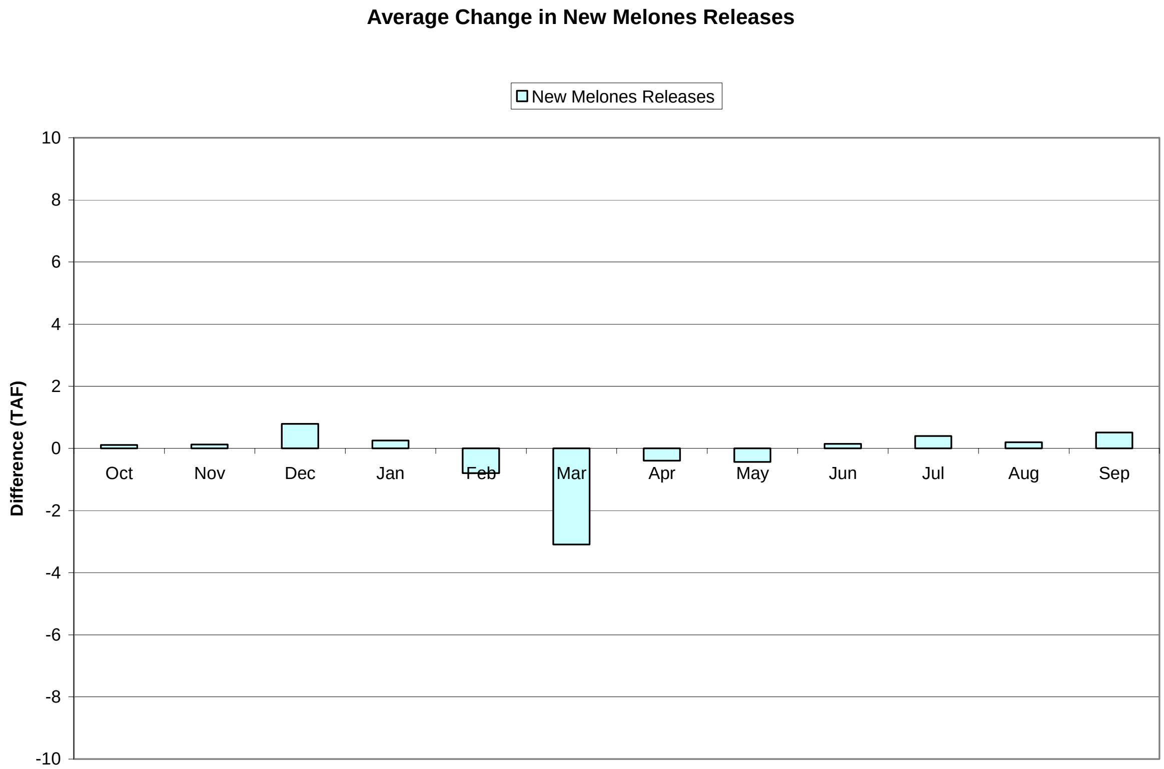

Figure D2-10 Average Monthly Change in Total New Melones Releases

D2.4 2030 Level of Development: Study 2A

Study 2A is the requested CALSIM II study to represent future (2030) conditions for the EIS. In this study, GDA drainage flows are assumed to no longer discharge in the San Luis Drain and the San Joaquin River. This study is similar to Study 1C except under future conditions (level of development) and future cumulative assumptions (facilities and operations). Comparison of this study to Study 1B allows for an assessment of the relative change in river flows and salinity due to the removal of San Luis drainage service under the future cumulative condition.

D2.4.1 Changes in San Joaquin River Flow and Salinity

The changes in San Joaquin River flow and EC due to the reduction in GDA drainage to the San Joaquin River (Study 2A minus Study 1B) are summarized on Figures D2-11 and D2-12. These figures show the average monthly change in flow and EC on the San Joaquin River from Lander Avenue to Vernalis. The change at Lander Avenue, however, is zero as the GDA drainage flows are downstream of this location.

The reduction in flow in the San Joaquin River upstream of the Stanislaus River is approximately 41,000 AF/year and approximately 45,000 AF/year downstream of the Stanislaus River. New Melones releases are reduced by an average of approximately 2,000 AF/year, primarily due to improved water quality at Vernalis and a reduced need for dilution flows from the Stanislaus River. The change in San Joaquin River flows follows the same pattern as the reduction in drainage discharge from the GDA. GDA drainage flows, assumed in Study 1B, are relatively constant, but with slight increases in February-March and July-August. The San Joaquin River flow reductions are of the same magnitude as the reduction in drainage flows, except where a change in New Melones operations was triggered either due to reduced water quality releases (i.e., February and March) or a change in flood control operations (i.e., December). The minor changes to New Melones operations are discussed in the subsequent section.

Changes in monthly average San Joaquin River salinity are presented on Figure D2-12. The relatively large reduction in San Joaquin River EC simulated downstream of Mud and Salt sloughs represents the reduction in salt load from the GDA. The reduction in river EC, however, is attenuated downstream as the tributary river flows and other return flows cause dilution along the river. The average reduction in EC in the San Joaquin River downstream of Mud and Salt sloughs is approximately 305 µS/cm, but represents an approximately 50 µS/cm EC reduction at Vernalis.

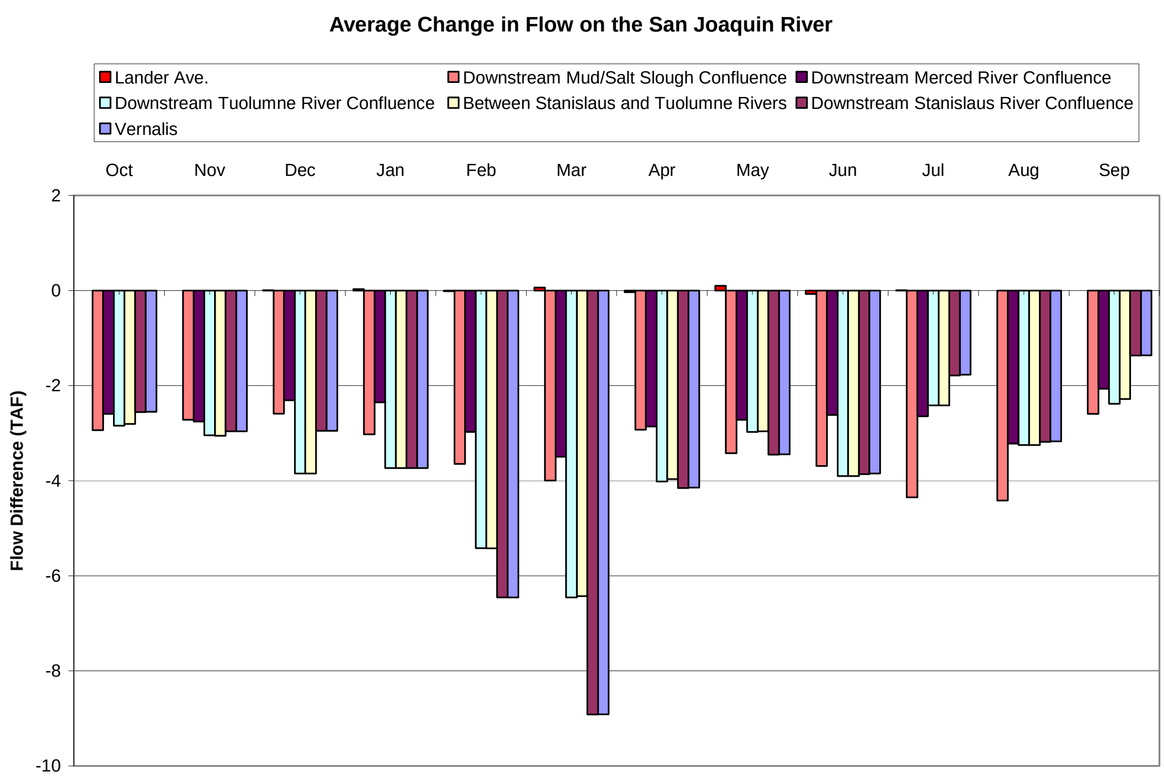

Figure D2-11 Flow Changes on the San Joaquin River under Study 2A Conditions

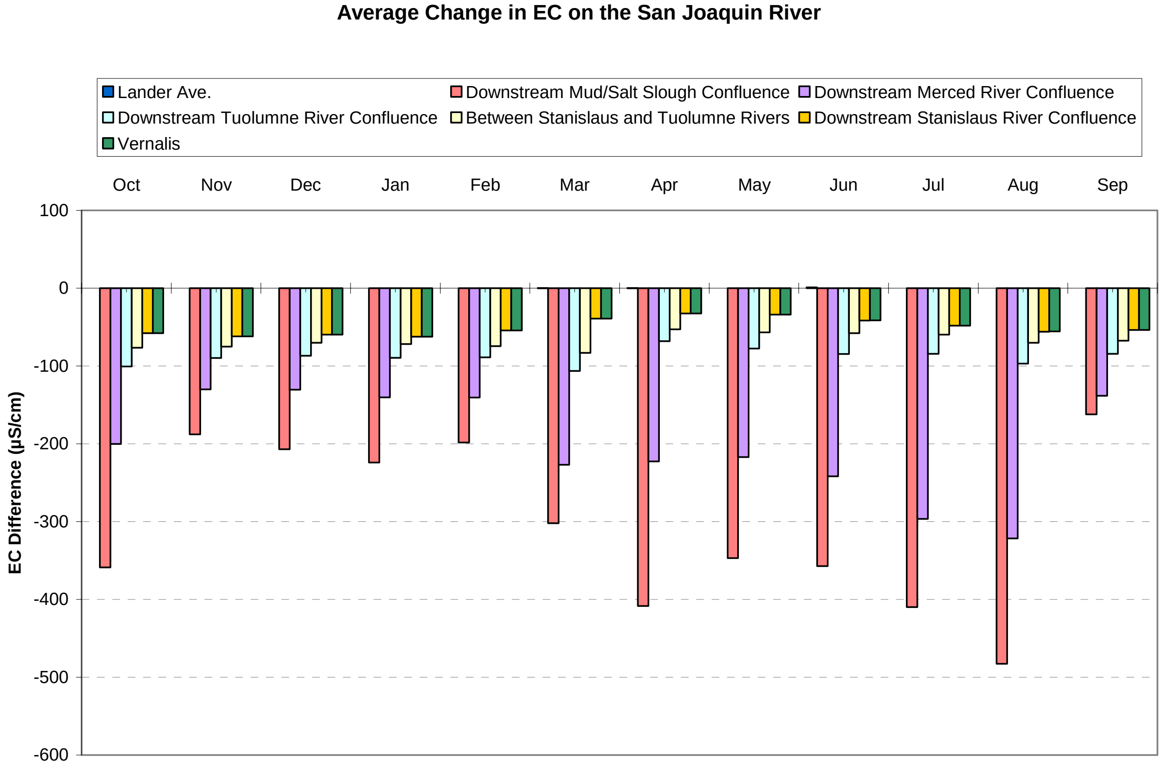

Figure D2-12 Electrical Conductivity Changes in the San Joaquin River under Study 2A Conditions

Figures D2-13 through D2-17 show the simulated monthly flows and EC for Studies 1B and 2A at locations along the San Joaquin River from Mud and Salt sloughs to Vernalis. The river flows are shown on the left vertical axis and the EC values are shown on the right vertical axis. The monthly differences between Studies 2A and 1B are also shown on these figures.

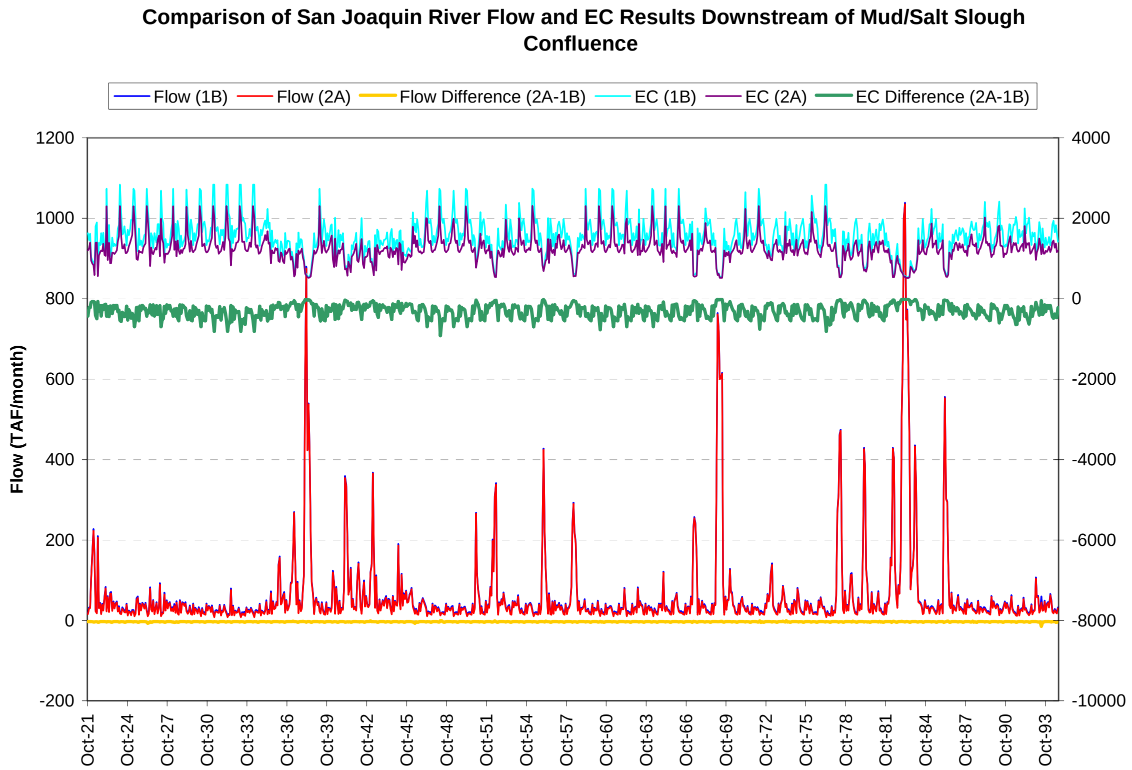

Figure D2-13 Flow and Electrical Conductivity Comparison between Studies 1B and 2A for the San Joaquin River Downstream of the Mud/Salt Slough Confluence

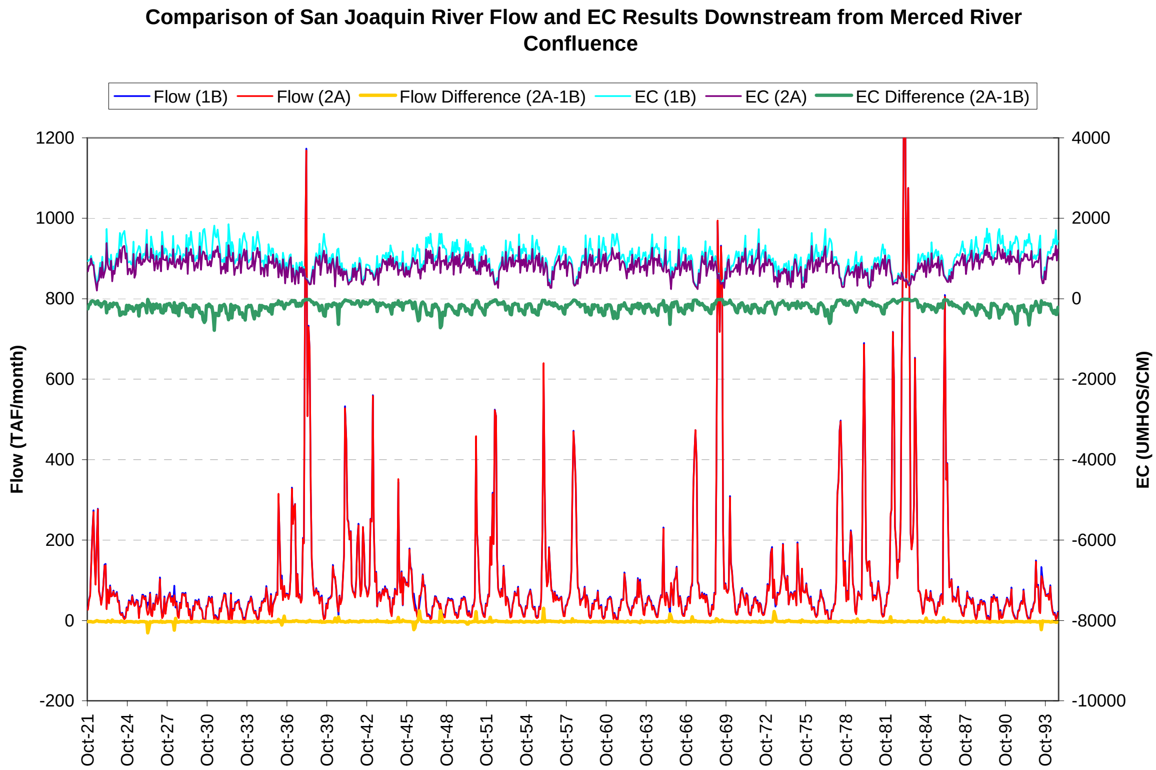

Figure D2-14 Flow and Electrical Conductivity Comparison between Studies 1B and 2A for the San Joaquin River Downstream of the Merced River Confluence

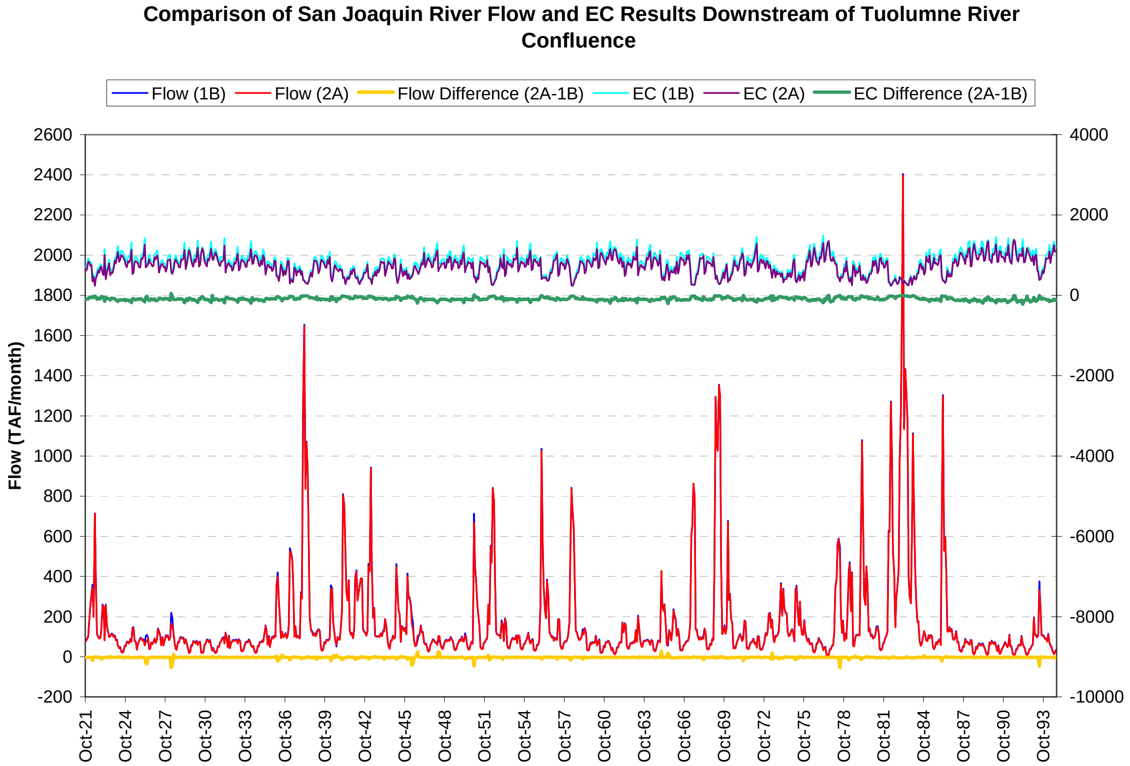

Figure D2-15 Flow and Electrical Conductivity Comparison Between Studies 1B and 2A for the San Joaquin River Downstream of the Tuolumne River Confluence

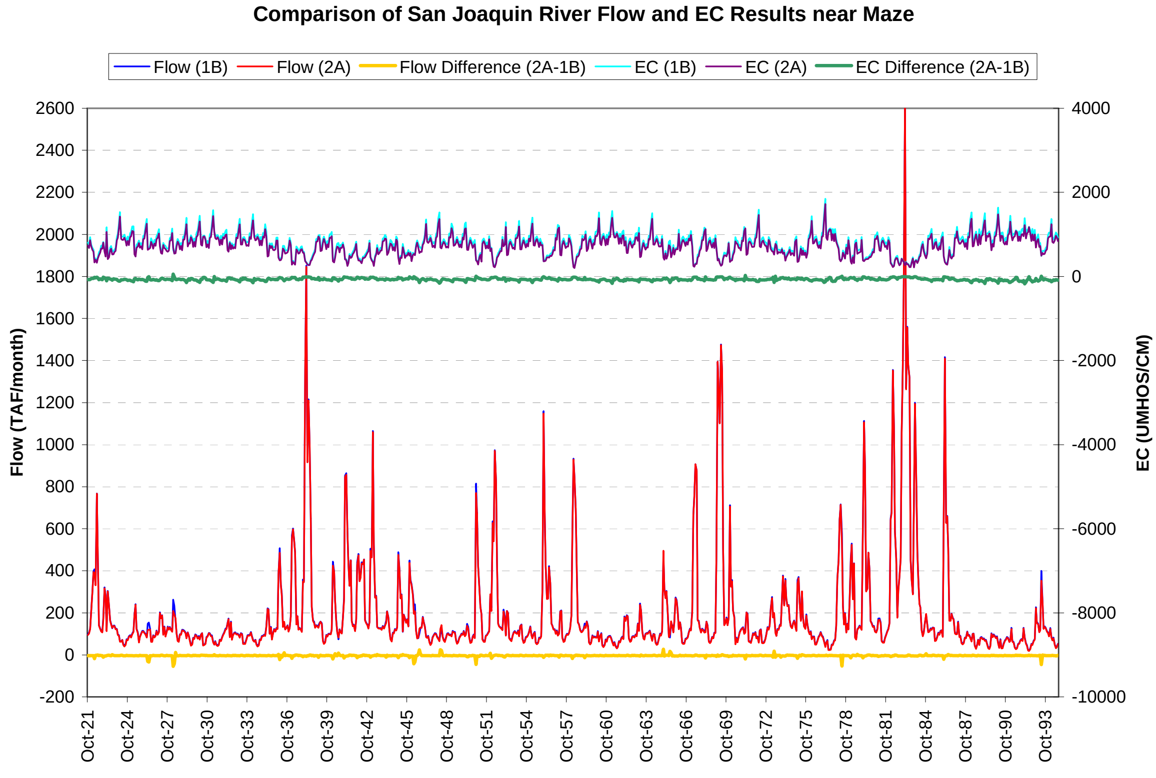

Figure D2-16 Flow and Electrical Conductivity Comparison Between Studies 1B and 2A for the San Joaquin River Near Maze

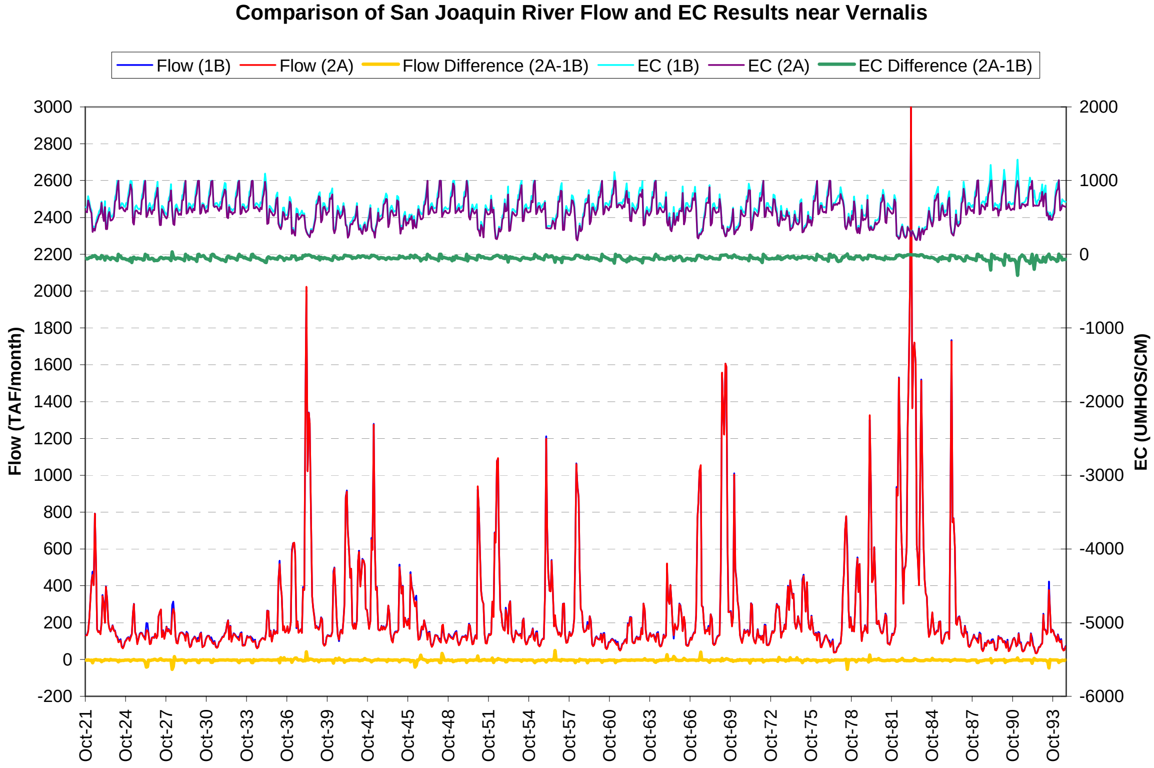

Figure D2-17 Flow and Electrical Conductivity Comparison Between Studies 1B and 2A for the San Joaquin River Near Vernalis

D2.4.2 Changes in New Melones Reservoir Operations

The reduction in drainage discharge from the GDA causes relatively minor changes in operations at New Melones Reservoir. As discussed previously, the improved water quality at Vernalis under Study 2A reduces the required quantity of water quality release from New Melones Reservoir. The average annual reduction in New Melones water quality releases is approximately 11,000 AF/year. The monthly pattern of the water quality release changes is shown on Figure D2-18. These reductions in New Melones required releases allow for small increases in New Melones Reservoir storage as shown on Figure D2-19. The average end of September storage is increased by approximately 39,000 AF/year. Changes in New Melones Reservoir operations, as compared between Studies 2A and 1B, are caused not only by changes in the San Luis Drain flows but also due other minor changes in assumed future San Joaquin River basin demands and operations that are listed in Table D2-2. The monthly average change in total New Melones releases is shown on Figure D2-20.

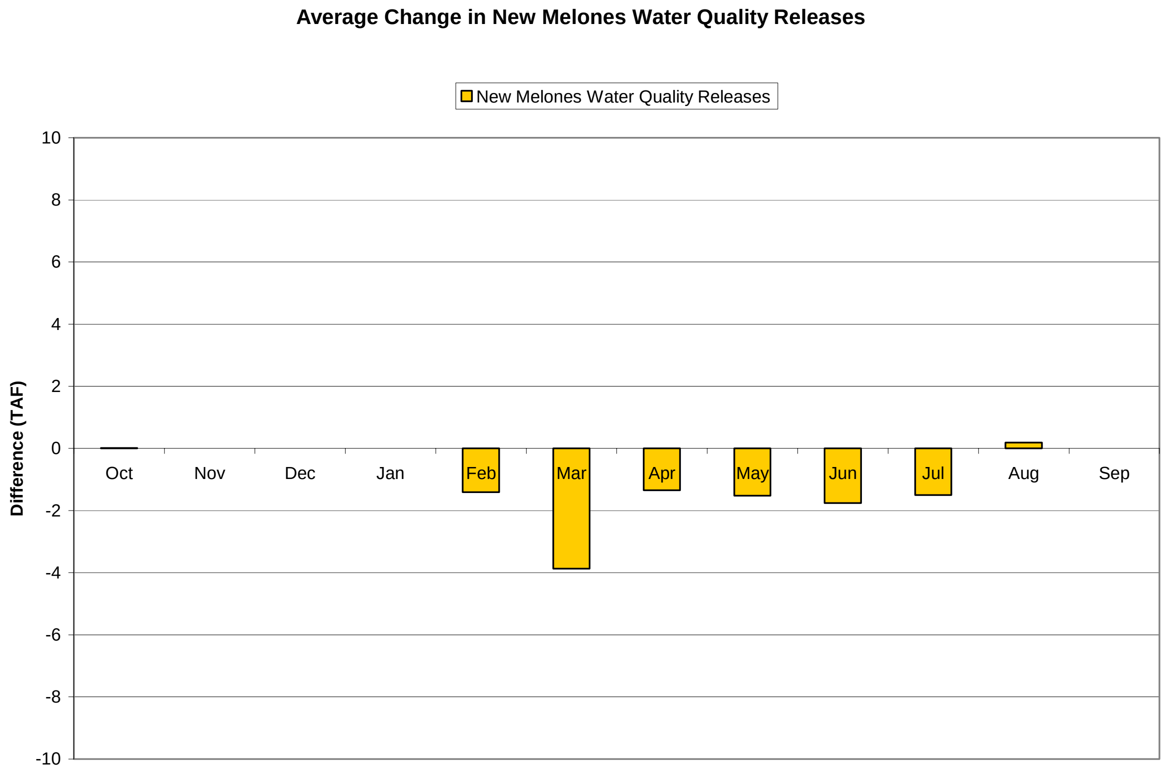

Figure D2-18 Average Monthly Change in New Melones Reservoir Releases for Vernalis Salinity Requirements

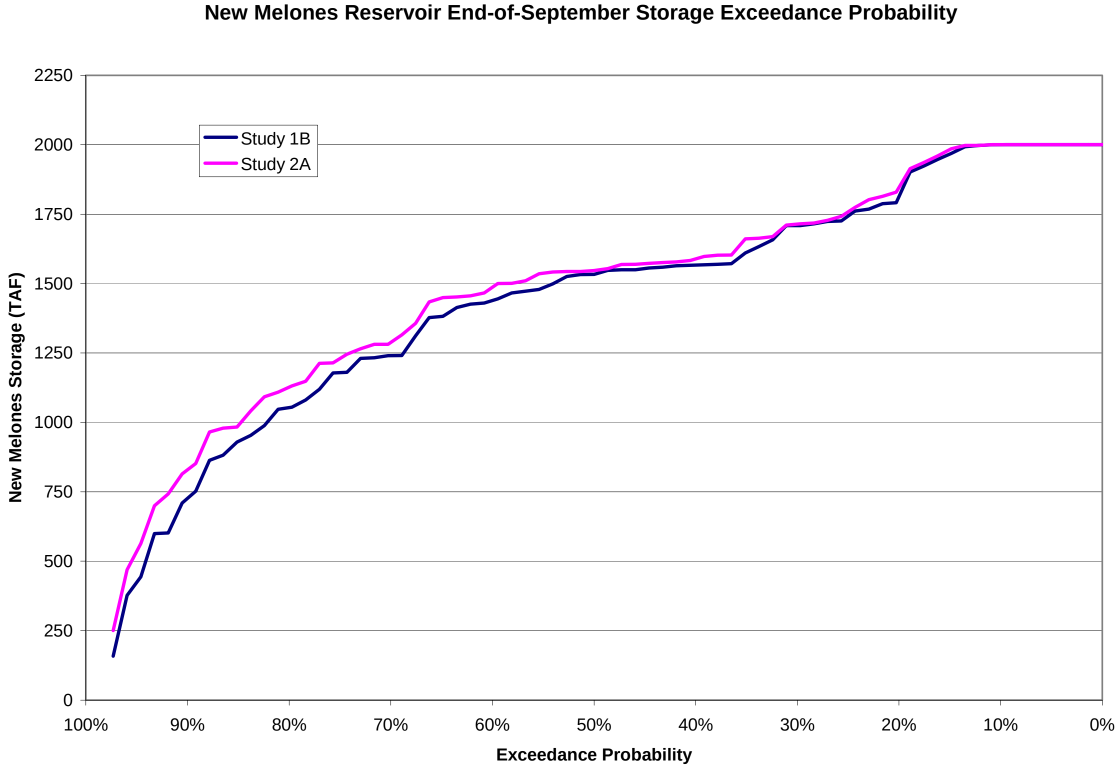

Figure D2-19 Exceedance Probability of the New Melones Reservoir End-of-September Storage

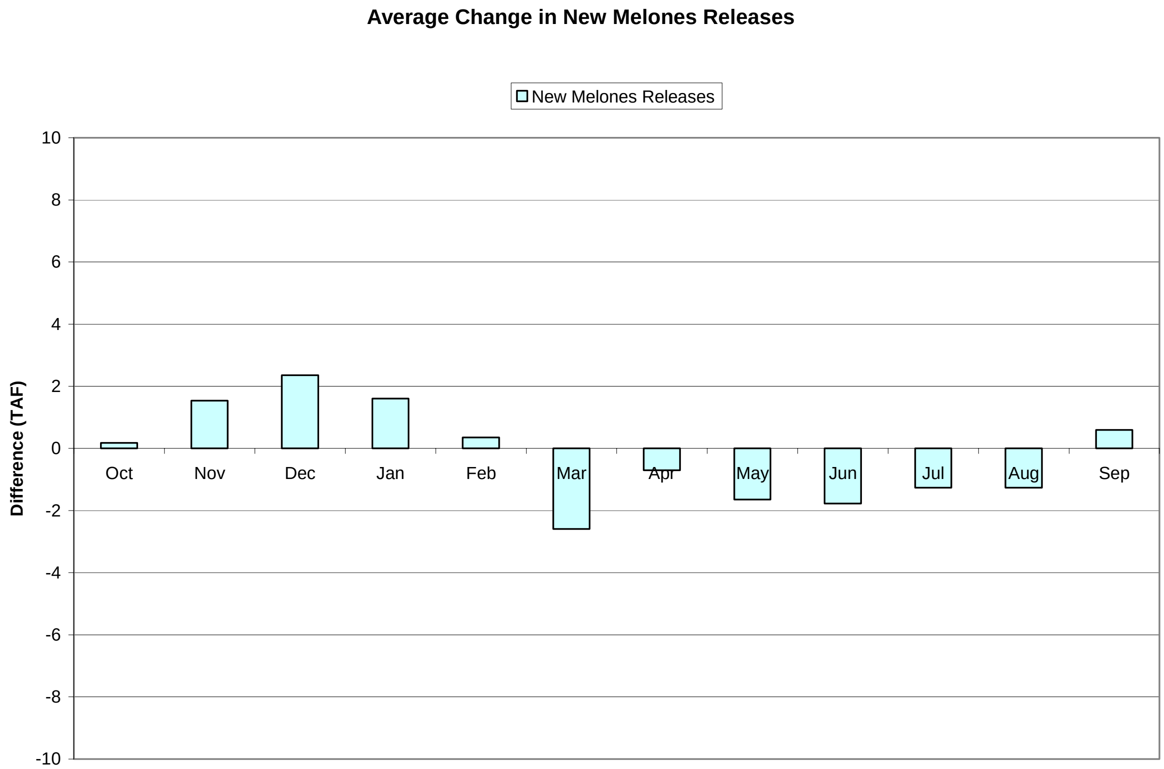

Figure D2-20 Average Monthly Change in Total New Melones Releases

D2.5 Model Limitations

The hydrologic analysis presented herein used the best available CALSIM II models to approximate the change in San Joaquin River flows, salinity, and reservoir system re-operation associated with the alternatives. A general external review of the methodology, software, and applications of CALSIM II was conducted in 2003 (Close et al. 2003). Recently, an external review of the San Joaquin River Valley CALSIM II model was conducted (Ford et al. 2006).

