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Land Disposal of San Luis Drain Sediments, Panoche Water District, South Dos Palos, California

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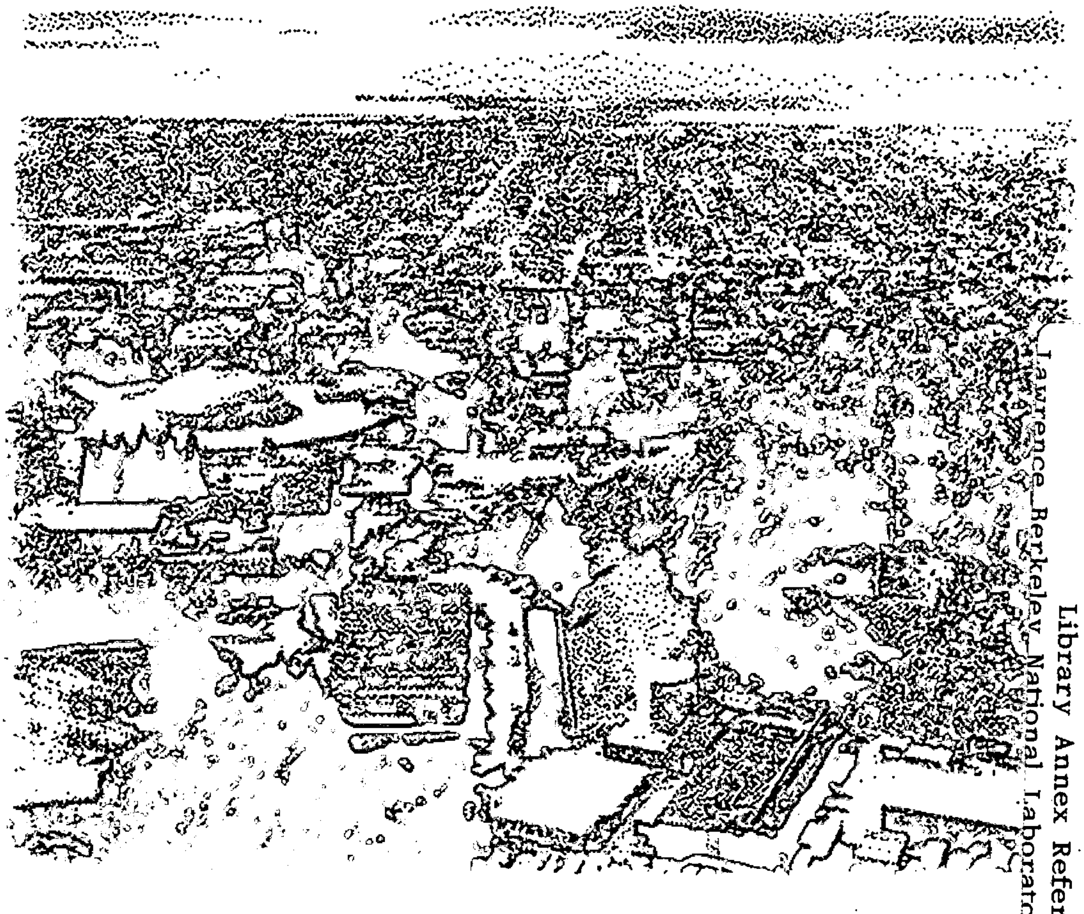
Earth Sciences Division

July 2002



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Land Disposal of San Luis Drain Sediments, Panoche Water District, South Dos Palos, California

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EXECUTIVE SUMMARY

Lawrence Berkeley National Laboratory (LBNL), LFR Levine-Fricke (LFR), the U.S. Bureau of Reclamation (USBR), and the Panoche Water District, have completed a pilot-scale test of the viability of land application of selenium- (Se-) enriched San Luis Drain (SLD) sediments. The project was initiated in October 1998 by LBNL. LFR assumed the role of primary subcontractor on the project in July 2001. Substantial portions of this report, describing work performed prior to November 2000, were previously prepared by LBNL personnel (Zawislanski et al. 2001). The data set, findings, and recommendations are herein updated with information collected since November 2000.

Agricultural drain water from surrounding areas in the Grasslands Drainage Area channeled via the SLD toward the San Francisco Bay Delta. The drain water carries with it and subsequently deposits Se-rich sediments washed out from drained fields. These sediments are further Se-enriched through biogeochemical processes. The need to periodically dredge and remove the sediments has prompted research into alternative means of disposal. In particular, local disposal through land application is an attractive option due to the low cost and the immediate proximity of available land. Field experiments were designed and carried out to measure the geochemical stability of Se in the applied sediments, rates of Se oxidation and solubilization, transfer from the surface to underlying soils, and uptake by plants. This report describes the process of site selection; site instrumentation, soil, sediment, water, and plant sampling; sample analysis; data analysis; and recommendations.

As part of the site selection process, detailed mapping of Se in SLD sediments was performed (Section 2). Both total Se concentrations and sediment thickness are greatest immediately downstream from check structures in the SLD. Consequently, most of the Se in the SLD is deposited within 60 meters (m; 200 feet [ft]) downstream from these structures. Selenium concentrations in the regions further away from the check structures are typically in the range of 1 to 10 milligrams per kilogram (mg/kg; dry weight). Concentrations generally increase downgradient, from the range of 1 to 2 mg/kg in the Grasslands Bypass Channel Inlet (near Check 18) to 4 to 10 mg/kg near Check 10. Selenium concentrations near the check structures range from 10 to 186 mg/kg. There is a general tendency for Se concentrations to increase with depth in the drain sediments. To ensure compliance with environmental regulations, land application permitting issues were reviewed and summarized. The Total Threshold Limit Concentration (TTLC; California EPA) for Se is 100 mg Se per kg wet soil, while the Soluble Threshold Limit Concentration (STLC; California EPA) is 1 mg Se per liter of extracted water. By the above thresholds, all the sediment applications in this investigation had non-hazardous Se concentrations.

Land application of SLD sediments was successfully performed at five sites at two locations near Dos Palos (Section 3). Three test plots were designed, instrumented, and monitored on an SLD embankment near the sediment source area. Two more test plots were set up on a nearby cultivated field, where the amended soil was used to grow cotton during the summer and fall 2000, wheat during the winter of 2000/2001, and cantaloupe during the summer/early fall of 2001. The field methods for dredging and spreading of the SLD sediments proved successful and efficient. Sediment dredging did not affect downstream Se concentrations in the SLD. Due to the different mode of sediment addition to the underlying soil or sediment, and differences in relative permeability at each site, findings differ between the embankment plots and the farm plots.

In the embankment plots (EPs), applied Se concentrations averaged 2.6, 37, and 19.5 mg/kg in EP-1, EP-2, and EP-3, respectively (Section 4). Soluble Se represents less than 1% of total Se. Monitoring equipment was used to measure moisture movement and Se displacement in the sediment profile. Results from monitoring soil water and groundwater, as well as from soil cores, indicate that the application did not result in the movement of dissolved Se to groundwater Se. Plants did not accumulate Se at levels of concern. Overall, Se remained physically stable and contained at the embankment site, although in situ Se oxidation was measurable. On average, soluble Se concentrations increased from less than 0.5% to about 3% in the first six months after application in test sites EP-2 and EP-3, similar to rates observed in Kesterson Reservoir soils over a 10-year period. Further oxidation may have occurred, but was not measurable. The low permeability of the underlying sediments is a likely barrier to Se movement toward the groundwater table.

In the farm plots (FPs), applied Se concentrations averaged 111.6 and 66.7 mg/kg in FP-1 and FP-2, respectively, with soluble Se making up 0.35% to 0.55% of total Se. As part of the process of field preparation for planting, the 10-centimeter- (cm-) thick sediment application was mixed with the underlying soil via disking and deep plowing, down to a depth of 75 cm. This resulted in the reduction of near-surface Se concentrations to around 10 to 15 mg/kg, but also an increase of Se concentrations down to 75 cm. Similarly, soluble Se concentrations increased in the soil profile due to physical mixing. There is some indication that rainfall and irrigation may have caused dissolved Se to move down to at least 1.50 m, and possibly even to the groundwater. However, soluble Se concentrations in soil cores from a control area are no different than those in cores from FP-1 and FP-2. Therefore, if soluble Se is moving toward the water table, the total mass is small.

Selenium uptake by cotton, wheat, and cantaloupe resulted in 5- to 20-fold increases in tissue Se relative to plants from a control area. In all plants, Se levels were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C. Despite Se uptake, the biomasses and yields of the crops were not affected. Therefore, the presence of high Se concentrations or other constituents from the dredged sediments was not an impediment to growth and overall health. Comparisons with guidelines for maximum recommended daily Se intake indicate that cantaloupe and wheat should not be grown in soils amended with very high Se sediment, in the 50 to 100 mg/kg range. Based on data interpolation, the anticipated uptake from soils amended with SLD sediments containing less than 10 mg/kg Se would likely result in uptake of Se levels well below the maximum Recommended Daily Intake (RDI).

Sequential extraction and X-ray spectroscopic results (Section 5) indicate that most of the Se in the applied sediment was strongly reduced, either as elemental Se or organically associated Se. Selenium oxidation and partial solubilization took place within the first six months after application, at a rate of about 0.5% per month. Oxidation over the subsequent 8 months was much slower, less than 1% per year.

Based on the findings of this study, land application of Se-enriched SLD sediments is a viable disposal alternative. The SLD embankment appears well suited for this purpose, due to low Se mobility, resulting from a combination of the absence of physical mixing, low soil permeability, and low Se solubility. Monitoring during high-rainfall years may be needed to supplement existing data. Land application of Se-enriched sediments to a farm field may result in excessive uptake of Se by crops. However, the sediments applied to the farm plots contained some of the highest Se concentrations measured in the SLD. These high-Se sediments make up a small fraction of the total sediment mass in the SLD. Therefore, application to farm plots is a good option for sediments containing Se in the 1 to 10 mg/kg range, which includes the majority of SLD sediments. Application of a thinner layer of high-Se sediments to farm plots is also viable. Additional studies of Se uptake by a wider range of crops may be needed to establish safe Se concentrations for farm plot application.

Periodic soil, groundwater, and crop monitoring will likely be necessary during initial stages of full-scale SLD sediment application. Eventually, this effort can be greatly reduced in scope and intensity.

1.0 INTRODUCTION

Lawrence Berkeley National Laboratory (LBNL), LFR Levine-Fricke (LFR), the U.S. Bureau of Reclamation (USBR) and the Panoche Water District, have completed a pilot-scale test of the viability of land application of selenium- (Se-) enriched San Luis Drain (SLD) sediments. The project was initiated in October 1998 by LBNL. LFR assumed the role of primary subcontractor on the project in July 2001. Substantial portions of this report, describing work performed prior to November 2000, were previously prepared by LBNL personnel. The data set, findings, and recommendations are herein updated with information collected since November 2000.

Local land disposal is an attractive option due to its low cost and the proximity of large areas of available land. Two modes of disposal are being tested: (1) the application to a nearby SLD embankment, and (2) the application to and incorporation with nearby farm soils. The study of these options considers the key problems that may potentially arise from this approach. These include disturbance of SLD sediments during dredging, resulting in increased downstream Se concentrations; movement of the land-applied Se to groundwater; reduced productivity of farm crops; and Se uptake by wild and crop plants.

This report describes field and laboratory activities carried out from 1998 through February 2002, and results of these investigations.

1.1 History of Selenium Issues

Sediments have been accumulating in the SLD since its completion in 1974. Dust, wind-blown plant debris, algae, cattails, and suspended sediments have accumulated largely up- and downstream from the check structures in the drain. Conveyance of Se-bearing drainage from the late 1970s to 1986, and more recently during the Grasslands Bypass Channel (GBC) Project, has resulted in accumulation of Se in these sediments. Consequently, an estimated 98,000 cubic yards (cy) of sediments currently reside in the SLD between Check 30 and the terminus. According to USBR surveys conducted in 1987, 1988, and 1994, these sediments contain an average of 44 parts per million (ppm; dry weight) Se. The sediments decrease the storage capacity of the drain and restrict its flow capacity, particularly during emergency operations created by storm events.

The San Luis and Delta Mendota Water Authority (SLDMWA) prepared a management plan for the SLD sediments that identified application to the SLD embankment as the most cost-effective disposal option. The plan is based, in part, on the determination that the SLD sediments are not classified as hazardous waste (wet weight concentrations do not exceed 100 ppm and the California Environmental Protection Agency [Cal-EPA] Soluble Threshold Limit Concentration [STLC)] does not exceed 1 milligram per liter [mg/l]). The sediments can exceed the STLC of 0.1 mg/l, the level for classification as a designated waste from the perspective of protecting water quality.

Review of this plan by the U. S. Environmental Protection Agency (U.S. EPA; April 1997), the USBR (April 1997), and the U.S. Geological Survey (USGS) identified several issues requiring more information before the plan could be implemented. Information needs included:

- more information to support the waste classification of the SLD sediments
- permitting requirements
- more detailed explanation of the plan for placing the sediments on the embankment
- methods for managing runoff and erosion
- updating information on the SLD sediments to include the latest information available
- evaluation of other options
- more effective demonstration that the selected option is the best choice
- evaluation of the uptake of Se by vegetation growing on the sediments
- more detailed plans for sediment removal
- a long-term plan for management of the sediment after application (e.g., monitoring, planting and maintenance of vegetation, upkeep and limitation of access, erosion control, storm-water management)

1.2 Purpose

The purpose of the pilot-scale test was to evaluate two options for removal and disposition of SLD sediments. Several disposal options have been considered by the SLDMWA:

- placement adjacent to the SLD on the right-of-way
- placement on agricultural land adjacent to the SLD
- transport to and disposal at Kesterson Reservoir
- disposal in a dedicated landfill
- transport to and disposal at a Class II landfill

This study focused on providing information to evaluate the first two of these alternatives. Tasks to complete this evaluation included:

- assessment of relevant regulations for land application of sediments
- analysis of the speciation of Se in the SLD sediments
- pilot trials of the two land application options
- assessment and evaluation of each option

The results of this study can be used to assist the SLDMWA and the USBR to identify the best option for managing sediments from the SLD and other Se-contaminated drainage ditches.

