APPENDIX B

# Pilot Studies

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**Figure**



**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 is scheduled to run August to October 2004. The pilot test of tubular nanofiltration pretreatment will be conducted between September 2004 and March 2005.

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 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 tests results are scheduled to be published in a report in September 2004.

### 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 published in a final report, which is scheduled to be completed in September 2004.

### 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 are to:

- Set up a pilot-scale Se treatment and evaporation basins system that will 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 moves 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 will flow into the evaporation basin facility. This facility will consist of three evaporation cells to be operated as an approximation of the full-scale system proposed by Reclamation. The cells will operate in series and the overall system will be designed to have zero net discharge under typical evaporation and weather conditions. Proposed depths in each cell will vary from approximately 3 to 5 feet, and the water-surface elevation in each cell will be controlled by overflow spillways discharging to the next cell. The permanent water-surface elevation in the three cells will decrease 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 will be regulated to provide constant inflow to all cells. The permanent pool in each cell will be controlled by the overflow spillway elevations and will remain constant. After all three cells are filled, the required flow rate to the first cell will be decreased to an average of 0.5 gpm, based on steady-state conditions. This rate will be adjusted as necessary based on actual evaporation rates to maintain the cells at full capacity. Cells will feed subsequent cells in an effort to match average evaporation rates. Due to the fact that downstream cells will be receiving effluent from upstream cells, the salinity is expected to increase from the first cell to the third cell.

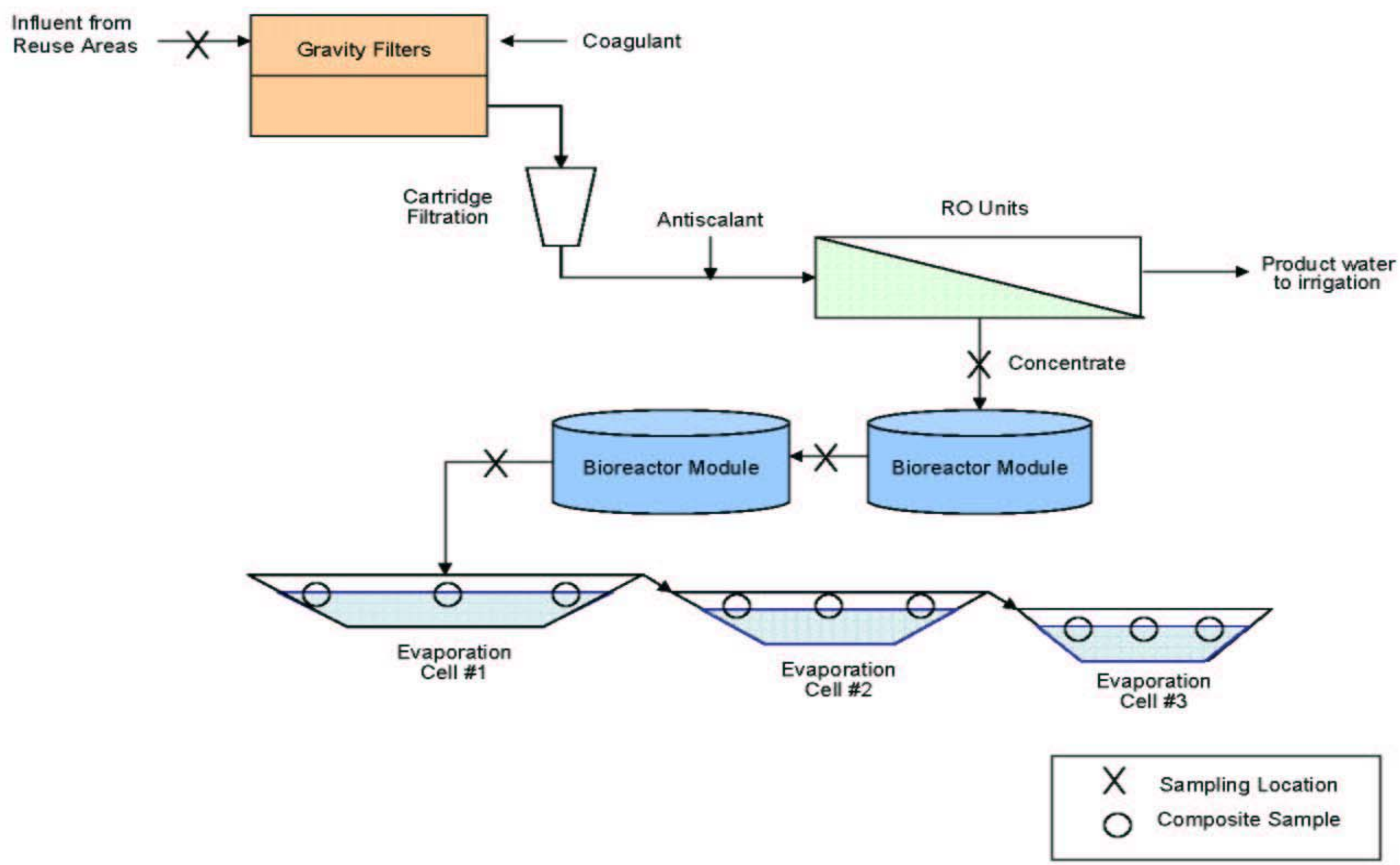



**Figure B-1 Pilot Selenium Treatment, Reverse Osmosis, and Evaporation Basin System**

### B4.2 Bioaccumulation Pilot Schedule and Results

The approximate project schedule is as follows:

- Cells will be prepared, filled, and seeded with invertebrates by August 2004.
- Se speciation and bioaccumulation will be monitored monthly from August to November 2004
- Data will be available by December 2004 for incorporation into the Draft EIS.

### 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.

## 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 x $10^6$ 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.

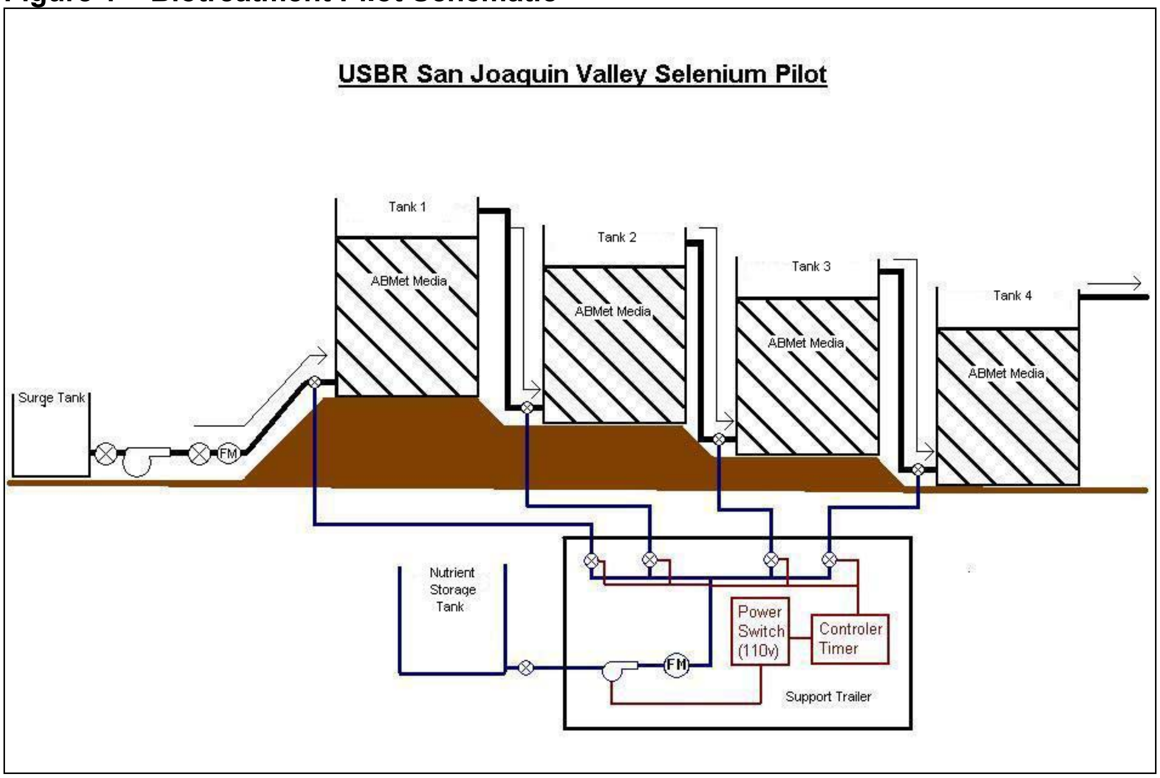
## MATERIALS AND METHOD

### ***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**

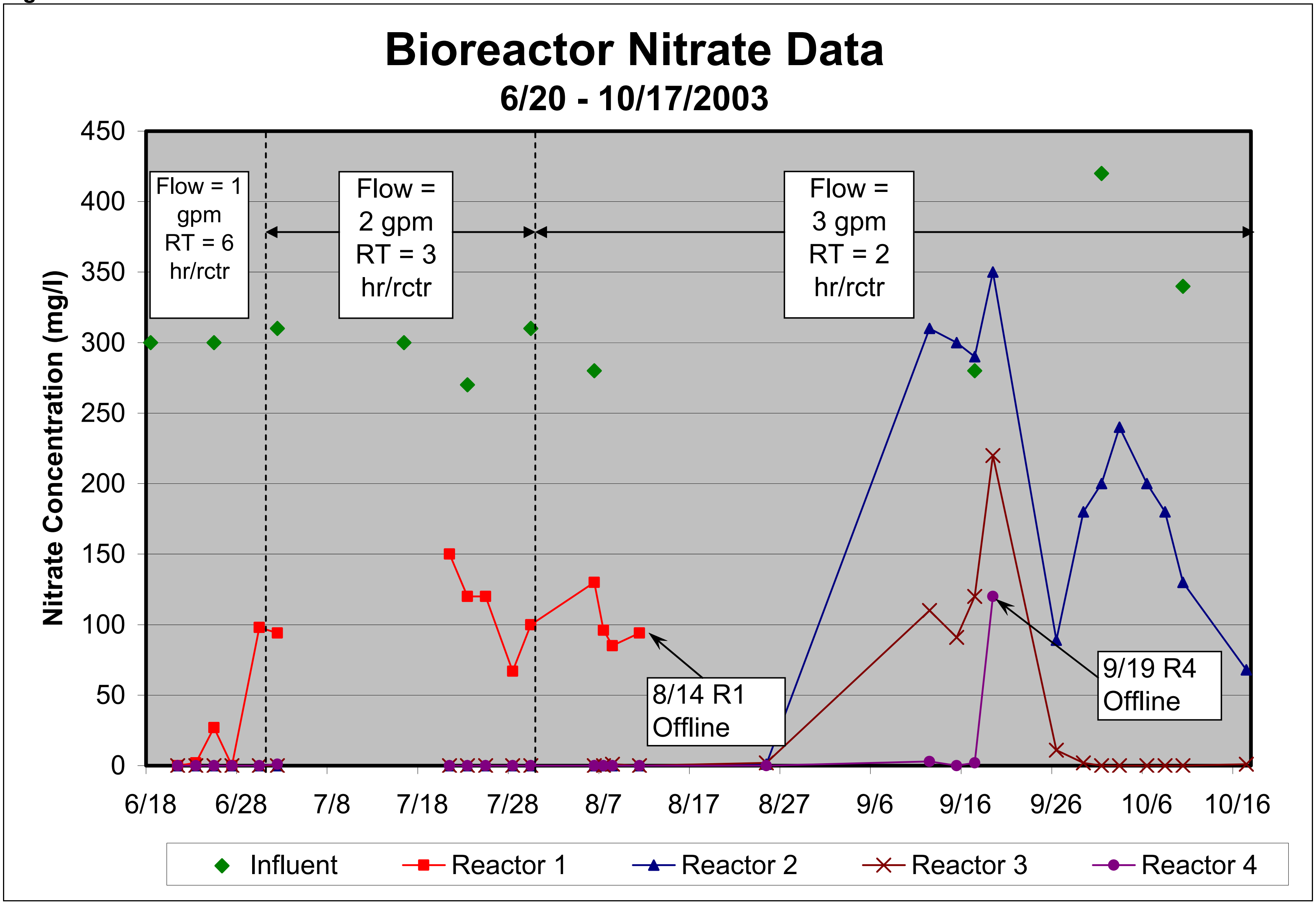
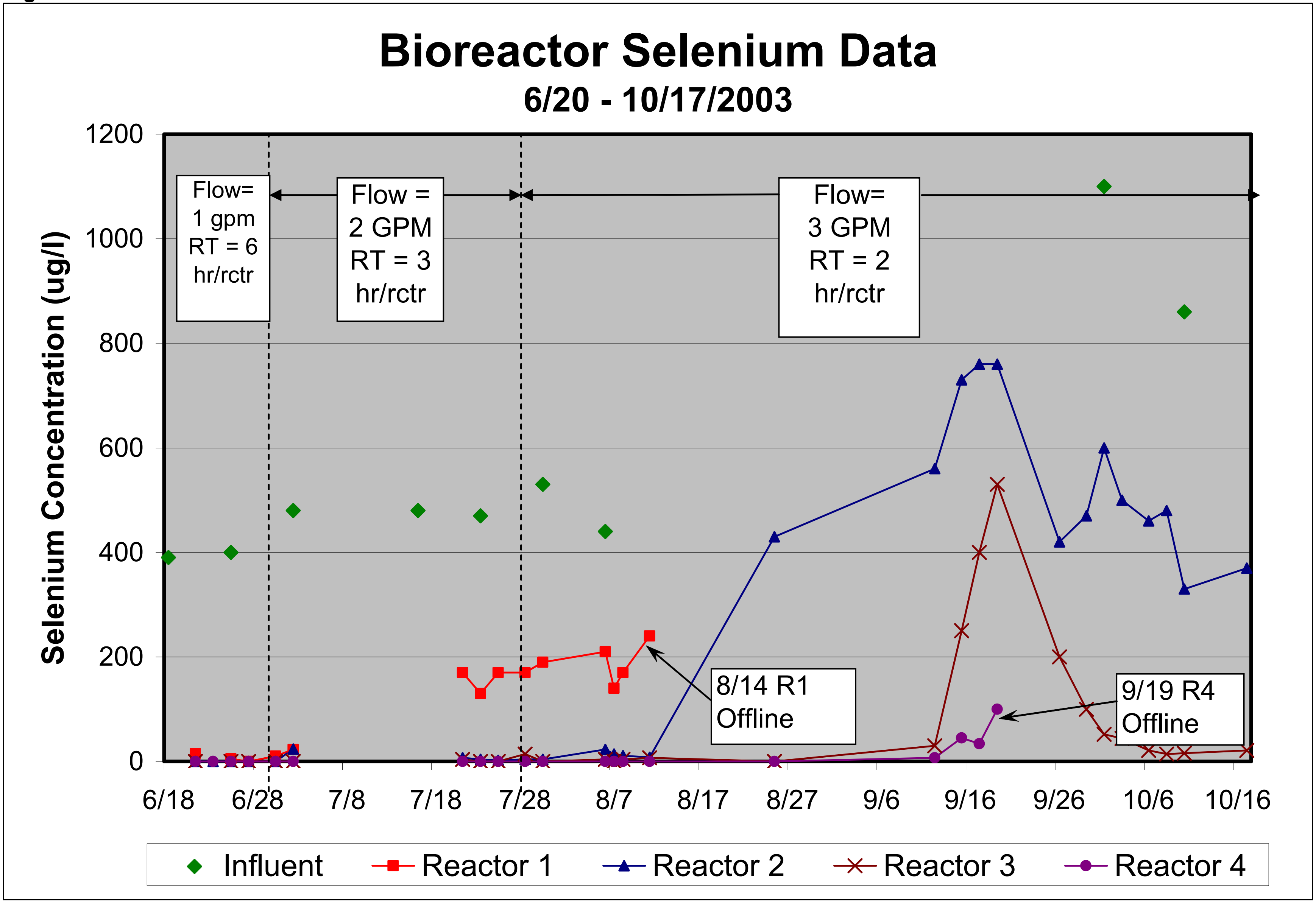


**Figure 5 – Selenium Data for duration 6/20 to 10/17/2003**



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**

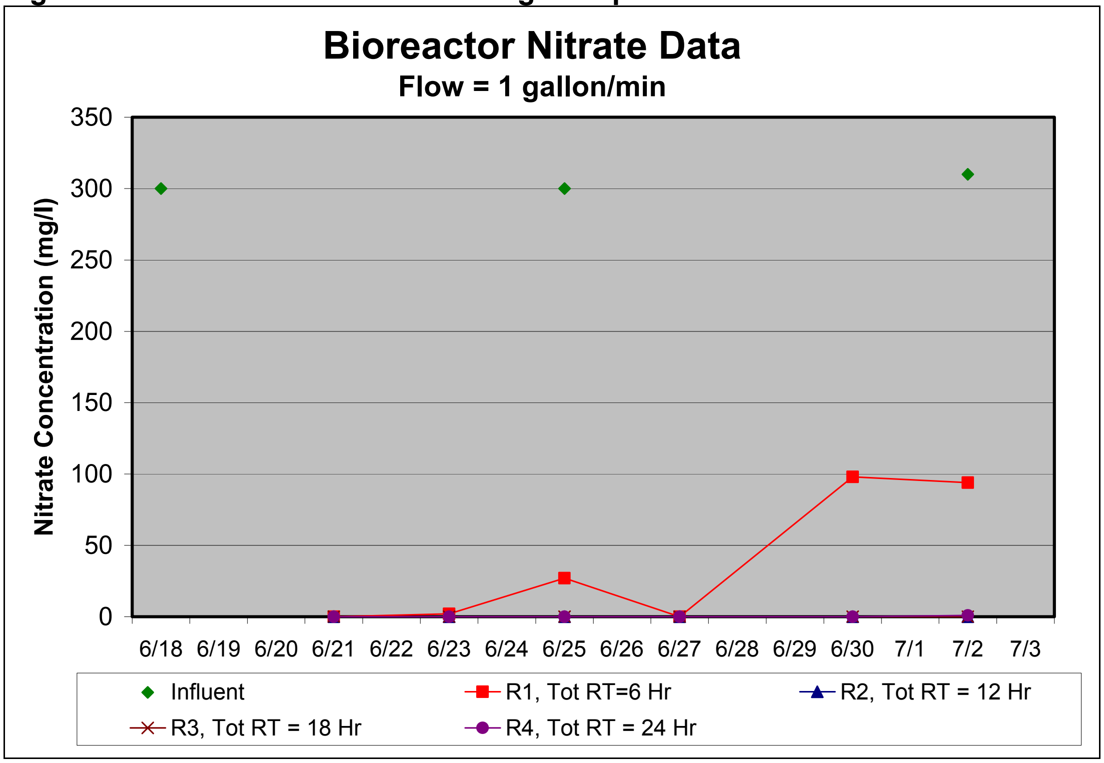



**Figure 7 – Selenium Concentration at 1 gallon per minute**

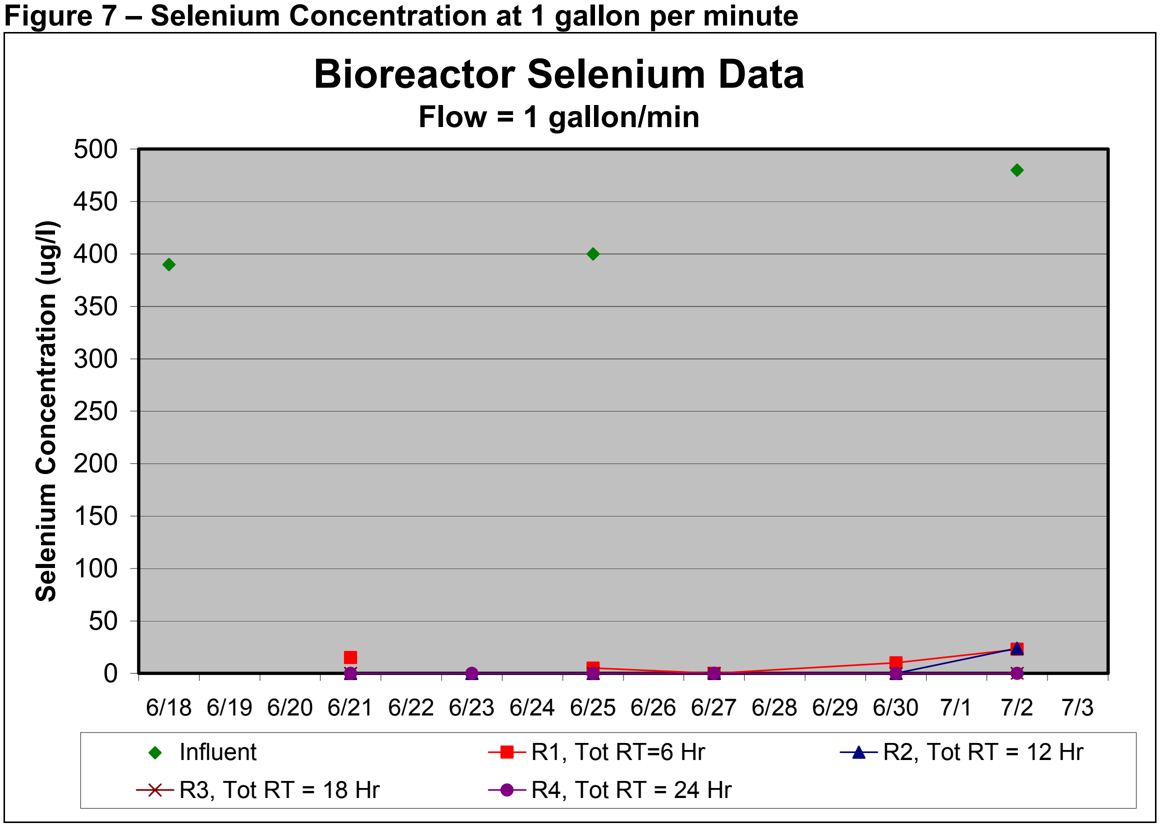


**Figure 8 – Nitrate Concentration at 2 gallons per minute**

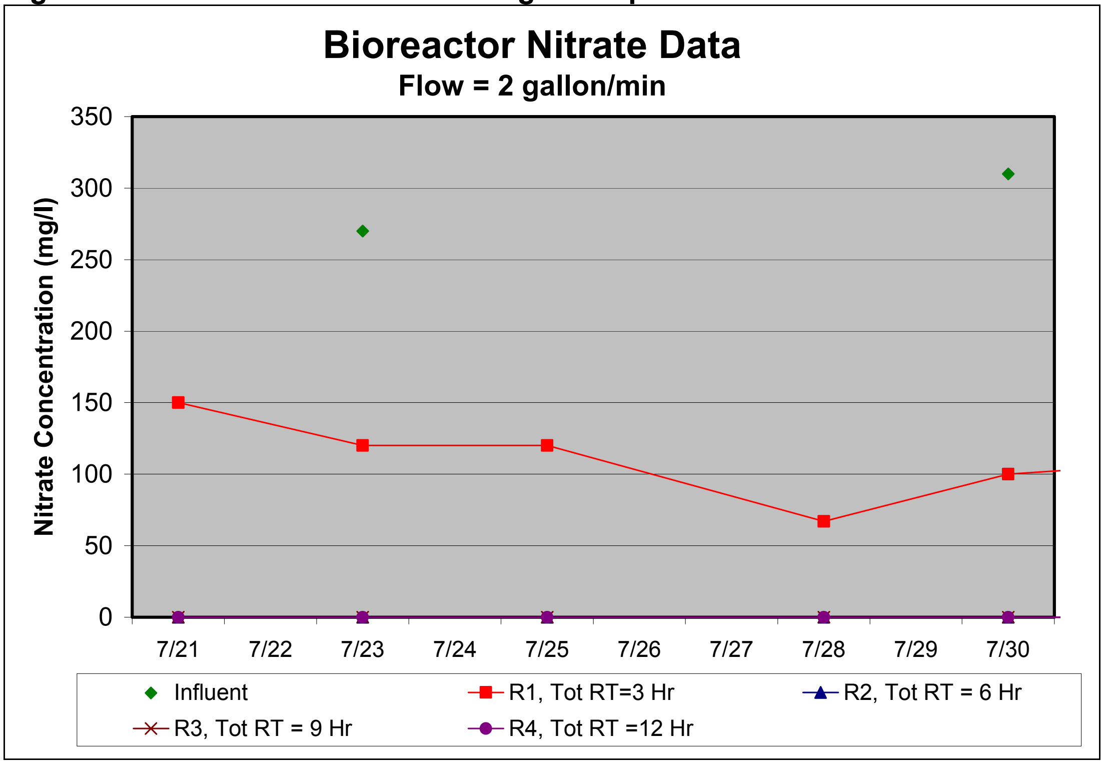
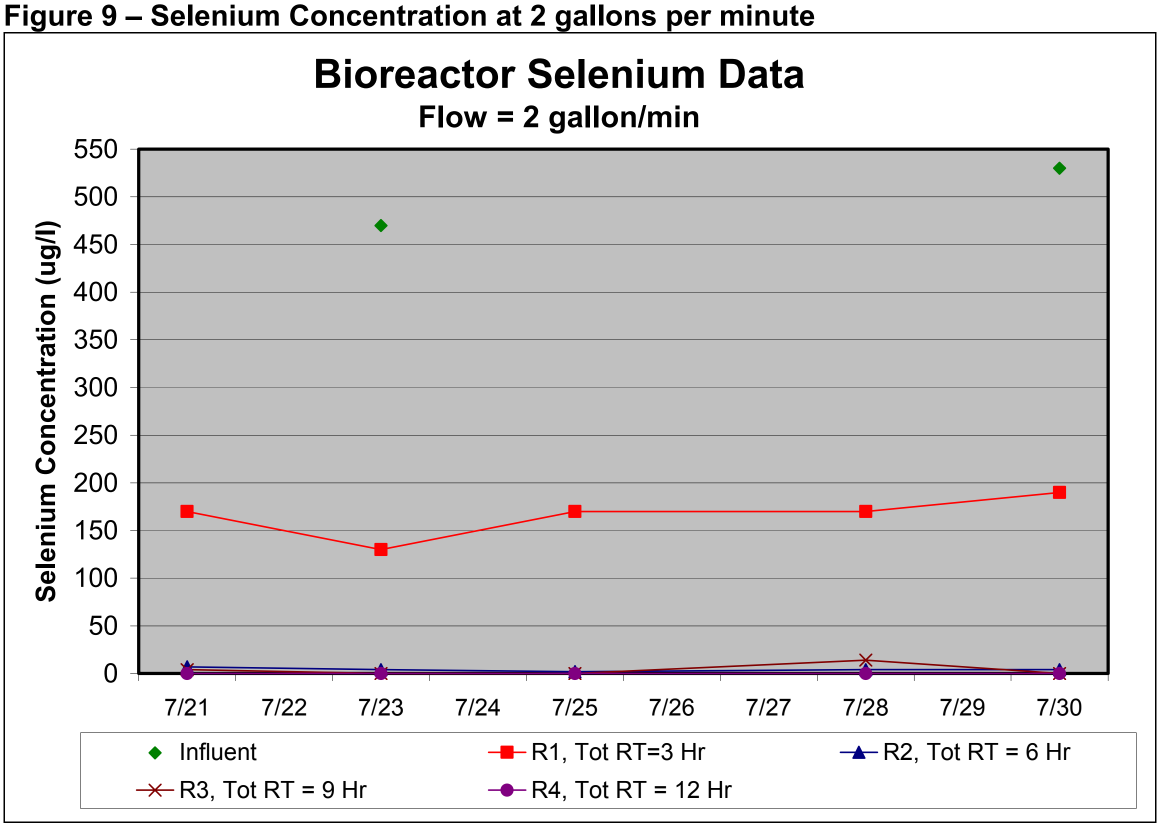



**Figure 9 – Selenium Concentration at 2 gallons per minute**



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 $14^{th}$ all the reactors were shut down due to plugging problems. On August $19^{th}$ 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**