The peer review suggested that the San Joaquin River Valley CALSIM II model is improved in many ways over the older CALSIM II model representation, specifically with improved Eastside hydrology and operations, Eastside water demands, San Joaquin River salinity, and documentation. The increased level of detail in the revised CALSIM II San Joaquin River model "will better reflect the correct change in water quality and needs for dilution flow from New Melones Reservoir in response to a reduction in tile drainage discharges from the Grasslands Bypass Project" (Ford et al. 2006). Several limitations with the CALSIM II models, however, were identified in these external reviews. The main limitations of the CALSIM II model are associated with the lack of a fully explicit groundwater representation in the San Joaquin River Valley, lack of explicit estimation or labeling of water and salt closure terms, and an underestimation of salinity at Vernalis in absolute terms. The CALSIM II models applied in this analysis also use a monthly time step that does not include daily variations occurring in the rivers under actual flow and climate conditions (Bureau of Reclamation 2004). Other limitations specific to the use of the models in this analysis are the lack of a dynamic integration between CALSIM II SAC/DELTA and CALSIM SJR models.

Although groundwater is dynamically simulated in the Sacramento River Valley basin, the San Joaquin River Basin uses a surrogate of minimum and maximum groundwater pumping and nondynamic assumptions for stream-groundwater interactions. Access to pumping data and incorporating dynamic groundwater interaction into the San Joaquin River Basin will improve the CALSIM II representation. Groundwater representation in the San Joaquin River Basin is a priority development task for Reclamation, and system-wide groundwater model development is an ongoing project for DWR.

The estimation of salinity in the San Joaquin River is limited by availability of monitored data and imperfect nonpoint source information. Additional water quality monitoring (in dry and critical year types) will improve the CALSIM San Joaquin River model salinity results and management decisions on which they rely. The simulated San Joaquin River salinity is significantly improved in this most recent version of the model (Ford et al. 2006). Reclamation is planning an assessment and data collection recommendation in the near future.

Reclamation, DWR, and the external reviews have identified the need for a comprehensive error and uncertainty analysis for various aspects of the CALSIM II model. The effects of error in estimating parameters such as agricultural efficiencies, water quality parameters, and return flows can be evaluated using sensitivity and uncertainty. DWR has issued the *CALSIM II Model Sensitivity Analysis Study* (DWR 2005) and Reclamation is currently embarking on a similar sensitivity and uncertainty analysis for the San Joaquin River Basin. This information will improve understanding of the modeled results and provide confidence intervals.

Despite these limitations, the monthly CALSIM II model results remain useful for comparative purposes. It is important to differentiate between “absolute” or “predictive” modeling applications and “comparative” applications. In “absolute” applications the model is run once to predict a future outcome, and errors or assumptions in formulation, system representation, data, operational criteria, etc., all contribute to total error or uncertainty in model results. In “comparative” applications the model is run twice, once to represent a base condition (no project) and a second time with a specific change (project) to assess the ***change*** in the outcome due to the input change. In this mode (the mode used in this application), the difference between the two simulations is of principal importance. Potential errors or uncertainties that exist in the “no project” simulation are also present in the “project” simulation such that the effects are reduced when assessing the change in outcomes.

D3 MIKE 21 MODEL CALIBRATION

D3.1 Overview of Method

The effect of the San Luis Drain discharge at Chipps Island and Carquinez Strait on TDS and Se concentrations in San Francisco Bay and the Delta was modeled in this study using the MIKE 21 software developed by the Danish Hydraulic Institute (DHI 1998a, b). MIKE 21 is a two-dimensional, finite difference, free surface modeling system that has been used to simulate hydraulics and hydraulics-related phenomena in estuaries, coastal waters, and seas where stratification can be neglected.

MIKE 21 consists of three linked modules. The first is a hydrodynamic module (MIKE 21 HD) that solves the time-dependent, vertically integrated equations of continuity and conservation of momentum in two horizontal directions. The second is an advection-dispersion module (MIKE 21 AD) that calculates the transport of conservative substances such as TDS in the water column. Lastly, the heavy metals module (MIKE 21 ME) uses the computational algorithms from MIKE 21 HD and AD, but additionally calculates nonconservative mass transfer (i.e., sorption) between dissolved Se and suspended or benthic sediment.

The first step in using this MIKE 21 modeling software was to properly define the system to be modeled, identify the important processes to be included, and calibrate the model. In this study, the model domain was the Bay-Delta Estuary from Jersey Island in the Delta to the Pacific Ocean, discretized into 200- by 200-meter rectangular grid cells (Figure D3-1). The processes included in the model were tides, wind, waves, erosion, deposition, diffusion, adsorption, and desorption. In addition, loading from major watersheds draining to the Bay was important for sediment, salt, and Se.

Due to the large computational time required to solve two-dimensional equations, a 12-month simulation period was selected for modeling. The first 6 months were used for spin-up, as initial model simulations indicated steady-state concentrations relative to the discharge were achieved after 3 to 6 months. To ensure that predictions are conservative, a 6-month period during the 1977 dry season was analyzed for TDS to represent the baseline conditions. The Delta flows from this period represent the lowest on record, thereby allowing the greatest transport of discharged components upstream. For Se, the model was calibrated to Water Year 1997 because water quality data for 1977 are limited. A hypothetical baseline condition was then created using hydrodynamic flows from 1997, but current refinery Se loads. Changes in dissolved, adsorbed, and benthic Se concentrations due to the Delta Disposal Alternatives were subsequently assessed by comparison to the baseline. The baseline simulations represent existing conditions under dry season flows. These simulations also provide an estimate of TDS and Se concentrations under the No Action Alternative; however, after 50 years under No Action, concentrations would likely be lower due to continuing efforts to lower TDS and Se concentrations in discharges to San Francisco Bay and the Delta.

The locations of the Chipps Island and Carquinez Strait discharges are displayed on Figure D3-1. The TDS simulation used a salt concentration of 21,000 ppm at a flow rate of 34 cfs. This results in an annual salt load of 640 million kilograms (kg) per year. The Delta Disposal Alternatives are expected to have an average discharge rate of 29.1 cfs with a final TDS concentration at the point of discharge of 19,000 ppm. This would result in an annual salt load of 490 million kg per year. Therefore, the changes in TDS concentrations shown for the modeled alternatives are conservatively high. The Se simulation used the expected discharge rate of 29.1 cfs with a Se concentration of 10 ppb. Results were analyzed temporally at six locations in the North and Central bays, including the Martinez and Suisun Bay stations analyzed by the FDM. Results are reported as time series and probabilities of exceeding given concentrations. Average concentrations for the North Bay and Delta are also presented.

D3.2 MIKE 21 HD Module Calibration

D3.2.1 Introduction

The hydrodynamic component of the MIKE 21 modules was previously calibrated to accurately represent tides and currents in San Francisco Bay (URS 2002). Consequently, the only modifications required in this study were supplying appropriate hydrodynamic input parameters for the modeled water years (1977 for MIKE 21 AD TDS modeling and 1997 for MIKE 21 ME Se modeling).

D3.2.2 Hydrodynamic Input Parameters

Hydrodynamic input parameters include bathymetry, hydrographic boundary conditions (e.g., inflows and tides), wind velocities, and source/sink flows.

The bathymetry modeled in this study is displayed on Figure D3-1 using 0.4-square-kilometer rectangular grid cells and National Geodetic Vertical Datum 1929. The Delta region east of Decker and Bradford islands on the figure were included as “boxes” with volumes approximating the Sacramento and San Joaquin Delta systems, respectively.

Boundary flows for the Delta for 1977 were obtained from the FDM, after subtracting the tidal component. For 1997, outflow was specified as the average daily flow rate estimated by the DWR using the DAYFLOW program (http://www.iep.water.ca.gov/dayflow). Water elevations at the Pacific Ocean boundary were obtained from the National Oceanic and Atmospheric Administration’s tide station located at Point Reyes for both water years.

Wind speed and direction were obtained from the National Climatic Data Center Station at San Pablo Bay owing to its proximity to the project location. Although hourly winds from the 1990 Dry Season were used for 1977, the strong daily and seasonal dependence was captured using this approach. Wind speed and direction for 1997 were obtained using corresponding data.

Flows for tributary sources were estimated for both water years from U.S. Geological Survey (USGS) stream gage measurements using a methodology described by Daum and Davis (2000). First, 70 watershed drainage areas in the Bay Area were delineated using GIS. USGS stream gauges in a number of creeks were then used to estimate flows in nearby streams by normalizing flows by watershed area. Thirty-six publicly owned treatment works and industrial facilities were also included in the model, using flows reported in 1997 National Pollutant Discharge Elimination System self-monitoring reports.

D3.3 MIKE 21 AD Module Calibration

D3.3.1 Introduction

MIKE 21 AD was used to predict changes in TDS. Because the hydrodynamic components of this module were previously shown to accurately represent tides and currents in San Francisco Bay (URS 2002), only those parameters governing advection and dispersion of dissolved substances required additional calibration.

Due to the large computational time required to solve the two-dimensional equations in MIKE 21, a 6-month simulation period during the 1977 dry season was selected for calibration. By choosing the period with the lowest Delta flows on record, the uncertainty associated with modeling extreme hydrologic events was minimized.

D3.3.2 Advection-Dispersion Input Parameters

Inputs to the MIKE 21 AD module include initial TDS fields, model boundary concentrations and source/sink discharge concentrations.

The initial salinity field was created utilizing the data collected by the USGS along the main channel in the Bay on June 8, 1977.

Model boundary concentrations were specified as 33 parts per thousand for the Pacific Ocean, 0.1 part per thousand for the Sacramento River, and 0.8 part per thousand for the San Joaquin River. The latter value was based on correlations developed between EC, flow, and salinity at the Vernalis Monitoring Station.

Concentrations of TDS in tributary, publicly owned treatment work, and industrial facility flows were set to zero.

D3.3.3 MIKE 21 AD Calibration Parameters

The primary calibration parameters in MIKE 21 AD are spatially varying dispersion coefficients. The values used in this study were 300 square meters per second for the Central and North bays, and 10 square meters per second in the South Bay, similar to coefficients reported by Monismith et al. (2001). The higher constants required to achieve calibration in the North Bay are related to the large vertical shear associated with stratification, an effect that cannot be resolved by a depth-averaged model.

D3.3.4 MIKE 21 AD Calibration Results

Predicted and observed TDS at the 18 USGS monitoring stations displayed on Figure D3-1 are shown on Figures D3-2 and D3-3 for four 1977 cruises. TDS is well calibrated by the model and no consistent bias occurs at any station. This result is reflected in Table D3-1, which shows that differences between predicted and observed TDS in the North and Central bays are less than 1 milligram per liter (mg/L). A 6-month mean TDS concentration for the simulation period is shown on Figure D3-4. TDS decreases from a relatively constant value of 33,000 ppm at the Pacific Ocean boundary to less than 4,000 ppm near the Sacramento and San Joaquin rivers. Mean concentrations at the Chipps Island and Carquinez Strait discharge locations are 10,000 and 24,000 ppm, respectively.

Table D3-1
Statistics on Total Dissolved Solids–Water Year 1977 Calibration

Bay Segment	Number of Data Points	TDS (mg/L)				
		Mean Concentration		Median Concentration		Average RMS Difference
		Predicted	Observed	Predicted	Observed	
Suisun Bay	27	17	18	17	18	0
San Pablo Bay	12	29	29	29	30	0
Central Bay	12	32	32	32	33	0

RMS = root-mean-squared

D3.4 MIKE 21 ME Module Calibration

D3.4.1 Introduction

MIKE 21 ME was used to predict changes in Se concentrations. Because the hydrodynamic and sediment transport components of this module were previously shown to accurately represent tides, currents, and suspended sediment concentrations in the Bay (URS 2002), only those parameters governing porewater and sorptive fluxes required additional calibration.

Due to the large computational time required to solve the two-dimensional equations in MIKE 21, a 6-month simulation during 1997 was chosen for calibration. This period was chosen to coincide with the 1997 Regional Monitoring Program (RMP) sampling schedule for San Francisco Bay.

D3.4.2 Heavy Metal Input Parameters

Inputs to the MIKE 21 ME module include initial Se concentrations, model boundary concentrations, and source/sink discharge concentrations.

Initial benthic sediment Se concentrations for most of the Bay were determined from benthic surveys conducted by the RMP (SFEI 1994-1998). Because the MIKE 21 ME module can only model one grain-size fraction (i.e., mud), average benthic concentrations for each San Francisco Bay monitoring station were first plotted against the average fraction of sediment that are fine-grained. A linear least squares regression was then fit to the data, with the intercept at 100 percent fines used to represent the initial benthic concentration. As shown on Figure D3-5, this intercept is 0.5 milligram per kilogram (mg/kg), with a correlation coefficient of 0.58. For the San Joaquin Delta, a value of 1 mg/kg was used based on average measurements at Vernalis (Luoma and Presser 2000).

Initial porewater Se concentrations were assumed to be 0.3 µg/L, based on depth-averaged measurements in two mudflats of Carquinez Straits (Zawislanski and McGrath 1998). Also, initial adsorbed concentrations in surface waters were obtained by assuming suspended sediment has the same Se concentration as the underlying benthic sediment. By making this assumption, initial dissolved Se concentrations in surface water were calculated using the equilibrium distribution coefficients represented by the calibrated adsorption and desorption rate constants described below.

At both the Pacific Ocean and Sacramento River boundaries, dissolved and adsorbed Se concentrations were assumed to be 0.06 µg/L and 0.2 mg/kg, respectively. For the Pacific Ocean, dissolved concentrations were based on measurements by Cutter and Bruland (1984), and adsorbed concentrations from equilibrium distribution coefficients determined during calibration. For the Sacramento River boundary, dissolved Se concentrations were based on measurements of Cutter and San Diego-McGlone (1990), and adsorbed concentrations from estimates of Luoma and Presser (2000). Finally, time-varying dissolved and adsorbed concentrations at the San Joaquin River boundary were based on measurements of total Se at Vernalis (CVRWQCB 1998) and an assumed equilibrium distribution coefficient of 1,000 liters per kilogram (L/kg) (Luoma and Presser 2000).

Total Se concentrations in tributary sources during storm events were obtained from a land-use summary of the Bay Area Stormwater Management Agencies Association data set (Daum and Davis 2000), where values of half the detection limit were used for nondetect measurements. Partitioning between adsorbed and dissolved Se for storm events was performed using the same equilibrium distribution coefficients calibrated for the ambient Bay. Total Se concentrations during dry weather flows (defined as being less than twice the July-August baseflow) were reduced from storm event concentrations to account for lower suspended sediment concentrations.

D3.4.3 MIKE 21 ME Calibration Parameters

The primary calibration parameters in the MIKE 21 ME module are rate constants for porewater Se diffusion and Se sorption. Porewater diffusion rate constants were assumed to be 6×10^{-6} cm^2/second based on estimates for other metals (Rivera-Duarte and Flegal 1997). A desorption rate constant of 0.8 day^{-1} was taken from the mean value measured by Glegg et al. (1988). Finally, an adsorption rate constant of 0.003 liter per milligram (L/mg) per day was determined through a calibration procedure where differences between predicted and measured dissolved Se concentrations in the Bay were graphically minimized. The final equilibrium distribution coefficient of 3,750 L/kg, calculated by dividing the adsorption rate constant by the desorption rate constant, is between the average (4,000 L/kg) and median (3,400 L/kg) values determined during the 1997 RMP.

D3.4.4 MIKE 21 ME Dissolved Selenium Calibration Results

Measured and predicted dissolved Se concentrations at the 12 RMP stations displayed on Figure D3-1 are shown as time series on Figures D3-6 and D3-7 for the calibration year 1997. Dissolved Se concentrations in the North and Central bays generally agree with measured concentrations, although the natural variability in concentration at any particular monitoring station is greater than the model predicts. Average RMS differences in the region selected for alternatives analysis are 0.02 µg/L (Table D3-2). The largest errors in model predictions occur for the South and Central bays, outside of the region analyzed in this study. A 6-month mean dissolved Se concentration for the 1997 base case is shown on the lower plot on Figure D3-8. Dissolved concentrations vary between 0.05 and 0.2 µg/L, with the highest concentrations near the San Joaquin River and the lowest concentrations near the Pacific Ocean and the mouth of several tributaries (including the Sacramento River).

Table D3-2
Statistics on Dissolved Selenium–Water Year 1997 Calibration

Bay Segment	Number of Data Points	Dissolved Selenium (μg/L)				
		Mean Concentration		Median Concentration		Average RMS Difference
		Predicted	Observed	Predicted	Observed	
Suisun Bay	13	0.11	0.12	0.09	0.12	0.02
San Pablo Bay	9	0.15	0.17	0.17	0.16	0.01
Central Bay	8	0.13	0.09	0.11	0.10	0.02
South Bay	9	0.16	0.22	0.16	0.15	0.05
Lower South Bay	5	0.17	0.54	0.17	0.38	0.22

D3.4.5 MIKE 21 ME Adsorbed and Total Selenium Calibration Results

Measured and predicted adsorbed Se concentrations on suspended sediment at the 12 RMP stations displayed on Figure D3-1 are shown as time series on Figures D3-9 and D3-10 for the calibration year 1997. Adsorbed concentrations on the plots were screened to remove values associated with suspended sediment concentrations less than 10 mg/L. This filtering of data was necessitated by the inaccuracies involved in measuring adsorbed concentrations when little suspended sediment is available, and the bias towards high adsorbed Se concentrations shown on Figure D3-11.

As illustrated on Figure D3-12, the variability in predicted values is considerably less than the measured variability; however, the model is consistent with the average adsorbed Se concentration for the data. Predictions are closest to observations in the North Bay (Table D3-3), with RMS differences less than 0.2 mg/kg. Predicted concentrations deviate the most from observations in the Central and South bays, although relatively few data points exist to draw distinctions.

Table D3-3
Statistics on Adsorbed Selenium–Water Year 1997 Calibration

Bay Segment	Number of Data Points	Adsorbed Selenium (mg/kg-dry-weight)*				
		Mean Concentration		Median Concentration		Average RMS Difference
		Predicted	Observed	Predicted	Observed	
Suisun Bay	12	0.40	0.66	0.35	0.42	0.19
San Pablo Bay	8	0.54	0.49	0.58	0.30	0.15
Central Bay	3	0.47	3.07	0.42	3.50	1.65
South Bay	3	0.59	1.56	0.58	1.23	0.73
Lower South Bay	5	0.64	4.19	0.64	1.00	3.46

*Based on measured total suspended sediments > 10 mg/L.

Concentrations of total (dissolved plus adsorbed) Se are shown on the upper plot of Figure D3-8 to be below the Chronic water quality objective (WQO) of 5 µg/L throughout the Bay. Maximum concentrations of total Se are between 0.25 and 0.30 µg/L, and occur near the San Joaquin River and in San Pablo Bay. These concentrations are influenced by the higher amount of suspended sediment (and consequently adsorbed Se) as shown on the upper plot on Figure D3-13. Finally, as illustrated on the lower plot on Figure D3-13, the highest benthic Se concentrations are generally predicted in the Central Bay (a consequence of only modeling mud as discussed above).

D3.5 Limitations

The first limitation of the MIKE 21 model is that only one grain-size fraction (i.e., mud) can be modeled. Because Se concentrations of sand are less than mud, Se concentrations tend to be overestimated in areas where sand is a significant fraction of the total benthic or suspended sediment concentration (e.g., the Central Bay). The second limitation is that only one partition coefficient is used to describe the interaction between dissolved and adsorbed Se, despite the fact that multiple forms of dissolved Se and multiple types of particles can act as sorptive surfaces. This leads to model predictions that better replicate average rather than instantaneous concentrations.

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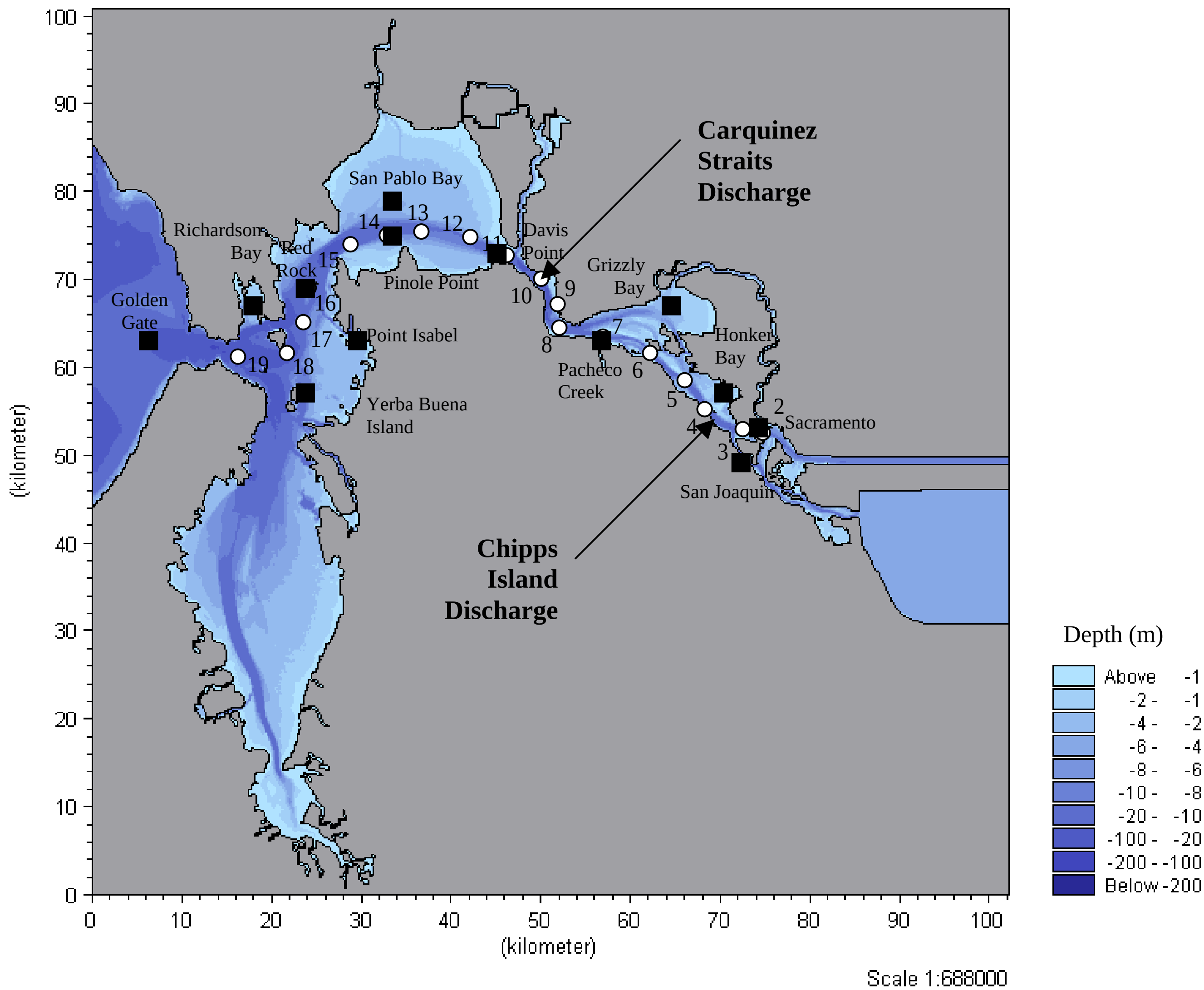

San Luis Drainage Feature Re-evaluation	Bathymetry for MIKE 21 Model and Location of Modeled Discharges and USGS (Open Circles) and RMP (Closed Squares) Monitoring Stations	Figure D3-1
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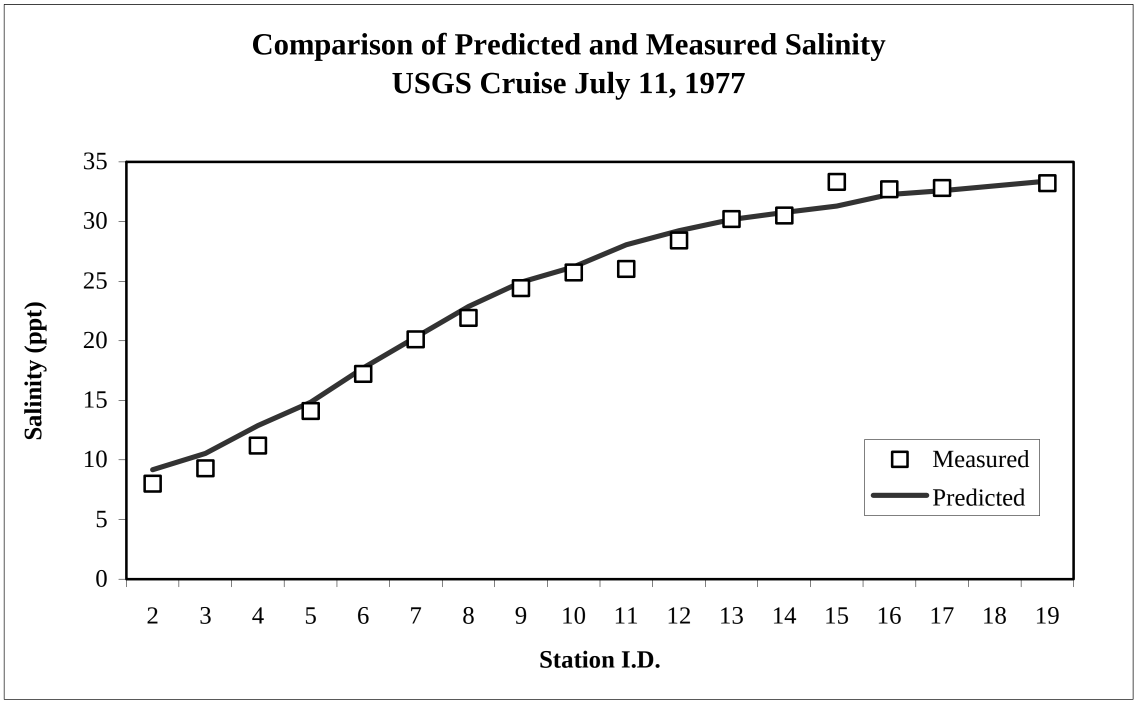

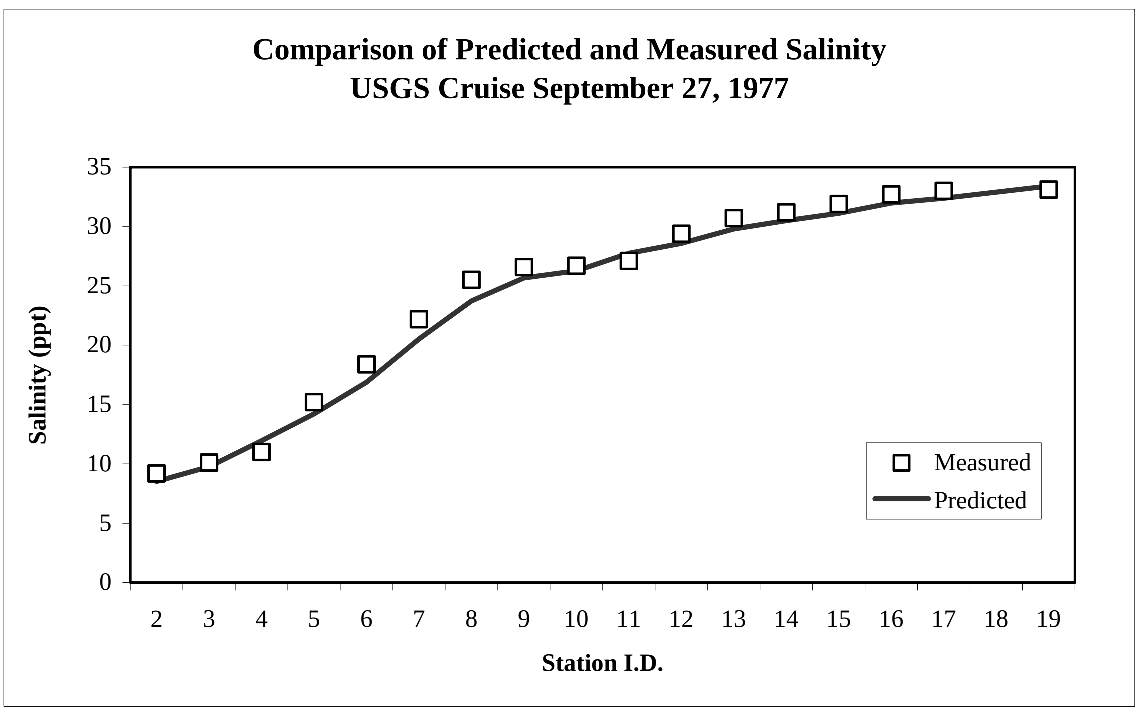

San Luis Drainage Feature Re-evaluation	MIKE 21 North and Central Bay Salinity Calibration Results For Water Year 1977 (July and September Cruises)	Figure D3-2
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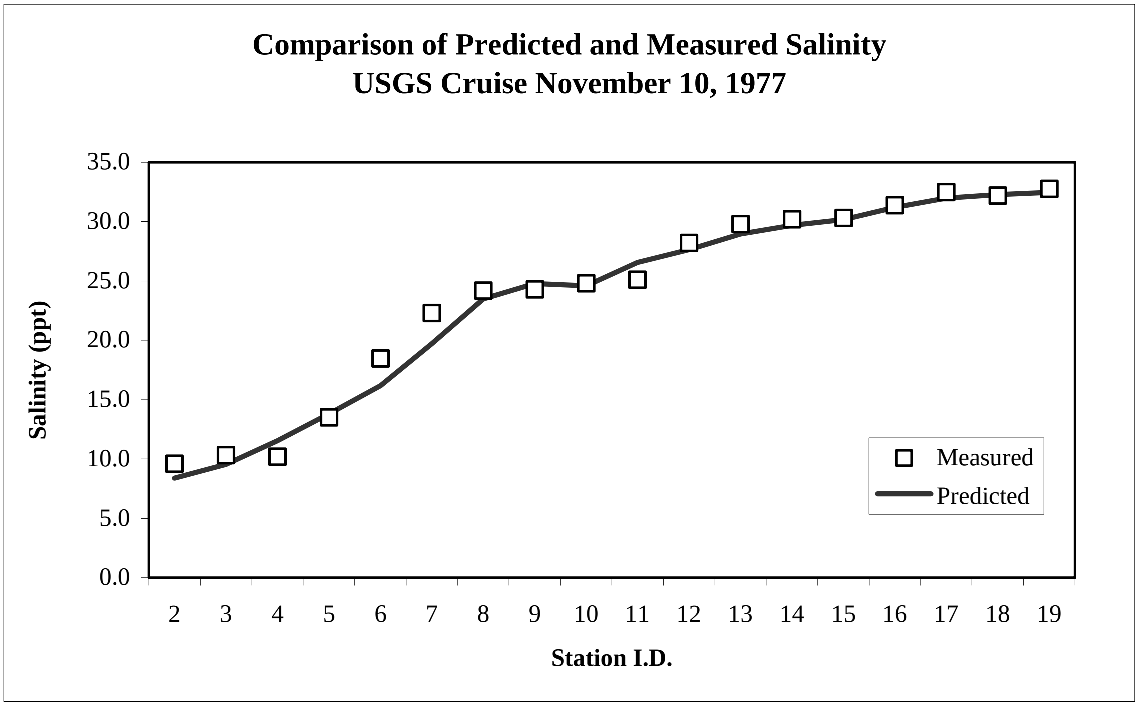