2.0 SITE SELECTION

2.1 Drain Surveys

During 1998 and 1999, sediments from the SLD were systematically sampled by LBNL along a length of approximately 18 km (11 miles), from the GBC Inlet to Check 10, due east of Los Baños. The sediments were analyzed by the LBNL's Environmental Measurements Laboratory (EML) for total Se. The goals of this task were (1) to obtain an improved estimate of the mass and distribution of Se in the SLD, and (2) to identify areas of elevated Se suitable for removal and land application. The details of this activity and complete results are given in Appendix A, while a summary is provided below and in Figure 1.

- Both total Se concentrations and sediment thickness are greatest immediately downstream from the check structures (or other structures that reduce flow rates) in the SLD. Consequently, most of the Se in the SLD is deposited within 60 meters (m; 200 feet [ft]) downstream from these structures.
- Selenium concentrations in the regions further away from the check structures are typically in the range of 1 to 10 mg/kg (dry weight). Concentrations increase generally downgradient, from the range of 1 to 2 mg/kg in the GBC Inlet (near Check 18) to 4 to 10 mg/kg near Check 10.
- Selenium concentrations near the check structures range from 10 to 186 mg/kg.
- There is a general tendency for Se concentrations to increase with depth in SLD sediments. This may suggest that the sediments currently being deposited in the SLD have lower Se concentrations than those deposited prior to operation of the GBC project. Alternatively, the sediment and algal matting that incorporates Se may have a concentrating effect with accumulated thickness, resulting in zonation of oxidized vs. reduced sediment within 8 to 15 cm of accumulated thickness.

2.2 Source Area and Experimental Plot Selection

The first sediment source area was 180 to 240 m downstream from the GBC Inlet. This location was characterized as having relatively low Se concentrations. The SLD survey described in Section 2.1 found that most of the sediment in this region ranged from 1 to 10 micrograms per gram (µg/g) Se (dry weight). For subsequent source areas, locations with elevated Se concentrations (Table 1) were chosen downstream and within 96 m (310 ft) of Check 18 (USBR ft marker 555484).

Two sites were selected for the pilot-scale application. Both are south of Dos Palos (Figure 2). Sediment from Source Areas 1 through 3 was laid down on the adjacent or nearby embankment, west of the SLD, in embankment plots (EPs) 1, 2, and 3 (EP-1, EP-2, and EP-3), respectively. The embankment was chosen because it is a likely candidate for large-scale sediment disposal, due to its proximity to the source area, easy access, and well-compacted, engineered soils, which limit infiltration. Sediment from Source Areas 4 and 5 was laid down on two farm plots (FPs) within a cultivated field, FP-1 and FP-2. This type of application is another candidate for large-scale disposal. It offers the advantage of a far greater area than that of SLD embankments. Furthermore, incorporation of the SLD sediment may provide an organic-rich amendment to the soil.

2.3 Permitting Issues

In late 1998, LBNL was granted a variance from the California State Water Resources Control Board (SWRCB) to operate the pilot tests, on land application of sediments, without normal compliance to applicable regulatory guidelines and permitting requirements. The exemption is consistent with Section 21565 of Article 1, Subchapter 3, Chapter 4, Subdivision 1, Division 2, Title 27 of California Code of Regulations (CCR), which states that:

1. The exemption is not against public interest.
2. The quantity of solid wastes is insignificant.
3. The nature of the solid wastes poses no significant threat to health, safety, or the environment.

If, or when, the SLDMWA operates a regional program for land application of sediments, it will need to be aware of all applicable guidelines and requirements, and particularly the data needs to address those requirements. The applicable regulations can be found within the CCR (online at http://ccr.oal.ca.gov/):

TITLE 27. Environmental Protection

Division 1. General Functions and Responsibilities
Division 2. Solid Waste

Subdivision 1. Consolidated Regulations for Treatment, Storage, Processing or Disposal of Solid Waste

Chapter 1. General

Chapter 2. Definitions

Chapter 3. Criteria for All Waste Management Units, Facilities, and Disposal Sites

Chapter 4. Documentation and Reporting for Regulatory Tiers, Permits, WDRs, and Plans

Chapter 5. Enforcement

Chapter 6. Financial Assurances at Solid Waste Facilities and at Waste Management Units for Solid Waste

Chapter 7. Special Treatment, Storage, and Disposal Units

The following summary was made, as of May 2000, to highlight the most relevant guidelines, permitting requirements, and related data needs for land application of Se-enriched canal sediment. The following discussion is not intended to be all-inclusive or comprehensive.

Chapter 3. Criteria for All Waste Management Units, Facilities, and Disposal Sites

The primary article of criteria states that the site must have an owner and operator.

Subchapter 2 on Siting and Design classifies the waste on the basis of concentration, solubility, and stability of the constituent contaminant. There are secondary variables, such as amount of material affected by contamination and location of end-users for affected waters, but the end classification on the basis of such variables is open to subjective decisions by the SWRCB. The important thresholds are:

100 mg Se/kg wet soil - TTLC - Total Threshold Limit Concentration (Cal-EPA)

1 mg Se/l of extracted water - STLC - Soluble Threshold Limit Concentration (Cal-EPA) determined by WET - Waste Extraction Test (Cal-EPA)

0.82 mg Se/l of wastewater

By the above thresholds, all the sediment applications in this investigation had non-hazardous concentrations of Se. If the Se contamination can be characterized as non-decomposable, the affected sediment would be further downgraded as inert.

Subchapter 2 on Siting and Design also classifies the level for containment on the basis of structures, such as landfills, waste piles, and land treatment facilities. Specific structures within a level of containment will have specifically recommended controls for operation, monitoring, and reporting. In this investigation, the following waste classifications and levels of containment for land treatment are pertinent:

Waste Classification	Minimum Permissible Containment
Non-hazardous	Class III
Inert	Unclassified

For land treatment units (LTUs), the treatment zone depth is left up to SWRCB discretion, but ideally the bottom of the treatment zone should be less than 1.5 m below the original soil surface and at least 1.5 m above the maximum anticipated water table level. Notably, the ideal criteria would disqualify most sites in the vicinity of our investigation, since the regional phreatic water table is approximately 1.5 m below the surface.

In Subchapter 3 on Water Monitoring, constituents of concern are defined as contaminants that are in or derived from the waste applied for land treatment. Constituents of concern will have concentration limits set at pre-application baseline concentrations. An analysis of variance is to be performed on post-application concentrations to assess the significance of increases in concentration.

Besides upgradient and downgradient water table monitoring wells, there is a requirement for lysimeters in evaluation monitoring of soil moisture in the treatment zone of LTUs (§20435, Article 4, Subchapter 3 on Water Monitoring).

Subchapter 4 on Criteria for Landfills and Disposal Sites provides stipulations on day-to-day operations, access, and amenities required for disposal sites. These stipulations are dependent on frequency of usage. A one-time application for land treatment will be subject to a sign requirement, which will direct interested parties to owners, operators, and site records. Other significant rules govern unloading and spreading processes (to minimize fluid losses off site), and the use of qualified personnel with training in hazardous waste handling.

Subchapter 5 on Closure and Post-Closure Maintenance has a section (§21420, Article 3) dedicated to the closure process requirements for LTUs. Closure and post-closure maintenance requires continued monitoring of groundwater and the unsaturated zone, while maintaining precipitation and drainage control systems.

Chapter 4. Documentation and Reporting for Regulatory Tiers, Permits, Waste Discharge Requirements, and Plans

Subchapter 3 on Development of Waste Discharge Requirements (WDRs) and Solid Waste Facility Permits describes the documentation required for the permit process. Initial written deliverables for permit application include a report of waste discharge (ROWD) to the RWQCB, or a Joint Technical Document (JTD) if the discharge will be subject to regulation by both the California Integrated Waste Management Board (CIWMB) and the RWQCB. Content should include waste characteristics, geologic and climatologic characteristics of the Unit and the surrounding region, installed features, operation plans for waste containment, precipitation and drainage controls, and closure and post-closure maintenance plans. For Class III landfills, the RWQCB can waive the submittal of information it deems unnecessary to rendering a decision on the issuance of appropriate WDRs. A preliminary Construction Quality Assurance Plan (CQA Plan) can be an integral or separable part of the initial ROWD/JTD.

Subchapter 4 on Development of Closure/Post-Closure Maintenance Plans is dedicated to the closure documentation requirements for waste management units.

Chapter 6. Financial Assurances at Solid Waste Facilities and at Waste Management Units for Solid Waste

This chapter details the requirements for financial assurance at the different phases of project development and allowable financial instruments/mechanisms.

3.0 SEDIMENT APPLICATION AND SAMPLING PROCEDURES

Dredging and application of sediments was performed by LBNL in collaboration with the Panoche Water District and the Firebaugh Water District. Sediment application to the embankment plots occurred in two stages. The sediment application procedure in plot EP-1 was initiated on December 9, 1998 and completed on January 14, 1999. Sediment was applied to Plots EP-2 and EP-3 on September 3 1999. Sediment application to the farm plots (FP-1 and FP-2) took place on October 21, 1999. The following sections describe the steps taken to prepare the site for application, pre-application sampling, sediment removal, the mixing and application procedure, and post-application sampling. Field and laboratory procedures are described in Appendix B. A photographic log of site preparation, dredging, application, and monitoring activities can be found in Appendix C.

3.1 Embankment Plot 1 (EP-1)

3.1.1 Pre-Application Sampling

Pre-application soil sampling was conducted at the drying pad on December 9, 1998. A scoop was taken using a trackhoe from five locations spaced approximately 11.5 m apart, to a 30-centimeter (-cm) depth into the roadbed. Sidewall samples were taken from the scooped hole, between 0 and 15 cm, and between 15 and 30 cm. The sidewall samples were collected with a trowel, which was decontaminated between samples. The consecutive 15-cm-interval samples were placed into plastic freezer bags with as little air space as possible.

On December 22, 1998, five boreholes were drilled for pre-application soil sampling at EP-1. One hole was drilled to 2.2 m in an effort to find the groundwater table, and four holes were drilled to 1.6 m, the approximate depth of the water table. Geological conditions were uniform across the plot with minor variations in color: light olive brown clayey silt from 0 to 0.15 m, dark olive brown clay with silt from 0.15 to 0.3 m, dark olive brown clay from 0.3 to 0.75, light olive brown clay from 0.75 to 1.5 m, and wet olive brown clay with minor silt from 1.5 to 2.2 m.

3.1.2 Sediment Dredging and Application

The first embankment plot (EP-1) was designed for sediment application after preliminary drying of removed sediment. The drying pad was located on the USBR right-of-way, west of the SLD (see Figure 2). The designated experimental plot area was in a 4-m-wide vacant space between the USBR right-of-way and an unlined drainage ditch to the west. On December 9, 1998, SLD sediments were removed from a part of SLD that was historically identified as having relatively high Se concentrations, and were applied to a 3-m-by-59-m drying area with no liner underneath. The dredged area is immediately downstream from the GBC Inlet (USBR ft markers 557068 to 557268). The sediments were removed from SLD using a trackhoe. Sediment was placed laterally on the adjacent embankment roadway. The resulting stockpile was allowed to air dry. Before and after sediment removal, LBNL personnel collected water samples in the SLD. Samples were collected at four ladder-access locations between Check 18 and the GBC Inlet, resulting in a total of eight samples. The removed sediment was sampled immediately after stockpiling. Forty-three grab samples were collected from the stockpile along a paced grid of approximately 1.3-m intervals. Shortly after January 14, 1999, the sediment stockpile was moved over and graded onto the embankment adjacent to the roadway (Figures 3 and 4).

3.1.3 Post-Application Sampling

The first round of post-application soil sampling at EP-1 took place on April 9, 1999. At that time, the application was visibly separable from underlying soil. The average thickness of applied sediment at that time was approximately 10 cm. Drilling locations included five within the test plot area, three outside the test plot area, and two in the former location of the drying pad. Five-cm-diameter cores were drilled to approximately 100 cm at each location. All cores were sectioned into 15-cm intervals for subsequent processing and analysis.

In May 1999, the vacant space between the USBR right-of-way and the unlined drainage ditch to the west was disked and land-planed by the landowner for weed control. This resulted in the mixing of applied sediments with underlying sediments to a depth of approximately 15 cm, which subsequently made it impossible to precisely separate the application from the embankment sediments.

From June 22, 1999 to July 6, 1999, five clusters of lysimeters, tensiometers, groundwater wells, and neutron probe access tubes were installed in EP-1. Installation design for each type of instrument is shown in Figure 5 and described in Table 2. Lysimeters were installed above the water table, complementary to groundwater monitoring wells. Tensiometers were installed in the unsaturated zone down to the water table. Neutron probe access boreholes were installed to depths just below the water table. Sediment cores were collected from the 0-1.65-m depth of the neutron probe access boreholes and from the 1.65- to 2.85-m intervals of the groundwater well boreholes. Subsequent neutron probe measurements were calibrated to the initial moisture contents obtained from cores at 0 to 1.65 m (calibration presented in Section 4.2). After installation, the instrumentation was monitored on a monthly basis through September 2000 and quarterly through March 2001.