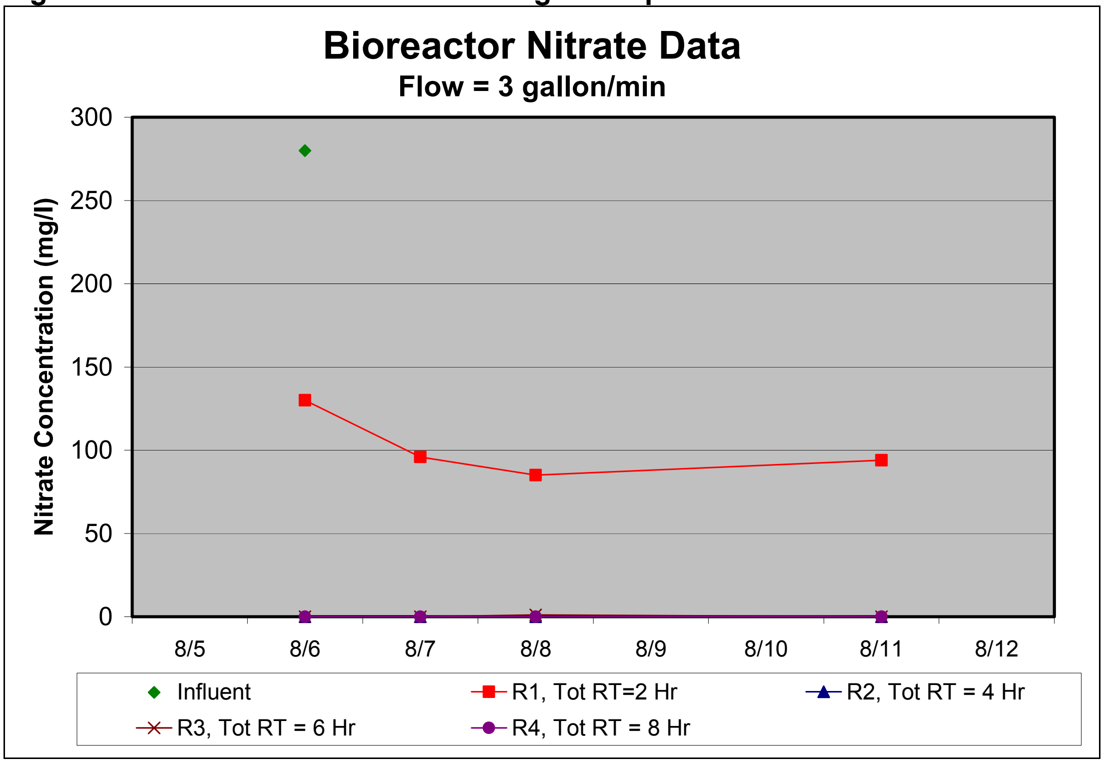



**Figure 11 – Selenium Concentration at 3 gallons per minute**

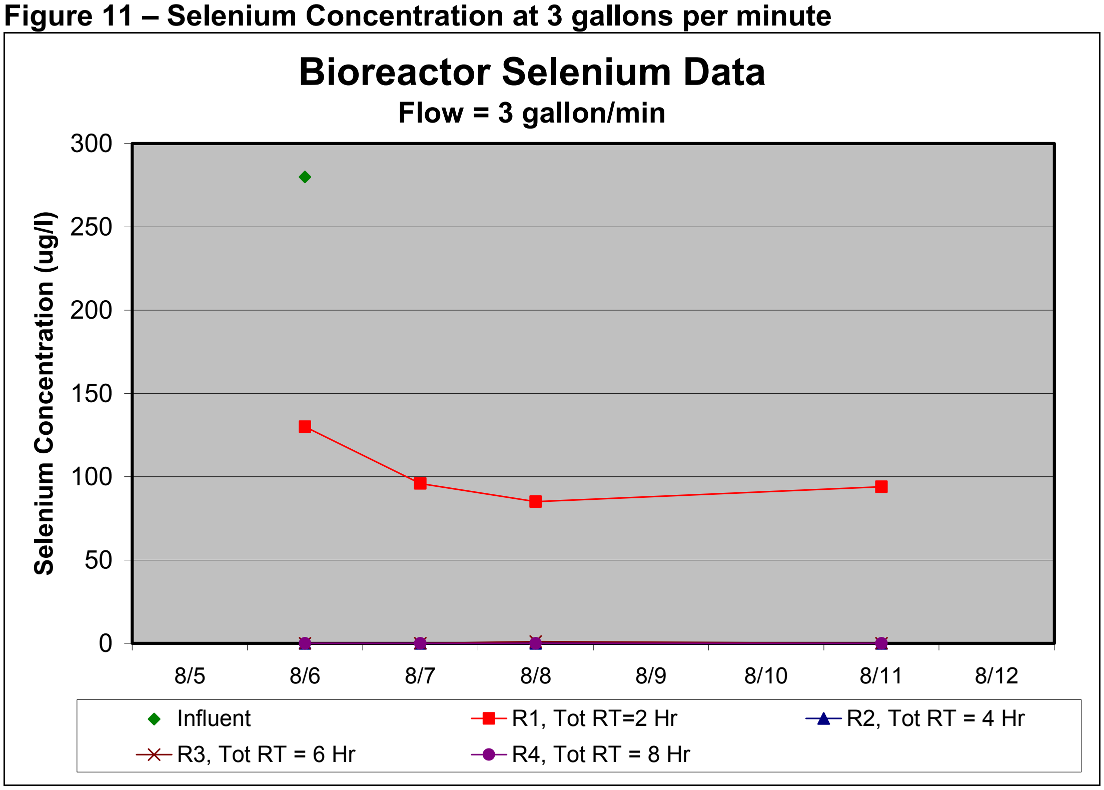


**Figure 12 – Nitrate Concentration for 9/12 – 10/17/2003, Flow = 3 gallons per minute**

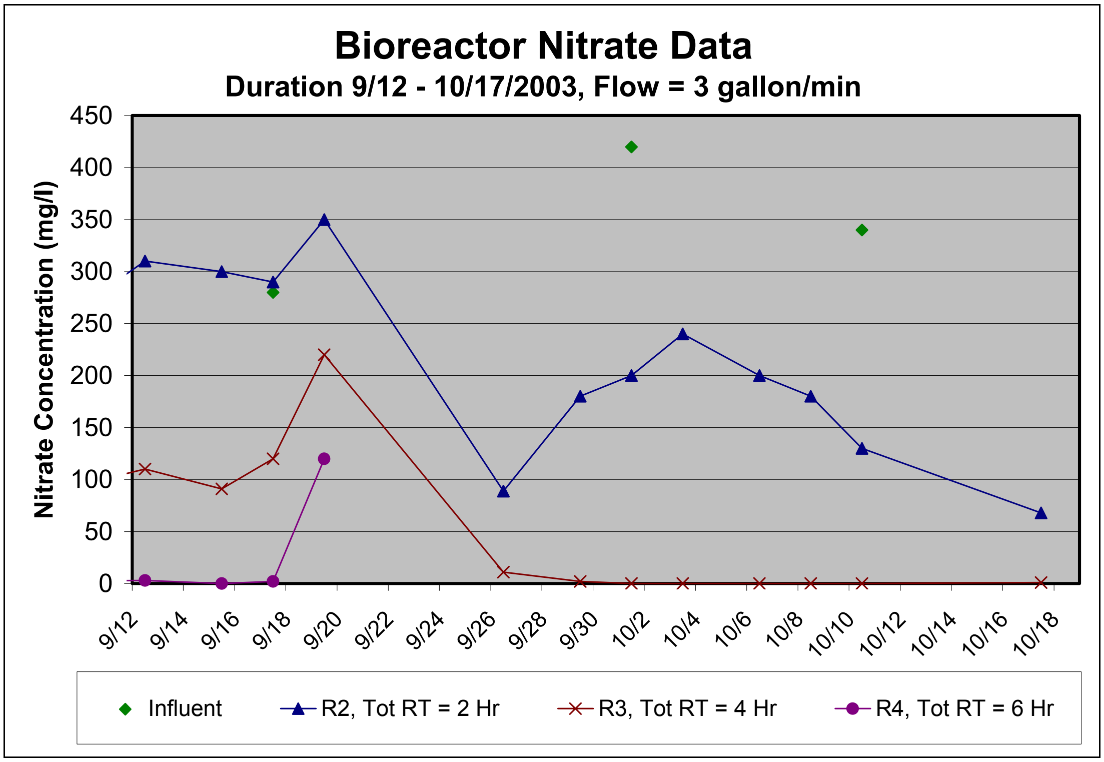
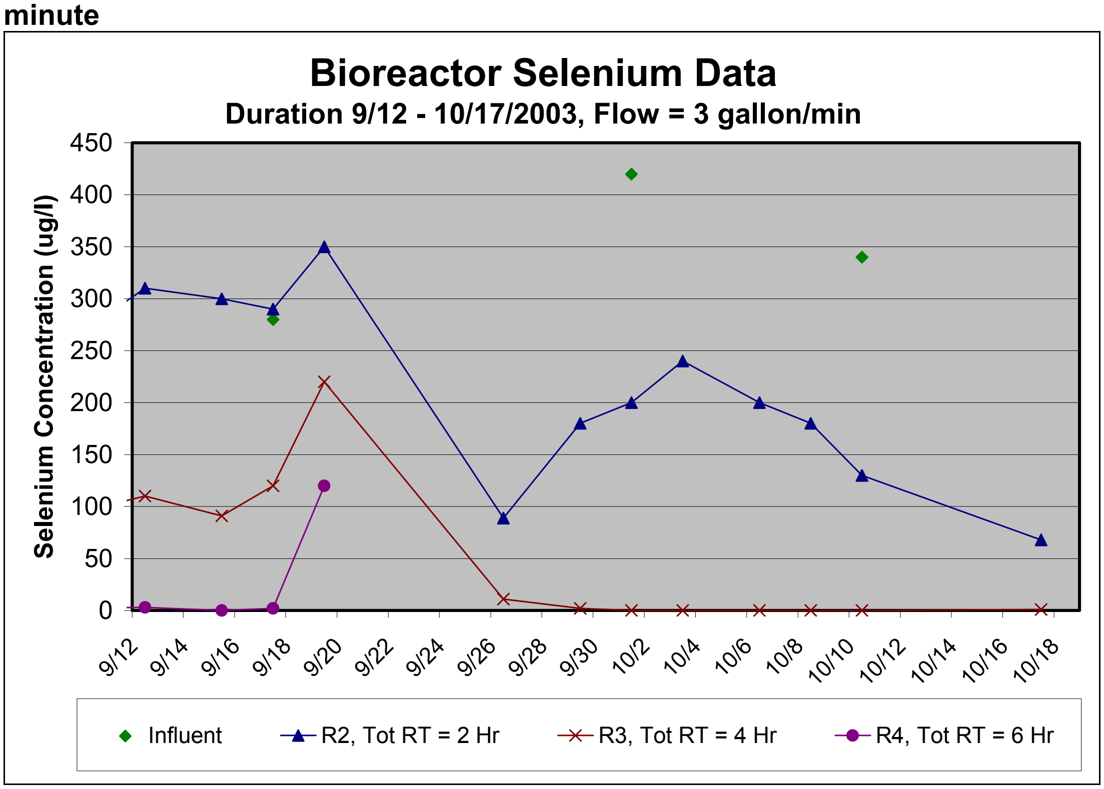



**Figure 13 – Selenium Concentration for 9/12 – 10/17/2003, Flow = 3 gallons per minute**



### 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**

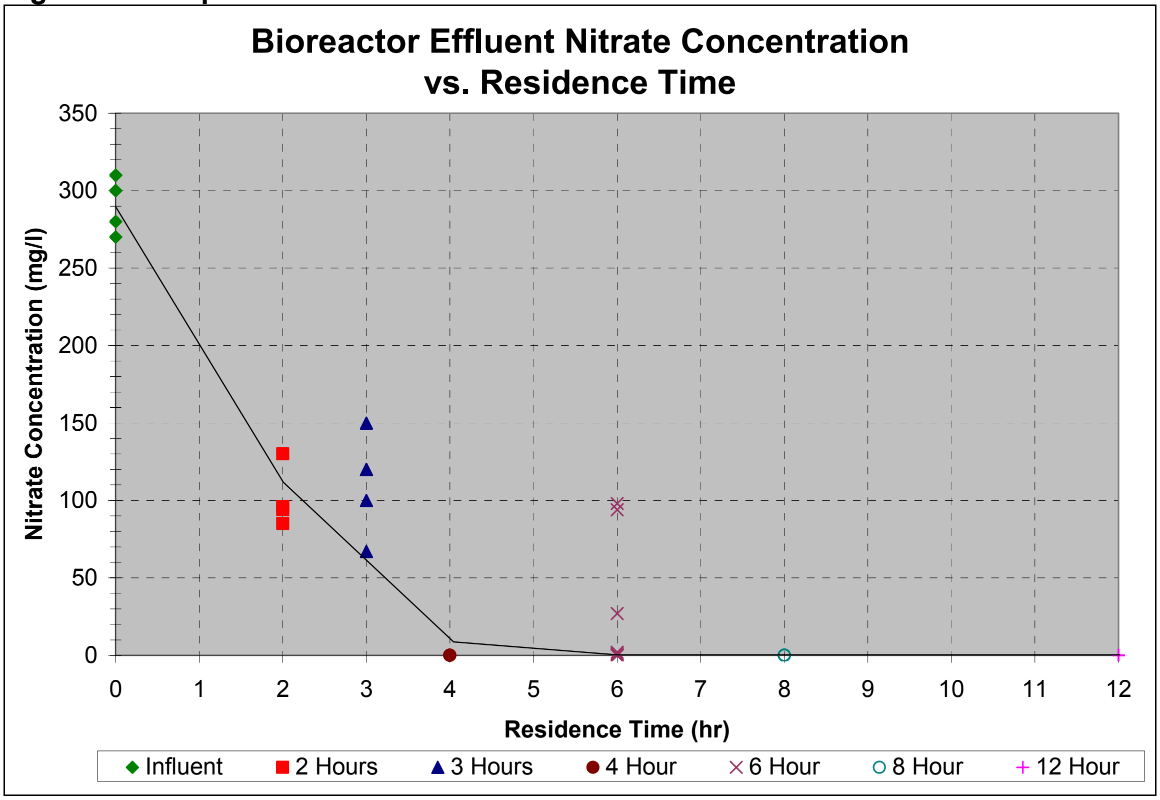



**Figure 15 – Impact of Residence Time on Nitrate Removal**

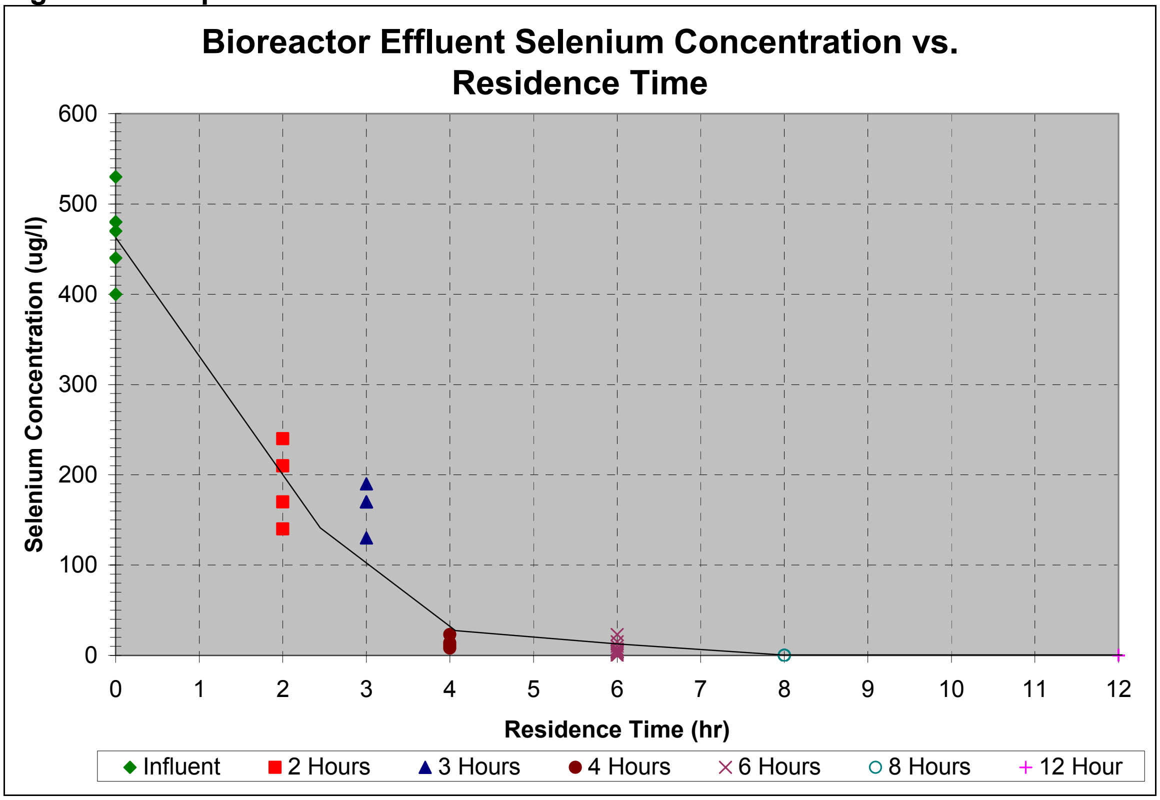


**Table 7 – Residence Time and Nitrate Concentration**

| 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.

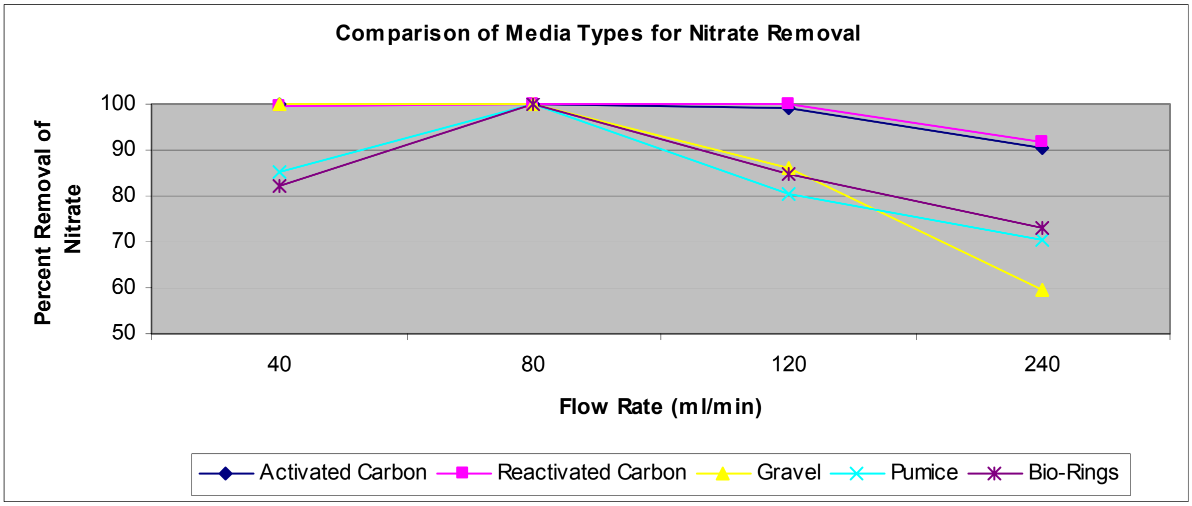
***Material and Method***

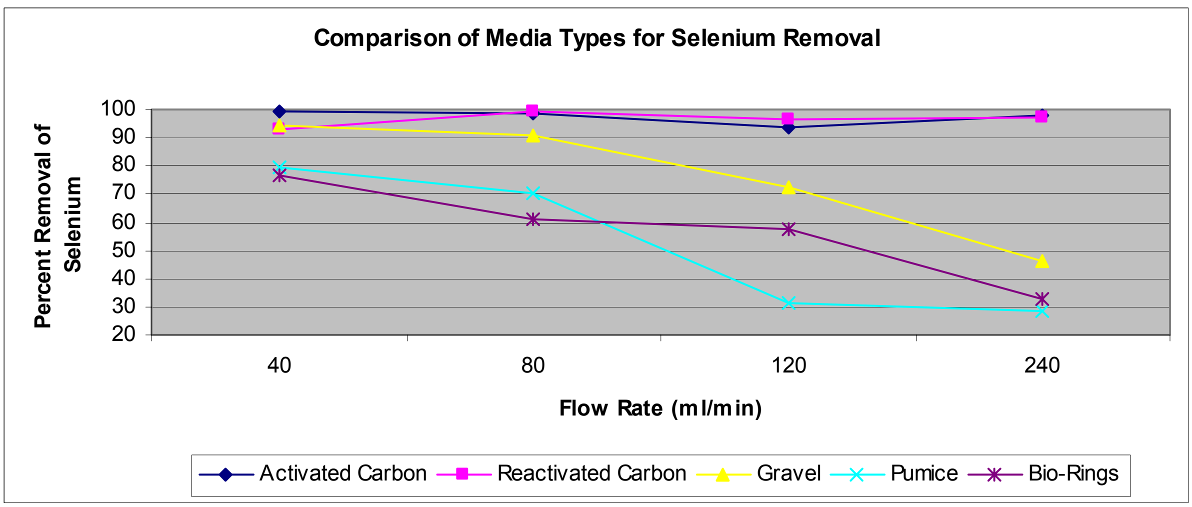
For this study Applied Biosciences personnel constructed five 30 gallon pilot scale reactors. Each reactor was plumbed with a water distribution system and automated nutrient delivery system. The reactors were filled to the same level with one of the five media types and inoculated with Applied Biosciences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

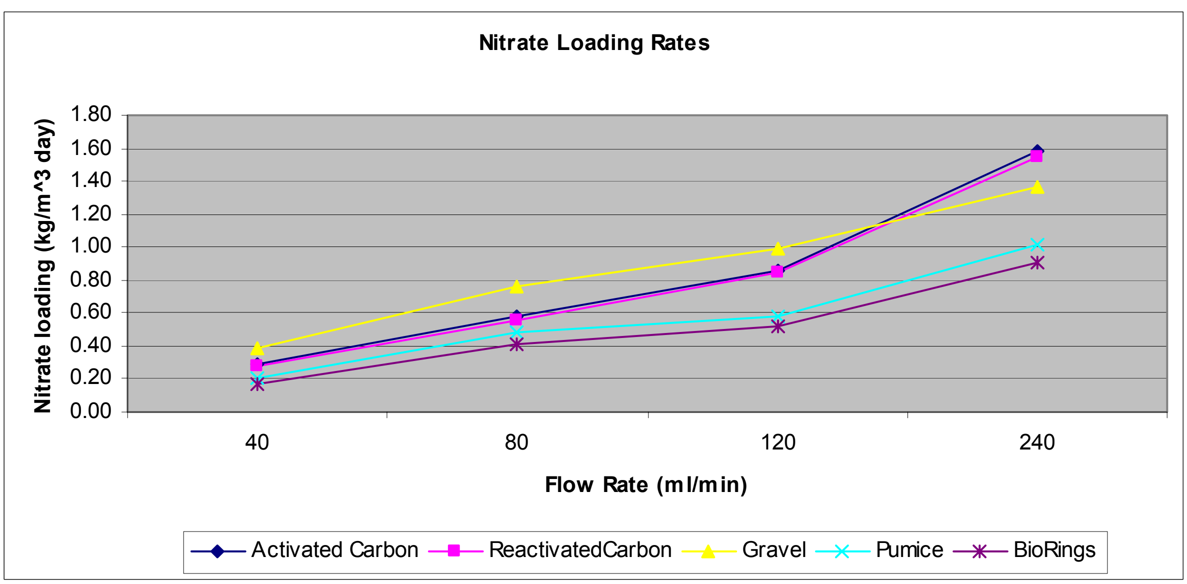
The system was tested at four flow rates over a period of six weeks. The reactor effluent was sampled three times per week and the supply was sampled once per week. All samples were collected by Panoche Water and Drainage District personnel and analyzed by BSK laboratories in Fresno California for nitrate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

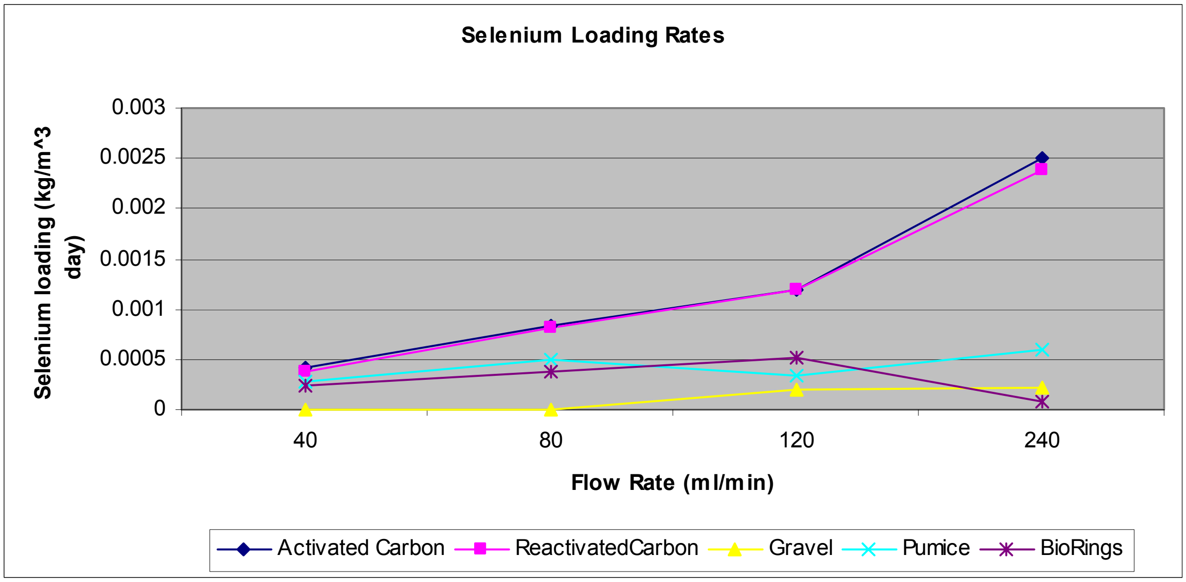
***Results***

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.

APPENDIX C

# DRAINWATER QUANTITY AND QUALITY

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## Tables

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### Figures



### 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) |
| EIS | Environmental Impact Statement |
| 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 |
| Westlands South | 92,000 |
| **Total** | **298,000** |

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

| Projection | Area (acres) |
|---|---|
| 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 cubic feet per second

## 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 cubic feet per second

## 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 cubic feet per second

**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 cubic feet per second

## 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 in 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 in 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 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.

**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**

| 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 | 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 Grassland 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 | 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 | 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 |

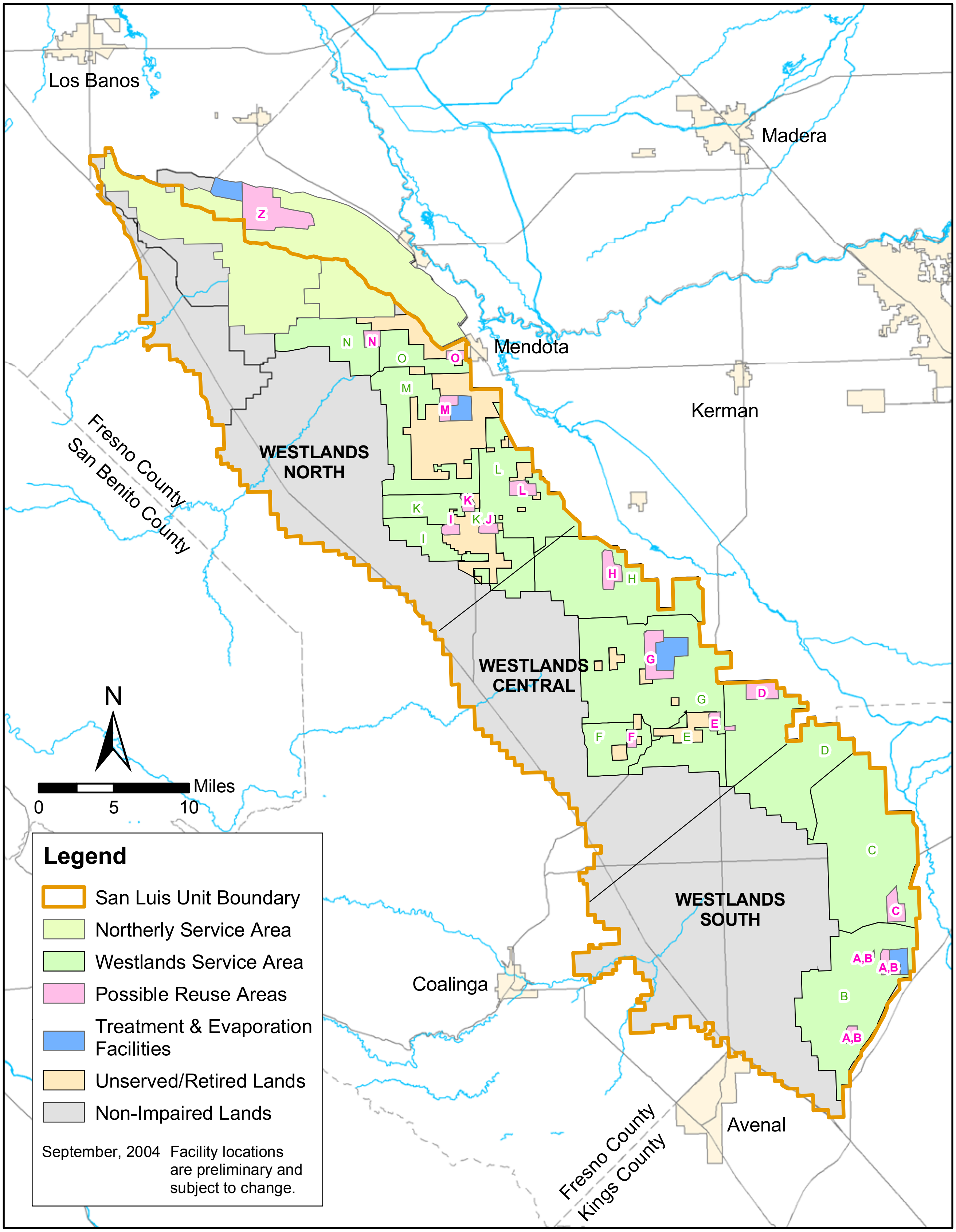
## Table C2-3
## Molybdenum Concentrations General Statistics

| Molybdenum | N | mean | median | min | max | std dev | p-value* | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Arith | 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 |

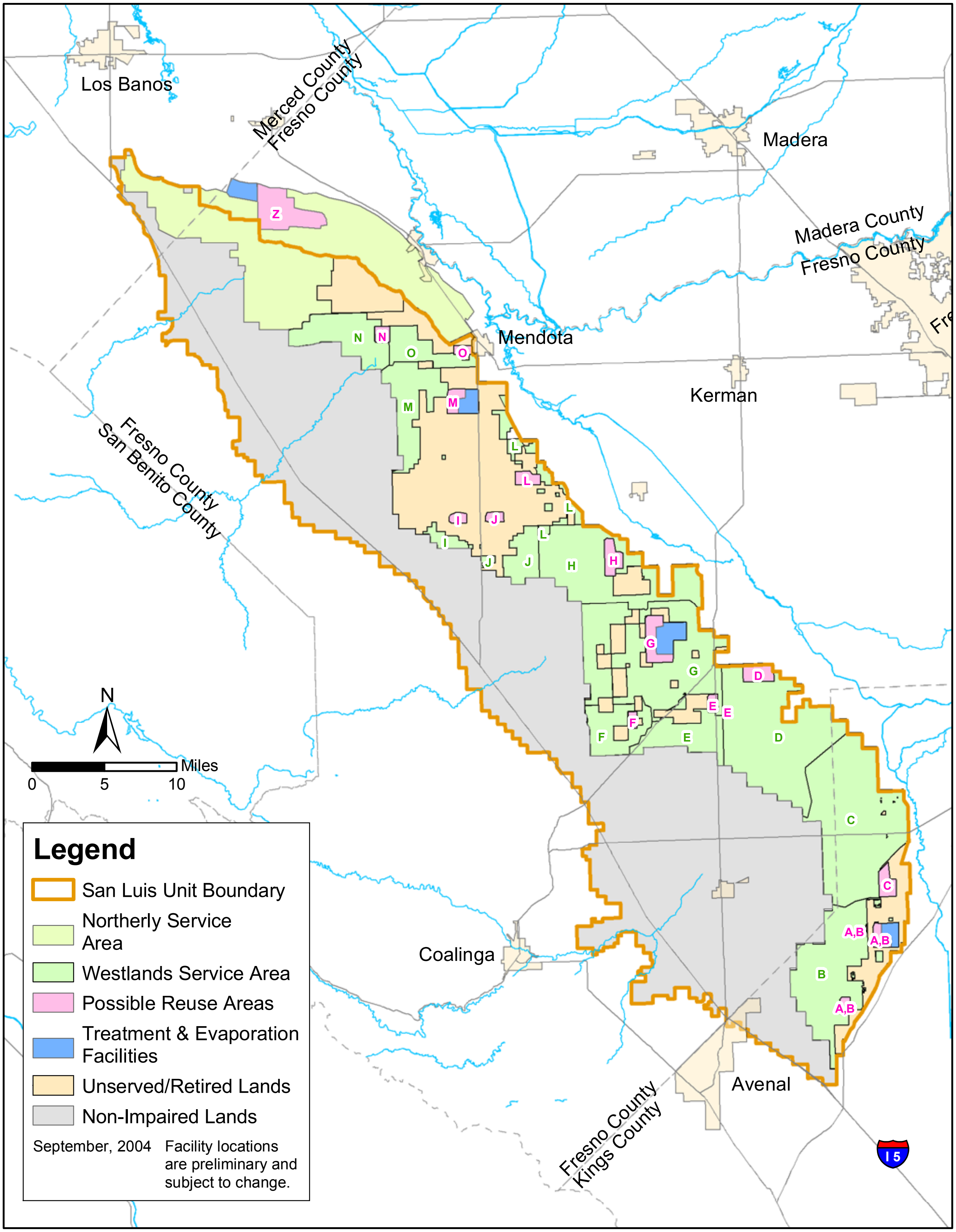
## Table C2-4
## Boron Concentrations General Statistics

| Boron | N | mean | median | min | max | std dev | p-value* | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Arith | 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 |

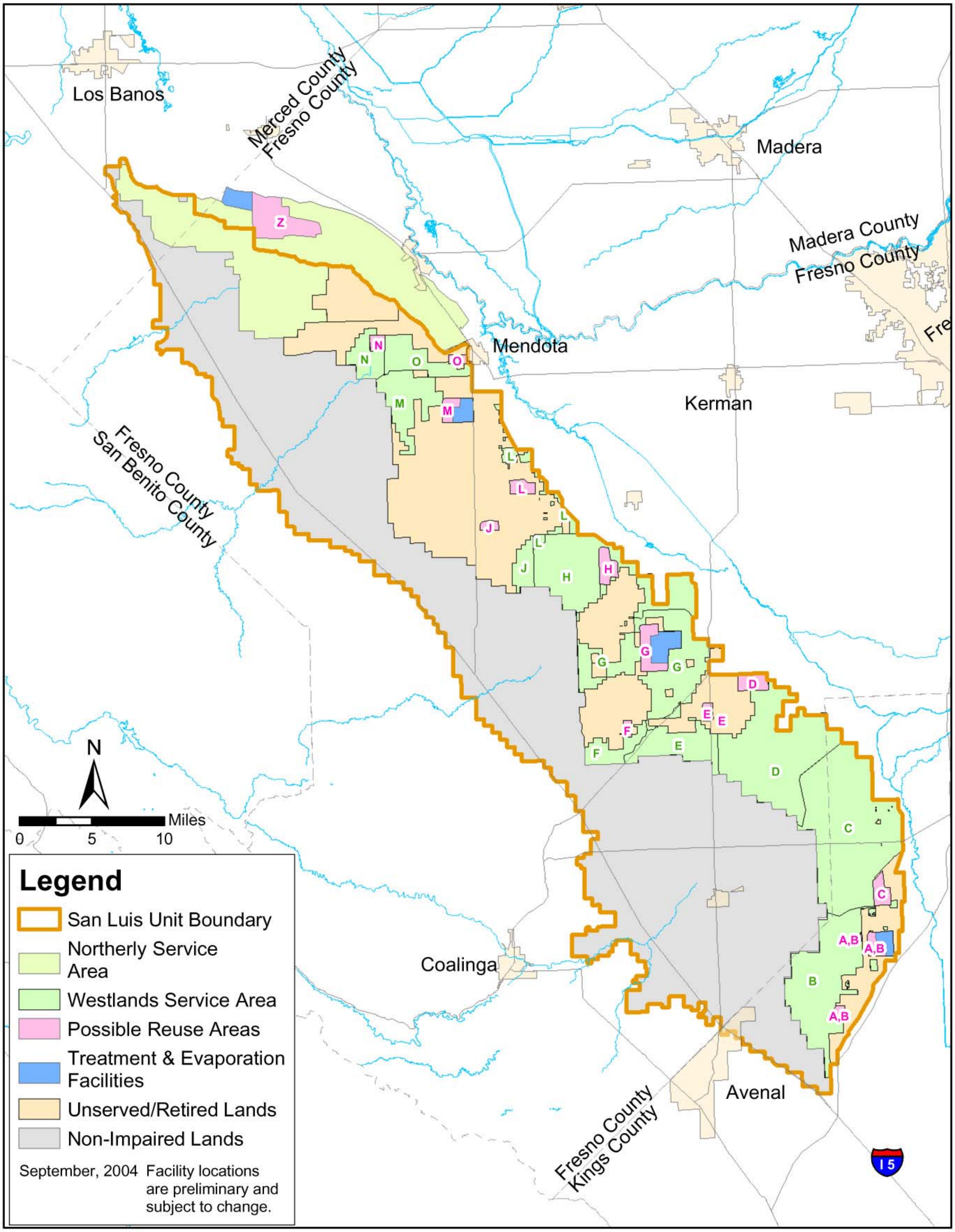
*Shapiro-Wilk W test. If the p-value reported is less than .05 (or some other alpha), then you conclude that the distribution is not normal.