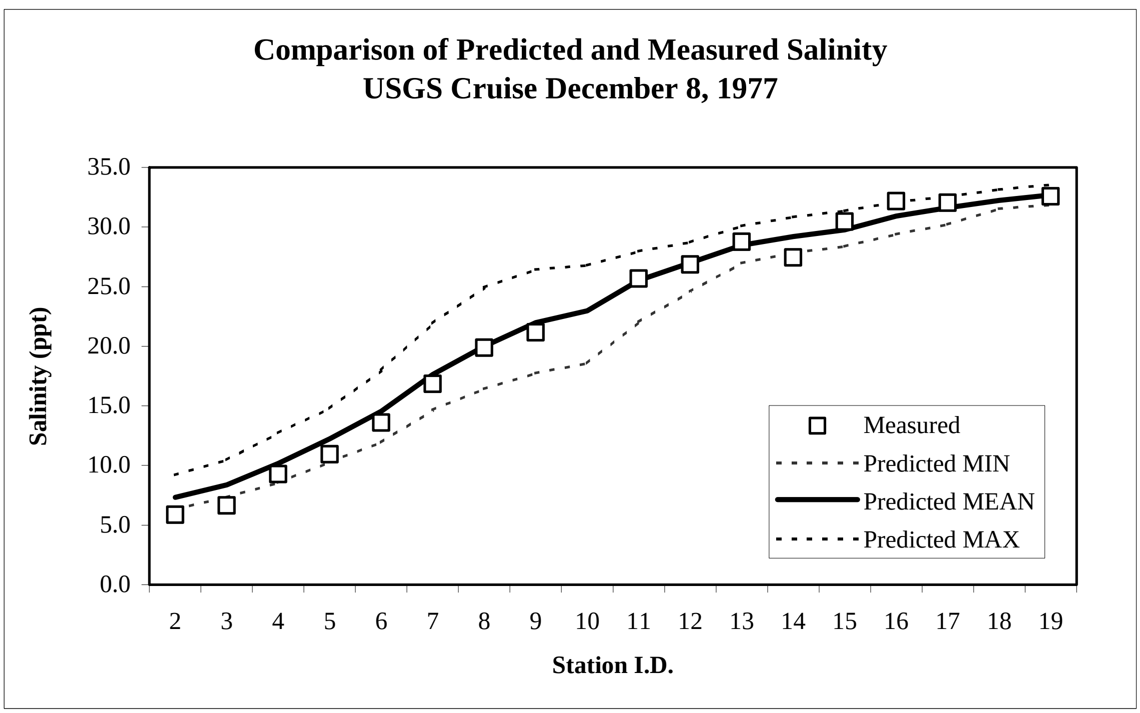

San Luis Drainage Feature Re-evaluation	MIKE 21 North and Central Bay Salinity Calibration Results For Water Year 1977 (November and December Cruises)	Figure D3-3
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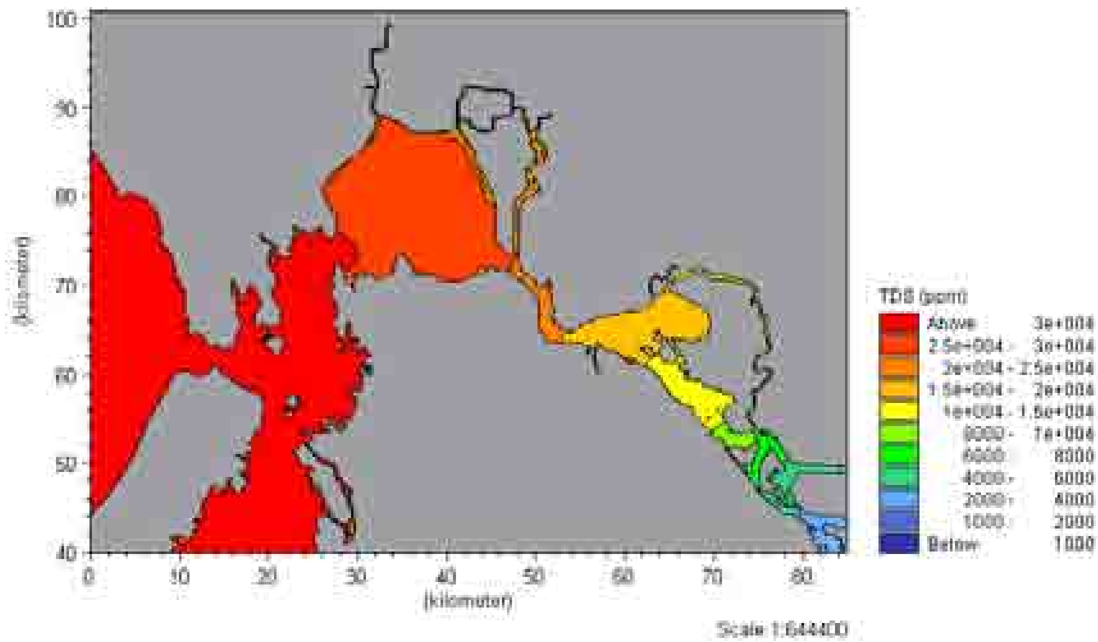

San Luis Drainage Feature Re-evaluation	MIKE 21 Predicted Existing Conditions Mean Total Dissolved Solids Concentration (July-December 1977)	Figure D3-4
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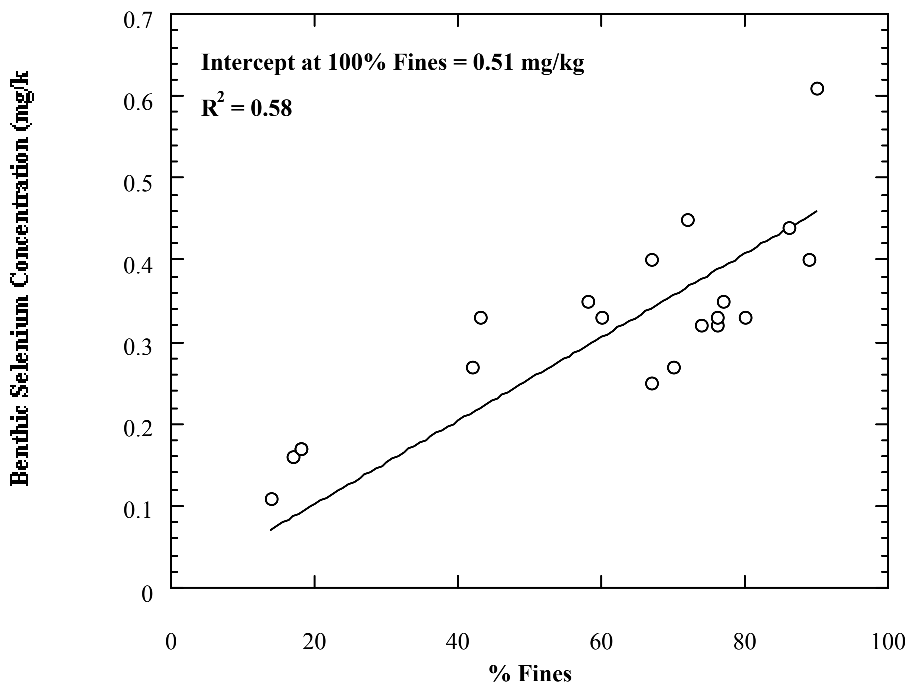

San Luis Drain Feature Re-evaluation	Average Benthic Selenium Concentrations and Average Fines at RMP Stations (SFEI 1994-1998)	Figure D3-5
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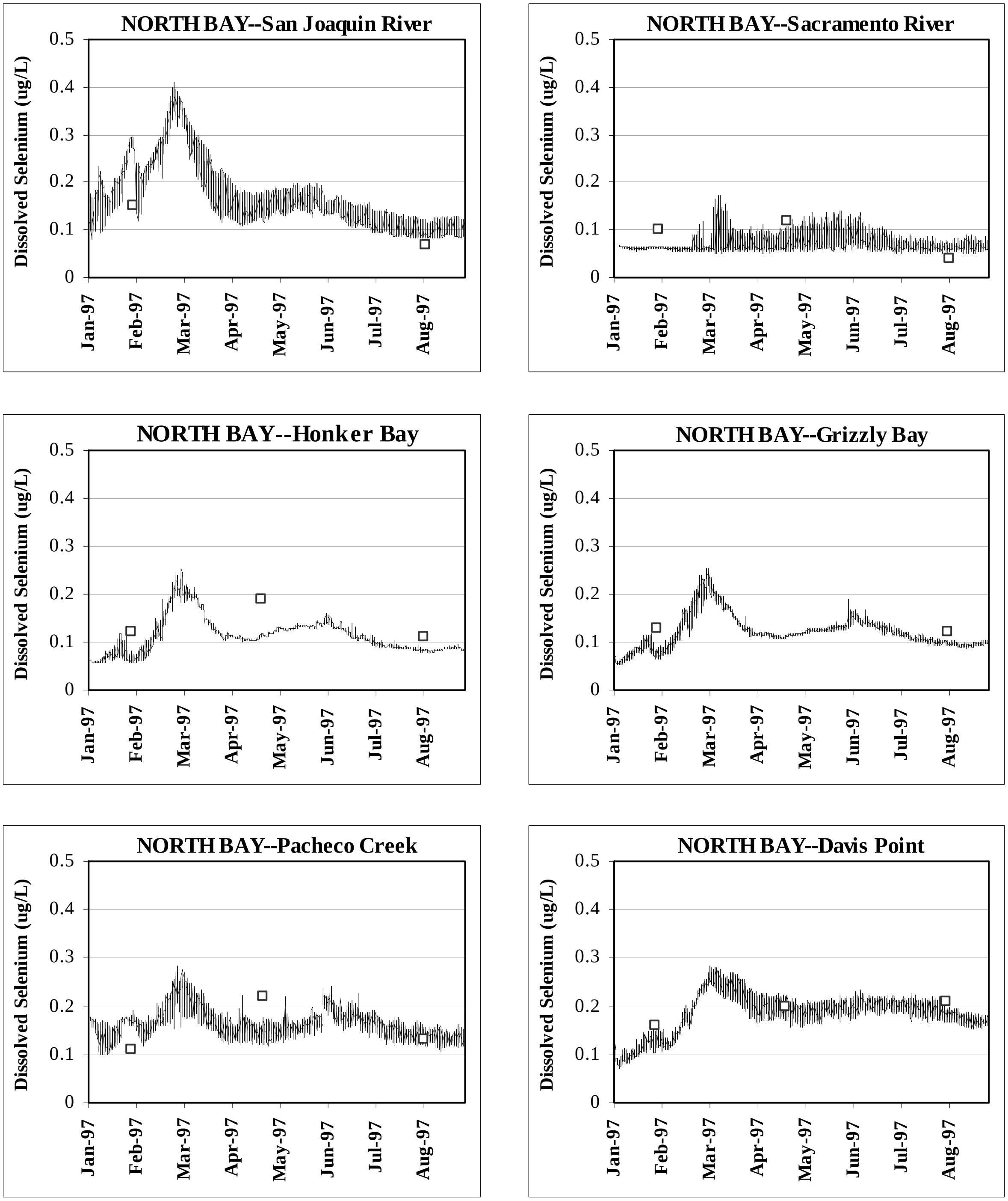

San Luis Drainage Feature Re-evaluation	MIKE 21 North Bay Dissolved Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises)	Figure D3-6
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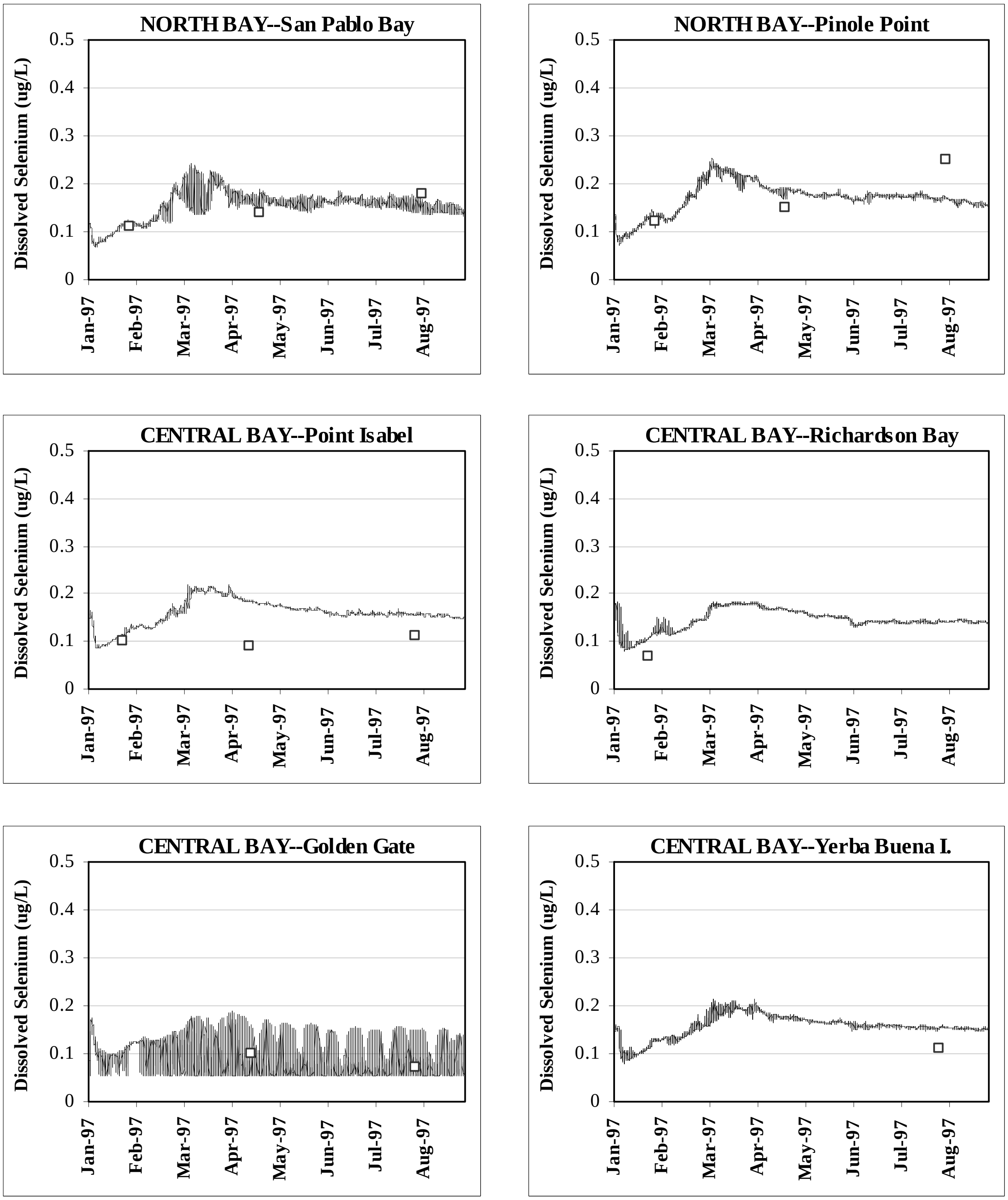

San Luis Drainage Feature Re-evaluation	MIKE 21 San Pablo Bay and Central Bay Dissolved Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises)	Figure D3-7
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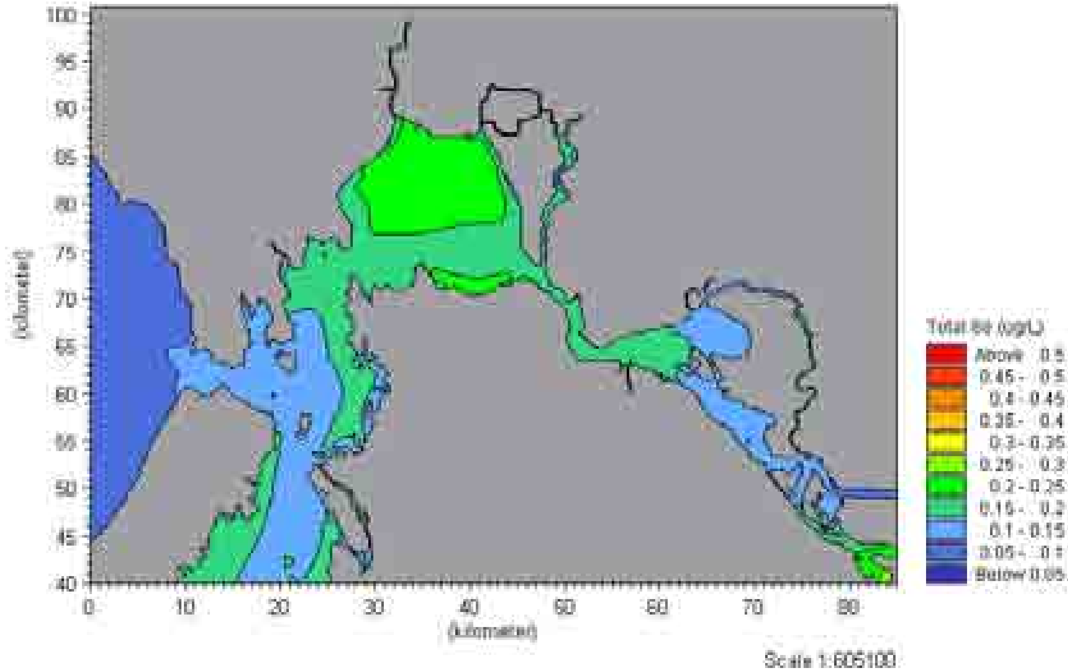

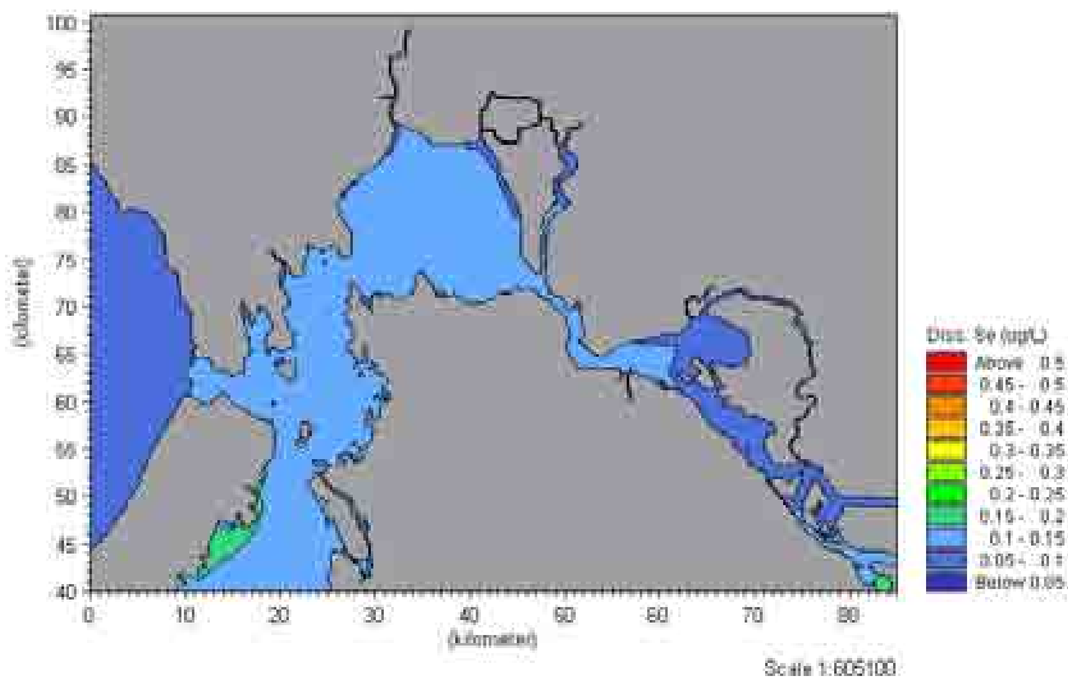

San Luis Drainage Feature Re-evaluation	MIKE 21 Predicted Existing Conditions Total and Dissolved Selenium Concentrations (June-November 1997)	Figure D3-8
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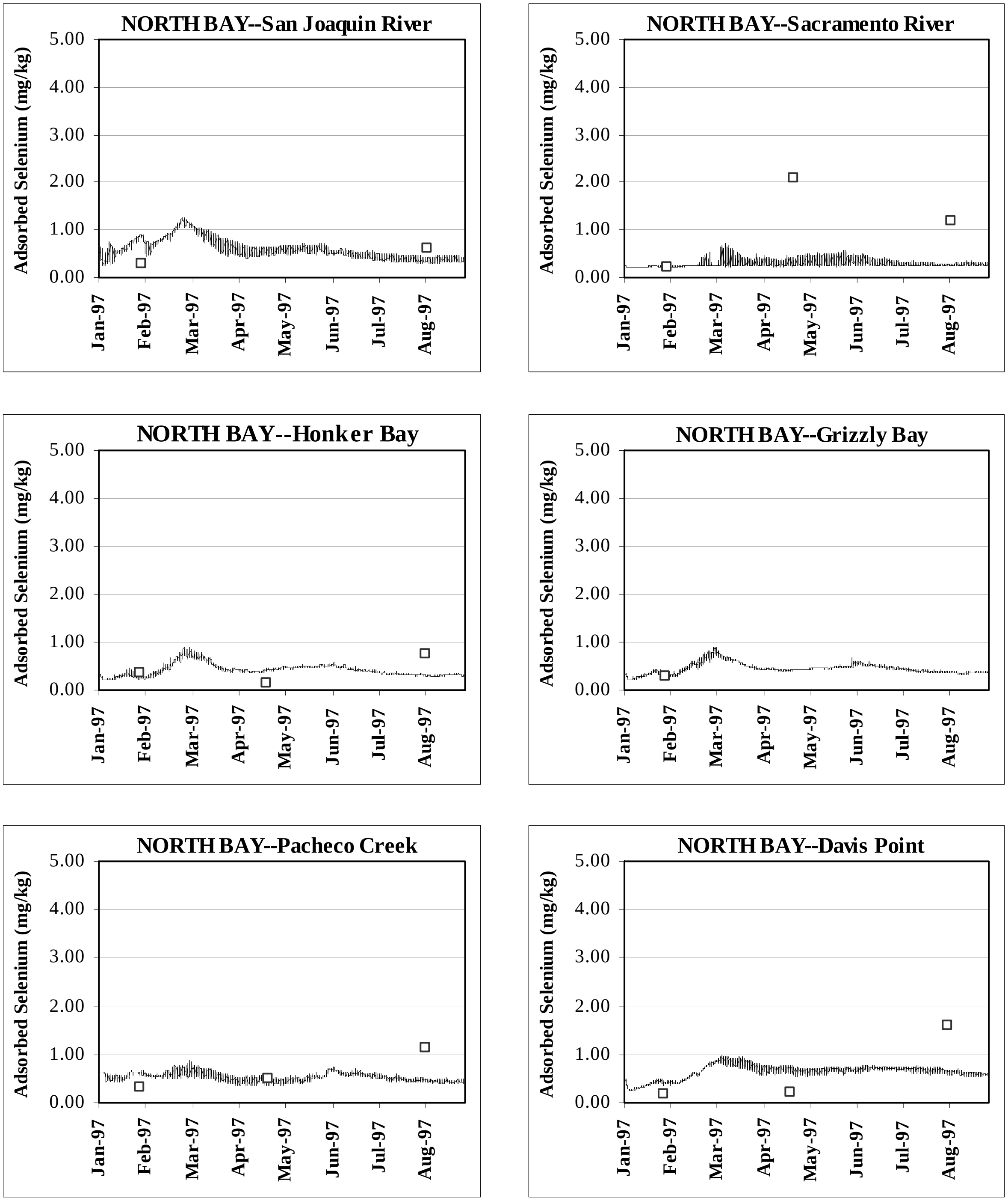

San Luis Drainage Feature Re-evaluation	MIKE 21 North Bay Adsorbed Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises)	Figure D3-9
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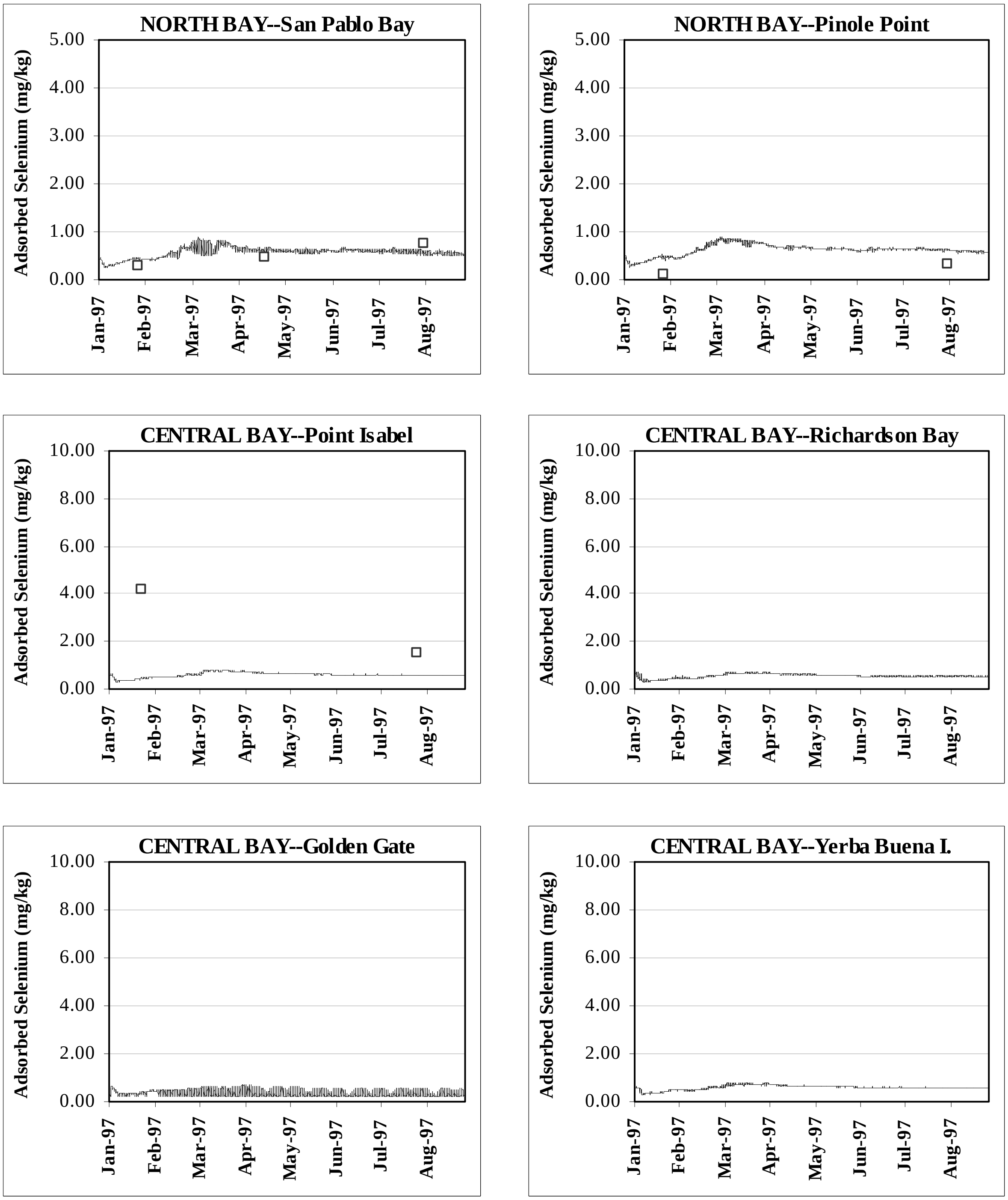

San Luis Drain Features Re-evaluation	MIKE 21 San Pablo Bay and Central Bay Adsorbed Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises)	Figure D3-10
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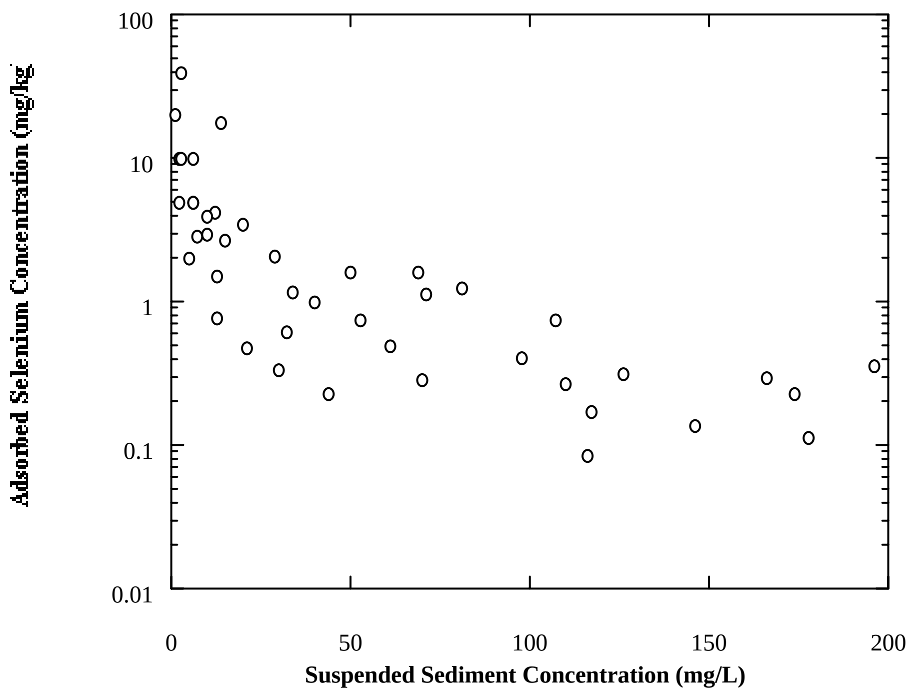

San Luis Drain Features Re-evaluation	Adsorbed Selenium and Suspended Sediment Concentrations at RMP Stations For Water Year 1997 (SFEI 1998)	Figure D3-11
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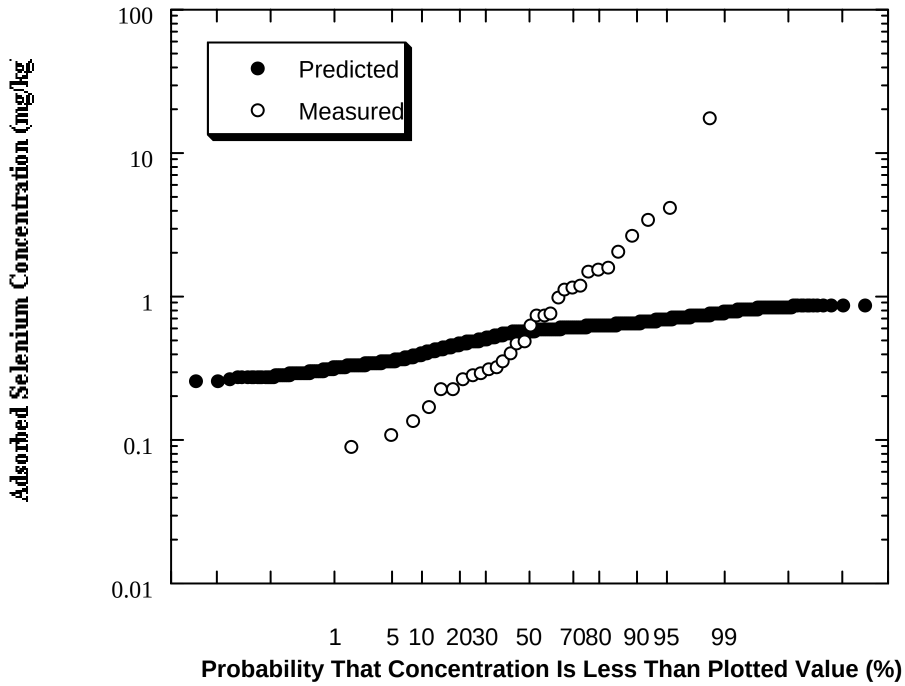

San Luis Drain Features Re-evaluation	MIKE 21 Predicted and RMP Measured Probability of Exceedance of Adsorbed Selenium Concentrations Water Year 1997	Figure D3-12
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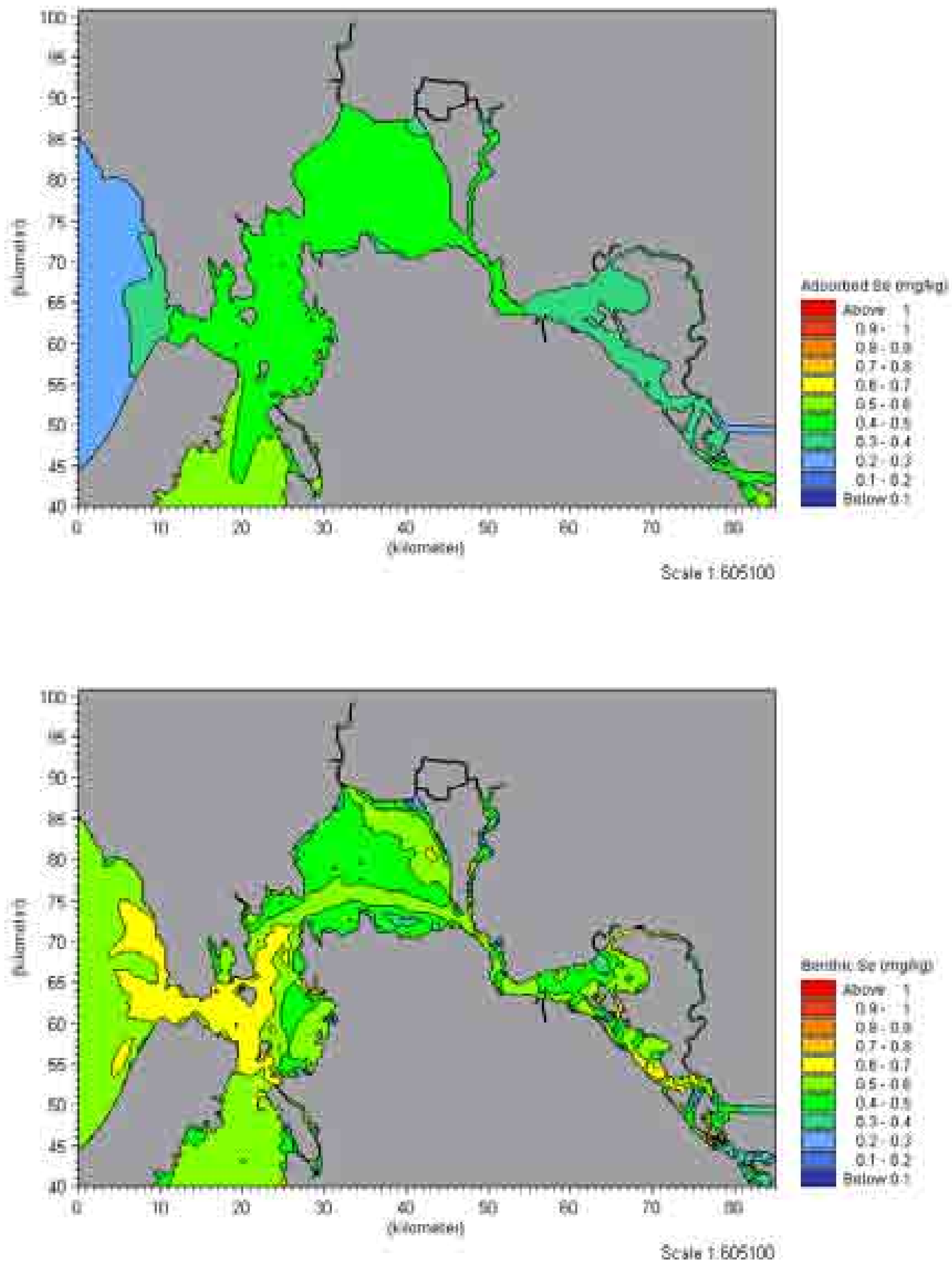

San Luis Drainage Feature Re-evaluation	MIKE 21 Predicted Existing Conditions Adsorbed and Benthic Selenium Concentrations (June-November 1997)	Figure D3-13
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D4 SAN JOAQUIN RIVER MODELING

D4.1 Background

The GDA is comprised of approximately 97,000 acres of agricultural land that currently discharges to the San Joaquin River by way of the San Luis Drain and Mud Slough. The Lower San Joaquin River is listed on the Federal Clean Water Act's 303(d) list as an impaired waterbody for a number of constituents, including EC, boron, and Se. The Clean Water Act requires that a TMDL be developed for each constituent listed.