As part of the continuing monitoring program, five borings were drilled in the EP-1 area on March 29, 2000, three borings on November 15, 2000, and five borings on August 7, 2001. During each sample collection:

- 5-cm-diameter cores were drilled for each boring
- an additional "control" core was collected from an adjacent area
- one core was drilled to 2 or 2.4 m and the remaining cores were drilled to 1.2 m
- all cores were retained and sectioned into 15-cm intervals for subsequent processing and analysis

3.2 Embankment Plots 2 and 3 (EP-2 and EP-3)

3.2.1 Pre-Application Sampling

Before sediment application began, two plots were set up end-to-end in a north-south alignment, with 9 m of space separating them (Figure 3). On June 29, 1999, four soil cores down to a depth of 150 cm were sampled from each site. A fifth core down to 2.75 m was also collected. From June 22, 1999 to July 6, 1999, nine clusters of lysimeters, tensiometers, and neutron probe access tubes were installed in EP-2 and EP-3 (Figure 5 and Tables 3 and 4). Of the nine clusters described, three were inside each of the two test plots, and three clusters were used as control points (Figure 3). Cores were collected from the 0- to 1.65-m depth of the neutron probe access boreholes and from the 1.65- to 2.85-m intervals of the groundwater well boreholes. Subsequent neutron probe measurements were calibrated to the initial moisture contents assessed on the cores from 0 to 1.65 m. Geological conditions were uniform across the plots with minor variations in color: olive gray sandy clay from 0 to 0.15 m, dark olive gray clay from 0.15 to 0.45 m, dark olive brown clay from 0.45 to 0.75, light olive brown clay from 0.75 to 1.5 m, and wet olive brown clay with minor silt from 1.5 to 2.85 m. The instrumentation was monitored on a weekly basis for six weeks before the September 3, 1999 application.

3.2.2 Sediment Dredging and Application

On September 3, 1999, SLD sediments were removed from two adjacent areas (Source Areas 2 and 3, described in Section 2.2) that were previously identified as having relatively high Se concentrations. The dredged sediment was applied to two test plots on a nearby drain embankment. A trackhoe scooped and unloaded sediment into a funneling hopper, which was then lifted and emptied into a cement mixer. The cement mixer rotated and mixed the accumulating load to ensure homogeneity throughout each application. Minor amounts of SLD water were added to the sediment to facilitate mixing and spreading.

Nine and 11 cy (6.9 and 8.4 cubic meters [m^3]) of sediment/water mixture were removed from Source Areas 2 and 3, respectively. Each load was mixed thoroughly (about 100 turns of the mixer between filling and application) and transported to its respective application site. Both test plots were bermed and instrumented, with 6 weeks of pre-application baseline monitoring. The homogenized sediment was applied within the berms via the cement truck chute, by moving the chute back and forth across the plot while the driver slowly moved the truck forward. The sediment was further spread to an even depth of approximately 15 cm using a cement rake. A quantity of 6.9 m^3 of sediment filled a 3-m-by-14-m space to a 15-cm depth, while 8.4 m^3 of sediment filled a 3-m-by-17-m space to a 15-cm depth. On completion, EP-2 and EP-3 were 9 m apart and the test plots were enclosed with fencing to prevent small animal access.

Immediately before and during sediment removal, LBNL personnel collected water samples in the SLD. Samples were collected approximately every 10 minutes, resulting in a total of 14 samples. The sampling point was at the first ladder downstream from Check 18, approximately 300 ft (90 m) downstream from Source Area 2 and 380 ft (116 m) downstream from Source Area 3. The homogenized removed sediment was sampled immediately after application. Ten grab samples were collected from each site along an evenly spaced grid.

3.2.3 Post-Application Sampling

Nine clusters of lysimeters, tensiometers, and neutron probe access tubes were monitored on a weekly basis for five weeks after the September 3, 1999 application, and on a monthly basis thereafter.

As part of a continuing monitoring program, 12 borings, including two control borings, were drilled over the two plots on March 28, 2000, November 15, 2000, and August 7, 2001. During each sample collection:

- Five 5-cm-diameter cores were drilled into each plot.
- For each plot, one core was drilled to 2.2 m and four cores were drilled to 1.2 to 1.3 m.
- All cores were retained and sectioned into 15-cm intervals for subsequent processing and analysis.

Dominant plant species in each test plot were periodically identified. Plant samples were collected on January 13, 2000 and June 30, 2000, and analyzed following procedures described in Appendix B.

3.3 Farm Plots FP-1 and FP-2

3.3.1 Pre-Application Sampling

Prior to sediment application, two 3 m × 17 m plots were measured and set up end to end in a north-south alignment, with 9.3 m of space separating them (Figure 6).

Pre-application drilling and sampling was performed on October 19, 1999:

- Five 5-cm-diameter cores were drilled into each plot.
- For each plot, one core was drilled to 2.4 m in an effort to locate the water table, one core was drilled to 1.5 m (the apparent water table), and three cores were drilled to 1.2 m.
- All cores were retained and sectioned into 15-cm intervals for subsequent processing and analysis.
- Geological conditions were uniform across both plots: dark gray silty clay from 0 to 0.45 m, medium olive brown clay from 0.45 to 1.5 m, and medium brown clay with sand from 1.5 to 2.4 m.
- Temporary lysimeters (4.7-cm diameter) were installed in 2.4-m- and 1.5-m-deep holes, reamed to 6.3 cm. The lysimeters were set with lines for water sampling and air venting to the surface. Silica flour was used to fill the annular space around the ceramic cup and

bentonite pellets were used to isolate the ceramic cup stratigraphically. Tie lines were attached to the lysimeter body to facilitate subsequent retrieval. The lysimeters were evacuated to -80 centibars.

On October 20, 1999, groundwater samples were collected from the lysimeters buried at 2.4 m. Lysimeters buried at 1.5 m did not accumulate water. Three of four lysimeters were then retrieved. All drill holes were backfilled with bentonite pellets up to the water table (1.5 m) and dry, fine-grained bentonite chips to 15 cm below the surface. The upper 15 cm was covered with loose soil.

3.3.2 Sediment Dredging and Application

The SLD sediments were removed from two segments of the SLD (Source Areas 4 and 5) as described in Section 2.1. The sediments were removed from the SLD using a trackhoe, as described in Section 3.2. Eleven cy (8.4 m^3) of sediment/water mixture was removed from each of these areas. These were mixed thoroughly (about 200 turns of the mixer between filling and application) and transported to the farm field. Each 8.4-m^3 load was applied to an outlined 3-m-by–17-m test plot. The homogenized sediment was applied via the cement truck chute, by moving the chute back and forth across the plot while the driver slowly moved the truck forward. The sediment was further spread to an even depth of approximately 15 cm using a cement rake. The plot outlines were referenced by distances from the Merrill and Folsom Avenue pavement boundaries. No enclosures, flags, or instruments were left on site to interfere with farming activities.

During sediment removal, LBNL personnel collected water samples in the SLD. A sample was collected approximately every 10 minutes, resulting in a total of 11 samples. The sampling point was at the first ladder downstream from Check 18, approximately 320 ft (100 m) downstream from Source Area 1 and 400 ft (120 m) downstream from Source Area 2. The homogenized sediment was sampled immediately after application. Ten grab samples were collected from each test plot along an evenly spaced grid.

The application was subsequently incorporated into the soil by the following sequence of events.

By October 28, 1999, the farm plot applications had become gray and fissured with drying cracks. There was record of rain at the test site up to November 5, 1999. On November 15, 1999, the farm plots were plowed by shanks that cut to 45 to 50 cm, with 45-cm lateral separation. On November 19, 1999, the plots were disked to 15 to 20 cm. Disks are 15 to 20 cm apart. On November 29, 1999, the plots were plowed by a deep chisel with shanks that cut to 70 to 75 cm, with 45 cm lateral separation. Plowing was performed in north-south furrows, the longer dimension of the field, while disking was performed in east-west traverses. Approximately weekly rainfall events occurred from January 12, 2000 to March 8, 2000. On March 27, 2000, the plots were again plowed by a deep chisel. By April 7, 2000, the field had been disked again twice and set with north-south furrows. On April 16, 2000, sprinkler irrigation was started on a 10-day cycle to continue through the summer. An isolated, 3-cm rainfall event, recorded on April 17, 2000 at Panoche Water District (CIMIS #124) weather station,.was the last rainfall event for the 2000 water year.

3.3.3 Post-Application Sampling

Soil from the farm plots was sampled on December 3, 1999, March 27, 2000, November 15, 2000, and August 7, 2001. The December 3, 1999 sampling occurred after several soil reworking procedures described in Section 3.3.2, and before the beginning of the 1999/2000 rainy season. The March 27, 2000 event took place after the 1999/2000 rainy season and between plowing and planting of the field. The November 15, 2000 sampling was done after the cotton harvest. The August 7, 2001 sampling was performed by LFR approximately one month after cantaloupe planting.

The following activities took place during the sampling on December 3, 1999:

- Five 5-cm-diameter cores were drilled into FP-1 and 4 into FP-2.
- For each plot, one core was drilled to 2.5 m in an effort to locate the water table and three cores were drilled to 1.2 m.
- One core was drilled to 1.8 m (the apparent water table) in FP-1.
- Cores were sectioned into 15-cm intervals for subsequent processing and analysis.
- Temporary lysimeters (4.7 cm diameter) were installed in the 2.5-m- and 1.8-m-deep holes, reamed to 6.3 cm. The annular space around the ceramic cup was filled with silica flour. The boreholes were backfilled to near-surface with uncoated, 6-mm bentonite pellets; the upper 10 to 20 cm of each borehole was backfilled with native soil.

On December 8, 1999, the three lysimeters were evacuated, but only the deepest (2.5-m-deep) lysimeters produced water samples. On December 17, 1999, two additional lysimeters were installed to 50 cm, one in each farm plot. No rainfall of record had occurred between lysimeter installation and the application. On January 5, 2000, all the lysimeters were purged and evacuated. As before, only the 2.5-m-depth lysimeters produced water.

Weekly rainfall events and sampling occurred from January12, 2000 to March 8, 2000. Water recovery from the 1.8-m- and 0.5-m-deep lysimeters commenced on February 24, 2000. Weekly water sampling from the lysimeters continued until March 13, 2000, when the lysimeters were removed in anticipation of spring plowing and planting.

A drilling and sampling event took place on March 27, 2000, between plowing and cotton planting.

- Drilling locations were chosen along one furrow valley to minimize crop disturbance and rig adjustment time.
- Five 5-cm-diameter cores were drilled into FP-1 and FP-2 each; two more were drilled off-plot.
- All cores were drilled to 1.2 m.
- Cores were sectioned into 15-cm intervals for subsequent processing and analysis.
- All boreholes were then backfilled to near-surface with uncoated, 6-mm bentonite pellets; the upper 10 to 20 cm of each borehole was backfilled with native soil.

After the furrows had been set, four temporary lysimeters were reinstalled on April 14, 2000.

- Drilling locations were chosen to coincide with selected soil boring locations from March 27, 2000.
- For each plot, one core was drilled to 2.2 m and one lysimeter was installed to 2 m.
- For each plot, one core was drilled to 1.8 m and one lysimeter was installed to 1.5 m.
- Cores from below 1.2 m were sectioned into 15-cm intervals for subsequent processing and analysis.

On May 2, 2000, two additional lysimeters were installed to 50 cm, one in each farm plot. The shallow lysimeters did not produce water. The farm plot lysimeters were subsequently sampled on a monthly basis.

On May 1, 2000, cotton was planted in a 4-m-wide swath of furrows on the west margin of the field in which the test plots are situated. The rest of the field was planted with red chili pepper seed. On May 31, 2000, sprouting crop was observed on furrow ridges. Tractor-drawn implements were used once, after the crop had grown to 15 cm, to remove weeds from the furrow valleys. The cotton started to bloom on September 13, 2000 and was picked during the week of November 6, 2000.

Three complete cotton plants were collected on July 14, 2000 from each experimental farm plot and from a control area. Roots and aboveground parts were processed separately. Plant tissue was analyzed using procedures described in Appendix B. On November 4, 2000, shortly before the cotton was picked, five complete plants were pulled from each test plot and a control area. In addition, plant density was measured (as number of plants per square meter [m^2]), permitting the calculation of biomass and cotton yield.

Soil samples were collected on November 15, 2000 and August 7, 2001 using the following scheme:

- Five 5-cm-diameter cores were drilled into FP-1 and FP-2 each; five more were drilled off-plot, and designated as control samples (FP-C).
- All cores were drilled to 1.2 m.
- Cores were sectioned into 15-cm intervals for subsequent processing and analysis.
- All boreholes were then backfilled to near-surface with uncoated, 6-mm bentonite pellets; the upper 10 to 20 cm of each borehole was backfilled with native soil.

On January 30, 2001, five sets of lysimeters were installed at the farm plot site, two in FP-1, two in FP-2, and one in the control area, FP-C. Each set consisted of 4 lysimeters, with sample point depths of 30, 60, 90, and 150 cm. These were evacuated several times over the course of the next two months, but only the 150-cm lysimeters ever yielded sufficient samples for analysis (greater than 5 ml).

On June 7, 2001, winter wheat samples were collected from FP-1, FP-2, and FP-C. A 0.25-m^2 grid made of polyvinyl chloride (PVC) pipe was used to designate the area for sampling.

The grid was randomly located within the sampling site, and all plants within the grid were collected. An effort was made to pull out each plant in its entirety, including roots, and with minimal loss of seeds. All of the plants from each grid were placed in a plastic bag. A total of five such grids were sampled from each test plot (FP-1, FP-2, and FP-C). The plant samples were transported to the laboratory at LBNL, where they were separated into roots, stems and leaves, and seeds. Each of the three components was separately weighed, dried, homogenized, and ground to a powder using a mill with a stainless-steel blade. The recorded masses were used to determine the average biomass and seed yield within each test plot.