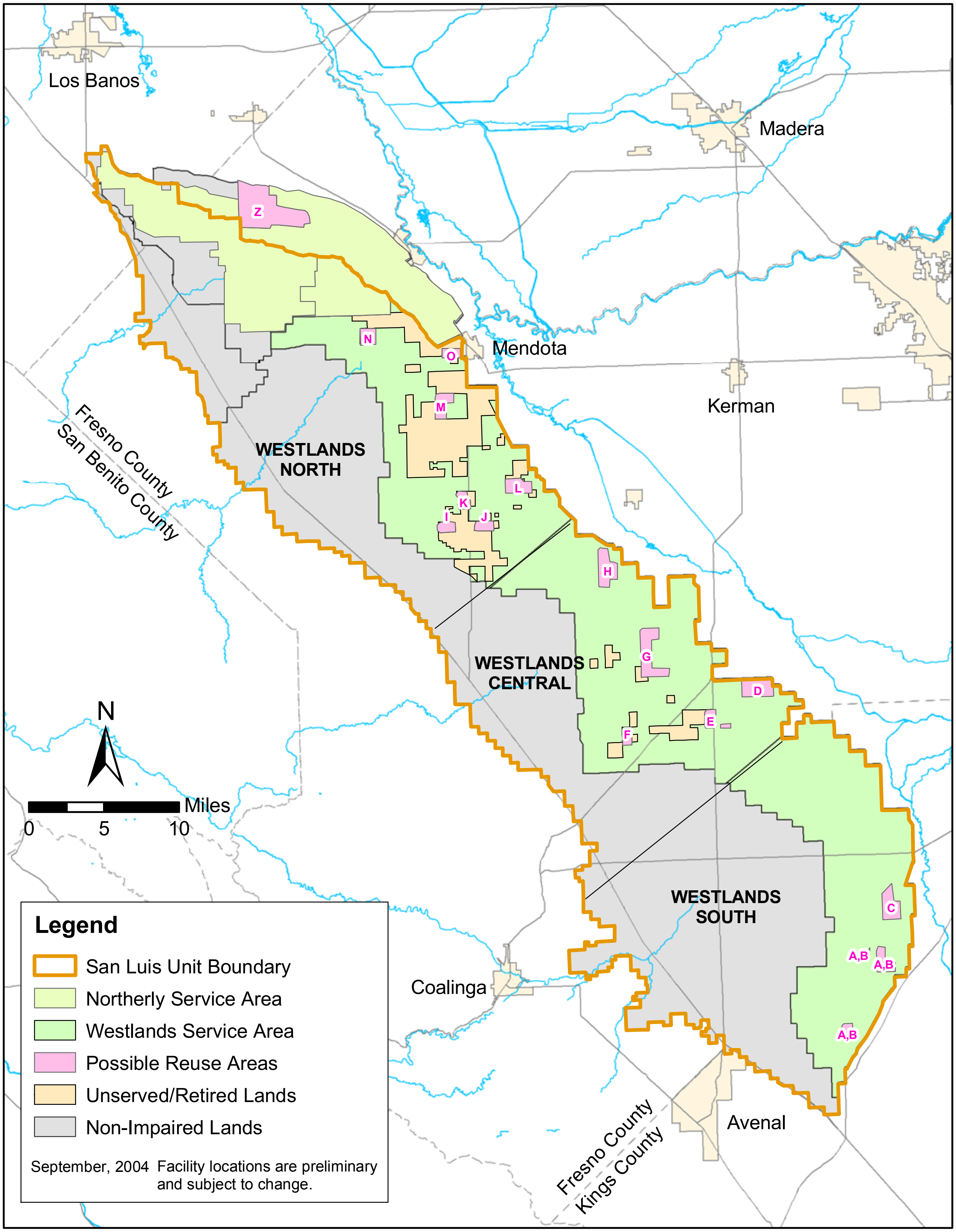

| San Luis Drainage Feature Re-evaluation | Drainage and Reuse Areas, In-Valley Disposal Alternative | Figure C2-1 |
|---|---|---|
| 17324004 | | |




| San Luis Drainage Feature Re-evaluation | Drainage and Reuse Areas, In-Valley/Groundwater Quality Land Retirement Alternative | Figure C2-2 |
|---|---|---|
| 17324004 | | |




| San Luis Drainage Feature Re-evaluation | Drainage and Reuse Areas, In-Valley/Water Needs Land Retirement Alternative | Figure C2-3 |
|---|---|---|
| 17324004 | | |




| San Luis Drainage Feature Re-evaluation | Drainage and Reuse Areas, Out-of-Valley Disposal Alternatives | Figure C2-4 |
|---|---|---|
| 17324004 | | |

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**

| | **Constituents** | | | |
|---|---|---|---|---|
| **Parameters*** | **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

$\sigma_n$ = 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:

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

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

$\sigma_n$ = 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**

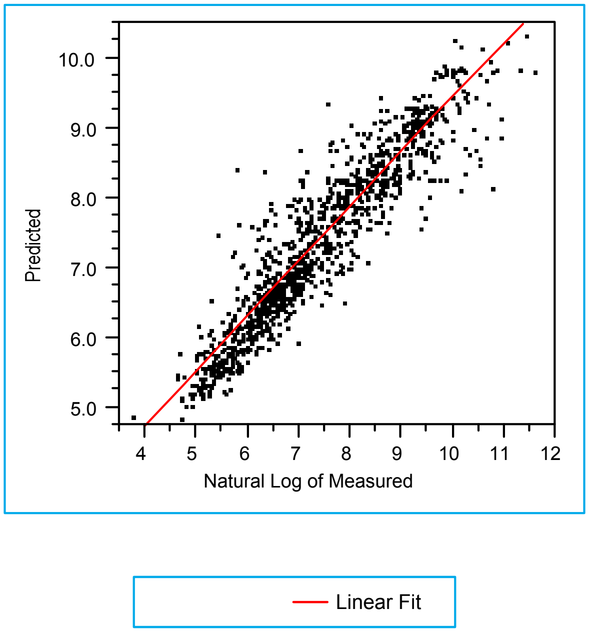
| | | Observed | Geostatistical Modeling | | | | |
|---|---|---|---|---|---|---|---|
| **Constituent** | **Units** | **Flow Weighted Mean Measured in Sumps*** | **Mean** | **Std error** | **95% UCL Mean** | **Scaled Mean** | **95% UCL Scaled Mean** |
| Se | µg/L | 132 | 43 | 38 | 118 | 44 | 119 |
| TDS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

*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 |

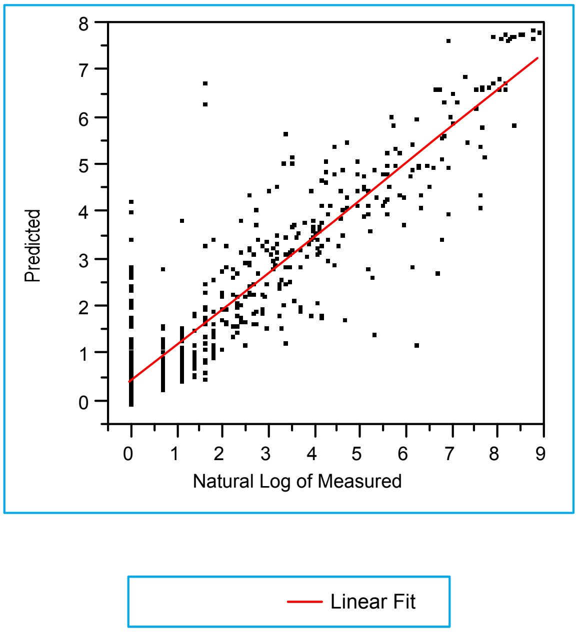
**Analysis of Variance**

| 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 |

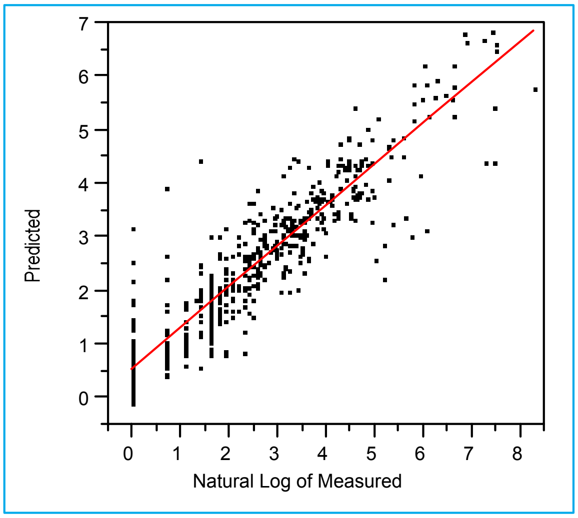
**Analysis of Variance**

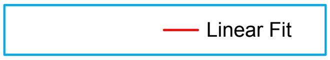
| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 1 | 2260.7353 | 2260.74 | 3660.545 |
| Error | 701 | 432.9343 | 0.62 | Prob>F |
| C Total | 702 | 2693.6696 | | <.0001 |

**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 |

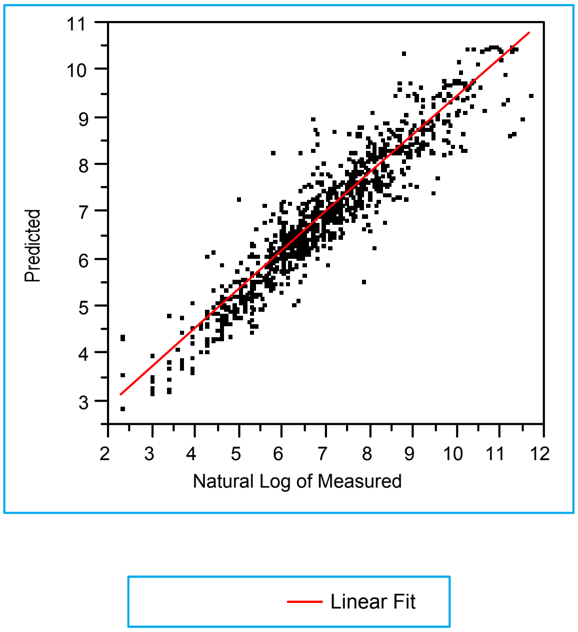
**Analysis of Variance**

| 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)**

| 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 (Reclamation 2001b), and other data (personal communication with Joe McGahan).

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 C2-8 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 |

**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 |
|---|---|---|---|---|---|---|
| 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 |
| 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 |
| 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 C2-20**
**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 C2-21 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 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 C2-23**
**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.

## C3 REFERENCES

Arroues. 2002. Supervisory Soil Scientist. Natural Resource Conservation Service. Personal communication with URS. April.

Bureau of Reclamation (Reclamation). 1984. Draft Environmental Impact Statement. Unpublished.

Bureau of Reclamation (Reclamation). 2001a. Preliminary Alternatives Report (PAR), San Luis Unit Drainage Feature Re-evaluation. December.

Bureau of Reclamation (Reclamation). 2001b. *Grassland Bypass Project, Final Environmental Impact Statement and Environmental Impact Report.* Volume I, main text and appendices A and I. U.S. Bureau of Reclamation, Sacramento and Fresno, CA, and San Luis & Delta-Mendota Water Authority, Los Banos, CA. May 25.

Bureau of Reclamation (Reclamation). 2002. San Luis Drainage Feature Re-evaluation Plan Formulation Report. December. Sacramento, CA.

Busch, Leo J., Agricultural Engineer. 1994. Evaluation Report of Present Drainage Requirements for San Luis Unit. August 1.

California Fertilizer Association. 1995. *Western Fertilizer Handbook*. Eighth edition.

California Fertilizer Association. 1995. *Western Fertilizer Handbook*. Eighth edition.

CH2MHILL. 1985. Report of Waste Discharge for Storage and Land Application of Subsurface Agricultural Drainwater - Westlands Water District, Fresno, California. June.

Johnston, W.R. 1993. Report on Current Estimates and Identification of Potential Alternatives to the Westlands Water District Drainage Problem. December 29.

Swain, W.C. 1990. Estimation of Shallow Groundwater Quality in the Western and Southern San Joaquin Valley, California. Technical Information Record. San Joaquin Valley Drainage Program, Interagency Study Team, Sacramento, CA. September.

URS. 2002. Source Control Technical Memorandum. Prepared for the Bureau of Reclamation. June 17.

APPENDIX D

# WATER QUALITY MODELING

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## Tables



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### Acronyms

| | |
|---|---|
| AD | MIKE 21 advection-dispersion module |
| CalCOFI | California Cooperative Oceanic Fisheries Investigations Program |
| CCCCS | Central California Coastal Circulation Study |
| CCWD | Contra Costa Water District |
| CDIP | Coastal Data Information Program |
| CUA | consumptive use allowance |
| CVRWQCB | Central Valley Regional Water Quality Control Board |
| cfs | cubic feet per second |
| cm | centimeter(s) |
| Delta | Sacramento-San Joaquin River Delta |
| EC | electrical conductivity |
| 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 |
| LSJR | Lower San Joaquin River |
| ME | MIKE 21 heavy metals module |
| µg/L | microgram(s) per liter |
| mg/kg | milligram(s) per kilogram |
| mg/L | milligram(s) per liter |
| NDBC | National Data Buoy Center |
| ppb | part(s) per billion |
| ppm | part(s) per million |
| ppt | part(s) per thousand |
| Re-evaluation | San Luis Drainage Feature Re-evaluation |
| RMS | root-mean-squared |
| RMP | Regional Monitoring Program for Trace Substances |
| SAE | seasonal application efficiency |
| Se | selenium |
| TDS | total dissolved solids |
| TOC | total organic carbon |
| TMDL | total maximum daily load |
| TMML | total maximum monthly load |
| USGS | U.S. Geological Survey |
| VAMP | Vernalis Adaptive Management Plan |
| VP | Visual Plumes program (EPA) |
| WQOs | water quality objectives |

# 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 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 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,<br>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 DIFFUSER ANALYSIS

This section summarizes the Flow Science, Inc. updated effluent plume analysis and preliminary diffuser designs for the Ocean and Delta Disposal Alternatives. Section D2.1 outlines key water quality criteria governing this analysis and the basic effluent data used, reflecting recent revisions. Section D2.2 focuses on the Ocean Disposal Alternative at Point Estero, and Section D2.3 focuses on the Delta Disposal Alternatives at Carquinez Strait and Chipps Island. Due to the close proximity and similar ambient conditions of the two Delta disposal sites, for the purposes of this analysis both were assumed to require the same diffuser design and result in the same effluent plume characteristics.

## D2.1 Key Water Quality Criteria and Effluent Data

In general, the concentrations of Se, TDS, TOC, and bromide resulting from the proposed discharges are the key water quality concerns for the project. However, for this localized diffuser analysis, Se water quality objectives (WQOs) were more restrictive than objectives for other constituents and, hence, Se objectives governed the analysis. Se concentration was used as the design criterion for this analysis, and TDS, TOC, and bromide concentrations resulting at the boundary of the zone of initial dilution were simply noted. The aquatic life criterion of 5 ppb of Se reported in the California Toxics Rule was used as the standard for evaluating the Delta diffuser design and resultant plume. The 6-month median marine aquatic life criterion of 15 ppb of Se reported in the State Water Resources Control Board's California Ocean Plan was used as the standard for evaluating the ocean diffuser design and resultant plume. These criteria are the most stringent currently applicable for Se.

The URS project team provided effluent data that formed the basis of the diffuser designs and plume analyses. Table D2-1 summarizes these data.

**Table D2-1**
**San Luis Drain Effluent Data**

| Effluent Characteristic | Value |
|---|---|
| Flow Rate | 29.1 cfs |
| TDS/Salinity concentration* | 19 ppt |
| Temperature | 50.7°F = 10.4°C (Winter)<br>79.4°F = 26.3°C (Summer) |
| Selenium concentration, discharge to the Delta | 10 ppb |
| Selenium concentration, discharge to the ocean | 220 ppb |
| TOC concentration, Delta and ocean | 8.5 ppm |
| Bromide concentration, Delta and ocean | 5.2 ppm |

**Source:** URS Corporation 2004.

*For the purposes of this analysis, the design TDS concentration of 19,000 ppm (19 parts per thousand [ppt]) was assumed to be equivalent to the effluent salinity. Although this correlation is not perfect, the assumption is reasonable given the preliminary nature of this analysis.

## D2.2 Ocean Discharge Location: Point Estero

In combination with the effluent data in Table D2-1, ambient ocean data gathered from several sources were used to formulate a preliminary diffuser design for the Point Estero ocean disposal site. Data sources included the California Cooperative Oceanic Fisheries Investigations program (CalCOFI), the Coastal Data Information Program of the Scripps Institution of Oceanography at UC San Diego (CDIP), National Oceanic and Atmospheric Administration's National Data Buoy Center (NDBC), and the Central California Coastal Circulation Study (CCCCS, sponsored by the U.S. Department of the Interior). Data were gathered from both web sites and published reports. CalCOFI data are from the cruise stations nearest the proposed outfall location, 25.5 miles away on average. CDIP data are for the Diablo Canyon buoy, approximately 19.0 miles from the proposed outfall location. NDBC data are for the buoy at Point San Luis, approximately 24.3 miles from the proposed outfall location. CCCCS data were collected at two stations, 19.3 and 22.3 miles from the proposed outfall location, respectively. Table D2-2 gives a summary description of each ambient ocean data source used in the analysis.

**Table D2-2**
**Ambient Ocean Data Sources and Descriptions**

| Source | # Data Points* | Date Range | Temperature Data | Salinity Data | Current Data |
|---|---|---|---|---|---|
| CalCOFI | 28 | January 1972 – March 1986 | • | • | |
| CDIP | 80,165 | June 1996 – August 2002 | • | | |
| NDBC | 82,513 | July 1997 – June 2002 | • | | • |
| CCCCS | 38,448 | February 1984 – July 1985 | • | • | • |

*One data point is defined as a temperature, salinity, or current *profile* taken at a specific location at a specific date. Each profile may consist of several measurements.

**Source:** Flow Science data collection, 2002.

It should be noted that ocean temperature, salinity, and especially current data can vary significantly due to local ocean floor topography and hydrodynamics. While the oceanographic data collected for this analysis are the most representative data readily available for the site, they may not perfectly represent conditions at the proposed outfall location. However, although neither a detailed long-term site-specific monitoring program nor a hydrodynamic modeling study of the project area have been conducted to date, it is our qualitative assessment that current data used for this analysis are reasonably representative of diffuser site conditions. It is not known whether the proposed diffuser site is a special null zone that would lead to short-term or long-term constituent accumulation. It should also be noted that the diffuser design-limiting condition is zero current (i.e., stagnant) conditions. Therefore, the design is not immediately dependent on precise current conditions at the site.

Both summer and winter ambient conditions were simulated since seasonal fluctuations can significantly alter the characteristics of the diffuser plume. As mentioned, we also simulated a worst-case zero current velocity scenario. It should be noted that this stagnant condition is unlikely to occur for any substantial time period. Table D2-3 summarizes the ambient ocean data used in this analysis.

**Table D2-3**
**Ambient Ocean Data, Point Estero, California**

| Depth (m) | Salinity, Summer & Winter (ppt) | Temperature (°C) | | Ocean Currents | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Summer | Winter | Worst-Case Velocity (m/s) | Maximum Speed, Summer (m/s) | Dominant Direction, Summer (°) | Maximum Speed, Winter (m/s) | Dominant Direction, Winter (°) |
| 0 | 33.4 | 16.8 | 11.3 | | | | | |
| 10 | | | | 0.0 | | | 0.447 | 75 |
| 20 | 33.4 | 15.0 | 11.3 | | | | | |
| 25 | | | | 0.0 | 0.470 | 95 | 0.678 | 275 |
| 41 | | | | 0.0 | 0.506 | 95 | 0.683 | 285 |
| 50 | 33.5 | 11.8 | 10.2 | | | | | |
| 57 | | | | 0.0 | 0.576 | 95 | 0.629 | 285 |
| 73 | | | | 0.0 | 0.485 | 95 | 0.588 | 105 |
| 75 | 33.6 | 10.3 | 9.6 | | | | | |
| 89 | | | | 0.0 | 0.514 | 95 | 0.545 | 95 |
| 100 | 33.7 | 9.5 | 9.0 | | | | | |
| 105 | | | | 0.0 | 0.440 | 105 | 0.486 | 95 |

**Sources:** CalCOFI, CDIP, NDBC, and CCCCS data collected by Flow Science, 2002.

Based on these data, the U.S. Environmental Protection Agency's Visual Plumes (VP) program was used to design a diffuser to meet the Se criterion of 15 ppb within a reasonable ZID. Two port sizes were modeled using VP, 10.2 centimeters (cm) and 15.2 cm. Modeling showed that the water quality criterion could reasonably be met using either port size. It is assumed that the 15.2-cm design would be preferable since it results in a shorter diffuser. However, it also requires water that is approximately 10 meters deeper than the 10.2-cm alternative. The cost trade-off between length of diffuser and water depth should be evaluated before a final diffuser design is selected. Tideflex® diffuser valves (Figure D2-1) were specified for all diffuser ports to maintain adequate diffuser velocity and minimize debris and sand accumulation within the diffuser. Key diffuser design parameters for both alternatives are listed in Table D2-4. These parameters are appropriate for the worst-case zero ocean current scenario.

**Table D2-4**
**Diffuser Design Parameters, Point Estero Diffuser**

| Diffuser Design Parameter | 10.2-cm Alternative | 15.2-cm Alternative |
|---|---|---|
| Diffuser port valve type | Tideflex (Figure D2-1) | Tideflex (Figure D2-1) |
| Port diameter | 10.2 cm | 15.2 cm |
| Approximate recommended diffuser depth | 10 meters | 20 meters |
| Port elevation above ocean floor | 0.61 meter | 0.61 meter |
| Port angle | Vertical ($0^o$) | Vertical ($0^o$) |
| Number of ports | 33 | 15 |
| Port spacing | 1.5 meters on center | 1.5 meters on center |
| Diffuser length | 48.8 meters | 21.3 meters |
| Diffuser discharge velocity | 3.08 meters/second (10.1 feet per second) | 3.01 meters/second (9.9 feet per second) |
| Approximate maximum height above diffuser where plume = 15 ppb Se | 6.3 meters | 12.5 meters |
| Maximum Plume Width at 15 ppb Se | 2.1 meters | 3.8 meters |
| Maximum Plume Length at 15 ppb Se | 51 meters | 25 meters |

**Source:** Flow Science VP analysis, 2004.

Under *maximum* ocean current conditions, the resulting Se plume would reach a concentration of 15 ppb at heights of less than 2 meters above the diffuser for both designs, in both summer and winter temperature conditions. At this elevation, under summer and winter conditions, the plumes would be less than 2 meters wide for both designs, and would be 50 and 21 meters long for the 10-cm and 15-cm port alternatives, respectively. At the 15 ppb Se contour, concentrations of TOC and bromide will vary based on background ambient concentrations, for which site specific data were unavailable. However, the diffuser concentration *increments* at the 15 ppb Se contour for TOC and bromide are estimated at 0.58 and 0.35 ppm, respectively, corresponding to a dilution ratio of approximately 14.5:1. TDS concentration will be approximately 33 ppt and will be largely governed by the ambient ocean concentration, which tends to be reasonably uniform at 34 ppt (one and one-half the discharge concentration).

## D2.3 Delta Discharge Locations: Carquinez Strait and Chipps Island

In combination with the effluent data provided in Table D2-1, ambient data for the Carquinez Strait near Martinez, reported by Brown and Caldwell (1987), were used to formulate a preliminary diffuser design for the two Delta Disposal Alternative sites. Temperature and salinity data for both summer and winter conditions were simulated since seasonal fluctuations can significantly alter the characteristics of the diffuser plume. As before, worst-case zero velocity scenarios were simulated, along with 0.91 meter/second (3.0 feet/second) current velocity scenarios. Table D2-5 summarizes the ambient temperature and salinity data used in this analysis.

**Table D2-5**
**Ambient Temperature and Salinity Data,**
**Carquinez Strait, California**

| Summer Conditions | | | Winter Conditions | | |
|---|---|---|---|---|---|
| **Depth (m)** | **Salinity (ppt)** | **Temperature (°C)** | **Depth (m)** | **Salinity (ppt)** | **Temperature (°C)** |
| 0.00 | 19.56 | 14.78 | 0.00 | 17.50 | 8.00 |
| 0.50 | 19.59 | 14.79 | 1.52 | 17.50 | 8.00 |
| 2.13 | 20.63 | 14.82 | 2.13 | 17.30 | 7.67 |
| 3.96 | 20.62 | 14.88 | 2.74 | 17.93 | 6.67 |
| 6.20 | 20.68 | 14.82 | 3.35 | 17.23 | 6.21 |
| | | | 3.96 | 17.26 | 6.21 |
| | | | 4.57 | 17.39 | 6.22 |
| | | | 5.18 | 17.52 | 6.26 |
| | | | 5.79 | 17.34 | 6.96 |
| | | | 6.10 | 17.34 | 6.96 |

**Source:** Brown and Caldwell 1987.

Based on these data, the VP program was used to design a diffuser to meet the California Toxics Rule Se concentration criterion of 5 ppb within a reasonable zone of initial dilution. The depth of the water column was assumed to be 6.2 meters, although depths at both Carquinez Strait and Chipps Island fluctuate daily due to tidal influence. According to U.S. Geological Survey (USGS) topographic surveys, a 6.2-meter depth represents a very low-tide condition, since depths generally exceed 9 meters at mean low tide in both locations. Tideflex diffuser valves (Figure D2-1) were specified for all diffuser ports to maintain adequate diffuser velocity and minimize debris accumulation within the diffuser. Three diffuser alternatives were developed for the Delta sites. Alternative 1 is an approximately 49-meter-long diffuser with 33 ports. Alternative 2 is an approximately 21-meter-long diffuser with 15 ports. Alternative 3 is an approximately 200-meter-long diffuser that stretches across two-thirds of the channel width, with 15 ports. Alternative 3 would achieve complete mixing across the channel width more quickly than the other two alternatives, and for this reason, if it is economically feasible, it should be selected over the other two alternatives. If Alternative 3 is economically infeasible, the least expensive of Alternatives 1 and 2 should be selected. Table D2-6 lists key diffuser design parameters for the three alternatives.

**Table D2-6**
**Diffuser Design Parameters, Delta Discharge Locations**

| Diffuser Design Parameter | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|
| Diffuser port valve type | Tideflex (Figure 1) | Tideflex (Figure 1) | Tideflex (Figure 1) |
| Port diameter | 10.2 cm | 15.2 cm | 15.2 cm |
| Diffuser depth | 5.6 meters | 5.6 meters | 5.6 meters |
| Port elevation above channel bottom | 0.61 meter | 0.61 meter | 0.61 meter |
| Port angle | 45° from vertical, alternate ports | 45° from vertical, alternate ports | 45° from vertical, alternate ports |
| Number of ports | 33 | 15 | 15 |
| Port spacing | 1.5 meters on center | 1.5 meters on center | 14.3 meters on center |
| Diffuser length | 49 meters | 21 meters | 200 meters |
| Diffuser discharge velocity | 3.08 meters/second | 3.01 meters/second | 3.01 meters/second |

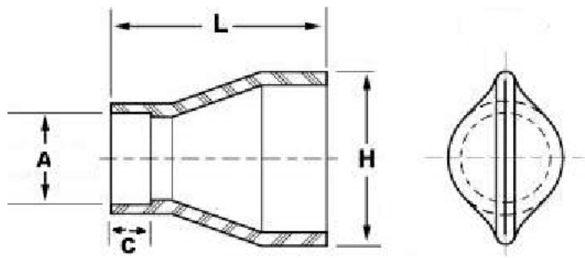
**Source:** Flow Science VP analysis, 2004.

Results for all three Delta diffuser alternatives are very similar. Under worst-case zero velocity conditions (both summer and winter), the contribution of the plume to Se concentrations would fall below 5 ppb (the California Toxics Rule criterion) at a depth of approximately 5.3 meters, some 0.3 meters above the diffuser ports. At this elevation, the plume would have traveled a horizontal distance of approximately 1.1 meters in the direction of the port angle. Under 0.91 meter per second current conditions (both summer and winter), the contribution of the plume to Se concentrations would fall below 5 ppb at a depth of approximately 5.4 meters, some 0.2 meters above the diffuser ports. Assuming Delta flow in the same direction as the port angle, at this elevation the plume would have traveled a horizontal distance of approximately 0.7 meters in the direction of the port angle. If Delta flow is in the opposite direction to the port angle, the plume would travel a maximum horizontal distance of 0.5 meters before its contribution to Se concentrations would fall below 5 ppb. Since diffusion occurs rapidly with each alternative, individual plumes from each port will not merge before the contribution to Se concentrations falls below 5 ppb. Instead, individual port plumes will have a diameter of approximately 1.2 meters and remain distinct above each port, over the length of the diffuser. At the point at which the contribution of the plume to Se concentrations falls below 5 ppb, absolute concentrations of TDS, TOC, and bromide will vary widely based on ambient concentrations. However, at that point the contributions of the plume to TOC and bromide concentrations are estimated at 4.25 and 2.6 ppm, respectively. Based on ambient and effluent TDS (salinity) data, the expected TDS concentration at the 5 ppb Se contour of the plume is approximately 19 ppt, which is very close to ambient.