In August 2001, the Central Valley Regional Water Quality Control Board (CVRWQCB) published the *Total Maximum Daily Load for Selenium in the Lower San Joaquin River*. The Se TMDL was approved by the U.S. Environmental Protection Agency in March 2002. The TMDLs were devised to meet the WQO of 5 µg/L for Se in the San Joaquin River downstream of the Merced River confluence. Load allocations were only developed for the GDA since drainage from the GDA is the primary source of Se in the Lower San Joaquin River.

The CVRWQCB published the *Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River* in January 2002, and it is currently being reviewed by the U.S. Environmental Protection Agency. The TMDLs were developed to "(1) identify the major sources of salt and boron loading to the Lower San Joaquin River; (2) determine the maximum amount of salt and boron loading that occur while still meeting water quality objectives; and (3) equitably allocate the available assimilative capacity among the identified sources" (CVRWQCB 2002).

D4.2 General Approach

Currently, the GDA discharges to the San Joaquin River through Mud Slough as a part of the Grassland Bypass Project. Under the action alternatives of the San Luis Drainage Feature Re-evaluation, this discharge would be shifted to one of the disposal alternatives, which would eliminate discharge of salt, boron, and Se from the GDA to the San Joaquin River. Under No Action, the Grassland Bypass Project would terminate, which would also prevent the GDA from discharging to the San Joaquin River.

Analysis of changes in salinity and flow are provided in Section D2.

The purpose of the following analysis was to estimate Se concentrations for existing conditions in the San Joaquin River and for No Action and the action alternatives. It was assumed that for existing conditions, the GDA would be allowed to discharge Se loads up to the Load Values that were in place in 2001. Se concentrations at Crows Landing were calculated using 14 years of flow records from October 1985 to September 1999 both with and without loads from the GDA.

Boron concentrations at Crows Landing were calculated similarly. At Vernalis, boron concentrations were developed by applying a correlation to the salinity results described in Section D2.

D4.3 Methodology and Results

D4.3.1 Selenium

The Se loads discharged from the GDA for existing conditions were assumed to be equivalent to the 2001 Selenium Load Values. It was assumed that the discharge from the GDA for existing conditions could be calculated as the maximum discharge allowed to meet the 2001 Selenium Load Values, using the measured calendar year 2001 Se concentrations. Figure D4-1 shows the historical discharge from the GDA (from measured data at Station B in the San Luis Drain) and the calculated discharge for existing conditions.

At Crows Landing, the Se loads for existing conditions were calculated as the sum of the allowed 2001 loads from the GDA and the background load. The background load at Crows Landing was provided in Appendix D of the Se TMDL (CVRWQCB 2001) from 1986 to 1999, and is comprised of estimated loads from the Merced River, the San Joaquin River at Lander Avenue, Mud Slough, and Salt Slough. For existing conditions, the flow at Crows Landing was assumed to be equivalent to the historical measured flows. The estimated loads and historical flows were used to calculate the Se concentration at Crows Landing for existing conditions.

For No Action and the action alternatives, the measured flow at Crows Landing was decreased by the calculated discharge from the GDA for existing conditions. The Se concentrations for No Action and the action alternatives were calculated using the decreased flows with the estimated background loads, and excluded loads from the GDA. The calculated Se concentrations at Crows Landing for existing conditions and for No Action and the action alternatives are shown on Figure D4-2. The line marking the 5 µg/L WQO is shown for comparison. The results show that for No Action and the action alternatives, the Se concentrations would be well below the WQO for the San Joaquin River below Merced.

D4.3.2 Boron

The boron concentrations at Crows Landing for existing conditions were calculated as the sum of the boron loads leaving the GDA and the background loads. The boron loads from the GDA were calculated using measured boron concentrations at Station B for calendar year 2001 and the maximum discharge calculated previously that resulted in meeting the 2001 Selenium Load Values. The background boron loads at Crows Landing were calculated as the sum of boron loads from the Merced River, the San Joaquin River at Lander Avenue, Mud Slough, and Salt Slough using concentrations and flows provided from October 1985 through September 1997 in Appendix A of the salt and boron TMDL (CVRWQCB 2002).

As assumed for the calculation of Se concentrations, the flow at Crows Landing under existing conditions was assumed to be equivalent to the historical measured flows. The historical flows and the sum of the GDA and background boron loads were used to calculate the boron concentration at Crows Landing for existing conditions.

To simulate the conditions under No Action and the action alternatives, the boron concentrations at Crows Landing were calculated using flows and loads that had been reduced by the contribution from the GDA. The calculated boron concentrations at Crows Landing for existing conditions and for No Action and the action alternatives are shown on Figure D4-3. The line marking the WQO is shown for comparison. The results show a reduction in boron concentrations from existing conditions under No Action and for the action alternatives; however, the boron concentrations at Crows Landing could still exceed the WQO for the San Joaquin River below Merced.

To evaluate the effects of No Action and the action alternatives on boron concentrations at Vernalis, a correlation between boron and salinity was applied to the results from the CALSIM model (described in Section D2). In Appendix A of the TMDL for salt and boron (CVRWQCB 2002), the ratio of EC, in umhos/cm, to boron, in mg/L, was calculated to be 0.0005 for the San Joaquin River near Vernalis. This linear correlation was based on data collected between 1985 and 1997 in the CVRWQCB water quality database (CVRWQCB 2002). The calculated boron concentrations at Vernalis for existing conditions and for No Action and the action alternatives are shown on Figure D4-4. This figure shows that the boron WQO (ranging between 0.8 and 1.0 mg/L) is not expected to be exceeded under existing conditions, and boron concentrations would be improved under No Action and for the action alternatives.

Figure D4-1. Historical and Modeled Discharge from the Grassland Drainage Area

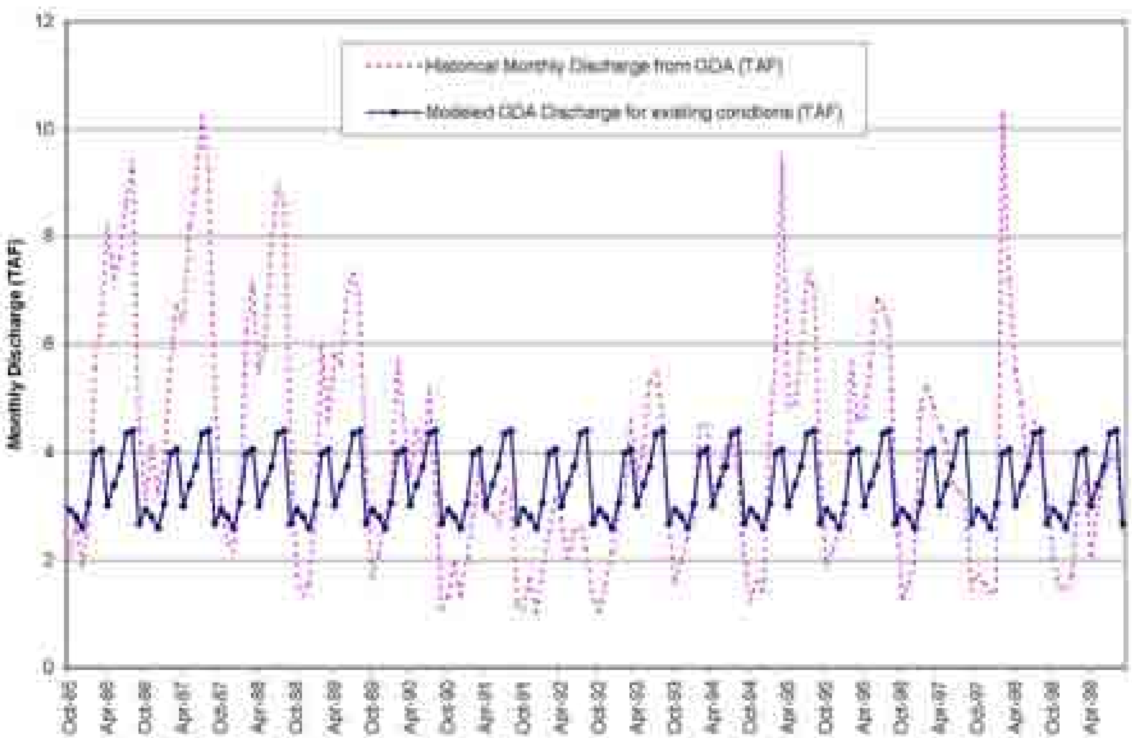


Figure D4-2. Selenium Concentration at Crows Landing for Existing Conditions and for the No Action and Action Alternatives

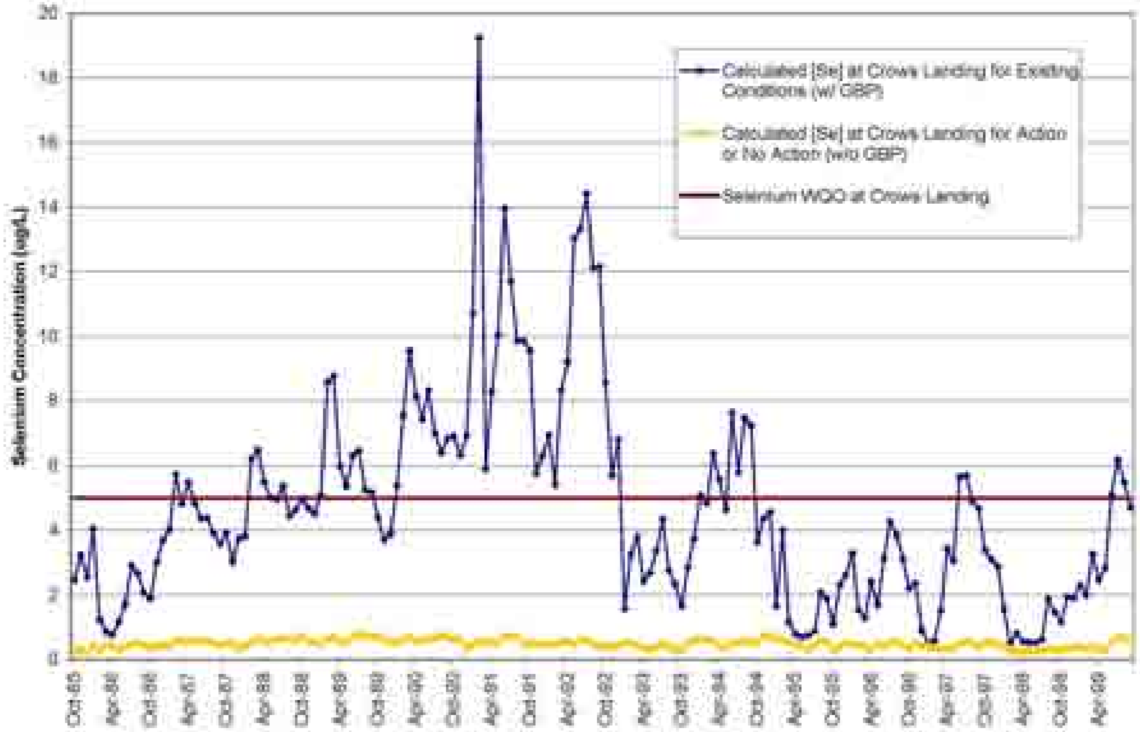


Figure D4-3. Boron Concentration at Crows Landing for Existing Conditions and for the No Action and Action Alternatives

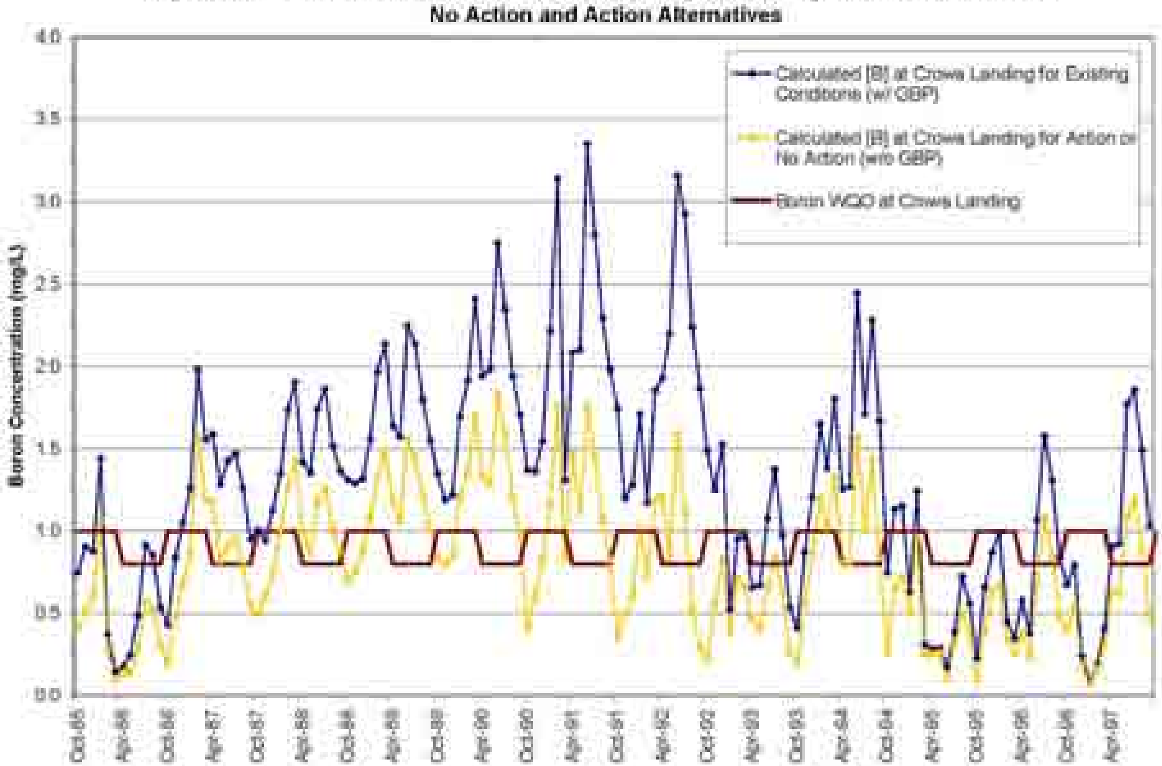
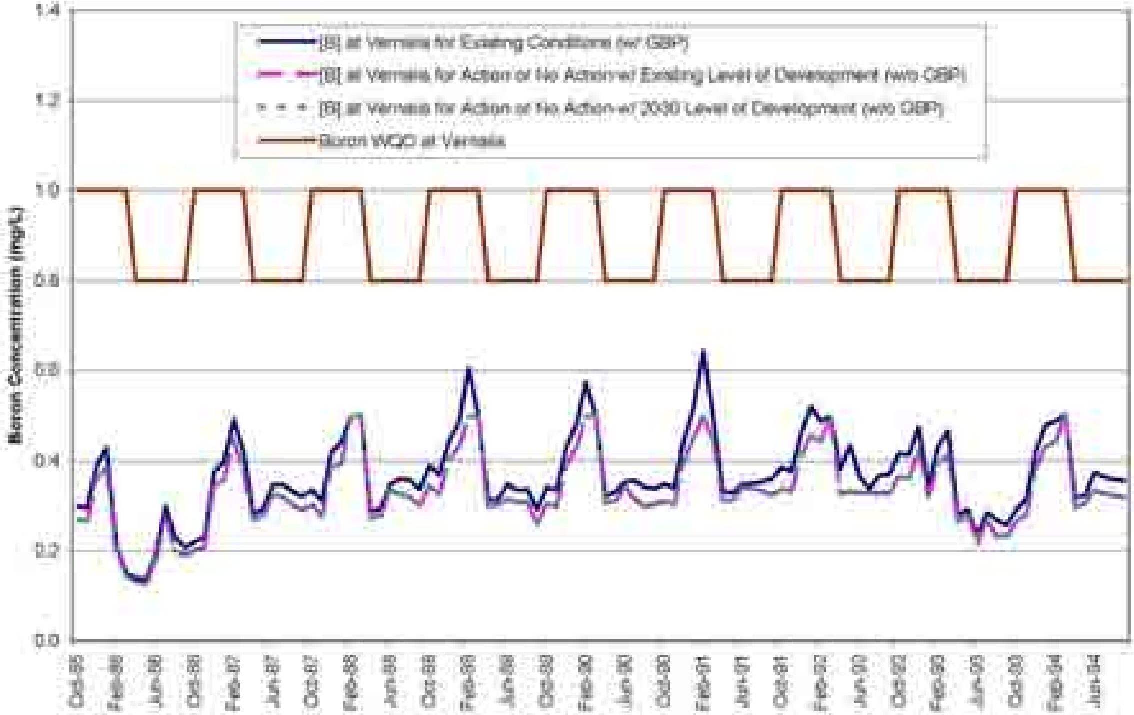


Figure D4-4. Boron Concentration in the San Joaquin River at Vernalis for Existing Conditions and for the No Action and Action Alternatives



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APPENDIX E

GROUNDWATER RESOURCES

APPENDIX E1

ESTIMATED EFFECTS OF EVAPORATION BASINS ON GROUNDWATER

Table of Contents

Tables

Figures

Acronyms

µg/L	microgram(s) per liter
mg/L	milligram(s) per liter
Se	selenium
Westlands	Westlands Water District

E1.1 METHODS

The In-Valley Disposal Alternative includes almost 6,150 acres of evaporation basins to reduce drainwater volumes. basin operation was assumed to begin in 2006 and thermodynamic equilibrium and mass balance calculations and groundwater flow modeling were used to estimate constituent concentrations in groundwater quality underlying evaporation basins, lateral groundwater flow, and seepage to adjacent lands. The proposed basins are located in the Northerly Area and Westlands Water District (Westlands) North, Central, and South.

To estimate concentrations in groundwater underneath the evaporation basins, a mixing cell model within the U.S. Geological Survey program PHREEQE (Parkhurst, Thorstenson, and Plummer 1980) was used in the upper 40 feet of the groundwater system. Using a basin bottom vertical hydraulic conductivity of 1×10^{-6} centimeters per second and unit hydraulic gradient, 1 foot/year of basin leakage to the underlying groundwater was initially estimated. The effective depth of groundwater was assumed to equal 40 feet. Evidence exists that the hydraulic conductivity of the basin bottom materials may decrease due to mineral precipitation and accumulation of microbial sludge.

Data for evaporation basin seepage in San Joaquin Valley are sparse. McCullough-Sanden and Grismer (1988) and Grismer and McCullough-Sanden (1989) estimated seepage rates and hydraulic conductivity values for evaporation basins in western and southern San Joaquin Valley. Their data indicate seepage rates ranging from 1 to several millimeters per day. During 1 month, Grismer and McCullough-Sanden (1987) measured hydraulic conductivity changes in basined San Joaquin Valley evaporation basin bottom sediments. In four columns, they reported 79 and 29 percent decreases in hydraulic conductivity for two of the columns and either no change or increased hydraulic conductivity for the other two columns. Visual inspection of bottom sediments indicated the presence of microbial sludge that probably fills soil pores and reduces permeability within months of initial operation (Kenneth Tanji, University of California, Davis, pers. comm., 2003).

Mineral precipitation may fill soil pores and reduce hydraulic conductivity. Stuart and Dixon (1973) reported that calcium carbonate coatings in the soil matrix impede water movement. Calcareous crusts may also impede infiltration. Other more soluble sodium and magnesium sulfate and halide minerals may also seal the soil (Driessen and Schoorl 1973). Increasing sodium on the soil exchange complex causes swelling and dispersion of clays, which impedes water movement (McNeal and Coleman 1966; McNeal 1968). High infiltrating-water solute concentrations counteract this effect. High pH above 7 can also reduce hydraulic conductivity (Suarez et al. 1984). The extent to which sodium on the soil exchange, pH, mineral precipitation, clay alteration, and microbiological sludge will reduce overall seepage from planned basins is uncertain. To bracket the possible effects of decreased seepage rates on groundwater quality, groundwater quality changes were estimated for varying seepage rate reductions.

A primary consideration in locating evaporation basin sites and basin construction is soil permeability and infiltration rates. Reducing the hydraulic conductivity through excavation and soil compaction may be part of evaporation basin construction. Perimeter interceptor drain installation may also reduce movement to groundwater.

E1.1.1 Thermodynamic and Mass Balance Calculations

Table E1-1 schematically shows the model calculations in which downward vertical movement of water from the evaporation basins to the resident groundwater were estimated. For salinity within each mixing cell (expressed as total dissolved solids concentrations), PHREEQE performed mixing, mineral equilibrium, and cation exchange calculations. The exchange complex composition was estimated based on Sposito et al. (1987). For the highest salinities, we used PHREEQPITZ (Plummer et al. 1988), which uses the Pitzer equations (Pitzer 1973) to more accurately calculate higher ionic strengths and mineral equilibrium associated with more soluble minerals. For all calculations, gypsum and calcite were the primary mineral phases affecting groundwater salinity. Constant groundwater partial pressure of CO_2 of $10^{-2.6}$ was assumed based on data in Bell (1988).

Table E1-1
Calculations for Estimating Groundwater Quality Changes

Basin/Layer	Calculation
Evaporation basin	Influent water salinity and selenium (Se), boron, and molybdenum concentrations increase over time per data provided by URS. For each time step, the model simulates 83 percent evaporation of influent water resulting in about a 5-fold concentration increase. The model simulates salt precipitation (primarily gypsum and calcite) as the result of evaporation. Se and molybdenum concentrations in water percolating to the groundwater were reduced (50 and 36 percent) by biogeochemical processes. Boron behaves conservatively. 1 foot/year of evaporated water moves down to layer 1.
Layer 1, 0–10 feet below water table	Simulated mixing of evaporated basin water with underlying resident groundwater, mineral equilibration, and cation exchange. Se, molybdenum, and boron behave conservatively in mixing of percolating basinwater and groundwater. Resulting solution moves down to layer 2 at a rate of 1 foot/year.
Layer 2, 10–20 feet below water table	Simulated mixing of water from layer 1 with underlying resident groundwater, mineral equilibration, and cation exchange. Resulting solution moves down to layer 3 at a rate of 1 foot/year.
Layer 3, 20–30 feet below water table	Simulated mixing of water from layer 2 with underlying resident groundwater, mineral equilibration, and cation exchange. Resulting solution moves down to layer 4 at a rate of 1 foot/year.
Layer 4, 30–40 feet below water table	Simulated mixing of water from layer 3 with resident groundwater, mineral equilibration, and cation exchange.

The individual ion concentrations for the groundwater and basinwater salinity values provided by URS were estimated from data in Deverel et al. (1984), Leighton et al. (1991), Swain and Duell (1995), Deverel and Fujii (1988), and Shelton and Miller (1988). Initial Se, boron, and molybdenum concentrations in the groundwater and evaporation basins were based on data from URS. Se, boron, and molybdenum were assumed to be concentrated in the basins proportional to the amount of evaporation (83 percent).

For Se and molybdenum, chemical reactions with basin sediments will probably reduce concentrations in the water percolating to the groundwater. In San Joaquin Valley evaporation basins and wetlands, Tanji (1990), Tanji and Grismer (1988), and Gao et al. (2003) showed 50 to 100 percent removal of Se and 36 to 55 percent removal of molybdenum due to biochemical transformation to insoluble and volatile forms in anaerobic basin sediments. Therefore, 50 and

36 percent of the Se and molybdenum were conservatively estimated to be removed from the basinwater prior to percolating to the groundwater. Se and molybdenum were assumed to behave conservatively in mixing with resident groundwater.

No evidence exists for mineral or biochemical reactions affecting boron concentrations in San Joaquin Valley evaporation basins. Smith et al. (1995) indicated the presence of borax ($Na_2B_4O_710H_2O$) in basin salt crusts upon dewatering of evaporation basins. However, our calculations using PHREEQPITZ indicate that even at the highest concentrations, basinwater remains undersaturated with respect to borax, and borax precipitation is concluded to not be a significant mechanism for boron removal from evaporation basinwaters. Therefore, boron from and in the evaporation basins was estimated to increase proportionally to evaporation and to mix conservatively with resident groundwater.

E1.1.2 Lateral Groundwater Flow and Groundwater Quality Effects

Groundwater also moves laterally and concern exists that evaporation basinwater will seep to adjacent lands causing increased soil and groundwater salinity and affecting crop production. A model developed from the Belitz et al. (1993) model was used to estimate lateral groundwater movement in the upper 50 feet. To estimate seepage onto adjacent lands, boundary conditions and input parameters from the Belitz et al. model and other sources were used to develop a more finely discretized groundwater flow model.

Specifically, a three-layer, three-dimensional flow model was developed. The top two layers were based on the Belitz model and represented the upper 50 feet. For the bottom layer, which represented about 120 feet of aquifer thickness, a general head (head-dependent flow) boundary was specified that approximated the vertical downward groundwater flow of about 0.7 foot/year. The hydraulic conductivity distribution was based on the Belitz model. The model was calibrated to Spring 1999 water levels provided by Westlands. The vertical hydraulic conductivity was equal to the Belitz model. The horizontal hydraulic conductivity was increased uniformly 8-fold relative to the Belitz model to match measured water-level elevations. The model matched April 1999 water-level elevations throughout the model within 5 feet (root mean square error) or 6 percent (normalized root mean square error) for the range of water levels in the model. The recharge distribution from the Belitz model was used. The volumetric fluxes for evapotranspiration, drainflow, and boundary fluxes for our model matched the fluxes from the Belitz model within 30 percent. To simulate the evaporation basins, a recharge rate of 1 foot/day was specified to percolate through the basin bottom. Using the results from this model, the extent to which lateral seepage would affect adjacent lands was estimated.

E1.2 RESULTS OF GROUNDWATER QUALITY CALCULATIONS

E1.2.1 Hydraulic Conductivity Reductions

Potential reductions in basin seepage due to mineral precipitation, increased sodium on the soil exchange, and pH were examined. Also, an attempt was made to account for the field and laboratory observations from the work of Grismer and McCullough-Sanden (1987), Tanji (1990), Tanji and Grismer (1988), and Gao et al. (2003). The primary minerals precipitated during basinwater evaporation are calcite and gypsum. Other more soluble magnesium, sodium, sulfate, and halide minerals precipitate upon dewatering of the basins. PHREEQC estimated the mass of calcite and gypsum precipitated during each time step. For example in the Northerly Area basin, about 783,000 kilograms/year of calcite were estimated to precipitate in the basin. Assuming that this entire amount is available for filling soil pores, about 0.4 percent of the effective porosity in the top 5 centimeters of the basin bottom would be filled by calcite per year. After 52 years, over 20 percent of the porosity could be affected. However, the presence of dissolved organic carbon limits calcite precipitation.

Substantially more gypsum, 3,500,000 kilograms/year, precipitates. However, it is unclear how this precipitation will affect soil porosity. Assuming that this total mass occludes soil pores in the top 5 centimeters of the basin bottom, about 2 percent of the porosity in the top centimeter would be filled per year.

No seepage reduction will occur due to increased exchangeable sodium on the basin bottom materials, due to the high electrolyte concentrations of the basinwaters. McNeal (1968) indicated no hydraulic conductivity reduction for electrolyte concentrations in the soil solution greater than 300 mmole/L. For all evaporated basinwater, concentrations were estimated to exceed this amount in the first year.

Increasing pH in the evaporation basins may reduce basin seepage. The reduction in hydraulic conductivity increases linearly from 0 near pH 6.8 to 78 percent reduction at pH 9.0 (Suarez et al. 1984). Our PHREEQC calculations indicate pH 8 in basinwaters resulting in about 42 percent reduction. These estimates are generally consistent with field pH values reported by Tanji and Grismer (1988) in San Joaquin Valley evaporation basins; however, they measured pH values as high as 9.0.

Based on above-estimated effects of mineral precipitation and pH and probable, but as yet unquantifiable, effects of microbial sludge on bottom sediment porosity, basin seepage is expected to decrease over time. However, quantification of the reduced seepage is difficult due to factors discussed here, the variability in column hydraulic conductivity measurements from Grismer and McCullough-Sanden (1987), and lack of field measurements. Therefore, the possible effects were bracketed by simulating groundwater concentrations for 0, 25, 50, and 90 percent reductions in seepage rates. These changes were simulated as occurring within the first 5 years of basin operation.

E1.2.2 Groundwater Salinity

Figure E1-1 shows increasing groundwater dissolved solids concentrations for a seepage rate of 1 foot/year. Based on kriging of groundwater samples collected in the mid-1980s, initial groundwater dissolved solids concentrations were 18,000, 15,000, 9,000 and 15,500 milligrams per liter (mg/L) for the Northerly Area, Westlands North, Westlands Central, and Westlands South evaporation areas, respectively. By 52 years after initial basin operation startup, large salinity increases (9.6-fold in the Northerly Area, 16-fold in Westlands South, 18-fold in Westlands North, and 21-fold in Westlands Central) were estimated in model layer 1 (0- to 10-foot saturated depth interval). For groundwater at greater depths, salinity increases are significant, but less than in model layer 1 (0 to 10 feet); after 52 years concentrations in layer 4 (31 to 40 feet) increased 4.6-fold in Westlands Central, 5.3-fold in the Northerly Area, 6.1-fold in Westlands South, and 6.5-fold in Westlands North. Large amounts of salt precipitation in model layer 1 (0 to 10 feet) result in less substantial concentration increases in layers 2–4.

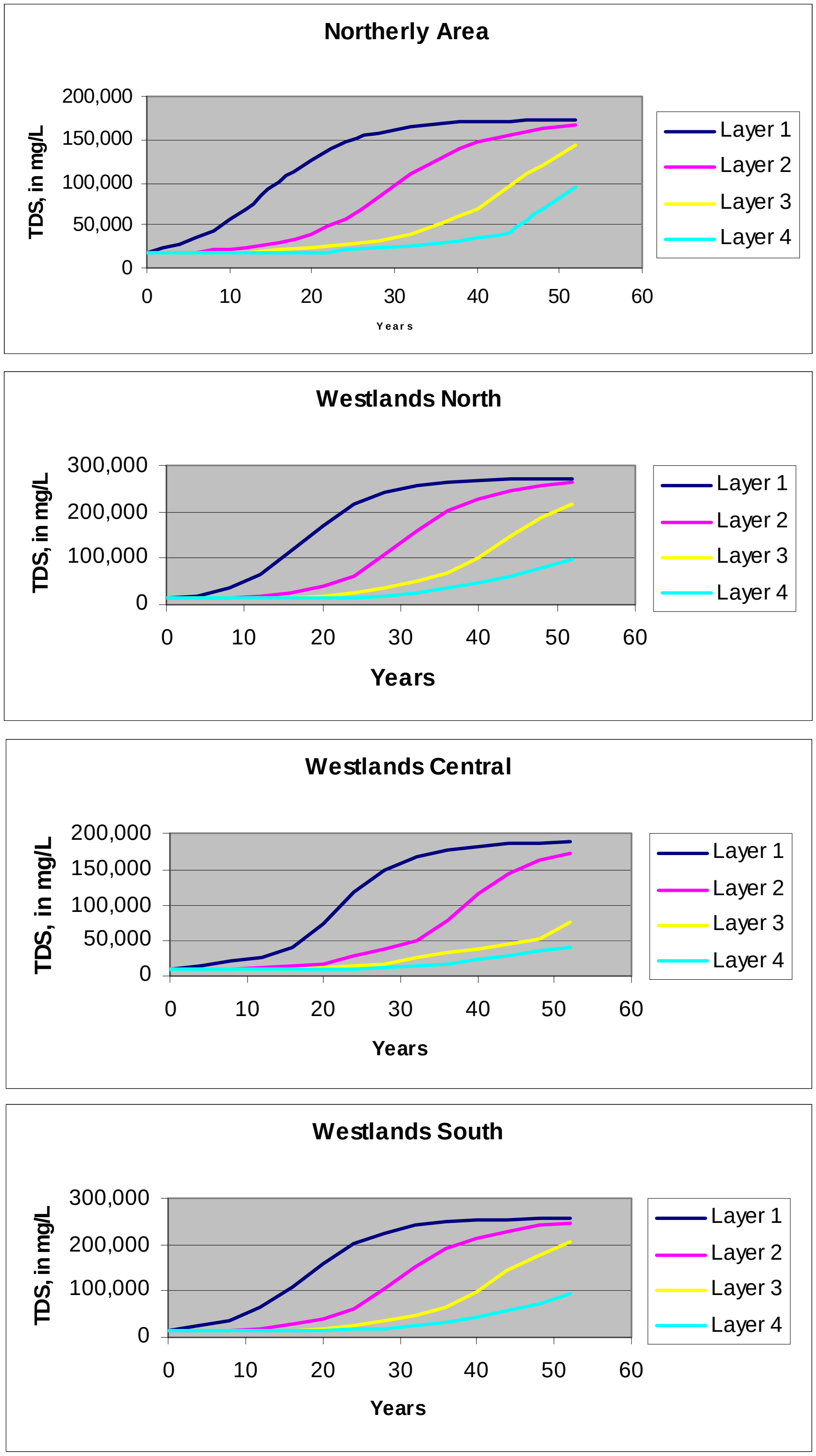

Figure E1-1
Estimated Total Dissolved Solids Concentrations in Groundwater Underlying Evaporation Basins

For reduced seepage rates, groundwater quality is less affected. For varying seepage rate reductions, Table E1-2 shows the maximum salinity in groundwater underlying the proposed basins by model layer after 52 years. Some degradation of the groundwater quality occurs for all layers for 0, 25, and 50 percent seepage-rate reductions. For the 90 percent seepage-rate reduction, only the groundwater quality in model layers 1 and 2 are degraded. By way of example, Figure E1-2 shows the salinity increase for the Northerly Area for reduced seepage rates.