On October 5, 2001, samples of cantaloupe were collected from FP-1, FP-2, and FP-C. The sampling grid described above was used to designate the area for sampling. The grid was randomly located within the sampling site, and all cantaloupe fruit within the grid were counted. The five largest, i.e., most ripe, cantaloupe fruit from each sampling grid were collected. A total of five such grids were sampled from each test plot (FP-1, FP-2, and FP-C). The plant samples were transported to the laboratory at LFR, where they were weighed whole, cut up, and dried in a 50° Celsius oven. After the fruits were completely dry, they were weighed, and the rind was removed. The remainder of the fruit was subsampled and ground to a powder using a mill with a stainless-steel blade. The recorded masses were used to determine the average cantaloupe yield within each test plot.

4.0 SAMPLING AND MONITORING RESULTS

The following data presentation contains the complete results from the initial application of SLD sediment to the subsequent monitoring through October 2001.

4.1 Initial Sediment Application

4.1.1 Drain Sediment Selenium

SLD sediments dredged for emplacement on embankment plot 1 (EP-1) were sampled from a bulk pile after dredging on December 9, 1998. Forty-three samples were collected. Total and water-soluble Se data, along with gravimetric moisture content, are shown in Table 5. The average total Se concentration was 2.56 mg/kg on a dry weight basis and 1.45 mg/kg on a wet weight basis. The wet weight concentration is well below the Cal-EPA total threshold limit concentration (TTLC) for hazardous waste of 100 mg/kg. Average total soluble Se was 0.021 mg/kg, which corresponds to less than 1% of total Se. Such low Se solubility is to be expected in chemically reduced bottom sediments (Weres et al. 1989a). Approximately 15% of total soluble Se was in the form of selenite. The average gravimetric moisture content of these sediments was 0.76 gram of water per gram of sediment (g/g).

SLD sediments applied to embankment plots 2 and 3 (EP-2, EP-3) were sampled shortly after dredging and spreading onto the designated area (September 3, 1999). Total Se, soluble Se, and moisture content for EP-2 and EP-3 are shown in Tables 6 and 7, respectively. The average total Se dry-weight concentrations were 37.1 mg/kg in EP-2 and 19.53 mg/kg in EP-3. Considering moisture content, the corresponding average wet-weight concentrations were 18.13 mg/kg in EP-2 and 10.79 in EP-3, both below the TTLC. Compared to the EP-1 sediments, soluble Se comprised an even smaller fraction of total Se, around 0.25%. Approximately 12% of total soluble Se was in the form of selenite. The average gravimetric moisture content was 1.05 g/g and 0.81 g/g for EP-2 and EP-3 sediments, respectively.

Sediments for application to the farm plots (FP-1 and FP-2) were dredged and sampled on October 21, 1999. Total Se, soluble Se, and gravimetric moisture content are shown in Tables 8 and 9. The average total Se was 111.6 mg/kg in FP-1 and 66.7 mg/kg in FP-2, on a dry-weight basis. On a wet-weight basis these concentrations (42.22 mg/kg and 25.46 mg/kg) do not exceed the TTLC. The average moisture contents of these two applications were higher than those of the EP applications (1.67 g/g vs. around 1 g/g). This is probably more a reflection of the amount of SLD water added during the mixing step rather than the retention properties of the sediment. Soluble Se concentrations in the FP applications were higher than in the EP applications, but still a low proportion of the total Se values (0.35% to 0.55%). Soluble Se was highest in FP-1-applied sediment, at 0.61 micrograms per kilogram (µg/kg). Soluble selenite was 12% and 16% of total soluble Se in FP-1 and FP-2 soils, respectively.

4.1.2 Drain Water Selenium

SLD water was sampled during the dredging of SLD sediments for the EP-1 application. Sample locations, time, and measured Se concentrations are shown in Table 10. The average total soluble Se was 68.6 micrograms per liter (µg/l), suggesting that the dredging operation did not cause a significant disturbance. Selenium concentrations in this part of the drain fall in the range of 20 to 100 µg/l (http://www.sfei.org/grassland/data/wq_site_a.dat). The measured Se levels did not exceed the TTLC for wastewater.

Similar sampling occurred during the dredging for EP-2 and EP-3, and for FP-1 and FP-2. The results are shown in Tables 11 and 12, respectively. The measured dissolved Se concentrations did not exceed levels observed immediately before dredging and, in the case of the EP dredging operation, 2 days prior to or 5 days after dredging.

4.2 Embankment Plots

4.2.1 Sediment Selenium

4.2.1.1 Embankment Plot 1 (EP-1)

The soil profile under the future EP-1 plot was cored on December 22, 1998 and after SLD sediment application on April 9, 1999, July 1, 1999, March 28, 2000, November 15, 2000, and August 7, 2001. The results of this sampling and the subsequent Se analysis are shown in Figures 7a and 7b, for total and soluble Se, respectively. The initial application of sediments containing on average 2.5 mg/kg Se is apparent in data from December 22, 1998 and April 9, 1999. After the plot was disked in May 1999, the applied sediment was not distinguishable during later sampling, and the near-surface concentrations were somewhat lower (1.25 mg/kg on July 1, 1999 and 1.75 mg/kg on March 28, 2000). Nonetheless, there is overlap in these data, as shown by the standard deviations, signifying a lack of profile-wide changes in Se concentrations. In 1999 and 2000, the applied Se did not move below a depth of 25 cm, as indicated by static Se concentration profiles. The increase in water-soluble Se between December 22, 1998 and April 9, 1999 at +5 cm is due to the oxidation of Se in the applied sediments. The difference of approximately 0.13 mg/kg corresponds to a net oxidation of 5% of the total Se inventory in the applied sediments. After the applied sediments were disked in, the increase in soluble Se is observed just below the new ground surface (July 1, 1999, at -5 cm). Apparent movement of low concentrations of Se was observed in samples collected on August 7, 2001. Increases in total and soluble Se are seen at depths of 20 to 150 cm below ground surface. Total Se concentrations remained between 1 and 2 mg/kg throughout the soil profile. Selenium concentrations in control samples collected on August 7, 2001 are also somewhat elevated relative to pre-application concentrations (December 22, 1998). The elevated selenium concentrations suggest that a process other than leaching may be responsible for Se increases at depth, since these increases are especially pronounced near the depth of 100 cm. The shape of the Se concentration profile can be attributed to evapotranspirative concentration of Se in the root zone. Evapotranspirative concentration is also indicated by measurements of electrical conductivity (EC) in soil water extracts (Figure 8). The data indicate an increase in total dissolved solids on August 7, 2001 below a depth of 50 cm. Prior to the application of SLD sediments, the embankment was regularly devegetated. Plants were allowed to grow in the test plots in 1999, 2000, and 2001, likely resulting in a redistribution of Se through the action of plant roots (Zawislanski et al. 1992).

The distribution of percent soluble Se is shown in Figure 7c. Soluble Se at depth fluctuates between 5 and 15%, without any consistent long-term trends. Although future increases in soluble Se concentrations near the soil surface can be anticipated, they will likely be small (Zawislanski and Zavarin 1996). Under present conditions, downward displacement of Se is not expected to be significant due to the flat concentration gradient and low permeability of underlying sediments.

4.2.1.2 Embankment Plots 2 and 3 (EP-2, EP-3)

The soil profile under the future EP-2 and EP-3 plots was cored prior to sediment application, on June 29, 1999. Assuming that Se concentrations in the unamended embankment sediments did not change over the following two months, the results of the June 29, 1999 sampling and analysis are combined with the analysis of dredged sediments and presented in Figures 9 and 10. These graphs also contain results from sediment cores collected on March 28, 2000, November 15, 2000, and August 7, 2001 from each of the test plots and from a control area outside the application, sampled on August 7, 2001. The results from EP-2 and EP-3 are similar. The applied sediments were not incorporated into the underlying sediment. No changes in total Se (beyond spatial variability expressed as one standard deviation) were observed in either the EP-2 or EP-3 soil profile in 1999 or 2000. Similar to plot EP-1, increases in total Se were observed on August 7, 2001, at depths between 50 and 100 cm below the ground surface (Figures 9a and 10a). Corresponding increases in soluble Se were observed at the same depths (Figures 9b and 10b). Total Se in the soil profile in both EP-2 and EP-3 remained at or below 2 mg/kg. It should be noted that the total Se concentration in the applied sediment (above the original ground surface) did not change in either EP-2 or EP-3, falling consistently between 30 and 40 mg/kg, or around 20 mg/kg, respectively. This, and an increase in both total and soluble Se concentrations in the control samples collected on August 7, 2001 relative to pre-application levels (June 29, 1999), suggests that evapotranspirative concentration of Se in the root zone is the process most likely responsible for these trends. This is confirmed by EC data presented in Figure 11. EC increased by August 7, 2001 throughout most of the soil profile.

Trends in percent soluble Se (Figures 9c and 10c) in EP-2 and EP-3 are similar to those observed in EP-1, in that soluble Se concentrations in the applied sediments (10-cm layer above the original ground surface) increase due to oxidation. These increases correspond to a net oxidation of 2 to 3% of the total Se inventory. The largest change occurred between September 3, 1999 and March 28, 2000. Subsequently, soluble Se increases in the applied sediment have been very small, generally less than 1% per year. Further discussion on Se oxidation is presented in Section 5. Soluble Se below the original ground surface did not change beyond the observed spatial variability. Given the increasing soluble Se concentrations in the applied sediment, a downward positive gradient of dissolved Se will result in some Se movement below the original ground surface, but soil water movement, as discussed in Section 4.2.2, is limited by low soil permeability and low rainfall.

4.2.2 Soil Water Movement

Soil water movement is driven by differences in water potential (pressure plus gravity under saturated conditions, or tension plus gravity under less than saturated conditions.) The main processes affecting water potential include regional fluctuations in groundwater table elevation, rainfall infiltration, evapotranspiration, and irrigation. The hydrology of the embankment plot sediments is also controlled by water levels in the drainage ditch to the west, and in the SLD to the east (Figure 3). The hydrologic parameters pertinent to the embankment plots are shown in Figure 12. Rainfall, temperature, and evapotranspiration (ET0) data were obtained from the Panoche Water District CIMIS Station (#124). The first cycle of post-application precipitation occurred from January 19, 2000 to March 8, 2000, with a significant event (3 cm) on April 17, 2000. Cumulative rainfall during this period was 10.9 cm. ET0 data are generated by CIMIS using an equation which accounts for temperature, wind speed, and humidity and assumes a uniform crop cover. Therefore, the results are only rough estimates of evapotranspiration at the site, and can only be interpreted qualitatively. Over any given year, cumulative ET0 greatly exceeds cumulative rainfall. On the other hand, most of the rainfall occurs during periods of very low ET0, thereby resulting in conditions more conducive to rainfall infiltration. Water levels in the unlined drainage ditch are also shown in Figure 12. These levels are seasonally affected, as seen by peak flows in the winter and low flows in the summer.

Wells distributed throughout the embankment plots (Figure 3) are used to measure the groundwater level. The depth of the water table in EP-1, EP-2, and EP-3 is shown in Figures 13, 14, and 15, respectively. With the exception of slow post-installation response of some of the wells, the water table fluctuated between 1 and 2 m below ground surface. The slow response of the wells after installation is an indicator of the low permeability of embankment soils. Groundwater levels decrease during the summer and fall, and start rising following the first major rainfall. This behavior does not correlate with trends in drainage ditch water levels, suggesting that the ditch affects the hydrology of embankment sediments less than anticipated.

Neutron probe measurements and tensiometer readings were used in the embankment plots to measure moisture content and water potential, respectively. Moisture content (expressed as saturation) was derived from a calibration based on moisture measured in sediment cores vs. neutron probe readings in those boreholes shortly after sampling. This calibration curve is shown in Figure 16. Representative results of moisture content measurements (expressed as saturation) from each of the embankment plots are shown in Figures 17, 18, and 19. Although there are some differences among the plots, the general trends are similar. Saturation increases in the winter, in particular at the sediment surface. Increases observed on February March 00 and March 3, 2000 follow the bulk of the year's rainfall events. Within one month of the latter measurement, near-surface moisture content decreases to background levels. The extent of rainfall infiltration is marked by increases in moisture at depths of 40 cm in EP-1, 20 cm in EP-2, and 10 cm in EP-3, relative to the original ground surface. Later decreases in saturation at greater depths (July 2000 to September 2000, between 50 cm and 100 cm) are likely a result of evapotranspiration.

Effects of SLD sediment application on EP-2 and EP-3 are shown in Figures 18 and 19, respectively. Because the calibration curve shown in Figure 16 was derived from embankment sediments and not SLD sediments, the saturation data for SLD sediments (aboveground values) is qualitative. Nevertheless, the original high moisture content of the applied sediments is clearly shown on September 3, 2000 (thick line), the day of the application. The data shown here, and other data collected subsequently, indicate that the wet SLD sediment did not affect the hydrology of the underlying embankment sediments. This can be explained by high moisture-retentive properties of the SLD sediments and the very high evaporation rate observed in the field immediately after application.

4.2.3 Soil Water and Groundwater Selenium and Salts

Soil water sampling in the embankment plots yielded nearly continuous data from the 100-cm-deep samplers, intermittent data from the 15-cm-deep samplers, and very rare data from the intermediate-depth samplers at 50 cm. This is due to limited rainfall infiltration, resulting in a matric potential close to or beyond the effective working range of vacuum lysimeters. The 100-cm samplers were close enough to the water table that they readily yielded samples. The 15-cm lysimeters produced samples following some of the larger rainfall events, specifically in February and March 2000. Samples from the 50-cm lysimeters were available on only a few days and in only 3 out of 14 monitoring clusters. Groundwater was collected regularly and without any difficulty. Selenium data from representative instrument clusters in EP-1, EP-2, and EP-3 are presented in Figures 20 through 22. Also shown is the depth to the water table at each of these locations. Corresponding results from a control site are shown in Figure 23.