# Tideflex® TF-2 Slip-On Check Valve

## Specification #RV-TF-2

**Note**: *Dimensions and weights represent standard valve configuration. Options and accessories may alter the size and /or weight of the valve. These drawings not suitable for submittal or approval purposes.*




| Pipe O.D. A | Length L | Bill Height H | Cuff Length C |
|---|---|---|---|
| 3/4" | 3” | 1 1/2” | 1” |
| 1" | 3” | 1 1/2” | 1” |
| 1 1/2" | 6” | 3” | 1” |
| 2" | 6” | 4” | 1” |
| 2 1/2" | 8” | 5” | 1” |
| 3" | 9” | 5 1/2” | 1 1/2” |
| 4" | 12” | 7” | 1 1/2” |
| 5" | 15 1/2” | 9” | 2” |
| 6" | 16” | 10 1/2” | 2” |
| 8" | 16 1/2” | 13” | 2” |
| 10" | 21 1/2” | 17” | 3” |
| 12" | 26 1/2” | 20 1/2” | 4 1/2” |
| 14" | 26” | 22” | 4” |
| 16" | 26” | 27” | 5” |
| 18" | 30” | 29” | 6” |
| 20" | 33” | 33” | 8” |
| 22" | 36” | 33” | 8” |
| 24" | 39” | 37” | 8” |
| 26" | 39” | 37” | 8” |
| 28" | 39” | 37” | 8” |
| 30" | 42” | 50” | 9” |
| 32" | 48” | 53” | 10" |
| 36" | 49” | 61” | 10" |
| 38" | 49” | 61” | 10" |
| 40" | 49” | 61” | 10” |
| 42" | 54” | 71” | 10" |
| 44" | 54” | 71” | 10" |
| 48" | 59” | 78” | 10" |
| 50" | 59” | 78” | 10" |
| 54" | 69” | 97” | 10" |
| 58" | 69” | 97” | 10" |
| 60" | 74” | 97” | 14” |
| 68" | 74” | 97” | 14” |

**Figure D2-1 Tideflex Valve**

**Source:** Red Valve Company Web site: www.redvalve.com

# 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 Department of Water Resources 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 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 ppt for the Pacific Ocean, 0.1 ppt for the Sacramento River, and 0.8 ppt for the San Joaquin River. The latter value was based on correlations developed between electrical conductivity, 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 x $10^{-6}$ $cm^2$/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**

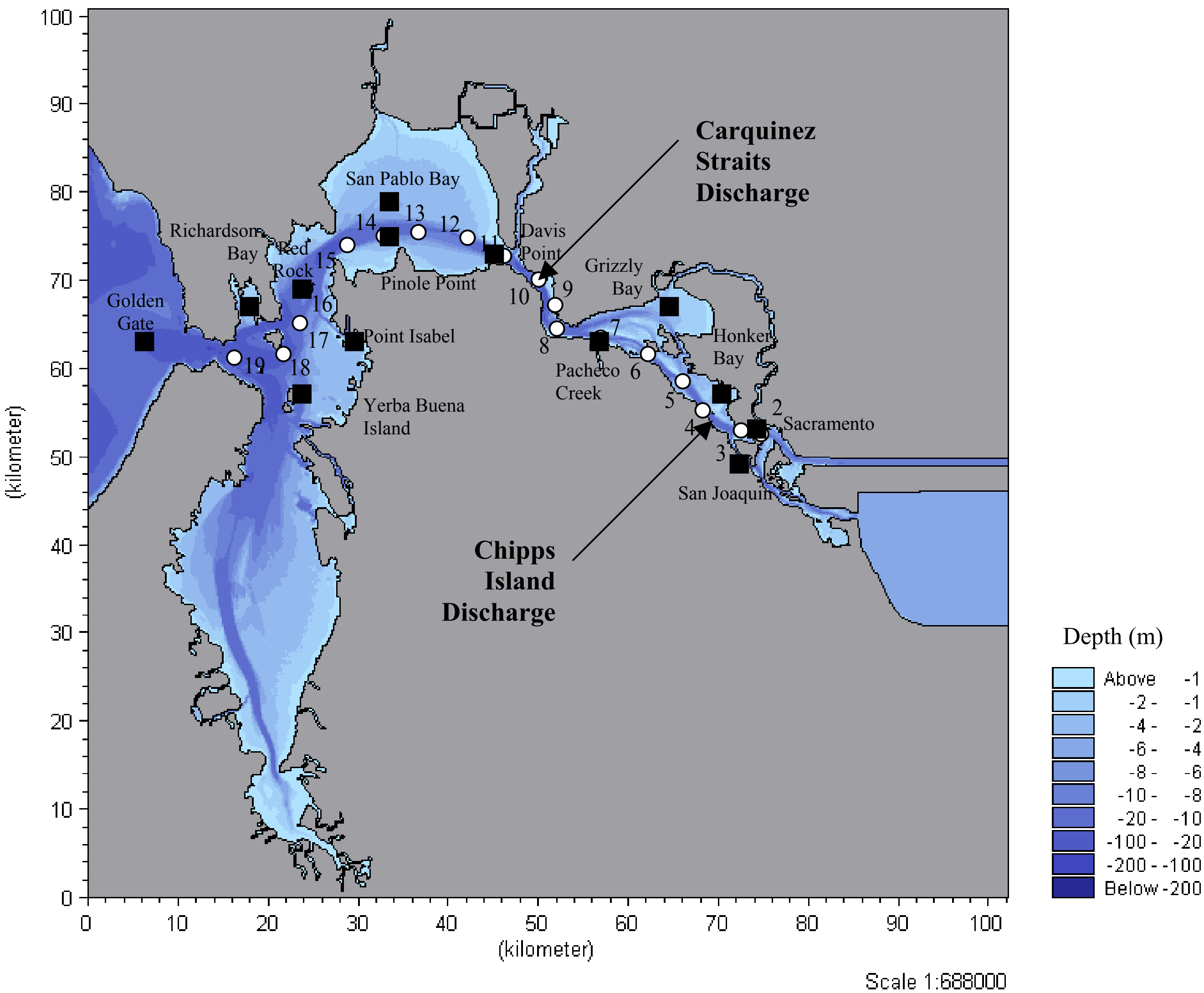
| Bay Segment | Number of Data Points | Adsorbed Selenium (mg/kg-dry-weight)* | | | | |
|---|---|---|---|---|---|---|
| | | Mean Concentration | | Median Concentration | | Average RMS Difference |
| | | Predicted | Observed | Predicted | Observed | |
| Suisun Bay | 12 | 0.40 | 0.66 | 0.35 | 0.42 | 0.19 |
| 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.

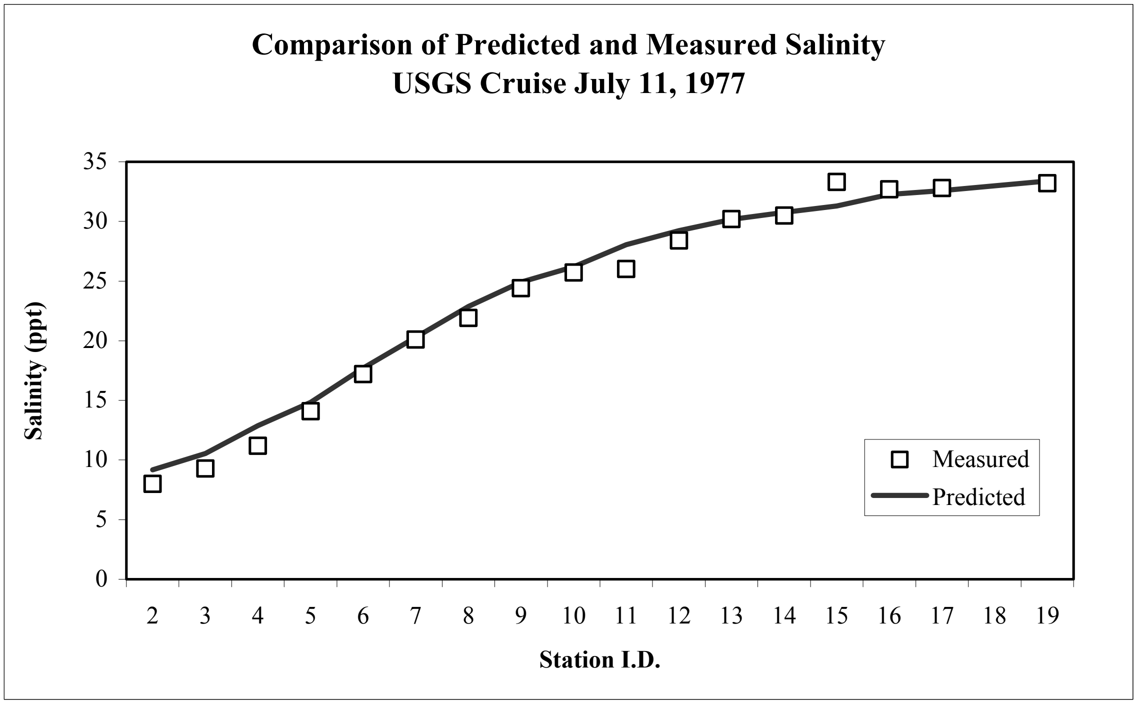
Concentrations of total (dissolved plus adsorbed) Se are shown on the upper plot of Figure D3-8 to be below the Chronic WQO of 5 µg/L throughout the Bay. Maximum concentrations of total Se are between 0.25 and 0.30 µg/L, and occur near the San Joaquin River and in San Pablo Bay. These concentrations 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).

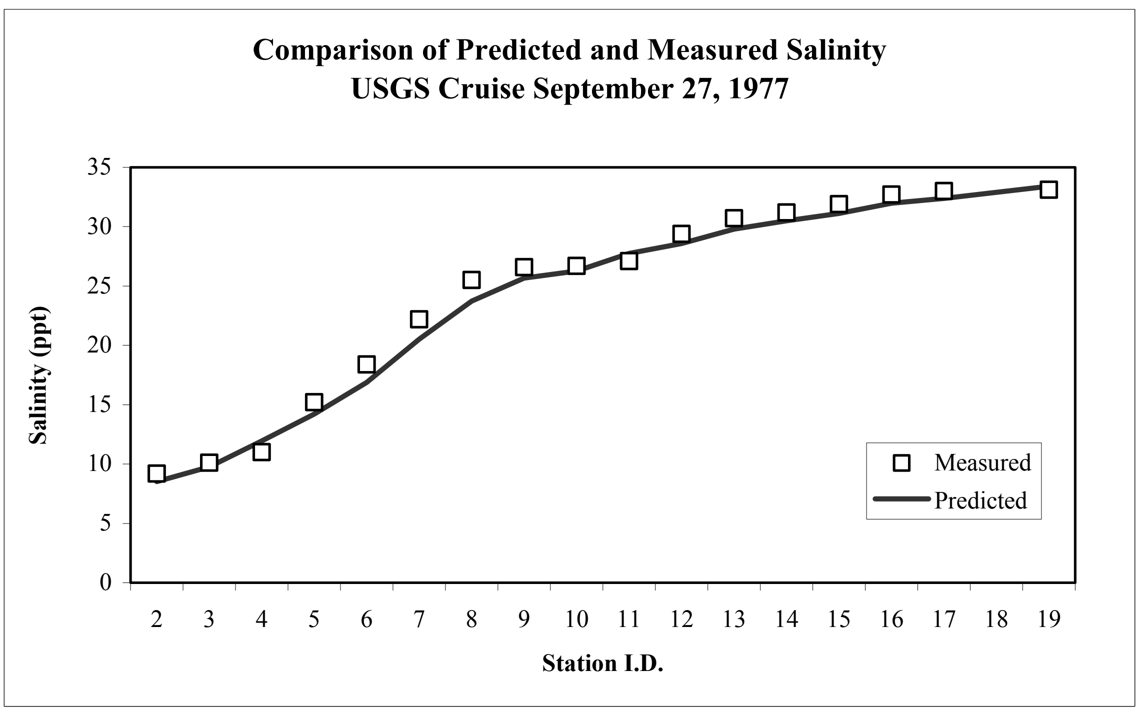
## D3.5 Limitations

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.

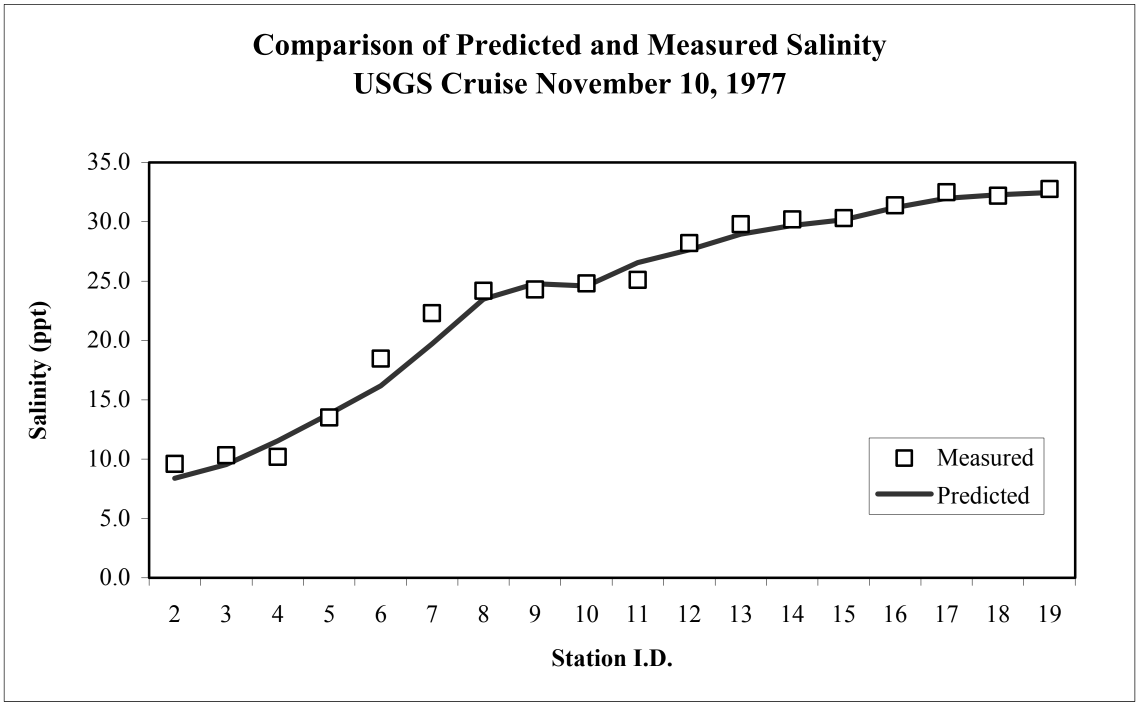


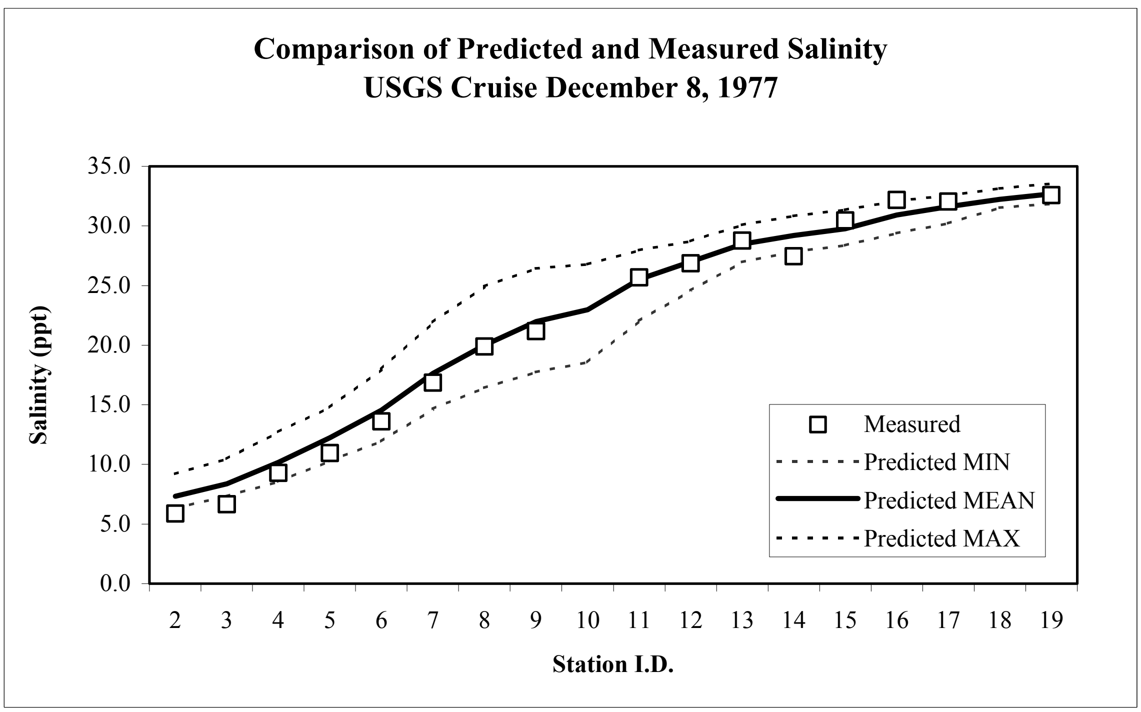

| San Luis Drainage Feature Re-evaluation | Bathymetry for MIKE 21 Model and Location of Modeled Discharges and USGS (Open Circles) and RMP (Closed Squares) Monitoring Stations | Figure D3-1 |
|---|---|---|
| 17324004 | | |



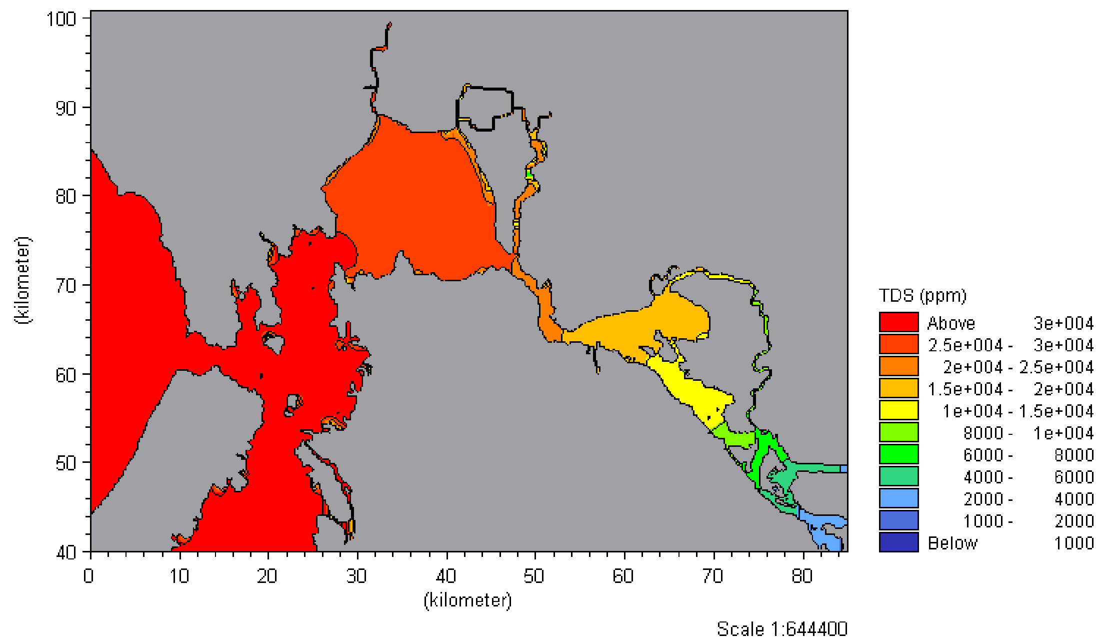




| San Luis Drainage Feature Re-evaluation | MIKE 21 North and Central Bay Salinity Calibration Results For Water Year 1977 (July and September Cruises) | Figure D3-2 |
|---|---|---|
| 17324004 | | |

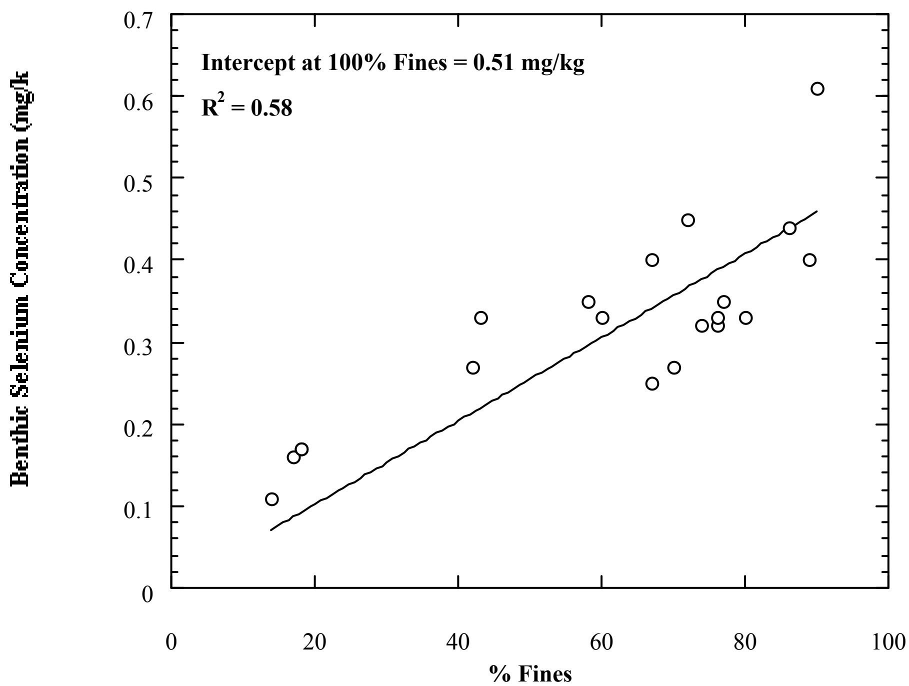


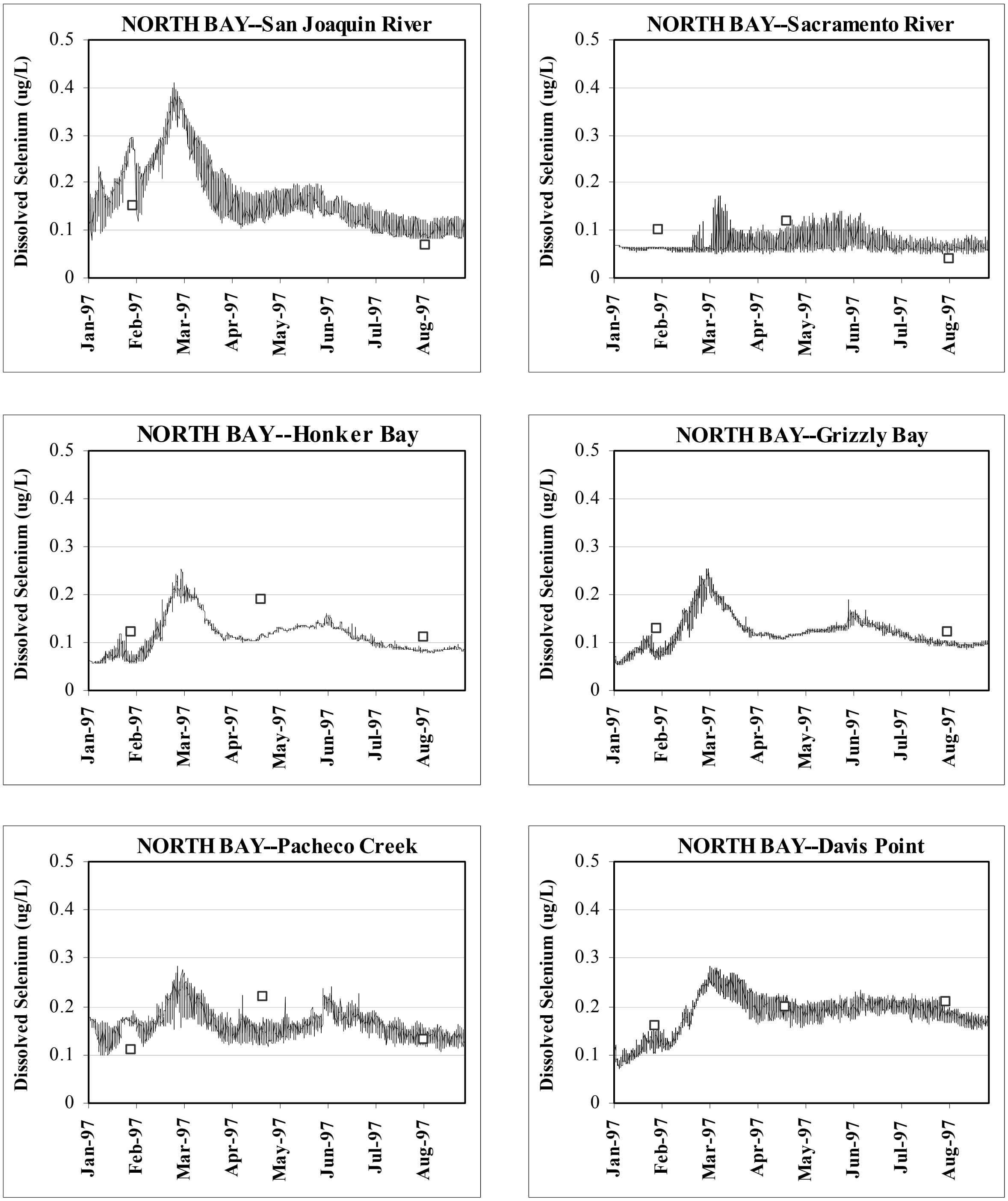

| San Luis Drainage Feature Re-evaluation | MIKE 21 North and Central Bay Salinity Calibration Results For Water Year 1977 (November and December Cruises) | Figure D3-3 |
|---|---|---|
| 17324004 | | |



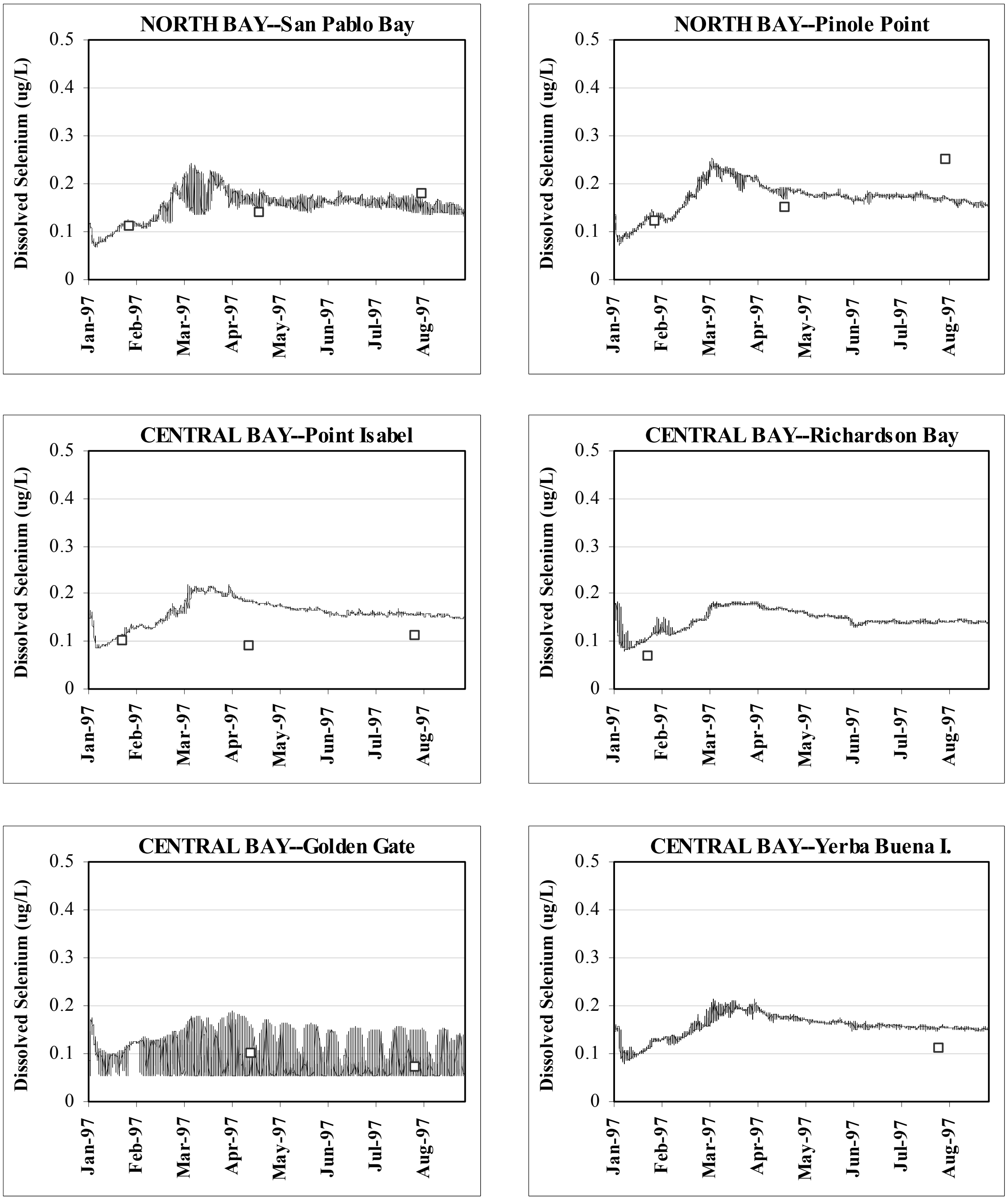

| San Luis Drainage Feature Re-evaluation | MIKE 21 Predicted Existing Conditions Mean Total Dissolved Solids Concentration (July-December 1977) | Figure D3-4 |
|---|---|---|
| 17324004 | | |




| San Luis Drain Feature Re-evaluation | Average Benthic Selenium Concentrations and Average Fines at RMP Stations (SFEI 1994-1998) | Figure D3-5 |
|---|---|---|
| 17324004 | | |




| | | |
|---|---|---|
| San Luis Drainage Feature Re-evaluation<br>17324004 | MIKE 21 North Bay Dissolved Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises) | Figure D3-6 |




