Chapter 2. Physical Impacts of Agricultural Land Retirement in the San Joaquin Valley

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2.1. Introduction

This chapter describes the physical setting at the Tranquillity and Atwell Island Project sites including soil, groundwater, and surface water conditions. The methods utilized for monitoring soil, groundwater, and surface water during the study are discussed. A conceptual model of the groundwater system at the Tranquillity site is presented with a discussion of soil and groundwater response to land retirement. Monitoring data from the Tranquillity Site are compared against performance criteria established by the U.S. Fish and Wildlife Service (FWS) and summarized in the table below.

FWS Performance Standard	Performance Standard Met?
Depth to groundwater will not show a net increasing trend (decreasing depth to soil surface) over 5 years of monitoring.	YES
Selenium concentration in groundwater will not show a net increasing trend over 5 years of monitoring.	NO
Standing water that persists more than 30 days in duration shall not exceed 2 µg/L (parts per billion) selenium and 2 ng/L (parts per trillion) mercury.	NOT MEASURED

2.2. Tranquillity Site

2.2.1. Geology

The Tranquillity Demonstration Project site is located in the western San Joaquin Valley, an asymmetrical basin bounded by the Coast Ranges on the west, the Tehachapi Mountains on the south, the Sierra Nevada on the east and the delta of the San Joaquin and Sacramento Rivers on the north. The axis of the valley trough is closer to the Coast Ranges than to the Sierra Nevada. The basin is filled with alluvium overlying older Mesozoic and Cenozoic marine and continental sediments. Alluvial deposits underlying the central San Joaquin Valley were shed from the adjacent Coastal and Sierra Nevada ranges and vary in thickness from 274 to 1,006 meters (m) (900 to 3,300 feet [ft]) (Miller et al. 1971). The Sierra Nevada consists mainly of granitic and metamorphic rocks of pre-Tertiary age. The Coast Ranges are composed primarily of folded and faulted beds of Cretaceous age marine shale and sandstone in the north and Cenozoic age sandstone and shale in the south (Prokopovich 1987). Bull (1964a and b) identified a series of alluvial fans derived from sediments from the coastal ranges that form the western margin of the San Joaquin Valley in the study area.

The Tranquillity demonstration project site is located in the trough of the San Joaquin valley in western Fresno County. The site is underlain directly by flood basin deposits derived from overbank deposition from the San Joaquin River and Fresno Slough. The flood basin deposits consist of fine textured, moderately to densely compacted clays that range in thickness from 1.5 to 10.7 m (5 to 35 feet) (Belitz and Heimes 1990). The flood basin clays have low-permeability and greatly impede the downward movement of water. On the northern part of the site (Section 10, Figure 2-1), the flood basin deposits rest upon well sorted micaceous sand derived from the Sierra Nevada. The Sierran sands are highly permeable, reduced in oxidation state, and vary in thickness between 122 and 152 m (400 and 500 feet) in the project vicinity. On the southern part of the site (Sections 15 and 16, Figure 2-1), the flood basin deposits overlie sediments derived from the coastal ranges. The coastal range sediments inter-finger with Sierran sands in the project vicinity, and are oxidized and primarily fine grained. The Corcoran clay is a regionally extensive fine grained lakebed deposit that underlies the site at a depth of approximately 152 m (500 feet).

2.2.2. Soils

Soils in the Tranquillity Demonstration Project area primarily consist of clays, silty clays, and silty clay loams, which formed in alluvium, derived from igneous and sedimentary rock. Individual soil mapping units at the project site include (in order of abundance) Tranquillity clay, Lillis clay, and Lethent silt loam. These soil series cover more than 56,658 hectares (ha) (140,000 acres) in western Fresno County, and are representative of soil conditions found in the drainage impacted lands in Western Fresno County. The Tranquillity mapping unit is the predominant soil type in the study area and covers approximately 80 percent of the site, while the Lillis and Lethent mapping units occur exclusively in Section 10 and cover the remainder of the site (Figure 2-1). The Tranquillity clay is a very deep, poorly to moderately drained saline-sodic soil found on low-lying alluvial fans and flood plains with slopes between 0 and 1 percent. The permeability of this soil is slow and the unit is suited to growing irrigated, salt-tolerant crops, or for wildlife habitat (USDA 1996). Runoff is low, and the hazard of water erosion is slight. The depth to the water table varies and is commonly highest during irrigation applications in the winter and early spring. These soils generally require intensive management to reduce salinity and maintain agricultural productivity.

The U.S. Department of Agriculture (USDA) took soil samples from the major soil horizons in a test pit located in the NW 1/4 of Section 16 (Figure 2-1) at the site in 1992. The samples were analyzed in the laboratory for particle size, chemistry, and mineralogy. These soils consist predominantly of clay-sized particles less than 0.002 millimeters (mm) in diameter. The USDA reported that the clay fraction from six samples taken from the test pit ranged from 48 to 52 percent of the total samples. Silt size particles (0.002-0.05 mm in diameter) ranged from 36-37 percent of the total samples, and sand-size particles made up from 11-16 percent of the total samples (USDA 1992). Total selenium concentrations ranged from 0.5 to 1.1 parts per million (ppm), and the

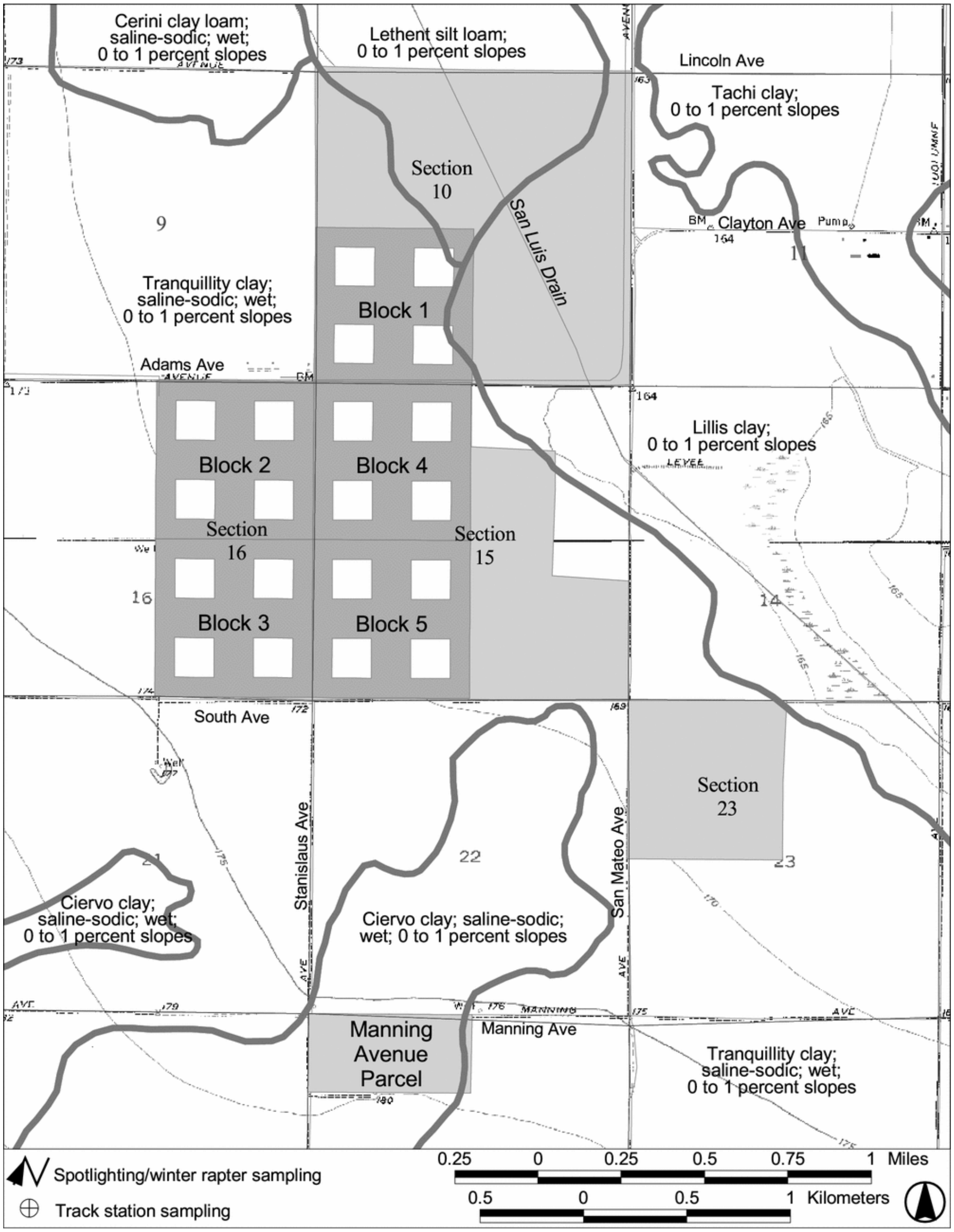

Figure 2-1. U.S. Department of Agriculture soil mapping units, Tranquillity site.

Electrical Conductivity (EC) of saturation extracts ranged from 3.7 to 10.9 deciSiemens/meter (dS/m). These soils are highly plastic with Plasticity Indices ranging from 23-52 percent. The predominant clay mineral is Montmorillonite, which can take on water in the crystal lattice, resulting in high shrink-swell potential and development of deep cracks at the soil surface upon drying.

The Lillis clay mapping unit covers about 10 percent of the study area in the eastern half of Section 10 (Figure 2-1). These soils are very deep, poorly drained, saline-sodic soils found typically on floodplains and basins. Permeability of the Lillis soil is extremely slow, water infiltration rate is high, and when the soil is dry, the surface cracks open. As the soil becomes wet and the cracks close, the infiltration rate greatly decreases. Surface water runoff is low and the hazard of water erosion is slight. The unit is used mainly for wildlife habitat and recreation.

The USDA took soil samples from the major soil horizons in a test pit located in the SW 1/4 of Section 10 at the site in 1992. The samples were analyzed in the laboratory for particle size, chemistry, and mineralogy. These soils consist predominantly of clay-sized particles less than 0.002 mm in diameter. The USDA reported that the clay fraction from nine samples taken from the test pit ranged from 59 to 66 percent of the total samples. Silt-size particles (0.002-0.05 mm in diameter) ranged from 29-36 percent of the total samples, and sand-sized particles made up from 2-7 percent of the total samples (USDA 1992). Total selenium concentrations ranged from 0.3 to 0.7 ppm, and the EC of saturation extracts ranged from 9.6 to 38.6 dS/m. These soils are highly plastic with Plasticity Indices ranging from 33-61 percent. The predominant clay mineral is Montmorillonite, which can take on water in the crystal lattice, resulting in high shrink, swell potential.

The Lethent silt loam mapping unit covers about 10 percent of the site in the north half of Section 10, Figure 2-1). These soils are deep, moderately well drained, saline-sodic soil found on low-lying alluvial fans and basin rims. Permeability of this soil is very slow; runoff is slow; and the hazard of water erosion is slight (USDA 1996).

2.2.3. Groundwater

A conceptual site model for current groundwater conditions at the Tranquillity site is shown in Figure 2-2. Prior to agricultural development, the site was a discharge point for groundwater. Recharge to the semi-confined aquifer occurred along the Coast Range and intermittent stream channels to the west of the site and groundwater generally flowed toward the axis of the valley, where it rose close to the land surface and was discharged by evapotranspiration and also contributed to streamflow along the valley trough (Belitz and Heimes 1990). Evaporation of groundwater from a shallow water table resulted in high concentrations of salt and trace elements in the soil near the land surface. Heavy groundwater pumping that occurred concurrently with agricultural development lowered the regional water table and created large downward hydraulic gradients in the semi-confined aquifer. Irrigation with imported surface water and pumped groundwater in the absence of artificial drains flushed the salts from the surface soils into the shallow

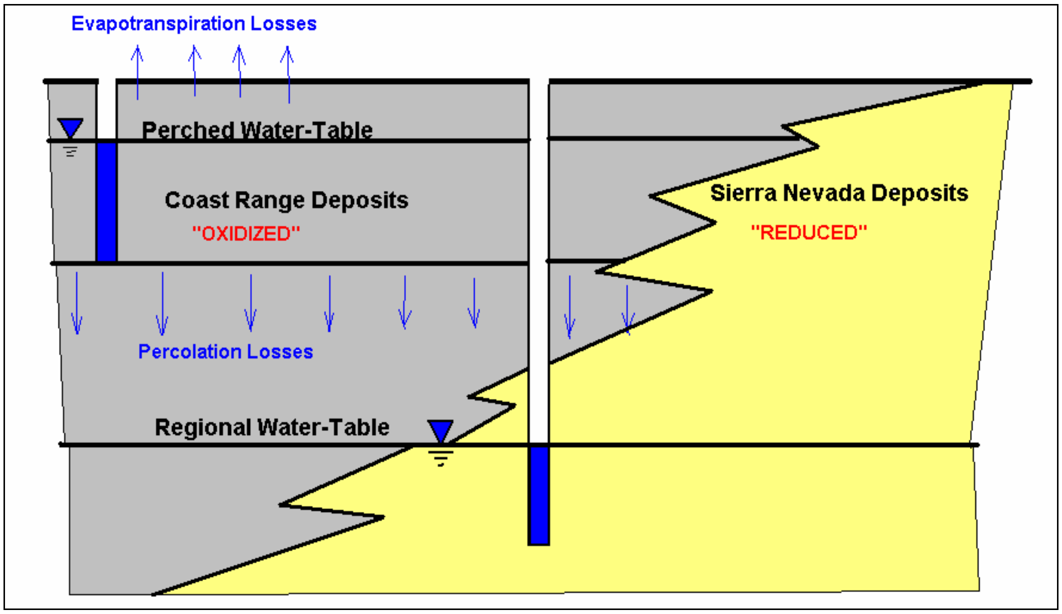

Figure 2-2. Conceptual site model for groundwater conditions at the Tranquillity site.

groundwater and created a perched water table condition in the heavy clay soils underlying the site. Evaporation from the shallow water table under irrigated conditions further concentrated high levels of salts and trace elements in the shallow groundwater. Retirement of the land from irrigated agriculture has resulted in a decline in the shallow water table as recharge has been essentially eliminated and perched groundwater is discharged by downward percolation from the bottom of the clay layer and evaporation from the near surface water table. Selenium is expected to be mobile in the oxidized geochemical conditions found in the Coast Range deposits at the site and immobile in the reduced conditions found in the Sierra Nevada deposits.

2.2.4. Climate and Weather

The Mediterranean climate in central California is characterized by cool, wet winters and hot, dry summers. The project site receives an average of about 7 inches of rainfall annually, with most of the rain occurring between the months of November through April. Hourly precipitation, temperature, wind, and relative humidity data are collected at the California Irrigation Management Information System (CIMIS) weather station No. 105, located 2.4 kilometers (km) (1.5 miles) west of the demonstration project site at the Westlands Water District (WWD) Tranquillity Field Office. The CIMIS station is operated and maintained by the California Department of Water Resources (CDWR), and is the best source of weather data for the Tranquillity site. As shown in Figure 2-3 and Figure 2-4, 4 of the 6 years (1993, 1995, 1996 and 1998) preceding the land retirement

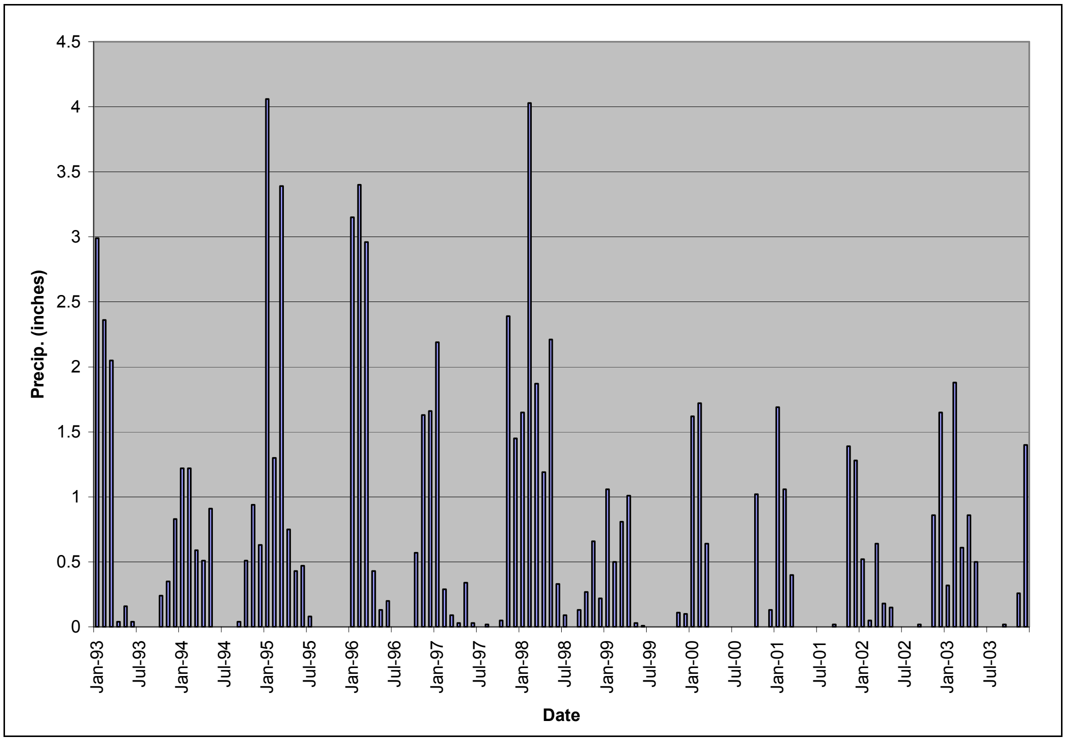

Figure 2-3. Monthly precipitation at CIMIS Station 105, Westlands Water District, near the Tranquillity site (1993-2003).

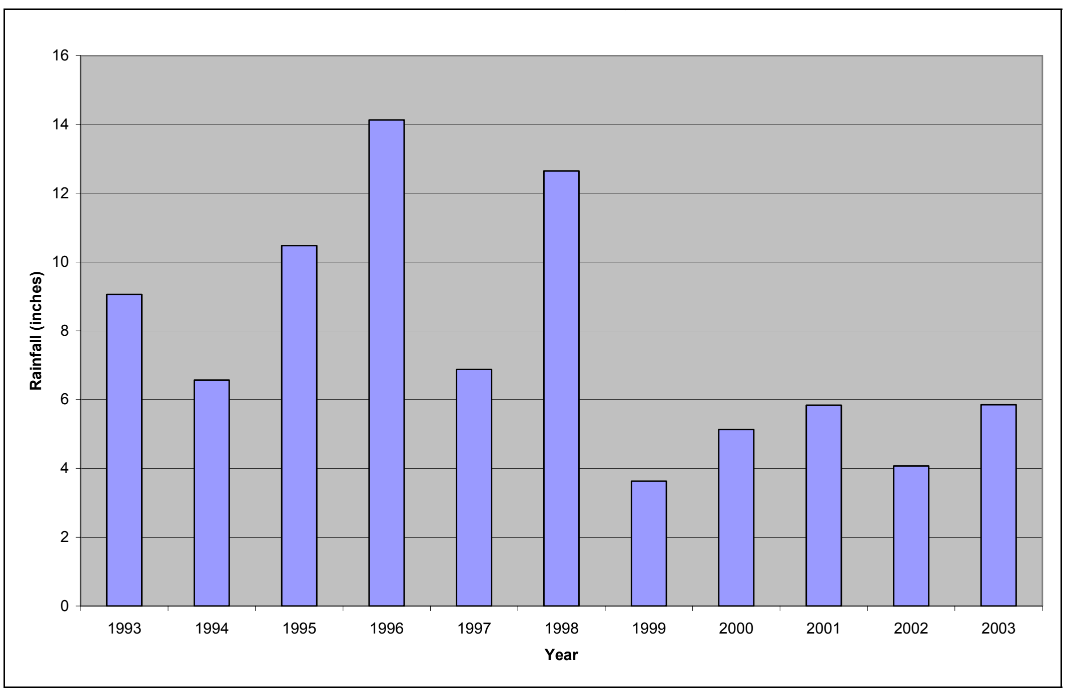

Figure 2-4. Annual precipitation at CIMIS Station 105, Westlands Water District, near the Tranquillity site (1993-2003).

demonstration project had above average rainfall, while the 5 years of monitoring during the demonstration project have been dry, with below average rainfall (1999-2003).

2.2.5. Irrigation

The demonstration project lands south of Adams Avenue were actively farmed and irrigated up to the time they were retired from irrigated agriculture in 1998 for the study. The crops consisted primarily of cotton, sugar beets, and alfalfa, which were irrigated by furrow or sprinkler irrigation systems. The land north of Adams Avenue has not been irrigated since 1989, except for a 24.3 ha (60 acre) field of safflower located in the northwest corner of section 10. Approximately 15.2 centimeters (cm) (6 inches) of water have been applied annually to the safflower field by the California Department of Fish and Game (CDFG). The safflower is left in the field to attract upland game birds for hunting. During the first 3 years of the demonstration project, a small quantity of irrigation water was applied to the barley crop planted in the habitat restoration study area. The barley covers an area of about 389 ha (960 acres) and serves as a cover crop to provide weed and dust control, as well as to isolate the experimental restoration plots from each other. Approximately 7.6, 12.4, and 11.7 cm (3.0, 4.9, and 4.6 inches) of water were applied to the barley during 1999, 2000 and 2001, respectively, using a hand moved sprinkler irrigation system. The barley buffer area has not been irrigated since 2001.

2.2.6. Monitoring of Selenium Levels

The monitoring of selenium levels in groundwater and biota followed a tiered sampling approach that was cooperatively developed with FWS specifically for this project (FWS 1999). The monitoring of selenium and salinity in soils was not a requirement in the FWS Biological Opinion for the project; however, the soil monitoring program was implemented to address concerns raised by the scientific community over potential impacts to soils that may result from land retirement

2.2.6.1. Surface Water Monitoring

In the Biological Opinion for the Land Retirement Demonstration Project, the FWS established performance standards for selenium and mercury concentrations in surface water. The performance standard specified that standing water that persists for more than 30 days shall not exceed 2 micrograms/liter (µg/L) selenium, and 2 nanograms/liter mercury (FWS 1999). Precipitation at the site was monitored by viewing the CIMIS website during the rainy season. The site was also visited during the wet season to document any standing water that persisted for more than 30 days in duration.

2.2.6.2. Soil Monitoring

The objective of the soil monitoring program for the demonstration project is to detect changes in levels of constituents of concern (COCs) including selenium, boron, and salinity that may result from land retirement over the 5-year life of the study. The soil sampling program was accomplished by members of the Interagency Land Retirement Team and Reclamation's Technical Service Center. Baseline soil samples were collected at the Tranquillity site during September and October 1999. The Tranquillity sites were re-sampled in November 2002 and August 2004 for the purpose of change detection. A rectangular sampling grid was chosen for monitoring soil chemistry at the demonstration project site (Figure 2-5). The sampling protocol used at the Tranquillity site is as follows.

Baseline soil samples were taken at the land surface at 124 locations. Surface soil samples were taken at the corners of the 4 ha (10 acre) study plots from a depth of 0-30 cm (0-1 foot) using a shovel. The samples were homogenized in the field at field moist conditions using a putty knife and stainless steel mixing bowls. The samples were collected at each site within a radius of about 1 meter of the staked locations. The coordinates of the sample locations were recorded in the field with a Global Positioning System (GPS) receiver. Discrete soil samples were taken at depths of 0-30 cm (0-1 foot), 60.9 - 91.4 cm (2-3 feet), and 121.9-152.4 cm (4-5 feet) at the centers of the 4 ha (10-acre) experimental plots to assess baseline soil chemistry with depth from the land surface (Figure 2-5). The baseline 60.9 to 91.4 cm and 121.9 to 152.4 cm (2-3 and 4-5 foot) depth samples were taken with a 10.1 cm (4-inch) inside diameter split barrel core sampler to a depth of 152.4 cm (5 feet). A continuous core was obtained at each site by pushing the core barrel with the hydraulic system of a Mobile Drill Model B-90 drill rig. Discrete depth samples were taken at a total of 26 locations at the site during the baseline sampling event. The discrete depth samples were homogenized in the field at field moist conditions using a putty knife and stainless steel mixing bowls. The coordinates of the sample locations were recorded in the field with a GPS receiver.

During the re-sampling events in 2002 and 2004, a slightly different sampling strategy was employed. Eight-increment composite soil samples were collected in a stratified random manner from the 0-30 cm (0-1 foot) depth within a 6.1 m (20-foot) radius of the original baseline sampling site. The 60.9 to 91.4 cm and 121.9 to 152.4 cm (2-3 and 4-5 foot) depth discrete soil samples were collected from a single core located approximately 152.4 cm (5 feet) south of the original site for the 2002 sampling event, and 152.4 cm (5 feet) west of the original site in the 2004 sampling event. The 152.4 cm (5 feet) offset was used to ensure that backfill from the original sampling site was not incorporated into the later sample. Identical sampling depths of 0-30, 60.9 to 91.4 and 121.9 to 152.4 cm (0-1, 2-3 and 4-5 feet) were used for all the surveys. The 0 to 30 cm (0-1 foot) depth samples were collected with a tile spade. A hand auger was used to collect all the 60.9 to 91.4 and 121.9 to 152.4 cm (2-3 and 4-5 feet) depth samples in the 2002 and 2004 sampling events. A total of 110 sites were re-sampled in 2004. A

Figure 2-5. Soil sample locations at the Tranquillity site.

subset of 57 sites, including nearly all of the 1.5 m (5 feet) deep (24 of 26) boring sites, were re-sampled in the 2002 sampling event.