Selenium concentrations in the 100-cm lysimeters fluctuate in a range from 150 to 400 µg/l, depending on the plot. The fluctuations generally reflect those in the groundwater data, suggesting the dominant influence of groundwater conditions on deep soil water. Groundwater Se concentrations are inversely correlated with the depth to the water table, which means that as the water table rises, it enters into more seleniferous soil, resulting in higher Se concentrations. During a period between January and March 2000, Se concentrations at 100 cm in EP-1, EP-2, and the control site dropped suddenly and then rebounded. This is not related to rainfall infiltration because the drop occurred before any major rainfall events and before any moisture breakthrough was observed in the 15-cm and 50-cm lysimeters. It is possible that these fluctuations, which coincide with the lowest groundwater levels, are influenced by water in the adjacent drainage ditch, which contains much lower Se levels (5 to 10 μg/l) and is at its highest point at this time. As mentioned above, soil water from the 15-cm sampler was available during a short period following the larger rainfall events of the season. The record of four to five data points is too small to ascribe any trends to it. Selenium concentrations at this depth ranged from 50 to 200 μg/l, generally less than Se in deeper soil water and groundwater. Selenium levels observed at 15 cm corresponded to the concentrations of Se in applied sediments. Shallow soil water Se was highest in EP-2 (applied sediment Se = 37.1 mg/kg), somewhat lower in EP-3 (applied sediment Se = 19.5 mg/kg), significantly lower in EP-1 (applied sediment Se = 2.56 mg/kg), and similarly low in the control plot, where native Se levels are around 1 mg/kg. No such correlation of concentrations was found in the 100-cm data, with EP-3 containing the highest deep soil water Se and EP-2 the lowest. The limited intermediate soil water data are represented in EP-3 (Figure 22). Selenium levels there are similar to those found at the 15-cm level. Limited soil water and groundwater data were collected in the late winter of 2001. Generally, Se concentrations fell within the previously established range. An apparent decrease in Se concentration in EP-1 groundwater, observed in March 2001, may be an analytical anomaly (Figure 4.20).

Dissolved salts are represented by measurements of EC. Data for EP-1, EP-2, and EP-3 and a control site are shown in Figures 24 through 27, respectively. Unlike Se, EC is consistently and substantially higher in groundwater than in overlying soil water, and ranges from 50 to 55 decisiemens per meter. EC trends in soil water at 100 cm are very similar to Se trends, although observed changes have a smaller amplitude. The initial EC gradient with depth was representative of an unvegetated site. Because the site became vegetated during the spring and summer 2000, a change in the distribution of salts and Se was anticipated, though most of those changes will occur in the top 50 cm of soil, where solute monitoring is impeded by low soil moisture content. Nonetheless, EC measurements in 2001 showed increases in dissolved solids in both groundwater (Figures 24 through 27) and soil water (Figures 26 and 27), including the control plot.

Selenium in groundwater data are summarized in Figure 28. The EP-1 data are an average of Se measurements from five wells, whereas EP-2 and EP-3 data represent one groundwater well each. The control data are an average of two wells. Groundwater Se does not fall into a long-term time trend, though short-term fluctuations are generally consistent among wells. Trends displayed by EP-1, EP-2, and EP-3 are in agreement with changes in the control wells.

All of the results presented above indicate that for the test duration, Se applied to the test plots does not influence Se concentrations in groundwater or deeper soil water. Dissolved Se is being mobilized from the applied sediment to a depth of 15 cm, but not much deeper. This is in agreement with findings in Section 4.2.2, where the absence of significant deep infiltration was shown. Low permeability soils on the embankment, combined with sparse rainfall, greatly reduce the likelihood of significant deep percolation of Se-enriched soil water. Increases in EC at depths of 1 m and deeper are the result of evapotranspirative concentration of salts, being drawn up from the groundwater, which is more saline than the overlying soil water. Enrichment of Se deep in the soil profile also occurs due to this process.

4.2.4 Plants and Plant Selenium

Alkali mallow (*Malvella leprosa*) was the dominant plant species on January 13, 2000 and a total of 5, 5, and 1 whole plants were sampled from plots EP-1, EP-2, and EP-3, respectively. Although roots were sampled, their mass at that time of year was very small and they were not processed any further. On June 30, 2000, alkali mallow and Russian knapweed (*Acroptilon repens*) dominated the embankment plot. At that time, a total of 11 whole alkali mallow and 7 Russian knapweed plants were collected from random locations in the embankment plots. Of those samples, roots from four alkali mallow plants from EP-2 were composited. Roots from a total of 3 Russian knapweed plants were also processed. Results of Se analyses of these samples are shown in Table 13.

Aboveground Se concentrations fell in a low range, 0.87 to 1.63 mg/kg on a dry weight basis. Small differences in concentrations among the three treatments were not statistically significant. These values are within the range of naturally occurring Se concentrations (Kabata-Pendias and Pendias 1992). Therefore, plant Se levels in the embankment plots are not of environmental concern.

4.3 Farm Plots

4.3.1 Sediment Selenium

The soil profile under the future farm plots was cored on October 19, 1999, two days prior to the application of SLD sediment. Results of this sampling and the subsequent Se analysis are shown in Figures 29 and 30 for FP-1 and FP-2, respectively. At FP-1, the initial application contained an average of 112 mg/kg total Se (standard deviation = 6.6 mg/kg), as seen in Figure 29a. After the application, several ripping and disking operations were performed, resulting in the mixing of sediments to a depth of approximately 75 cm. This is apparent in the distribution of Se in the soil profile on December 3, 1999, where Se concentrations exceeded 2 mg/kg down to a depth of about 80 cm. Large spatial variability, as expressed by the standard deviations around the means (n = 5), was observed on December 3, 1999. The effect of disking on the average Se concentration in the top 45 cm of the soil profile is shown in Figure 31.

Data from a subsequent sample collection on March 27, 2000, which followed additional soil disking, shows much less variability. In addition, mean Se concentrations on March 27, 2000 were lower than on December 3, 1999. This is commonly observed in small sample populations with greater spatial variability, due to the strong influence of outliers with very high values. A similar effect was observed at a Se-contaminated test plot at Kesterson Reservoir (Zawislanski et al. 1996). The reduced Se concentrations may be in part due to deep chiseling of the soil profile. Uprooting 75 cm of soil may result in lateral displacement of a certain fraction of Se-amended soil outside the test plots and addition of non-amended soil from the adjacent area. Soluble Se in FP-1 soil (Figure 29b) is also clearly higher in the 0- to 75-cm depth interval. In addition, the total mass of soluble Se in the soil profile has increased, due to the oxidation process discussed in Section 4.2.1. Soluble Se concentrations measured below 75 cm on December 3, 1999 and March 27, 2000 are higher than pre-application levels, but they are not different from those measured in a control soil core, sampled outside the test plots. The differences are probably due to spatial variability and the fact that only one out of five cores was sampled below 1.50 m. In FP-2, the initial application of 67 mg/kg was distributed over the top 75 cm of soil and similar patterns of reduced spatial variability with time are observed. Although Se concentrations in samples taken on March 27, 2000 are lower than on December 3, 1999, they are not statistically different (Figure 30a,b).

Subsequent plowing and disking of the FP sites resulted in further homogenization of Se concentrations, as seen in the total and soluble Se profiles on November 29, 2000, and especially on August 7, 2001. Over time, the shape of the total Se concentration profile in FP-1 and FP-2 stabilizes, as seen in the similarity between the November 29, 2000 and August 7, 2001 data (Figures 29a and 30a). The absence of significant solute movement is also evident from EC data (Figure 32). After the initial plowing and mixing, the EC profile has remained stable. Small increases in EC immediately above the groundwater table, observed on August 7, 2001, are likely a result of the upward movement of salts due to evapotranspiration.

Percent soluble Se in FP-1 and FP-2 is shown in Figures 29c and 30c, respectively. The values fluctuate mostly in the 5 to 15% range. With the exception of the initial increase following the incorporation of SLD sediments, no consistent changes in percent soluble Se are observed.

4.3.2 Soil Water and Groundwater Selenium and Salts

Soil water sampling in the farm plots was limited due to periodic soil disking. Initially, temporary lysimeters were installed at three depths in each farm plot. The deepest of these lysimeters (at 2.25 m in FP-1 and 2.50 m in FP-2) were below the water table and therefore sampled groundwater rather than soil water. These deep lysimeters yielded nearly continuous data from December 1999 through August 2000. The intermediate depth lysimeter in FP-1 (at 1.45 m) started to yield soil water on February 24, 2000 and continued to do so through August 2000. The shallow sampler in FP-1 (at 50 cm) also produced sample starting in February 2000, but produced only one sample after the peak of the rainy season. Similar trends in sample recovery were observed in FP-2, except the intermediate sampler at 175 cm did not yield water until May 2000. The pattern of sampler response suggests that increases in moisture content in shallow and intermediate intervals are the direct result of rainfall and, to a smaller extent, irrigation. Irrigation started in the summer (Figure 33) and, due to much higher concurrent evapotranspiration, its effect on the soil water regime at 50 cm and below was minor, whereas rainfall events during winter months resulted in short-term lysimeter response. Soil water and groundwater Se data from FP-1 and FP-2 are presented in Figures

34 and 35, respectively. Measurements of EC at the same locations are shown in Figures 37 and 38, respectively.

Groundwater Se concentrations in FP-1 and FP-2 remained in the range of 10 to 100 μg/l. Although there appears to be an increase in groundwater Se at times corresponding to the heavy rainfall periods in February and March 2000, the absence of groundwater level measurements makes it difficult to establish whether this change is due to Se leaching or simply to differences in soil water Se at different depths in the soil profile. It should be noted that groundwater Se levels prior to any possible leaching of applied sediments were already in the 20 to 50 μg/l range. In samples from intermediate lysimeters, Se levels are initially high, especially in FP-1 (Figure 34), but quickly dissipate to less than 100 μg/l and by June 2000 are less than 10 μg/l. The initial higher concentrations are perhaps indicative of a high-Se pulse followed by rainfall and irrigation infiltration after the more soluble Se fraction was leached. Shallow FP-1 data is too sparse to confirm this, but soil water at 50 cm in FP-2 shows a similar pattern in soluble Se concentrations. Initial values in February 2000 were around 250 μg/l, but dropped by March to 175 μg/l and by June to less than 100 μg/l. Groundwater Se concentrations are plotted on a time scale along with irrigation and rainfall events in Fig. 36. There is no short-term or long-term correlation between irrigation and rainfall events, and groundwater Se.

Patterns in EC (Figure 32) roughly correspond to Se trends. It is reasonable to assume that the disking and mixing of applied sediments with farm soil resulted in aeration and some Se oxidation and solubilization. This more readily soluble fraction could potentially be leached by rainfall and irrigation. Given the low total rainfall between January and March 2000 (8 cm), it is difficult to explain leaching down to 145 or 175 cm. Therefore, the effect of rising groundwater also needs to be considered.

Temporary lysimeters installed on January 30, 2001 yielded very few samples through March 2001, indicating the relative dryness of the soil. Samples were collected only from the 150-cm-deep lysimeters, which are generally somewhat above the groundwater table, and are comparable to the 145-cm and 175-cm lysimeters, the data from which are presented in Figures 34 and 35. Selenium concentrations in 15-cm-deep samples fell in the range of 7.37 to 56.49 μg/l, with most values around 30 μg/l, showing no change from values measured in 1999 and 2000. This indicates that irrigation and rainfall in the winter of 2000/2001 did not result in significant Se leaching to groundwater.

4.3.3 Plants and Plant Selenium

All plant Se concentrations are presented on a dry-weight basis, except where noted.

Three complete cotton plants were collected on July 14, 2000 from each experimental farm plot and from a control area. Roots and aboveground parts were processed separately. Results of Se analyses of these samples are shown in Figure 39. The data suggest that cotton plants accumulated Se in the amended plots relative to those in the control plot. Furthermore, the degree of Se enrichment was proportional to soil Se concentrations. The highest cotton tissue Se was observed in FP-1 at 22.7 mg/kg.

A more comprehensive sampling of cotton took place at full maturity (November 4, 2000), shortly after the application of exfoliant. Five complete plants were randomly pulled from each test plot and a control area. In addition, plant density was measured (as number of plants per m^2), permitting the calculation of biomass and cotton yield. Results of Se analysis of various plant parts (aboveground, i.e., roots and stems; belowground, i.e. roots, seeds, and lint) are shown in Figure 40. Selenium concentrations in the aboveground parts were lower than those measured on July 14, 2000. Selenium in roots remained the same, between 0.5 and 3.5 mg/kg. Seeds contained the highest Se concentrations, the highest being 16.6 mg/kg in FP-1. Selenium concentrations in lint were lowest, at or below 2 mg/kg. Selenium levels in all plant parts were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C.

Total biomass and cotton (lint) mass are shown in Figure 41. There are only small differences in both measures among the three plots. Due to large spatial variability, these small differences are not statistically significant. Given that soil Se is highest in FP-1 and yet the FP-1 biomass and lint yield are higher than in FP-2, the application of Se-enriched sediment does not negatively affect cotton growth. The removal of cotton lint and seeds during harvest has a negligible effect on the Se mass balance, as it accounts for less than 0.1% of the amended Se. Because the stems, leaves, and roots are eventually incorporated back into the soil, all but 0.1% of the Se is retained. If the entire cotton plant were removed from the plot, a net loss of as much as 0.5% of the total added Se would result. This number is small because, despite significant Se accumulation relative to dissolved Se in soil, the cotton biomass is low.