| 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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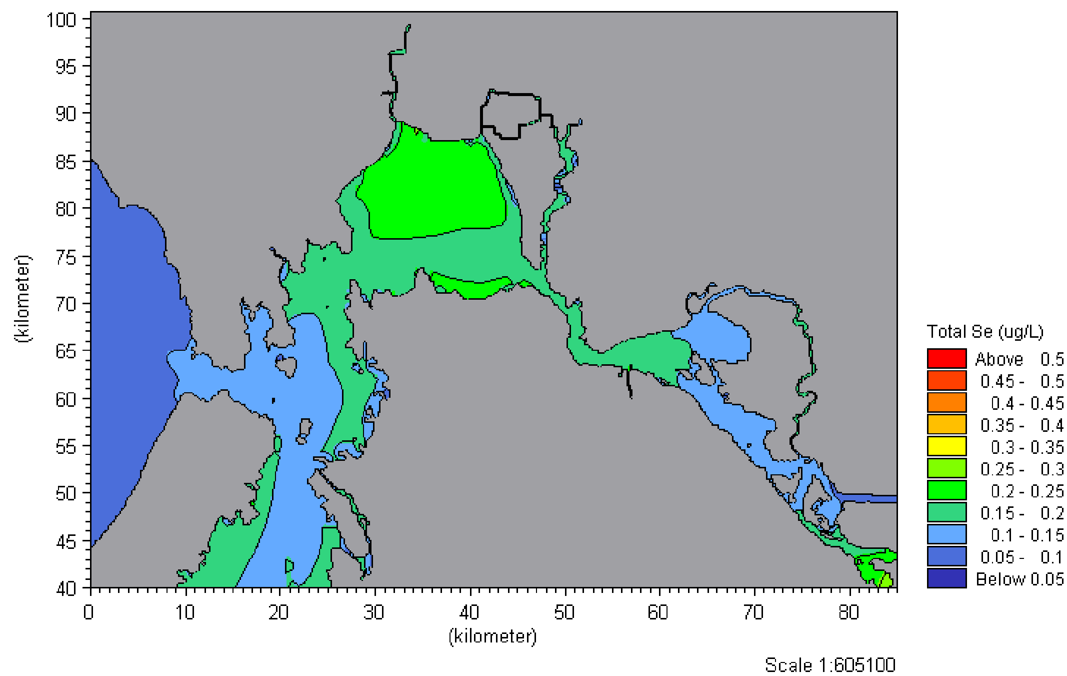
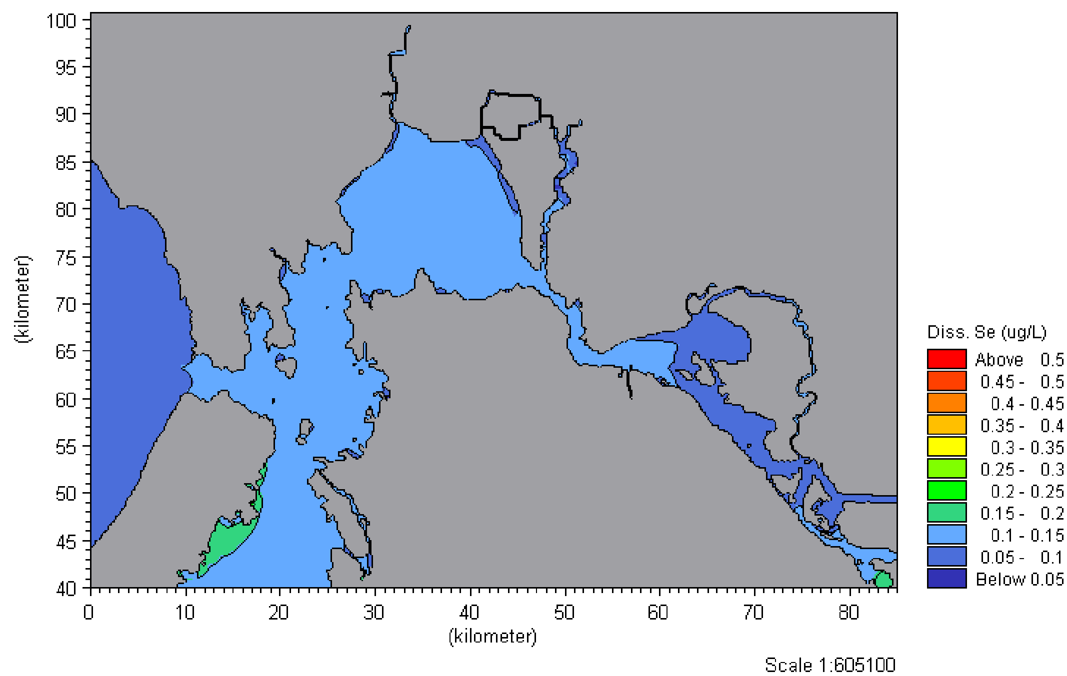
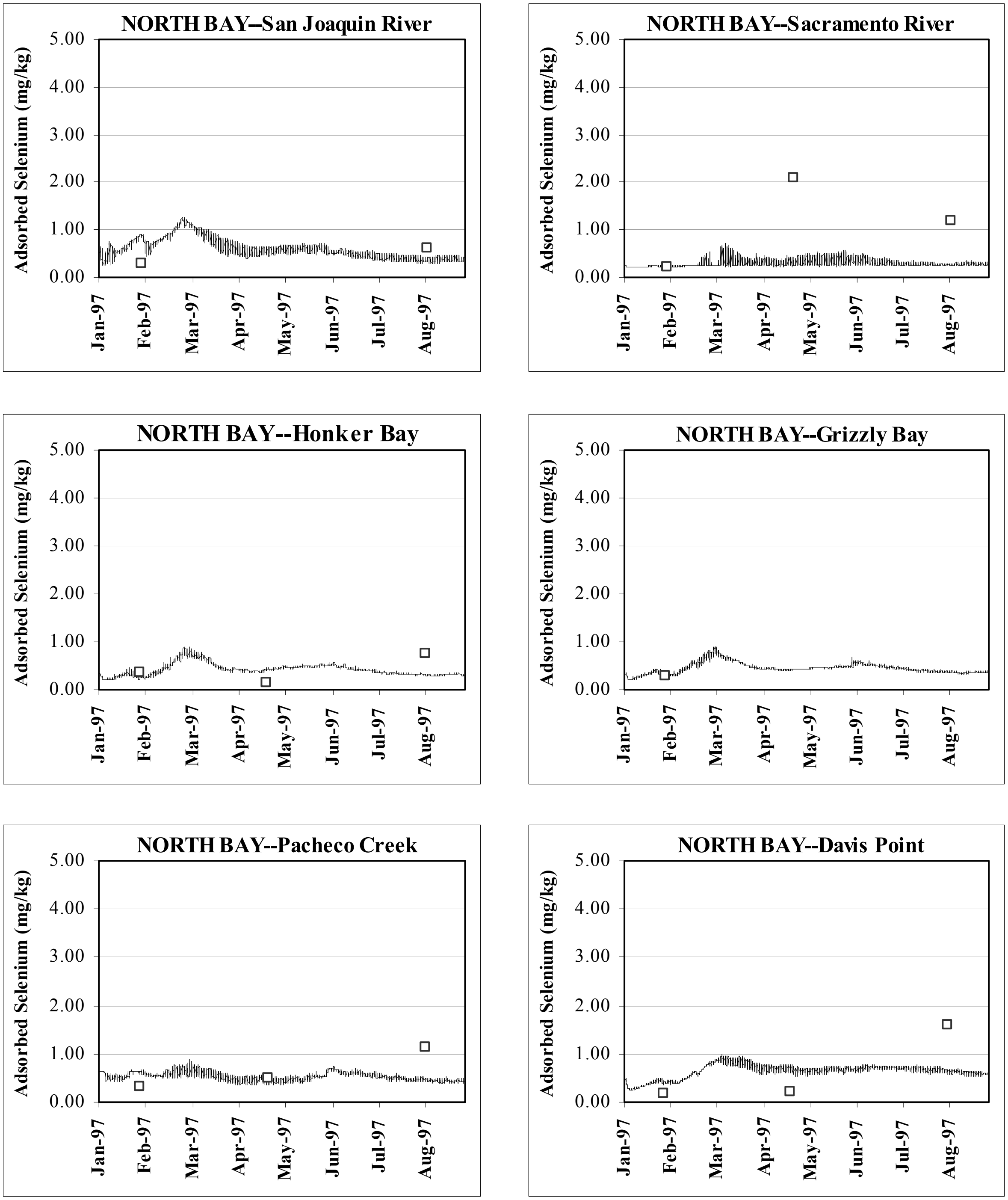
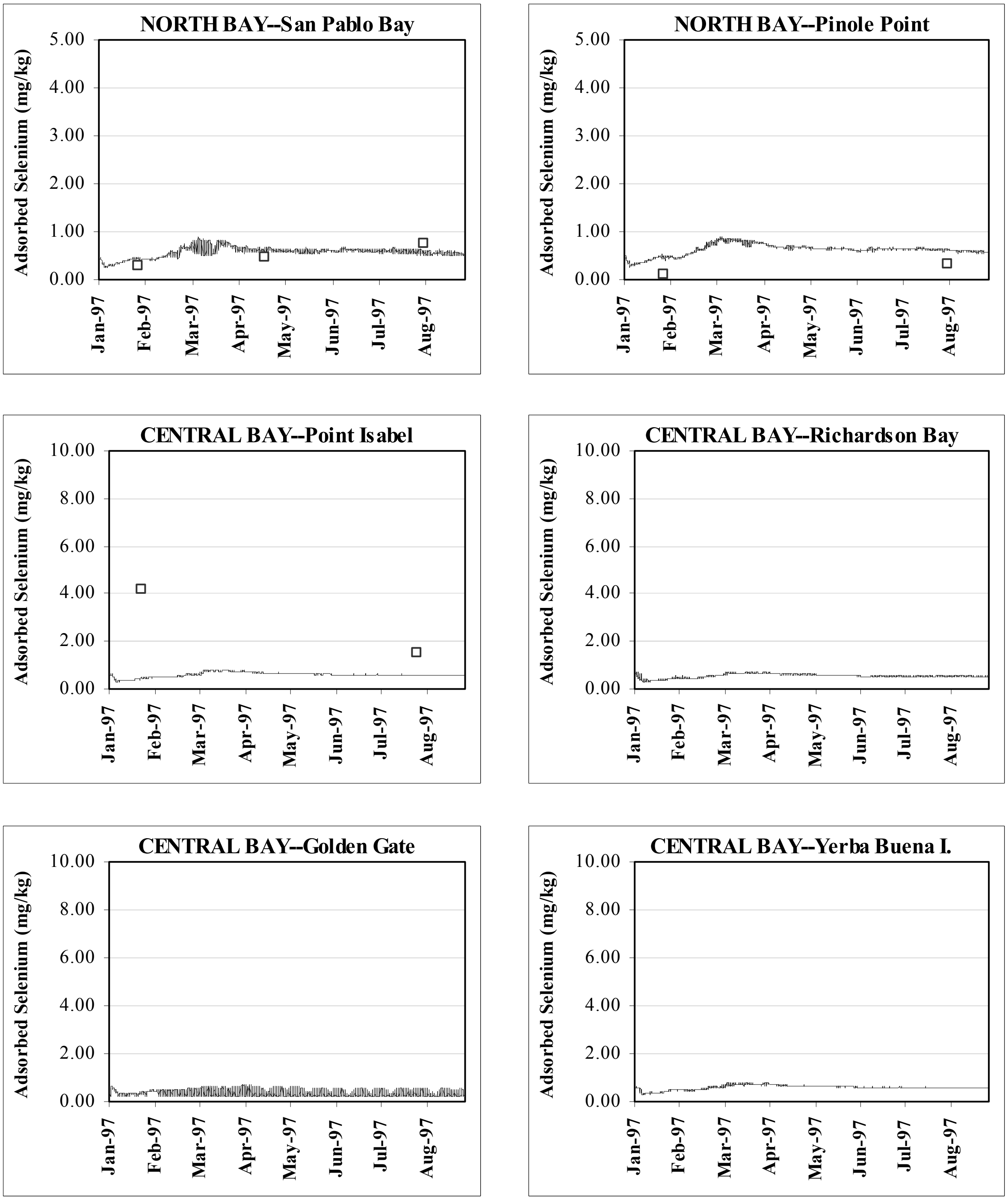


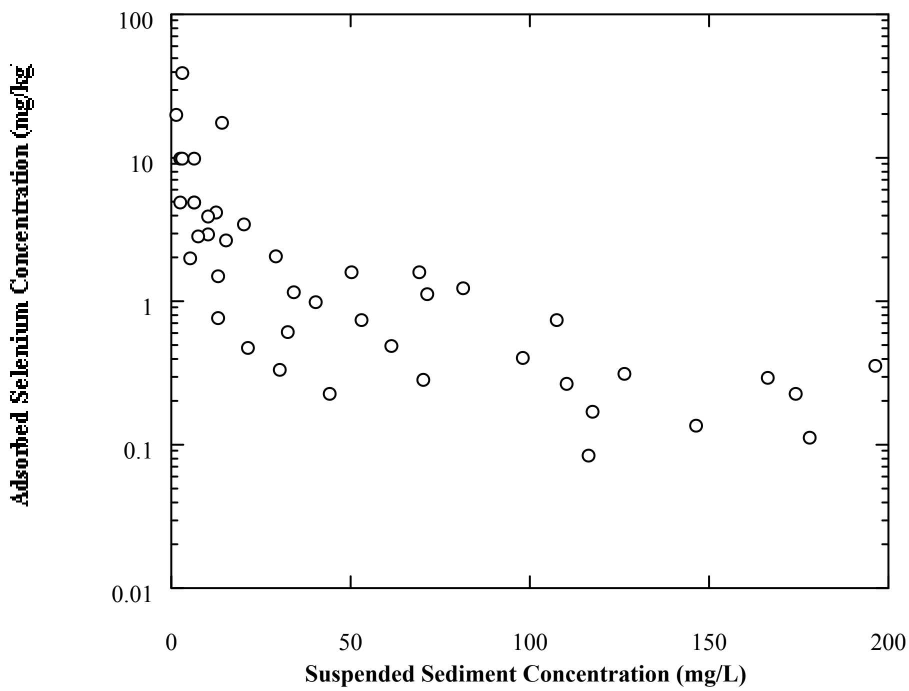

| San Luis Drainage Feature Re-evaluation | MIKE 21 Predicted Existing Conditions Total and Dissolved Selenium Concentrations (June-November 1997) | Figure D3-8 |
|---|---|---|
| 17324004 | | |



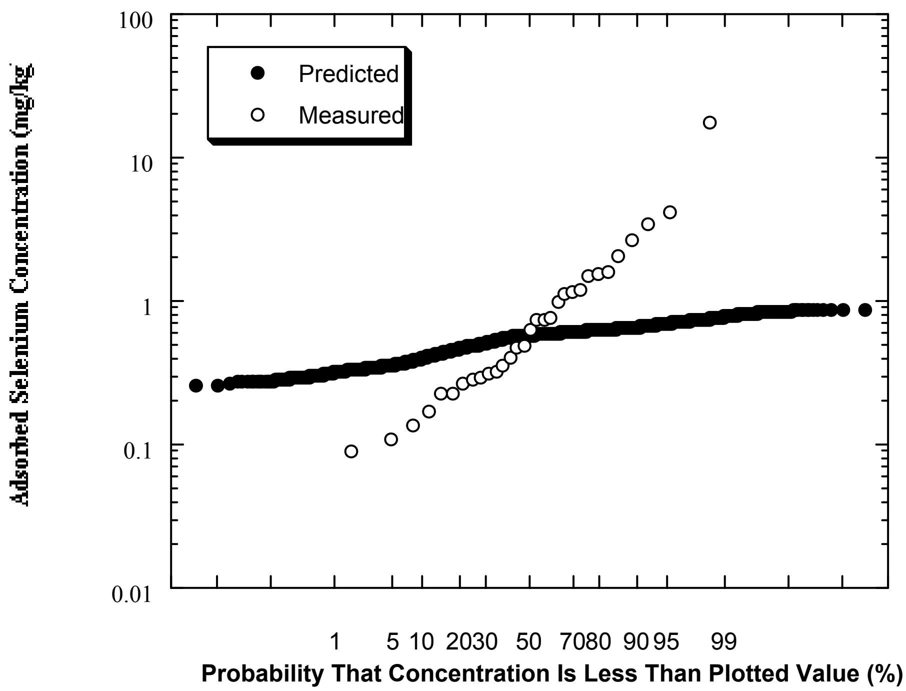

| San Luis Drainage Feature Re-evaluation | MIKE 21 North Bay Adsorbed Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises) | Figure D3-9 |
|---|---|---|
| 17324004 | | |



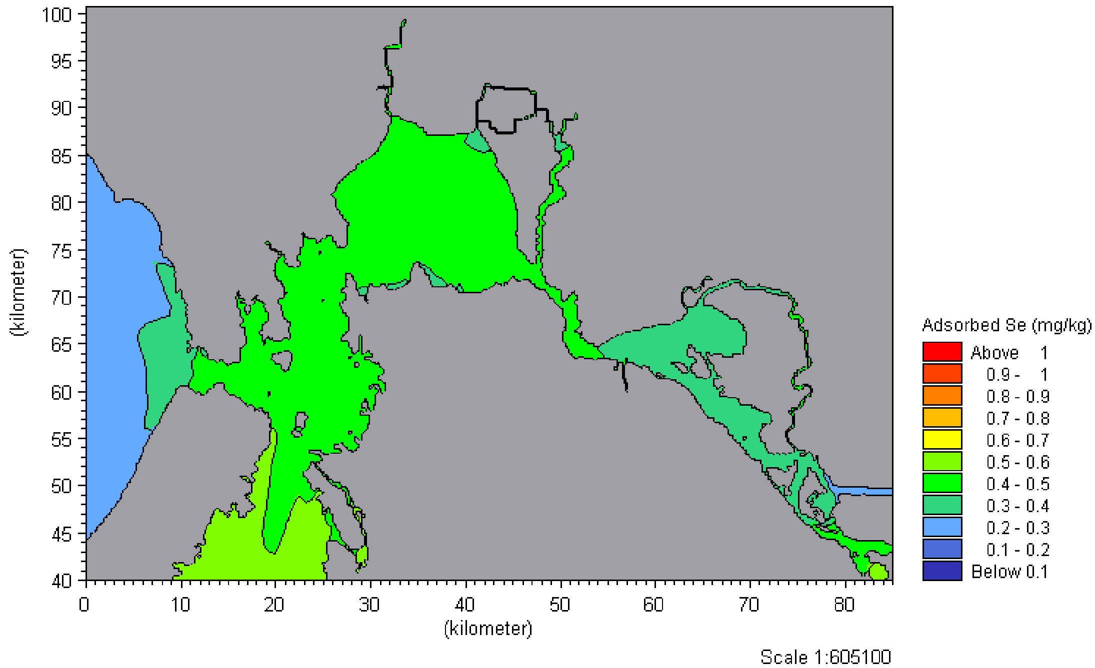

| San Luis Drain Features Re-evaluation | MIKE 21 San Pablo Bay and Central Bay Adsorbed Selenium Calibration Results For Water Year 1997 (January through August RMP Cruises) | Figure D3-10 |
|---|---|---|
| 17324004 | | |

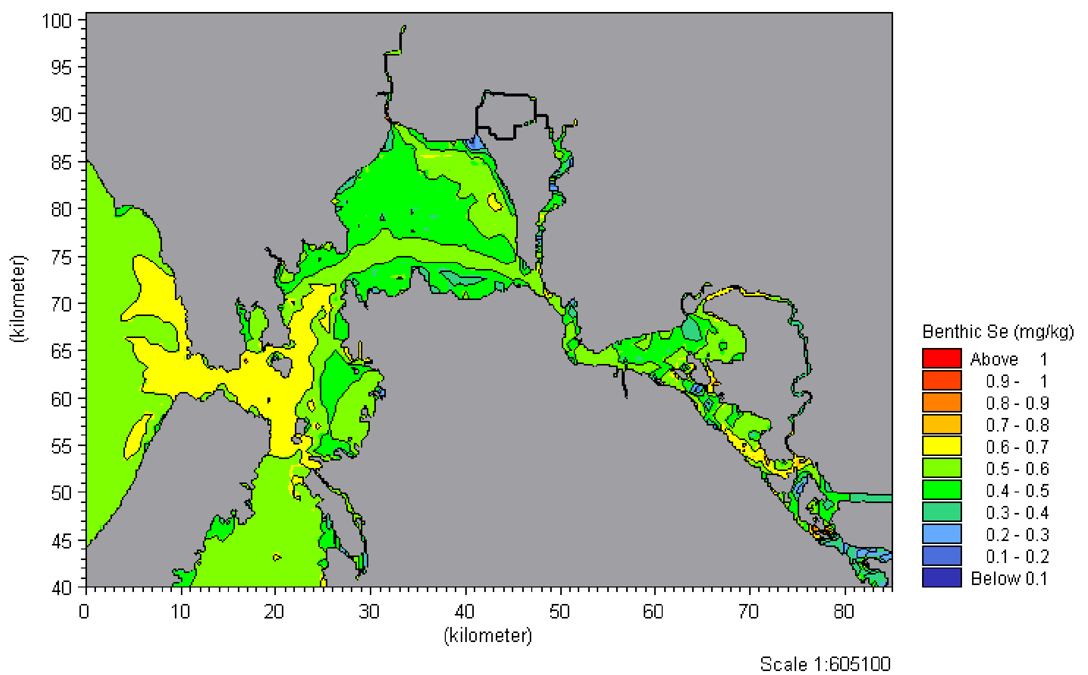



| San Luis Drain Features Re-evaluation | Adsorbed Selenium and Suspended Sediment Concentrations at RMP Stations For Water Year 1997 (SFEI 1998) | Figure D3-11 |
|---|---|---|
| 17324004 | | |




| 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 |
|---|---|---|
| 17324004 | | |




| San Luis Drainage Feature Re-evaluation<br>17324004 | MIKE 21 Predicted Existing Conditions Adsorbed and Benthic Selenium Concentrations (June-November 1997) | Figure D3-13 |
|---|---|---|

# D4 SAN JOAQUIN RIVER MODELING

## D4.1 Background

The Grassland Drainage Area (GDA) is composed 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 (LSJR) is listed on the Federal Clean Water Act's 303(d) list as an impaired waterbody for a number of constituents, including electrical conductivity (EC), boron, and Se. The Clean Water Act requires that a total maximum daily load (TMDL) be developed for each constituent listed.

The Central Valley Regional Water Quality Control Board (CVRWQCB) published the *Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River* in January 2002. The TMDLs were developed to "(1) identify the major sources of salt and boron loading to the LSJR; (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).

In August 2001, the CVRWQCB published the *Total Maximum Daily Load for Selenium in the Lower San Joaquin River*. 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 LSJR.

## D4.2 General Approach

The action alternatives of the San Luis Drainage Feature Re-evaluation would eliminate discharge of salt, boron, and Se from the GDA to the San Joaquin River. The purpose of the following analysis was to estimate the changes in San Joaquin River water quality due to implementation of the action alternatives. First, the historical monthly discharges from the GDA were modified so they were in compliance with the TMDLs during a 9-year flow record used in the TMDL (from October 1985 to September 1994). This period was chosen based on the combined availability of flow data for the San Joaquin River at Vernalis (from DWRSIM for CALFED Study 771) and water quality data for the GDA. The water quality in the LSJR was calculated using the methodology from the CVRWQCB's TMDLs for salt, boron, and Se. Then the loads from the GDA were removed (to simulate implementation of the action alternatives), and the resulting change in water quality was calculated. There were still some months when the Total Maximum Monthly Loads (TMMLs) were met, but WQOs were exceeded. It was assumed that releases from New Melones would be made to meet the WQOs. The decrease in the quantity of the releases required from New Melones after implementation of the action alternatives was also determined.

## D4.3 Methodology and Results

The CVRWQCB used slightly different approaches to calculate the water quality of the LSJR and to apportion the load allocations to the contributing watersheds for salt and boron and for Se. The methodology for this analysis was based mainly on the TMDL for salinity and boron, as described below.

The CVRWQCB divided the LSJR watershed into seven subareas to account for geographic differences in salt and boron loading patterns. Base load allocations were apportioned to each subarea based on the total acreage of nonpoint source land uses (agriculture and wetlands) within the area. Table D4-1 describes the load allocation components that make up the TMDLs devised to meet WQOs for salt and boron in the LSJR near Vernalis. The GDA is included in the 430,722-acre Grasslands subarea.

**Table D4-1**
**Load Allocation Summary**

| Allocation Type | Description |
|---|---|
| Waste Load Allocations | Point source allocations |
| Base Load Allocation | Base load allocation for each geographic subarea with no relaxations |
| Consumptive Use Allocation | A formulaic allowance that is based upon the volume of water being discharged |
| Delta-Mendota Canal Supply Water Relaxation | Additional load allocation provided to users that receive supply water from the Central Valley Project's Delta-Mendota Canal |
| San Joaquin River Supply Water Relaxation | Additional load allocation provided to users that divert supply water from the San Joaquin River |
| Bureau of Reclamation Load Allocation | Load allocation provided to Reclamation; Reclamation is responsible for mitigation of salt loads delivered in excess of these allocations |
| Real Time Relaxation | An additional load allocation provided to allow for discharge of salt loads when assimilative capacity is present |

**Source**: CVRWQCB 2002

Based on the CVRWQCB's methodology, the GDA would be allowed a base load allocation, a consumptive use allocation, and a Delta-Mendota Canal supply water allocation. The load allocations vary by month and by water year type. The CVRWQCB did not perform calculations with a daily time-step and used monthly flows and concentrations to come up with a TMML instead of a daily load.

The flows used to calculate the TMML were based on results of the California Department of Water Resources DWRSIM model output for CALFED Study 771 to account for existing infrastructure and operational policies. Flow releases made from the New Melones Reservoir by Reclamation to meet WQOs at Vernalis were excluded from the total flow at Vernalis to establish the design flows used in the TMML. The flows were sorted into groups by month and water year type to determine the minimum flow occurring in that group. Using the minimum flow as the design flow establishes an intrinsic margin of safety. The months of April and May were further divided to allow for the calculation of load allocations during the Vernalis Active Management Plan's pulse period.

The TMML was calculated using Equation D4-1 (CVRWQCB 2002, Equation 4-12).

$$TMML = WLA + LA + L_{BG} + CUA + L_{GW} + MOS \qquad (D4\text{-}1)$$

where:

WLA = waste load allocation (for municipal and industrial point source discharges)
LA = load allocation (to nonpoint source discharges from the 7 subareas)
$L_{BG}$ = background loads (natural runoff from upstream sources, reservoir releases)
CUA = consumptive use allowance
$L_{GW}$ = estimated groundwater contributions
MOS = margin of safety

Since the margin of safety was inherently included in the determination of design flows, an additional margin of safety was not actually used in the calculation of the TMML.

## D4.4 Grassland Drainage Area Load Allocations

The base load allocation for the GDA was determined by multiplying the base load allocations in pounds per acre (CVRWQCB 2002, Table 4-14) by the 97,000 acres within the GDA. The results are shown in Table D4-2.

**Table D4-2**
**Calculated Base Load Allocations of Salt for Grassland Drainage Area**

| Month/Period | GDA Base Load Allocations by Water Year Type (tons) | | | | |
|---|---|---|---|---|---|
| | Wet | Above Norm | Below Norm | Dry | Critical |
| **Jan** | 3,541 | 3,735 | 1,892 | 2,474 | 1,601 |
| **Feb** | 7,227 | 7,227 | 1,989 | 3,395 | 1,310 |
| **Mar** | 9,749 | 5,384 | 2,619 | 2,134 | 970 |
| **Beg. Apr*** | 1,940 | 2,183 | 970 | 388 | 0 |
| **VAMP Pulse Period**** | 6,111 | 6,014 | 3,832 | 2,086 | 0 |
| **End May***** | 2,668 | 1,164 | 679 | 97 | 0 |
| **Jun** | 0 | 0 | 0 | 0 | 0 |
| **Jul** | 0 | 0 | 0 | 0 | 0 |
| **Aug** | 388 | 0 | 0 | 0 | 0 |
| **Sep** | 3,686 | 3,589 | 3,104 | 1,989 | 1,504 |
| **Oct** | 8,197 | 4,753 | 3,395 | 2,571 | 2,474 |
| **Nov** | 3,638 | 2,910 | 2,765 | 2,280 | 2,086 |
| **Dec** | 3,007 | 2,716 | 2,522 | 2,377 | 1,940 |
| | | | | | |
| **TOTAL** | **50,149** | **39,673** | **23,765** | **19,788** | **11,883** |

* Beginning of April runs 4/1-4/14
** Vernalis Adaptive Management Plan (VAMP) runs from 4/15-5/15
*** End of May runs from 5/16-5/31

The consumptive use allowance accounts for the beneficial impact of discharges of high quality water. The CUA was calculated using Equation D4-2 (CVRWQCB 2002, Equation 4-11).

$$CUA = (Q_{DF} - Q_{GW}) * (TV - C_{BG}) * \text{conversion factor} \qquad \text{(D4-2)}$$

where:

$Q_{DF}$ = design flow
$Q_{GW}$ = volume contributed by groundwater
TV = trigger value
$C_{BG}$ = concentration of background runoff (52 mg/L TDS)

The trigger value is defined as the expected quality of discharge from a nonpoint source receiving high quality water. It was calculated using a supply water concentration of 52 mg/L TDS and a seasonal application efficiency (SAE) of 73 percent. The Department of Water Resources defines the SAE as the sum of the evapotranspiration of applied water plus cultural water requirements (such as for leaching salts) divided by the total applied water (CVRWQCB 2002). The trigger value was calculated to be 193 mg/L TDS using Equation D4-3 (CVRWQCB 2002, Equation 4-10).

$$TV = \frac{C_{BG}}{(1 - SAE)} \qquad \text{(D4-3)}$$

where:

TV = trigger value
CBG = background concentration/supply quality (52 mg/L)
SAE = seasonal application efficiency (0.73)

All discharges at concentrations less than or equal to the trigger value would be allowed in addition to the base load allocations.

Based on historical water quality of the discharge from the GDA, it was assumed that the CUA would not apply to the GDA discharge. The typical TDS levels of the GDA discharge are an order of magnitude larger than the trigger value.

The Delta-Mendota Canal supply water relaxation load for the Central Valley Project water supplied to the GDA from the canal was estimated based on the ratio of deliveries to the GDA in Water Year 1999 and the deliveries to the entire 430,722-acre Grassland subarea. This ratio of 20 percent was applied to the supply water relaxation loads for the entire Grassland subarea (from CVRWQCB 2002, Table 4-19) to obtain the loads shown in Table D4-3.

The total load allocations for the GDA are shown in Table D4-4, and were calculated as the sum of the base load allocations and the supply water relaxation loads. The actual load allocations could possibly be increased if discharge occurred at a concentration less than the trigger value of 193 mg/L or if real-time projections determined a greater assimilative capacity of the LSJR.

Boron load allocations were not explicitly determined because the boron WQOs for the LSJR near Vernalis were automatically met after compliance with the salt load allocations.

The CVRWQCB performed a linkage analysis to demonstrate that compliance with the TMMLs would result in meeting WQOs for the LSJR at Vernalis. This analysis used design flows at Vernalis based on output from the DWRSIM model over the period from Water Years 1922 through 1994. The total expected salt load at Vernalis with the TMMLs in place was calculated by adding the waste load allocations, load allocations for the seven subareas, the estimated salt loading from groundwater, background loading, and consumptive use allowance loading (CVRWQCB 2002).