2.2.6.3. Soil Chemical Analyses

The soil samples were tested for total selenium, soluble boron, soluble selenium, and soil salinity. Soil salinity analysis included the electrical conductivity of one part soil, five-part water extracts (EC_e), and the electrical conductivity of saturation extracts (EC_e). The EC_e test was used to be consistent with the baseline sampling event while the saturation extracts were run to evaluate soil salinity in relation to plant growth response.

The Quality Assurance Project Plan (QAPP) for the Land Retirement Demonstration Project describes in detail the analytical procedures and quality assurance measures taken to ensure soil and water data quality (CH2MHill 1999). Data quality analysis and data validation were conducted by Reclamation's Mid-Pacific Regional Office, Environmental Monitoring Branch. Soil samples were sent to Reclamation's Technical Service Center in Denver (D-8570), Soil and Sediment Laboratory to be dried, ground, mixed, and split for chemical analysis. The D-8570 laboratory determined pH5, pH paste, EC_e, percent field soil moisture by weight, and saturation percentage. The soil preparation lab also inserted about 15 percent certified reference materials and water samples in the sample batches that were sent to the analytical laboratory. These samples were double blind to the analytical laboratory. Samples were sent to the U.S. Geological Survey (USGS) Rock and Mineral Analysis Laboratory for selenium and boron analysis. Selenium was run by hydride generation (Method A011), while boron was determined by ICAP (Method E011) analysis. Total selenium was determined on a multi-acid digest. All USGS testing procedures used in this investigation are listed in their analytical methods manual (USGS 1996).

2.2.6.4. Groundwater Level Monitoring

One of the primary objectives of the Demonstration Project is to measure the response of the shallow water table to land retirement. Various conceptual and numerical models (SJVDP 1990a, Fio 1999, and Belitz and Phillips 1992) predicted a decline in the shallow water table in response to land retirement. FWS established a performance objective for the project that the depth to groundwater will not show a net increasing trend (decreasing depth to the soil surface) over a 5-year monitoring period (FWS 1999). There are approximately 50 monitor wells and 3 drain sumps in the project vicinity that are used to measure groundwater levels beneath the site on a quarterly basis. Water levels are measured to the nearest 3 millimeter (mm) (0.01 foot) using an electric well sounding device. The water level data are recorded in a field book and is on file at the Reclamation office in Fresno, California. The locations of the monitoring wells and sumps are shown on Figure 2-6. Existing wells constructed prior to the 1998 purchase of the demonstration project lands were installed by Westlands Water District and Reclamation for the primary purpose of measuring depths to

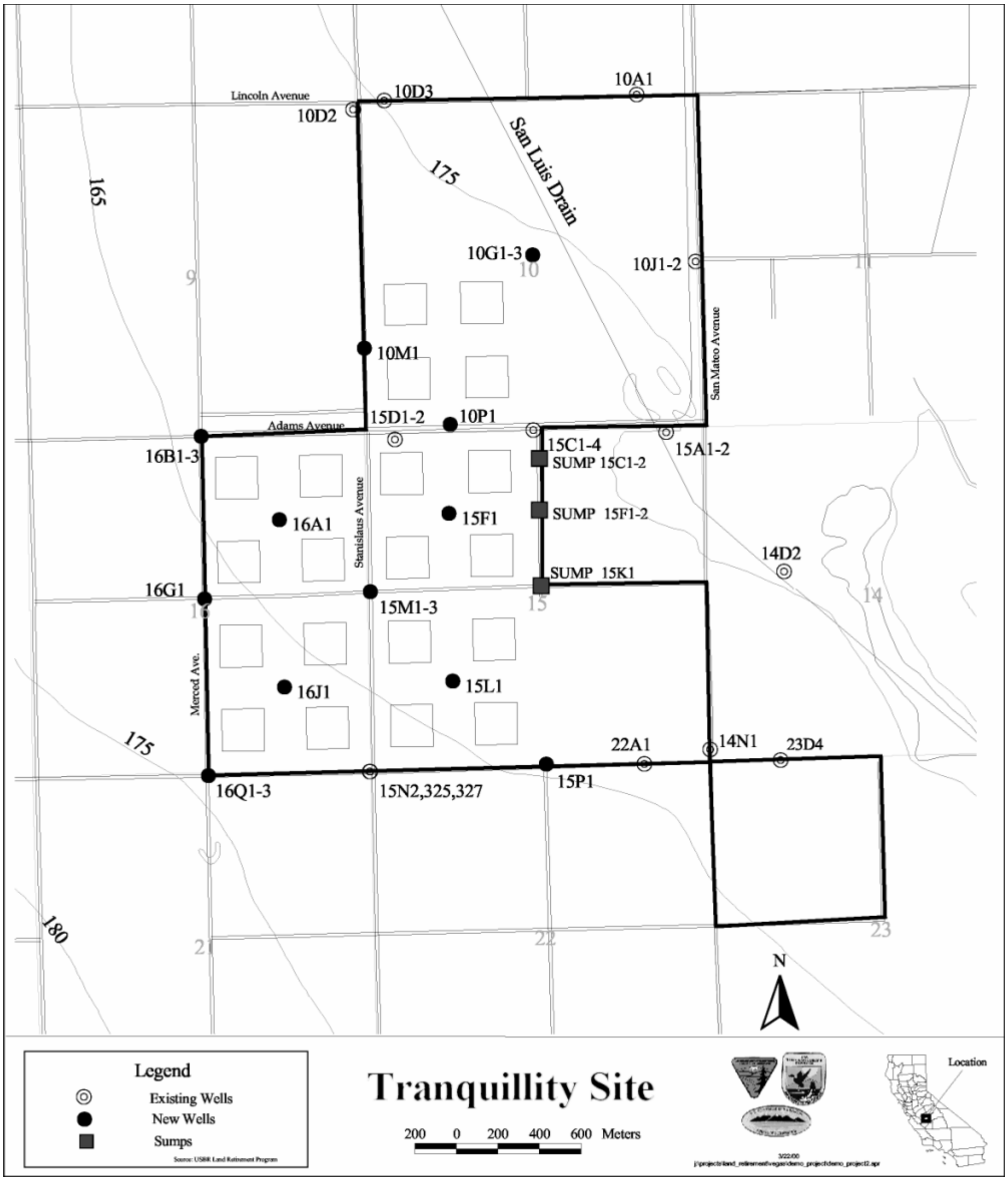

Figure 2-6. Monitor well and sump location map, Tranquillity site.

groundwater beneath drainage impacted lands in WWD. The previously existing wells are constructed of polyvinyl chloride (PVC) casing ranging in diameter from 1.9 to 10.1 cm (0.75 to 4 inches) and vary in depth from 0.9 to 26 m (3 to 86 feet) below the ground surface. These wells were installed using various construction techniques that range from jetting a short length of pipe into the ground to standard rotary drilling with hydraulic drill rigs. A complete set of water level data are available from 20 monitoring wells at the project site for the entire period of record from October 1999 to October 2004.

During summer 1999, Reclamation installed 15 additional wells to measure groundwater levels and to obtain representative groundwater samples for water quality analyses for this study. The new wells were installed using a hollow stem-auger drill rig and are constructed of 5 cm (2-inch) PVC casing and 3 m (10 feet) sections of 0.5 mm (0.020 inch) slotted PVC wellscreen. A commercial filter pack was placed around the wellscreen with a tremie pipe. Screened intervals were chosen after reviewing the soil cores during drilling. Typical screened intervals for the shallow wells are 4.3 to 7.3 m (14 to 24 feet) below land surface. The wellscreens for the deeper wells were placed in the more permeable materials encountered during drilling and range in depth (to bottom of wellscreen) from 15 to 24 m (50 to 78 feet) from land surface. Well construction diagrams for the new wells are on file at the Reclamation office in Fresno, California. Well construction diagrams for the previously existing wells are unavailable.

There are 18 subsurface drain water collection sumps located in a north-to-south alignment bisecting the northern half of Section 15 at the site. The sumps are part of an experimental drainage system that was installed at the site in 1966. Subsurface tile drains lines were installed beneath the northwest quarter of Section 15 at a depth of approximately 1.8 m (6 feet), with a drain spacing of approximately 46 m (150 feet) and a length of approximately 366 m (1,200 feet). The drain lines are 5 to 10 cm (2 to 4 inches) in diameter and discharge to 91.4 cm (3 feet) diameter concrete outlet stands that are open to the atmosphere. The outlet stands are connected to a master sump by a 39 cm (12 inch) collector pipe. Water levels have been measured quarterly using an electric sounding device in the three outlet stands shown in Figure 2-6. No drain water was discharged by pumping the master drain sump during this study.

2.2.6.5. Groundwater Quality Monitoring

A groundwater quality monitoring program was implemented to assess project performance against standards set by FWS (FWS 1999). The groundwater quality performance standard states that the selenium concentration in the groundwater will not show a net increasing trend over 5 years of monitoring. Groundwater samples were taken on a quarterly basis during year 1 and year 5 of monitoring at the Tranquillity site. The baseline year groundwater quality samples were taken in October 1999 and February, May, and July 2000. The 5-five groundwater samples were taken in October 2003 and February, May, and July 2004. Annual groundwater samples were taken in May 2001, 2002, and 2003. Unfiltered groundwater samples were taken from 12 wells and 2 drain sumps to assess baseline groundwater quality at the site. Shallow wells were sampled with a peristaltic pump or bailer while the deep wells were sampled with a submersible pump (Grundfos Redi Flo 2). Standard operating procedures for groundwater sampling used by the Mid-Pacific Region of Reclamation and those outlined in the Quality Assurance Project Plan for the Land Retirement Demonstration Project (CH2M Hill 1999) were employed to obtain, preserve, and analyze groundwater samples.

Unfiltered groundwater samples were analyzed for major ions (calcium, magnesium, potassium, sodium, chloride, sulfate, total alkalinity), trace elements (selenium, boron, iron, manganese), and isotopes (H^2, O^{18} and H^3). Specific conductance (electrical conductivity), pH, and temperature of groundwater samples were measured in the field at the time of sampling. Fluorometric analyses of groundwater samples for selenium were performed by Olsen Biochemistry Laboratories, South Dakota State University. Analyses for isotopes (H^2, O^{18}) were performed by the USGS Water Resources Division Laboratory in Reston, Virginia. Analyses for tritium (H^3) were performed by the USGS Water Resources Division laboratory in Menlo Park, California. All other analyses were performed by various contract laboratories with oversight from the environmental monitoring branch of Reclamation in Sacramento, California.

The selenium data in groundwater were evaluated for seasonal bias using the SYSTAT (SPSS 2000) nonparametric Kruskal-Wallis one way analysis of variance procedure. The selenium trends for individual monitor wells were analyzed with SYSTAT using both parametric and non-parametric regression techniques. The Wilcoxon sign rank test was used to analyze the selenium data for soil.

2.2.7. Groundwater Response to Land Retirement

Groundwater level data were analyzed by plotting hydrographs for individual monitoring wells—hydrographs are time series plots of groundwater levels measured in monitor wells. Synoptic groundwater maps depicting the depth to shallow water table on a site-wide basis on specific dates were also used to examine water table response over time. The synoptic maps were produced using the Spatial Analyst module of the Environmental Systems Research Institute (ESRI) ArcView software. A contour map showing net water table declines over the 5-year monitoring period was produced using version 8 of Surfer (Golden Software 2004) to show the spatial distribution of the water table response.

Groundwater level data from the demonstration site support the conceptual model of a declining shallow groundwater table in response to land retirement. All of the wells monitored at the Tranquillity site have shown a declining water level trend over the 5-year period of record. The hydrographs for the drain sumps and wells shown in Figure 2-7 are representative of the declining groundwater level trend observed at the site during the 5 years of monitoring. The hydrographs shown in Figure 2-7 represent water levels measured in three drain sumps (15C1, 15F2, 15K1) during the time period from July 1998 to July 2000. The drain sumps are connected to tile drain lines that underlie the northwest quarter of Section 15, and are useful for measuring shallow groundwater trends in that portion of the site. The drain sump locations are shown in Figure 2-6. No water was pumped from the sumps during the demonstration project. All three of these sumps show an overall declining trend in groundwater levels for the period of record. Total water-level declines observed in sumps 15C1, 15F2, and 15K1 are 1.4, 0.9, and

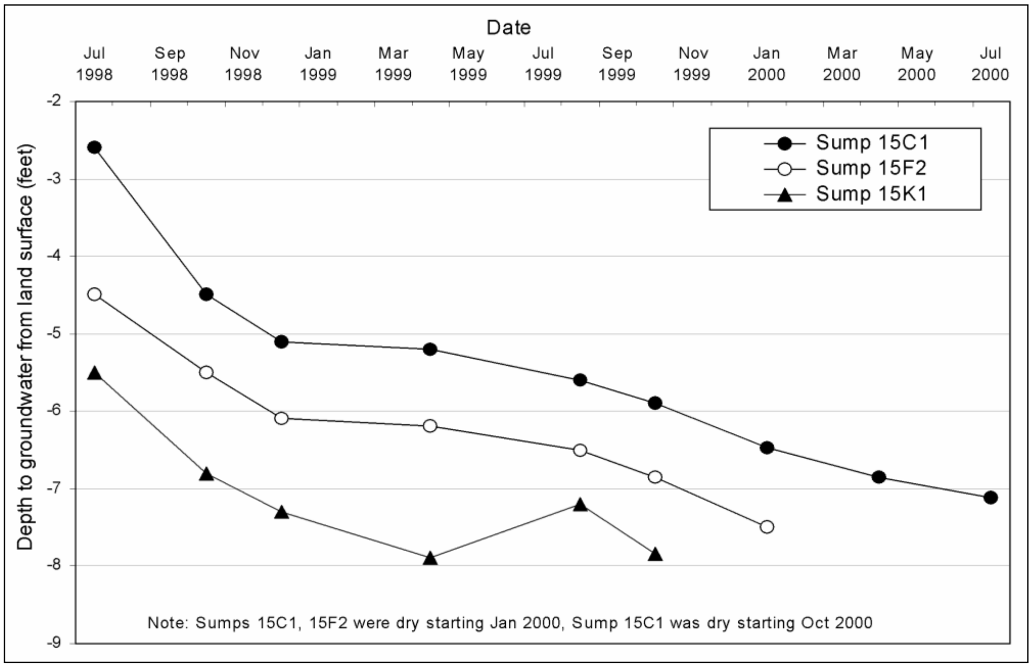

Figure 2-7. Hydrographs for three agricultural drain sumps at the Tranquillity site showing a declining shallow groundwater trend.

0.7 m (4.5, 3.0, and 2.4 feet), respectively. Sumps 15C1 and 15 F2 were observed to be completely dry starting in January 2000, while sump 15C1 was observed to be completely dry starting in October 2000. The drain sumps have remained dry as of October 2004.

The hydrographs for wells 325 and 326 are shown in Figure 2-8. These hydrographs are representative of the declining water level trends observed at the site during the 5 years of monitoring. The total water-level declines observed in wells 325 and 326 for the period of record are 3.08 and 3.14 m (10.1 and 10.3 feet), respectively. These wells constitute a nested pair of wells that were drilled in the same location but are completed at different depths. All of the nested well pairs at the site have significant vertical (downward) groundwater gradients, indicating perched water table conditions at the site. A declining groundwater level trend was observed in wells 15M1 and 16A1 (Figure 2-9). The total water-level declines observed in wells 15M1 and 16A1 were 2.7 and 3 m (8.8 and 9.8 feet), respectively.

Synoptic depth to groundwater maps are another way to portray the decline of the shallow water table at the Tranquillity site. Figure 2-10 through Figure 2-12 show the depth to groundwater from the land surface as measured in monitor wells at the site in October 1999, 2000, and 2001. The measured depth to groundwater data was contoured using ESRI ArcView Spatial Analyst software. During October 1999, approximately 30 percent 243 ha (600 acres) of the site was underlain by a water table within 2.1 m (7 feet) of the land surface. During

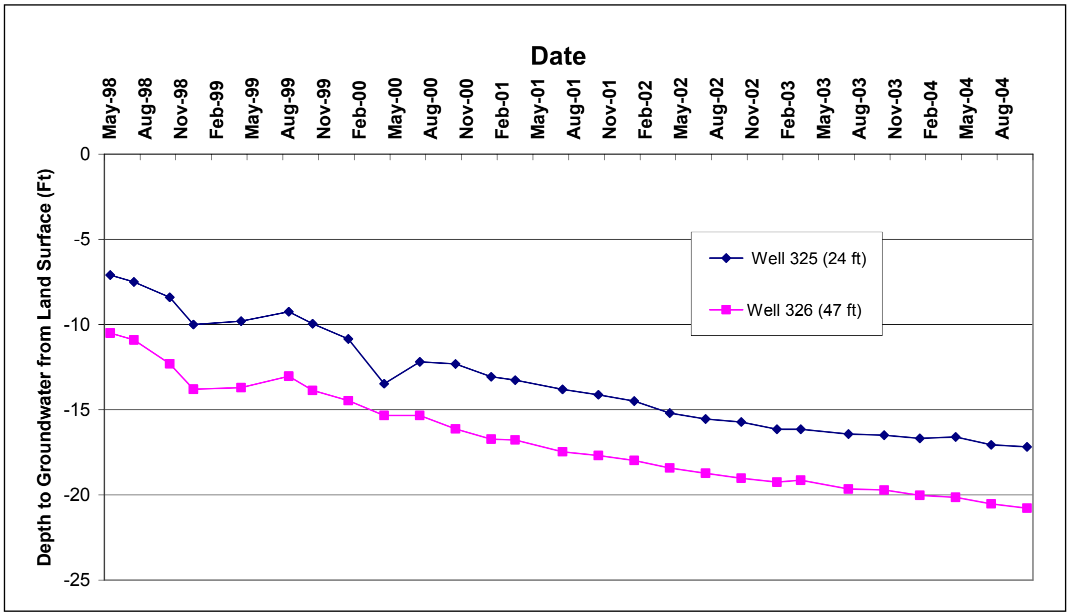

Figure 2-8. Hydrographs for the monitor well cluster site 325 and 326 at the Tranquillity site showing a declining shallow groundwater trend and vertical (downward) hydraulic gradient.

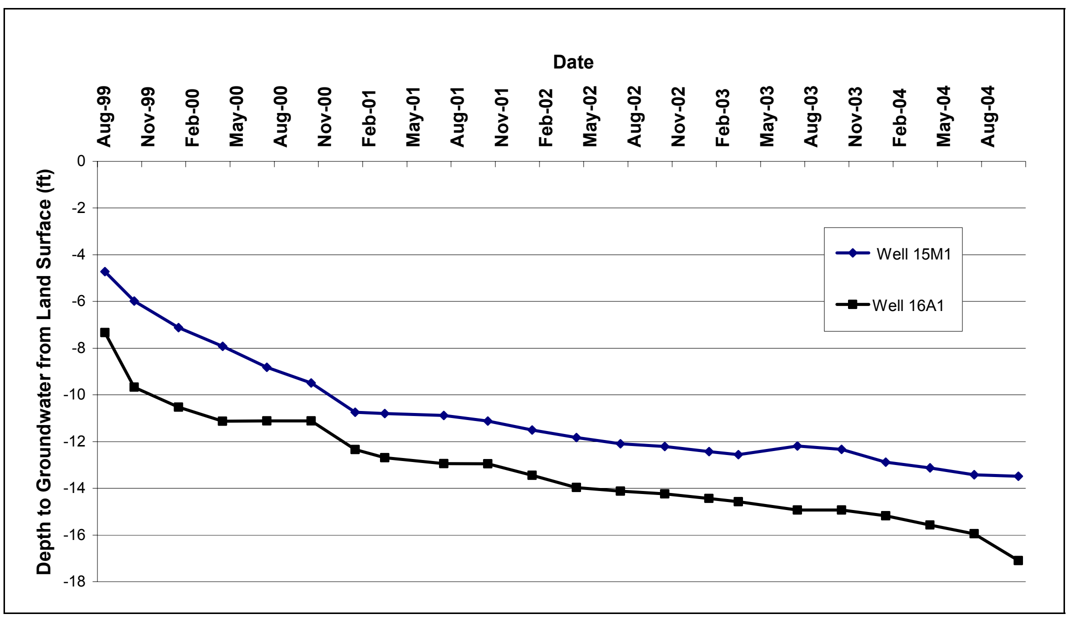

Figure 2-9. Hydrographs for monitor wells 15M1 and 16A1 at the Tranquillity site showing a declining shallow groundwater trend.

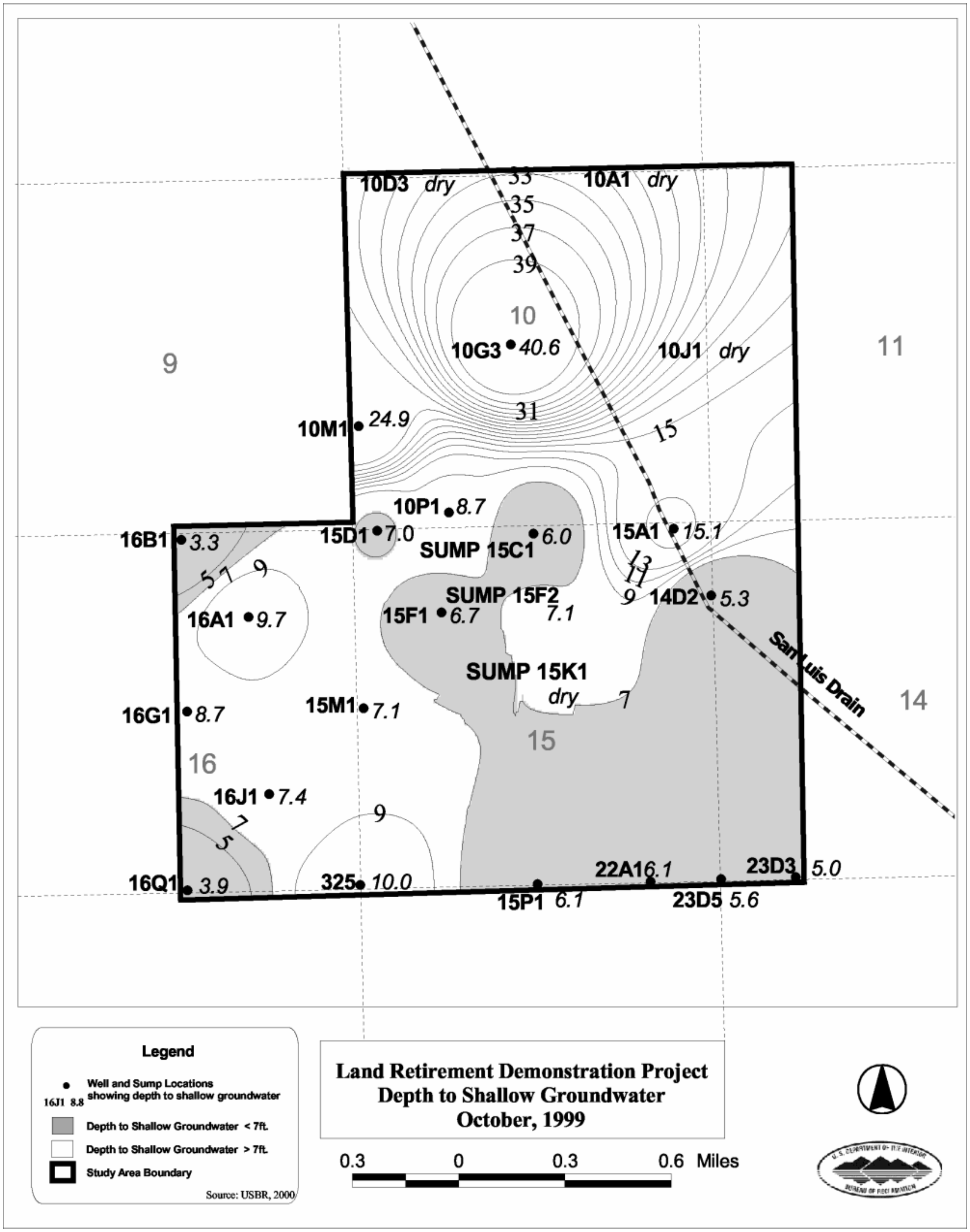

Figure 2-10. Depth to shallow groundwater, October 1999. The project area underlain by shallow groundwater within 2.1 m (7 feet) of the land surface is approximately 243 ha (600 acres).