Samples of winter wheat were collected on June 7, 2001, shortly before harvest. Results of Se analysis of aboveground parts, belowground parts, and seeds are shown in Figure 42. Selenium concentrations in all plant parts were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C. Wheat roots accumulated higher Se concentrations than seeds, which accumulated more Se than stems and leaves. Overall, Se concentrations in wheat tissue were comparable to those in cotton tissue, except in the stems and leaves, which were about 50% lower than in cotton.

Total wheat biomass and seed mass are shown in Figure 43. There are very small differences in total biomass among the three plots. The seed biomass seems to have been slightly affected by the Se application, with FP-1 biomass being lowest and FP-C highest. However, an accurate measurement of seed biomass is made difficult by the fact that many seeds are lost during sample collection. The wheat biomass is about 50% lower than cotton biomass, and therefore the wheat harvest would have a negligible effect on Se removal from the plot.

Cantaloupe was sampled on October 5, 2001, shortly before harvest. Only the fruit was collected. Results of Se analysis of the fruit are shown in Figure 44. Selenium concentrations were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C. The data are presented in three ways: as Se concentration relative to dry weight, as Se concentration relative to wet weight, and as mass of Se per average cantaloupe. The dry weight Se concentration is comparable to Se levels in both cotton and wheat. Due to the very high moisture content, the wet weight Se concentration in cantaloupe fruit is very low, less than 1 mg/kg.

Cantaloupe productivity for plots FP-1, FP-2, and FP-C is shown in Figure 45, and is expressed as both the average number of cantaloupes per m^2 and as the average cantaloupe mass. There are no significant differences in among the three plots, indicating that the applied Se does not affect cantaloupe productivity.

The uptake of Se by cotton is not a potential health issue, because cotton is not a food crop. However, this may not be the case for wheat and cantaloupe. Wheat seed and cantaloupe Se concentrations in the amended plots are several times higher than in the control plot. The question is whether the observed Se accumulation poses a risk to the consumer.

Wheat Se concentrations are expressed in Figure 46 in terms of the mass of Se to be found in a single slice of whole wheat bread made from seeds collected from FP-1, FP-2, and FP-C. These values are then compared to the maximum recommended daily Se intake (RDI) for the average adult (Institute of Medicine 2000), which is 0.40 mg. Although the hypothetical bread slice made from wheat from FP-1 and FP-2 would contain about one quarter to one half of the maximum RDI, Se concentrations in the majority of SLD sediments fall in the range of 1 to 10 mg/kg. This range is shown in Figure 46. Based on an interpolation of the existing data, the mass of Se in a slice of bread produced from wheat grown on soils amended with up to 10 mg/kg Se will not be much greater than background.

Because cantaloupes are consumed individually, the mass of Se within an average cantaloupe needs to be considered. This is shown on the right-hand side of Figure 44. The Se mass in the average cantaloupe from both FP-1 and FP-2 exceeds the maximum RDI, while the cantaloupe from FP-C is significantly below that level. This indicates that growing cantaloupe on soils amended with 67 and 112 mg/kg Se is not recommended. However, as noted earlier, the majority of SLD sediments contain less than 10 mg/kg Se, which would result in a proportionally lower, and likely insignificant, Se uptake.

5.0 SELENIUM FRACTIONATION AND SPECIATION

The vertical movement of Se in a sediment profile is limited by its solubility. Current and future solubility, mobility, and bioavailability of sediment-bound Se are determined largely by Se speciation. Selenium speciation in most soils and sediments is generally dominated by chemically reduced and adsorbed forms (Tokunaga et al. 1994; Zawislanski and Zavarin 1996). Periodic measurements of Se speciation give estimates of Se oxidation rates, which in turn can help predict future concentrations and distribution of soluble Se.

The determination of Se species in solids is challenging. Sequential or selective extraction techniques are commonly used for Se fractionation (Weres et al. 1989a; Lipton 1991; Tokunaga et al. 1991), but provide only an approximation of the distribution of Se (or any other element) among species. This is due to the inability of wet extraction procedures to objectively discriminate among Se species without affecting the redox status, pH, and physical state of the sediment sample, which can in turn cause changes in Se speciation (Tokunaga et al. 1994). Therefore, the results of sequential extractions are defined by the sequence of operations applied to the sample. Sequential fractionation methods are capable of distinguishing among only the different "associations" of Se with soil or sediment fractions (Tokunaga et al. 1996). Nonetheless, sequential extractions provide the only currently available means for studying Se fractionation in soils and sediments containing less than 10 mg/kg Se. For samples with higher concentrations, non-destructive X-ray spectroscopic methods have been used to determine Se speciation (Pickering et al. 1995). X-ray absorption near-edge structure (XANES) spectroscopy is a technique that can directly determine the valence of elements, including Se. This method can distinguish among organic Se, elemental Se, selenite, and selenate. The distinction among different organic forms is generally non-unique due to the unknown variety of environmentally relevant species and the similarity of their spectra. Finally, when several Se species are present, total soil Se levels of tens of mg/kg are necessary for a quantitative measurement of their percentages. The advantages and limitations of this technique are discussed by Tokunaga et al. (1996).

Both sequential extractions and XANES were used to identify and quantify the dominant Se species in the SLD sediments at the time of application, after several months, and after one to two years. In the case of the embankment plots, the application sediments were separate from the underlying sediments, while at the farm plots, the SLD sediments were mixed in with the cultivated soil. This makes a "before and after" comparison of the farm plot application Se speciation somewhat ambiguous, and the X-ray spectroscopy of these diluted samples impossible.

5.1 Sequential Extraction Procedure

5.1.1 Lab Methods

A sequential extraction procedure was developed based on existing techniques used for Se fractionation and speciation (Weres et al. 1989a,b; Velinsky and Cutter 1990; Lipton 1991; Tokunaga et al. 1991). Table 14 contains the sequence of extractions and the target species each extraction is designed to remove. Samples were extracted without drying, after removal of soil water and determination of water content. The elemental Se extract and subsequent extracts were performed after NaOH extraction, drying, and grinding. Residual Se is defined as the difference between total Se, as obtained from the analysis of an acid digest of the sample, and the sum of sequentially extracted Se. All supernatant solutions were passed through a 0.45-micrometer (-µm) nitrocellulose filter immediately after extraction. Discussions of the limitations of this and other sequential extraction procedures may be found in Tokunaga et al. (1994) and Zawislanski and Zavarin (1996). The 0.02M NaOH extraction is intended to quantify Se associated with the more readily available organic soil fractions, though not specifically organo-Se compounds. The NaOCl wash is a standard method to remove all soil organic matter (SOM) and thereby SOM-Se. Organic carbon (OC) content was estimated using the Walkley-Black dichromate procedure (Nelson and Sommers 1982).

A strong acid digest procedure (Zawislanski and Zavarin 1996) is the final step of the sequential procedure and extracts total Se from post-NaOCl extraction residue. The sample is oven dried (105°Celsius) and powdered (425-µm mesh) in an agate ball-mill, then digested using hot, concentrated HNO_3 and 30% H_2O_2 for 24 h. The residue is then refluxed using 6 M HCl, and washed several times with HCl. Supernatant solutions were passed through a

0.45-µm, nitrocellulose filter immediately after extraction. The method was tested using NIST standards (NIST 2709, San Joaquin Soil; NIST 1646, Estuarine Sediment; NIST 1646a, Estuarine Sediment), with good recovery over a wide range of concentrations (Table 15). Sediment digests and extracts were analyzed for total dissolved Se using hydride generation atomic absorption spectrometry (HG-AAS; Perkin Elmer Model 3030) (Weres et al. 1989b).

5.1.2 Sample Collection

Sediments for the sequential extraction were chosen from the initial application at the embankment plots (September 3, 1999) and the farm plots (October 21, 1999), and from soil cores collected on March 27, 2000 and March 28, 2000 at these two locations. The samples were stored frozen prior to sequential extraction.

5.1.3 Results

The sequential extraction results confirm the dominance of reduced and insoluble Se species in SLD sediments. Data, expressed as percent of each fraction, are shown in Figures 47 through 50. Samples obtained from the SLD applications in 1999 (hereafter referred to as "initial") contained between 0.11 and 0.37% soluble Se. Organically associated Se and SOM-Se dominate the initial Se fractionation, followed by elemental Se. Ten to 20% of the Se falls in the refractory pool. Adsorbed Se generally comprises less than 10% of the total inventory. In March 2000, soluble Se ranged from 2.21 to 3.76%. The adsorbed Se pool also increased to as much as 17%. These increases in oxidized Se (selenate and selenite) indicate oxidation and solubilization due to the drying out of previously water-saturated sediments. In the embankment plot soil, the increase in soluble Se which occurred over the five to six months following sediment application, is mirrored by a decrease in the SOM-Se, organically associated Se, and elemental Se fractions. The interpretation of the farm-plot Se fractionation is made difficult by the "dilution" of applied SLD sediments with farm soils, at a ratio of roughly 6 parts soil to 1 part applied sediment. Although the soluble and adsorbed Se fractions increased significantly, so did the organically associated Se, whereas the elemental Se fraction did not change. The SOM-Se and the residual fraction decreased substantially. This pattern is also indicative of a net oxidation of Se. A preliminary estimate of an overall oxidation rate for SLD sediments is on the order of 1% per month. This rate is much higher than long-term rates measured under field conditions (Benson et al. 1996). However, oxidation rates decrease as readily oxidizable Se is depleted (Zawislanski and Zavarin 1996). This has already been noted in the percent-soluble-Se present in sediments applied in the embankment plot, as shown in Figures 7c, 9c, and 10c. Decreases in OC content are evidence of the net oxidation of the sediment samples. OC in applied sediments from all test sites decreased between the time of application and March 28, 2000. Organic carbon decreased from 2.23% (±0.15%) to 1.80% (±0.13%) in EP-2 and from 1.64% (±0.06%) to 1.45% (±0.05%) in EP-3. Decreases in the farm plots were somewhat greater but are ambiguous due to the physical incorporation of applied sediments and native soil.

Long-term changes in percent soluble Se in the sediment applied to EP-2 and EP-3 are shown in Figure 51. The initial, more rapid oxidation between the application date

(September 3, 1999) and approximately six months later (March 28, 2000) is apparent in both plots. If subsequent increases in soluble Se occurred, they were not statistically significant. It could be argued that concurrent solubilization and leaching of soluble Se from the surface sediment and deeper into the soil profile could produce similar results. However, no significant changes in total Se in the applied sediment were observed in the nearly two-year course of the study (September 3, 1999 to August 7, 2001). Given the uncertainty (both analytical and due to spatial variability), a total Se concentration change of at least 10% would be required before it would appear statistically significant. Therefore, some amount of Se leaching into the immediately underlying soil may be taking place, but cannot be discerned on the time scale of this study.

5.2 X-Ray Spectroscopy

Selenium K-edge X-ray spectroscopy data were collected at the Stanford Synchrotron Radiation Laboratory (SSRL) on Beam Line 4-1. X-rays were passed through an Si (220) double crystal monochromater and detuned to 50% to remove higher-order harmonics. The samples were packed in a holder with dimensions of 28 mm x 2 mm x 2 mm and placed at a 45° angle to the beam. Fluorescence X-ray spectra of the samples and of Se standards were measured using a Lytle detector with a xenon-filled chamber. Periodic scans of a Se(IV) standard were used to correct for beam energy shifts. Data were processed by averaging multiple scans and subtracting a background function which was fit from the pre-edge spectra. The data were then fit from the sum of the edges from standard materials allowing a scale factor and an edge shift. All samples used for X-ray spectroscopy runs were stored frozen until immediately before the run.

The findings confirm the dominance of reduced Se species. In sample EP2-9-SV, (Figure 52), which represents the initial sediment application to plot EP-2, and contained 37.7 mg/kg Se, the spectrum can best be fit with 100% elemental Se, although fits with 53% Se0 and 47% Se-cysteine are also satisfactory. Spectra of standard Se compounds are shown for qualitative comparison. The shape of the curve over the range of 12650 to 12680 eV was taken into account when running a fit for one, two, or three Se species. The initial SLD sediment sample applied to FP-1 is represented by sample FP1-7-SV and is shown in Figure 53. The shape of the data is more complex and suggests the presence of Se+4. Both a 100% Se-cysteine fit and an 87% Se0 plus 13% Se+4 fit adequately matched the data. The similarity of the elemental Se and organo-Se (especially Se-cysteine) standard spectra, and particularly their peak positions, is a reminder that the distinction of these species in complex field samples is challenging. Nonetheless, the data confirm the predominance of reduced Se species in the dredged SLD sediment, with no detectable Se+6. These findings agree qualitatively with results of sequential extractions.

Additional X-ray runs conducted in March and November 2001 were used to examine changes in Se speciation over time. The results of these runs are summarized in Figure 54, where spectra for samples collected on September 3, 1999 (initial application), March 27, 2000, and November 15, 2000 from EP-3, are compared to each other and to standard spectra. A substantial peak shift is observed between September 3, 1999 and March 27, 2000. The differences between the peak positions in samples collected on March 27, 2000 and November 15, 2000 are much smaller. The September 3, 1999 spectrum is best fit with 100%

Se-methionine, although a 100% fit with Se-cysteine is also satisfactory. The March 27, 2000 spectrum is best fit with either 49% Se-methionine and 51% selenite, or 39% Se-cysteine and 61% selenite. The November 15, 2000 spectrum is best fit with 36.8% Se-methionine, 57.7% selenite, and 5.5% selenate. These results indicate a fairly rapid Se oxidation during the first six months after application, followed by a much slower oxidation rate during the subsequent 8-month period. The appearance of selenate in the November 15, 2000 sample must be cautiously interpreted, because of the very low relative concentration implied by the data. Likely, the method is only marginally able to quantify any Se species at 5.5% of 19.5 mg/kg.