Table E1-2
Model-Estimated 52-Year Groundwater Dissolved Solids Concentrations (mg/L) for Varying Seepage Rate Reductions

Evaporation Basin Area and Layer	Seepage Rate Reductions 0 % (1 ft/yr)	25 % (0.75 ft/yr)	50 % (0.5 ft/yr)	90 % (0.1 ft/yr)	Estimated Original Groundwater Concentration
Northerly Area – Layer 1	172,199	167789	146,334	27,701	18,000
Layer 2	165,488	131,571	56,075	18,000	18,000
Layer 3	142269	51,747	26,578	18,000	18,000
Layer 4	94,833	29,600	20,166	18,000	18,000
Westlands North – Layer 1	274,102	265,418	216,280	15,237	15,000
Layer 2	263,920	201,199	63,151	15,000	15,000
Layer 3	217,876	70,667	24,267	15,000	15,000
Layer 4	97,664	33,389	16,445	15,000	15,000
Westlands Central – Layer 1	189,365	177,413	119,995	21,095	9,000
Layer 2	77,606	77,606	27,226	11,134	9,000
Layer 3	31,743	31,743	14,290	9,000	9,000
Layer 4	17,878	17,878	11,305	9,000	9,000
Westlands South– Layer 1	256,283	247,785	226,969	36,288	15,500
Layer 2	247,140	189,296	103,297	17,161	15,500
Layer 3	206,699	67,341	34,155	15,500	15,500
Layer 4	94,073	32,574	20,286	15,500	15,500

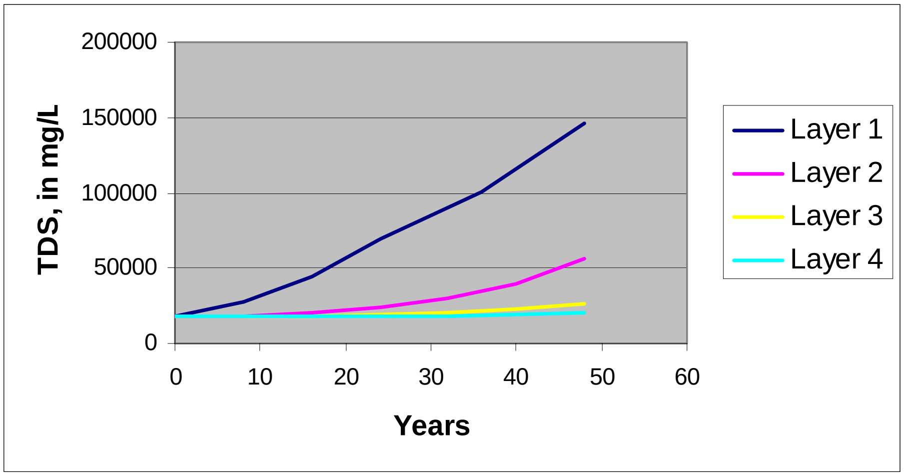

Figure E1-2
Estimated Total Dissolved Solids Concentrations in Groundwater Underlying Evaporation Basins for the Northerly Area with 50 Percent Seepage Reduction

E1.2.3 Selenium, Molybdenum, and Boron

For the 1-foot/year seepage rate and relative to salinity, smaller Se increases were estimated in groundwater underlying the proposed basins due to removal by anaerobic basin sediments and biochemical transformations (Figure E1-3). Unlike salinity, in groundwater beneath the proposed Northerly Area, Westlands North, and Westlands Central basins, Se concentrations decreased due to lower Se concentrations percolating from the evaporation basins. After 52 years, groundwater Se concentrations in all model layers decreased from 72.5 to about 30 micrograms per liter (µg/L) in the Northerly Area basin, from 37 to about 29 µg/L in the Westlands North basin, and from 65 to about 29 µg/L in the Westlands Central basin. In the Wetlands South basin Se concentrations increased from 13 to about 28 µg/L in all model layers.

For groundwater underlying all the proposed basins, increased Se reduction in basin sediments would result in less Se impacts in groundwater. In contrast to salinity changes, the changes in each layer are not dramatically different and are due to the delay in the percolating basin water reaching the different layers. Also in contrast to salinity, no mineral or biochemical controls on Se concentrations in the groundwater that would reduce the groundwater concentrations were assumed. This assumption is consistent with Deverel and Gallanthine (1989), Deverel and Fujii (1988), and Presser et al. (1990), who show that Se is not affected by biochemical reactions or mineral precipitation in this concentration range and for the oxidizing and alkaline conditions in most groundwater in the western San Joaquin Valley. For reduced seepage rates, Table E1-3 shows Se concentration increases in groundwater underlying the proposed basins in all model layers in the Northerly Area, Westlands North, and Westlands Central basins relative to the initial seepage rate. For the 90 percent seepage rate reduction, Se concentration in these three basins decreased in model layer 1 relative to the original groundwater Se concentration. Only the Westlands Central basins showed a reduction in Se concentration in model layer 2 using the 90 percent seepage rate reduction. For groundwater underlying the proposed Westlands South area basins, reduced seepage resulted in reduced groundwater Se concentrations relative to the original concentrations.

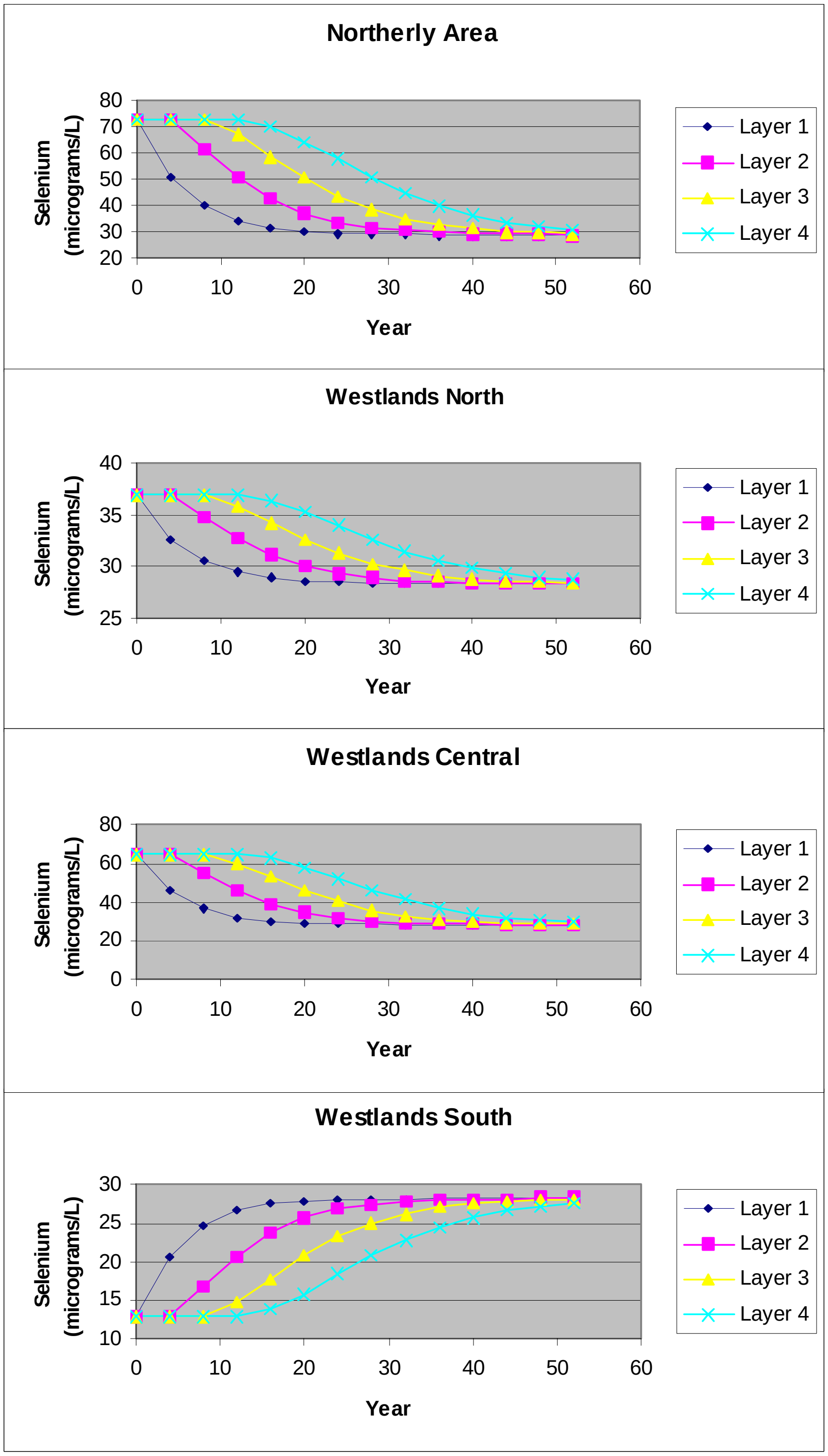

Figure E1-3
Estimated Selenium Concentrations in Groundwater Underlying Evaporation Basins

Table E1-3
Model-Estimated 52-Year Groundwater Selenium Concentrations (µg/L) for Varying Seepage Rate Reductions

Evaporation Basin Area and Layer	Seepage Rate Reductions				
	0 % (1 ft/yr)	25 % (0.75 ft/yr)	50 % (0.5 ft/yr)	90 % (0.1 ft/yr)	Estimated Original Groundwater Concentration
Northerly Area – Layer 1	29	29	30	51	72.5
Layer 2	29	30	34	73	72.5
Layer 3	29	35	44	73	72.5
Layer 4	31	45	58	73	72.5
Westlands North – Layer 1	28	28	29	32	37
Layer 2	28	28	29	36	37
Layer 3	28	29	31	37	37
Layer 4	29	30	34	37	37
Westlands Central – Layer 1	28	28	28	36	65
Layer 2	28	29	30	55	65
Layer 3	29	30	36	65	65
Layer 4	30	34	46	65	65
Westlands South – Layer 1	28	28	28	25	13
Layer 2	28	28	27	17	13
Layer 3	28	27	25	13	13
Layer 4	28	26	23	13	13

Figure E1-4 shows estimated molybdenum concentration changes in groundwater underlying the proposed basins. Concentrations initially increased rapidly in groundwater underneath the Northerly Area basins due to large molybdenum concentrations in the percolating basin waters relative to estimated initial groundwater concentrations. As basin water concentrations leveled off during the latter part of the simulation period, groundwater molybdenum concentrations also leveled off. Overall, molybdenum concentrations increased from 40 to about 4,370 (layer 4) and 5,090 (layer 1) µg/L in 52 years. Underneath the Westlands North basin, groundwater concentrations increased from 100 to 1,430 (layer 4) and 1,700 (layer 1) µg/L. In Westlands Central, groundwater concentrations increased from 140 to 1,970 (layer 4) and 2,160 (layer 1) µg/L. In Westlands South, groundwater concentrations increased from 530 to 3,960 (layer 4) and 4,300 (layer 1) µg/L. Concentrations increased due to increasing evaporative concentration and increased concentrations in the evaporation basins. Similar to Se and consistent with Deverel and Millard (1988), molybdenum was not assumed to be subject to mineral or biochemical changes in groundwater within the measured and simulated concentration range. As described above, 36 percent of the molybdenum in the basin water was assumed to be removed during percolation through the basin sediments. Lower groundwater molybdenum concentrations would have resulted from increased removal (up to 50 percent) based on references cited above.

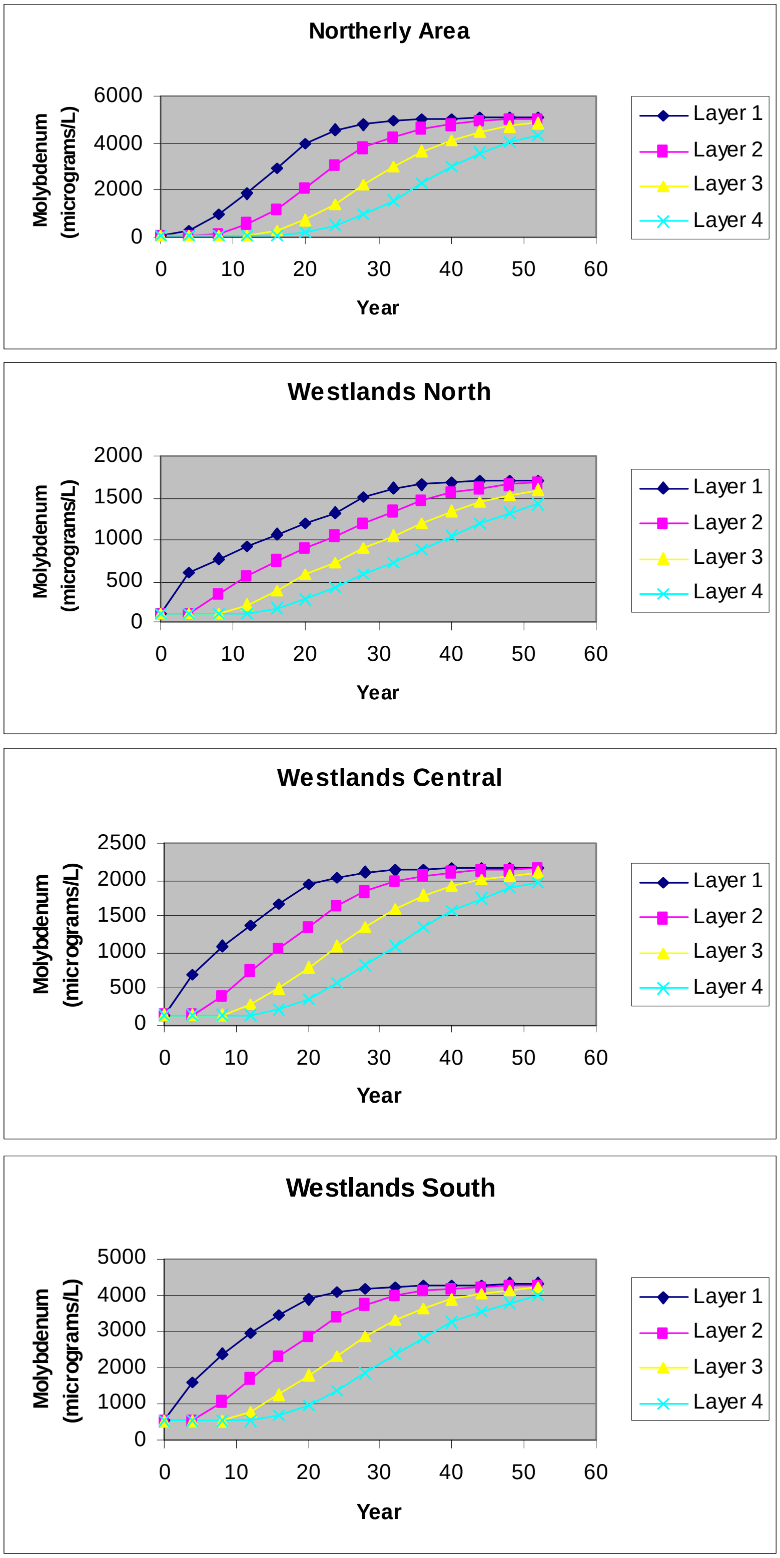

Figure E1-4
Estimated Molybdenum Concentrations in Groundwater Underlying Evaporation Basins

For lower seepage rates, Table E1-4 shows lower simulated molybdenum concentrations groundwater underlying the proposed basins in all model layers. For the 90 percent seepage reduction rate, molybdenum concentrations increased in layer 1 and layer 2 relative to the original groundwater molybdenum concentration.

Table E1-4
Model-Estimated 52-Year Groundwater Molybdenum Concentrations (µg/L) for Varying Seepage Rate Reductions

Evaporation Basin Area and Layer	Seepage Rate Reductions				
	0 % (1 ft/yr)	25 % (0.75 ft/yr)	50 % (0.5 ft/yr)	90 % (0.1 ft/yr)	Estimated Original Groundwater Concentration
Northerly Area – Layer 1	5,090	5060	4551	278	40
Layer 2	5,048	4,830	3,040	140	40
Layer 3	4,864	4,148	1,426	40	40
Layer 4	4,372	2,983	490	40	40
Westlands North – Layer 1	1,703	1,682	1,319	773	100
Layer 2	1,680	1,568	1,043	346	100
Layer 3	1,599	1,334	731	100	100
Layer 4	1,428	1,037	420	100	100
Westlands Central – Layer 1	2,161	2,153	2,106	1,080	140
Layer 2	2,151	2,101	1,875	420	140
Layer 3	2,106	1,925	1,367	140	140
Layer 4	1,975	1,375	829	140	140
Westlands South – Layer 1	4,302	4,288	4,197	2,366	530
Layer 2	4,284	4,189	3,734	1,063	530
Layer 3	4,200	3,868	2,859	530	530
Layer 4	3,961	3,229	1,859	530	530

Figure E1-5 shows substantial simulated boron concentration increases. After 52 years, groundwater concentrations increased from 17.5 mg/L to 36.9 (layer 1) and 37.3 (layer 4) mg/L in the Northerly Area, from 17.5 mg/L to 59.5 (layer 1) and 53.8 (layer 4) mg/L in Westlands North, from 7.5 mg/L to 36.6 (layer 1) and 32.8 (layer 4) mg/L in Westlands Central, and from 15.5 mg/L to 45.2 (layer 1) and 41.5 (layer 4) mg/L in Westlands South. The decrease in boron concentrations followed by decreasing concentrations during the first 20 years of basin operation was due to projected decreases in boron concentrations for basin inflows. In contrast to Se and molybdenum, no evidence exists for boron removal in evaporation basin sediments. Also, consistent with Deverel and Millard (1988) and our geochemical calculations, there do not appear to be mineral or biochemical controls on boron concentrations in groundwater. For lower seepage rates, Table E1-5 shows lower simulated boron concentrations in all model layers in groundwater underlying basins for lower seepage rates. For the 90 percent seepage reduction rate, boron concentrations in layers 3 and 4 did not change relative to the original groundwater boron concentrations.

Table E1-5
Model-Estimated 52-Year Groundwater Boron Concentrations (mg/L) for Varying Seepage Rate Reductions

Evaporation Basin Area and Model Layer	Seepage Rate Reduction				
	0 % (1 ft/yr)	25 % (0.75 ft/yr)	50 % (0.5 ft/yr)	90 % (0.1 ft/yr)	Estimated Original Groundwater Concentration
Northerly Area – Layer 1	36.9	37	38	18	17.5
Layer 2	37	37	39	18	17.5
Layer 3	37.2	38	36	18	17.5
Layer 4	37.3	36	29	18	17.5
Westlands North – Layer 1	59.5	59	57	33	17.5
Layer 2	59.1	57	49	22	17.5
Layer 3	57.6	52	38	18	17.5
Layer 4	53.8	44	29	18	17.5
Westlands Central – Layer 1	36.6	36	35	15	7.5
Layer 2	36.4	35	30	9	7.5
Layer 3	35.4	32	21	7.5	7.5
Layer 4	32.8	25	14	7.5	7.5
Westlands Central – Layer 1	45.2	45	44	24	15.5
Layer 2	45	44	39	17	15.5
Layer 3	44	40	30	15.5	15.5
Layer 4	41.5	34	23	15.5	15.5

For lower seepage rates, Table E1-4 shows lower simulated boron concentrations in all model layers in groundwater underlying basins in all three areas. For the 90 percent seepage reduction rate, boron increased only in model layers 1 and 2.

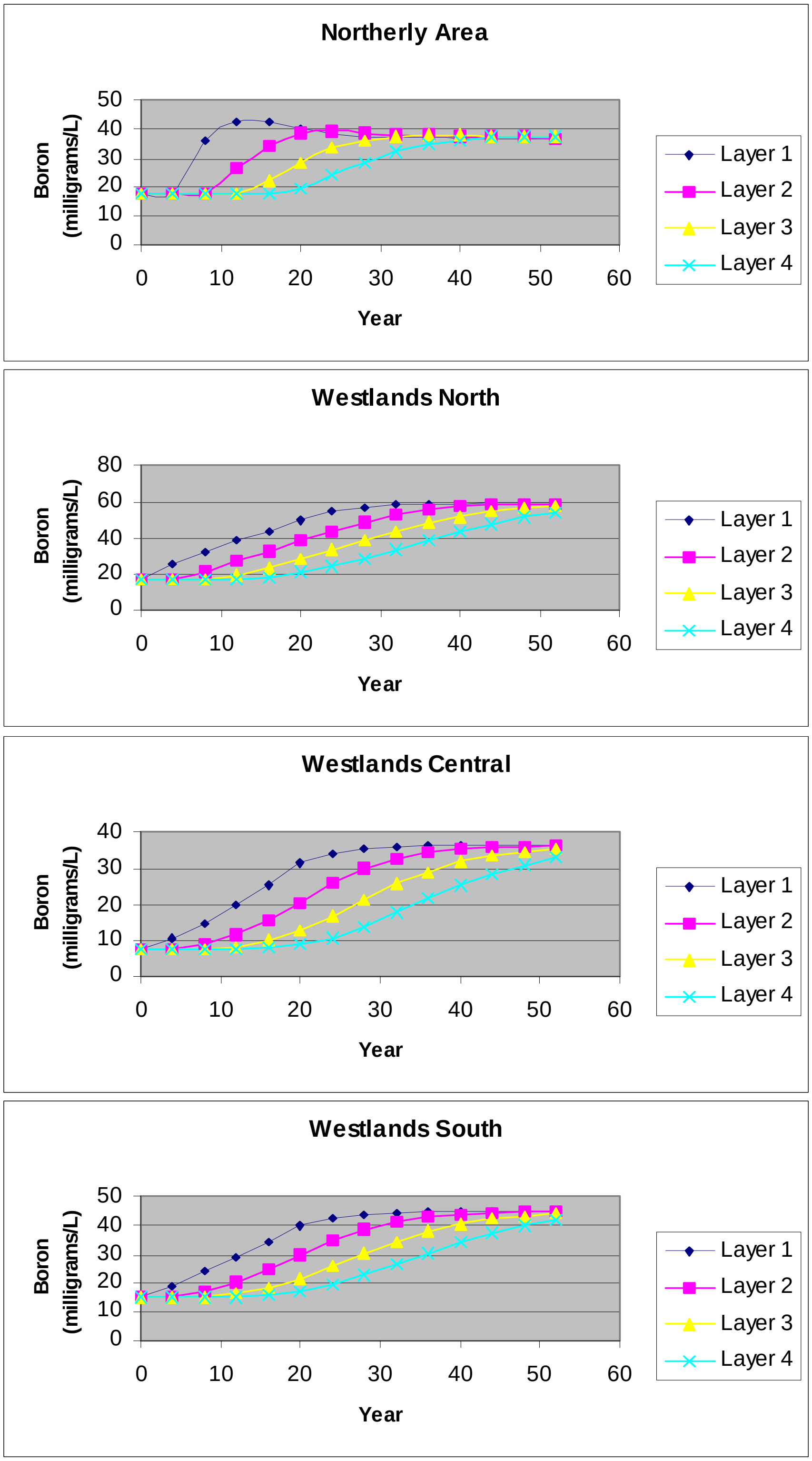

Figure E1-5
Estimated Boron Concentrations in Groundwater Underlying Evaporation Basins

E1.2.4 Lateral Groundwater Flow and Seepage onto Adjacent Land

Using the model developed from the Belitz et al. (1993) model, water-level increases on adjacent land were estimated. The predicted water level rise decreased with distance from the basins. At 700 feet of the edge of the basins, the predicted average water level rise was 0.65 foot. At 2,500 feet, the average water level rise was 0.46 foot. At 3,500 feet, the average water level rise was 0.25 foot. Using particle tracking (Pollock 1994), groundwater was estimated to travel an average of 500 feet/year in the upper 50 feet of the saturated zone or about 20,000 feet downgradient from the basins. These figures represent maximum distances as reduced seepage rates would decrease groundwater velocities and net lateral movement.

E1.3 SUMMARY

Our geochemical and mass balance calculations indicate that salinity, Se, molybdenum, and boron concentrations will increase or decrease to varying degrees in groundwater underlying evaporation basins. A summary of our methods and results follows.

E1.3.1 Methods

- Initially, 1 foot/year of evaporation basin water was estimated to percolate to the groundwater during 52 years.
- Based on the literature and data for evaporation bottom sediments in the San Joaquin Valley, seepage was determined to be reduced by mineral precipitation, increasing pH, and accumulation of microbial sludge.
- Initial groundwater concentrations came from kriging of well sample analysis conducted during the mid-1980s.
- Thermodynamic equilibrium and mass balance calculations were used to estimate changes in groundwater quality underlying evaporation basins in the Northerly Area, Westlands North, Westlands Central, and Westlands South.
- 50 and 36 percent of the Se and molybdenum in evaporation basin water were assumed removed by basin sediments prior to reaching the groundwater.
- A model developed from the Belitz et al. (1993) model was used to estimate lateral groundwater movement within 50 feet of land surface. To estimate seepage onto adjacent lands, boundary conditions and input parameters from the Belitz et al. model and other sources were used to develop a more finely discretized groundwater flow model.

E1.3.2 Results

- For a 1-foot/year seepage rate and 52 years after initial basin operation startup, large salinity increases (9.6-fold in the Northerly Area, 16-fold in Westlands South, 18-fold in Westlands North, and 21-fold in Westlands Central) were estimated in model layer 1 (0- to 10-foot saturated depth interval). Higher evaporation basin influent concentrations in later years contributed to the larger increase in the groundwater below the Westlands basins.

- In the 30- to 40-foot depth interval (model layer 4) and after 52 years, salinity concentrations increased 4.6-fold in Westlands Central, 5.3-fold in the Northerly Area, 6.1-fold in Westlands South, and 6.5-fold in Westlands North.
- After 52 years, groundwater Se concentrations in all model layers decreased from 72.5 to about 30 µg/L in the Northerly Area basin, from 37 to about 29 µg/L in the Westlands North basin, and from 65 to about 29 µg/L in the Westlands Central basin. In the Wetlands South basin Se concentrations increased from 13 to about 28 µg/L in all model layers.
- After 52 years, molybdenum concentrations in groundwater underlying the proposed Northerly Area basin increased from 40 to about 4,370 (layer 4) and 5,090 (layer 1) µg/L in 52 years. In Westlands North, groundwater concentrations increased from 100 to 1,430 (layer 4) and 1,700 (layer 1) µg/L. In Westlands Central, groundwater concentrations increased from 140 to 1,970 (layer 4) and 2,160 (layer 1) µg/L. In Westlands South, groundwater concentrations increased from 530 to 3,960 (layer 4) and 4,300 (layer 1) µg/L.
- After 52 years, boron concentrations in groundwater increased from 17.5 mg/L to 36.9 (layer 1) and 37.3 (layer 4) mg/L in the Northerly Area, from 17.5 mg/L to 59.5 (layer 1) and 53.8 (layer 4) mg/L in Wetlands North, from 7.5 mg/L to 36.6 (layer 1) and 32.8 (layer 4) mg/L in Westlands Central, and from 15.5 mg/L to 45.2 (layer 1) and 41.5 (layer 4) mg/L in Westlands South.
- For reduced seepage rates of 0.1, 0.5, and 0.75 foot/year, reduced groundwater quality impacts were estimated. Some degradation of the groundwater quality occurs for all layers for 0, 25, and 50 percent seepage-rate reductions. For the 90 percent seepage-rate reduction, the groundwater quality changes are generally limited to model layers 1 and 2.
- Using the Belitz et al. (1993) groundwater flow model, average water-level rises were predicted as follows: 0.65 foot at 700 feet of the edge of the basins, 0.46 foot at 2,500 feet, and 0.25 foot at 3,500 feet. Groundwater was estimated to travel an average of 500 feet/year in the upper 50 feet of the saturated zone or about 20,000 feet downgradient from the basins.

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APPENDIX E2

RESULTS OF GROUNDWATER SAMPLING IN WESTERN SAN JOAQUIN VALLEY, AUGUST 2002

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Acronyms

LCS	laboratory control sample
LCSD	laboratory control sample duplicate
mg/L	milligram(s) per liter
MS	matrix spike
MSD	matrix spike duplicate
QA/QC	quality assurance/quality control
RPD	relative percent difference
Westlands	Westlands Water District

E2.1 INTRODUCTION AND BACKGROUND

Estimates of drainwater chemical composition are critical for determining future drainage loads. For Westlands Water District (Westlands), recent drainwater quality data are generally lacking. The most recent shallow groundwater quality data for Westlands were collected by the U.S. Geological Survey in 1984 and 1987 (Deverel et al. 1984; Deverel and Gallanthine 1989). More recent drainwater quality data are available (Thad Bettner, Westlands, pers. comm., 2002). However, since drainage systems have not operated in Westlands since 1985, drain data are difficult to interpret. Also, drainwater quality is available only for Westlands North. Concentrations of salt and trace Results of Groundwater Sampling In Western San Joaquin Valley, August 2002 elements in shallow groundwater will be used to estimate drainwater concentrations for most of Westlands.

Land and water management practices changed since the 1980s. The area of fallow land and shallow groundwater levels changed. These changes may have caused shallow groundwater concentrations to change. The primary objective of the August 2002 groundwater sampling and analysis was to determine how groundwater concentrations of selenium, boron, and molybdenum and salinity may have changed since the mid-1980s.

Results of groundwater sampling in the mid-1980s (Deverel et al. 1984; Deverel and Millard 1988; Deverel and Gallanthine 1989) illustrated the processes affecting concentrations of dissolved solids, selenium, and other trace elements in shallow groundwater. Deverel and Millard (1988) elucidated the effects of geologic origin on groundwater sample composition. They delineated valley sediments into the alluvial fan and basin-trough geologic zones that are of Coast Range and mixed Coast Range and Sierra Nevada origin, respectively. The mobile oxyanions boron and molybdenum were significantly correlated with salinity and appear equally present in both geologic zones. Selenium was more enriched and was strongly correlated with salinity in the alluvial fan zone.

Deverel and Gallanthine (1989) collected additional samples and further examined processes affecting selenium concentrations in the alluvial-fan-zone shallow groundwater. They concluded that shallow groundwater occurring in small ephemeral stream alluvial fans and at the margins of major perennial-stream alluvial fans (e.g., Cantua, Panoche, and Los Gatos creek alluvial fans) had the highest selenium and dissolved solids concentrations. These are recently irrigated areas where saline soils historically predominated. This groundwater was subject to evaporative concentration from a shallow water table near the valley axis. In the absence of drainage in Westlands, concern exists about rising groundwater levels and resultant increasing groundwater selenium concentration and salinity due to evaporative concentration. Most shallow (within 50 feet of land surface) groundwater in western San Joaquin Valley is chemically oxidized and selenium is in the selenate (+6 valence) form.

E2.2 METHODS

Deverel et al. (1984) was used to identify over 60 wells throughout Westlands that were sampled in 1984. Each site was then visited to determine if the well still existed. If a well was at the correct location, an attempt was made to determine if the well was the same well sampled in 1984. Most of the wells are marked with the California well number listed in Deverel et al. (1984). In many cases, the state well numbers were different than listed in Deverel et al. (1984)

indicating that wells were replaced. Many of the wells no longer exist. With a high degree of certainty, 21 wells from Deverel et al. (1984) were identified for sampling from Firebaugh to the Kings County line. One well was dry, so a total of 20 wells were actually sampled (Figure E2-1).

Using a high pressure water jet, the wells were installed by the Bureau of Reclamation in the 1960s, 1970s, and 1980s to depths of 18 to 30 feet by hydraulically forcing the well casing into the subsurface. The casing is 1- to 1.25-inch-diameter polyvinyl chloride tubing slotted along the entire length. The well casings were capped at the bottom and annular spaces filled in with saturated soil that sloughed around the well.

During the week of August 6, 2002, the wells were sampled for the constituents shown in Table E2-1. The wells were sampled according the following protocol:

1. At least three casing volumes were pumped from each well. Wells were pumped until temperature and conductivity did not vary more that 10 percent for two consecutive casing volumes. Wells were sampled with peristaltic pumps using Teflon tubing. Tubing was dedicated for each well and was left in the well after sampling was completed.
2. If the well was pumped dry, it was allowed to recover and then samples were collected.
3. Temperature, pH, and conductivity were recorded for each well. Information was also recorded about meter calibration, well development, samples collected, pH, conductivity, and temperature for each casing volume, land use, and any irrigation occurring adjacent to the well.
4. All sampling apparatus was rinsed thoroughly with deionized water after sampling and well water before sampling. Sample containers were rinsed three times with well water.
5. Samples for determination of selenium molybdenum, boron, and other trace elements and major cations were filtered through 0.45-micrometer cellulose-nitrate filters and then acidified to less than pH 2 with concentrated nitric acid in 250-milliliter polyethylene bottles. Samples for determination of chloride and sulfate were filtered into 250-milliliter plastic bottles but not acidified. Alkalinity was determined on unfiltered samples.
6. Duplicate samples were collected for quality control at four locations and submitted with false site identifications.

Samples were analyzed by Weck Laboratories, City of Industry, California, by methods shown in Table E2-1.

The results were analyzed using standard statistical and graphical methods. Regression and nonparametric statistical methods were used to evaluate differences between geologic zones and the 1984 and 2002 samplings, and the relationships among variables. For these analyses, analytical nondetects were set to a value midway between zero and the detection limit. Because the concentrations and electrical conductivity are lognormally distributed, the log values of the concentrations were used for regression analyses. To examine possible land use and hydrologic changes, groundwater levels for the two sampling events were also compared.