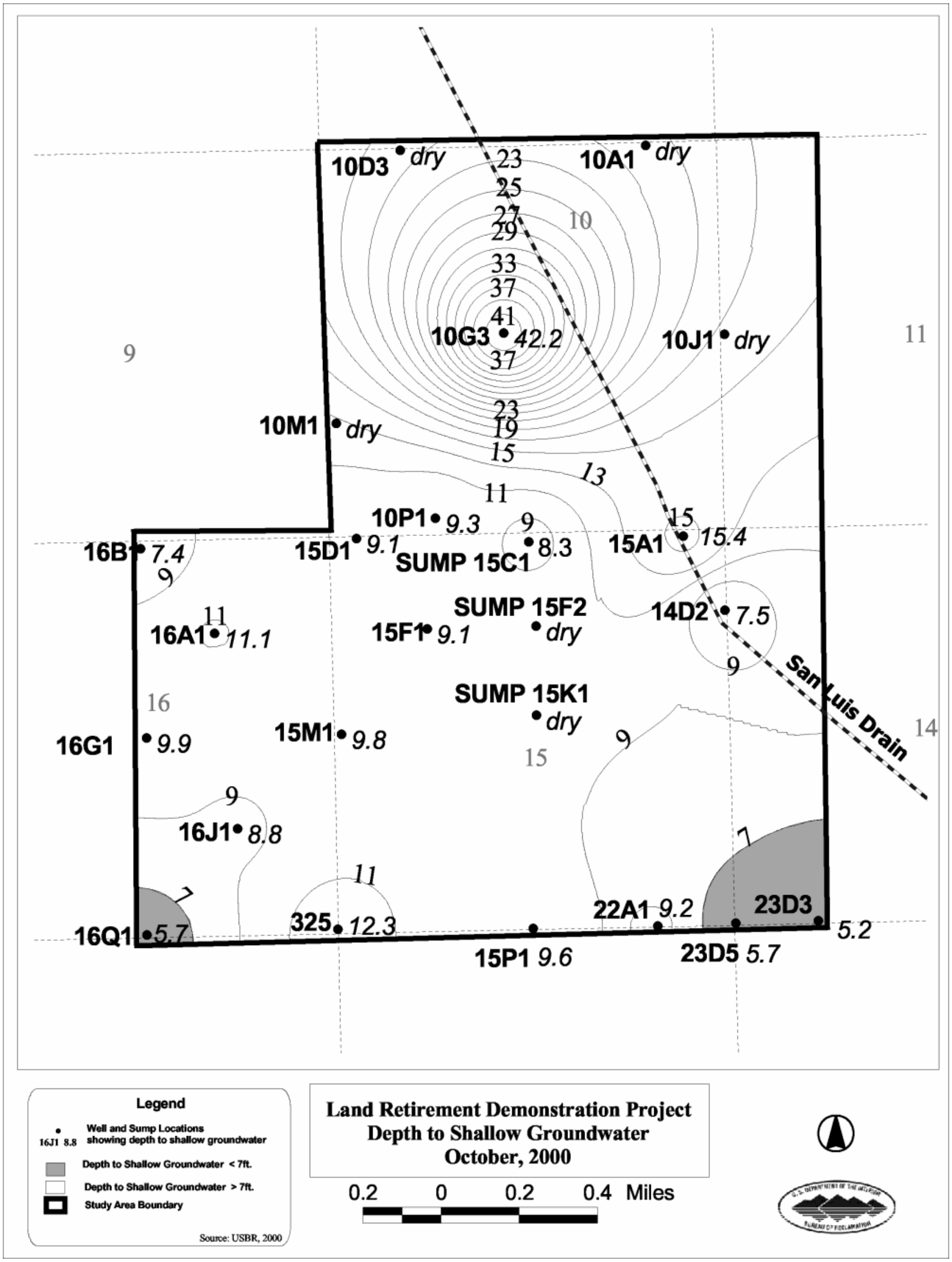

Figure 2-11. Depth to shallow groundwater, October 2000. The project area underlain by shallow groundwater within 2.1 m (7 feet) of the land surface is approximately 22 ha (55 acres).

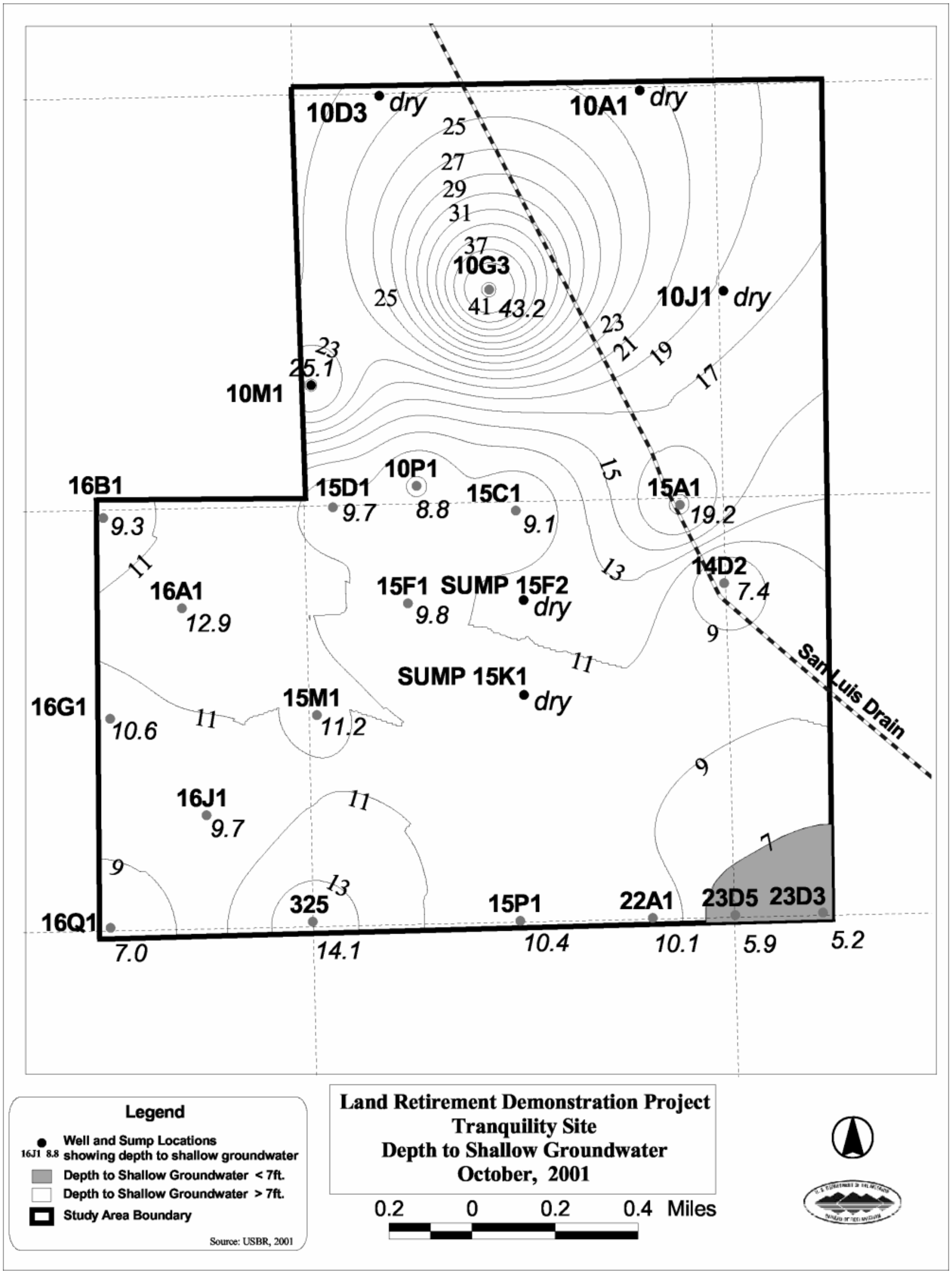

Figure 2-12. Depth to shallow groundwater, October 2001. The project area underlain by shallow groundwater within 2.1 m (7 feet) of the land surface is approximately 14 ha (34 acres).

October 2000, approximately 3 percent of the site (22 ha or 55 acres) was underlain by a water table within 2.1 m (7 feet) of the land surface. In October 2001 the area of the site underlain by a water table within 2.1 m (7 feet) of the land surface decreased to less than 2 percent of the site (14 ha or 34 acres). As of October 2002, no part of the site had a shallow water table within 2.1 m (7 feet) of the land surface.

The site can be divided into two distinct areas based on the depth to groundwater observations. The depth to the water table north of Adams Avenue (Section 10) was significantly greater than that observed south of Adams Avenue. The differences can be attributed to two factors. This northern part of the site (Section 10) has been retired from irrigated agriculture since 1994, and has not received significant application of irrigation water (groundwater recharge) since that time. Section 10 is also underlain by more permeable Sierran sand deposits, which allow more rapid percolation of applied irrigation water.

Analyses of the groundwater data at the Tranquillity site indicate a decreasing rate of water table decline over time. The slopes of the hydrographs shown in Figure 2-8 and Figure 2-9 show a flattening trend over time. Examination of individual wells suggests that the extinction depth for groundwater evaporative discharge may be about 3 m (10 feet). The volume and flow of upflux is so small between a depth of 2.1 and 3 m (7 and 10 feet) that evaporative discharge in the soil cracking system at the 60.9 to 121.9 cm (2-4 feet) depth may be sufficient to maintain a very small amount of unsaturated upward flow. Once the water table receded below 3 m (10 feet), all discharge is believed to be vertical deep percolation through the first barrier layer. Deep percolation rates are controlled by the permeability of the first barrier layer and the hydraulic head on the barrier. Examination of well logs, cone penetrometer data, and nested well water levels indicates the first barrier layer is present at depths ranging from 4.0 to 9.1 m (13-30 feet) below the ground surface (average 6.1 m or 20 feet) and that unsaturated conditions are present below the first barrier layer. The average annual rate of decline was about 44 cm (1.2 feet) per year which equates to a water volume of about 1.8 cm (.06 feet) per year. This rate is expected to decrease as less head is available to push water through the barrier layer.

2.2.7.1. Natural Drainage Rates

The Tranquillity site is currently isolated from actively irrigated lands; however, during the first few years of the study irrigation of lands near site 16Q1 may have contributed some lateral flows to that site. No commercial irrigation was conducted near well 15M1 and lateral gradients (.0008) have remained nearly flat in that area. The natural drainage at the demonstration site is controlled by the permeability of the first barrier layer, the depth of saturation above the barrier, and the thickness of the barrier layer. All nested wells in the area indicate unsaturated conditions below the first barrier layer and perched water table conditions.

Based on observations of soil substrata at drill sites, examination of 12 cone penetrometer logs, as well as hydraulic conductivity testing in the area, the specific yield of the substrata in the 1.8 to 3.7 m (6-12 feet) zone is estimated at about 5 percent and the average depth to barrier is about 6.1 m (20 feet). Substrata soil textures at site 16Q1 were somewhat coarser in the deep substrata and a specific yield of 10 percent was estimated for that boring. Hydraulic barriers were also noted in the two drill holes. The barrier was at 6.2 m (20.5 feet) in well 15M1 and about 4.2 m (13.8 feet) in well 16Q1. Based on the water table decline over the 5-year period, the depth of the head on the hydraulic barriers and the assumption that lateral water movement and evaporative discharge is negligible, a vertical permeability and natural drainage rate could be estimated. Vertical permeability and natural drainage estimates are shown in Table 2-1. Soil data for site 15 M1 was used to estimate the natural drainage rates for the min, max, and average water table declines.

Table 2-1. Estimates of Natural drainage rates and vertical permeability at the Tranquillity site.

Site	Water table decline (feet)	Natural drainage rate (feet/year)	Vertical permeability of barrier (feet/day)
15M1	6.01	0.060	5.48 x 10-5
15M1*	2.38	0.040	4.38 x 10-5
16Q1	6.38	0.128	2.06 x 10-4
Min	0.51	0.005	nd
Max	9.54	0.095	nd
Ave	5.79	0.058	nd

* last 3 years after water receded below 10 feet.
nd = not determined

The FWS performance objective regarding declining groundwater levels in response to land retirement was clearly met. The combination of dry climatic conditions and greatly reduced application of irrigation water associated with land retirement have resulted in significant declines of the shallow water table at the Tranquillity demonstration site. Every monitor well at the site showed a declining water level trend over time. The average decline in the water table measured in 15 wells at the site during the 5-year period of record is approximately 1.8 m (6 feet). The average rate of decline in the water table measured in these wells over the 5-year period of record was approximately 0.4 m (1.2 feet) per year. The maximum decline of the water table was 2.9 m (9.54 feet) (Well 16G1), while the minimum decline of the water table was 0.15 m (0.51 feet) (Well 10M1) (Table 2-2 and Figure 2-13) The largest drop in the water table occurred on the westernmost part of the site in section 16, while the smallest drop observed was in the northern part of the site in Section 10 (Figure 2-13).

Table 2-2. Groundwater level decline observed in fifteen wells at the Tranquillity site for the time period from October 1999 to October 2004.

Well	Water Level Decline (Feet)
10M1	0.51
15A1	5.94
15A2	5.99
15C2	5.65
15M1	6.38
15N2	6.90
325	7.23
15P1	6.78
15F1	4.44
16A1	7.69
16B1	8.10
16G1	9.54
16J1	4.44
16Q1	6.01
23D4	4.27
MAX	9.54
MIN	0.51
AVG	5.99
RATE	1.20

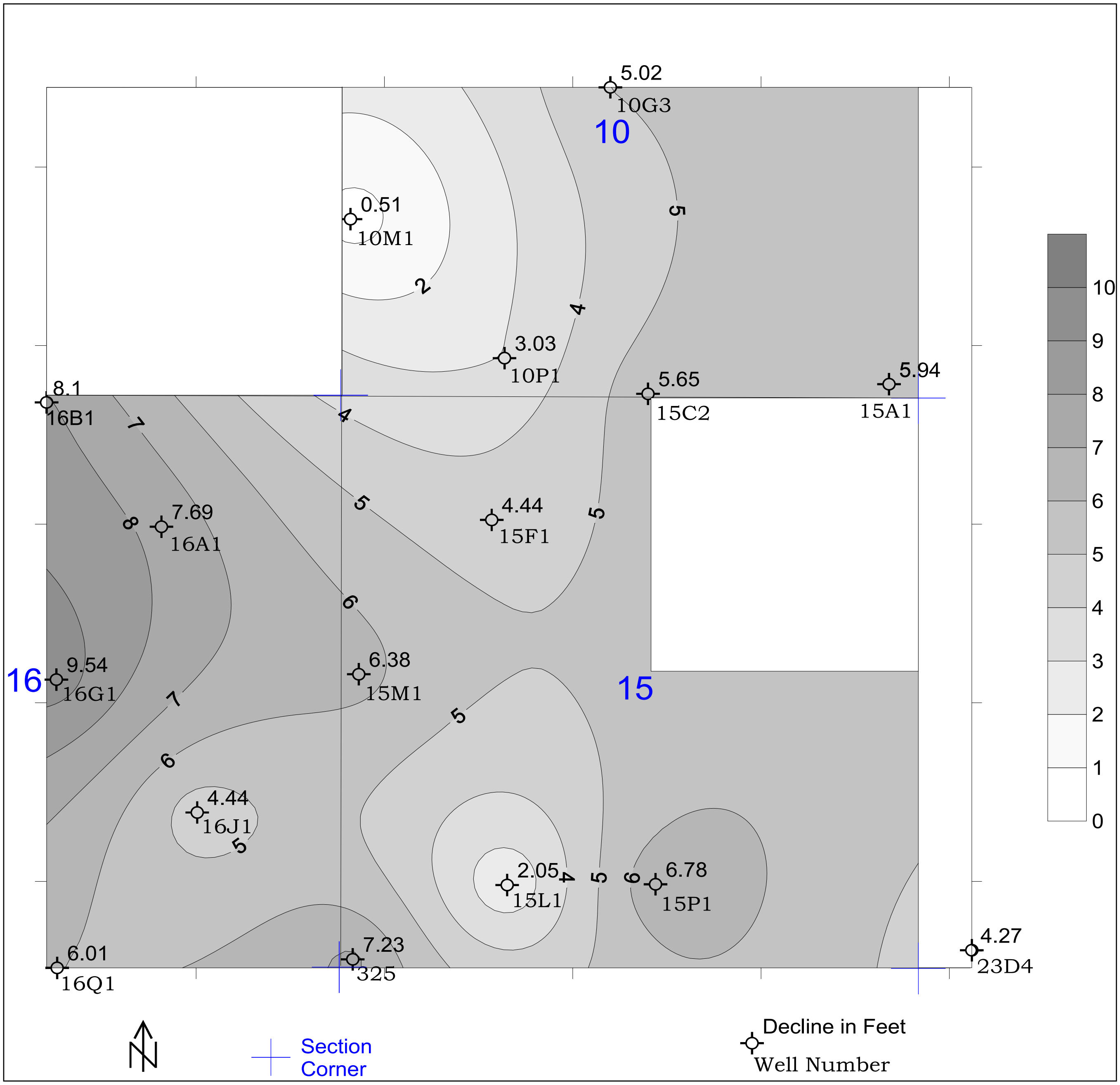

Figure 2-13. Contour map showing spatial distribution of net water table declines at the Tranquillity site from October 1999 to October 2004.

2.2.8. Groundwater Quality

2.2.8.1. Groundwater Salinity

A general indication of the total dissolved ionic constituents in the groundwater can be obtained by determining the capability of a groundwater sample to conduct an applied electrical current. This property is reported as specific conductance (also electrical conductivity, EC), and is expressed in terms of the conductivity of a cube of water 1 square centimeter on a side. EC is expressed in units of microSiemens/cm (µS/cm).

Baseline EC data for the groundwater samples collected during the first year of monitoring are presented in Table 2-3 and Table 2-4. The shallow, perched groundwater is extremely saline in nature. Salinity in the shallow groundwater and drain sump samples, expressed as EC, ranged from 11,500 to 76,980 µS/cm, with a median value of 43,925 µS/cm. By comparison, drinking water typically is less than 750 µS/cm, irrigation water is less than 1,250 µS/cm, and seawater is about 50,000 µS/cm. The groundwater samples obtained from the underlying semi-confined aquifer are much less saline. Salinity in the groundwater samples obtained from the deep wells (> 50 feet deep), expressed as EC, ranged from 5,630 to 18,580 µS/cm, with a median value of 7,675 µS/cm.

The extreme salinity of the shallow groundwater at the site is a result of the irrigation of saline soils. Naturally occurring salts have been leached from the soil profile under irrigated conditions. Salts also have been transported to the site in the applied irrigation water. Direct evaporation from the shallow water table and transpiration of applied water by crops has concentrated salts in the shallow groundwater, resulting in the high EC values observed in the shallow groundwater samples.

2.2.8.2. Groundwater Major Ion Chemistry

Baseline major ion chemistry for the groundwater samples collected during year 1 of monitoring at the Tranquillity site are presented in Table 2-5 and Table 2-6. The groundwater found in the perched zone and in the underlying semi-confined aquifer is best described as a sodium-sulfate type of water. Sodium is the dominant major cation found in the shallow groundwater samples, with sodium concentrations ranging from 2,300 to 25,000 milligrams per liter (mg/L), and a median concentration of 13,000 mg/L. Sodium is also the dominant major cation found in groundwater samples taken from the deep wells, with concentrations ranging from 760 to 3,800 mg/L, and a median concentration of 1,100 mg/L. Sulfate is the dominant major anion found in both the shallow, perched groundwater and in the underlying semi-confined groundwater at the site.

Table 2-3. Baseline year groundwater quality data for shallow wells at the Tranquillity site — major ions and field parameters.

Statistic	Min.	25th percentile	Median	75th percentile	Max.	Mean
Number of Samples	44	44	44	44	44	44
EC(field) (μS/cm)	11,500	32,620	43,260	52,350	76,980	41,987
pH (field)	6.74	7.54	7.78	7.9	8.37	7.73
Calcium (mg/L)	250	400	420	450	500	417
Magnesium (mg/L)	42	250	525	663	1300	515
Sodium (mg/L)	2,300	8,725	13,000	16,500	25,000	13,009
Potassium (mg/L)	7	20	30	42	94	32
Total Alkalinity (mg/L)	150	260	330	423	610	351
Chloride (mg/L)	380	1,150	2,700	3200	4,100	2,332
Sulfate (mg/L)	4,300		24,500	31,000	62,000	26,330

Table 2--4. Baseline year groundwater quality data for deep wells at the Tranquillity site — major ions and field parameters.

Statistic	Min.	25th percentile	Median	75th percentile	Max.	Mean
Number of Samples	12	12	12	12	12	12
EC(field) (μS/cm)	5,630	6,763	7,675	17,315	18,580	10,633
pH (field)	6.82	7.13	7.21	7.28	7.46	7.21
Calcium (mg/L)	280	300	320	360	390	327
Magnesium (mg/L)	280	300	310	328	350	315
Sodium (mg/L)	760	823	1,100	2,425	3,800	1,714
Potassium (mg/L)	6	9	13	14	20	12
Total Alkalinity (mg/L)	200	250	270	329	340	277
Chloride (mg/L)	300	410	540	1,700	1,900	924
Sulfate (mg/L)	2,100	2,750	3,100	5,525	7,300	4,067

Table 2--5. Baseline groundwater quality data for shallow wells at the Tranquillity site — trace elements and tritium.

Statistic	Min.	25th percentile	Median	75th percentile	Max.	Mean
Number of Samples	44	44	44	44	44	44
Boron (mg/L)	10	26	46	55	81	42
Iron (mg/L)	0.1	0.8	2.1	15	160	19.4
Manganese (mg/L)	0.008	0.11	0.23	1.1	3.9	0.757
Selenium (mg/L)	0.005	0.195	1.28	3.812	5.39	2.095
Tritium (TU)	0	0.9	2.4	3.7	6	2.3

Table 2-6. Baseline groundwater quality data for deep wells at the Tranquillity site— trace elements and tritium.

Statistic	Min.	25th percentile	Median	75th percentile	Max.	Mean
Number of Samples	12	12	12	12	12	12
Boron (mg/L)	2.5	2.8	3.2	6.6	8.3	4.4
Iron (mg/L)	0.3	0.6	1.2	1.3	1.6	1
Manganese (mg/L)	0.25	0.318	1.75	2.5	4.3	1.718
Selenium (mg/L)	< 0.0004	0.0005	1.84	1.91	1.95	1.0873
Tritium (TU)	0	0.4	10.1	11.6	14	7.5

TU = tritium units

Sulfate concentrations found in groundwater samples from the shallow wells (< 15 m or 50 feet deep) ranged from 4,300 to 62,000 mg/L, with a median concentration of 24,500 mg/L. Sulfate concentrations in groundwater samples from the deep wells (> 15 m or 50 feet deep) completed in the semi-confined aquifer ranged from 2,100 to 7,300 mg/L, with a median concentration of 3,100 mg/L (Figure 2-14).

High sodium and sulfate concentrations in the groundwater on the west side of the San Joaquin Valley result from weathering of sulfate rich rocks in the adjacent Coast Ranges. Davis (1961) hypothesized that the sulfate in groundwater in the study region originates from the oxidation of organic marine shales containing reduced iron sulfide minerals. Presser et al. (1990) reported oxidation of iron sulfide minerals for west-side streams in the study vicinity. Another probable source of sulfate in the shallow groundwater is from gypsum (calcium sulfate) that has historically been applied to soils by farmers in the region as a method of soil salinity (sodium) management.

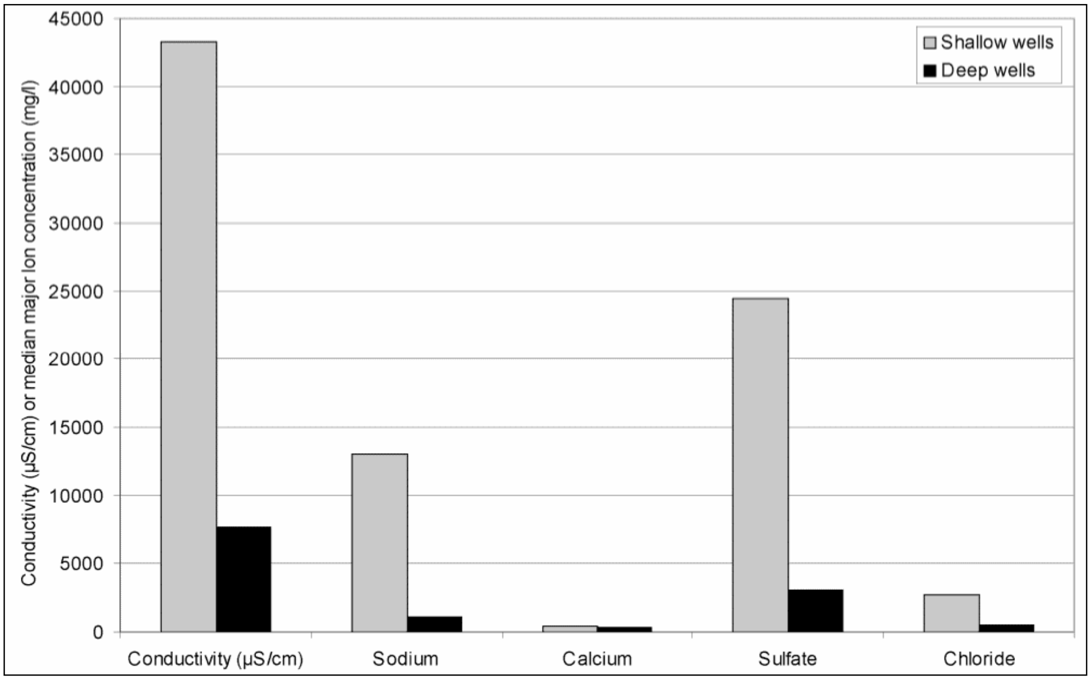

Figure 2-14. Comparison of dominant major ion concentrations and electrical conductivity for groundwater samples from shallow and deep wells.