The X-ray spectroscopy results are in qualitative agreement with sequential extraction data. Both approaches show the rapid oxidation/solubilization of Se during the first six months after application, followed by much slower, possibly negligible oxidation thereafter. The overall Se solubility shown by percent soluble Se data in Figure 51 indicates that while Se oxidation is taking place, Se remains largely water-insoluble, likely due to the strong sorption of selenite onto soil oxides and clay edges (Tokunaga et al. 1994).

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary of Findings

Land application of SLD sediments was successfully performed at five sites at two locations near Dos Palos. Three test plots were designed, instrumented, and monitored on an SLD embankment near the sediment source area. Two more test plots were set up on a nearby cultivated field, where a crop rotation of cotton, winter wheat, and cantaloupe was grown on the amended soil. The field methods for dredging and spreading of the SLD sediments proved successful and efficient. Sediment dredging did not affect downstream Se concentrations in SLD. Due to the different mode of sediment addition to the underlying soil or sediment, and differences in relative permeability at each site, findings differ between the embankment and the farm plots.

In the embankment plots, applied sediment Se concentrations averaged 2.56, 37.10, and 19.53 mg/kg, in EP-1, EP-2, and EP-3, respectively. Less than 1% of total sediment Se was soluble. Although the initial gravimetric moisture content of the applied sediments was high (around 1 g/g), the sediments dried out very quickly and within one week of the application, a network of drying cracks appeared. Monitoring equipment was used to measure moisture movement and Se displacement in the sediment profile. Results from monitoring soil water and groundwater, as well as from soil cores, indicate that the application did not result in the movement of dissolved Se below a depth of 15 cm (relative to the original ground surface). There was no significant effect on groundwater Se levels due to leaching during the test period. An increase in Se was observed on August 7, 2001 between the depths of 25 and 100 cm, to concentrations exceeding those in overlying soils. This suggests that the increase is not due to leaching, but rather due to evapotranspirative concentration. This is confirmed by increases in salt concentrations in this depth interval, as represented by electrical conductivity measurements in both soil water and soil. Plants did not accumulate Se at levels of concern. Overall, Se remained physically stable and contained at this site, although in situ Se oxidation was measurable. On average, soluble Se concentrations increased from less than

0.5% to about 3% in the first six months after application in test sites EP-2 and EP-3. Subsequent Se solubilization was negligible. Further oxidation of the Se inventory is anticipated at a slower rate. The low permeability of the underlying sediments is a barrier to Se movement toward the groundwater table.

In the farm plots, applied Se concentrations averaged 111.6 and 66.7 mg/kg, in FP-1 and FP-2, respectively. Of the total Se, 0.35% to 0.55% was soluble. As part of the process of field preparation for planting, the 10-cm-thick sediment application was mixed with the underlying soil via disking and deep plowing, down to a depth of 75 cm. This resulted in the reduction of near-surface Se concentrations to around 10 mg/kg, but also an increase of Se concentrations down to 75 cm. There is some indication that rainfall and irrigation caused dissolved Se to move down to at least 150 cm, and possibly even to the groundwater. However, soluble Se concentrations in soil cores from a control area are no different than those in cores from FP-1 and FP-2. Therefore, if soluble Se is moving toward the water table, the total mass is small. Only a few temporary lysimeters were installed due to the periodic disking of the field. Deep soil water and groundwater data indicate seasonal fluctuations in Se concentrations, but no consistent long-term trends, and no apparent response to rainfall or irrigation events

Selenium uptake by cotton, wheat, and cantaloupe resulted in 5- to 20-fold increases in tissue-Se relative to plants from a control area. In all plants, Se levels were proportional to soil Se in the given plot; i.e., FP-1 > FP-2 > FP-C. Despite Se uptake, the biomass and yield of the crops was not affected. Therefore, the presence of high Se concentrations in the soil was not an impediment to growth and overall health. Comparisons with guidelines for maximum recommended daily Se intake indicate that cantaloupe and wheat should not be grown in soils amended with very high Se sediment, in the 50- to 100-mg/kg range. Based on data interpolation, the anticipated uptake from soils amended with SLD sediments containing less than 10 mg/kg Se would likely result in uptake of Se levels well below the maximum RDI.

Sequential extractions and X-ray spectroscopic results indicate that most of the Se in the applied sediment was strongly reduced, either as elemental Se or organically associated Se. Most of the Se oxidation and partial solubilization took place within the first six months after application. Results from samples collected 13 months after application show only minor Se oxidation relative to the six-month sample.

6.2 Recommendations

Based on the findings summarized above, the following recommendations are made regarding future land application of SLD sediment.

- The absence of Se movement to groundwater in the embankment plots indicates that the roadbed permeability and Se solubility are sufficiently low to effectively minimize Se leaching. The uptake of Se by plants in the embankment plot was negligible. Under non-experimental conditions, plant growth would be controlled or eliminated. Therefore, the embankment plot appears well suited for the application of SLD sediment.

- One potential drawback to the embankment application is the potential surface runoff created during heavy rainfall. This was not observed over the course of the pilot-scale test due to the below-average rainfall and the stabilizing presence of plant cover. Mixing in of the application layer with the top 10 to 30 cm of the embankment soil, and mechanical compaction may diminish this effect.
- The uptake of Se by crops, in particular wheat and cantaloupe, indicates that the mass of Se applied to the farm plots was too large. This can be ameliorated in two ways, either by applying SLD sediments containing lower Se concentrations, or by applying a thinner sediment layer, or a combination of both. For instance, the application and incorporation of 10 cm of SLD sediment containing 10 mg/kg Se or less is not likely to result in excessive uptake of Se by crops. Alternatively, the application and incorporation of 2 cm of SLD sediment containing 50 mg/kg Se would yield the same net Se mass concentration in the soil profile.
- The potential for the application of a thin (1 to 5 cm) layer of SLD sediments to a large area of farmland makes this alternative viable and attractive for the disposal of the majority of SLD sediments.
- After incorporation a depth of 75 cm, an application thickness of 1 cm, if possible, would not result in measurable changes in soil Se.
- The need for further evaluation of this approach with respect to Se uptake by a variety of crops needs to be established. A literature search on crop uptake of Se may yield sufficient information for crops other than cotton, wheat, and cantaloupe. Additional information could be collected in pot studies or further crop rotations at the existing farm plot site or new sites.
- Full-scale application of SLD sediments will require periodic monitoring of Se concentrations in soil, groundwater, and crops. After one year and one crop rotation, the monitoring could be reduced to periodic groundwater sampling, to ensure that Se is not being leached out of the root zone.

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Table 1: Locations of Sediment Sources and Se Levels in Nearest Sediment Core

Source Area #	Distance up/downstream from Check 18	USBR ft markers	Se concentrations in nearest core (µg/g, dry mass)	Location of nearest core (USBR ft marker)
1	483-543 m upst.	557068-557268	2, 1, 2, 1, 2[1]	557068
2	87-96 m downst.	555200-555174	4, 22, 59, 114 [2]	555204
3	62-70 m downst.	555280-555254	12, 56, 124 [3]	555284
4	79-87 m downst.	555224-555199	4, 22, 59, 114 [2]	555204
5	50-62 m downst.	555319-555279	12, 56, 124 [3]	555284

[1] at 0-5, 5-10, 10-15, 15-18 cm depth, respectively

[2] at 0-3, 3-8, 8-23, 23-32.5 cm depth, respectively

[3] at 0-3, 3-8, 8-23 cm depth, respectively

Table 2: Embankment Plot 1 Instrumentation Depths

Lysimeter Installations all depths are cm below original ground surface	L1-S, -M, -D	L2-S, -M, -D	L3-S, -M, -D	L4-S, -M, -D	L5-S, -M, -D
Top of shallow silica flour interval	7	22	22	21	22
Base of cup in shallow lysimeter	**15**	**30**	**30**	**30**	**30**
Base of shallow silica flour interval	17	32	32	34	32
Top of intermediate silica flour interval	41	57	57	57	57
Base of cup in intermediate lysimeter	**49**	**65**	**65**	**65**	**63**
Base of intermediate silica flour interval	51	67	67	67	67
Top of deep silica flour interval	91	107	107	107	107
Base of cup in deep lysimeter	**100**	**115**	**115**	**115**	**115**
Base of deep silica flour interval	101	117	117	117	117
Tensiometer Installations all depths are cm above or below original ground surface	T1-S, -M, -D	T2-S, -M, -D	T3-S, -M, -D	T4-S, -M, -D	T5-S, -M, -D
Depth of shallow tensiometer cup	**30**	**30**	**30**	**31**	**31**
Initial stick-up	10	10	10	9	9
Depth of intermediate tensiometer cup	**92**	**93**	**91**	**89**	**94**
Initial stick-up	10	9	11	13	8
Depth of deep tensiometer cup	**153**	**154**	**154**	**154**	**153**
Initial stick-up	10	9	9	9	10
Neutron Probe Access Tube Installations all depths are cm above or below original ground surface	NPAT-1	NPAT-2	NPAT-3	NPAT-4	NPAT-5
Internal depth of tube	168	167	167	164	166
Initial stick-up	14	15	15	18	16
Groundwater Well Installations all depths are cm above or below original ground surface	GW-1	GW-2	GW-3	GW-4	GW-5
Initial stick-up on 7/2/99	19	15	15	15	19
Stick-up on 8/11/99	12	12	14	14	16
Top of bentonite pellets	0	0	0	0	0
Base of bentonite pellets/Top of sand	145	146.7	127	146	145
Top of screen	**149**	**153**	**153**	**153**	**149**
Base of screen	**269**	**273**	**273**	**273**	**269**
Base of sand/Total drilled depth	290	294	294	294	290

Table 3: Embankment Plot 2 Instrumentation Depths

Lysimeter Installations all depths are cm below original ground surface	L6-S, -M, -D	L7-S, -M, -D	L8-S, -M, -D	L9-S, -M, -D	L10-S, -M, -D
Top of shallow silica flour interval	13	7	7	10	8
Base of cup in shallow lysimeter	**20**	**15**	**15**	**15**	**15**
Base of shallow silica flour interval	22	17	17	17	17
Top of intermediate silica flour interval	47	40	42	42	39
Base of cup in intermediate lysimeter	**55**	**48**	**50**	**50**	**47**
Base of intermediate silica flour interval	57	50	52	52	50
Top of deep silica flour interval	97	92	92	90	91
Base of cup in deep lysimeter	**104**	**100**	**100**	**98**	**99**
Base of deep silica flour interval	107	102	102	102	101
Tensiometer Installations all depths are cm above or below original ground surface	T6-S, -M, -D	T7-S, -M, -D	T8-S, -M, -D	T9-S, -M, -D	T10-S, -M, -D
Depth of shallow tensiometer cup	**15**	**12**	**17**	**16**	**15**
Initial stick-up	25	28	23	24	25
Stick-up after application dried		16	14	11	
Depth of intermediate tensiometer cup	**75**	**74**	**74**	**77**	**77**
Initial stick-up	27	28	28	25	25
Stick-up after application dried		17	19	12	
Depth of deep tensiometer cup	**138**	**136**	**137**	**139**	**137**
Initial stick-up	25	27	26	24	26
Stick-up after application dried		17	16	14	
Neutron Probe Access Tube Installations all depths are cm above or below original ground surface	NPAT-6	NPAT-7	NPAT-8	NPAT-9	NPAT-10
Internal depth of tube	144	151	150	155	153
Initial stick-up	29	25	32	27	29
Stick-up after application dried	29	13	20	20	28
Groundwater Well Installations all depths are cm above or below original ground surface	GW-6	GW-7			
Initial stick-up on 7/2/99	35	30			
Stick-up on 8/11/99	33	28			
Stick-up after application dried					
Top of bentonite pellets	0	0			
Base of bentonite pellets/Top of sand	123	121			
Top of screen	**133**	**138**			
Base of screen	**253**	**258**			
Base of sand/Total drilled depth	274	279			

Table 4: Embankment Plot 3 Instrumentation Depths

Lysimeter Installations all depths are cm below original ground surface	L10-S, -M, -D	L11-S, -M, -D	L12-S, -M, -D	L13-S, -M, -D	L14S, -M, -D
Top of shallow silica flour interval	8	7	6	8	7
Base of cup in shallow lysimeter	**15**	**15**	**15**	**15**	**15**
Base of shallow silica flour interval	17	17	17	17	17
Top of intermediate silica flour interval	39	42	42	42	42
Base of cup in intermediate lysimeter	**47**	**50**	**50**	**50**	**50**
Base of intermediate silica flour interval	50	52	52	52	52
Top of deep silica flour interval	91	92	92	92	92
Base of cup in deep lysimeter	**99**	**100**	**100**	**100**	**100**
Base of deep silica flour interval	101	102	102	102	106
Tensiometer Installations all depths are cm above or below original ground surface	T10-S, -M, -D	T11-S, -M, -D	T12-S, -M, -D	T13-S, -M, -D	T14-S, -M, -D
Depth of shallow tensiometer cup	**15**	**15**	**16**	**14**	**16**
Initial stick-up	25	25	24	26	24
Stick-up after application dried		14	14	14	
Depth of intermediate tensiometer cup	**77**	**74**	**77**	**76**	**76**
Initial stick-up	25	28	25	26	26
Stick-up after application dried		16	14	15	
Depth of deep tensiometer cup	**137**	**137**	**136**	**137**	**138**
Initial stick-up	26	26	27	26	25
Stick-up after application dried		16	17	15	
Neutron Probe Access Tube Installations all depths are cm above or below original ground surface	NPAT-10	NPAT-11	NPAT-12	NPAT-13	NPAT-14
Internal depth of tube	153	153	153	149	150
Initial stick-up	29	29	29	33	32
Stick-up after application dried	28	19	19	22	32
Groundwater Well Installations all depths are cm above or below original ground surface				GW-13	GW-14
Initial stick-up on 7/2/99				30	32
Stick-up on 8/11/99				32	39
Stick-up after application dried					
Top of bentonite pellets				0	0
Base of bentonite pellets/Top of sand				128	116
Top of screen				**138**	**136**
Base of screen				**258**	**256**
Base of sand/Total drilled depth				279	277