**Table D4-3**
**Estimate of Delta-Mendota Canal Supply Water Relaxation Salt Load for Grassland Drainage Area**

| | Estimated Supply Water Relaxation Load by Water Year Type (tons) | | | | |
|---|---|---|---|---|---|
| **Month/Period** | **Wet** | **Above Norm** | **Below Norm** | **Dry** | **Critical** |
| **Jan** | 420 | 240 | 280 | 440 | 660 |
| **Feb** | 1,180 | 960 | 1,140 | 1,340 | 1,780 |
| **Mar** | 2,780 | 1,880 | 2,760 | 3,180 | 3,440 |
| **Beg. Apr*** | 1,560 | 2,080 | 2,500 | 2,220 | 2,040 |
| **VAMP Pulse Period**** | 3,460 | 4,940 | 5,900 | 4,680 | 4,820 |
| **End May***** | 1,760 | 2,720 | 3,180 | 2,240 | 2,660 |
| **Jun** | 4,520 | 5,520 | 6,520 | 4,580 | 6,660 |
| **Jul** | 4,160 | 4,060 | 5,840 | 4,620 | 6,500 |
| **Aug** | 4,640 | 4,900 | 5,960 | 4,800 | 6,360 |
| **Sep** | 3,440 | 4,780 | 6,580 | 5,600 | 5,500 |
| **Oct** | 3,200 | 3,320 | 5,060 | 4,740 | 5,740 |
| **Nov** | 2,080 | 1,500 | 2,560 | 2,600 | 2,720 |
| **Dec** | 740 | 520 | 900 | 1,060 | 1,180 |
| | | | | | |
| **Total** | **33,940** | **37,420** | **49,180** | **42,100** | **50,060** |

* Beginning of April runs 4/1-4/14
** VAMP runs from 4/15-5/15
*** End of May runs from 5/16-5/31

**Table D4-4**
**Estimate of Total Salt Load Allocation for Grassland Drainage Area**

| | Estimated Total Load Allocation by Water Year Type (tons) | | | | |
|---|---|---|---|---|---|
| **Month/Period** | **Wet** | **Above Norm** | **Below Norm** | **Dry** | **Critical** |
| **Jan** | 3,961 | 3,975 | 2,172 | 2,914 | 2,261 |
| **Feb** | 8,407 | 8,187 | 3,129 | 4,735 | 3,090 |
| **Mar** | 12,529 | 7,264 | 5,379 | 5,314 | 4,410 |
| **Beg. Apr*** | 3,500 | 4,263 | 3,470 | 2,608 | 2,040 |
| **VAMP Pulse Period**** | 9,571 | 10,954 | 9,732 | 6,766 | 4,820 |
| **End May***** | 4,428 | 3,884 | 3,859 | 2,337 | 2,660 |
| **Jun** | 4,520 | 5,520 | 6,520 | 4,580 | 6,660 |
| **Jul** | 4,160 | 4,060 | 5,840 | 4,620 | 6,500 |
| **Aug** | 5,028 | 4,900 | 5,960 | 4,800 | 6,360 |
| **Sep** | 7,126 | 8,369 | 9,684 | 7,589 | 7,004 |
| **Oct** | 11,397 | 8,073 | 8,455 | 7,311 | 8,214 |
| **Nov** | 5,718 | 4,410 | 5,325 | 4,880 | 4,806 |
| **Dec** | 3,747 | 3,236 | 3,422 | 3,437 | 3,120 |
| | | | | | |
| **Total** | **84,089** | **77,093** | **72,945** | **61,888** | **61,943** |

* Beginning of April runs 4/1-4/14
** VAMP runs from 4/15-5/15
*** End of May runs from 5/16-5/31

## D4.5 Water Quality Benefit of the Action Alternatives

To determine the benefit to water quality at Vernalis by excluding salt loads from GDA, EC at Vernalis was recalculated after taking out the flow that would have been contributed by the GDA if the TMDL had been met historically. Water Years 1986 to 1994 were modeled. It was assumed that the quality of discharge measured during this period would be the same, and the quantity of discharge was limited so that the load discharged would not exceed the calculated load allocations shown in Table D4-4. The resulting water quality at Vernalis was calculated using Equation D4-4.

$$C_{Vnew} = \left( \frac{TMML - LA_{GDA}}{Q_{DF} - Q_{GDA}} \right) \div \text{conversion factor} \qquad \text{(D4-4)}$$

where:

$C_{Vnew}$ = New concentration at Vernalis without loads from GDA
TMML = Total maximum monthly load for salt calculated by the CVRWQCB for the LSJR at Vernalis

$LA_{GDA}$ = Salt load allocation calculated for the GDA, and shown in Table D4-4.
$Q_{DF}$ = Design flow at Vernalis from DWRSIM model output.
$Q_{GDA}$ = Modeled discharge from the GDA.

As part of the conversion factor, the ratio of TDS (in mg/L) to EC (in µS/cm) used for Vernalis was 0.61.

Figure D4-1 shows the decreased discharge that would have been necessary for the GDA to meet the load allocations for salt and boron in comparison to the actual discharge measured during the modeled period. Figure D4-2 shows how the EC at Vernalis will change over the modeled period from Water Years 1986 to 1994 if the load allocations from the GDA were removed. On average, the EC at Vernalis would be reduced by 7 percent.

The improvement in boron concentrations at Vernalis was determined similarly to the salt. The measured boron concentration of the discharge from the GDA over the modeled period was applied to the modeled discharge used in Equation 4 to calculate the load that would be eliminated from the total load at Vernalis. The boron concentrations at Vernalis calculated with the TMMLs in place and with the loads from the GDA removed are shown on Figure D4-3. This represents an average reduction in boron concentrations of approximately 17 percent.

The improvement in Se concentrations at Crows Landing that could be achieved by removing discharge from the GDA was calculated for Water Years 1986 to 1994 using the same methodology as described above for salt, except that the design flows were for Crows Landing, rather than Vernalis. The design flows and background loads were taken from Appendix D of the *Total Maximum Daily Load for Selenium in the Lower San Joaquin River* (CVRWQCB 2001). The comparison of Se concentrations in the San Joaquin River at Crows Landing is shown on Figure D4-4. On average, the Se concentrations would be reduced by approximately 70 percent with the implementation of the action alternatives.

It was assumed that the Se concentration of the GDA discharge would be the same as was measured during the period from 1986 to 1994, so the quantity of discharge was limited to not exceed the load allocations. This discharge is shown on Figure D4-1, as well as the discharge that would have been necessary to meet the salt load allocations.

In Water Years 1986 and 1993 (both classified as wet years), during periods of a few months the TMML for salt requires a greater decrease in the amount of discharge from the GDA compared to the TMML for Se. However, for the rest of the years in the modeled period (classified as critically dry), the TMML for Se would generally have been the most limiting, assuming that the discharge would have been at the same quality as it had been historically. If recycling of sumps with the highest concentrations were used to meet the load allocations, the quality of the discharge could be improved.

The reduction of dilution flow releases from New Melones was calculated during months where WQOs for EC were exceeded. Compliance with the WQOs for EC automatically resulted in compliance of WQOs for boron. Compliance with the TMMLs for Se also met the Se WQOs without requiring releases from New Melones. With implementation of the San Luis Drainage Feature Re-evaluation, the dilution flows would be decreased. It was assumed that the New Melones TDS quality would be at the background level, which was 52 mg/L. The reduction of dilution flow releases is shown in Table D4-5 and displayed as a function of time on Figure D4-5.

**Table D4-5**
**Effect of Action Alternatives on Dilution Flow Releases from New Melones During Modeled Period of TMML Compliance from October 1985 to September 1994[1]**

| | Releases from New Melones needed to meet EC WQO at Vernalis[2] | | Decrease in Dilution Flows due to the Project |
|---|---|---|---|
| Month/Year | Without Project (includes loads from GDA) (TAF) | With Project (no loads from GDA) (TAF) | Difference (w/o Project - w/ Project) )(TAF) |
| Jan-86 | 0.6 | 0 | 0.6 |
| Jul-86 | 9.8 | 3.4 | 6.4 |
| Jun-87 | 40.1 | 30.5 | 9.6 |
| Jul-87 | 27.9 | 18.3 | 9.5 |
| Jun-88 | 43.9 | 34.3 | 9.6 |
| Jul-88 | 46.0 | 37.2 | 8.8 |
| Aug-88 | 14.1 | 4.3 | 9.8 |
| Jun-89 | 42.0 | 32.1 | 9.9 |
| Jul-89 | 42.9 | 34.1 | 8.8 |
| Aug-89 | 12.8 | 3.2 | 9.7 |
| May-90 | 8.2 | 0 | 8.2 |
| Jun-90 | 52.6 | 42.8 | 9.8 |
| Jul-90 | 49.7 | 41.4 | 8.4 |
| Aug-90 | 17.8 | 8.0 | 9.8 |
| Jan-91 | 0.8 | 0 | 0.8 |
| Jun-91 | 50.1 | 40.2 | 10.0 |
| Jul-91 | 49.1 | 39.9 | 9.2 |
| Aug-91 | 19.7 | 9.9 | 9.8 |
| Oct-91 | 0.04 | 0 | 0.0 |
| May-92 | 1.3 | 0 | 1.3 |
| Jun-92 | 65.8 | 56.8 | 9.0 |
| Jul-92 | 52.2 | 43.0 | 9.3 |
| Aug-92 | 24.1 | 14.2 | 9.8 |
| Apr-93 | 0.0 | 0 | 0.0 |
| May-93 | 1.3 | 0 | 1.3 |
| Jul-93 | 3.5 | 0 | 3.5 |
| Jun-94 | 32.0 | 21.3 | 10.8 |
| Jul-94 | 32.9 | 22.6 | 10.3 |
| Aug-94 | 6.6 | 0 | 6.6 |

[1] Months where WQOs are met without implementation of the action alternatives are not shown.
[2] Assumed TDS of New Melones releases would be at background water quality (52 mg/L).

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

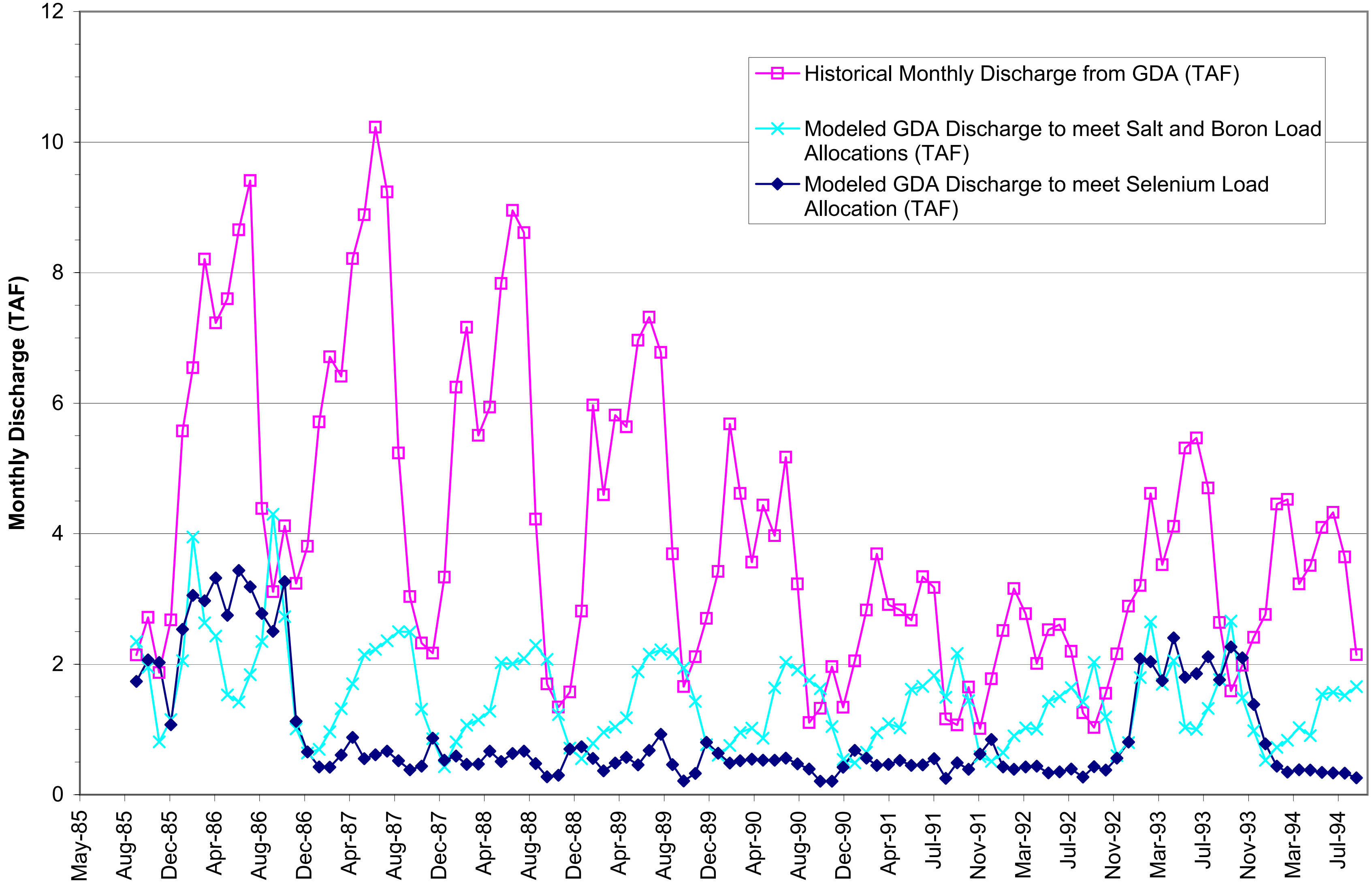


**Figure D4-2. Electrical Conductivity at Vernalis using TMMLs with and without Grassland Drainage Area Drainage**

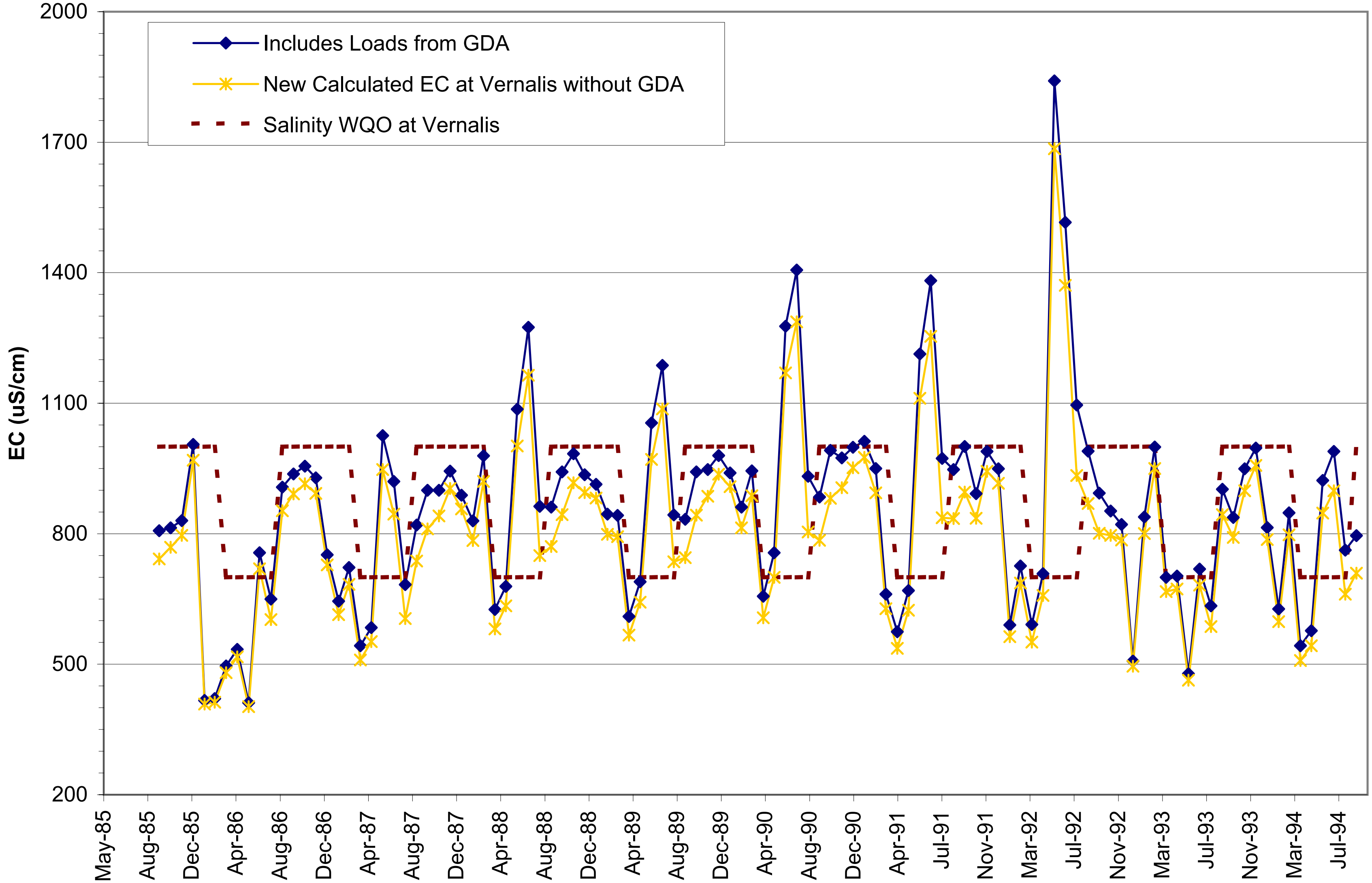


**Figure D4-3. Boron Concentration at Vernalis using Salt TMMLs with and without Grassland Drainage Area Drainage**

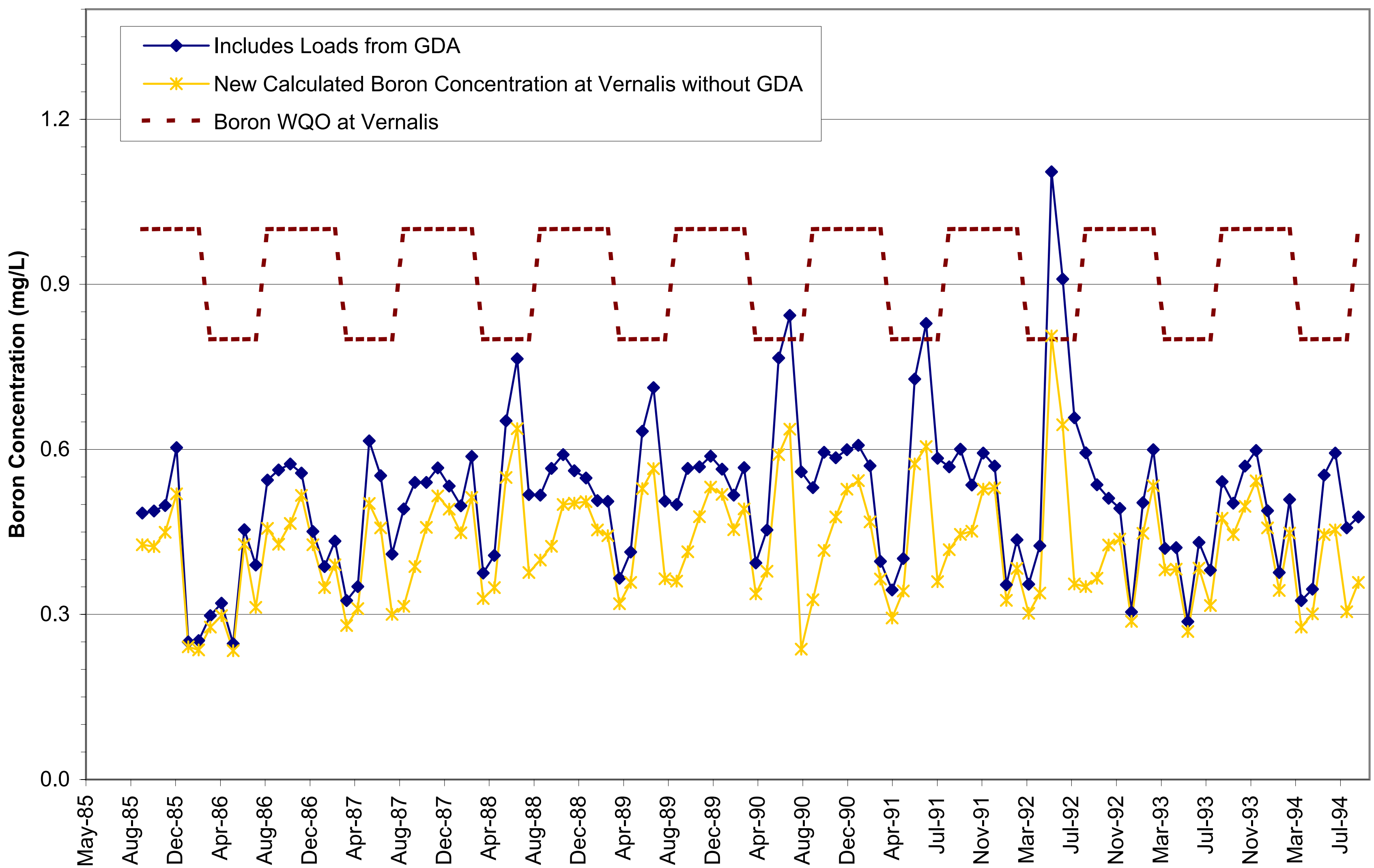


**Figure D4-4. Selenium Concentration at Crows Landing using TMMLs with and without Grassland Drainage Area Drainage**

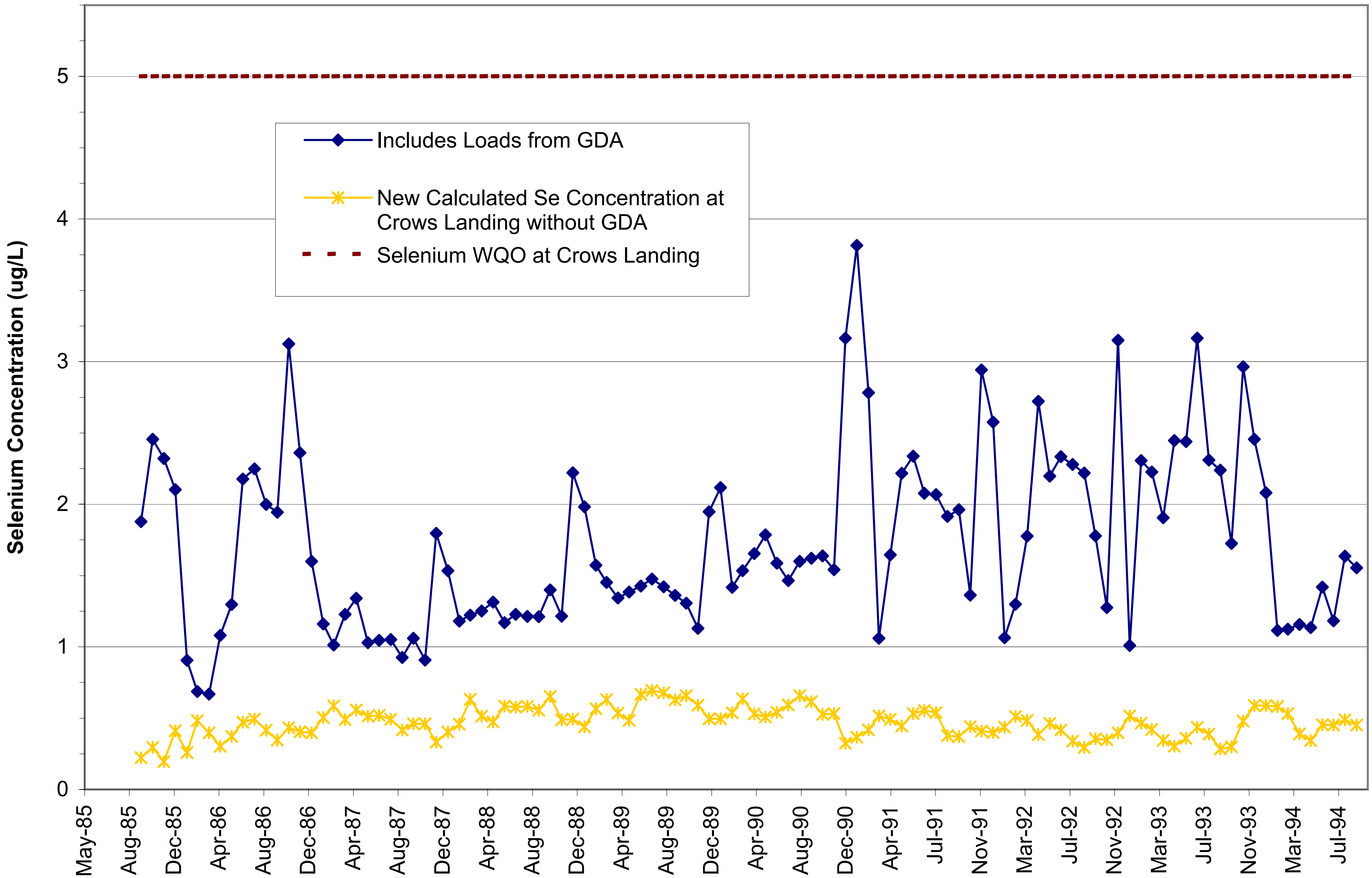
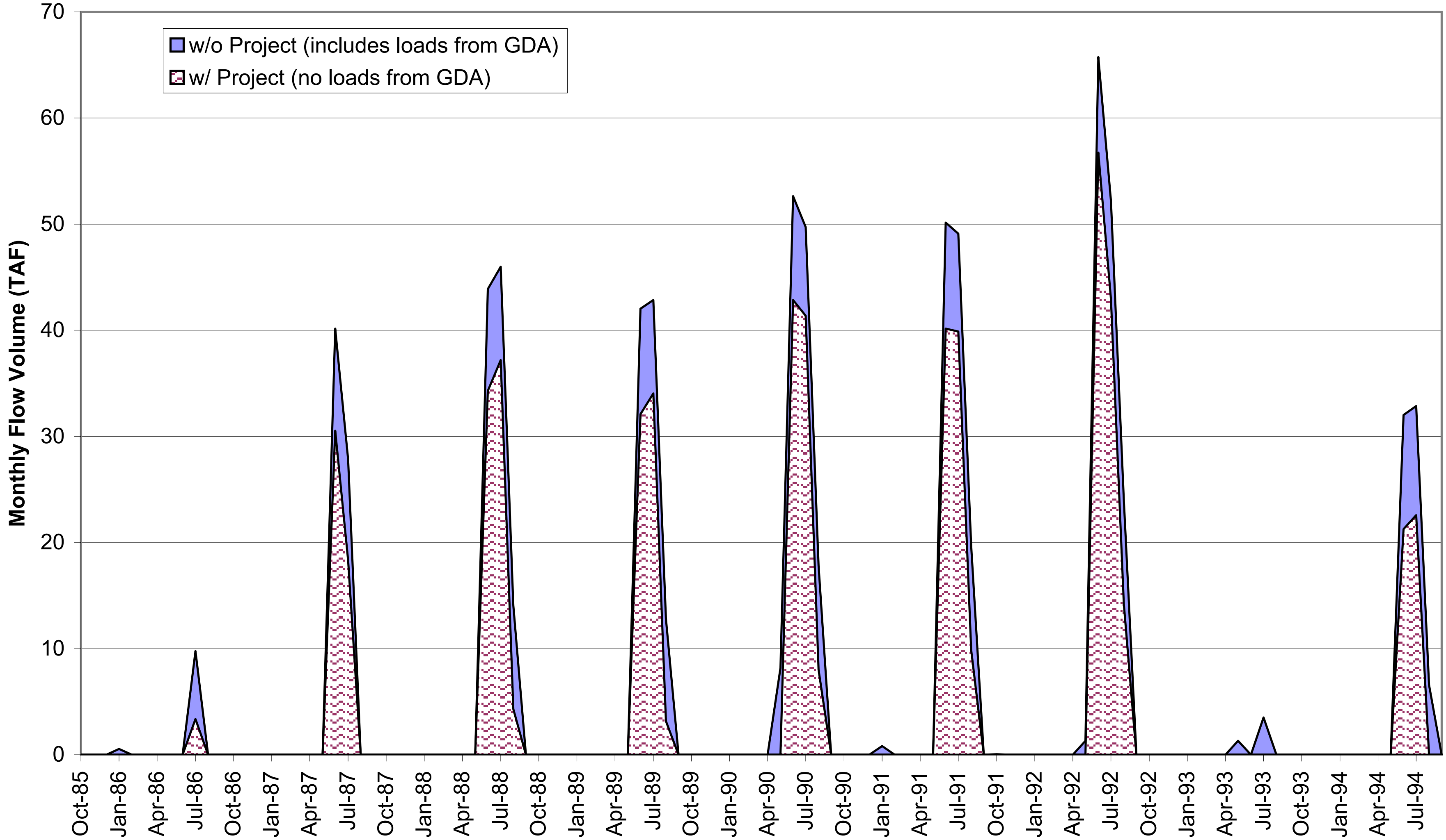


**Figure D4-5. Dilution Flow Releases from New Melones Needed to Meet Water Quality Objectives for Electrical Conductivity at Vernalis During Modeled Period of TMML Compliance from October 1985 to September 1994**



## D5 REFERENCES

Brown and Caldwell Consulting Engineers. 1987. Screening Potential Alternative Geographic Disposal Areas. Prepared for the San Joaquin Valley Drainage Program under contract with the U.S. Bureau of Reclamation. April.

California Central Valley Regional Water Quality Control Board (CVRWQCB). 1998. Loads of salt, boron, and selenium in the Grassland watershed and lower San Joaquin River, May 1985 to September 1998. Electronic file.

CVRWQCB. 2001. Total Maximum Daily Load for Selenium in the Lower San Joaquin River. Sacramento, CA. August.

CVRWQCB. 2002. Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River. Sacramento, CA. January.

Cutter, G.A. and K.W. Bruland. 1984. The marine biogeochemistry of selenium: A re-evaluation. *Limnology and Oceanography* 29: 1179-1192.

Cutter, G.A. and M.L.C. San Diego-McGlone. 1990. Temporal variability of selenium fluxes in San Francisco Bay. *The Science of the Total Environment* 97/98: 235-250.

Danish Hydraulics Institute (DHI). 1998a. MIKE 21 Heavy Metals Module Users Guide and Reference Manual.

Danish Hydraulics Institute (DHI). 1998b. MIKE 21 Advection-Dispersion Module Users Guide and Reference Manual.

Daum, T. and J.A. Davis. 2000. Coastal Watershed Mass Loading Report. San Francisco Estuary Institute.

Glegg, G.A., J.G. Titley, G.E. Millward, D.R. Glasson, and A.W. Morris. 1988. Sorption behavior of waste-generated trace metals in estuarine waters. *Water Sci. Technol*. 20: 113-121.

Luoma, S.N. and T.S. Presser. 2000. Forecasting selenium discharges to the San Francisco Bay-Delta estuary: ecological effects of a proposed San Luis Drain extension. *USGS Open-File Report* 00-416.

Monismith, S. G., W. Kimmerer, J.R. Burau, and M. T. Stacey. 2001. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. Draft submitted to Journal of Hydrology. May 7.

Rivera-Duarte, I. and A. R. Flegal. 1997. Porewater gradients and diffusive benthic fluxes of Co, Ni, Cu, Zn, and Cd in San Francisco Bay. *Croatia Chemica Acta* 70: 389-417.

San Francisco Estuary Institute (SFEI). 1994-1998. Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. Richmond, CA.

URS. 2002. Source Control Technical Memorandum. Prepared for the Bureau of Reclamation. June 17.

Zawislanski, P.T. and A.E. McGrath. 1998. Selenium cycling in estuarine wetlands: Overview and new results from the San Francisco Bay. In *Environmental Chemistry of Selenium*, pp. 223-242.

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 $1 \times 10^{-6}$ 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.