2.2.8.3. Trace Elements in Groundwater

The trace elements of concern monitored for this study include selenium and boron. High concentrations of selenium and boron in the shallow groundwater are of concern due to potential toxicity to wildlife and plants. Iron and manganese concentrations were also monitored because they provide insight into geochemical conditions in the groundwater system. A summary of baseline trace element data for the first year of groundwater monitoring is presented earlier in Table 2-5 and Table 2-6.

Selenium concentrations measured in the shallow groundwater system (wells < 15 m or 50 feet deep) during the first year of monitoring were high, ranging from 5 to 5,390 µg/L (0.005 to 5.390 mg/L), with a median concentration of 1,280 µg/L (1.280 mg/L). By comparison, the Environmental Protection Agency (EPA) water-quality criterion for long-term exposure in aquatic environments is 5 µg/L (EPA 1988). It becomes clear why the conceptual model of a declining shallow water table is an essential element of land retirement in light of the extremely high concentrations of selenium observed in the shallow groundwater. Deverel and Millard (1988) concluded that the main factors affecting selenium concentrations in the shallow groundwater of the western San Joaquin Valley are the degree of groundwater salinity and the geologic source of the alluvial soils.

Selenium concentrations measured in the deep wells (> 15 m or 50 feet deep) at the site showed considerable spatial variation (Table 2-6). Selenium concentrations found in well 15M3 (21 m or 69 feet deep), ranged from 1,840 to 1,950 µg/L during the first year of monitoring, while selenium concentrations found in wells 15C3 and 10G3 (25 and 23 m or 83 and 75 feet deep, respectively) ranged from the analytical limit of detection (< 0.0004 mg/L) to 0.0005 mg/L. The large variation in selenium concentration seen in the deep wells may be explained due to differing geochemical conditions found in Coast Range deposits and the Sierran sands underlying the site. Well 15M3 is perforated in Coast Range sediments, while wells 15C3 and 10G3 are perforated in sediments derived from the Sierra Nevada Range.

Dubrovsky et al. (1993) noted high concentrations of selenium in shallow groundwater in Coast Range sediments and low concentrations in underlying Sierra Nevada sediments in previous groundwater quality investigations in the western San Joaquin Valley. The authors hypothesized that the absence of selenium in groundwater from wells screened in the Sierra Nevada deposits may be due to a redox (chemical reduction or oxidation) process. Selenium can exist in four valence states; -2, 0, +4, and +6. The +6 and +4 valences occur as the oxyanions selenate (SeO^{42}) and selenite (SeO^{32}) under alkaline, oxidizing conditions. Selenate is the most oxidized form of selenium, is relatively mobile in aqueous environments, and does not associate with solid phase materials (Leckie et al. 1980, Frost and Griffin 1977, and Hingston et al. 1974). Deverel and Fujii (1988) reported that the selenium in soil solutions and shallow groundwater in the western San Joaquin Valley is in the selenate form, and a very small percentage of soil selenium is in the absorbed phase. Although no attempt has been made to speciate selenium in groundwater samples from the Land Retirement Demonstration Project, the selenium found in the shallow groundwater at the site probably occurs predominantly as selenate.

Under more reduced conditions, such as those found in the underlying Sierra Nevada deposits in the northern part of the site, selenium can exist as elemental selenium (zero valence) and selenide (Se^{2}). The solubility of selenate minerals generally is high (Elrashadi et al. 1987), and there are no apparent solubility constraints on selenate in shallow groundwater in the western San Joaquin Valley, even in groundwater saturated with respect to sulfate minerals (Deverel and Gallanthine 1989). Consequently, selenate tends to behave conservatively in oxidizing groundwater. The mobility of selenite in groundwater is severely constrained by adsorption onto a variety of mineral surfaces (Balistrieri and Chao 1987, Neal et al.1987, Goldberg and Glanbig 1988). The solubilities of the reduced forms of selenium (elemental selenium and selenide) are extremely low (Elrashadi et al. 1987). Field and laboratory studies of selenium contamination at Kesterson Reservoir demonstrated selenium removal by reduction of selenate to less mobile forms (Lawrence Berkeley Laboratory 1987, White et al. 1988, Weres et al. 1989). Similar geochemical processes may be responsible for the extremely low selenium concentrations observed in Wells 15C3 and 10G3 at the Tranquillity site.

Dubrovsky et al. (1993) noted that selenium concentrations in groundwater decreased rapidly at the same depth at which manganese concentrations increase at a research site located in the vicinity of the Tranquillity site in the western San Joaquin Valley. The authors concluded that the decrease in selenium is due to a process that occurs under reducing conditions. High concentrations of dissolved iron and manganese in groundwater can indicate geochemically reducing conditions. A similar trend is observed at the land retirement study site when ratios of selenium to manganese concentrations are plotted verses well depth. The selenium/manganese ratios are generally high in the shallow wells and extremely low in the deep wells, especially those perforated in the Sierran deposits (Figure 2-15). This supports the conceptual model that oxidizing conditions are prevalent in the shallow groundwater, and that reducing conditions are prevalent in the deep groundwater found in the Sierran deposits. The presence of reducing geochemical conditions in the Sierran deposits probably play a significant role in the extremely low selenium concentrations observed in wells 15C3 and 10G3.

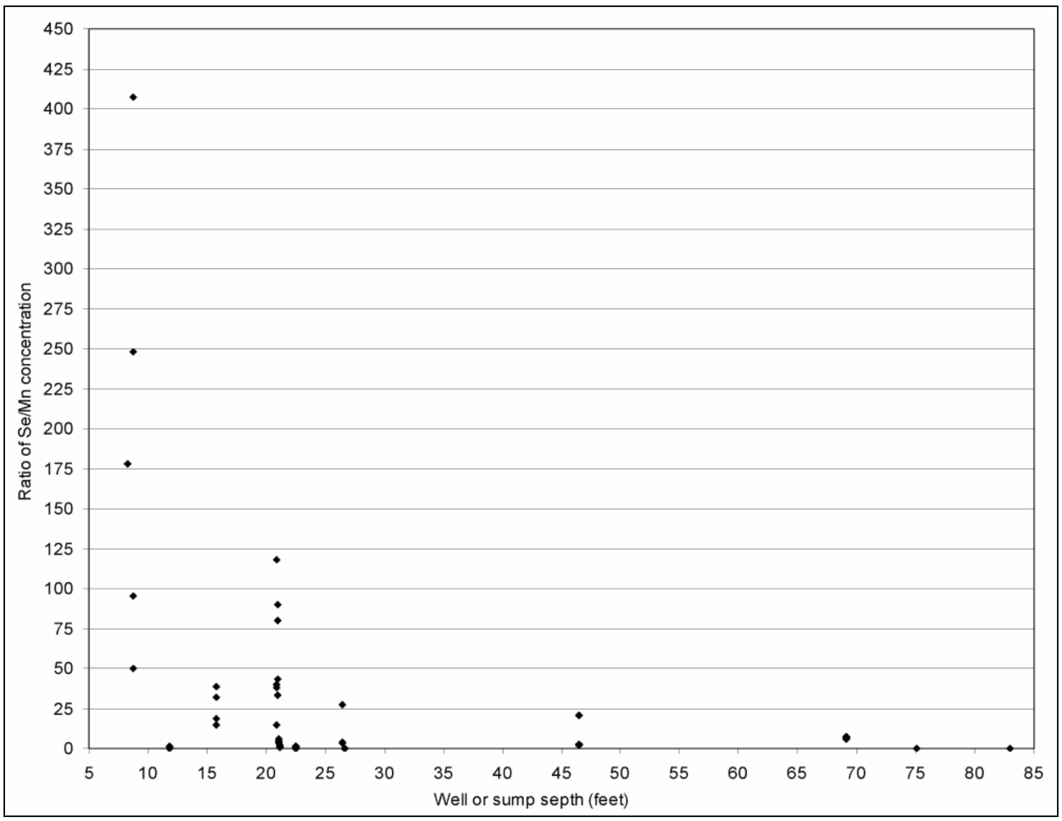

Figure 2-15. Ratio of selenium to manganese (Se/Mn) concentration in groundwater samples plotted verses well depth. The Se/Mn ratio shows a decreasing trend with depth indicating oxidizing geochemical conditions in the shallow wells and reducing conditions in the deep wells.

2.2.8.4. Selenium Trend in Groundwater

The Fish and Wildlife Service established performance standards for selenium in groundwater in the Biological Opinion for the Land Retirement Demonstration Project (FWS 1999). The performance standard for selenium in groundwater specifies that the selenium concentration in groundwater will not show a net increasing trend over the 5-year monitoring period. The summary statistics for the annual selenium data for the wells monitoring Coast Range deposits at the Tranquillity site are shown in Figure 2-16 and Table 2-7. The annual selenium data for the Coast Range wells show a relatively high degree of spatial variability. The coefficients of variation (standard deviation/mean) for the annual data ranged from 0.79-0.89 mg/L. The 95 percent confidence intervals calculated for the median annual selenium data were also large, indicating high spatial variability.

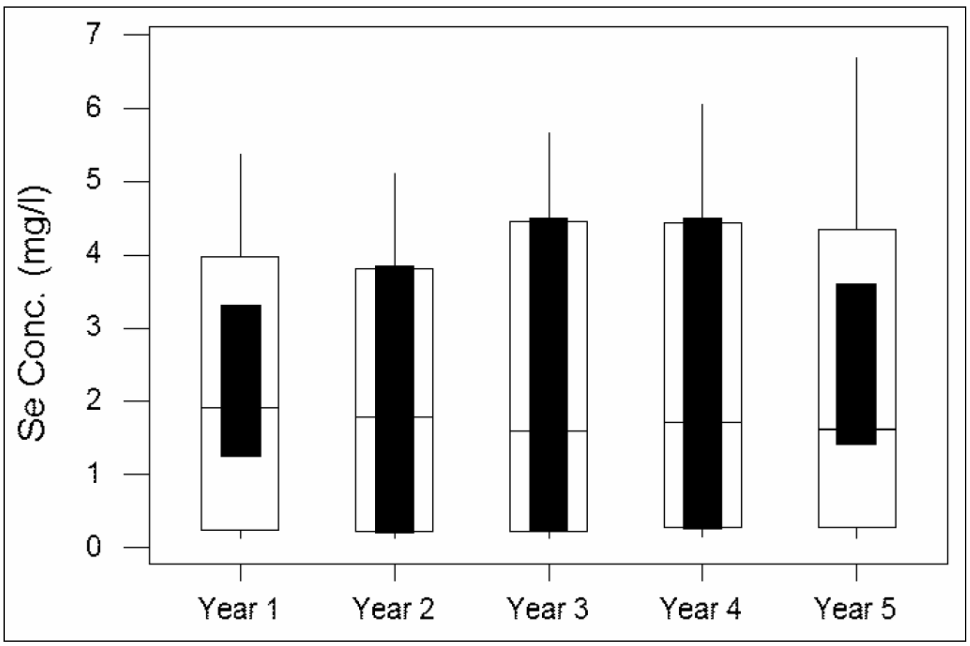

Figure 2-16. Boxplots of selenium concentrations in Coast Range deposits for the 5 years of groundwater sampling at the Tranquillity site. The inner black boxes represent the 95 percent confidence interval of the median concentration.

Table 2-7. Summary statistics for selenium concentrations measured in groundwater samples taken from Coast Range deposits for the 5 years of groundwater monitoring at the Tranquillity Site. All selenium concentrations are reported in milligrams/liter (mg/L).

Year	Number samples	Min	25th percentile	Median	Mean	75th percentile	Max	Std. Dev.	Coeff. of variation
1	45	0.095	0.237	1.910	2.237	3.975	5.39	1.782	0.79
2	10	0.104	0.212	1.785	2.111	3.820	5.14	1.795	0.85
3	10	0.110	0.222	1.595	2.367	4.468	5.70	2.107	0.89
4	11	0.119	0.262	1.710	2.403	4.450	6.08	2.125	0.88
5	44	0.110	0.272	1.610	2.441	4.345	6.72	2.089	0.85

Regression analyses of selenium concentrations over time for individual wells were performed as a way to evaluate observed trends against the FWS performance standard for selenium in groundwater.

A problem often encountered in time series analysis of groundwater quality data is the inherent seasonality sometimes present in the data. The seasonal variation in time series data may overwhelm any longer term trend. This is particularly true in a small data set. The Tranquillity well data consist of 11 samples collected from 10 wells and 8 samples from 1 other well between October 1999 and July 2004. The samples are not consistent within the years. Of the 11 samples, 5 were collected during May and the remainder were collected during February, July, and October (2 in each month). The data were evaluated for seasonal bias using the SYSTAT (SPSS 2000) nonparametric Kruskal-Wallis one way analysis of variance procedure. The results are shown in Table 2-8. The seasons were represented by the 4 months in which the samples were collected. None of the well data sets showed any significant degree of seasonality ($\alpha < 0.05$). It should be noted that there were only 8 samples from well 10M1 and that none of those samples were collected during October. The lack of seasonality helps to validate the use of linear regressions of selenium on time as a way to evaluate project performance.

Table 2-8. Analysis of seasonality of selenium data based on Kruskal-Wallis 1-way analysis of variance (ANOVA).

Well	K-W Stat.	Prob. > K-W Stat
10M1	1.409	0.4945
15F1	1.618	0.6553
15M1	0.955	0.8122
15M3	3.711	0.2944
15P1	4.950	0.1755
16A1	0.589	0.8989
16B1	1.372	0.7122
16B3	0.354	0.9496
16G1	0.275	0.9646
16J1	2.653	0.4483
16Q1	2.954	0.3988

Parametric and non-parametric regression analyses were performed to analyze the selenium trends in eleven of the wells at the Tranquillity site using the SYSTAT statistical software (SPSS 2000). All of the wells with the exception of well 10M1 monitor groundwater in the Coast Range deposits at the site. A way of eliminating the influence of large values early or late in the series is to run non-parametric (rank-order) correlations, rather than parametric correlation/ regressions. It should be noted that influence by large values also affects the distribution of residuals. Parametric correlation/regression analysis assumes that the residuals are normally distributed. The SYSTAT regression routine generates a number of statistics associated with the regression, including a list of outliers, identification of samples that exert undue influence on the result, and test statistics (F and t) for evaluating the significance of the relationship. None of the results showed observations that exerted undue influence on the results, but most included outliers. The effect of outliers is discussed later in this document.

Table 2-9 shows a comparison of the results of the nonparametric correlations with those of parametric correlation/regression analysis, including tests of significance based on the F-value of the regression. In addition to the r^2-value, the parametric regression generates an r-value (correlation coefficient), which is the same as if only a correlation was calculated. The nonparametric (Spearman) correlations generate a statistic known as ρ. The probability distribution associated with the significance of r and ρ is slightly different when the number of pairs is 10 or less, but is the same when the number of pairs is 11 or greater.

The parametric correlations show a significant increasing trend in selenium in 8 of the 11 wells (Table 2-9). The remaining three wells shown generated nonsignificant regressions and consequently showed no trend. There were also three wells that did not show a significant trend based on the nonparametric Spearman correlations. However, one of the nonsignificant parametric correlations shows a significant decreasing trend based on its Spearman correlation and one of the highly significant parametric trends (well 16J1 – r = 0.787, probability < 0.01) becomes non-significant based on the non-parametric correlation. The correlations for the remaining wells indicate the same trend based on either of the correlations, although the trend for well 16B3 is less definitive (compare r and ρ) based on the nonparametric correlation.

Table 2-9. Parametric and nonparametric correlations of selenium concentration in the Tranquillity wells on time

Well	r^2	Pearson r	Prob. > r[1]	Spearman ρ	Prob. > ρ[1]
10M1	0.4465	-0.6682	N.S.[2]	-0.8193	< 0.05
15F1	0.6931	0.8325	< 0.01	0.8091	< 0.01
15M1	0.5133	0.7164	< 0.05	0.8364	< 0.01
15M3	0.1099	0.3315	N.S.	0.5023	N.S.
15P1	0.0639	-0.2527	N.S.	0.1142	N.S.
16A1	0.8099	0.8999	< 0.01	0.8246	< 0.01
16B1	0.9049	0.9513	< 0.01	0.9589	< 0.01
16B3	0.7874	0.8874	< 0.01	0.7608	< 0.05
16G1	0.6621	0.8137	< 0.01	0.8585	< 0.01
16J1	0.6195	0.7871	< 0.01	0.5695	N.S.
16Q1	0.5291	0.7274	< 0.05	0.6865	< 0.05

[1] Prob.: probability of a Pearson's r or Spearman's ρ of the magnitude shown occurring by chance alone.
[2] N.S. - not significant, i.e. prob. > 0.05.

After a preliminary review of the regressions of the selenium data, it appeared that the outliers all occurred in the early part of the monitoring period. Because the data were not evenly distributed over time; i.e., four samples were collected during each of water years 2000 and 2004, with only one each in 2001, 2002, and 2003, there could be a biasing effect. Because of the possible bias, the regressions were recalculated after deleting the outliers. The review also indicated that rather than being outliers, the samples that appeared to be outliers were showing that a nonlinear, rather than a linear, regression might be more appropriate. To evaluate this, nonlinear regressions were calculated both with and without the outliers. The results are summarized in Table 2-10 and some of the regressions are shown in Figure 2-17, Figure 2-18, Figure 2-19, and Figure 2-20. Where Table 2-10 indicates that there is no trend, either there was no significant regression or the regression was significant, but no trend could be discerned. Significant regressions showing no trend were confined to nonlinear regressions.

Table 2-10. Summary of results of linear and nonlinear trends without and with adjustment for outliers.

Well	Outlier (Date)	Trend without adjustment		Trend with outliers deleted	
		Linear	Nonlinear	Linear	Nonlinear
15M1	May-01	Increase	Increase(?)	Increase	N/A[1]
15P1	Jul-00	None	None	None	None
15M3	May-02	None	None[2]	Increase	Increase
16B3	None	Increase	Increase	——	——
16J1	None	Increase	Decrease[3]	——	——
16A1	May-01	Increase	Increase	Increase	Increase
15F1	None	Increase	Increase	——	——
16Q1	Oct-99	Increase	Decrease[3]	Increase	Decrease[3]
16G1	Oct-99	Increase	Increase	Increase	Increase[4]
16B1	May-02	Increase	Increase	Increase	Increase
10M1	May-00	None	None[2]	Decrease	None[2]

[1] Linear trend is more significant
[2] Regression shows no current trend, but is statistically significant
[3] Following an initial increase, Se has been decreasing in more recent data
[4] Increase initially, but eventually forms an asymptote

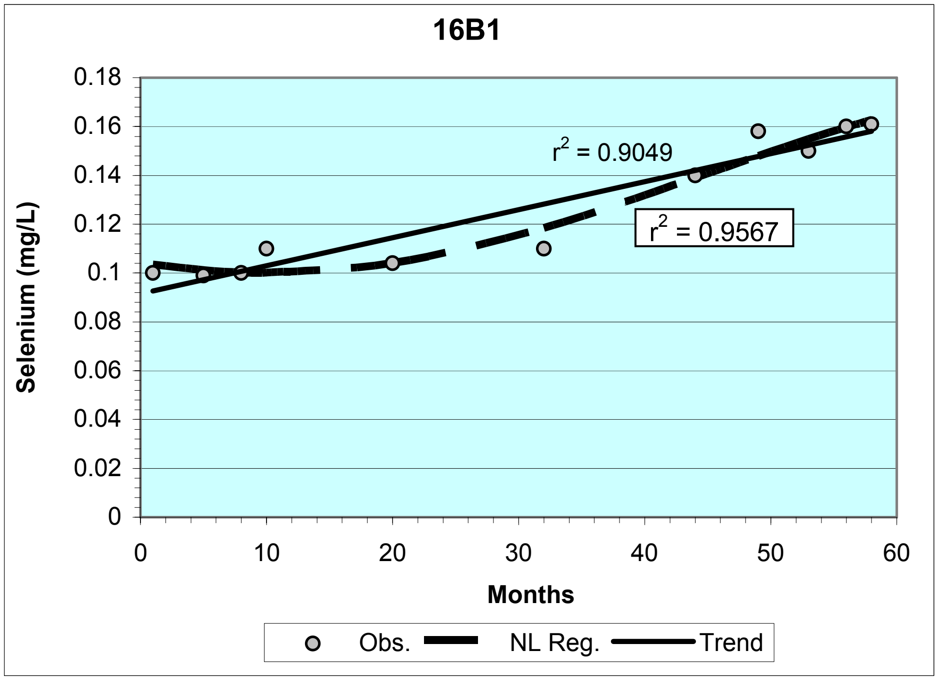

Figure 2-17. Selenium data and trend in well 16B1 along with "best fit" nonlinear regression [Sinusoidal Fit: y=a+b*cos(cx+d)].

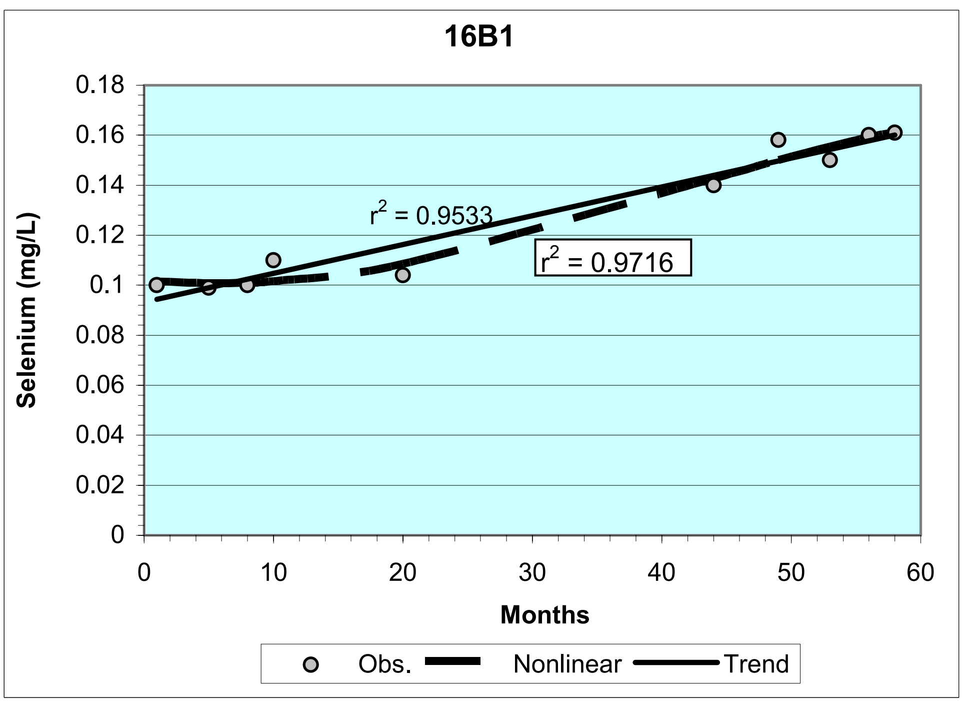

Figure 2-18. Selenium data and trend in well 16B1 without outlier datum along with "best fit" nonlinear regression - [Sinusoidal Fit: y=a+b*cos(cx+d)].

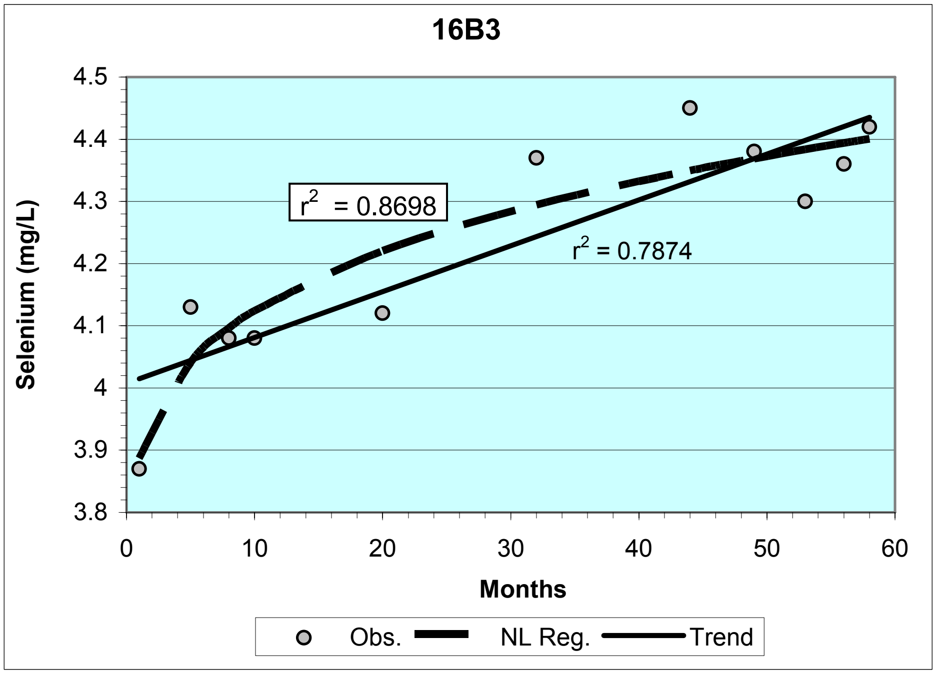

Figure 2-19. Selenium data and trend in well 16B1 along with "best fit" nonlinear regression - [Harris Model: $y=1/(a+bx^c)$].