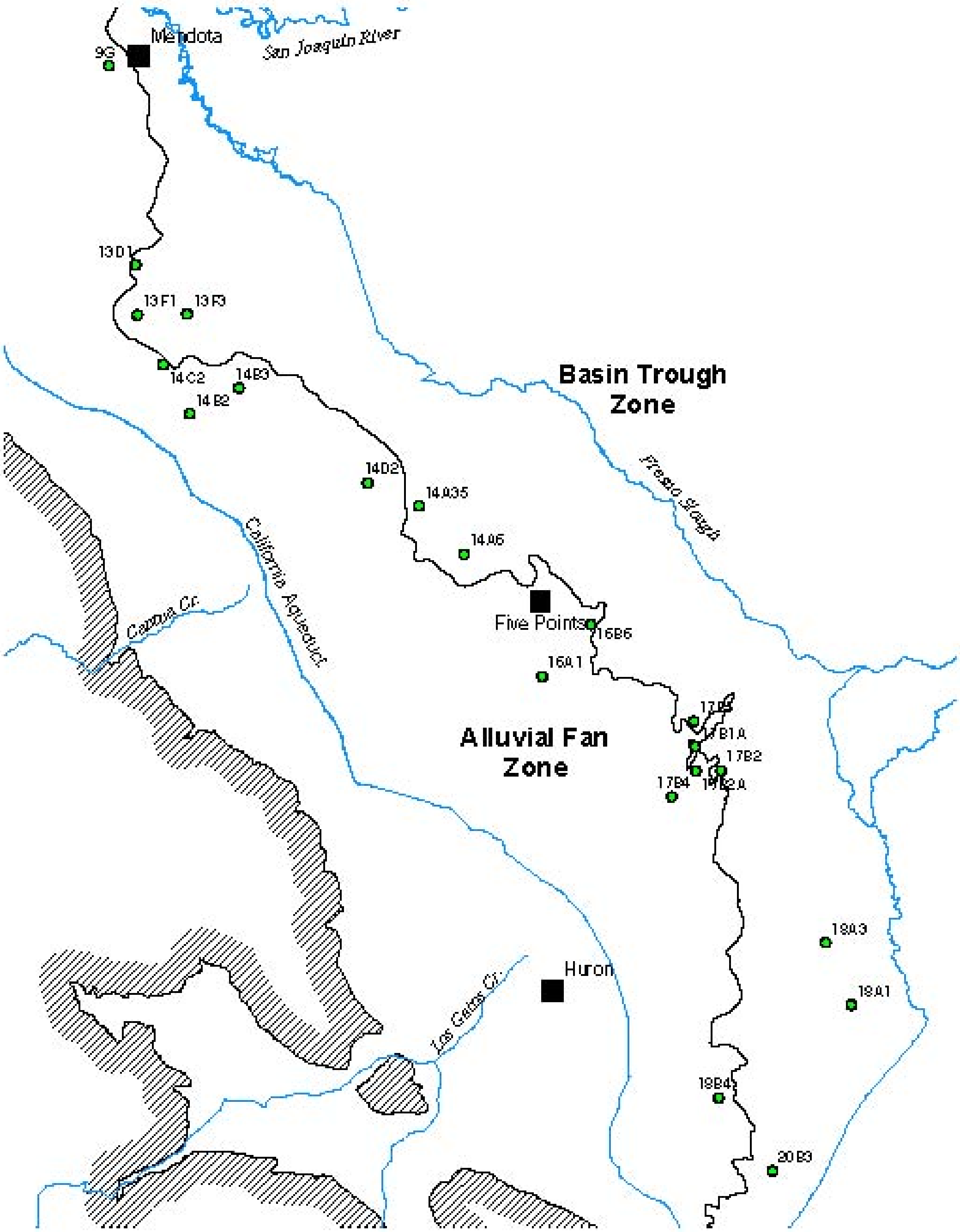

Figure E2-1
Location of Wells and Geologic Boundary (Black Line)

Table E2-1
List of Constituents and Methods of Analysis

Analyte	Method of Analysis
Selenium	Inductively coupled plasma/mass spectrophotometery with hydride generation (EPA Method 200.8)
Molybdenum, arsenic, aluminum, barium, beryllium, cadmium, chromium, calcium, magnesium, sodium, potassium, copper and iron, manganese, silica	Inductively coupled plasma and mass spectrophotometery (EPA Methods 200.7 and 200.8)
Chloride, sulfate	Ion chromatography (EPA Method 300)
Alkalinity	Acid titration (EPA Method 2320B)
Dissolved solids	Residue upon evaporation

E2.3 RESULTS

E2.3.1 Differences Between Sampling Events

Figure E2-1 shows the locations of the sampled wells relative to the alluvial fan and basin-trough geologic zones (Mathews and Burnett 1965). Eleven wells were in the basin-trough zone and nine were in the alluvial fan zone.

Attachment E2-1 shows the analytical results for the samples for both sampling events. Analysis of sample quality assurance and control (see Attachment E2-2) indicated acceptable results for all samples and constituents of concern. Figure E2-2 shows the graphical comparison between sampling events. Figure E2-2 generally indicates little concentration change between sampling events for boron, molybdenum, or electric conductivity. While region-wide changes were not observed for selenium, large changes were measured in several wells as discussed below. Figure E2-3 shows the comparison of the depth to groundwater in wells for the two sampling events. The Wilcoxon rank sum test was used for possible differences between sampling events for concentrations of selenium, molybdenum, boron, and salinity as represented by electrical conductivity and depth to groundwater. For all constituents of concern, no statistically significant (alpha = 0.05) differences existed between sampling events. Differences between samplings for other constituents listed in Attachment E2-1 were also tested. No differences occurred between constituents where detection limits and censored values were comparable between samplings. Statistically significant differences occurred for arsenic, iron, copper, and zinc. However, large numbers of censored values and detection limits were different, making comparison difficult.

The water table was significantly deeper (alpha = 0.05) for the 2002 sampling event. Examination of depth to groundwater relative to land use for individual samples provides further insight. During the May 1984 sampling, most of the areas surrounding the sampled wells were actively farmed. In August 2002, in the middle of the growing season, the areas surrounding 12 wells were fallow or partially fallow, and the surrounding areas were fully cropped for 6 wells. For the remaining 2 wells, land use was not recorded. The mean increase in depth to groundwater was 3.03 feet for the wells surrounded by fallow or partially fallow land, and 0.21 foot for wells surrounded by cropped land (Figure E2-3). Under irrigated and fully cropped conditions, groundwater levels were expected to increase from May to August during the irrigation season (Deverel and Fio 1991; Lieghton et al. 1991).

The observed water-level decrease is consistent with modeling results and data from the Bureau of Reclamation’s land-retirement project (Belitz and Phillips 1992; Bureau of Reclamation 2000), indicating significant water table declines under fallowed and unirrigated lands. Also, continued groundwater pumping for water supply in Westlands has probably contributed to increased water table depths. Land fallowing and pumping probably prevented significant increased groundwater salinization that may have otherwise occurred due to rising groundwater levels.

Differences in selenium concentrations between sampling events appear related to groundwater movement and land use. Large decreases in selenium and salinity were measured in four samples; 17B1A, 17B2, 18A3, and18B4 (Figure E2-2, Attachment E2-1). The latter three wells were surrounded by cropped land and all are in the southeastern part of Westlands. Sufficient downward groundwater movement may have allowed for displacement of high salinity water by lower salinity irrigation water. Laudon and Belitz (1991) and Deverel and Gallanthine (1989) identified this area as having a greater proportion of coarse-grained subsurface shallow deposits from the Los Gatos Creek Alluvial Fan, which may contribute to increased vertical groundwater movement.

A large increase in selenium was measured in well 13F1; the 1984 concentration was less than detectable and the 2002 concentration was 1,300 micrograms per liter (Figure E2-2). This well is located in the basin-trough geologic zone, close to the alluvial-fan zone boundary. The increase is probably due to observed groundwater movement from southwest to northeast from the selenium-enriched alluvial-fan geologic zone to the basin-trough zone. Assessment of geochemical interrelationships provides further insight about processes affecting concentrations.

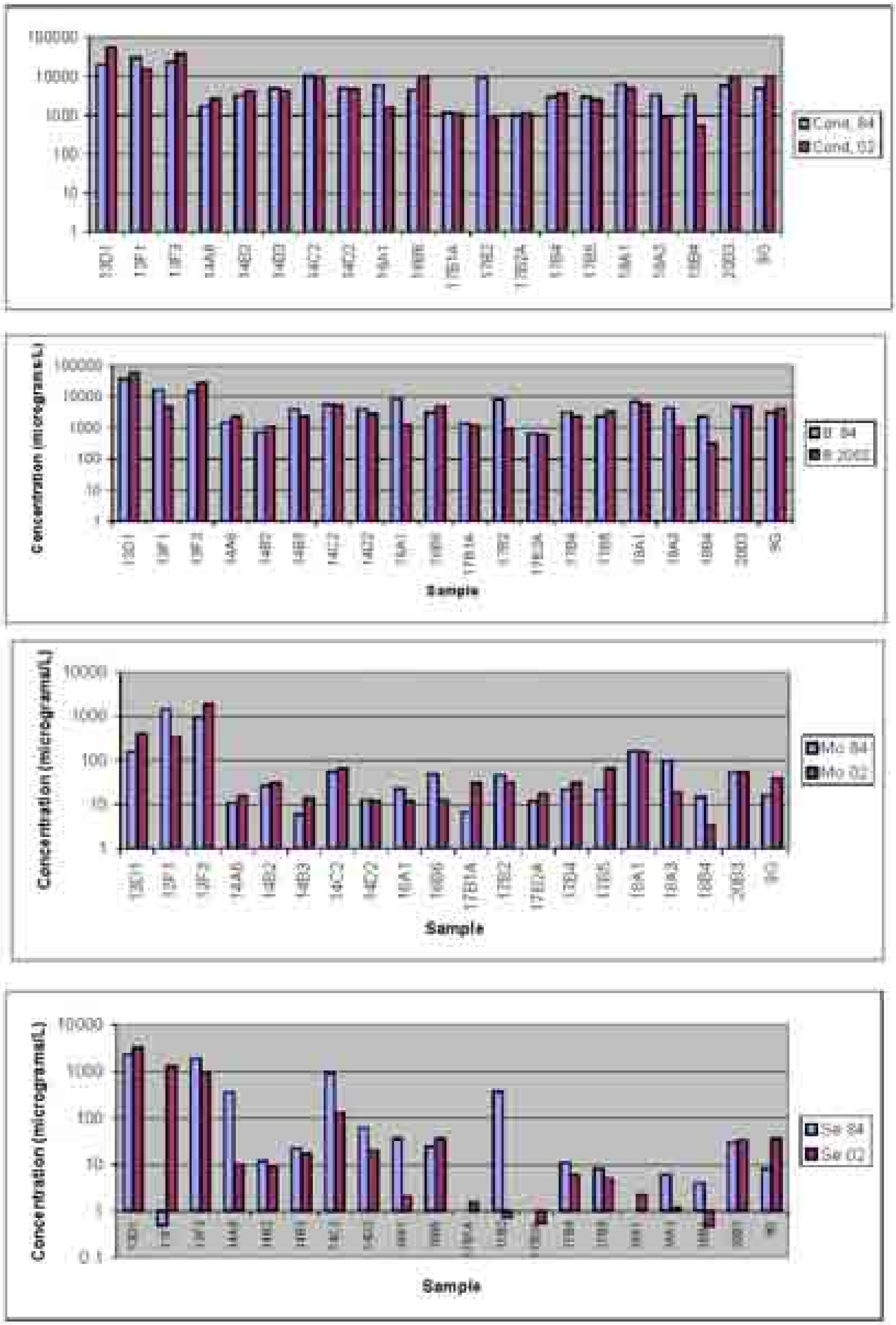

Figure E2-2
Comparison of Electrical Conductivity and Concentrations of Boron, Molybdenum, and Selenium Between Samplings

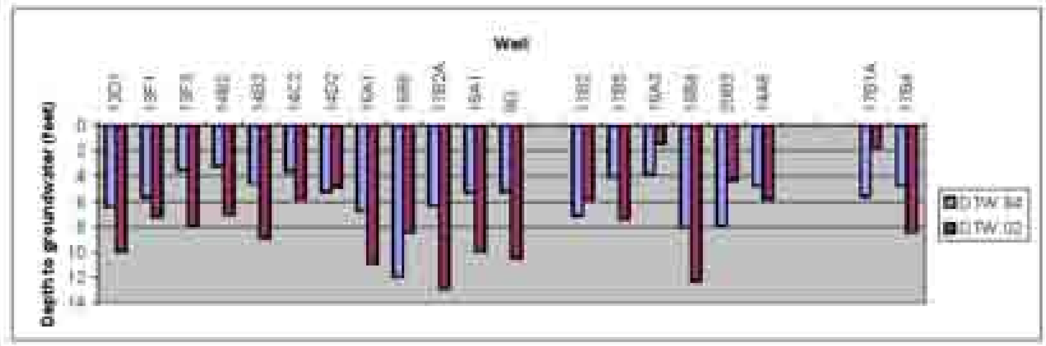

Figure E2-3
Comparison of Depth to Groundwater Between Samplings

E2.3.2 Geochemical Interrelationships

Deverel and Millard (1988) reported the results of regression analysis for logarithms of concentrations of boron, molybdenum, and selenium. We performed the same analysis. A comparison of the analyses is shown in Table E2-2.

Table E2-2
Results of Regression Analysis

Correlation	Correlation Coefficient, Alluvial Fan Zone	Correlation Coefficient, Basin-Trough Zone	Slope/Intercept, Alluvial Fan Zone	Slope/Intercept, Basin-Trough Zone
Boron vs. electrical conductivity, this study	0.9	0.94	1.11/-1.54	0.85/0.86
Boron vs. electrical conductivity, D and M*	0.9	0.93	1.37/-3.2	1.34/-3.2
Molybdenum vs. electrical conductivity, this study	0.69	0.80	0.95/-4.9	1.1/-4.9
Molybdenum vs. electrical conductivity, D and M*	0.58	0.85	1.03/-5.9	1.37/0.17
Selenium vs. electrical conductivity, this study	0.95	0.90	2.05/-14.63	1.92/-13.36
Selenium vs. electrical conductivity, D and M*	0.79	0.44	2.10/-1.44	0.93/-6.5

*Deverel and Millard (1988)

Interrelationships between salinity as represented by electrical conductivity and boron, molybdenum, and selenium are generally similar for the two geologic zones for this study and for the two sampling events. Covariance analysis (Steel and Torrie 1960) was used to evaluate differences in the regression relationships between geologic zones. Similar to Deverel and Millard (1988), no significant (p=0.001) difference occurred in the correlation for the boron/electrical conductivity relationship between geologic zones, but a significant difference for molybdenum did occur. Also, the selenium/salinity correlation is similar for the alluvial fan zone for the two sampling events.

In contrast to Deverel and Millard (1988), the selenium/electrical conductivity relationship was not significantly different between the two geologic zones. However, Deverel and Millard (1988) reported a high correlation coefficient for basin-trough samples collected within 1 mile of the geologic-zone boundary. Also, they reported a regression equation for selenium concentrations and salinity similar to the alluvial fan, thus indicating transport from the alluvial fan. zone to the downgradient basin-trough zone. For the 2002 sampling, the similarity of the regression relations and correlation coefficients further indicate downgradient transport of high selenium groundwater. All except two of the basin trough samples for this study were collected within 2.1 miles of the geologic boundary. The remaining two samples, 18A1 and 18A3, were collected from wells 4.4 and 3.4 miles from the boundary. Figure E2-4 shows the plots of boron, molybdenum, and selenium versus electrical conductivity.

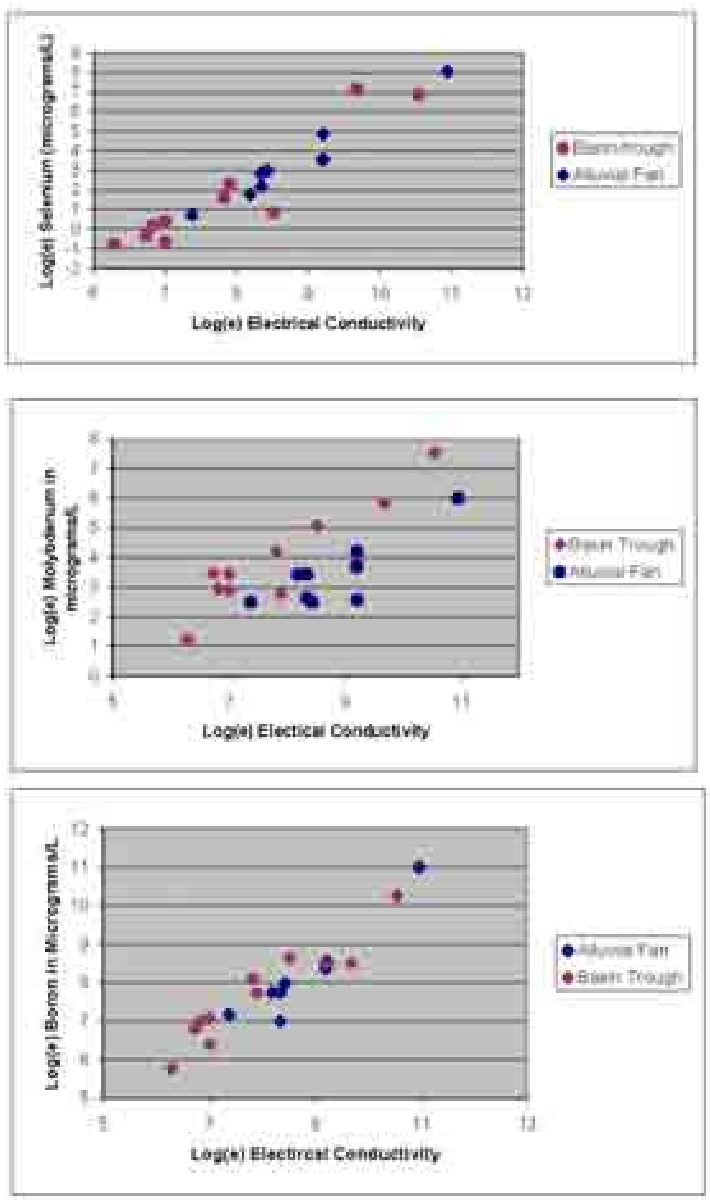

Figure E2-4
Relation of Selenium, Molybdenum, and Boron to Electrical Conductivity for 2002 Sampling

E2.3.3 Uncertainty

Although the data indicate that shallow groundwater concentrations generally did not change significantly during the 19 years since the 1984 sampling event, the location of the wells may have influenced the results. Recent litigation (*Sumner Peck et al. vs. United States)* indicated increased soil salinity and reduced crop production in Westlands. Increased soil salinity probably resulted from decreasing depth to groundwater in the absence of drainage in selected areas. All the sampled wells were on county road right-of-ways adjacent to agricultural fields. Data reported in Deverel and Fio (1991) and Leighton et al. (1991) indicate higher salinity, boron, molybdenum, and selenium concentrations in samples collected from wells located in agricultural fields relative to samples from wells located adjacent to agricultural fields. Also, water levels were generally lower in off-field wells. Higher groundwater levels in agricultural fields relative to adjacent areas may have resulted in evaporative concentration of shallow groundwater and higher concentrations not apparent in the sampled wells. This and increased groundwater and soil salinity in areas not sampled may result in higher-than-predicted loads if these areas are drained. Increased certainty in the delineation of salinity and trace element concentrations in shallow groundwater will require a more comprehensive sampling

E2.4 SUMMARY

The results of groundwater sampling conducted during August 2002 and May 1984 in Westlands were analyzed. Twenty wells located throughout Westlands were sampled. This analysis focused on possible differences among boron, molybdenum, selenium, and salinity as represented by electrical conductivity. Key conclusions follow.

- The quality of the 2002 groundwater sampling and analytical data was acceptable for the study objective.
- Results of the Wilcoxon rank sum test indicated no statically significant differences between sampling events for boron, molybdenum, selenium, or salinity as represented by electrical conductivity.
- Groundwater levels in the sampled wells were significantly deeper during the 2002 sampling.
- For wells surrounded by fallow or partially fallow land, average groundwater water levels were over 3 feet deeper during the 2002 sampling relative to 1984 sampling.
- For wells surrounded by cropped land, average groundwater levels were 0.2 foot deeper.
- Land fallowing and groundwater pumping probably caused water levels to decrease, thus preventing evaporative concentration and increased salinity and concentrations of boron, selenium, and molybdenum.
- A large increase in selenium in one well in the northwestern part of Westlands appears to be the result of groundwater movement from the Coast Range alluvial fan geologic zone to the basin-trough geologic zone.
- Decreases in selenium and salinity in wells in fully cropped areas may be the result of downward displacement of higher quality irrigation water in the southeastern part of Westlands where subsurface coarse-grained deposits appear to predominate.

- Uncertainty results from low sampling density and possible differences between groundwater quality underlying and adjacent to agricultural fields.

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Attachment E2-1

Analytical Results for Both Sampling Events

Attachment E2-1
Analytical Results for Both Sampling Events

Site	Date	pH	Electrical Conductivity mS/cm	Temperature Degrees C	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO4 mg/L	HCO3 mg/L	As mgram/L	B mgram/L	Cr mgram/L	Cu mgram/L	Cd mgram/L	Fe mgram/L	Mn mgram/L	Mo mgram/L	Pb mgram/L	Se mgram/L	Zn mgram/L
13D1	5/10/1984	7.8	19900	19	430	4.7	210	4600		10000	277	5	37000	70		< 1	140	40	160	4	ND	620
13D1	8/5/2002	7.61	57000	22.6	440	18	420	11000	4700	17000	330	15	60000	72	< 2	0.92	< 1	86	410	< 1	3200	< 10
13F1	5/17/1984	7.8	30400	19.5	460	5.5	110	8900	3100	14000	334	2	17000	75	9	< 1	140	50	1500	6	< 1	40
13F1	8/5/2002	7.48	16000	20.2	820	10	82	1800	1000	5800	220	16	4900	16	3.6	0.73	< 20	120	340	< 1	1300	< 10
13F3	5/17/1984	8	23900	18.5	480	11	130	6900	1300	13000	290	2	15000	58	9	< 1	130	20	920	8	1900	30
13F3	8/6/2002	7.71	38000	24.29	460	12	140	6200	940	11000	240	20	28000	14	< 2	2.5	< 20	220	1900	< 1	970	< 10
14A6	5/17/1984	7.6	1700	19	96	3.2	33	260	82	460	420	2	1500	12	3	< 1	15	2	11	13	360	17
14A6	8/5/2002	7.62	2700	24.3	170	5.2	50	320	120	870	220	< 10	2300	21	2.4	< .5	< 20	1	16	< 1	10	< 10
14B2	5/15/1984	7.4	3280	18.5	560	2.5	90	160	69	1800	233	1	720	< 1	3	< 1	20	10	27	1	12	10
14B2	8/5/2002	7	4200	22.32	670	4.9	80	150	68	1800	310	15	1100	< 4	4.8	< .5	< 20	35	31	< 1	9	< 10
14B3	5/15/1984	7.5	4900	19	480	8.9	250	470	160	2900	236	2	4000	6	2	< 1	30	30	6	< 1	22	10
14B3	8/6/2002	7.21	4200	22.5	420	5.7	190	110	200	1800	180	< 10	2300	< 4	2.8	< .5	86	550	14	< 1	17	< 10
14C2	5/16/1984		10200	18	480	7.1	94	2200	720	4700	236	4	5700	20	5	< 1	130	40	57	3	920	20
14C2	8/6/2002	7.53	10000	22.1	440	10	90	1300	370	3500	270	15	5200	10	< 2	< .5	< 20	49	67	< 1	130	< 10
14D2	5/17/1984	7.5	4900	18	530	1.9	200	510	230	2500	374	2	3900	70	2	< 1	30	30	13	8	62	20
14D2	8/5/2002	6.83	4600	22.05	530	5.6	160	200	110	2100	260	16	2900	17	4.4	< .5	< 20	220	12	< 1	20	< 10
16A1	5/17/1984	7.4	6010	20	430	6.7		770	300	3000	318	2	8600	60	< 10	< 1	60	130	23	< 1	36	20
16A1	8/5/2002	7.27	1600	27.29	120	2.4	46	140	85	210	390	< 10	1300	48	< 2	< .5	< 20	24	12	< 1	2.1	< 10
16B6	5/17/1984	7.8	4470	19	490	1.6	110	450	150	2400	119	< 1	3100	33	< 5	< 1	40	30	48	3	24	< 10
16B6	8/6/2002	7.25	10000	20.1	790	3.1	210	900	200	2300	220	17	5100	26	< 2	< .5	< 20	< 1	13	< 1	36	< 10
17B1A	5/17/1984	7.1	1160	18.5	120	3.3	39	120	58	99	673	82	1400	< 1	8	1	11	1200	7	< 1	1	25
17B1A	8/5/2002	7.2	1100	25.95	52	5.8	15	140	80	250	160	< 10	1200	< 4	6.6	< .5	< 20	< 1	31	< 1	1.5	< 10
17B2	5/20/1984	7.3	9180	19	550	4.5	220	1600	800	4500	280	< 1	8100	< 1	1	< 1	50	20	47	< 1	370	< 10
17B2	8/6/2002	7.44	840	24.4	33	2.7	7.6	110	85	130	160	< 10	900	< 4	< 2	< .5	< 20	< 1	32	< 1	0.72	< 10
17B2A	5/17/1984	7.6	1010	19.5	73	2.1	24	130	49	160	373	2	660	5	9	< 1	12	2	12	4	1	29
17B2A	8/6/2002	6.87	1100	20.5	77	1.5	25	100	92	250	190	< 10	600	< 4	< 2	< .5	< 20	2.9	18	< 1	0.53	< 10
17B4	5/18/1984	7.6	3020	19.5	210	1	62	370	230	1000	333	1	3200	40	2	< 1	50	< 10	22	< 1	11	< 10
17B4	8/6/2002	7.16	3600	21.51	280	1.5	94	300	180	1200	180	< 10	2300	25	< 2	< .5	< 20	< 1	31	< 1	5.9	< 10
17B5	5/17/1984	7.5	3050	19	440	6	110	230	42	1800	216	2	2300	4	15	< 1	100	80	22	< 5	8	10
17B5	8/5/2002	7.14	2500	22.5	150	2.5	82	260	84	820	250	< 10	3300	14	< 2	< .5	< 20	28	67	< 1	5	< 10
18A1	5/18/1984	7.5	6450	22	490	4.3	110	1100	300	3500	247	3	7100	4	3	< 1	30	340	170	1	1	20
18A1	8/6/2002	7.36	5000	22.3	600	3.2	98	380	120	2200	240	14	5600	< 4	5.1	< .5	< 20	660	160	< 1	2.3	< 10
18A3	5/19/1984	7.6	3290	20	380	2	110	260	64	2000	187	1	4400	9	1	< 1	30	10	100	< 1	6	10
18A3	8/6/2002	7.56	920	25	64	4.7	19	79	110	84	200	< 10	1100	< 4	6.1	< .5	< 20	2	19	< 1	1.2	< 10
18B4	5/17/1984	7.5	3300	21	290	1.1	48		97	3300	420	< 1	2300	20	2		60	30	15	3	4	10
18B4	8/6/2002	7.75	540	24.4	30	2.6	10	53	62	36	140	< 10	320	< 4	2.5	< .5	60	2.7	3.4	< 1	0.46	< 10
20B3	5/18/1984	7.7	5800	19.5	560	11	69	930	370	2800	175	< 1	4900	40	4	< 1	60	30	55	8	30	20
20B3	8/6/2002	7.4	10000	23.3	630	6.2	110	1100	1300	2500	240	15	4800	21	< 2	< .5	38	230	54	< 1	34	< 10
9G	5/20/1984	7.4	4940	20	320	8.3	120	750	630	1700	475	1	3100	5	3	< 1	100	1000	16	2	8	< 10
9G	8/5/2002	7.07	9900	22.1	500	6.1	220	670	1000	1600	410	16	4300	< 4	3.5	< .5	300	900	40	< 1	36	< 10

Attachment E2-2

QA/QC Evaluation of Shallow Groundwater Sample Analyses, Western San Joaquin Valley, August 2002

INTRODUCTION AND BACKGROUND

The quality assurance/quality control (QA/QC) review process was used to evaluate the usability of the analytical data. A summary of the parameters that were reviewed as part of the QA/QC evaluation process and a brief explanation of the results follows.

QA/QC REVIEW PARAMETERS

Method Holding Times

The analytical methods used for the investigation have prescribed holding times. The method holding time is defined as the maximum amount of time after collection that a sample may be held prior to extraction and/or analysis. Sample integrity becomes questionable for samples extracted and/or analyzed outside of the prescribed holding times due to degradation and/or volatilization of the sample. The analytical results of such samples extracted and/or analyzed outside the prescribed method holding time are suspect.

Method Blanks

Method blanks are prepared in the laboratory using deionized, distilled (Reagent Grade Type II) water. Method blanks are extracted and/or analyzed following the same procedures as an environmental sample. Analysis of the method blank indicates potential sources of contamination from laboratory procedures (e.g., contaminated reagents, improperly cleaned laboratory equipment) or persistent contamination due to the presence of certain compounds in the ambient laboratory environment. The QA/QC review identifies method blanks with detections of target analytes and evaluates the effect of the detections on associated sample results.

Matrix Spikes and Laboratory Control Samples

Matrix spikes (MSs), matrix spike duplicates (MSDs), laboratory control samples (LCSs), and laboratory control sample duplicates (LCSDs) were analyzed by the laboratory to evaluate the accuracy and precision of the sample extraction and analysis procedures and to evaluate potential matrix interference. Matrix interference, the effect of the sample matrix on the analysis, may partially or completely mask the response of analytical instrumentation to the target analyte(s). Matrix interference may have a varying effect on the accuracy and precision of the extraction and/or analysis procedures, and may bias the sample results high or low.

The MS or MSD samples were prepared by adding a known quantity of the target compound(s) to a sample. The samples were then extracted and/or analyzed as a typical environmental sample and the results are reported as percent recovery.

The spike percent recovery is defined as:

$$\text{Recovery (\%)} = \frac{\text{spike analysis result - original sample concentration}}{\text{concentration of spike addition}} \text{ x100\%}$$

The MS and MSD recoveries were reviewed for compliance with laboratory-established control limits to evaluate the accuracy of the extraction and/or analysis procedures.

LCS samples were prepared exactly like MS samples using a clean control matrix rather than an environmental sample. Typical control matrices include Reagent Grade Type II water and clean sand. LCSs and LCSDs are used to evaluate laboratory accuracy independent of matrix effects.

The QA/QC review identifies spike recoveries outside laboratory control limits and evaluates the effect of these recoveries on the associated sample results.

Laboratory Duplicate Analyses

Duplicate analyses were performed by the laboratory to evaluate the precision of analytical procedures. The laboratory performed LCSD analyses. Precision is evaluated by calculating a relative percent difference (RPD) using the following equation:

$$\text{RPD (\%)} = \left| \frac{(\text{Spike Concentration} - \text{Spike Duplicate Concentration})}{\frac{1}{2}(\text{Spike Concentration} + \text{Spike Duplicate Concentration})} \right| \text{ x } 100\%$$

The RPD was compared to laboratory-established control limits to evaluate analytical precision. The QA/QC review identifies RPDs outside laboratory control limits and evaluates the effect of these recoveries on the associated sample results.

Field Duplicate Analyses

Duplicate samples were collected in the field and analyzed to evaluate the heterogeneity of the matrices. At four sites, duplicate samples were collected, processed identically and submitted to the laboratory with dummy site ID labels.

Explanation of Analytical Data Qualifiers

The qualifiers assigned to results during the QA/QC process are defined below:

J The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.

QA/QC Analysis for Major Ion Data

The following checks were preformed with the major ion (calcium, magnesium, potassium, sodium, sulfate, chloride, and bicarbonate) data. The suggested ranges are from the U.S. Geological Survey.

1. The anion-cation charge balance was calculated using the concentrations of the major anions and cations in milliequivalents per liter. The difference between the two sums was calculated as a percentage as follows.

$$\frac{Anions - Cations}{Anions + Cations} \times 100$$

Five percent was used as a guide for an acceptable percent difference.

2. The ratio of calculated sum of dissolved solids to specific conductance was calculated as the sum of dissolved solids (in milligrams per liter [mg/L]) divided by the specific conductance. This number should fall within the range 0.55 to 0.81. Values outside this range suggest an error in the analysis.
3. The ratio of the sum of reacting constituents to specific conductance was calculated by adding the reacting concentrations (in meq/L) of the cations or anions and dividing the sum by 0.01 x specific conductance. The ratio should be within the range of 0.92 to 1.24.
4. The ratio of the residue upon evaporation to the specific conductance should be within the range of 0.55 to 0.86. Samples with a high silica concentration or a high organic content may have ratios higher than 1.0 in some cases.

RESULTS OF QA/QC REVIEW

Holding Times and Method Blanks

Total dissolved solids holding times were exceeded by at least two times for all samples. As a result of this discrepancy all total dissolved solids results were qualified as estimated and flagged with a "J". Holding times were not exceeded for any other analysis. Method blanks did not reveal any laboratory contamination.

Laboratory Control Samples and Matrix Spike Samples

All LCS sample spikes percent recoveries were within the established range. Four sets of MS and MSD were analyzed for selenium, and three sets were analyzed for selected trace elements (beryllium, aluminum, chromium, manganese, nickel, copper, zinc, molybdenum, silver, cadmium, barium, and lead). For all except two of the trace element MS analyses, percent recoveries ranged from 80.4 to 114 and were well within the established limits. For the two remaining analyses, percent recoveries for manganese in sample 14B3 were 54 and 82, while percent recoveries were not reported for sample 9G. In both cases the original sample concentration exceeded the spike concentration by more than 4 times; therefore, the percent recoveries were not meaningful. The percent recoveries for the selenium matrix spike samples ranged from 87 to 112 for sample concentrations ranging from 0.72 to 210 mg/L. RPD values ranged from 0.570 to 5.36, less than the RPD limit of 10. For the other trace element analysis, RPD values ranged from 0 to 7.54, well within the RPD limit of 20.

Four sets of MS and MSD samples were analyzed for arsenic, boron, calcium, potassium, magnesium, sodium, and silicon. In a few cases the original sample concentration exceeded the spike concentration by more than 4 times; therefore, the percent recoveries were not meaningful. For the remaining analyses, percent recoveries ranged from 73.7 to 120, within the limits of 70 to 130. The RPD values ranged from 0 to 8.13, below the limit of 20.

Of the samples selected for MS and MSD analyses for specific conductance, total dissolved solids, chloride, sulfate, and bicarbonate all were within range for percent recovery and RPD except matrix spikes for chloride and sulfate for samples 9G and 17B4. In these two cases the original sample concentration exceeded the spike concentration by more than 4 times; therefore, the percent recoveries were not meaningful.

Field Duplicates

Four field duplicates (samples 16B6, 17B2A, 17B4, and 20B3) were submitted to the laboratory with dummy sample identifications. Analytical results show good agreement. For all detected analytes the RPDs ranged from 0 to 14.8. The mean absolute percent difference was 4.73 and the standard deviation was 4.14. Eighty percent of the values ranged between plus or minus 8 percent. Percent differences for selenium duplicate analyses for samples 16B6, 17B2A, 17B4, and 20B3 were 11.8, 14.1, 8.9, and 2.98, respectively. The selenium values for these samples were 36, 0.53, 5.9, and 34 mg/L, respectively.

Major Ion Data

1. The charge balances for most of the samples was less than or equal to 5.25 percent. Exceptions are as follows:

Sample	**Charge Balance (percent)**
13F1	-9.5
16A1	9.5
16B6	24.8

2. The ratio of calculated sum of dissolved solids to specific conductance. Values for five samples fell outside the suggested range for 0.55 to 0.81 as follows:

Sample	**Ratio of Calculated Sum of Dissolved Solids to Specific Conductance**
13F3	0.50
16A1	0.50
16B6	0.45
18A3	0.51
18B4	0.50
9G	0.43

3. Values of the ratio of the sum of reacting constituents to specific conductance fell outside the suggested range of 0.92 to 1.24 for 8 samples as follows:

Sample	Ratio of the Sum of Reacting Constituents to Specific Conductance
13F1	0.79
13F3	0.80
14C2	0.86
17B2	0.85
18A3	0.90
18B4	0.87
20B3	0.89
9G	0.73

4. All sample values for the ratio of the residue upon evaporation to the specific conductance were within the range of 0.55 to 0.86.