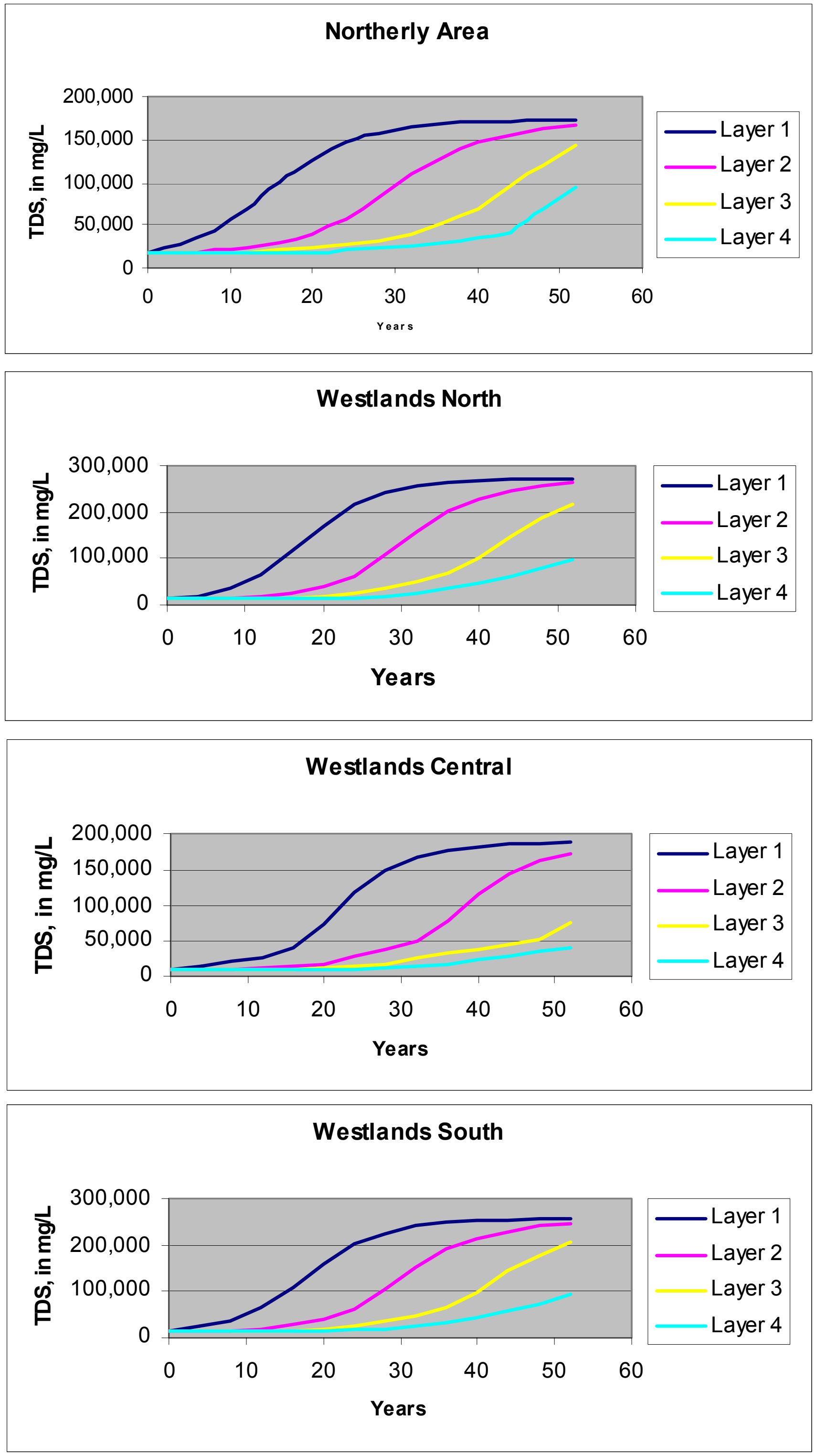



**Figure E1-1**
**Estimated Total Dissolved Solids Concentrations in Groundwater Underlying Evaporation Basins**

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 |

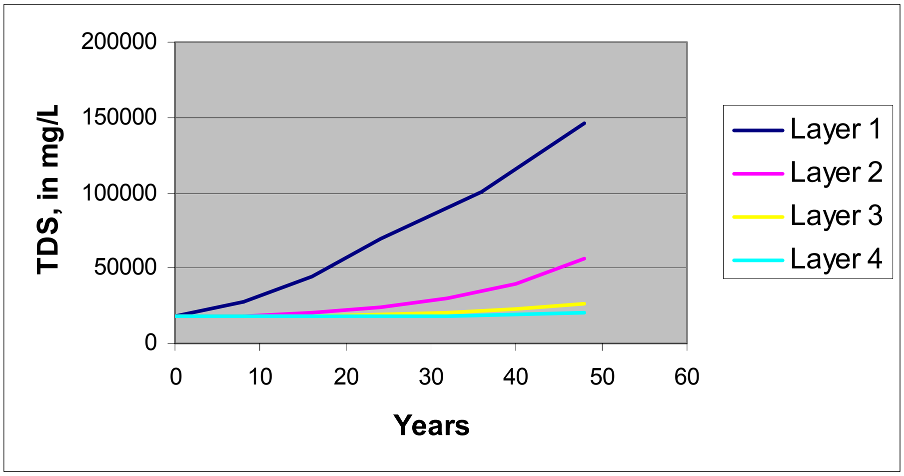



**Figure E1-2**
**Estimated Total Dissolved Solids Concentrations in Groundwater Underlying Evaporation Basins for the Northerly Area with 50 Percent Seepage Reduction**

### 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.

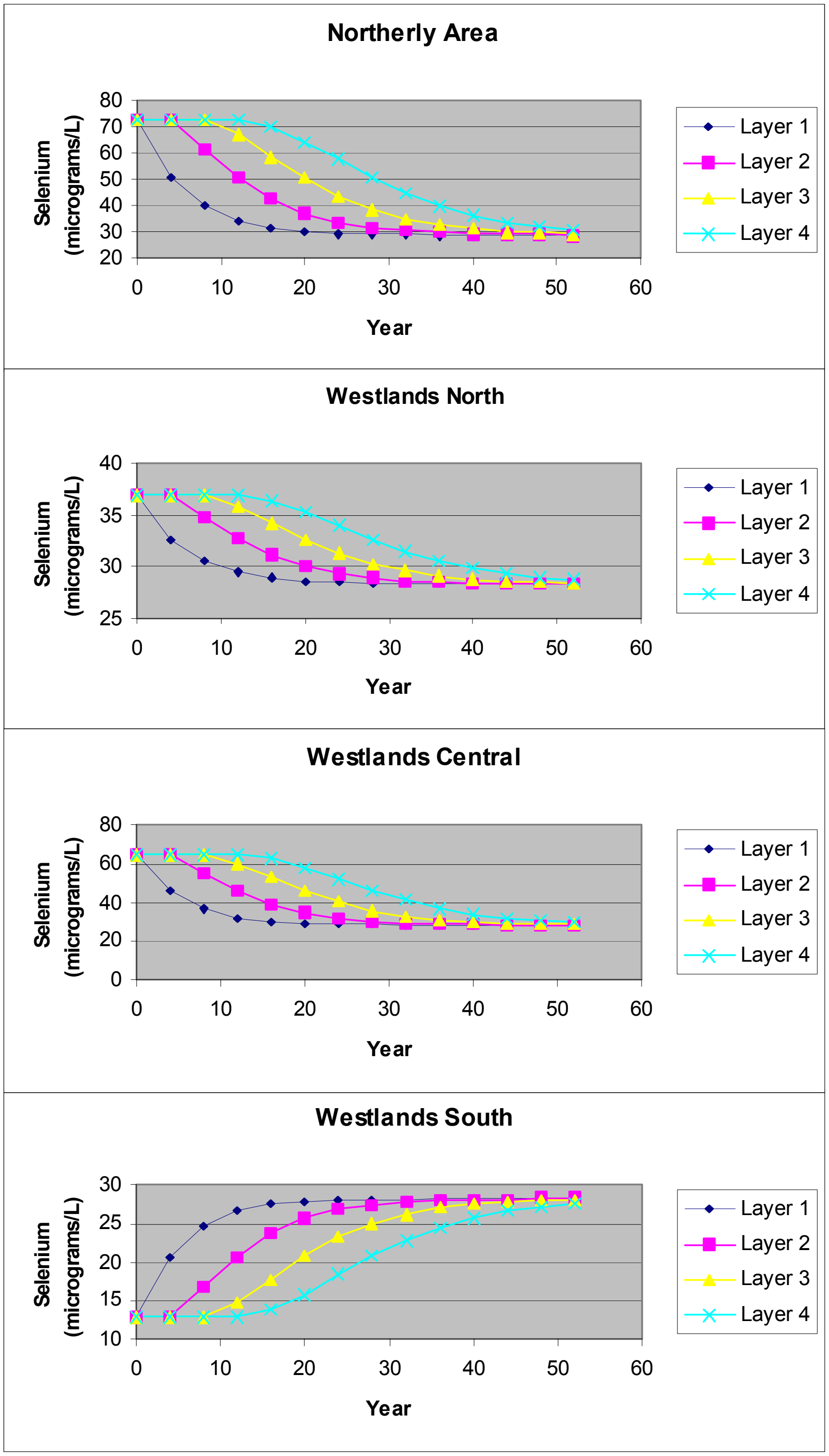



**Figure E1-3**
**Estimated Selenium Concentrations in Groundwater Underlying Evaporation Basins**

**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.

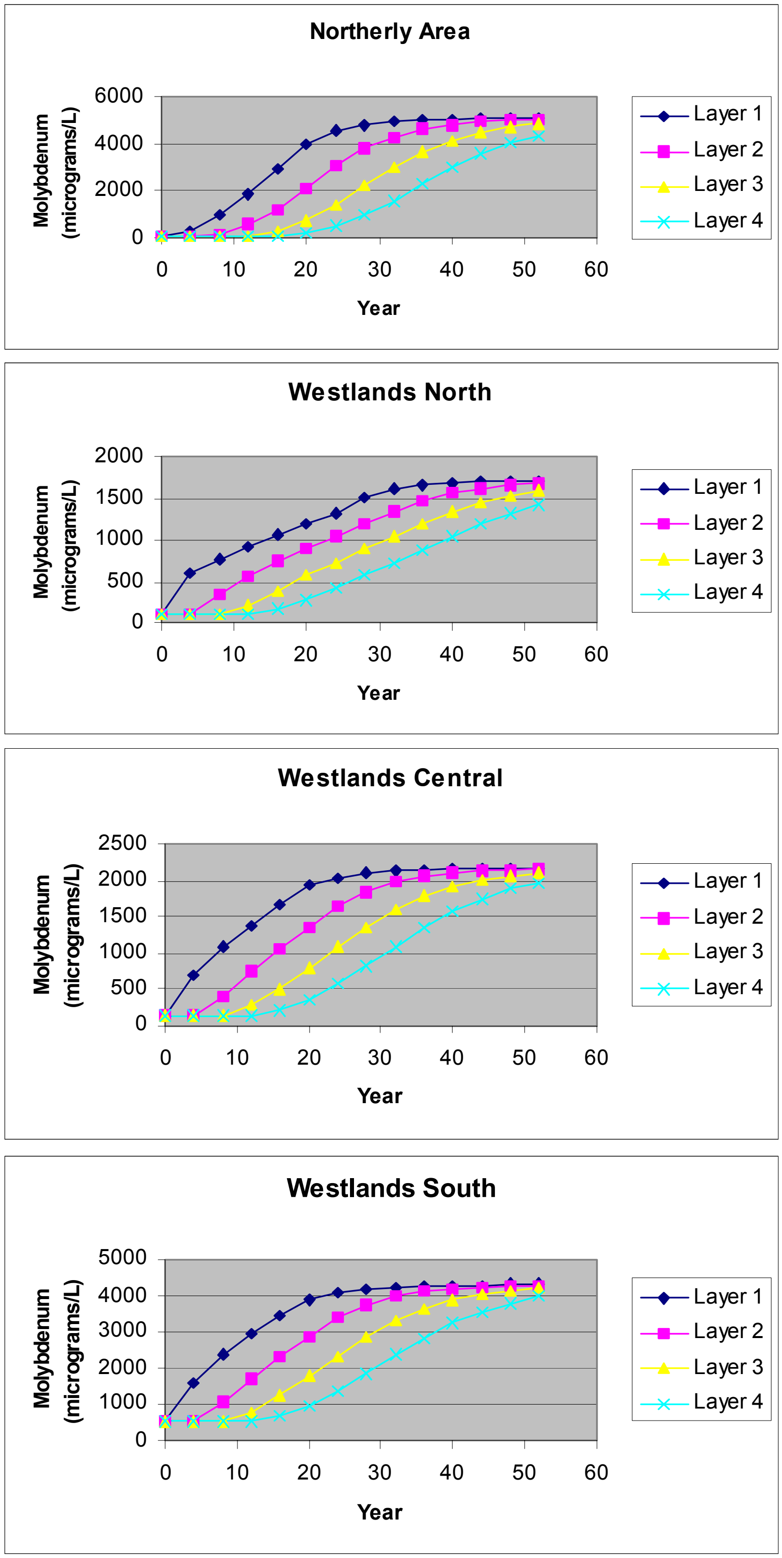



**Figure E1-4**
**Estimated Molybdenum Concentrations in Groundwater Underlying Evaporation Basins**

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**

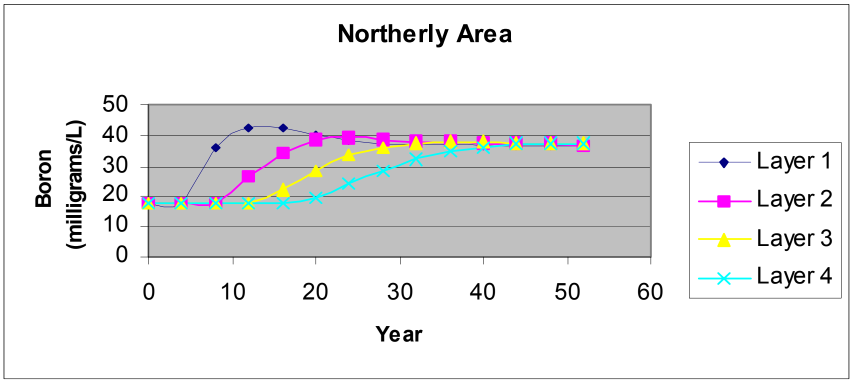
| Evaporation Basin Area and Layer | Seepage Rate Reductions | | | | |
|---|---|---|---|---|---|
| | 0 % (1 ft/yr) | 25 % (0.75 ft/yr) | 50 % (0.5 ft/yr) | 90 % (0.1 ft/yr) | Estimated Original Groundwater Concentration |
| Northerly Area – Layer 1 | 5,090 | 5060 | 4551 | 278 | 40 |
| Layer 2 | 5,048 | 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 |

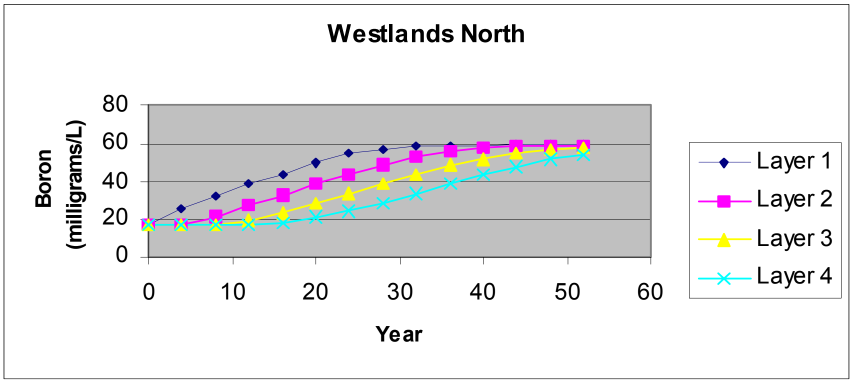
Figure E1-5 shows substantial simulated boron concentration increases. After 52 years, groundwater concentrations increased from 17.5 mg/L to 36.9 (layer 1) and 37.3 (layer 4) mg/L in the Northerly Area, from 17.5 mg/L to 59.5 (layer 1) and 53.8 (layer 4) mg/L in Westlands North, from 7.5 mg/L to 36.6 (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.

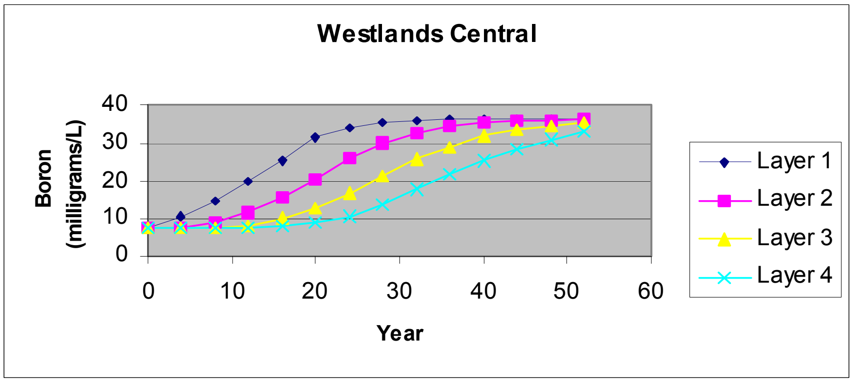
**Table E1-5**
**Model-Estimated 52-Year Groundwater Boron Concentrations (mg/L) for Varying Seepage Rate Reductions**

| 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.



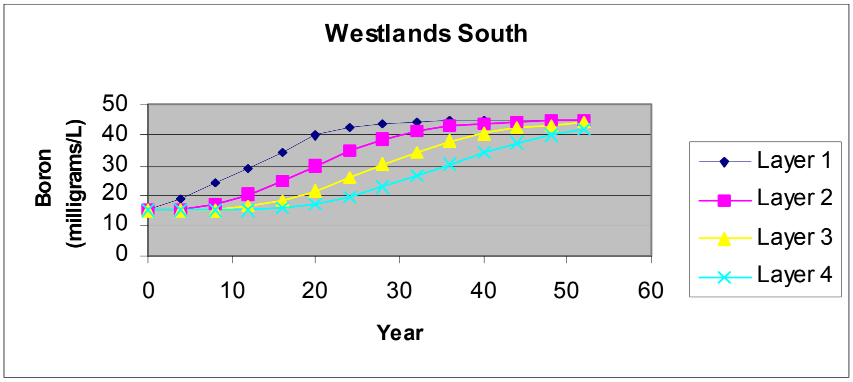




**Figure E1-5**
**Estimated Boron Concentrations in Groundwater Underlying Evaporation Basins**

### 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.

## E1.4 REFERENCES

Belitz, K., S.P. Phillips, and J.M. Gronberg. 1992. Numerical simulation of groundwater flow in the central part of the western San Joaquin Valley, California: *U.S. Geological Survey Open-File Report* 91-535.

Bell, R. 1984 (1988). Isotopic composition of soil carbon dioxide and groundwater in an irrigated cotton field, San Joaquin Valley, California. Master's thesis, University of California, Earth Science and Resources, Davis, CA.

Deverel, S.J. and R. Fujii. 1988. Processes affecting the distribution of Se in shallow groundwater of agricultural areas, western San Joaquin Valley, California. *Water Resources Research* 24:516-524.

Deverel, S.J. and S.P. Millard. 1988. Distribution and mobility of Se and other trace elements in shallow ground water of the western San Joaquin Valley, California. *Environmental Science and Technology* 22:697-702.

Deverel, S.J. and S.K. Gallanthine. 1989. Distribution of salinity and Se in relation to hydrologic and geochemical processes, San Joaquin Valley, California. *Journal of Hydrology* 109:125-149.

Deverel, S.J., R.J. Gilliom, R. Fujii, J.A. Izbicki, and J.C. Fields. 1984. Distribution of Se and other inorganic constituents in shallow ground water of the San Luis Drain Service Area, San Joaquin Valley, California: A preliminary study. *U.S. Geological Survey Water Resources Investigation Report* 84-4319.

Driessen, P.M. and R. Schoorl. 1973. Mineralogy and morphology of salt efflorescences on saline soils in the Great Konya Basin, Turkey. *J. Soil Sci.* 24: 436-442.

Gao, S., K.K. Tanji, Z.Q. Lin, N. Terry, and D.W. Peters. 2003. Selenium removal and mass balance in a constructed flow-through wetland system. *Journal of Environmental Quality*, in press.

Grismer, M.E. and B.L. McCullough-Sanden. 1987. Evaporation basin seepage. *California Agriculture.* November-December.

Grismer, M.E. and B.L. McCullough-Sanden. 1989. Correlation of laboratory analyses of soil properties and infiltrometer seepage from dainwater evaporation basins. *Trans. American Society of Agricultural Engineers*. 32:173-180.

Leighton, D.L., S.J. Deverel, and J. McDonald. 1991. Spatial distribution of Se and other inorganic constituents in groundwater underlying a drained agricultural field, western San Joaquin Valley, California. *U.S. Geological Survey Water Resources Investigation Report* 91-4119.

McCullough-Sanden, B.L. and M.E. Grismer. 1988. Field analysis of seepage from drainwater evaporation basins. *Trans. American Society of Agricultural Engineers* 31:1710-1714.

McNeal, B.L. 1968. Prediction of the effect of mixed-salt solutions on soil hydraulic conductivity. *Soil Sci. Soc. Amer. Proc.* 32:190-193.

McNeal, B.L. and N.T. Coleman. 1966. Effect of solution composition on soil hydraulic conductivity. *Proc. Soil Sci. Soc. Amer.* 30:308-312.

Parkhurst, D.L., D.C. Thorstenson, and L.N. Plummer. 1980. PHREEQE – A computer program for geochemical calculations. *U.S. Geological Survey Water Resources Investigations Report* 80-96.

Pitzer, K.S. 1973. Thermodynamics of electrolytes. I. Theoretical basis and general equations. *J. Phys. Chem.* 77:268-277.

Plummer, L.N., D.L. Parkhurst, G.W. Fleming, and S.A. Dunkle. 1988. A computer program incorporating Pitzer's equations for calculation of geochemical reactions in brines. *U.S. Geological Survey Water Resources Investigations Report* 88-4153.

Pollock, D.W. 1994. User's guide for MODPTH/MODPATH-PLOT, Version 3: A particle tracking post processing pakage for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model. *U.S. Geological Survey Open-File Report* 94-464.

Presser, T.S., W.C. Swain, R.R. Tidball, and R.C. Severson. 1990. Geologic sources, mobilization and transport of Se for the California Coast Ranges to the western San Joaquin Valley: a reconnaissance study. *U.S. Geological Survey Water Resources Investigation Report* 90-4070.

Shelton, L.R. and L.K. Miller. 1988. Water-quality data, San Joaquin Valley, California, March 1985 to March 1987. *U.S. Geological Survey Open File Report* 88-479.

Smith, G.R., K.K. Tanji, R.G. Burau, and J.J. Jurinak. 1995. CSALT–A chemical equilibrium model for multicomponent solutions. In *Chemical Equlibrium and Reaction Models.* Soil Science Society of America Special Publication 42.

Suarez, D.L., J. Rhoades, R. Lavado, and C.M. Grieve. 1984. Effect of pH of saturated hydraulic conductivity and soil dispersion. *Soil Sci. Soc. Am. J.* 48:50-55.

Swain, W.C. and L.F.W. Duell. 1993. Water-quality data for shallow wells in the western and southern Tulare Basin, San Joaquin Valley, California, May to August 1989. *U.S. Geological Survey Open File Report* 92-655.

Sposito, G., K. Holtzclaw, C. Thellier, and J. Rhoades. 1987. Chemical effects of saline drainage waters on irrigated San Joaquin Valley soils. California Water Resources Center, University of California, Davis, CA. Contribution number 196.

Stuart, D.M. and R.M. Dixon. 1973. Water movement and calcite formation in layered arid and semi-arid soils. *Soil Sci. Soc. Am. Proc.* 37:323-324.

Tanji, K.K. 1990. Accumulation of salts and trace elements in agricultural evaporation basins. *Transactions 14th International Congress of Soil Science* 8:180-185.

Tanji, K.K. 2003. Professor, University of California, Davis. Personal communication with Steve Deverel, Principal Hydrologist, HydroFocus, Inc., April 2003.

Tanji, K. K. and M.E. Grismer. 1988. Evaporation basins for disposal of agricultural waste water. Draft final report submitted to State Water Resources Control Board (contract number WRCB 5-190-150-0).

APPENDIX E2

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

# TABLE OF CONTENTS



## Tables



## Figures



## 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.

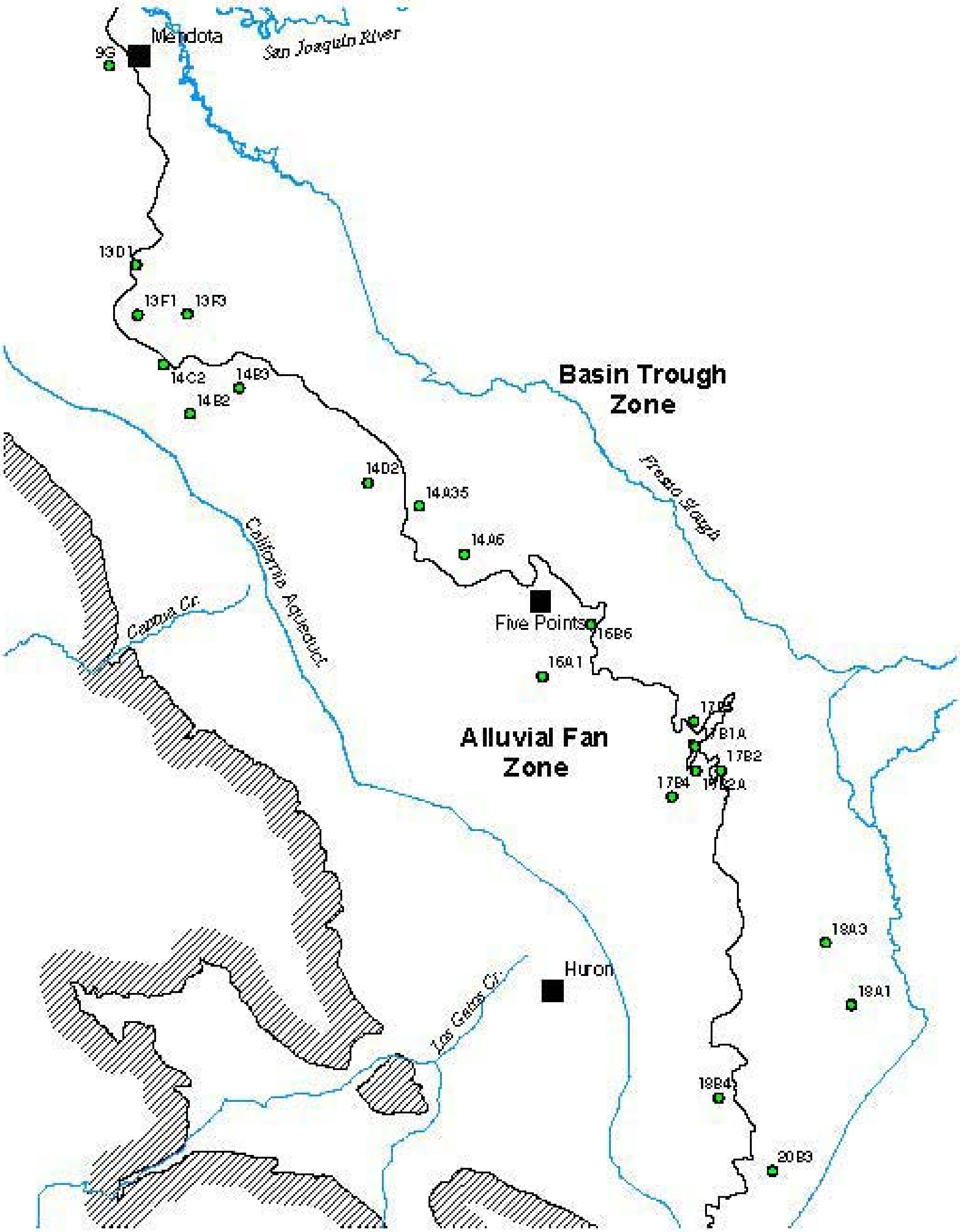



**Figure E2-1**
**Location of Wells and Geologic Boundary (Black Line)**

**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.

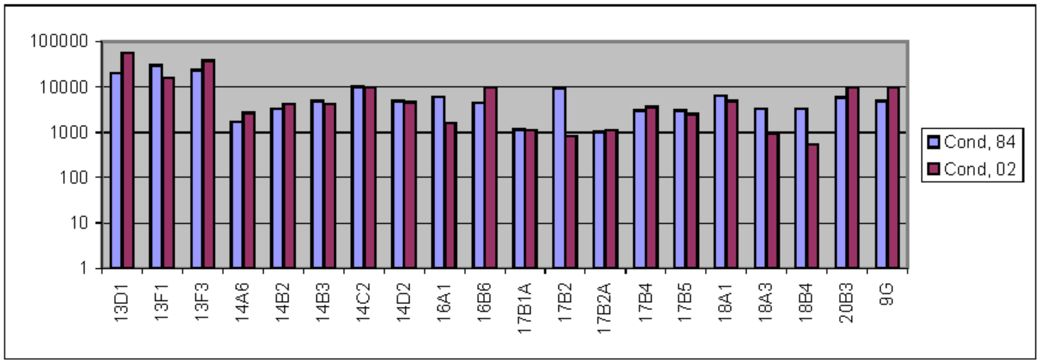
Attachment E2-1 shows the analytical results for the samples for both sampling events. Analysis of sample quality assurance and control (see Attachment E2-2) indicated acceptable results for all samples and constituents of concern. Figure E2-2 shows the graphical comparison between sampling events. Figure 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.

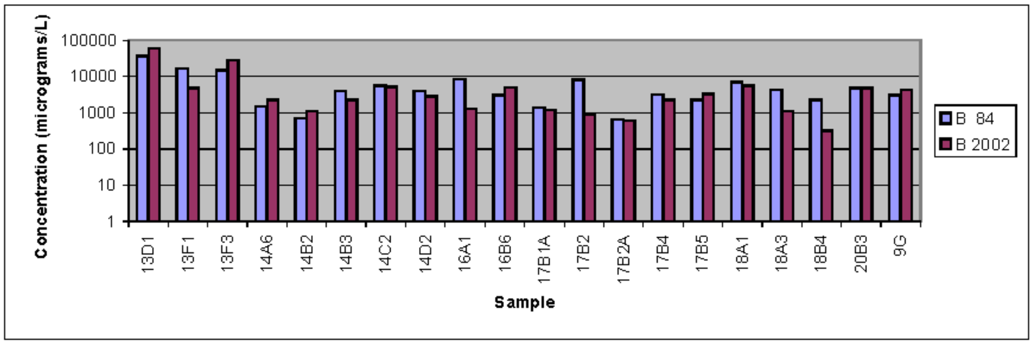
The water table was significantly deeper (alpha = 0.05) for the 2002 sampling event. Examination of depth to groundwater relative to land use for individual samples provides further insight. During the May 1984 sampling, most of the areas surrounding the sampled wells were actively farmed. In August 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).