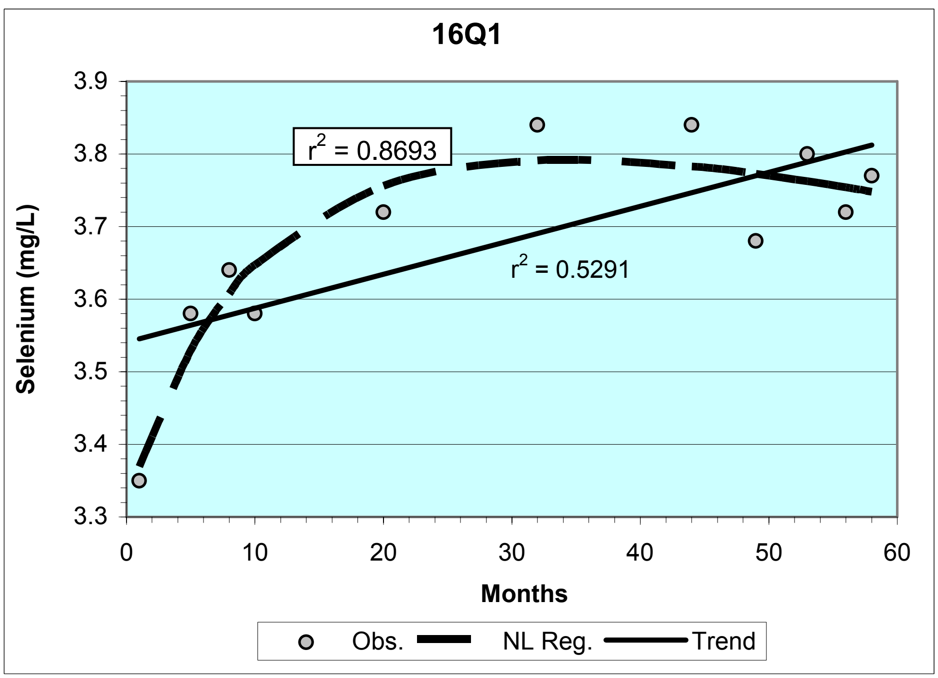

Figure 2-20. Selenium data and trend in well 16Q1 along with 'best fit" nonlinear regression - [Rational Function: $y=(a+bx)/(1+cx+dx^2)$].

The performance objective for selenium in groundwater at the Tranquillity site established by FWS stated that the selenium concentration in groundwater shall not show a net increasing trend over the life of the project. The FWS performance objective was clearly not met. Rising levels of selenium observed in the shallow groundwater in the Coast Range deposits are likely a result of oxidation and advective transport of mobile selenium species in the alkaline conditions near the falling shallow water table. As long as the water table continues to decline as expected in response to land retirement, the high concentrations of selenium in the groundwater should have no consequences to biota at the site. In contrast, selenium is present at very low concentrations in the groundwater found in the coarse-textured Sierran deposits at the Tranquillity site. In the reducing geochemical environment observed in the Sierran groundwater, selenium is relatively insoluble and immobile.

2.2.8.5. Boron in Groundwater

The presence of high concentrations of boron in the shallow groundwater is of concern due to potential toxicity to plants and wildlife. Boron concentrations in the shallow groundwater at the site are very high. The boron concentrations measured in the shallow wells during the first year range from 10 to 81 mg/L, with a median value of 45.5 mg/L (Table 2-5). No water-quality criteria for boron exist for aquatic life or human health. No more than 750 µg/L of boron should be applied to sensitive crops (EPA 1986). Perry et al. (1994) proposed a toxicity threshold in water for crops and aquatic plants of 10 mg/L. Deverel and Millard (1988) noted that boron is geochemically mobile and present as oxyanions in oxidized, alkaline environments such as the western San Joaquin Valley shallow groundwater.

The authors also reported high correlation between log transformed boron and specific conductance data for shallow groundwater in the western San Joaquin Valley. Boron concentrations observed in the deep wells at the site are an order of magnitude lower than those in the shallow wells. Boron concentrations measured in the deep wells during year 1 of monitoring range from 2.5 to 8.3 mg/L, with a median concentration of 3.2 mg/L (Table 2-6). The large difference in boron concentration between the shallow and deep groundwater at the site may be due to adsorption onto soil surfaces or differing geochemical conditions between the shallow and deep groundwater systems. Adsorption of boron on soil particles can affect and limit its solubility (Keren and Bingham 1985). Fujii and Swain (1995) concluded that the relatively conservative behavior of boron observed in shallow groundwater in the San Joaquin Valley probably reflects the presence of high concentrations of competing constituents for adsorption sites.

2.2.8.6. Origin and Isotopic Composition of Groundwater

Groundwater samples were analyzed for tritium and stable isotope ratios of oxygen and hydrogen during the first 3 years of monitoring. A summary of the tritium data are presented in Table 2-5 and Table 2-6. The oxygen and hydrogen isotope data shown in Figure 2-21 can provide insight into the evaporation history of the water, while the tritium data can be used to develop an understanding of the age and origin of the groundwater at the site.

2.2.8.7. Groundwater Age

The levels of tritium, a radioactive isotope of hydrogen with a half-life of 12.43 years, rose in the environment during the 1950s and 1960s because of atmospheric detonation of nuclear weapons. Tritium concentrations can be used to develop an understanding of the origin and history of water samples. Tritium concentrations in water samples are reported in tritium units (TU). Prior to 1952, precipitation contained < 5 TU. Due to radioactive decay, groundwater derived from precipitation before 1952 now has < 0.5 TU. Groundwater derived from precipitation recharged since 1952, including canal water used as irrigation since 1968, commonly has a tritium concentration exceeding 10 TU. Groundwater with

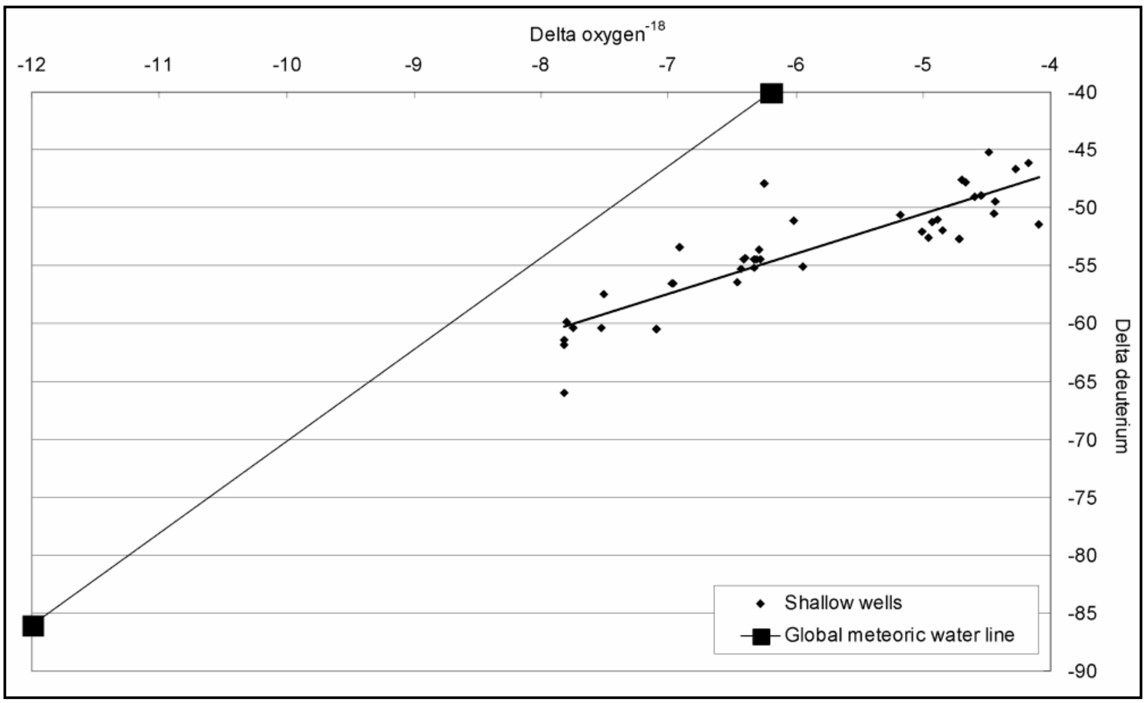

Figure 2-21. Plot of stable isotope data for groundwater samples from the Tranquillity site indicating the shallow groundwater has undergone significant evaporation.

a tritium concentration of < 1.6 TU either has recharged prior to 1952 or may have originated as post-1952 irrigation water from deep wells. This large contrast in tritium concentration allows comparison of older groundwater, much of which was recharged prior to agricultural development, to young water recharged since 1952 and derived from irrigation (Dubrovsky et al. 1993).

The tritium data from the shallow wells indicate that the shallow, perched groundwater consist of a mixture of water recharged before and after 1952. Tritium concentrations of the shallow groundwater samples range from 0 to 6 TU, with a median concentration of 2.4 TU. Low tritium concentrations (< 1 TU) observed in wells 16Q1 and 16F1 may indicate recharge from irrigation water that was pumped from deep production wells completed in the sub-Corcoran aquifer. The tritium data from the deep wells (well 15M3 and 16B3) completed in coastal range deposits indicate that the groundwater was recharged before 1952. Tritium concentrations observed in these two wells ranged from 0 to 0.5 TU, with a median concentration of 0.1 TU. The tritium data from the deep wells completed in Sierra Nevada sediments indicate that the groundwater has been recharged since 1952. Tritium concentrations found in wells 15C3 and 10G3 range from 9.6 to 14.0 TU, with a median concentration of 10.5 TU.

2.2.9. Evaporative Concentration of Shallow Groundwater

In areas where the water table is shallow in the western San Joaquin Valley, particularly at depths less than 1.5 m (5 feet) below land surface, evaporative concentration of dissolved solids in groundwater can increase salinity and selenium concentrations far above the levels resulting from leaching of soil salts by irrigation (Deverel and Fujii 1988). Under irrigated conditions, loss of water by evapotranspiration tends to concentrate salts in groundwater rather than soil because the salts are regularly flushed downward by percolating irrigation water and net groundwater movement is generally downward (Dubrovsky et al. 1993).

Hydrogen and oxygen isotope concentrations from shallow groundwater samples at the Tranquillity site show that groundwater salinity is primarily a result of evaporation and evapotranspiration of the shallow groundwater. The evaporation process adds kinetic separation to the hydrogen^{2} (deuterium) and oxygen^{18} species causing increased enrichment in the O^{18} species (Gat and Gonfiantini 1981). This results in a plot of the delta deuterium (D) verses delta O18 that has a smaller slope than the meteoric water line. The comparison of delta D and delta O^{18} shown in Figure 2-21 illustrates the evaporation that has taken place in the shallow groundwater at the site. Similar evaporative trend lines have been reported by Deverel and Fujii (1988) and Presser and Barnes (1984) for shallow groundwater in the western San Joaquin Valley.

2.2.9.1. Surface Water

In the Biological Opinion for the Land Retirement Demonstration Project, the FWS established performance standards for selenium and mercury concentrations in surface water. The performance standard specified that standing water that persists for more than 30 days shall not exceed 2 micrograms/liter (µg/L) selenium, and 2 nanograms/liter mercury (FWS 1999). Standing water at the site was monitored by examining precipitation data on the CIMIS website and periodically visiting the site during the wet season to document any standing water that persisted for more than 30 days in duration. Since groundwater levels beneath the site have steadily declined over the 5-year study, the only source of standing water would presumably come from precipitation that does not infiltrate, run off the site or evaporate within 30 days of a winter or spring storm event.

No vernal pools that persisted for more than 30 days were observed at the Tranquillity site during the 5-year study. Precipitation during the study has been below average (Figure 2-4), and the maximum monthly rainfall observed during the study was just below 5 cm (2 inches) (Figure 2-3). The precipitation threshold for formation of vernal pools at the site is unknown, but is certainly in excess of 5 cm (2 inches) per month. An important factor governing the formation of vernal pools at the site is the clay content of the soils. These basin rim clay soils have high plasticity indices (33-61 percent), and thus have a tendency to shrink upon drying and swell upon wetting as water enters and leaves the crystal lattice of the clay mineral structure. The shrink-swell behavior of the soil has resulted in a large network of surface cracks during the extended period of below-average rainfall (Figure 2-22). Before vernal pools can form on the surface, enough moisture must be absorbed by the clay soil to cause swelling sufficient to seal the surface cracks. Several unsuccessful attempts were made in 2004 to artificially simulate vernal pool formation by excavating small "ponds" and filling them with irrigation water. In all cases, the water seeped into the surface cracks after several days.

Figure 2-22. Photos of open surface cracks in Tranquillity clay soils at the Tranquillity site (Jan 2005).

The crack was open to a depth of approximately 42 inches on this date. Soil moisture from fall and winter storms had penetrated to a depth of about 12 inches. The extensive network of surface cracks in the soil at the site inhibits the formation of surface water ponds (vernal pools).

2.2.10. Trend Analysis for Soils

One of the objectives of the demonstration project was to evaluate the effect that land retirement would have on soils. Concerns were raised that upflux of shallow, saline groundwater with high selenium content on retired lands would salinize the surface soil and create potentially toxic conditions for wildlife. No performance objectives for soil salinity or soil selenium concentrations were established for the demonstration project. Constituents of concern for soil monitoring include soil salinity (EC_e), selenium and boron. Soil salinity and selenium data collected at 24 paired sites in 1999, 2002 and 2004 are presented in Figure 2-23 through Figure 2-31. This data are from the central sampling location in each 10-acre demonstration plot at the Tranquillity site as well as four sites located on retired lands east of the plots in sections 10 and 15. The bar graphs indicate that most of the changes in constituents of concern (COC) concentrations occurred during the first 3 years of the demonstration project.

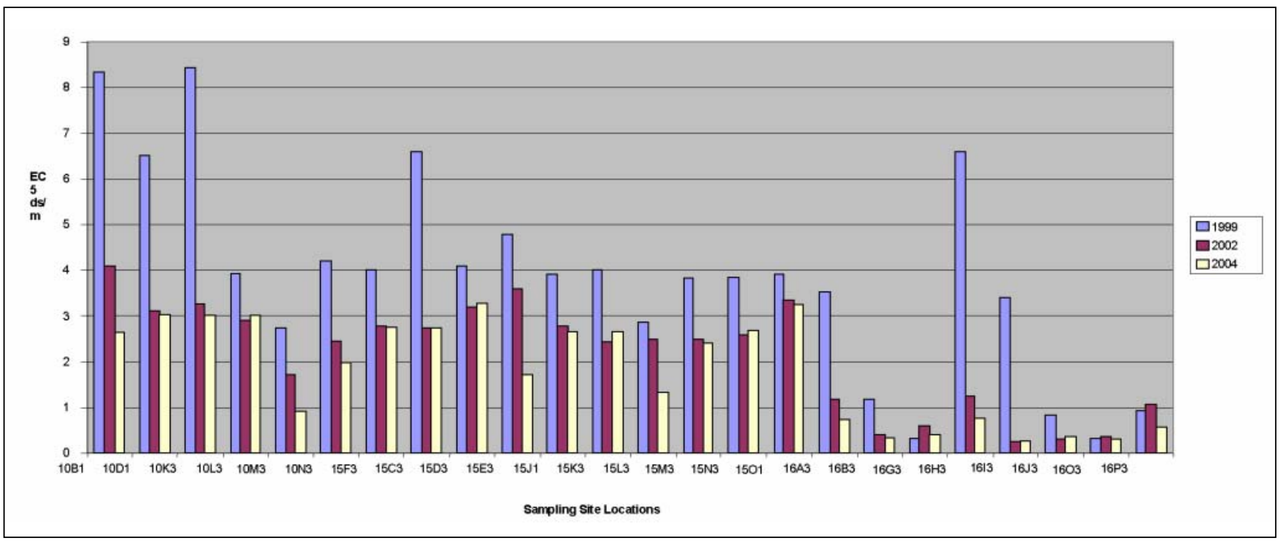

Figure 2-23. EC_e Trends in top foot of soil from 1999 to 2004.

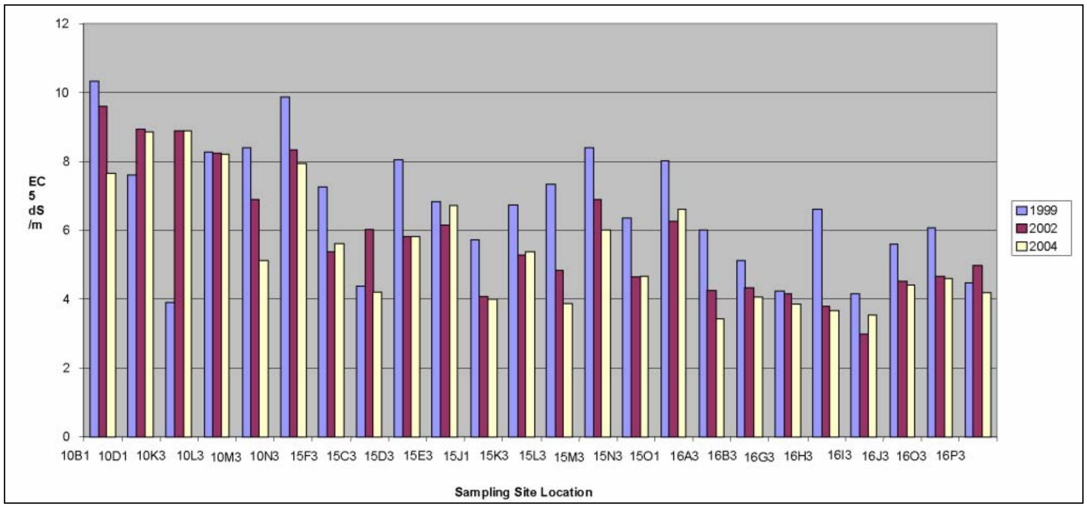

Figure 2-24. EC_e Trends in 2 to 3 foot depth of soil from 1999 to 2004.

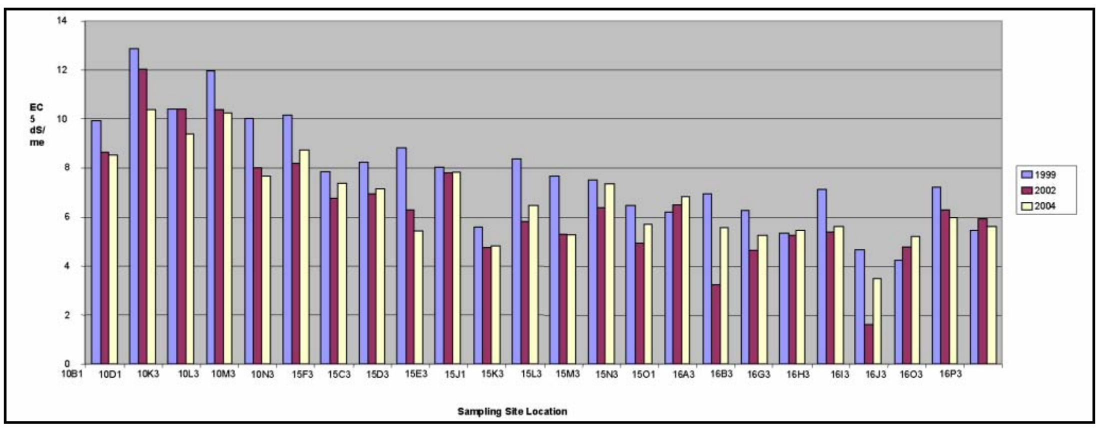

Figure 2-25. EC_e Trends in 4 to 5 foot depth of soil from 1999 to 2004.

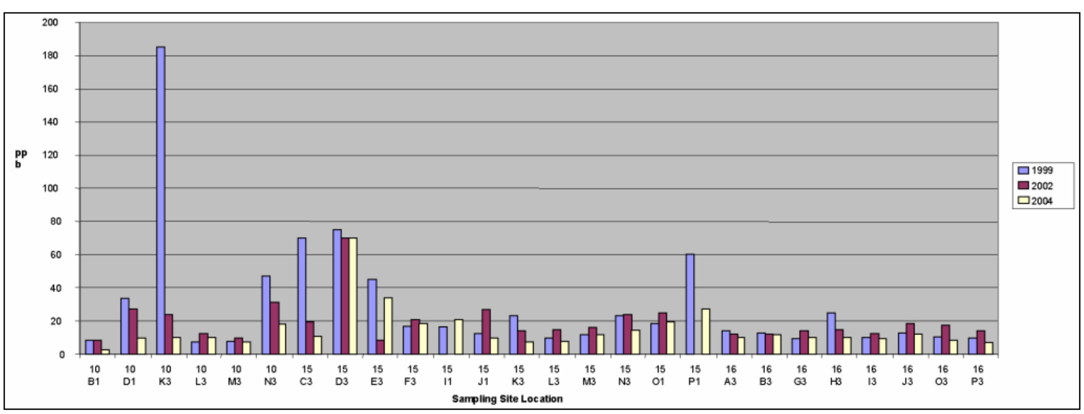

Figure 2-26. Soluble selenium trends in top foot of soil from 1999 to 2004.

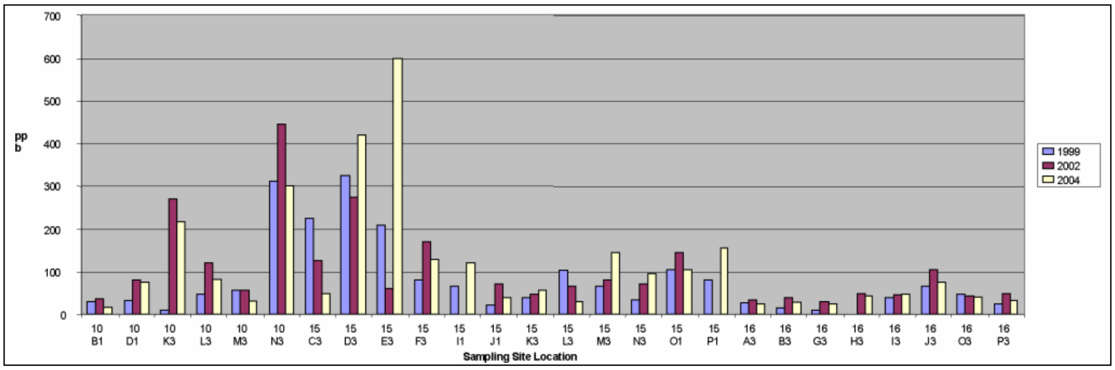

Figure 2-27. Soluble selenium trends in 2 to 3-foot depths of soil from 1999 to 2004.

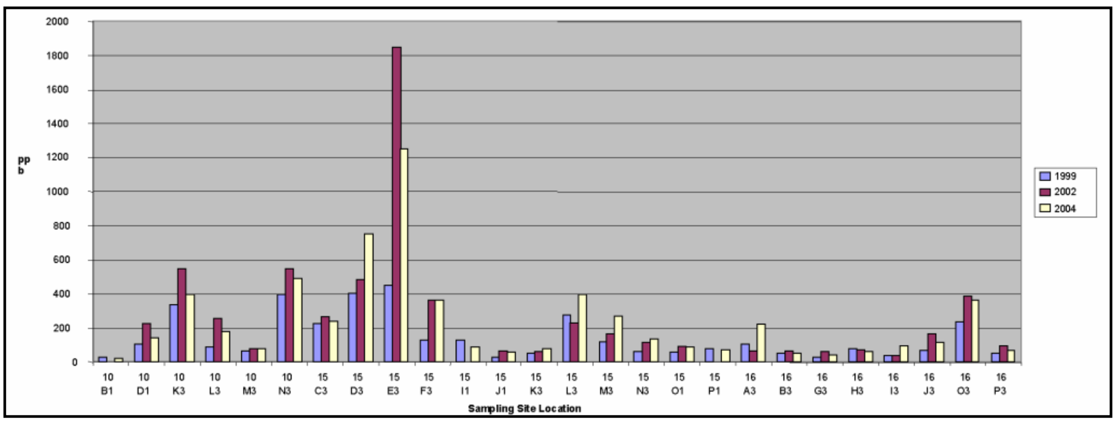

Figure 2-28. Soluble selenium trends in 4 to 5 foot depths of soil from 1999 to 2004.

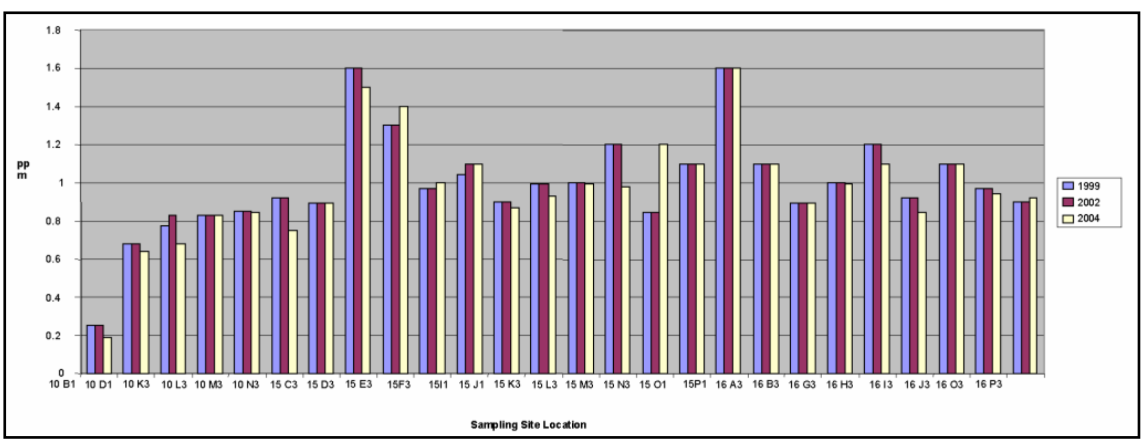

Figure 2-29. Total selenium trends in top foot of soil from 1999 to 2004.