QA/QC EVALUATION SUMMARY

In summary, the QA/QC review found the data to be generally of acceptable quality for the intended use of preliminarily evaluating changes in trace element concentrations and salinity since the mid-1980s. All total dissolved solids results were qualified as estimated due to exceeded holding times; however, they may still be useful for project purposes. While the use of total dissolved solids or specific conductance as an indication of changes in salinity does not appear problematic, problems appear to occur with the major ion data in selected samples. One potential problem is the lack of nitrate data, which may affect the cation-anion balance. The charge balances for samples 13F1, 16A1, and 16B6 exceeded 5 percent. In addition, results for samples 9G and13F3 indicate problematic major ion analyses.

APPENDIX E3

SOIL SALINITY EVALUATION

TABLE OF CONTENTS

Tables

Figures

Acronyms

CO_2	carbon dioxide
dS/m	deciSiemen(s) per meter
ET	evapotranspiration
mg/L	milligram(s) per liter
Westlands	Westlands Water District

E3.1 INTRODUCTION

The San Luis Drainage Feature Re-Evaluation utilizes APSIDE to consider the relationships between drainage and root zone salinity, crop yields, crop revenues, and drainage quantity and quality changes (see Section 12, Agricultural Production and Economics). Chemical reactions influence soil salinity changes, and an APSIDE submodule (CRZMOD) incorporates a set of generalized relationships that account for gypsum dissolution and precipitation effects on soil salinity. A geochemical model was utilized to simulate soil-salinity reactions that probably occur in western San Joaquin Valley soils, and results where compared to CRZMOD. The primary differences between CRZMOD and our modeling analysis are the simulation of calcium carbonate equilibrium and the seasonal variation in water movement and soil moisture content. The purpose of our comparison was to assess limitations, if any, in the soil-salinity results calculated by CRZMOD and utilized by APSIDE.

E3.2 BACKGROUND

Previous research identified mineral controls on soil and shallow groundwater salinity in western San Joaquin Valley (e.g., Deverel and Fujii 1988; Fujii, Deverel, and Hatfield 1988; Deverel and Gallanthine 1989; Tanji et al. 1977). Gypsum is the primary control on soil total dissolved solids concentrations; it dissolves or precipitates depending on salinity. Deverel and Gallanthine (1989) indicated gypsum saturation above about 3,900 milligrams per liter (mg/L) in shallow groundwater samples collected throughout western San Joaquin Valley. At lower salinity values, calcium carbonate dissolution and precipitation influences the shallow groundwater and soil solution chemical composition. Tanji et al. (1977) estimated gypsum amounts in western San Joaquin Valley soils. The average amount of gypsum increased with depth from less than 1 ton/acre-foot of soil in the top foot to over 11 tons/acre-foot of soil at the 7- to 8-foot depth interval.

Few data exist to establish historical and present-day soil salinity conditions. In western San Joaquin Valley, the spatial variability of soil salinity is high (Deverel and Gallanthine 1989; Fujii, Deverel, and Hatfield 1988; Corwin et al. 1996, 1999). For example, 1991 soil core data collected at 315 locations in Broadview Water District indicated the spatial coefficient of variation for soil electrical conductivity was about 55 percent (Corwin et al. 1999). The average soil salinity for the top 4 feet of soil was 4.4 deciSiemen/meter (dS/m). Similarly, the average soil salinity and coefficient of variation reported for 66 Broadview soil samples from the upper 3 feet was 3.9 dS/m and 48 percent (Wichelns 1989). Harradine (1950) determined soil salinity in over 500 samples throughout western San Joaquin Valley in the 1940s. Doner et al. (1989) evaluated changes in soil chemical composition between some of Harradine’s samples and samples collected at the same locations in 1985 and 1987. For the Panoche soils, characteristic of western San Joaquin Valley soils, average soil salinity of the unirrigated archived samples was 0.6 to 2.9 dS/m higher than the samples collected in 1985 and 1987.

The primary chemical reactions affecting the soil solution and shallow groundwater chemistry are the dissolution and precipitation of gypsum,

$$CaSO_4\ 2H_2O \leftarrow\!\!-\!\!-\!\!\rightarrow Ca^{++} + SO_4^{=} + 2H_2O \qquad (1)$$

and calcite,

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{++} + 2HCO_3^- \qquad (2)$$

At salinities above about 3,900 mg/L total dissolved solids, shallow groundwater chemical composition is predominated by sodium and sulfate ions and is saturated with gypsum (Deverel and Gallanthine 1989). At lower total dissolved solids concentrations, the chemical composition is increasingly dominated by calcium and bicarbonate due to equilibrium with calcium carbonate. The geochemical model PHREEQC (Parkhurst and Appelo 1999) was utilized to estimate changes in soil solution chemistry based on the chemical reactions represented by equations (1) and (2) and physical processes occurring in the crop root zone. The results were then compared with annual soil salinity calculations from the CRZMOD model.

E3.3 METHODS

Using the basic structure and data in CRZMOD, a water budget were developed to estimate monthly soil moisture and deep percolation changes using a mass balance equation for each of the four layers of the soil profile represented by CRZMOD,

$$SM_t = SM_{t-1} + ID + Pe + ETgw - ET - R$$

where:

SM_t = soil moisture in the current month t

SM_{t-1} = soil moisture from previous month

ID = the irrigation depth or percolation from above layer

Pe = the effective precipitation

Etgw = the evapotranspiration of shallow groundwater

ET = crop evapotranspiration of root zone moisture

R = the deep percolation to the groundwater or deeper layer

Figure E3-1 shows the change in soil moisture predicted by the model for the northern districts. The data were aggregated for 4 quarters that represent different soil moisture and deep percolation conditions. During January through March, preirrigation and rain results in deep percolation to shallow groundwater and high soil moisture; ET is low. Little irrigation during April through June, negligible deep percolation, and moderate ET occur. During July through September, substantial irrigation, deep percolation to shallow groundwater, and high ET occur. During October through December, negligible irrigation and rainfall, no deep percolation, and low to moderate ET occur. Figure E3-2 shows the monthly distributions of irrigation, rain, and ET used in the water budget.

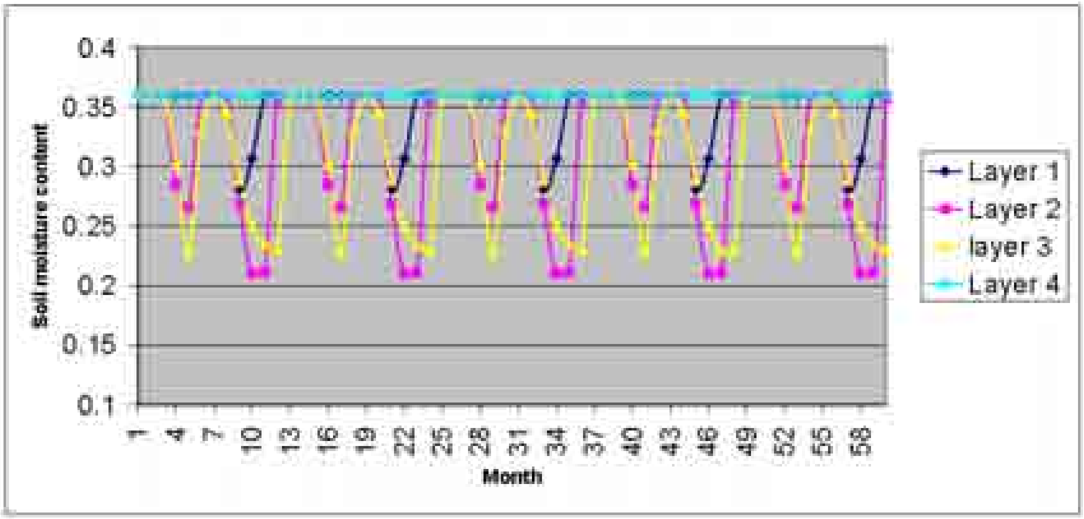

Figure E3-1
Predicted Monthly Soil Moisture Changes

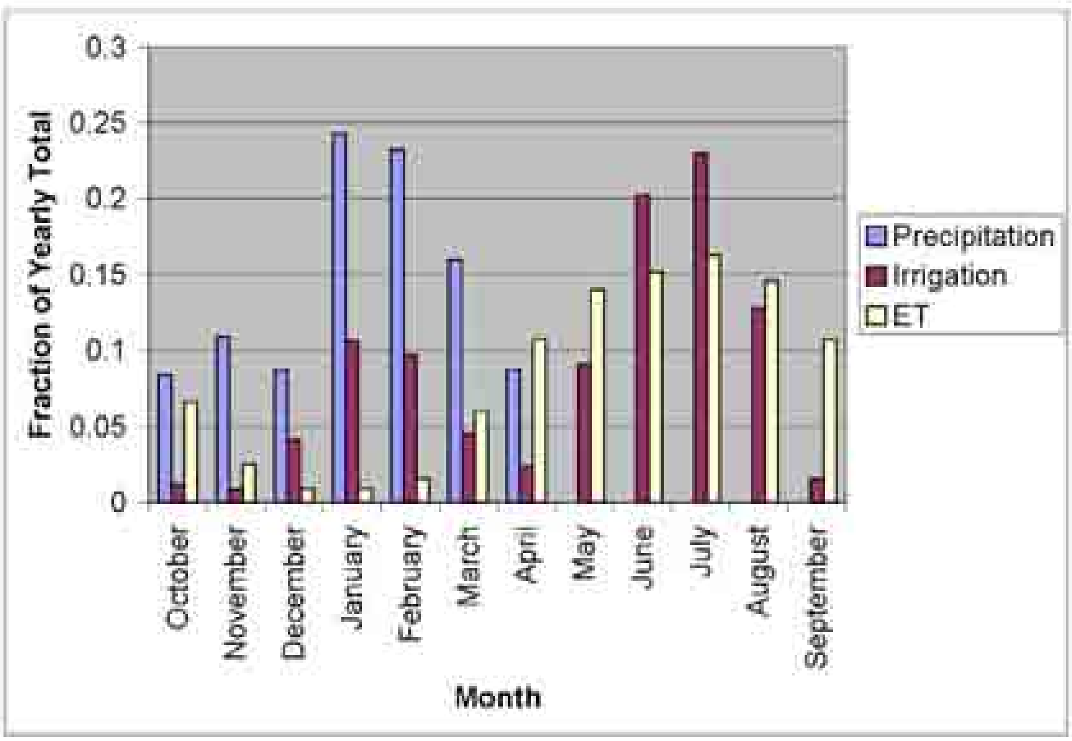

Figure E3-2
Monthly Distributions for Fractions of Precipitation, Irrigation, and Evapotranspiration

To estimate quarterly soil salinity changes, the USGS geochemical equilibrium program PHREEQC (Parkhurst and Appelo 1999) was used to calculate mixing, mineral, and cation exchange equilibria and evaporative concentration within each layer of the soil profile. The initial total dissolved solids concentrations from the CRZMOD model were used and the literature and databases for equivalent soil salinity values and their corresponding chemical composition were searched. Soil chemical data were also provided by Panoche Water District (Chris Linneman, Summers Engineering, 2002). In some cases, sodium, chloride, and sulfate concentrations were adjusted by less than 5 percent to match the beginning soil solution salinities from CRZMOD and to achieve charge balance. For precipitation, the chemical composition of rain in Menlo Park, California, from Hem (1985) was used. The composition of irrigation water was obtained from Sposito et al. (1987). Groundwater chemical composition data came from Deverel et al. (1984) and Leighton et al. (1991). The exchange complex composition was estimated based on analyses reported in Sposito et al. (1987).

Table E3-1 shows the process used to estimate soil solution chemical composition and salinity in PHREEQC. Quarterly mixing fractions were estimated for each layer based on the water budget calculations. Soil solution total dissolved solids were estimated by summing the PHREEQC output concentrations of calcium, magnesium, sodium, potassium, sulfate, chloride, and bicarbonate (multiplied by 0.4917). All soil profile layers were assumed to contribute equally to the average soil salinity value.

Table E3-1
Processes Simulated in PHREEQC

Layer	Process
Layer 1	Mixing of irrigation, rain and soil solution based on spreadsheet values and monthly fractions. Evaporation of water based on ET (40 percent of total average crop ET) Equilibration of mixed and evapoconcentrated solution with cation exchange complex, gypsum, CO_2 and calcite. Movement of resulting solution to layer 2.
Layer 2	Mixing of percolate from layer 1 with layer 2 soil solution. Evaporation. (30 percent of total average crop ET) Equilibration with cation exchange complex, gypsum, CO_2, and calcite. Movement of resulting solution to layer 3.
Layer 3	Mixing of percolate from layer 2 with layer 3 soil solution and shallow groundwater used for crop water requirement. Evaporation (20 percent of total average crop ET). Equilibration with cation exchange complex, gypsum, CO_2, and calcite. Movement of resulting solution to layer 4.
Layer 4	Mixing of percolate from layer 3 with layer 4 soil solution and shallow groundwater used for crop water requirement Evaporation (10 percent of total average crop ET). Equilibration with cation exchange complex, gypsum, CO_2, and calcite. Movement of resulting solution to deep percolation.

Soil salinity was estimated using different assumptions about the presence of soil gypsum for the two CRZMOD scenarios in the Northerly Area and Westlands Water District (Westlands). Deverel and Gallanthine (1989) reported that shallow groundwater is generally undersaturated with gypsum in nonsaline areas of the Panoche, Cantua, and Los Gatos creek alluvial fans, and groundwater is generally saturated with gypsum in the distal, saline areas of these alluvial fans and on the ephemeral stream alluvial fans. Moreover, soil salinity and gypsum content increase with depth in irrigated, naturally, or artificially drained soils (Fujii, Deverel, and Hatfield 1988; Fio and Fujii 1990; Tanji et al. 1977). For the Northerly Area scenario soil salinity was estimated with and without gypsum in all layers. For Westlands, soil salinity was estimated (1) without gypsum in only the bottom two-soil profile layers and (2) with gypsum in all four layers. Soil carbon dioxide (CO_2) partial pressures were varied as follows: $10^{-2.5}$ during January through June, $10^{-1.85}$ during October through December, and $10^{-1.4}$ from July through August based on Bell (1988).

Common assumptions to the CRZMOD and PHREEQC models are:

- A steady-state soil moisture regime with no net annual change in soil moisture
- Applied irrigation water reaching the groundwater within 1 year
- Complete mixing of resident and incoming water in each soil layer
- Equilibrium chemical thermodynamics apply in the treatment of solid, aqueous and gaseous phases in the soil
- Unlimited amounts of calcite and gypsum when these minerals were simulated as present in the soil

Over the period of a few years, these assumptions are probably not valid. However, over longer periods (for example, decades), these assumptions generally apply and results represent long-term steady-state and chemical equilibria. The assumption of unlimited amounts of gypsum may not be valid for all soil layers. Dissolution of gypsum in the upper soil layers may have resulted in the complete removal of gypsum in some locations. Quarterly calculations were designed to simulate and examine the seasonal variability in chemical reactions, soil moisture, and water movement and incorporate this variability into the annual average estimate.

E3.4 RESULTS

E3.4.1 Northerly Area

E3.4.1.1 Soil Salinity Without Gypsum

To evaluate changes in soil salinity in nonsaline, nongypsiferous soils and to compare our calculations with CRZMOD, the PHREEQC model was used to perform the calculations on Table E3-1 when gypsum is absent from the soil profile. CRZMOD initial soil solution values of 500, 800, 1,400, and 2,400 mg/L dissolved solids were used for layers 1 through 4, respectively, and the corresponding chemical composition for soils in Panoche Water District. Irrigation water and precipitation dissolved solids concentrations were the same as CRZMOD. Figure E3-3 shows the comparison of annual salinity estimates for the CRZMOD and PHREEQC calculations for a 10-year period. The primary differences between CRZMOD and PHREEQC estimates are the simulation of calcium carbonate equilibrium and seasonal variation in water flow and moisture in the soil profile. Figure E3-4 shows little difference in the depth-averaged soil salinity (1,137 mg/L for CRZMOD versus 1,118 mg/L for PHREEQC) at year 10. Dissolution or precipitation of calcium carbonate and dissolution or outgassing of CO_2 appear to account for the differences between individual layers.

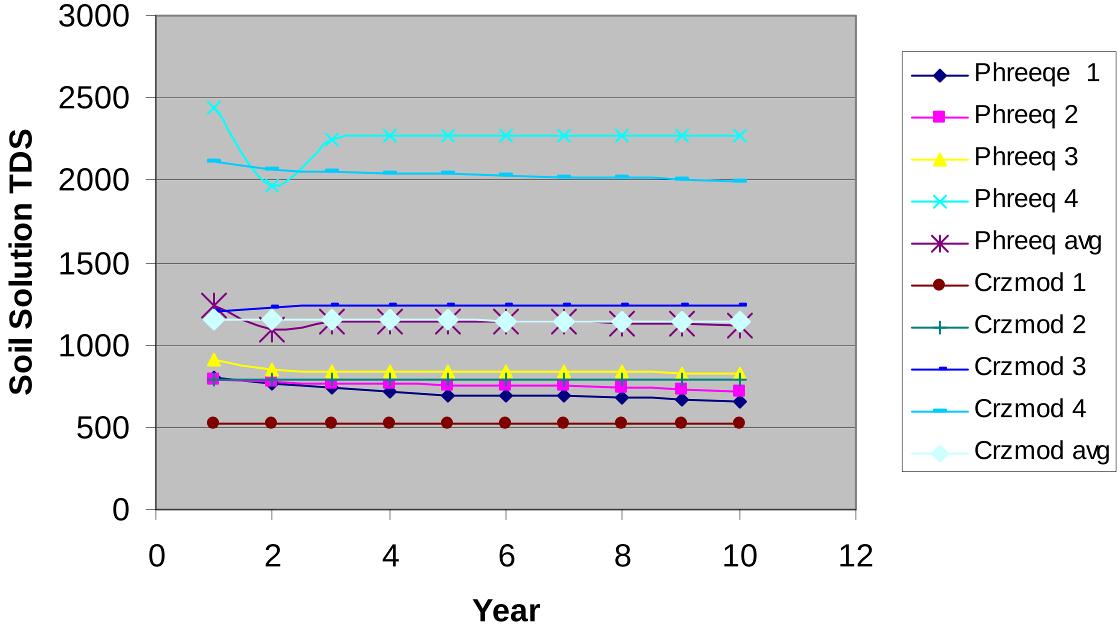

Figure E3-3
Comparison of Soil Salinity Estimates without Gypsum, Northerly Area

On an annual basis, calcium carbonate and CO_2 dissolve in layer 1, and calcium carbonate precipitates and CO_2 outgasses from layers 2, 3, and 4. Calcium carbonate dissolution increases the soil solution dissolved solids concentration, and precipitation decreases the soil solution dissolved solids concentration. Therefore, PHREEQC overestimates soil salinity relative to CRZMOD in layer 1 (656 versus 526 mg/L), and underestimates soil salinity relative to CRZMOD in layers 2 and 3 (715 and 822 mg/L versus 790 and 1,236 mg/L, respectively). The 10 percent difference in concentrations between CRZMOD and PHREEQC in the bottom layer is probably due to slight differences between the models mixing of soil solution and groundwater. This comparison indicates that the soil moisture and water flow accounting are generally equivalent for the two models.

E3.4.1.2 Soil Salinity with Gypsum

Figure E3-4 shows the estimated soil salinity assuming gypsum in all soil layers. The initial average soil salinity for the two models agrees, but simulated soil salinity from PHREEQC declines at a faster rate than CRZMOD. After 20 years, when the PHREEQC soil salinity estimates level off, the soil salinity calculated by CRZMOD is about 500 mg/L greater than the average PHREEQC value. This appears to be due primarily to the different methods employed to calculate gypsum dissolution. PHREEQC calculates gypsum equilibrium for each layer, which varies according to the soil solution chemical composition. In contrast, CRZMOD adds a constant gypsum contribution to the average soil salinity. The amount of gypsum dissolved in PHREEQC decreases as the soil salinity decreases, causing the average soil solution to decrease faster with time, which is due to increasing gypsum solubility at higher soil salinity. Sodium and chloride concentrations increase with increasing evaporative concentration, and gypsum solubility increases due to ion association and ionic strength effects (Tanji 1969).

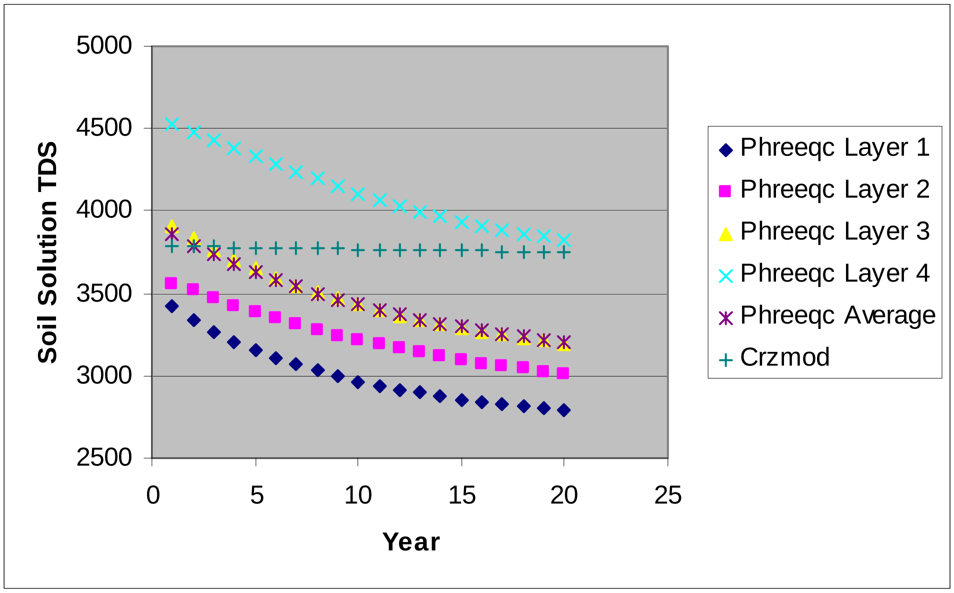

Figure E3-4
Comparison of Soil Salinity Estimates with Gypsum, Northerly Area

E3.4.2 Westlands Water District

Figure E3-5 shows soil salinity estimates assuming gypsum presence in the bottom two soil layers. The PHREEQE simulations underpredict the average, steady-state soil salinity relative to the CRZMOD results by almost 2,000 mg/L. The difference is attributed to the lack of soil gypsum in layers 1 and 2. In general, calcite and CO_2 dissolve in layer 1, and calcite precipitates and CO_2 outgasses in layers 2, 3, and 4. Gypsum dissolves in layers 3 and 4. Figure E3-6 shows the results assuming gypsum presence throughout the four-layer soil profile. Similar to results for the Northerly Area, PHREEQC underpredicts average soil salinity relative to the CRZMOD simulation. Gypsum dissolves in layers 1 to 3 but precipitates in layer 4.

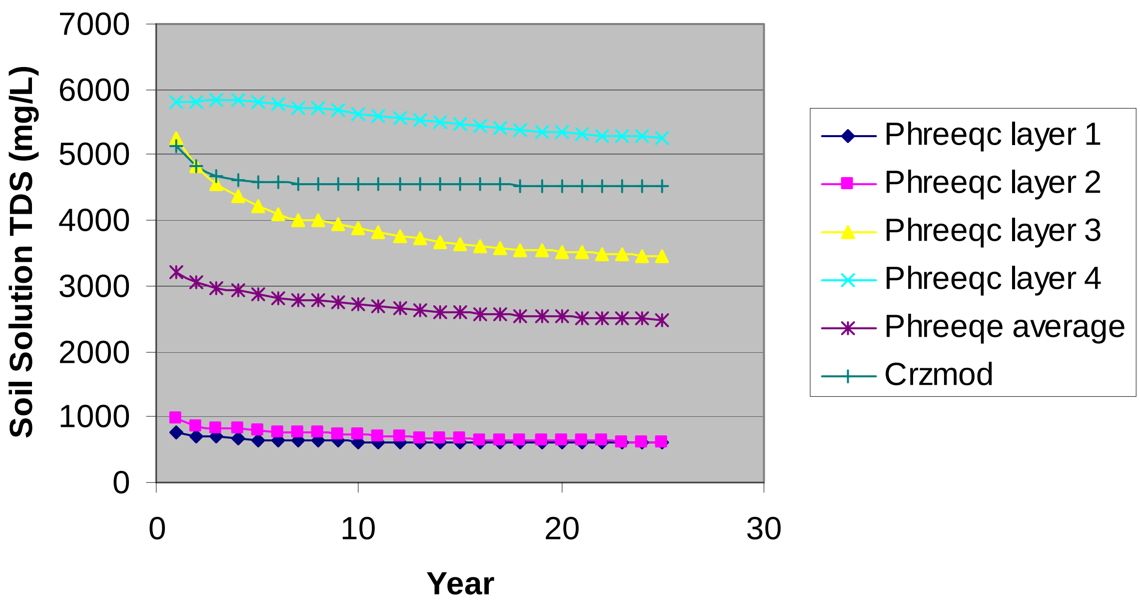

Figure E3-5
Estimated Changes in Soil Salinity in Westlands with Gypsum in the Bottom Two Layers

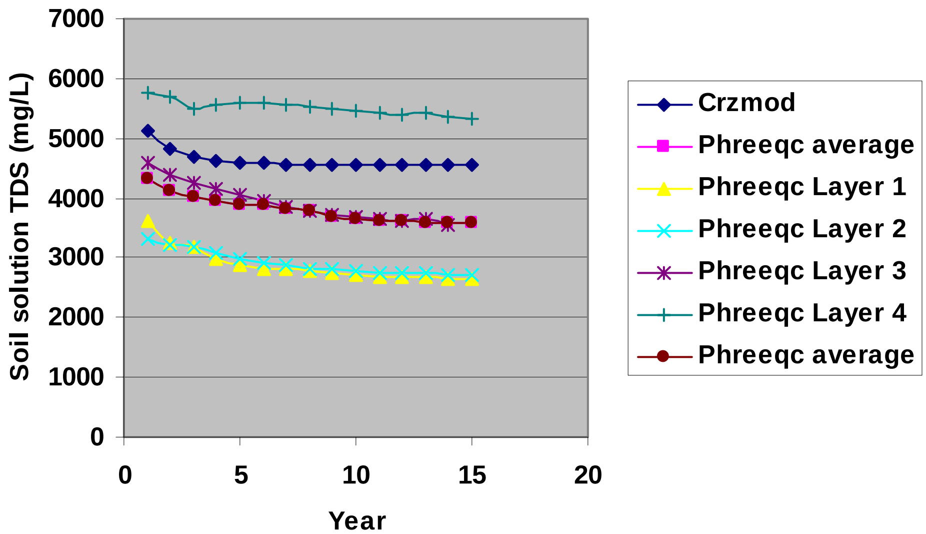

Figure E3-6
Estimated Soil Solution Total Dissolved Solids in Westlands with Gypsum in All Layers

E3.5 SUMMARY AND CONCLUSIONS

This analysis elucidates the key processes affecting soil salinity in western San Joaquin Valley. In general, gypsum precipitation or dissolution is the primary control on soil solution concentrations in most of the areas where soil salinity would affect crop yields. In lower salinity areas, calcite, and CO_2 are the primary controls on soil salinity. Soil salinity estimates calculated by the chemical equilibrium model PHREEQC and the CRZMOD submodule of the APSIDE model were compared; the PHREEQC comparison employed the same general assumptions about water flow and soil moisture as specified in CRZMOD. PHREEQC calculations consistently underpredict soil salinity for the Northerly Area and Westlands simulations relative to the CRZMOD results, which appears primarily related to CRZMOD's handling of gypsum equilibration. In PHREEQC, gypsum dissolution and precipitation in individual layers depends on the soil solution salinity, whereas CRZMOD dissolves a constant amount of gypsum for the average soil salinity of the entire soil profile. Based on the analysis presented here, the Ag Production analysis procedures may overestimate soil salinity increases.

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APPENDIX E4

Simulated Groundwater Use and Water Table Recharge Rates in Westlands Water District, San Luis Drainage Feature Re-Evaluation

Tables

Figures

Acronyms

AF	acre-feet or acre-foot
Westlands	Westlands Water District

Appendix E4
Simulated Groundwater Use and Water Table Recharge Rates in Westlands Water District, San Luis Drainage Feature Re-Evaluation

The San Luis Drainage Feature Re-Evaluation is utilizing the U.S. Geological Survey's western San Joaquin Valley groundwater-flow model (Belitz et al. 1993) to simulate groundwater flow and drainage in drainage-impaired lands within the San Luis Unit. The model specifies water table recharge and groundwater pumpage within 11 water budget subareas (Figure E4-1). Most subareas correspond with individual water district boundaries; however, Westlands Water District (Westlands) is subdivided into additional subareas based on depth to the water table (10 feet below land surface or less, 10 to 20 feet below land surface, and greater than 20 feet below land surface).

In Westlands, land retirement can remove agricultural areas that utilize groundwater to partially meet their annual irrigation demand. As these lands are removed from agricultural production, the resulting changes in recharge and pumping can influence shallow groundwater flow. It is important, therefore, to accurately describe the magnitude and spatial distribution of groundwater pumpage. To do so, utilized reported well data and Westlands-wide annual pumping rates were utilized to answer three questions:

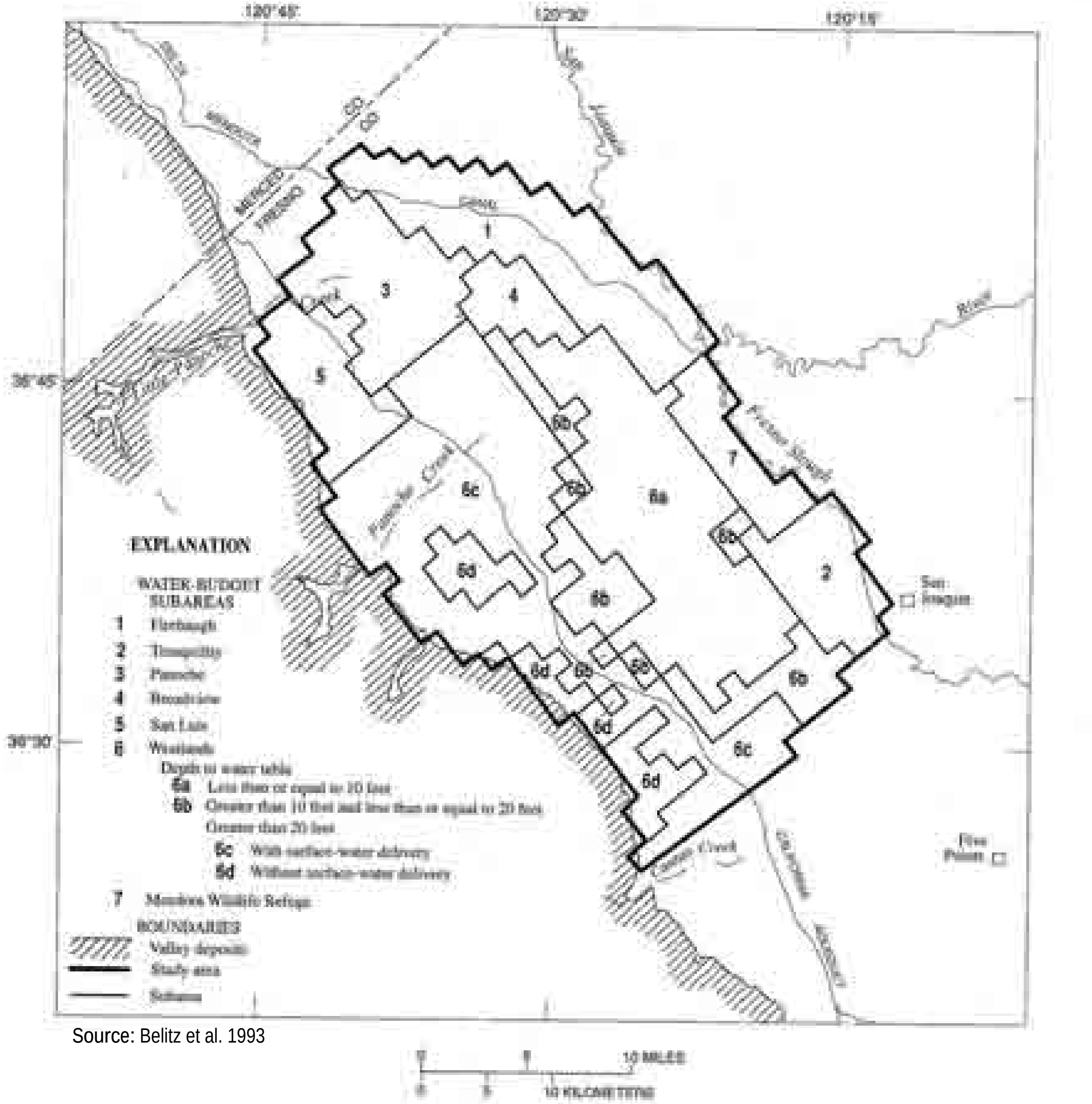
1. What is the relationship between the number of operational wells and annual pumpage within Westlands Water District?
2. What is the distribution of wells within the model areas that represent Westlands Water District?
3. What is the pumping rate and distribution in the model area representing Westlands Water District?

The results of the assessment are described below.

E4.1 WHAT IS THE RELATIONSHIP BETWEEN THE NUMBER OF OPERATIONAL WELLS AND ANNUAL PUMPAGE WITHIN WESTLANDS WATER DISTRICT?