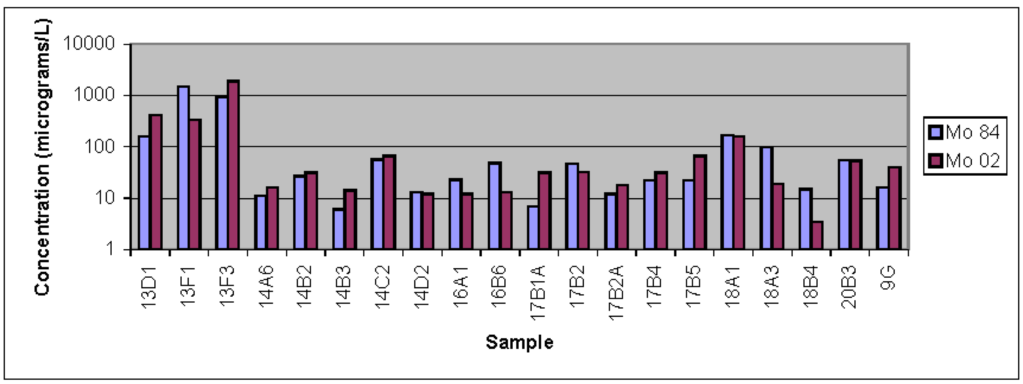
The observed water-level decrease is consistent with modeling results and data from the Bureau of Reclamation's land-retirement project (Belitz and Phillips 1992; Bureau of Reclamation 2000), indicating significant water table declines under fallowed and unirrigated lands. Also, continued groundwater 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.



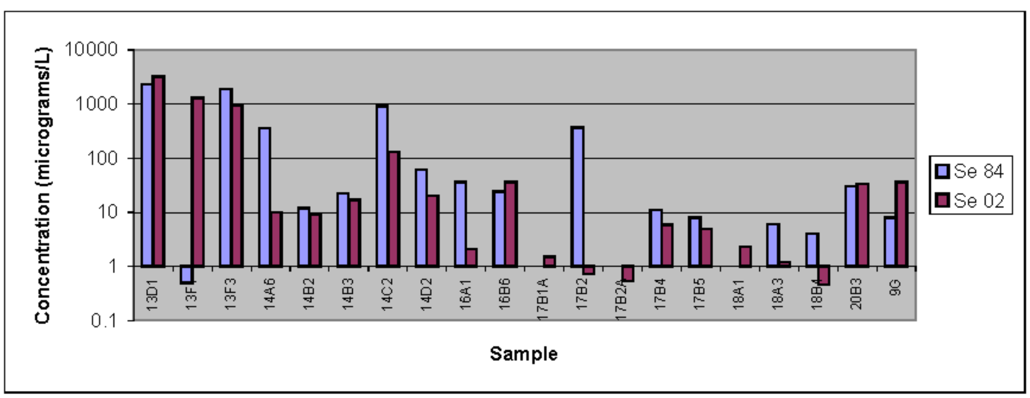




**Figure E2-2**
**Comparison of Electrical Conductivity and Concentrations of Boron, Molybdenum, and Selenium Between Samplings**

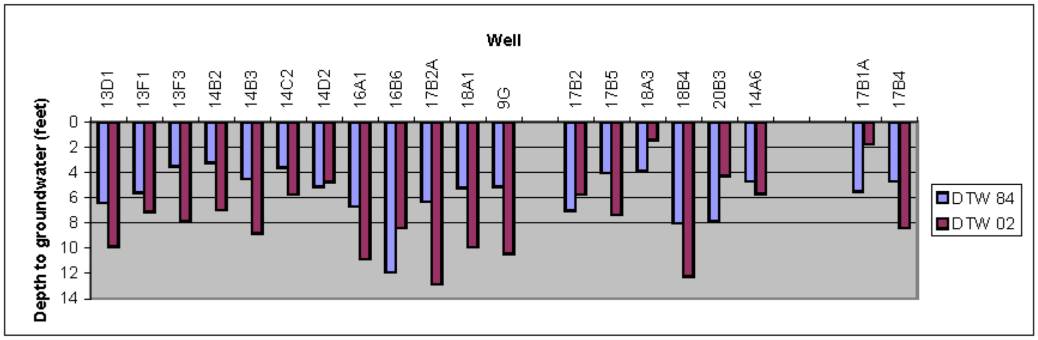



**Figure E2-3**
**Comparison of Depth to Groundwater Between Samplings**

## 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.

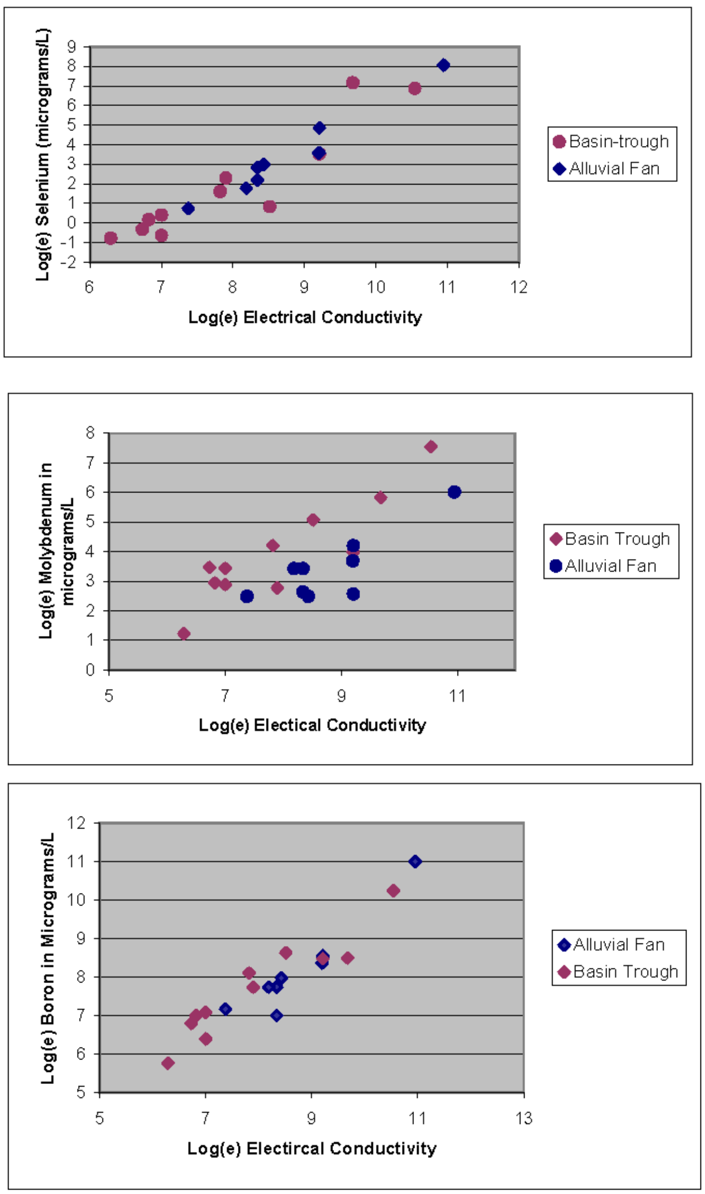



**Figure E2-4**
**Relation of Selenium, Molybdenum, and Boron to Electrical Conductivity for 2002 Sampling**

### 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.

## E2.5 REFERENCES

Belitz, K. and S. P. Phillips. 1992. Simulation of water-table response to management alternatives, central part of the western San Joaquin Valley, California. *U.S. Geological Survey Water Resources Investigations Report* 91-4193.

Bureau of Reclamation. 2000. Land Retirement Demonstration Project, Annual Report. Fresno, CA.

Deverel, S.J., R.J. Gilliom, R. Fujii, J.A. Izbicki, and J.C. Fields. 1984. Distribution of selenium and other inorganic constituents in shallow ground water of the San Luis Drain Service Area, San Joaquin Valley, California: a preliminary study. *U.S. Geological Survey Water Resources Investigation Report* 84-4319.

Deverel, S.J. and S.P. Millard. 1988. Distribution and mobility of selenium and other trace elements in shallow groundwater of the western San Joaquin Valley, California. *Environmental Science and Technology* 22:697-702.

Deverel, S.J. and S.K. Gallanthine. 1989. Distribution of salinity and selenium in relation to hydrologic and geochemical processes, San Joaquin Valley, California. *Journal of Hydrology* 109:125-149.

Deverel, S.J. and J.L. Fio. 1991. Groundwater flow and solute movement to drain laterals, western San Joaquin Valley, California. I. Geochemical assessment. *Water Resources Research* 27:2233-2246.

Leighton, D.L., S.J. Deverel, and J. McDonald. 1991. Spatial distribution of selenium and other inorganic constituents in groundwater underlying a drained agricultural field, western San Joaquin Valley, California. *U.S. Geological Survey Water Resources Investigation Report* 91-4119.

Laudon, J. and K. Belitz. 1991. Texture and depositional history of Late Pleistocene-Holocene Alluvium in the central part of the western San Joaquin Valley, California. *Bulletin of the Association of Engineering Geologists* 28:73-88.

Mathews, R.A. and J.I. Burnett. 1965. Fresno Sheet, Geologic Map of California. California Division of Mines and Geology, Sacramento, CA.

Steel, R.G.D. and J.H. Torrie. 1960. *Principles and Procedures of Statistics*. New York: McGraw Hill.

# 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.

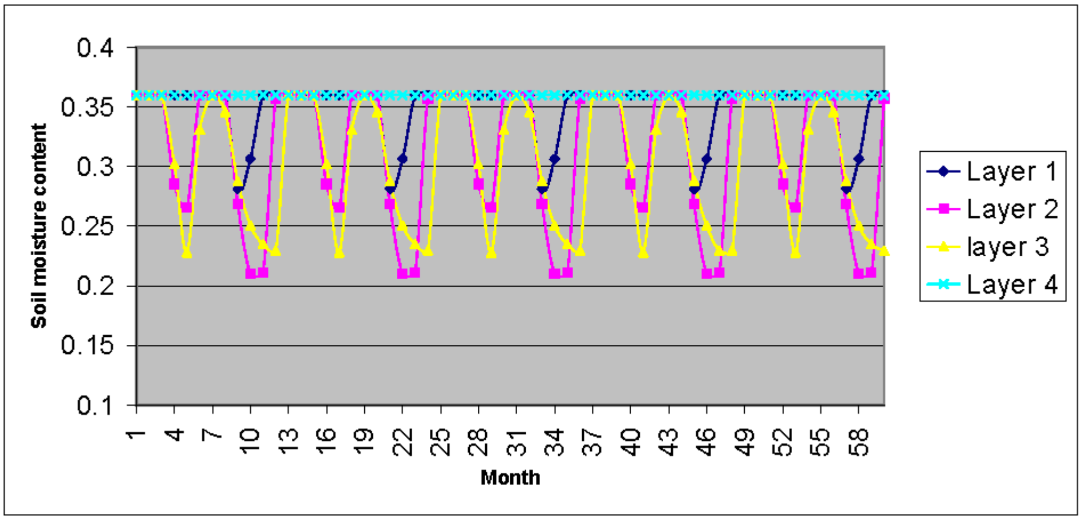



**Figure E3-1**
**Predicted Monthly Soil Moisture Changes**

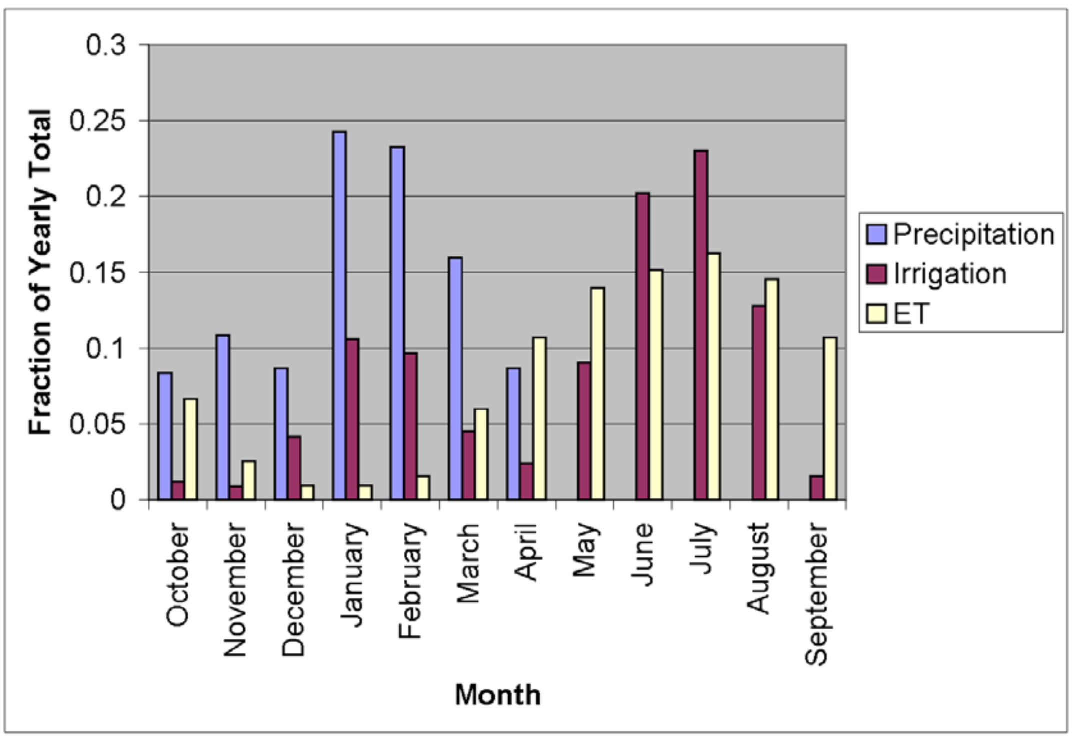



**Figure E3-2**
**Monthly Distributions for Fractions of Precipitation, Irrigation, and Evapotranspiration**

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.<br>Evaporation of water based on ET (40 percent of total average crop ET)<br>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.<br>Evaporation. (30 percent of total average crop ET)<br>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.<br>Evaporation (20 percent of total average crop ET).<br>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<br>Evaporation (10 percent of total average crop ET).<br>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.

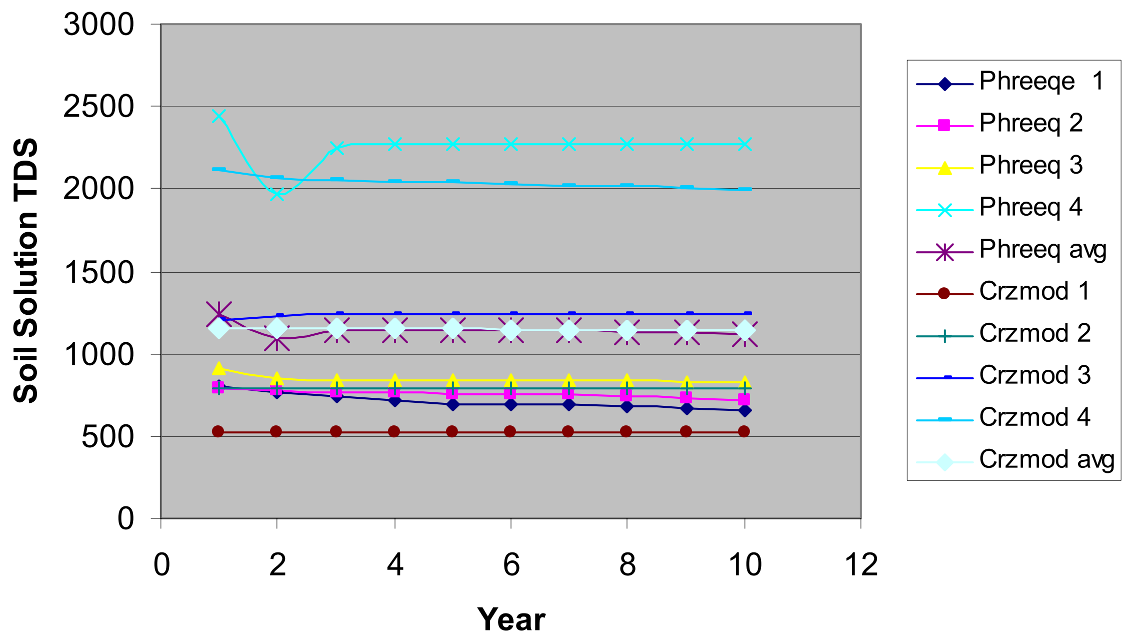



**Figure E3-3**
**Comparison of Soil Salinity Estimates without Gypsum, Northerly Area**

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).

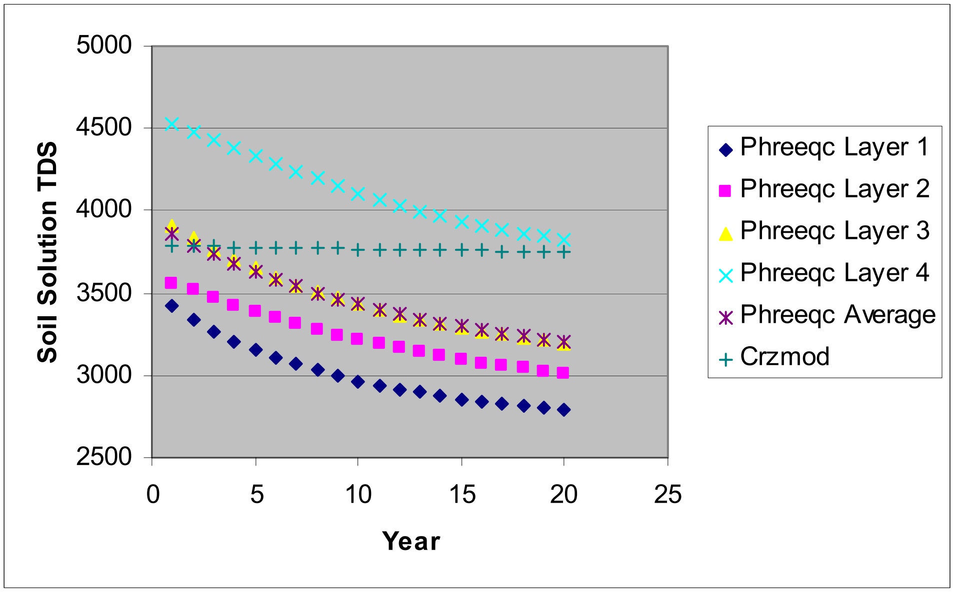



**Figure E3-4**
**Comparison of Soil Salinity Estimates with Gypsum, Northerly Area**

### 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.

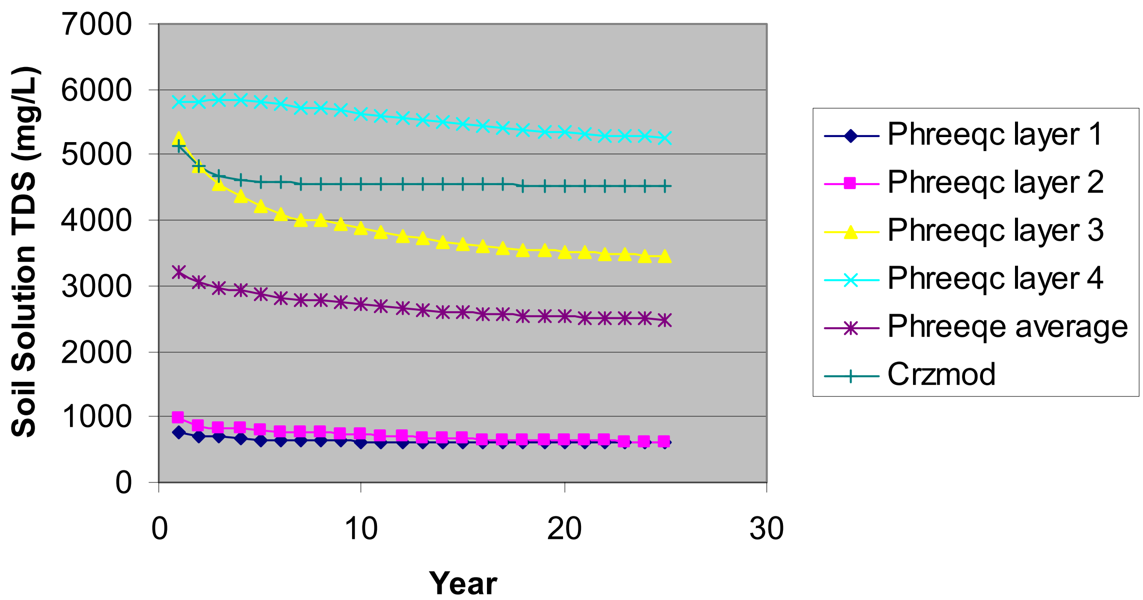



**Figure E3-5**
**Estimated Changes in Soil Salinity in Westlands with Gypsum in the Bottom Two Layers**

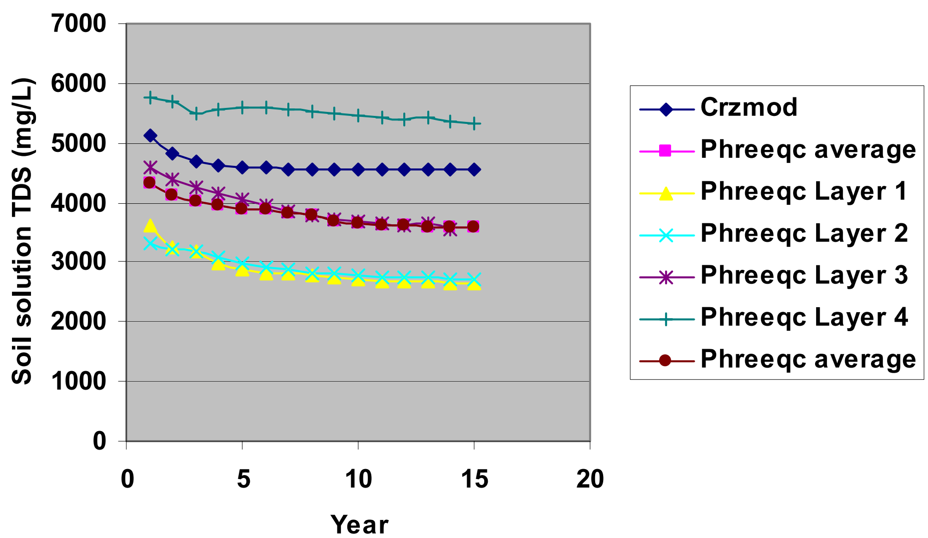



**Figure E3-6**
**Estimated Soil Solution Total Dissolved Solids in Westlands with Gypsum in All Layers**

## 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.

## E3.6 REFERENCES

Bell, R. 1988. Isotopic composition of soil carbon dioxide and groundwater in an irrigated cotton field, San Joaquin Valley, California. Masters Thesis, University of California, Earth Science and Resources, Davis, California.

Corwin, D.L., M.L.K. Carillo, P.J. Vaughan, J.D. Rhoades, and D.G. Cone. 1999. Evaluation of a GIS-linked model of salt loading to groundwater. *Journal of Environmental Quality* 28(2): 471-480.

Corwin, D.L, J.D. Rhoades, and P.J. Vaughan. 1996. GIS applications to the basin-scale assessment of soil salinity and salt loading to groundwater. In *Applications of GIS to the modeling of non-point source pollutants in the vadose zone,* D.L Corwin and K. Loague, eds. Soil Science Society of America, Madison, WI.

Deverel, S.J. and R. Fujii. 1988. Processes affecting the distribution of selenium in shallow groundwater of agricultural areas, western San Joaquin Valley, California. *Water Resources Research* 24:516-524.

Deverel, S.J. and S.K. Gallanthine. 1989. Distribution of salinity and selenium in relation to hydrologic and geochemical processes, San Joaquin Valley, California. *Journal of Hydrology* 109:125-149.

Doner, H.E., R.G. Amundsen, and B. Lilieholm. 1989. A comparison of Se and As concentrations in soils of western San Joaquin Valley, California: 1946-1985. *Arid Soil and Research and Rehabilitation* 3:315-325.

Fio, J.L. and R. Fujii. 1990. Selenium speciation methods and application to soil saturation extracts from the San Joaquin Valley, California. *Soil Science Society of America Journal* 54:363-369.

Fujii, R., S.J. Deverel, and D.B. Hatfield. 1988. Distribution of selenium in soils of agricultural fields, western San Joaquin Valley, California. *Soil Science Society of America Journal* 52:1274-1283.

Harradine, F.F. 1950. *Soils of Western Fresno County.* Berkeley: University of California Press.

Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. *U.S. Geological Survey Water Supply Paper* 2254.

Leighton, D.A, S.J. Deverel, and J. McDonald. 1991. Spatial distribution of selenium and other inorganic constituents in groundwater underlying a drained agricultural field, western San Joaquin Valley. *U.S. Geological Survey Water Resources Investigation Report* 91-4119.

Parkhurst, D.L. and C.A.J. Appelo. 1999. User's guide to PHREEQC – A computer program for speciation, batch reaction, one-dimensional transport and inverse geochemical calculations. *U.S. Geological Survey Water Resources Investigations Report* 99-4259. Denver, CO.

Sposito, G., K. Holtzclaw, C. Thellier, and J. Rhoades. 1987. Chemical effects of saline drainage waters on irrigated San Joaquin Valley soils. California Water Resources Center, University of California, Davis, California, Contribution number 196.

Tanji, K.K. 1969. Solubility of gypsum in aqueous electrolytes as affected by ion association in ionic strengths up to 0.15 M at $25^{o}$ C. *Environmental Science and Technology* 3:356-361.

Tanji, K.K., J.W. Biggar, G.L. Horner, R.J. Miller, and W.O. Pruitt. 1977. Irrigation tailwater management, second-year annual progress report. *Water Science and Engineering Paper* 4014, Department of Land, Air and Water Resources, University of California. Davis, CA.

Wichelns, D. 1989. Economic Analysis and Farm-level implications of Regional Drainage Policies. Report to the San Joaquin Valley Drainage Program, Sacramento, CA.

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:

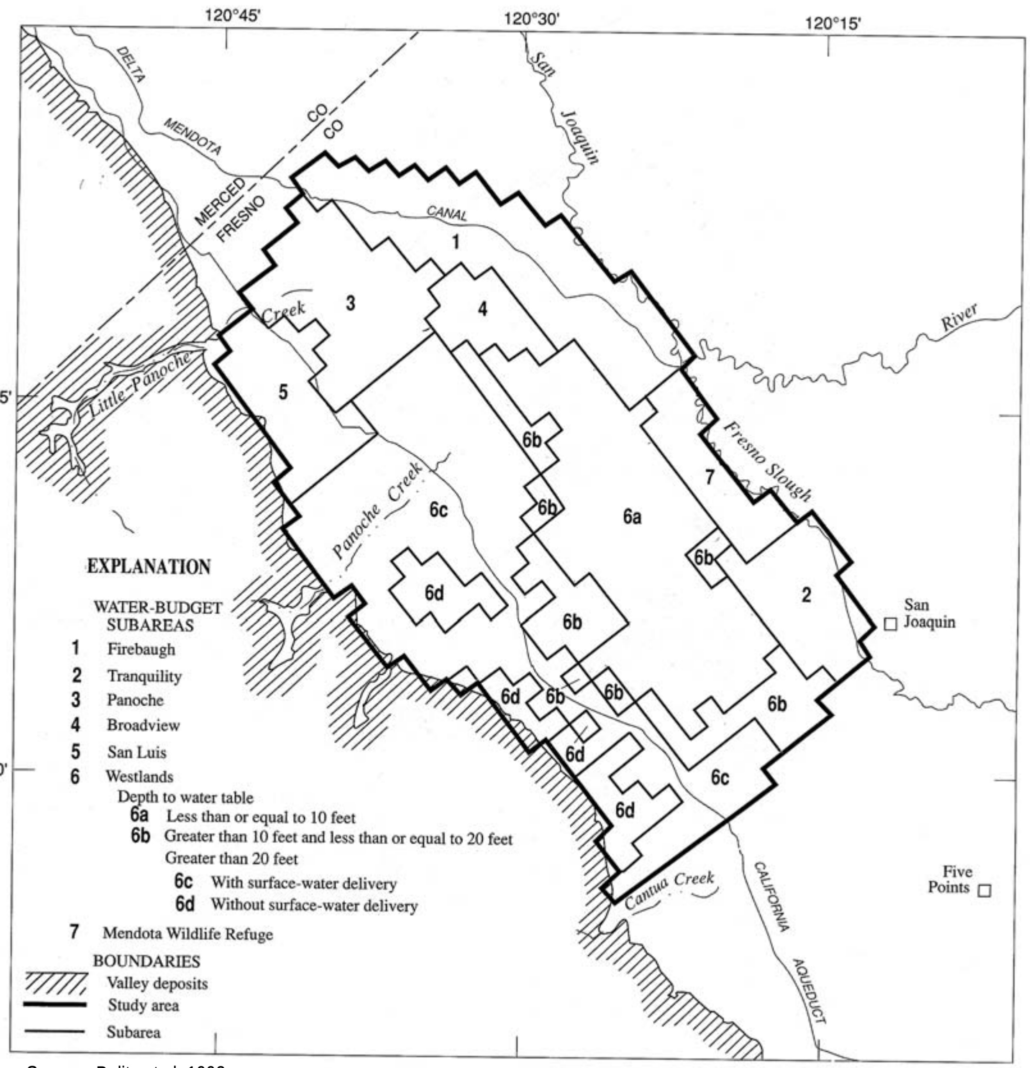
1. What is the relationship between the number of operational wells and annual pumpage within Westlands Water District?
2. What is the distribution of wells within the model areas that represent Westlands Water District?
3. What is the pumping rate and distribution in the model area representing Westlands 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?

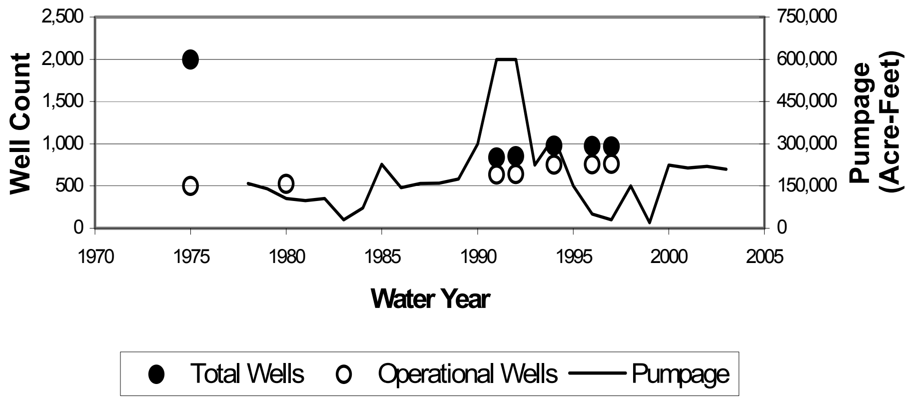
Figure E4-2 shows the relationship between the reported number of operational wells within Westlands and annual, Westlands-wide groundwater pumpage. Annual pumpage varied substantially and ranged from a minimum of 20,000 acre-feet (AF) in 1999 to a maximum of 600,000 AF in 1992 and 1993. However, the 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

Brush, Charles. 2004. Hydrologist, U.S. Geological Survey. Written communication with Michael Delamore, San Joaquin Valley Drainage Program Manager, Bureau of Reclamation, March 9, 2004.

Belitz, K., S.P. Phillips, and J.M. Gronberg. 1993. Numerical simulation of ground-water flow in the central part of the western San Joaquin Valley, California. *U.S. Geological Survey Water-Supply Paper* 2396.

Bureau of Reclamation. 2003. Westlands water needs assessment table faxed to John Fio, HydroFocus, Inc., November 2003.

HydroFocus, Inc. 1998. Model post-audit and projected water-table response to land retirement strategies in the San Luis Unit, western San Joaquin Valley, California.

Rangel, Jose. 2004. Westlands Water District. Personal communication with John Fio, Principal Hydrologist, HydroFocus, Inc., June 24, 2004.

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 |
| 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* d*raytonii* | 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 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 |

**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 |
|---|---|---|---|---|---|---|---|
| **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 |

**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 |
|---|---|---|---|---|---|---|---|
| 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 | |

**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 |
|---|---|---|---|---|---|---|---|
| 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 |

**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 |
|---|---|---|---|---|---|---|---|
| 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)