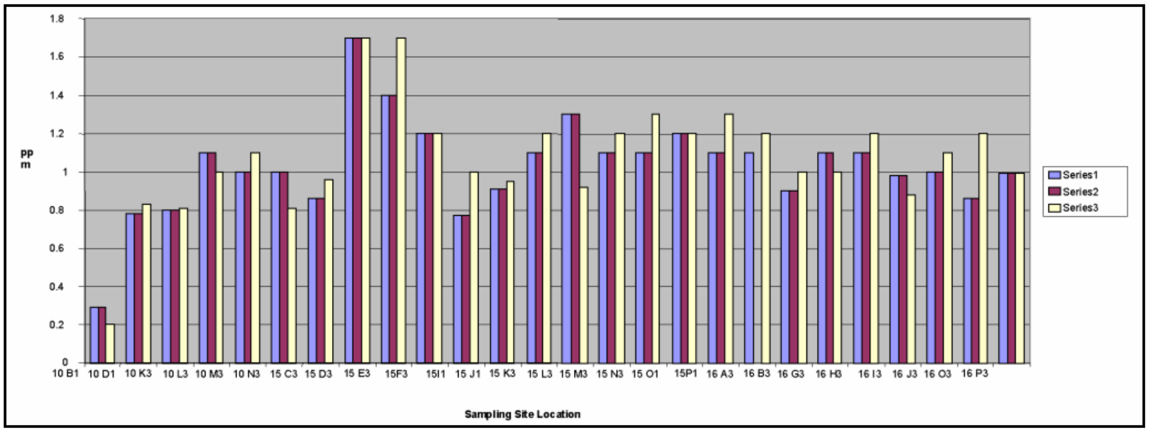

Figure 2-30. Total selenium trends in 2 to 3 foot depth from 1999 to 2004.

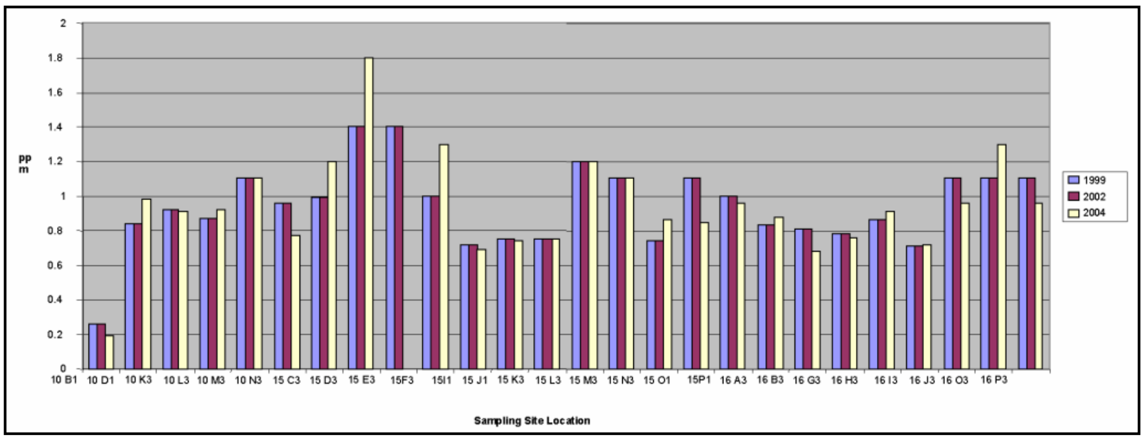

Figure 2-31. Total selenium trends in 4 to 5 foot depth from 1999 to 2004.

2.2.11. Change Detection Analyses

The Wilcoxon sign rank test was used to determine if the concentration changes at the paired soil sampling sites were statistically significant at the 95 percent confidence level. All data presented in the following statistical summaries are on a dry soil weight basis except for the soil salinity data, which are the concentration of the extract. Table 2-11 summarizes statistical analysis of the 1999 and 2004 data using the Wilcoxon sign-rank tests for each constituent of concern.

Table 2-11. Change detection analyses for COCs in soil at the Tranquillity site.

Constituents of Concern	Depth (feet)	Median 1999 ug/kg	Median 2004 ug/kg	Sites decreasing	Sites increasing	Z change direction	Prob>Z	Significant (95% CI)
Soluble Selenium	0-1	18	11	96	12	-8.03 down	<0.00001	Yes
Soluble Selenium	2-3	47	65	7	17	2.357 up	0.0184	Yes
Soluble Selenium	4-5	82.5	125	4	22	3.823 up	0.000132	Yes
Total Selenium	0-1	1000	990	66	19	-4.14 down	0.000035	Yes
Total Selenium	2-3	940	1075	7	17	2.959 up	0.0031	Yes
Total Selenium	4-5	920	910	11	10	0.400 up	0.6892	No
Salinity (ECe) dS/m	0-1	3.66	1.53	102	8	-8.74 down	<0.000001	Yes
Salinity (ECe) dS/m	2-3	6.67	4.99	24	2	-3.54 down	0.00396	Yes
Salinity (ECe) dS/m	4-5	7.35	5.88	22	4	-4.00 down	0.000063	Yes

2.2.12. Soil Interpretive Summary

Total selenium concentrations, soluble selenium concentrations, and salinity (ECe) in the surface soil (depth 0-30 cm or 0-1 foot) at the Tranquillity site showed a decreasing trend over the 5-year study. Soils at the Tranquillity site contain moderately elevated concentrations of selenium (mean selenium 1.0 milligrams per kilogram [mg/kg]) when compared to values reported for western U.S. and San Joaquin Valley soils (Table 2-12).

Table 2-12. Comparison of total selenium concentrations at the Tranquillity site to Western U.S. and San Joaquin Valley soils.

Mean selenium western states soils (Shacklette and Boerngen 1984)	0.34 mg/kg
Mean selenium San Joaquin Valley soils (Tidball et. al. 1986)	0.14 mg/kg
Mean selenium Tranquillity site (1999)	1.05 mg/kg
Max selenium Tranquillity site (2004)	1.7 mg/kg
Uncommonly high selenium western soils (Shacklette and Boerngen 1984)	1.4 mg/kg
Typical sediment toxicity threshold	4 mg/kg
Kesterson Reservoir sediment criteria (Benson et. al. 1993)	4 mg/kg

The spatial variability for total selenium in the Tranquillity soil series is low (Figure 2-23). The coefficient of variation for total selenium in the Tranquillity soils was about 18 percent during the baseline sampling event in 1999. Total selenium concentrations appear to be slowly decreasing in surface soils at the site.

This is an important trend because this represents the total inventory of selenium in the soil and is not subject to seasonal or temporary concentration changes due to climatic factors or soil reaction changes. Soluble selenium concentrations in surface soils (depth 0-30 cm or 0-1 foot) also decreased which is considered a positive change since most biologic activity takes place in surface soils. The soluble selenium concentrations in the substrata and the percent of soluble/ total selenium increased during the first 3 years but tended to decline during the 3-5-year demonstration period. A summary of soluble selenium percentages is presented in Table 2-13.

Table 2-13. Average soluble to total selenium percentages all sites at Tranquillity.

Depth zone	1999 (57 sites)	2002 (57 sites)	1999 (all sites)	2004 (all sites)
1 foot	3.2	2.5	2.9	1.5
2-3 feet	8.1	13.2	8.1	10.1
4-5 feet	15.3	28.7	15.2	19.1

* 2002 data are for about 50 percent of the shallow sites but include 22 of 26 substrata sites.

The surface soils appear to have been leached of selenium while the soluble selenium content of the substrata zones (60.9-91.4 cm and 121.9-152.4 cm or 2-3 and 4-5 foot depth) appears to have been enriched somewhat by leaching from surface layers. The principal reason for soluble selenium increases in substrata appears to be the slight increase in soil reaction (pH) and the increased oxidized conditions present as the water table elevation and associated capillary fringe zone declined during the study period.

Surface soil (0-30 cm or 0-1 foot depth) salinity (ECe) at the Tranquillity site decreased over the 5 years of monitoring for this study. Soil salinity decreased at 102 out of 110 sites sampled from the 0-30 cm (0-1 foot) depth from 1999 to 2004. Decreases in soil salinity based on 1-5 extract concentrations were statistically significant. Salinity declines were surprisingly large in soil surface samples. Decreases in soil salinity were also observed in the substrata (depths 60.9-91.4 and 121.9-152.4 cm or 2-3 and 4-5 feet). Some of the soil salinity reduction in surface layers may be due to the beneficial leaching effects of rainfall. The predominant salt at the site is sodium sulfate which is very soluble in water. The magnitude of the soil salinity reduction may also be related to the soils tendency to form deep and wide cracks upon drying. Before the land was retired from irrigation, bare soil surface evaporation may have formed a salt concentration in the upper few inches of soil. Upon extended drying, the soil cracked deeply while the saline surface layers developed a loose crumb structure. Much of the loose surface material dropped into the deep cracks and was deposited in the substrata. Some of the cracks observed at the Tranquillity Site were more than 1.5 m (5 feet) deep and 30 cm (1 foot) wide. These soils are commonly termed vertisols since they have the ability to invert over many wetting and drying cycles.

2.2.12.1. Saturation Extract Testing

Saturation extract testing was also conducted to determine plant adaptability, relative growth potential, and other agronomic factors. Soluble selenium concentrations are not limiting for plant growth at the site. The average concentration found in saturation extracts from samples collected in the top foot of soil was 4.6 µg/liter. The element most limiting plant growth and adaptability in the site surface soils probably is boron. Soil salinity was decreasing and average ECe values in the 2004 surveys were 3.3 dS/m in the top foot of soil. Soil salinity levels and boron levels sharply increased with depth in substrata. Boron and soil salinity are both elevated at the site and would limit plant selections as well as plant growth of many plants. Figures 2-32 through 2-35 show the ECe, SEe and the soluble boron concentration of surface soils 0-30 cm (0-1 foot) at the site during the 2004 soil surveys in September 2004. Soil boron phytotoxicity threshold levels are about 2 mg/L in a saturation extract and about 4 mg/kg on a soil dry weight basis. ECe thresholds are about 4 ds/m. About 40 percent of the survey area surface soils exceed soil salinity thresholds and about 95 percent exceed the boron threshold. Limited data collected during the survey indicate that soil salinity is lowest in the seedbed 0-10.1 cm (0-4 inch) inch zone. Seedbed soil salinity levels should permit germination, emergence, and growth of most climatically adapted native plants.

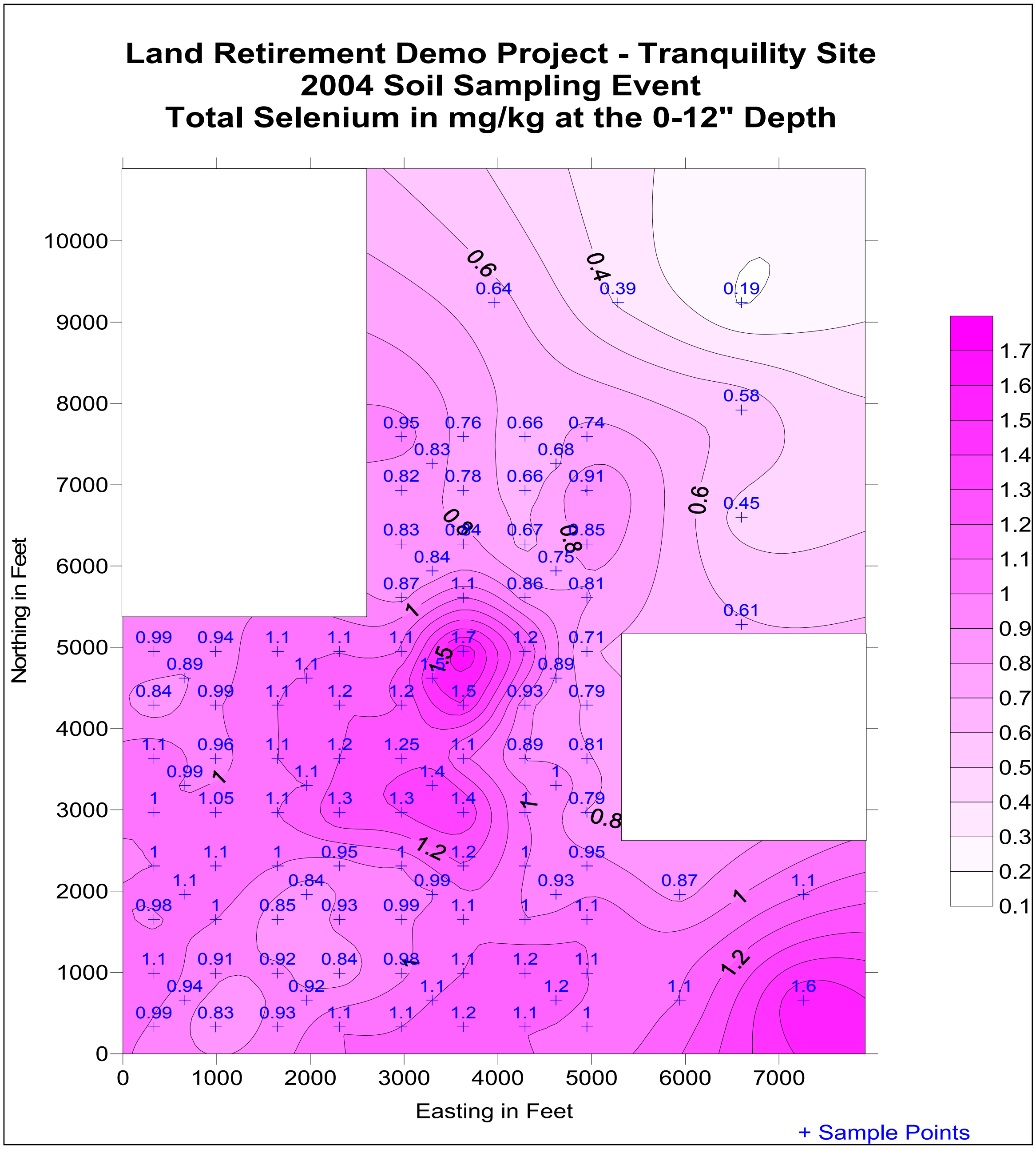

Figure 2-32. Total selenium concentrations in surface soils 0-30 cm (0-1 foot) at the Tranquillity site from the 2004 sampling event.

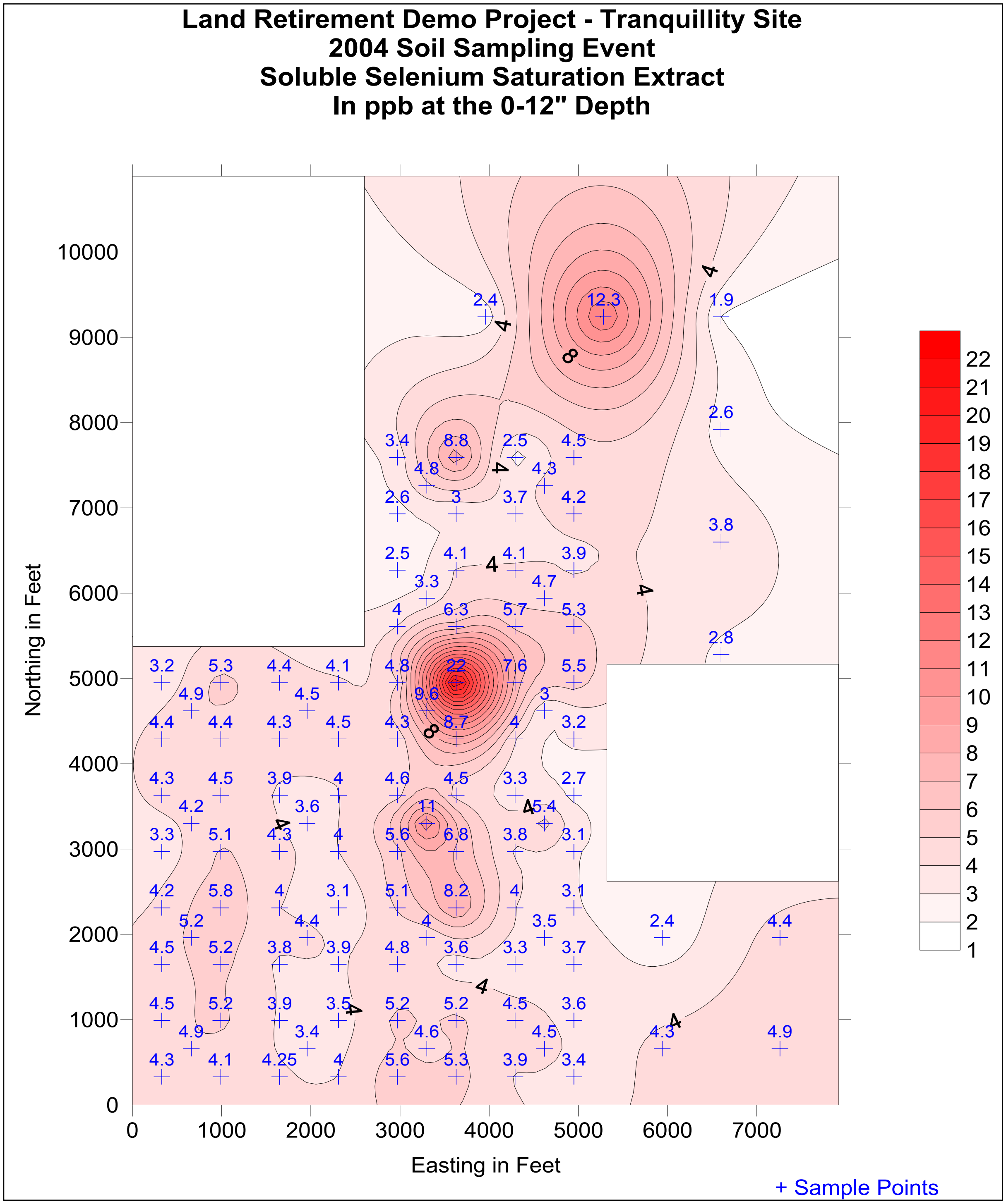

Figure 2-33. Soluble selenium in surface soils 0-30 cm (0-1 foot) at the Tranquillity site from the 2004 sampling event.

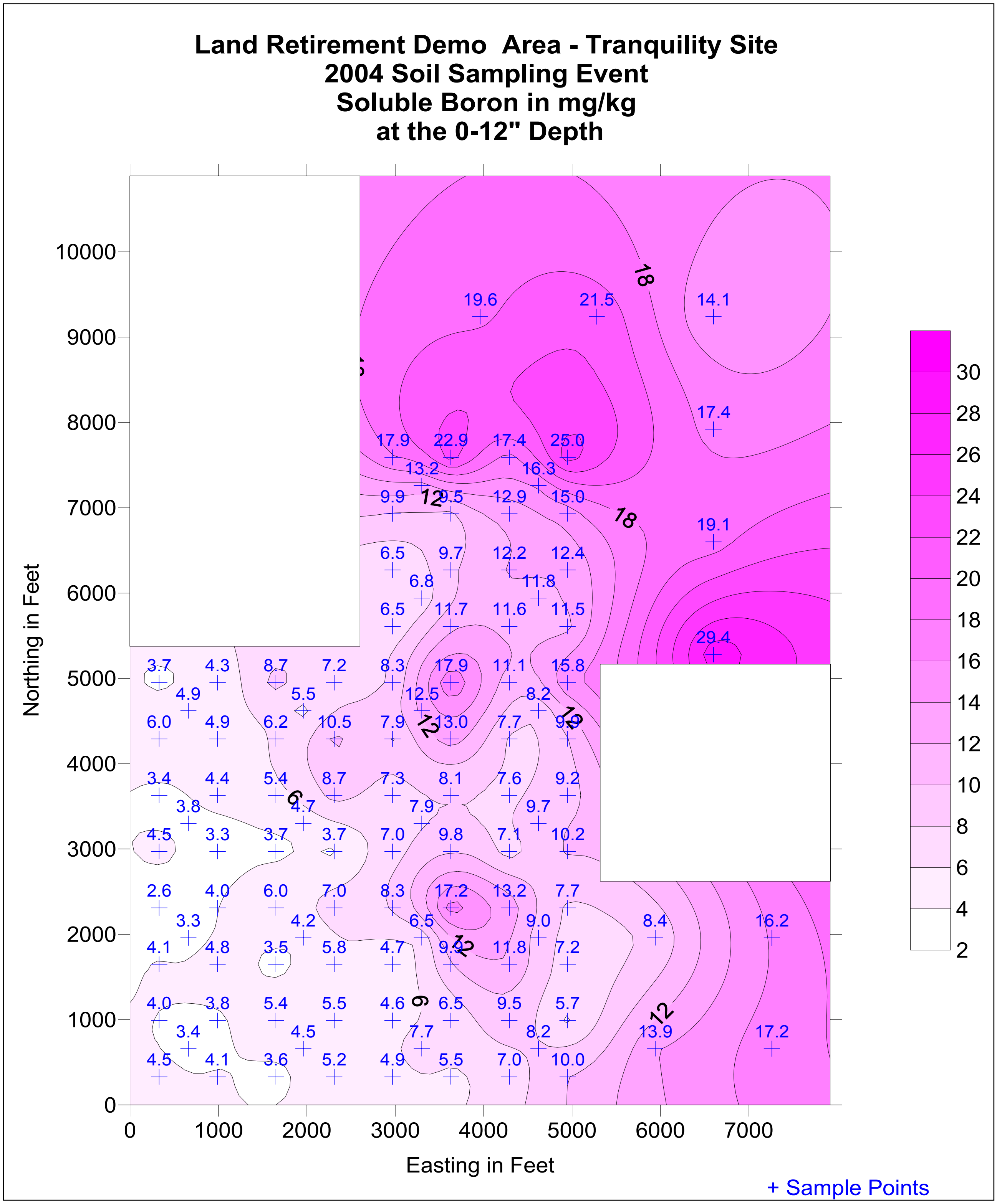

Figure 2-34. Soluble boron concentrations in the surface soils 0-30 cm (0-1 foot) at the Tranquillity site from the 2004 sampling event.

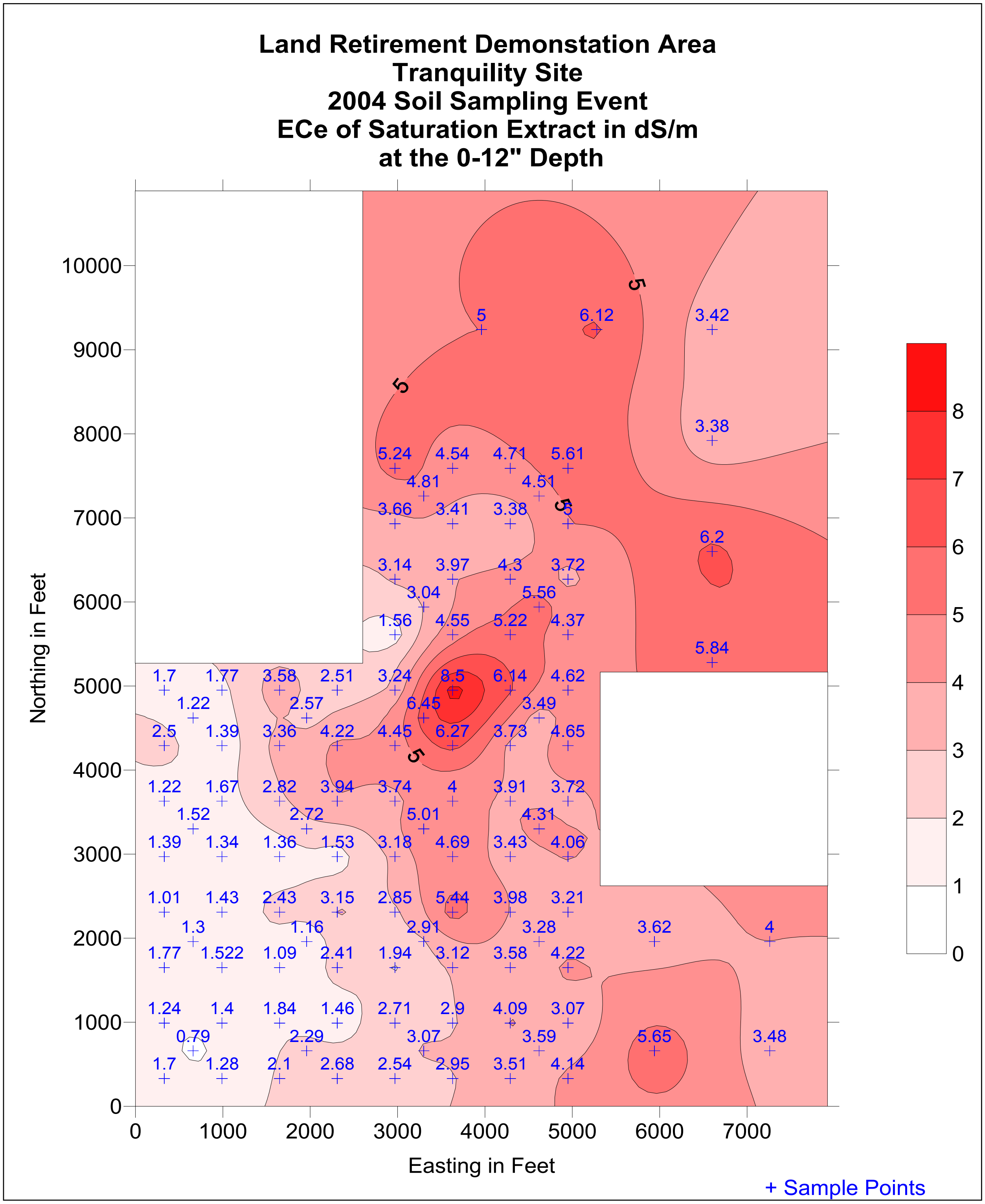

Figure 2-35. Soil salinity (ECe) concentrations (dS/m) in the surface soils 0-30 cm (0-1 foot) at the Tranquillity site from the 2004 sampling event.