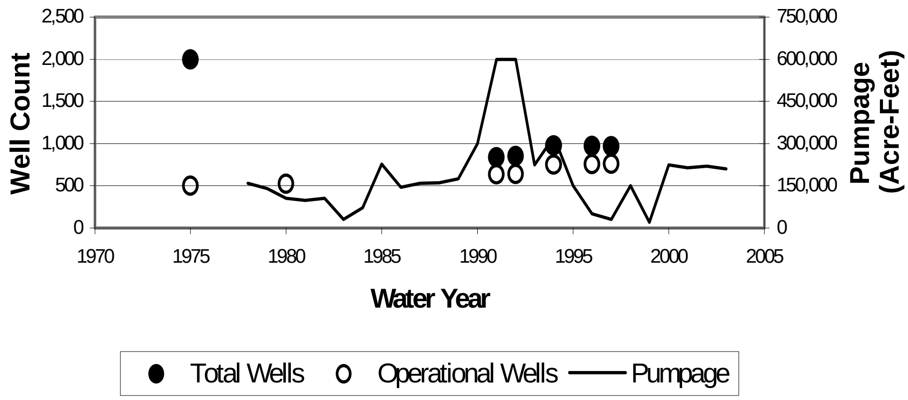
Figure E4-2 shows the relationship between the reported number of operational wells within Westlands and annual, Westlands-wide groundwater pumpage. Annual pumpage varied substantially and ranged from a minimum of 20,000 acre-feet (AF) in 1999 to a maximum of 600,000 AF in 1992 and 1993. However, the number of operational wells was fairly constant during the period 1991 to 1997. On the basis of Figure E4-2, pumpage was concluded to vary independently of well status. One or more of the following reasons can explain this observation:

- Well status is not an indicator of the number of wells actually pumped.
- If all operational wells are indeed active, an increase in the annual extraction rate indicates an increase in their operation time.
- The method employed to estimate Westlands-wide pumpage does not reflect the number of operational wells.



Source: Belitz et al. 1993

Figure E4-1
Map Showing Boundaries of Water Budget Subareas in Groundwater-Flow Model



Data sources: Westlands Water District operational well status maps; HydroFocus (1998); Westlands Water District website (www.westlandswater.org).

Figure E4-2
Relationship Between Annual Well Status and Reported Pumpage

E4.2 WHAT IS THE DISTRIBUTION OF WELLS WITHIN THE MODEL AREAS THAT REPRESENT WESTLANDS WATER DISTRICT?

Using maps provided by Westlands, the number of wells located within and outside the model boundaries was summed (Table E4-1). On the average, 26 percent of the mapped wells are located within the model area; on the basis of metered pumpage, 15 percent of the annual pumpage occurred within the model area.

Table E4-1
Reported Well Count and Metered Pumpage, 1999-2003

Water Year	Well Count		Metered Pumpage (AF)	
	In Model	Outside Model	In Model	Outside Model
1999	15	77	1,557	29,383
2000	43	184	10,676	108,821
2001	48	183	22,092	114,428
2002	53	181	24,734	114,098
2003	52	195	23,804	118,256
Average	42	164	16,572	96,997
Percentage	26	74	15	85

Source: Jose Rangel, Westlands Water District, June 2004.

Table E4-2 compares metered pumpage with reported Westlands-wide groundwater use. Metered pumpage represents 51 to 89 percent of the Westlands supply. If the reported Westlands-wide groundwater use numbers represent the actual annual groundwater extraction rate, it is concluded that not all active wells are metered and/or the method employed to estimate Westlands-wide pumpage is independent of the metered well data. Hence, uncertainty exists in the relationships between actual groundwater use and the well status information (Figure E4-2) and metered pumpage data (Table E4-1).

Table E4-2
Comparison Between Reported Westlands Water District Supply and Total Metered Groundwater Pumpage, 1999–2003

Water Year	Reported Annual Pumpage (AF)		Metered/Westlands (percent)
	Metered	Westlands Supply	
1999	30,940	60,634	51
2000	119,497	225,000	53
2001	136,520	215,000	63
2002	138,832	205,000	68
2003	142,060	160,000	89

E4.3 WHAT IS THE PUMPING RATE AND DISTRIBUTION IN THE MODEL AREA REPRESENTING WESTLANDS WATER DISTRICT?

Using the average reported private supply of 175,000 AF/year (Bureau of Reclamation 2003), the annual pumping rate in the Westlands areas represented by the model might range between 26,250 to 45,500 AF/year (15 to 26 percent of the reported average private supply). For the purposes of the San Luis Drainage Feature Re-Evaluation, 20 percent of the average private supply (35,000 AF/year) was assumed to occur within the Westlands area represented by the model.

Table E4-3 reports the spatial distribution of pumpage specified within the model based on maps of well location and metered pumpage. Most of the pumpage (55 percent) appears to occur within areas having a water table within 10 feet of land surface.

Table E4-3
Distribution of Specified Pumpage in Model Area Representing Westlands Water District

Subarea	Percent	Pumpage (AF/year)
Water table <10 bls	55	19,250
Water table 10-20 bls	20	7,000
Water table >20 bls	25	8,750
Sum	100	35,000

The U.S. Geological Survey utilized reported cropping patterns, surface-water deliveries, and estimated cropwater requirements to estimate pumpage. They concluded that the pumping rate within model areas representing Westlands might be considerably greater than our estimate (35,000 AF/year). Belitz et al. (1993) concluded that for 1980 water budget conditions, groundwater pumpage in model areas representing Westlands was 110,500 AF/year. More recently, the U. S. Geological Survey estimated that for 2000 water budget conditions the pumping rate was 223,400 AF/year (Charles Brush, written communication, March 2004). If actual pumpage is indeed greater than the reported annual supply, then land retirement can result in a substantially greater reduction in groundwater use than implied by Tables E4-2 and E4-3.

Table E4-4 reports 2001 simulated water table recharge and pumpage rates. Land retirement eliminates pumping (and recharge) from the areas retired. If the average pumping rate is to be maintained within Westlands, pumping must either continue within the retired lands or the annual pumping rates within the remaining irrigated lands must be increased. Even though pumping may cease under retired lands, continued downward groundwater movement results from pumping that occurs under nonretired lands. In the irrigated areas that remain, application rates and consumptive use are assumed to remain the same for the entire model area. Hence, land retirement does not alter the simulated recharge rates, but land retirement does decrease the area to which the recharge rates are applied.

Table E4-4
Existing (2001) Recharge and Pumping Conditions

Water Budget Subarea[a]	Model Area (acres)	Water Table Recharge[b] (foot/year)	Pumping (foot/year)
Northerly Area			
Firebaugh	46,720	0.57	0.00
Panoche	30,720	0.72	0.00
San Luis	19,200	0.59	0.00
Broadview	10,240	0.59	0.00
Westlands			
WT < 10	62,080	0.32	0.31
10 < WT < 20	26,880	0.52	0.26
WT > 20	123,520	0.65	0.07
Outside Study Area			
Tranquility	19,840	0.81	0.38
Mendota Wildlife Refuge	14,080	0.00	0.00

Notes:

WT = water table depth

[a]Model subareas are shown on Figure E4-1.

[b]Beginning in 2005, Northerly Area recharge rates decrease 0.04 foot/year owing to seepage reduction; recharge rates decrease 0.10 foot/year in the Northerly Area, 0.20 foot/year in the 10<WT<20 Westland Subarea, and 0.10 foot/year in the WT>20 Westland subarea owing to irrigation system improvements.

E4.4 REFERENCES

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APPENDIX F

Special-Status Species

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Tables

The following tables list special-status species that may occur in the general project area.

Table F-1 includes all Federally and State-listed *Endangered* and *Threatened* species, as well as species identified as *Candidates for Listing* or *Proposed for Listing*, reported by the U.S. Fish and Wildlife Service in their memorandum and species list dated June 3, 2003. The Service's June 3, 2003, list was subsequently modified to include several recent listing changes, additions, and deletions. Additional State-listed species in Table F-1 were added following a review of California Department of Fish and Game databases and websites.

Table F-2 includes all Federal *Species of Concern* identified in the June 3, 2003, memorandum and species list, and also includes additional State-listed *Species of Concern* and California Native Plant Society's protected plant species.

Table F-1
Federal Endangered Species Act and California Endangered Species Act Listed Species That May Occur in the Project Area

Common Name	Scientific Name	FED Status	CA/Additional CA Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
Marine Mammals							
Blue whale	*Balaenoptera musculus*	E	--/--	MAR		X	
Finback whale	*Balaenoptera physalus*	E	--/--	MAR		X	
Guadalupe fur seal	*Arctocephalus townsendi*	T	--/CFP[a]	MAR		X	
Humpback whale	*Megaptera navaeangliae*	E	--/--	MAR		X	
Right whale	*Eubalaena glacialis*	E	--/CFP	MAR		X	
Sei whale	*Balaenoptera borealis*	E	--/--	MAR		X	
Southern sea otter	*Enhydra lutris*	T	--/CFP	MAR		X	
Sperm whale	*Physeter macrocephalus*	E	--/--	MAR		X	
Steller sea lion	*Eumentopias jubatus*	T	--/--	MAR		X	
Other Mammals							
Fresno kangaroo rat	*Dipodomys nitratoides exilis*	E	E/--	AGS, ASC, FEW		X	X
Giant kangaroo rat	*Dipodomys ingens*	E	E/--	AGS, ASC		X	X
Morro Bay kangaroo rat	*Dipodomys heermanni morroensis*	E	E/--	CSC		X	
Riparian brush rabbit	*Sylvilagus bachmani riparius*	E	E/--	VRI, ASC			X
Salt marsh harvest mouse	*Reithrodontomys raviventris*	E	E/CFP	SEW			X
San Joaquin antelope squirrel	*Ammospermophilus nelsoni*	FC	T/--	AGS, ASC		X	X

Table F-1
Federal Endangered Species Act and California Endangered Species Act Listed Species That May Occur in the Project Area

Common Name	Scientific Name	FED Status	CA/Additional CA Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
San Joaquin kit fox	*Vulpes macrotis mutica*	E	T/--	AGS, ASC, CRP, VOW	X	X	X
San Joaquin Valley (=Riparian) woodrat	*Neotoma fuscipes riparia*	E	CSC/--	VOW, ASC			X
Tipton kangaroo rat	*Dipodomys nitratoides nitratoides*	E	E/--	AGS, ASC		X	X
Birds							
American peregrine falcon	*Falco peregrinus anatum*	--	E/CFP	CRP, AGS, RIV, FEW, SEW, VOW, VRI,	X	X	
Bald eagle	*Haliaeetus leucocephalus*	T	E/CFP	COW, VRI	X	X	X
Bank swallow	*Riparia riparia*	--	T/--	RIV, VRI		X	X
California black rail	*Laterallus jamaicensis coturniculus*	FSC	T/CFP	SEW, FEW	X		X
California brown pelican	*Pelecanus occidentalis californicus*	E	E/CFP	SEW		X	
California clapper rail	*Rallus longirostris obsoletus*	E	E/CFP	SEW		X	X
California condor	*Gymnogyps californianus*	E	E/CFP	ASC, AGS, PJN, savannah, rock outcrops		X	
California least tern	*Sterna antillarum browni*	E	E/CFP	CSC	X	X	X
Greater sandhill crane	*Grus canadensis tabida*	--	T/CFP	CRP,FEW,RIV	X	X	X
Least Bell's vireo	*Vireo bellii pusillus*	E	E/--	VRI		X	X
Marbled murrelet	*Brachyramphus marmoratus*	T	E/--	COW, MAR		X	
Southwestern willow flycatcher	*Empidonax traillii extimus*	E	--/--	VRI		X	
Swainson's hawk	*Buteo swainsoni*	--	T/--	AGS, CRP, VRI	X	X	X
Western burrowing owl	*Athene cunicularia hypugaea*	FSC	CSC[b]/--	AGS, CRP	X	X	X
Western snowy plover (coastal population)	*Charadrius alexandrinus nivosus*	T	CSC/--	CSC	X	X	X

Table F-1
Federal Endangered Species Act and California Endangered Species Act Listed Species That May Occur in the Project Area

Common Name	Scientific Name	FED Status	CA/Additional CA Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	FC	E/--	VRI	X	X	X
Reptiles							
Alameda whipsnake	*Masticophis lateralis euryxanthus*	T	T/--	CSC			X
Blunt-nosed leopard lizard	*Gambelia silus*	E	E/CFP	AGS, ASC		X	X
Giant garter snake	*Thamnophis gigas*	T	T/--	FEW, VRI	X	X	X
Green sea turtle	*Chelonia mydas*	T	--/--	MAR		X	
Hawksbill sea turtle	*Eretmochelys imbricate*	E	--/--	MAR		X	
Leatherback sea turtle	*Dermochelys coriacea*	E	--/--	MAR		X	
Loggerhead sea turtle	*Caretta caretta*	T	--/--	MAR		X	
Olive Ridley sea turtle	*Lepidochelys olivacea*	T	--/--	MAR		X	
Amphibians							
Arroyo toad	*Bufo microscaphus californicus*	E	CSC/--	VRI		X	
California red-legged frog	*Rana aurora* draytonii	T	CSC/--	FEW, RIV, VRI, AGS	X	X	X
California tiger salamander	*Ambystoma californiense*	T[c]	CSC/--	AGS, VOW, Vernal pools		X	X
Fish							
Chinook salmon (Central Valley Spring-run)	*Oncorhynchus tshawytscha*	T	T/--	RIV			X
Chinook salmon (Central Valley Fall/Late Fall-run)	*Oncorhynchus tshawytscha*	FC	CSC/--	RIV			X
Chinook salmon (Winter-run)	*Oncorhynchus tshawytscha*	E	E/--	RIV			X
Coho salmon (Central California Coastal)	*Oncorhynchus kisutch*	T	E/--	RIV			X
Delta smelt	*Hypomesus transpacificus*	T	T/--	RIV			X

Table F-1
Federal Endangered Species Act and California Endangered Species Act Listed Species That May Occur in the Project Area

Common Name	Scientific Name	FED Status	CA/Additional CA Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
Green sturgeon	*Acipenser medirostris*	FC[d]	CSC/--	EST			X
Sacramento splittail	*Pogonichthys macrolepidotus*	FSC[e]	CSC/--	RIV	X		X
Steelhead (Central Valley ESU)	*Oncorhynchus mykiss*	T	--/--	RIV			X
Steelhead (South/Central California)	*Oncorhynchus mykiss*	T	CSC/--	RIV		X	
Tidewater goby	*Eucyclogobius newberryi*	E	CSC/--	RIV, SEW		X	
Invertebrates							
Conservancy fairy shrimp	*Branchinecta conservation*	E	--/--	AGS, Vernal pools		X	X
Longhorn fairy shrimp	*Branchinecta longiantenna*	E	--/--	AGS, Vernal pools		X	X
Morro shoulderband snail	*Helminthoglypta walkeriana*	E	--/--	CSC, Coastal dunes		X	
Valley elderberry longhorn beetle	*Desmocerus californicus dimorphus*	T	--/--	VRI			X
Vernal pool fairy shrimp	*Branchinecta lynchi*	T	--/--	AGS, Vernal pools		X	X
Vernal pool tadpole shrimp	*Lepidurus packardi*	E	--/--	AGS, Vernal pools		X	X
Plants							
Antioch Dunes evening-primrose	*Oenothera deltoids ssp. Howellii*	E	E/1B	Coastal dunes			X
California jewelflower	*Caulanthus californicus*	E	E/1B	AGS, ASC		X	
California seablite	*Suaeda californica*	E	--/1B	SEW		X	
Camatta Canyon amole	*Chlorogalum purpureum var. reductum*	T	--/1B	COW		X	
Chorro Creek bog thistle	*Cirsium fontinale var. obispoense*	E	E/1B	AGS		X	
Contra Costa goldfields	*Lasthenia conjugens*	E	--/1B	AGS, Vernal pools			X
Contra Costa wallflower	*Erysimum capitatum var. angustatum*	E	E/1B	Coastal dunes			X

Table F-1
Federal Endangered Species Act and California Endangered Species Act Listed Species That May Occur in the Project Area

Common Name	Scientific Name	FED Status	CA/Additional CA Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
Delta button-celery	*Eryngium racemosum*	--	E/1B	CSC			X
Fleshy owl's-clover	*Castilleja campestris ssp. succulenta*	T	E/1B	AGS			X
Gambel's watercress	*Rorippa gambelii*	E/	T/1B	FEW, SEW		X	
Hartweg's golden sunburst	*Pseudobahia bahiifolia*	E	E/1B	AGS			X
Indian Knob mountainbalm	*Eriodictyon altissimum*	E	E/1B	COW, CSC		X	
La Graciosa thistle	*Cirsium loncholepis*	E	T/1B	Coastal dunes, SEW		X	
Large-flowered fiddleneck	*Amsinckia grandiflora*	E	E/1B	AGS			X
Marsh sandwort	*Arenaria paludicola*	E	E/1B	FEW, SEW		X	
Morro manzanita	*Arctostaphylos morroensis*	T	--/1B	CSC		X	
Nipomo Mesa lupine	*Lupinus nipomensis*	E	E/1B	Coastal dunes		X	
Palmate-bracted bird's-beak	*Cordylanthus palmatus*	E	E/1B	AGS, ASC (Alkali sink scrub)			X
Pismo clarkia	*Clarkia speciosa ssp. immaculate*	E	--/1B	COW, CSC		X	
Purple amole	*Chlorogalum purpureum var. purpureum*	T	--/1B	COW		X	
Salt marsh bird's-beak	*Cordylanthus maritimus ssp. Maritimus*	E	E/1B	SEW		X	
San Joaquin woolly-threads	*Monolopia congdonii*	E	--/1B	AGS, ASC		X	
Soft bird's-beak	*Cordylanthus mollis ssp. mollis*	E	--/1B	SEW			X
Suisun thistle	*Cirsium hydrophilum var. hydrophilum*	E	--/1B	SEW			X

Notes:
[a] CFP = Fully protected species (California Fish and Game Code Sections 3505, 3511, 3513, 4700, and 5050).
[b] Petitioned for listing as state-threatened or endangered in April 2003.
[c] Central California Distinct Population Segment (DPS) listed as Threatened August 4, 2004. Critical habitat proposed August 10, 2004.
[d] Petitioned to list as threatened or endangered in 2001. In January 2003, citing insufficient evidence to list as endangered, the petition to list was rejected. The January 2003 finding was then remanded for redetermination on June 18, 2004, and is currently under status review.
[e] Delisted September 22, 2003 (formerly Threatened, now Federal and State Species of Concern).

Table F-1
Federal Endangered Species Act and California Endangered Species Act Listed Species That May Occur in the Project Area

AGS = Annual Grassland, ASC = Akali Desert Scrub, COW = Coastal Oak Woodland, CRC = Chamise-Redshank Chaparral, CRP = Croplands, CSC = Coastal Scrub, EST = Estuary, FEW = Freshwater Emergent Wetland, MAR = Marine, MHW = Montane Hardwood, PJN = Pinyon-Juniper Woodland, RIV = Riverine, SEW = Saltwater Emergent Wetland, VOW =Valley Oak Woodland, VRI = Valley Foothill Riparian

Federal Status Definitions

E = Endangered (a species that is in danger of extinction throughout all or a significant portion of its range)
T = Threatened (a species that is likely to become endangered within the foreseeable future)
P = Proposed for listing (a species that has been formally proposed for listing in the Federal Register as endangered or threatened)
FC = Candidate (a species for which the U.S. Fish and Wildlife Service has sufficient biological information to support a proposal to list as endangered or threatened)
FSC = Species of Concern (a species for which existing information indicates may warrant listing, but for which substantial biological information to support a proposed rule is lacking)
(--) = Not listed under the Federal Endangered Species Act

State Status Definitions

E = Endangered (a native species or subspecies of a bird, mammal, fish, amphibian, reptile, or plant that is in serious danger of becoming extinct throughout all, or a significant portion, of its range due to one or more causes, including loss of habitat, change in habitat, overexploitation, predation, competition, or disease)
T = Threatened (a native species or subspecies of a bird, mammal, fish, amphibian, reptile, or plant that, although not presently threatened with extinction, is likely to become an endangered species in the foreseeable future in the absence of special protection and management efforts required by Chapter 1.5 of the California Fish and Game Code)
C = Candidate (a native species or subspecies of a bird, mammal, fish, amphibian, reptile, or plant that the Commission has formally noticed as being under review by the California Department of Fish and Game for addition to either the list of endangered or threatened species, or a species for which the Commission has published a notice of proposed regulation to add the species to either list)
CSC = Species of Special Concern (a native species of subspecies of a bird, mammal, fish, amphibian, reptile, or plant that has become vulnerable to extinction because of declining population levels, limited range, or rarity. The goal is to prevent these animals from becoming endangered by addressing the issue of concern early enough to secure long-term viability for the species)
(--) = Not listed under the California Endangered Species Act

California Native Plant Society (CNPS) Status

1A = Presumed extinct in California
1B = Rare or endangered in California and elsewhere
2 = Rare or endangered in California, more common elsewhere
3 = Plants for which more information is needed (Review List)
4 = Plants of limited distribution (Watch List)

Table F-2
Federal and State Species of Concern That May Occur in Areas Potentially Affected by Project Alternatives

Common Name	Scientific Name	FED Status	State Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
Bats and Myotis							
Long-eared myotis	*Myotis evotis*	FSC	--	Various forest and woodland habitats		X	
Small-footed myotis	*Myotis ciliolabrum*	FSC	--	Various arid upland habitats	X	X	
Long-legged myotis	*Myotis volans*	FSC	--	Various wooded habitats in mountainous terrain		X	
Fringed myotis	*Myotis thysanodes*	FSC	--	Various wooded habitats, preferring higher elevations		X	X
Yuma myotis	*Myotis yumanensis*	FSC	--	Open woodlands and forest near water	X	X	X
Greater western mastiff bat	*Eumops perotis californicus*	FSC	CSC	Various arid upland habitats	X	X	
Pacific western (=Townsends's big-eared bat	*Corynorhinus (=Plecotus) townsendii townsendii*	FSC	CSC	Various mesic upland habitats	X	X	X
Other Mammals							
San Joaquin pocket mouse	*Perognathus inornatus inornatus*	FSC	--	AGS, DSC	X	X	X
Southern grasshopper mouse	*Onychomys torridus ramona*	FSC	CSC	DSC	X	X	X
Tulare grasshopper mouse	*Onychomys torridus tularensis*	FSC	CSC	DSC	X	X	X
Birds							
Allen's hummingbird	*Selasphorus sasin*	FSC	--	CSC, VOW, VRI			X
Bell's sage sparrow	*Amphispiza belli belli*	FSC	CSC	CSC, DSC, CRC			X
Black skimmer	*Rynchops niger*	FSC	CSC	EST, Beaches, sandbars, flats			X
Black swift	*Cypseloides niger*	FSC	CSC	Sea cliffs, steep canyons		X	X
Black tern	*Chlidonias niger*	FSC	CSC	FEW, SEW		X	
California thrasher	*Toxostoma redivivum*	FSC	--	CRC, MRI	X	X	X
Costa's hummingbird	*Calypte costae*	FSC	--	DSC	X	X	X

Table F-2
Federal and State Species of Concern That May Occur in Areas Potentially Affected by Project Alternatives

Common Name	Scientific Name	FED Status	State Status	Primary Habitat	In-Valley Alts	Ocean	Delta Alts
Ferruginous hawk	*Buteo regalis*	FSC	--	AGS, CRP	X	X	X
Grasshopper sparrow	*Ammodramus savannarum*	FSC		AGS		X	
Lawrence's goldfinch	*Carduelis lawrencei*	FSC		VOW, COW	X	X	X
Lewis' woodpecker	*Melanerpes lewis*	FSC		VOW	X	X	X
Little willow flycatcher	*Empidonax traillii brewsteri*	FSC	--	VRI, MRI	X	X	X
Loggerhead shrike	*Lanius ludovicianus*	FSC	CSC	VOW, VRI, CRP	X	X	X
Long-billed curlew	*Numenius americanus*	FSC	CSC	AGS, CRP, EST	X	X	X
Marbled godwit	*Limosa fedoa*	FSC	--	EST, SEW, AGS			X
Mountain plover	*Charadrius montanus*	FSC	CSC	AGS, CRP	X	X	X
Nuttall's woodpecker	*Picoides nuttallii*	FSC	CSC	VRI, VOW	X	X	X
Oak titmouse	*Baeolophus inornatus*	FSLC	--	COW, VOW, MRI, VRI	X	X	X
Prairie falcon	*Falco mexicanus*	FSC	CSC	DSC, AGS, CRP	X	X	X
Red knot	*Calidris canutus*	FSC	--	EST, Mudflats			X
Rufous hummingbird	*Selasphorus rufus*	FSC	--	VOW, MRI, VRI, Chaparral	X	X	X
Saltmarsh common yellowthroat	*Geothlypis trichas sinuosa*	FSC	CSC	FEW, SEW, VRI			X
San Joaquin LeConte's thrasher	*Toxostoma lecontei macmillanorum*	FSC	CSC	DSC, desert washes		X	
San Pablo song sparrow	*Melospiza melodia samuelis*	FSC	CSC	SEW			X
Short-eared owl	*Asio flammeus*	FSC	CSC	AGS, CRP, FEW, SEW		X	
Suisun song sparrow	*Melospiza melodia maxillaris*	FSC	CSC	SEW			X
Tri-colored blackbird	*Agelaius tricolor*	FSC	CSC	FEW, AGS, CRP	X	X	X
Vaux's swift	*Chaetura vauxi*	FSC	CSC	COW		X	
Western burrowing owl	*Athene cunicularia hypugaea*	FSC	CSC[a]	AGS, CRP	X	X	X
White-faced ibis	*Plegadis chihi*	FSC	CSC	FEW, CRP	X	X	X
White-tailed kite	*Elanus leucurus*	FSC	CFP	COW, VOW, CRP, AGS	X	X	X

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Reptiles							
Northwestern pond turtle	*Clemmys marmorata marmorata*	FSC	CSC	FEW, VRI, RIV			X
Southwestern pond turtle	*Clemmys marmorata pallida*	FSC	CSC	FEW, VRI, RIV		X	
San Joaquin coachwhip (=whipsnake)	*Masticophis flagellum ruddocki*	FSC	CSC	AGS, ASC		X	X
Silvery legless lizard	*Anniella pulchra pulchra*	FSC	CSC	AGS, CSC, VOW, Coastal Dunes	X	X	X
California horned lizard	*Phrynosoma coronatum frontale*	FSC	CSC	ASC, VRI, AGS, CRC	X	X	X
Amphibians							
Foothill yellow-legged frog	*Rana boylii*	FSC	CSC	MRI, VRI, VOW, CSC, RIV		X	X
Western spadefoot toad	*Scaphiopus hammondii*	FSC	CSC	AGS, VOW, ASC	X	X	X
Fish							
Longfin smelt	*Spirinchus thaleichthys*	FSC	CSC	EST, RIV			X
Sacramento splittail	*Pogonichthys macrolepidotus*	FSC[b]	CSC	EST, RIV	X		X
Kern brook lamprey	*Lampetra hubbsi*	FSC	CSC	RIV			X
Pacific lamprey	*Lampetra tridentata*	FSC	--	EST			X
River lamprey	*Lampetra ayresi*	FSC	CSC	RIV			X
Invertebrates							
Antioch cophuran robberfly	*Cophura hurdi*	FSC	--	Antioch dunes			X
Antioch andrenid bee	*Perdita scituta antiochensis*	FSC	--	Antioch dunes			X
Antioch Dunes anthicid beetle	*Anthicus antiochensis*	FSC	--	Antioch dunes			X
Antioch efferian robberfly	*Efferia antiochi*	FSC	--	Antioch dunes			X
Antioch mutillid wasp	*Myrmosula pacifica*	FSC	--	Antioch dunes			X
Antioch sphecid wasp	*Philanthus nasilis*	FSC	--	Antioch dunes			X

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California linderiella fairy shrimp	*Linderiella occidentalis*	FSC	--	AGS, Vernal pools	X	X	X
Ciervo aegialian scarab beetle	*Aegialia concinna*	FSC	--	Inland dunes	X	X	X
Curved-foot hygrotus diving beetle	*Hygrotus curvipes*	FSC	--	AGS, Vernal pools			X
Doyen's trigonascuta dune weevil	*Trigonoscuta doyeni*	FSC	--	Interior Dunes		X	
Hurd's metapogon robberfly	*Metapogon hurdi*	FSC	--	Unknown			X
Middlekauf's shieldback katydid	*Idiostatus middlekaufi*	FSC	--	Antioch dunes			X
Midvalley fairy shrimp	*Branchinecta mesovallensis*	FSC	--	AGS, Vernal pools	X	X	X
Molestan blister beetle	*Lytta molesta*	FSC	--	AGS, VOW, ASC	X	X	X
Moestan blister beetle	*Lytta moesta*	FSC	--	AGS, VOW, ASC			X
Morrison's blister beetle	*Lytta morrisoni*	FSC	--	Unknown	X		
Ricksecker's water scavenger beetle	*Hydrochara rickseckeri*	FSC	--	Small freshwater ponds & marshes			X
Sacramento anthicid beetle	*Anthicus sacramento*	FSC	--	Dunes or sandy substrates			X
San Francisco lacewing	*Nothochrysa californica*	FSC	--	AGS			X
San Joaquin dune beetle	*Coelus gracilis*	FSC	--	Interior dunes	X	X	
Yellow-banded andrenid bee	*Perdita hirticeps luteocincta*	FSC	--	Antioch dunes			X
Plants							
Alkali milkvetch	*Astragalus tener tener*	FSC	--/1B	Alkali AGS, Vernal pools			X
Big tarplant	*Blepharizonia plumosa plumosa*	FSC	--/1B	AGS			X
Blochman's dudleya	*Dudleya blochmaniae blochmaniae*	--	--/1B	AGS, CSC		X	
Blochman's leafy daisy	*Erigeron blochmaniae*	--	--/1B	Coastal dunes		X	
Brewer's spineflower	*Chorizanthe breweri*	--	--/1B	MHW, VOW, CSC, serpentine		X	

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Brittlescale	*Atriplex depressa*	FSC	--/1B	Alkali AGS, ASC, Vernal pools	X		X
Caper-fruited tropidocarpum	*Tropidocarpum capparideum*	FSC	--/1A	AGS			X
Diamond-petaled Calif poppy	*Eschscholzia rhombipetala*	FSC	--/1A	AGS			X
Dwarf calycadenia [Dwarf western rosinweed]	*Calycadenia villosa*	FSC	--/1B	AGS, MHW, CRC		X	
Franciscan onion	*Allium peninsulare var. franciscanum*	FSLC	--/--	AGS, MHW			X
Hall's tarplant	*Deinandra halliana*	FSC	--/1B	AGS, ASC, VOW		X	
Heartscale	*Atriplex cordulata*	FSC	--/1B	AGS, ASC	X		X
Hispid bird's-beak	*Cordylanthus mollis hispidus*	FSLC	--/1B	Alkali sinks	X		X
Jared's pepper-grass	*Lepidium jaredii jaredii*	FSC	--/1B	Alkali sinks		X	
Jones's layia	*Layia jonesii*	FSC	--/1B	AGS, Chaparral		X	
Kellogg's horkelia	*Horkelia cuneata sericea*	FSC	--/1B	CSC, Chaparral		X	
Lemmon's jewelflower	*Caulanthus coulteri lemmonii*	FSC	--/1B	AGS, PJN		X	
Lesser saltscale	*Atriplex minuscule*	FSC	--/1B	Alkaline AGS, ASC,	X		
Little mousetail	*Myosurus minimus apus*	FSC	--/3	Vernal pools			X
Lost Hills saltbush [=crownscale]	*Atriplex vellicola*	FSC	--/1B	AGS, ASC, Vernal pools	X		
Mason's neststraw	*Stylocline masonii*	FSC	--/1B	ASC, PJN		X	
Miles's milk-vetch	*Astragalus didymocarpus milesianus*	--	--/1B	CSC		X	
Munz's tidy-tips	*Layia munzii*	FSC	--/1B	AGS, ASC	X	X	
Obispo Indian paintbrush	*Castilleja densiflora obispoensis*	--	--/1B	AGS		X	
Pale-yellow layia	*Layia heterotricha*	FSC	--/1B	AGS, PJN		X	
Panoche pepper-grass	*Lepidium jaredii album*	FSC	--/1B	AGS	X	X	
Perennial goldfields	*Lasthenia macrantha macrantha*	FSLC	--/1B	CSC, Coastal dunes & bluffs			X
Prostrate navarretia	*Navarretia prostrata*	FSC	--/1B	AGS, CSC, Vernal pools			X

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Recurved larkspur	*Delphinium recurvatum*	FSC	--/1B	AGS, ASC, VOW	X	X	
Round-leaved filaree	*Erodium macrophyllum*	--	--/2	AGS, VOW		X	
San Benito fritillary	*Fritillaria viridea*	FSC	--/1B	Chaparral		X	
San Joaquin spearscale (=saltbush)	*Atriplex joaquiniana*	FSC	--/1B	AGS, ASC		X	X
San Luis Obispo monardella	*Monardella frutescens*	FSC	--/1B	CSC, Coastal dunes		X	
Showy (=golden) madia	*Madia radiata*	FSC	--/1B	AGS, ASC, VOW		X	
Slough thistle	*Cirsium crassicaule*	FSC	--/1B	FEW, SEW, Riparian scub			X
Spiny-sepaled coyote-thistle (=button-celery)	*Eryngium spinosepalum*	FSC	--/1B	AGS, Vernal Pools			X
Tremblor buckwheat	*Eriogonum temblorense*	FSC	--/4	AGS		X	
Valley sagitteria (=Sanford's arrowhead)	*Sagittaria sanfordii*	FSC	--/1B	FEW, ponds, ditched	X		X
Sacramento (=vernal pool) saltbush (=saltscale)	*Atriplex persistens*	FSC	--/1B	AGS, Vernal pools			X

Notes:
[a] Petitioned for listing as state-threatened or endangered April 2003.
[b] Formerly listed as threatened (delisted September 22, 2003).
AGS = Annual Grassland, ASC = Akali Desert Scrub, COW = Coastal Oak Woodland, CRC = Chamise-Redshank Chaparral, CRP = Croplands, CSC = Coastal Scrub, EST = Estuary, FEW = Freshwater Emergent Wetland, MAR = Marine, MHW = Montane Hardwood, PJN = Pinyon-Juniper Woodland, RIV = Riverine, SEW = Saltwater Emergent Wetland, VOW =Valley Oak Woodland, VRI = Valley Foothill Riparian

Federal Status Definitions
FSC = Species of Concern (species for which existing information indicates may warrant listing, but for which substantial biological information to support a proposed rule is lacking)
FSLC = Species of local concern or conservation importance
(--) = not listed under the Federal Endangered Species Act

State Status Definitions
CSC = Species of Special Concern (native species of subspecies that has become vulnerable to extinction because of declining population levels, limited range, or rarity. The goal is to prevent these animals from becoming endangered by addressing the issue of concern early enough to secure long-term viability for the species)
(--) = Not listed under the California Endangered Species Act.

California Native Plant Society (CNPS) Status
1A = Presumed extinct in California
1B = Rare or endangered in California and elsewhere
2 = Rare or endangered in California, more common elsewhere
3 = Plants for which more information is needed (Review List)
4 = Plants of limited distribution (Watch List)