2.2.13. Conclusions

Five years of groundwater monitoring at the Tranquillity site support conceptual and numerical models that predicted a declining shallow water table in response to land retirement. FWS performance objective regarding water table response to land retirement at the Tranquillity site was clearly met. Percolation of applied irrigation water prior to land retirement was the primary source of groundwater recharge that sustained the high water table. In the absence of irrigation recharge the shallow water table has steadily receded from the land surface over the 5-year study. Large downward hydraulic gradients measured at the site confirm the presence of perched water table conditions in the fine-grained Coast Range deposits. Discharge of the shallow groundwater occurs primarily through slow downward percolation through surficial clay deposits at the site. Some shallow groundwater was also discharged by evaporation from the water table when it was in close proximity to the land surface at the beginning of the study. The water table response observed at the Tranquillity site is representative of conditions that would be present at a high percentage of lands that are targeted for retirement on the lower alluvial fan and basin rim settings in the western San Joaquin Valley.

The declining shallow water table is an important aspect of land retirement due to poor quality of the shallow groundwater observed beneath the Tranquillity Site. The high salinity and selenium concentrations in the shallow groundwater found in the Coast Range deposits at the site are a result of leaching under irrigated conditions and evaporation from the shallow water table. Evaporation from the shallow water table has concentrated salts and trace elements in the shallow groundwater. The FWS performance objective for selenium in groundwater at the Tranquillity site was clearly not met. Rising levels of selenium observed in the shallow groundwater of the Coast Range deposits are likely a result of oxidation and advective transport of mobile selenium species in the groundwater near the falling shallow water table. **As long as the water table continues to decline as expected in response to land retirement, the high concentrations of selenium in groundwater should have no consequences to biota at the site.** In contrast, selenium is present at very low concentrations in the groundwater of the coarse textured Sierran deposits at the Tranquillity site. In the reducing geochemical environment observed in the Sierran groundwater, selenium is relatively insoluble and immobile.

The predominant soil type at the Tranquillity site is Tranquillity clay. This is the most extensive soil type mapped by the Natural Resources Conservation Service on the lower alluvial fans and basin rim landforms in the areas targeted for land retirement by district and federal programs. Soils at the Tranquillity site contain moderately elevated concentrations of selenium (average 1.0 mg/kg) when compared to the common range (0.1-1.4 mg/kg) for western U.S. and San Joaquin Valley soils; however, they are still well within the range commonly found in western soils. Total selenium concentrations, soluble selenium concentrations, and salinity in the surface soil (depth 0-1 foot) showed a decreasing trend over the 5 years of monitoring at the Tranquillity site. The decreasing selenium and salinity trends in the surface soil indicate that upflux of salt and selenium from capillary rise and evaporation of shallow groundwater at the soil surface is minimal, and that some leaching of soluble selenium and salt from surface soils occurred during the 5-year study despite dryer-than-average climatic conditions. About 10-20 per cent of the selenium present in the subsoils is soluble and mobile in the alkaline, oxidizing chemical conditions found in the soil. Soluble selenium concentrations and percentages are much lower in the surface soils (average 4.6 parts per billion [ppb] in saturation extracts). Even if surface water ponding should occur during very wet periods, it is probable that selenium concentrations in the ponded water would be below the aquatic life criteria of 5 ppb. No performance objectives were established for soil selenium levels for the demonstration project; however, the maximum surface soil concentration observed during the 5 years of monitoring at the Tranquillity site was well below typical soil toxicity thresholds for sediment (4 mg/kg).

FWS established performance standards for selenium and mercury in ponded surface water that lasts for more than 30 days. Due to dry climatic and soil conditions during the study, no surface water ponding was observed at the site that lasted for more than 30 days. Monitoring of precipitation during the course of the study suggests that the precipitation threshold to cause ponding of surface water at the site is well in excess of 5 cm (2 inches) of rainfall per month. The extensive network of desiccation cracks in the clay soils at the Tranquillity site greatly inhibits the formation of surface water ponds.

2.3. Atwell Island Site

2.3.1. Geology

The Atwell Island demonstration site lies on the southwestern margin of the Tulare Lake bed, which is the dominant geologic feature in the study area. The site is underlain by lakebed and marsh deposits consisting primarily of clay and silt with some sand with a thickness in excess of 1,097 m (3,600 feet) (Page 1986). The Corcoran Clay member of the Tulare Formation is a regionally extensive, fine-grained lake-bed deposit that underlies the Atwell Island site at a depth of approximately 274 m (900 feet) below the land surface. A relict sand dune deposit consisting of fine-grained wind-blown sand from the former shoreline of the Tulare Lake bed traverses the western boundary of the site from southwest to northeast.

2.3.2. Soils

Soils in the Atwell Island study area consist of silt loam and fine sandy loams that are formed in alluvium derived from igneous and sedimentary rocks. Silty clay loam soils are also present in the southeast portion of the site. Individual soil mapping units found in the study area, in the order of abundance, include the Posochanet silt loam, Nahrub silt loam, the Westcamp silt loam, Excelsior fine sandy loam, and Lethent fine sandy loam. The Posochanet soils occur primarily in the central portion of the site and cover about 30 percent of the total study area. These soils are saline, alkaline, very deep, and moderately well-drained with slow permeability. Subsoil and substrata textures are commonly silty clay loam and silty clay. Salinity ranges from 4 to 8 dS/m in the upper portion and 4 to 30 dS/m in the lower portion. Surface runoff is generally slow, with a low hazard of water erosion.

Nahrub silt loam occurs on basin rims and consists of mixed alluvium from granitic rocks. Nahrub soils cover about 30 percent of the total surface area in the southeast part of the site. These soils are very deep, somewhat poorly drained, with very slow permeability. Salinity ranges from 1-16 dS/m in the upper part to 8-30 dS/m in the lower part. Surface runoff is very slow with low surface erosion hazard.

Westcamp silt loam soils cover the northwest corner of the study area. The Westcamp soils are saline, alkaline soils that have a perched water table. These soils are very deep, somewhat poorly drained, with very slow permeability. A transient perched water table occurs at a depth of 1.2-1.8 m (4-6 foot). Salinity ranges from about 2-16 dS/m.

Excelsior fine sandy loam soils are found on the sand ridge that traverses the site from northeast to southwest. The sand ridge covers about 15 percent of the total study area. The Excelsior soils are very deep, somewhat excessively drained, alkaline soils. Permeability of the sand ridge soil is moderately rapid, runoff is very slow and hazard of water erosion is slight; however, the potential for wind erosion is high under sparsely vegetated conditions. Salinity ranges from 0-8 dS/m in the upper part and 2-16 dS/m in the lower part.

The Lethent fine sandy loam occurs in a small area in the southwest part of the study area. This soil is saline, alkaline, very deep, and moderately well drained. Permeability is very slow and the hazard of water erosion is slight.

2.3.2.1. Soil Monitoring

Soil Sampling Baseline soil sampling was conducted at the Atwell Island site during spring 2002. Sixteen sites were sampled within each experimental study area. Each site was located at the approximate center of the 0.8 ha (2-acre) research plots (Figure 2-36). Three soil samples were collected from each site. A 0-30 cm (0-12 inch), four increment composite soil sample was collected within 3 m (10 feet) of the central boring. A single soil sample was collected from the 30-76 cm (12-30-inch) depth interval. This sample represents the active root zone of irrigated soils. A single soil sample was also collected from the 76-152 cm (30-60-inch) substrata zone. This zone represents the lower root zone just above the vadose zone. All soil material was sampled in the 30-76 cm and 76-152 cm (12-30 and 30-60-inch) samples. Sampling in this manner resulted in 48 soil samples collected on each 65 ha (160-acre) study area (Figure 2-36). Two field replicate (QC) samples were collected from each quarter section. Field replicate

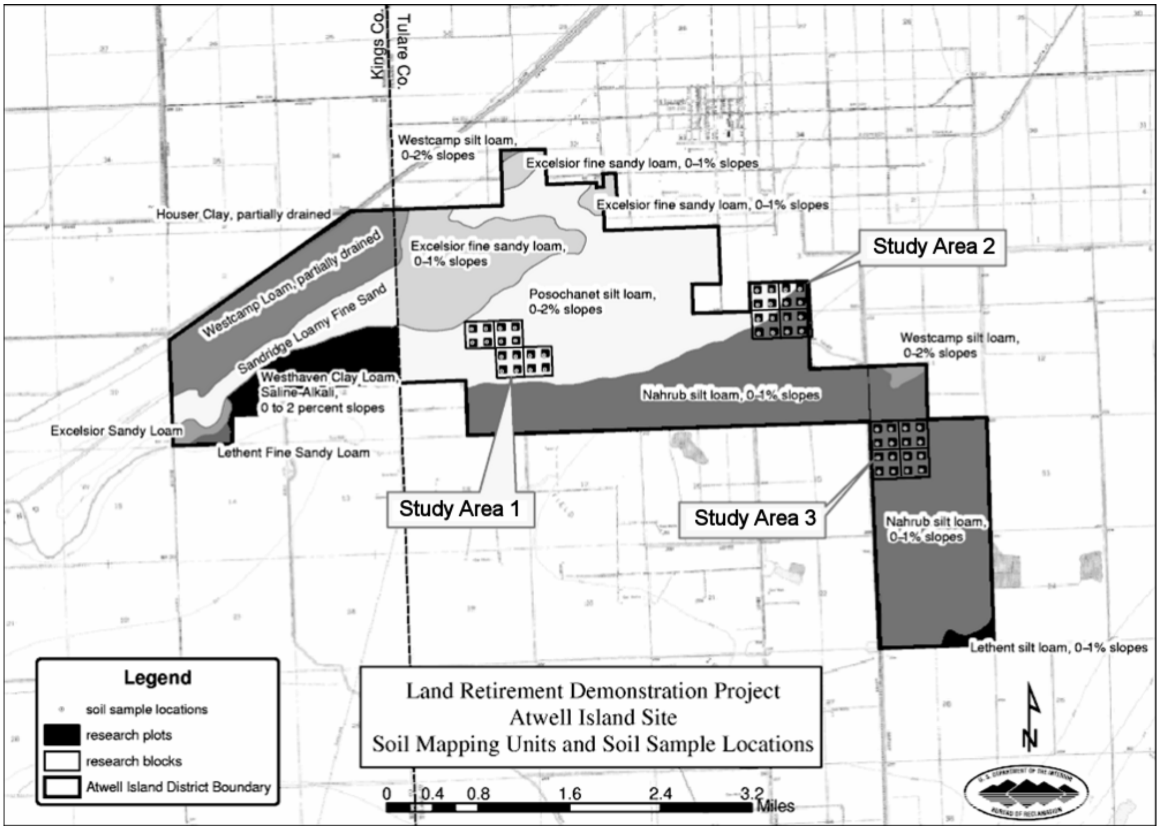

Figure 2-36. U.S. Department of Agriculture soil mapping units and soil sample locations at the Atwell Island site.

samples were obtained using the fractional shoveling method (Gerlach 2002). All sample sites were located and mapped using a global positioning system receiver.

Soil samples were analyzed for total and water-soluble selenium, sulfate, chloride, electrical conductivity, and moisture. All surface soil samples were analyzed for boron, magnesium, potassium, sodium, carbonate, and nitrate. The Quality Assurance Project Plan (QAPP) for the Land Retirement Demonstration Project described in detail the analytical procedures and quality assurance measures taken to ensure soil data quality (CH2M Hill 1999). The soils analyses were performed by the USGS and Reclamation analytical laboratories in Denver, Colorado.

The baseline soil-sampling event was completed during March of 2002. Surface 0-30 cm (0-12 inch) four increment soil samples where collected within 3 m (10 feet) of central deep boring sites. Deeper (30-76 cm and 76-152 cm or 12-30 inch and 30-60 inch) samples where collected from a single hand auger boring. All soil layers where included in the sampling. The soil samples have been analyzed and the data collected has been validated. A statistical summary of the baseline data are presented in the next section.

Statistical summary of the baseline data Statistical summaries of data collected during the 2002 baseline soil sampling event are presented in Table 2-14 through Table 2-18. All data are on a dry soil weight basis except for the soil salinity data, which are the concentration of the extract.

Table 2-14. Total selenium (mg/kg dry soil)

Study area	Depth (inches)	Median	Average	95 % CI
Study Area 1	0-12	0.100	0.097	0.076 - 0.118
	12-30	0.050	0.087	0.062 - 0.112
	30-60	0.050	0.076	0.061 - 0.091
	0-60 Weighted average	0.080	0.084	0.069 - 0.099
Study Area 2	0-12	0.115	0.144	0.092 - 0.196
	12-30	0.120	0.118	0.090 - 0.146
	30-60	0.120	0.139	0.100 - 0.178
	0-60 Weighted average	0.120	0.132	0.110 - 0.154
Study Area 3	0-12	0.100	0.104	0.083 - 0.125
	12-30	0.100	0.086	0.071 - 0.101
	30-60	0.145	0.141	0.110 - 0.172
	0-60 Weighted average	0.120	0.120	0.104 - 0.136

Total selenium A statistical summary of total selenium concentrations is presented in Table 2-15. In Study Area 1, there appears to be a slightly inverted selenium distribution, possibly from upflux and evaporative processes; however, this trend is not significant at the 95 percent confidence level. In Study Area 2, no trends with depth are apparent. In Study Area 3, the 76-152 cm (30-60 inch) substrata zone is significantly higher in total selenium than the 30-76 cm (12-30 inch) zone.

Table 2-15. Soluble selenium 1-5 extract (mg/kg dry soil)

Study area	Depth (inches)	Median	Geo Mean	Average	95% CI
Study Area 1	0-12	2.50	4.31	5.63	3.23 - 8.03
	12-30	2.50	3.46	4.5	2.23 - 6.73
	30-60	2.50	3.26	4.06	2.27 - 5.85
	0-60 Weighted average	3.35	3.92	4.53	3.22 - 5.84
Study Area 2	0-12	7.00	9.90	15.22	7.43 - 23.01
	12-30	12.00	16.48	24.22	11.89 – 36.54
	30-60	26.75	29.93	44.59	22.76 – 66.42
	0-60 Weighted average	19.55	24.52	32.63	18.44 – 46.82
Study Area 3	0-12	3.75	4.07	4.69	3.35 - 6.03
	12-30	13.75	16.64	18.03	13.97 – 22.09
	30-60	33.50	31.74	34.59	27.84 – 41.34
	0-60 Weighted average	21.10	22.18	23.67	19.45 – 27.89

Soluble selenium 1-5 extract A statistical summary of soluble selenium concentrations is presented in Table 2-15. The data are for 1 part soil to 5 parts DI water extracts. The concentrations found in the extracts were multiplied by a factor of 5 to determine the micrograms per kilogram (μg/kg) dry weight concentration in the soil.

In Study Area 1, no significant differences in soluble selenium occurred with depth. Study Area 2 showed no significant differences in soluble selenium concentrations due to the high selenium concentration variability. There appeared to be an increasing selenium concentration with depth in Study Area 2. However, the trend is not significant at the 95 percent confidence level. In Study Area 3, there was a significant increase in soluble selenium concentration with depth at this site (Table 2-15).

Soluble selenium commonly exhibits high, random spatial variability. The soils of the Atwell Island site were no exception, as coefficients of variation values were quite high (Table 2-15). The three study areas all had low total selenium values, yet it appears that a significant portion of the selenium at many of the sampled sites is in soluble form (Table 2-16). The alkaline soil reaction at the sites and the oxidized nature of the soils tend to favor the selenate selenium species, which is very soluble.

Table 2-16. A comparison of total selenium concentrations with soluble selenium concentrations

Study area	Weighted average of total selenium (mg/kg)	Weighted average of soluble selenium (mg/kg)	Percent soluble
1	0.084	0.0045	5.4
2	0.132	0.0326	24.7
3	0.120	0.0237	19.8

Study Area 1 was much lower in soluble selenium than the other two study areas. The distribution in the profile also was more uniform, probably indicative of upflux from shallow groundwater and the medium textured soils in Study Area 1 that are more conducive to capillary rise of water from the water table. Concentrations in surface soils were not elevated enough to warrant concern about terrestrial wildlife poisoning or accumulation in plants. The low total selenium concentrations at the site might cause selenium deficiencies for some organisms. However, a relatively large portion of the selenium probably is present in soluble and biologically available forms due to the oxidized, alkaline conditions prevailing in Atwell Island site soils.

The data summarized in Table 2-15 contains many values below the reporting limit. In all cases, the value used for statistical purposes was one-half of the lower reporting limit value.

Soil salinity A statistical summary of soil salinity concentrations is presented in Table 2-17. Although the variation in soil salinity with depth is not significant at the 95 percent confidence level in Study Area 1, the data indicate an inverted salinity profile. Study Area 1 contains medium textured soils that can conduct large amount of groundwater and salt into the root zone. Because of this soil texture, it will be important to lower the water table to at least 3.7 m (12 feet) on this study area in order to avoid salt accumulation in the active root zone. Winter rains should gradually leach out excess salts in the 0-76 cm (0-30-inch) active root zone if the water table is lowered to 3.7 m (12 feet) or greater.

Table 2-17. Soil salinity (EC_e dS/m) at the Atwell Island site

Study area	Depth (inches)	Median	Average	95% CI
Study Area 1	0-12	8.71	9.25	7.75 - 10.75
	12-30	7.53	7.59	6.42 - 8.75
	30-60	5.56	5.66	4.75 - 6.55
	0-60 Weighted average	6.85	6.92	5.95 - 7.89
Study Area 2	0-12	2.50	3.85	1.54 -6.16
	12-30	4.95	7.34	4.71 - 9.97
	30-60	12.13	12.61	9.98 - 15.24
	0-60 Weighted average	8.24	9.28	7.18 - 11.38
Study Area 3	0-12	4.85	4.29	3.46 - 5.12
	12-30	8.80	9.21	8.19 - 10.24
	30-60	13.66	13.52	11.62 - 15.44
	0-60 Weighted average	10.30	10.39	9.16 - 11.61

The 76-152 cm (30-60 inch) substrata zone in Study Area 2 was significantly higher in salinity than the 0-30 cm and 30-76 cm (0-12 and 12-30 inch) zone. The soil profile exhibited what is termed a regular soil salinity pattern with salinity increasing with depth. Variability was very high in this study area; it appears we should evaluate dividing the study area into two areas for the purpose of trend analysis.

The profile for Study Area 3 shows a favorable regular salinity distribution. The salinity increase with depth is significant at the 95 percent level. The clay soils at this site tend to discourage upflux from the groundwater table. As long as the water table remains below 2.7 m (9 feet), this site should be slowly leached of salts in the 0-76 cm (0-30 inch) active root zone. Variation of soil salinity was low on this study area.

The weighted average soil salinity is higher in Study Area 3 than in Study Area 1 but this is somewhat misleading. Surface soil salinity is significantly higher on

Study Area 1 than on the other two study areas. The elevated surface soil salinity could inhibit germination and emergence of seeds of salt sensitive plants; however, most weedy plants can germinate and emerge from moderately saline surface soils.

Soluble boron A statistical summary of the data is presented Table 2-18. The data are from 1 part soil to 5 parts DI water extracts prepared on a weight basis. The data were converted to mg/kg dry soil by multiplying the 1/5 extract concentration by a factor of 5.

Table 2-18. Soluble boron 1-5 extract (mg/kg dry soil) at the Atwell Island site.

Study area	Depth (inches)	Median	Average	95% CI
Study Area 1	0-12	4.05	4.10	3.72 - 4.48
	12-30	2.98	2.99	2.67 - 3.30
	30-60	8.50	8.45	7.1 - 9.8
	Weighted average	5.75	5.93	5.23 - 6.64
Study Area 2	0-12	1.95	2.32	1.81 - 2.83
	12-30	13.00	14.13	10.80 - 17.4
	30-60	22.75	22.5	21.05 - 23.95
	Weighted average	15.55	15.94	14.47 - 17.41
Study Area 3	0-12	3.10	2.99	2.47 - 3.51
	12-30	13.75	14.91	12.56 - 17.24
	30-60	22.00	20.56	18.32 - 22.80
	Weighted average	16.35	15.34	13.68 - 17.00

The concentrations at all depths in Study Area 1 were significantly different from one another. In Study Areas 2 and 3, boron concentrations increased sharply with depth with each depth increment significantly higher than the shallower sample zone. The surface 0-30 cm (0-12 inch) concentration is suited for all plants but deeper concentrations could be phytotoxic to most plants (Table 2-18).

Spatial trends between study areas Study Area 2 had the highest weighted-average total selenium values, while Study Area 3 is intermediate, and Study Area 1 has the lowest values (Table 2-14). At the 95 percent confidence level Study Areas 2 and 3 are significantly higher than Study Area 1 but are not significantly different from one another.

The 76-152 cm (30-60 inch) substrata zone in Study Areas 2 and 3 are significantly higher than the substrata zone in Study Area 1 (95 percent confidence level).

Soil selenium values are low at the Atwell Island site. USGS reports that the average total selenium value of a large random sample of western states soils is about 0.34 mg/kg. The geometric mean (median) value from the western states suite of soils was 0.23 mg/kg.

The selenium values at all three Atwell Island study areas are below toxic levels and may be deficient for some organisms. Soluble selenium data from the site will be examined to gain a better understanding of the selenium readily available for plant uptake and animal nutrition.

Boron concentrations in Study Area 1 were much lower than in the other two study areas. Study Area 2 and Study Area 3 had similar elevated concentrations of soluble boron in substrata. Only boron-tolerant plants are recommended for Study Areas 2 and 3. Shallow rooted annual grasses may also tolerate the high boron concentrations at these sites. Plants moderately tolerant to boron should be successful at Study Area 1.

Soil interpretive summary The Atwell Island site was relatively low in both soluble and total selenium. Boron concentrations were moderate in surface soils and are elevated in subsoils. Both boron and soil salinity are plant-growth-limiting factors at the Atwell Island sites. Study Area 1 appeared to be using moisture from the water table. While this has benefitted plant growth in the short term, it may indicate soil salinity problems in the future. The medium-textured soils at the Study Area 1 site exhibited capillary fringe zones approaching 1.5 m (5 feet) thick. A declining shallow water table in response to land retirement will lessen the likelihood of salinization of surface soils.

2.3.3. Weather

Precipitation, temperature, and wind data are collected at the National Weather Service weather station #42, which is located approximately 32 km (20 miles) southeast of the Atwell Island site in Wasco. The data from the Wasco station are available on the Western Region Climate Information website at http://www.wrcc.dri.edu. Precipitation has been below average during the first 3 years of hydrologic monitoring at the Atwell Island site. The average annual rainfall for the 51-year period of record at Wasco is approximately 17.5 cm (6.9 inches). Rainfall totals measured at the Wasco station for 2002, 2003, and 2004 were 10.8, 13.5, and 11.4 cm (4.27, 5.33 and 4.50 inches), respectively. Most of the rainfall has occurred from November through April.

2.3.4. Irrigation

The largest volume of irrigation water applied at the site during the baseline year of monitoring (2002) was from ongoing farming operations. Farming operations continued on approximately 951 ha (2,350 acres) of the Atwell Island site. Irrigation applications on these lands are currently scheduled based on a calendar or rotational approach. Metered pumping volumes for applied irrigation water are not available. Typical irrigation applications consist of gravity flow (flood irrigation) of about 15.2 cm (6 inches) per acre. An estimate of applied water and deep percolation (groundwater recharge) for irrigated lands within the demonstration project boundary at the Atwell Island site during 2002 is shown in Table 2-19. Estimated deep percolation losses in 2002 are about 15 percent less than those in 2001. Irrigation of high water use crops such as alfalfa will be phased out as restoration of the site to native upland progresses. Fifty seven hectares (140 acres) of barley were planted on the habitat restoration study blocks to provide weed and dust control and to isolate the individual study plots. The barley crop was not irrigated in 2002.

Table 2-19. Estimated 2002 net crop water requirement and deep percolation losses at the Atwell Island site.

Crop	Acreage	Total crop water requirement[1] CWR (acre-feet)	Irrigation water application requirement[2] IWAR (acre-feet)	Estimated deep percolation[3] DP (acre-feet)
Alfalfa	1,179	4,710	7,246	2,536
Oats	1,137	932	1,433	502
Safflower	37	96	148	52
Total	2,353	5,738	8,827	3,090

[1] CWR = Crop ET - Effective Precip. + Leaching Requirement (after Smith 2001)
[2] Assumes an Irrigation Efficiency of 65 percent
[3] IWAR - CWR = DP

2.3.5. Hydrology and Surface Water Monitoring

The natural drainage in the study area is to the north-northwest with ground surface elevations ranging from about 62.5 m (205 feet) above mean sea level (msl) in the southeast portion of the site to about 65.5 m (215 feet) above msl in the northeastern portion of the site. A pronounced sand ridge traverses the northern boundary of the site in a northeasterly direction. The sand ridge was formed from windblown sand deposited along the southern shore of the Tulare Lake bed. Surface water courses within the study area consist primarily of irrigation supply canals and irrigation return flow ditches. The site has an artificially constructed 8 ha (20 acres) wetland that is filled from surface irrigation water supplies. Shallow ephemeral surface water ponds may form on low-lying portions of the site due to localized sheet flow run-off during prolonged winter storm events. The surrounding areas near the Atwell Island site receive periodic unregulated winter storm flows from Deer Creek, Poso Creek, and the White River. The central portion of the Atwell Island site is generally not subject to long term flooding, due to its higher topographic position with respect to the adjacent lower lying lands. Although no flooding has been observed on the eastern portion of the Atwell Island site during this study to date, these lands are subject to periodic flooding due to topography and proximity to Poso and Deer Creeks.

The biological opinion for the demonstration project requires water quality monitoring for ephemeral surface water pools that form as a result of rainfall. No surface-water ponding that lasted more than 30 days was observed at the site during the first 3 years of monitoring due to dry climatic conditions. However, ponded water from the artificial wetland at the site was sampled and analyzed for selenium in January, July, and October 2002. Selenium concentrations were below detection limits (<0.4 µg/L) in the January and July samples. A selenium concentration of 0.6 µg/L was observed in the October sample, which is below the 5 µg/L EPA water-quality criteria for long term exposure in aquatic environments (EPA 1988).

2.3.6. Groundwater Level Monitoring

Approximately 20 monitor wells in the project vicinity are used to measure groundwater levels beneath the site on a quarterly basis. The well locations are shown on Figure 2-37. Existing wells constructed prior to the purchase of the demonstration project lands were installed by the USGS, the California Department of Water Resources (CDWR) and Reclamation to assess groundwater conditions in the Tulare basin.

These existing wells are constructed of PVC casing ranging in diameter from 1.9 to 7.6 cm (0.75 to 3 inches) and vary in depth from 6.1 to 58 m (20 to 190 feet) below the ground surface. The wells were installed using various construction techniques that range from jetting a short length of pipe into the ground to standard rotary drilling with hydraulic drill rigs. During fall 1999, Reclamation installed 17 new monitoring wells to measure groundwater levels and obtain representative groundwater samples for water quality analyses for the Land Retirement Demonstration Project. The new wells range in depth from 4.6 to 18.3 m (15 to 60 feet) below land surface and were installed using a hollow stem auger drill rig and are constructed of 5 cm (2-inch) PVC casing. Well construction diagrams for the new wells are on file in Reclamation offices in Fresno and Sacramento. Well construction information for the USGS wells are published by Beard et al. (1994), Fujii and Swain (1995) and Swain and Duell (1993).

2.3.7. Groundwater Quality Monitoring

The purposes of groundwater-quality monitoring at the site are to observe selenium concentrations over time and to evaluate selenium exposure risk to wildlife via the groundwater pathway. Baseline groundwater samples were taken on a quarterly basis during 2002 at the Atwell Island site. The baseline groundwater quality samples were taken in January, May, July, and October 2002. Annual groundwater sampling began at Atwell Island in May 2003, and will continue for 5 years. Sampling was conducted in spring to coincide with the seasonal high water table in the region. Annual and baseline groundwater quality data will be compared to evaluate changes in groundwater quality. Unfiltered groundwater samples were taken from 16 wells to assess baseline groundwater quality at the site. Standard operating procedures for groundwater sampling used by the Mid-Pacific Region of Reclamation and those outlined in the Quality Assurance Project Plan for the Land Retirement Demonstration Project (CH2M Hill 1999) were employed to obtain groundwater samples.

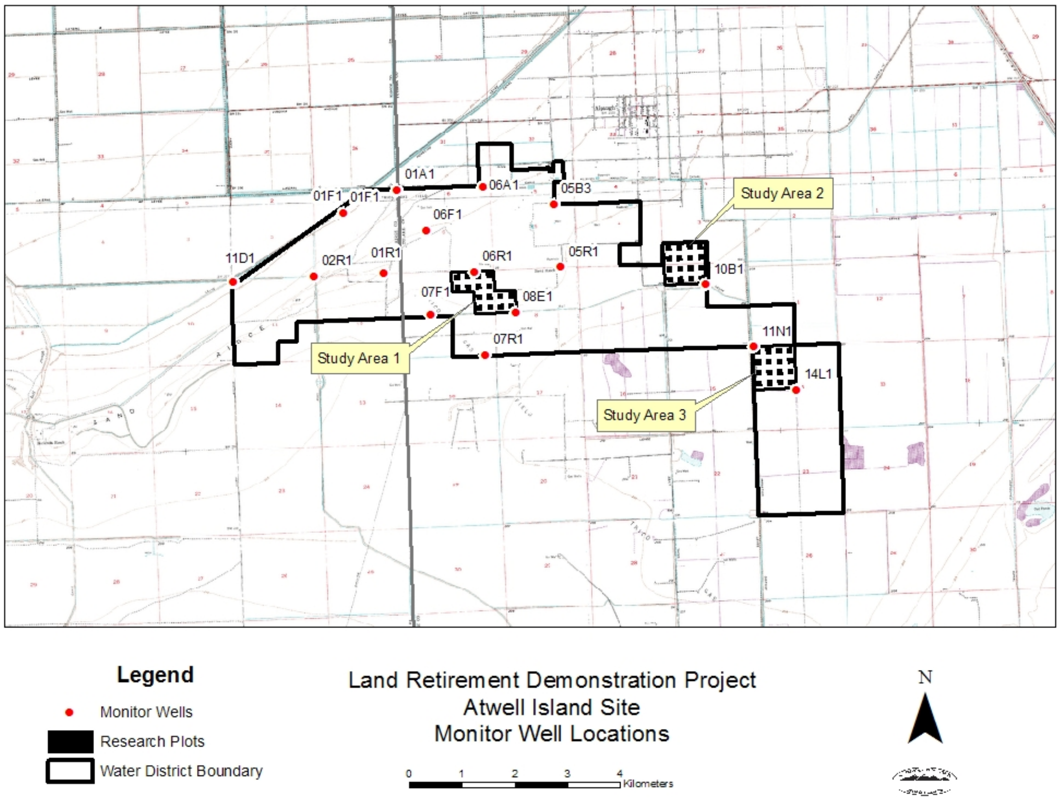

Figure 2-37. Monitor well locations at the Atwell Island site.

Unfiltered groundwater samples were analyzed for major ions (calcium, magnesium, potassium, sodium, chloride, sulfate, total alkalinity), trace elements (selenium, boron, iron, manganese) and isotopes (H^{-2}, O^{-18} and H^{-3}). Specific conductance (electrical conductivity [EC]), pH, and temperature of groundwater samples were measured in the field at the time of sampling. Fluorometric analyses of groundwater samples for selenium were performed by Olsen Biochemistry Laboratories, South Dakota State University. Analyses for isotopes (H^{-2}, O^{-18}) were performed by the USGS Water Resources Division laboratory in Reston, Virginia. Analyses for tritium (H^{-3}) were performed by the USGS Water Resources Division laboratory in Menlo Park, California. All other analyses were performed by commercial laboratories under contract to Reclamation. The Quality Assurance Project Plan for the Land Retirement Demonstration Project describes in detail the analytical procedures and quality assurance measures taken to ensure groundwater data quality (CH2M Hill 1999).

2.3.7.1. Groundwater Response to Land Retirement

Calendar year 2002 was the baseline year for monitoring groundwater levels and groundwater quality at the Atwell Island site. Groundwater levels measured in 20 wells confirm the presence of shallow, perched water table conditions at the Atwell Island site. Groundwater levels observed during the baseline year of monitoring (2002) in the shallow groundwater system range from 4.3 to 14.8 feet below land surface. In general, the water table is highest (nearest the land surface) in the northwest corner of the site and becomes deeper in the southeast portion of the site. These observations are consistent with those of Beard et al. (1994) and Reclamation (1982).

A declining shallow water table in response to land retirement has been observed on parts of the site where irrigation has ceased or been greatly reduced (Figure 2-38). Pre-project water level data reported by the USGS (Beard et al. 1994) show seasonal high groundwater levels around 5 feet below land surface. Post-project, seasonal high water levels measured in well 5B3 during 2002 have dropped to a depth ranging from approximately 7 to 8 feet below land surface (a decline of 2-3 feet). Groundwater level monitoring will continue at the site to evaluate shallow water table response to land retirement.

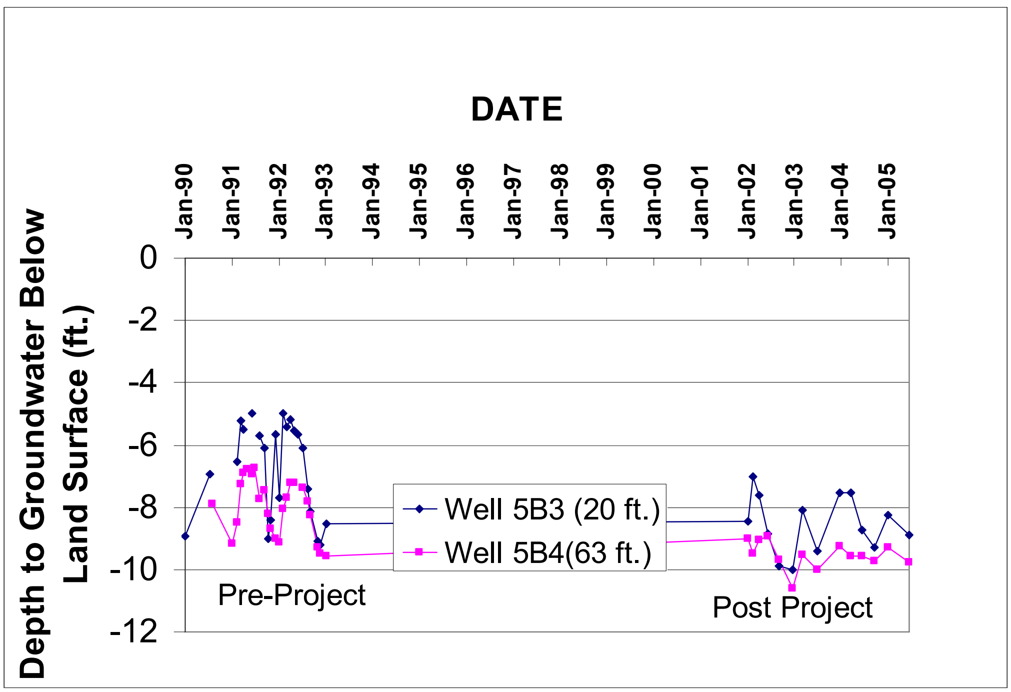

Figure 2-38. Hydrographs of groundwater levels observed in Wells 5B3 and 5B4 showing pre-project and post-project groundwater levels.

2.3.7.2. Groundwater Salinity

Baseline electrical conductivity data for the groundwater samples collected during the first year of monitoring are presented in Table 2-20. The shallow groundwater is moderately saline in nature. Salinity in the shallow groundwater samples, expressed as EC, ranged from 575 to 52,925 µS/cm, with a median value of 13,740 µS/cm. By comparison, drinking water typically is less than 750 µS/cm, irrigation water is less than 1,250 µS/cm, and seawater is about 50,000 µS/cm.

The elevated salinity of the shallow groundwater at the site is a result of the irrigation of saline soils. Naturally occurring salts have been leached from the soil profile under irrigated conditions. Salts also have been transported to the site in the applied irrigation water. Direct evaporation from the shallow water table and transpiration of applied water by crops has concentrated salts in the shallow groundwater, resulting in the high EC values observed in the shallow groundwater samples.

2.3.7.3. Groundwater Major Ion Chemistry

Baseline major ion chemistry data for the groundwater samples collected during 2002 at the Atwell Island site are presented in Table 2-20. The shallow groundwater at the site is best described as a sodium sulfate type of water. Sodium is the dominant major cation found in the shallow groundwater samples, with sodium concentrations ranging from 469 to 15,100 mg/L, and a median concentration of 4,500 mg/L. Sulfate is the dominant major anion found in the shallow groundwater with sulfate concentrations ranging from 261 to 22,200 mg/L, and a median concentration of 5,700 mg/L. By comparison, Fujii and Swain (1995) reported median shallow groundwater concentrations of 8,400 and 13,000 mg/L for sodium and sulfate, respectively, in nine samples taken from the southwestern margin of the Tulare Lake bed.

Table 2-20. Baseline groundwater quality data for shallow wells at the Atwell Island site - major ions, field parameters, and selenium. Note: selenium concentrations are expressed in micrograms/liter (µg/L). 72 samples were used to calculate the selenium statistics.

Statistic	Minimum	25th percentile	Median	75th percentile	Maximum	Mean
Number of Samples	64	64	64	64	64	64
EC(field) (µS/cm)	575	4,615	13,740	26,095	52,925	18,059
pH (field)	6.24	7.21	7.49	7.93	9.12	7.60
Calcium (mg/L)	3	40	320	438	850	282
Magnesium (mg/L)	1	21	148	590	1800	390
Sodium (mg/L)	469	1,290	4,500	11,350	15,100	6,180
Potassium (mg/L)	1	4	9	30	152	23
Total Alkalinity (mg/L)	366	429	580	881	2,050	736
Chloride (mg/L)	216	549	3,400	7,385	12,800	4,312
Sulfate (mg/L)	261	1,225	5,700	17,325	22,200	8,382
Selenium (mg/L)	<0.4	0.54	8.56	68.25	208	34.2

2.3.7.4. Selenium in Groundwater

Selenium concentrations measured in the shallow groundwater wells at the site during the baseline year of monitoring range from less than the detection limit of 0.4 to 208 micrograms per liter (µg/L), with a median concentration of 8.56 µg/L (Table 2-20). The EPA water-quality criteria for long-term exposure to selenium in aquatic environments are 5 µg/L (EPA 1988). Approximately 50 percent of the groundwater samples (35 of 72 samples) collected during the baseline year of sampling were less than the EPA aquatic life criteria. Selenium concentrations in the shallow groundwater show considerable spatial variation throughout the site. In general, the highest selenium concentrations in groundwater range from approximately 60 to more than 200 µg/L, and are found in the central portion of the site in sections 5, 6, 7, and 8 (Figure 2-37). These high selenium areas are associated with the Excelsior and Posochanet soil series (Figure 2-36). The Posochanet soils found within Study Area 1 also contained the highest selenium concentrations observed in the baseline soil investigation. The groundwater underlying the eastern and western portions of the site contain much lower levels of selenium (<0.4 to 17 µg/L). Fujii and Swain (1995) noted that the distribution of selenium in shallow groundwater in the Tulare basin is strongly influenced by sources of selenium, selenium concentrations in soil, evaporation of shallow groundwater, and redox conditions.

2.3.8. Conclusions

The soils at the Atwell Island site have relatively low concentrations of both soluble and total selenium. Boron concentrations were moderate in surface soils and are elevated in subsoils. Both boron and soil salinity are plant growth limiting factors at the Atwell Island sites. Study Area 1 appeared to be using moisture from the water table. While this has benefitted plant growth in the short term, it may indicate soil salinity problems in the future. The medium textured soils at the Study Area 1 site exhibited capillary fringe zones approaching 1.5 m (5 feet) thick. A declining shallow water table in response to land retirement will lessen the likelihood of salinization of surface soils.

No surface-water ponding that lasted more than 30 days was observed at the site during the first 3 years of monitoring due to dry climatic conditions. However, ponded water from the artificial wetland at the site was sampled and analyzed for selenium in January, July, and October 2002. Selenium concentrations were below detection limits (<0.4 µg/L) in the January and July samples. A selenium concentration of 0.6 µg/L was observed in the October sample, which is below the 5 µg/L EPA water-quality criterion for long term exposure in aquatic environments (EPA 1988).

A declining shallow water table in response to land retirement has been observed on parts of the Atwell Island site where irrigation has ceased or been greatly reduced. The seasonal pattern shown by some of the monitor well hydrographs is a result of periodic recharge to the shallow groundwater from irrigation that continues in the central portion of the project site. Sodium and sulfate are the dominant ions found in the shallow groundwater at the site. The elevated salinity and moderately high concentrations of selenium in the shallow groundwater are a result of leaching during irrigation and evaporation from the shallow water table. Selenium concentrations in groundwater at Atwell Island show considerable spatial variability, with the highest concentrations associated with Excelsior and Posochanet soils in the central part of the site. Groundwater, surface water and soils will continued to be monitored for five years as required in the FWS Biological Opinion for the Land Retirement Demonstration Project.

2.4. Literature Cited

Balistrieri, L.S. and T.T. Chao. 1987. Selenium adsorption by goethite. Soil Science Society of America 51: 1145-51.

Belitz, K. and F.J. Heimes. 1990. Character and evolution of the ground-water flow system in the central part of the western San Joaquin Valley, California. U.S. Geological Survey water supply paper 2348. U.S. Geological Survey, Denver, Colorado. 28 pp.

Belitz, K. and Phillips, S. 1992. Simulation of Water-Table Response to Management Alternatives, Central Part of the Western San Joaquin Valley, California. U.S. Geological Survey Water-Resources Investigation Report 91-4193. U.S. Geological Survey, Sacramento, California. 41 pp.

Benson, S.M., Delamore, M., and Hoffman, S., 1993. Kesterson Crisis. Journal of Irrigation and Drainage Engineering, Vol. 119, No. 3, May/June, 1993.

Bull, W.B. 1964a. Geomorphology of segmented alluvial fans in western Fresno County, California. U.S. Geological Survey professional paper 352-E. U.S. Geological Survey, Denver, Colorado. pp 89-129.

Bull, W.B. 1964b. Alluvial fans and near-surface subsidence in western Fresno County, California. U.S. Geological Survey professional paper 437-A. U.S. Geological Survey, Denver, Colorado. 71 pp.

California Department of Water Resources. 1999. CIMIS weather station information, explanation of Eto: http://wwwcimis.water.ca.gov/cimis/infoEtoOverview.jsp.

CH2M Hill. 1988. San Joaquin Valley hydrologic and salt load budgets. A report prepared for the San Joaquin Valley Drainage Program, Sacramento, California.

CH2M Hill. 1999. Quality assurance project plan, Land Retirement Demonstration Project, soil, groundwater, and surface water monitoring. 41 pp.

Davis, G.H. and J.F. Poland. 1957. Ground water conditions in the Mendota-Huron area, Fresno and Kings counties, California. U.S. Geological Survey water supply paper 1360-G. U.S. Geological Survey, Denver, Colorado. pp 409-588.

Davis, G.H. 1961. Geologic control of mineral composition of stream waters of the eastern slope of the southern Coast Ranges, California: Geochemistry of water. U.S. Geological Survey water supply paper 1535-B. U.S. Geological Survey, Denver, Colorado. pp 1-30.

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(4): 516-524.

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(6): 697-702.

Deverel, S.J. and S.K. Gallanthine. 1989. Relation of salinity and selenium in shallow groundwater to hydrologic and geochemical processes, western San Joaquin Valley, California. Journal of Hydrology 109: 125-49.

Dubrovsky, N.M., S.J. Deverel, and R.J Gilliom. 1993. Multiscale approach to ground water quality assessment: selenium in the San Joaquin Valley, California. Pages 537-560 in Alley, W.M. ed. Regional groundwater quality. VanNostrand Reinhold, New York.

Elrashadi, A.M., D.C. Adriano, S.M. Workman and W.L. Lindsay. 1987. Chemical equilibria of selenium in soils: a theoretical development. Soil Science 144 (2): 141-52.

Fio, J. 1999. Model Postaudit and Projected Water-Table Response to Land Retirement Strategies in the San Luis Unit, Western San Joaquin Valley, California. Report to the Interagency Land Retirement Team. Fresno, California. 37 pp.

Frost, R.R, and R.A Griffin. 1977. Effect of pH on adsorption of arsenic and selenium from landfill leachate by clay minerals. Soil Science Society of America 41: 53-57.

Fujii, R. and W.C. Swain. 1995. Area distribution of selected trace elements, salinity, and major ions in shallow groundwater, Tulare Basin, southern San Joaquin Valley, California. U.S. Geological Survey water resources investigation report 95: 40-48.

Gerlach, R.W., D.E. Dobb, J.M. Nocerino, and G.A. Raab. 2002. Gy Sampling Theory in Environmental Studies 1: Assessing Soil Splitting protocols. Journal of Chemometrics, 16:321-328.

Goldberg, S. and R.A. Glanbig. 1988. Anion sorption on a calcareous montmorillonitics soil - selenium. Soil Science Society of America 52 (4): 954-58.

Hingston, F.J., Posner, A.M., Quirk, J.P. 1974. Anion adsorption by goethite and gibbsite. Journal of Soil Science, 25, 16-26.

Keren, R., and F.T. Bingham. 1985. Boron in water, soils and plants. Pages 229-276 in Stewart. B.A. ed. Advances in soil science, Volume 1. Springer-Verlag, New York.

Leckie, J.O., M.M. Benjamin, K. Hayes, G. Kanjman, and S. Altman. 1980. Co-precipitation of trace elements from water with iron oxyhydroxide. Electric Power Research Institute report CS-1513. Electric Power Research Institute, Palo Alto, California. pp 4-4 - 4-18.

Lawrence Berkeley Laboratory. 1987. Hydrological, geochemical, and ecological characterization of Kesterson Reservoir. Annual report, October 1986 - September, 1987. University of California Berkeley, Earth Sciences Division, Lawrence Berkeley Laboratory.

Miller, R.E., J.H. Green, and G.H Davis. 1971. Geology of the compacting deposits in the Los Banos-Kettleman City subsidence area, California. U.S. Geological Survey professional paper 497-E. U.S. Geological Survey, Denver, Colorado. 46 pp.

Neal, R.H., G. Sposito, K.M. Holtzclaw and S.J. Traina. 1987. Selenite adsorption on alluvial soils I: soil composition and pH effect. Soil Science Society of America 51: 1161-1165.

Perry, D.M., I.S. Suffet, M. Wilhelm, J.A. Noblet, and A. Maliglig. 1994. Boron environmental chemistry, distribution, bioaccumulation, and toxicity in aquatic ecosystems and recommendations for establishment of a boron water quality criterion for natural waters in the San Joaquin Valley, California. Final report for Contract No.1-192-150-0. Submitted to the California Regional Water Quality Control Board, Central Valley Region and the California Environmental Protection Agency. 270 pp.

Prokopovich, N.P. 1987. Textural composition of near-surface alluvium in west-central San Joaquin California. Bulletin of the Association of Engineering Geologists 24 (1): 59-81.

Pruitt, W.O., and Doorenbos, J. 1977. Empirical calibration, a requisite for evapotranspiration formulae based on daily or longer mean climatic data. Presented at the ICID conference on Evapotranspiration, Budapest, Hungary, May 26-28, 1977. 20 pp.

San Joaquin Valley Drainage Program (SJVDP). 1990a. A management plan for agricultural subsurface drainage and related problems on the westside San Joaquin Valley. Final report of the San Joaquin Valley Drainage Program, U.S. Department of the Interior and the California Resources Agency. Sacramento, California. 183 pp.

Shacklette, H. T., and Boerngen, J. G. 1984. Element Concentrations in Soils and other Surficial Materials of the Conterminous U.S. U.S. Geological Survey Professional Paper 1270. 104 pp.

Smith, R.B. 2001. Evaluation of irrigation system alternatives: Atwell Island Water District area. Final report to the U.S. Bureau of Reclamation Land Retirement Program. pp. 1-27.

SPSS. 2000. SYSTAT 10. User's Manual. SPSS, Inc. Chicago, Illinois. 7 Vols. Swain, D.G. 1990.

Tidball, R.R., Grundy, W.D., and Swatzky, D.L., 1986. Kriging Techniques applied to Element Distribution in Soils of the San Joaquin Valley, California: HAZTECH International Conference, Denver, Colorado, August 11-15, 1986, proceedings, pp. 992-1009.

U.S. Bureau of Reclamation. 1986. Final EIS, Contingency Program for Westlands Water District Drainage Disposal Project. 175 pp.

U.S. Department of Agriculture, Natural Resources Conservation Service. 1996. Unpublished soil survey data for western Fresno County, California. 294 pp.

U.S. Department of Agriculture, Natural Resources Conservation Service. 1992. Unpublished soil sample data for western Fresno County, Tranquillity area, California.

U.S. Environmental Protection Agency. 1986. Quality criteria for water. U.S. Environmental Protection Agency report 440/5-86-001. 453 pp.

U.S. Environmental Protection Agency. 1988. Water quality criteria documents. Federal Register 53 (2): 177-179.

Weres, O., A.R. Jaoni, and L. Tsao. 1989. The distribution, speciation, and geochemical cycling of selenium in a sedimentary environment, Kesterson Reservoir, California, U.S.A. Applied Geochemistry 4: 543-563.

White, A.F., S.M. Benson, A.W. Yee, H.A. Wollenberg, Jr., and S. Flexser. 1988. Groundwater contamination at the Kesterson Reservoir, California: geochemical parameters influencing selenium mobility. Water Resources Research 27(6): 1085-1098.