Table 5: Total and Soluble Se in SLD Sediments Applied to Embankment Plot 1 (EP-1)

Sample	Location ($\text{m}^{\dagger}$)	$[\text{Se}]_{\text{total}}$ dry weight (µg/g)	Moisture Content (g/g)	$[\text{Se}]_{\text{total}}$ wet weight (µg/g)	$[\text{Se}^{+4}]_{\text{soluble}}$ dry weight (µg/g)	$[\text{Se}]_{\text{soluble}}$ dry weight (µg/g)
SLD 1	0.7	2.65	0.534	1.73	0.003	0.028
SLD 2	1.8	2.19	0.632	1.34	0.005	0.019
SLD 3	3.1	1.35	0.429	0.95	0.001	0.015
SLD 4	4.2	3.36	0.774	1.89	0.003	0.027
SLD 5	5.3	3.24	0.754	1.85	0.002	0.026
SLD 6	6.3	1.31	0.459	0.90	0.003	0.011
SLD 7	7.5	1.83	0.624	1.13	0.005	0.026
SLD 8	8.6	2.05	0.673	1.23	0.005	0.015
SLD 9	9.6	2.55	0.721	1.48	0.008	0.025
SLD 10	11	1.65	0.718	0.96	0.006	0.016
SLD 11	12.3	2.18	0.714	1.27	0.003	0.024
SLD 12	14	2.11	0.594	1.32	0.002	0.012
SLD 13	15.5	4.27	0.885	2.26	0.005	0.025
SLD 14	17	2.71	0.723	1.57	0.002	0.018
SLD 15	18.5	2.49	0.740	1.43		
SLD 16	20	2.08	0.689	1.23		
SLD 17	21.5	2.26	0.644	1.38		
SLD 18	23	6.04	0.994	3.03		
SLD 19	24.5	2.22	0.381	1.61	0.002	0.019
SLD 20	26	2.11	0.726	1.22		
SLD 21	27.5	7.22	1.192	3.29		
SLD 22	29	2.23	0.812	1.23		
SLD 23	30.5	2.10	0.663	1.26		
SLD 24	32	2.39	0.771	1.35	0.006	0.023
SLD 25	33.5	2.03	0.729	1.17		
SLD 26	35	5.22	1.088	2.50		
SLD 27	36.5	2.38	0.703	1.40		
SLD 28	38	2.58	0.825	1.41		
SLD 29	39.5	3.45	0.849	1.87	0.003	0.024
SLD 30	41	3.85	1.043	1.88		
SLD 31	42.5	2.35	0.750	1.34		
SLD 32	44	2.54	0.751	1.45		
SLD 33	45.5	2.31	0.705	1.35		
SLD 34	47	1.86	0.590	1.17	0.003	0.023
SLD 35	48.5	3.54	0.931	1.84		
SLD 36	50	2.41	0.720	1.40		
SLD 37	51.5	2.49	0.822	1.37		
SLD 38	53	2.11	0.674	1.26		
SLD 39	54.5	2.96	0.809	1.63	0.004	0.017
SLD 40	56	2.18	0.629	1.34		
SLD 41	57.5	2.63	0.753	1.50		
SLD 42	59	3.30	0.973	1.67		
SLD 43	60.5	2.14	0.661	1.29		
Average		***2.56***	*0.76*	***1.45***	***0.004***	***0.021***
Std dev		*0.55*	*0.13*	*0.21*	*0.002*	*0.005*
Cal EHS Aqueous Waste Category Threshold				100.00		

† Distance from north to south end of 63 m long stockpile removed from San Luis Drain

Table 6: Total and Soluble Se in SLD Sediments Applied to Embankment Plot 2 (EP-2)

Sample	$[\text{Se}]_{\text{total}}$ dry weight (μg/g)	Moisture Content (g/g)	$[\text{Se}]_{\text{total}}$ wet weight (μg/g)	$[\text{Se}^{+4}]_{\text{soluble}}$ dry weight (μg/g)	$[\text{Se}]_{\text{soluble}}$ dry weight (μg/g)
EP2-1-SV	38.13	0.995	19.12	0.015	0.105
EP2-2-SV	40.10	1.001	20.04	0.017	0.100
EP2-3-SV	37.41	1.035	18.38	0.016	0.122
EP2-4-SV	34.19	1.084	16.40	0.006	0.113
EP2-5-SV	31.70	1.124	14.93	0.016	0.094
EP2-6-SV	33.93	1.101	16.15	0.013	0.098
EP2-7-SV	38.52	1.059	18.71	0.018	0.105
EP2-8-SV	37.93	1.099	18.07	0.009	0.091
EP2-9-SV	37.73	1.045	18.45	0.015	0.087
EP2-10-SV	41.34	0.964	21.06	0.010	0.074
Average	***37.10***	***1.05***	***18.13***	***0.013***	***0.099***
Std dev	*2.96*	*0.05*	*1.85*	*0.004*	*0.014*
Cal EHS Aqueous Waste Category Threshold			100.00		

Table 7: Total and Soluble Se in SLD Sediments Applied to Embankment Plot 3 (EP-3)

Sample	$[\text{Se}]_{\text{total}}$ dry weight (μg/g)	Moisture Content (g/g)	$[\text{Se}]_{\text{total}}$ wet weight (μg/g)	$[\text{Se}^{+4}]_{\text{soluble}}$ dry weight (μg/g)	$[\text{Se}]_{\text{soluble}}$ dry weight (μg/g)
EP3-1-SV	19.69	0.758	11.20	0.003	0.041
EP3-2-SV	19.88	0.882	10.56	0.007	0.045
EP3-3-SV	18.70	0.851	10.10	0.007	0.039
EP3-4-SV	20.02	0.808	11.07	0.006	0.040
EP3-5-SV	20.15	0.798	11.21	0.002	0.039
EP3-6-SV	21.53	0.815	11.86	0.004	0.043
EP3-7-SV	21.26	0.827	11.64	0.006	0.042
EP3-8-SV	18.05	0.835	9.83	0.002	0.042
EP3-9-SV	18.38	0.757	10.46	0.002	0.044
EP3-10-SV	17.65	0.776	9.94	0.007	0.046
Average	***19.53***	***0.81***	***10.79***	***0.005***	***0.042***
Std dev	*1.31*	*0.04*	*0.71*	*0.002*	*0.002*
Cal EHS Aqueous Waste Category Threshold			100.00		

Table 8: Total and Soluble Se in SLD Sediments Applied to Farm Plot 1 (FP-1)

Sample	$[\text{Se}]_{\text{total}}$ dry weight (µg/g)	Moisture Content (g/g)	$[\text{Se}]_{\text{total}}$ wet weight (µg/g)	$[\text{Se}^{+4}]_{\text{soluble}}$ dry weight (µg/g)	$[\text{Se}]_{\text{soluble}}$ dry weight (µg/g)
FP1-1-SV	116.0	1.716	42.72	0.112	0.609
FP1-2-SV	96.9	1.884	33.58	0.100	0.637
FP1-3-SV	112.4	1.629	42.73	0.085	0.533
FP1-4-SV	121.5	1.922	41.60	0.097	0.628
FP1-5-SV	114.2	1.656	43.00	0.038	0.516
FP1-6-SV	113.7	1.253	50.46	0.070	0.665
FP1-7-SV	111.6	1.634	42.35	0.082	0.622
FP1-8-SV	108.4	1.485	43.63	0.044	0.551
FP1-9-SV	106.8	1.756	38.76	0.043	0.644
FP1-10-SV	114.7	1.648	43.32	0.065	0.688
Average	***111.62***	***1.66***	***42.22***	***0.074***	***0.609***
Std dev	*6.58*	*0.19*	*4.21*	*0.026*	*0.057*
Cal EHS Aqueous Waste Category Threshold			100.00		

Table 9: Total and Soluble Se in SLD Sediments Applied to Farm Plot 2(FP-2)

Sample	$[\text{Se}]_{\text{total}}$ dry weight (µg/g)	Moisture Content (g/g)	$[\text{Se}]_{\text{total}}$ wet weight (µg/g)	$[\text{Se}^{+4}]_{\text{soluble}}$ dry weight (µg/g)	$[\text{Se}]_{\text{soluble}}$ dry weight (µg/g)
FP2-1-SV	67.59	1.729	24.77	0.036	0.224
FP2-2-SV	63.26	1.547	24.84	0.032	0.210
FP2-3-SV	64.97	1.622	24.78	0.038	0.249
FP2-4-SV	66.15	1.636	25.10	0.038	0.237
FP2-5-SV	64.44	1.600	24.79	0.049	0.238
FP2-6-SV	65.23	1.668	24.45	0.038	0.260
FP2-7-SV	70.22	1.599	27.02	0.038	0.234
FP2-8-SV	68.38	1.571	26.59	0.035	0.216
FP2-9-SV	69.04	1.619	26.36	0.032	0.221
FP2-10-SV	67.99	1.627	25.88	0.046	0.224
Average	***66.73***	***1.62***	***25.46***	***0.038***	***0.231***
Std dev	*2.25*	*0.05*	*0.92*	*0.005*	*0.015*
Cal EHS Aqueous Waste Category Threshold			100.00		

Table 10: Selenium in SLD Water Collected Downstream from the EP-1 Dredging Operation

Sample location†	Time	$[Se^{+4}]$ (µg/l)	[Se] (µg/l)
SLD 1	10:00	2.00	65.52
SLD 2	10:05	1.90	69.09
SLD 3	10:10	1.75	68.46
SLD 4	10:14	1.84	69.93
SLD 1a	15:06	1.79	70.98
SLD 2a	15:10	1.81	68.25
SLD 3a	15:14	1.69	68.46
SLD 4a	15:18	1.62	68.46
Average		***1.80***	***68.64***
Standard Deviation		*0.12*	*1.57*
Cal EHS Wastewater Standards			820

† Stepladder locations from Grasslands Bypass inlet to Check 18 in San Luis Drain

Table 11: Se in SLD Water Collected Downstream from the EP-2 and EP-3 Dredging Operation

Sample location	Time	$[Se^{+4}]$ (µg/l)	[Se] (µg/l)
100 m downstream of sediment removal, 200 m downstream from Check 18	8:23	1.78	44.00
	9:19	1.51	41.90
	9:27	1.11	41.48
	9:34	1.08	41.37
	9:40	1.43	40.64
	9:47	1.45	40.74
	9:54	1.56	39.69
	11:42	1.39	39.27
	11:49	1.24	36.02
	11:55	1.35	37.70
	12:00	1.30	38.75
	12:05	1.22	37.07
	12:34	1.33	37.70
Average		***1.37***	***39.71***
Standard Deviation		*0.19*	*2.25*
Check 17 (Site A) 9/1/99			*45.70*
Check 17 (Site A) 9/8/99			*46.70*
Cal EHS Wastewater Standards			820

Table 12: Se in SLD Water Collected Downstream from the FP-1 and FP-2 Dredging Operation

Sample location	Time	[Se^{+4}] (μg/l)	[Se] (μg/l)
100 m downstream from sediment removal, 200 m downstream from Check 18	8:31	1.81	69.30
	8:40	1.87	63.84
	8:47	1.50	64.68
	8:55	1.84	70.98
	9:05	1.72	72.24
	9:21	1.76	66.99
	10:46	1.92	61.95
	10:56	2.01	72.03
	11:12	2.09	64.89
	11:26	1.73	67.83
	11:36	1.52	64.89
Average		***1.80***	***67.24***
Standard Deviation		***0.18***	***3.52***
Cal EHS Wastewater Standards			820

Table 13: Se Concentrations in Embankment Plot Plants

Species (Date)	**Mean aboveground Se, [std dev] (μg g^{-1})**	**Mean belowground Se, [std dev] (μg g^{-1})**
alkali mallow (*Malvella leprosa*; 1/13/00)	1.63 [1.57]	–
alkali mallow (*Malvella leprosa*; 6/30/00)	1.00 [0.30]	2.78 [–]
Russian knapweed (*Acroptilon repens*; 6/30/00)	0.87 [0.37]	0.58 [0.39]

Table 14: Sequential Extraction Procedure for Se Species in Sediments

Target Se species	Solution/reagents	Solid:solution mass ratio	Procedure
Soluble	0.25 M KCl	1:5	Samples shaken on reciprocating shaker for 1 hr, centrifuged at 10,000 rpm for 30 min
Adsorbed	0.1 M Na_2HPO_4	1:10	Samples shaken on reciprocating shaker for 24 hr, centrifuged at 10,000 rpm for 30 min
Organic matter; loosely assoc.	0.02 M NaOH	1:10	Samples heated at 85°C for 2 hr, shaken for 5 min every 30 min, centrifuged at 10,000 rpm for 30 min
Elemental	1.0 M Na_2SO_3 (pH = 7.0)	†	†
Soil organic matter	4% NaOCl, pH 9.5	1:4	Residue from sulfite extract reacted in boiling water bath for 30 min. Centrifuged, decanted and repeated.
Residual (oxide-bound and other recalcitrant Se)	($HNO_3/H_2O_2/HCl$)	See text	An acid digest, as described in text, removes all remaining Se

† See Velinsky and Cutter (1990) for details on this procedure.

Table 15: Analysis of Selenium in NIST Reference Materials

Reference Material	Certified value (mean ± SD)	Measured value (mean ± SD, n=10)
NIST 2709 (San Joaquin Soil)	1.57 ± 0.08	1.68 ± 0.15
NIST 1646 (Estuarine Sediment)	0.6†	0.68 ± 0.12
NIST 1646a (Estuarine Sediment)	0.193 ± 0.028	0.213 ± 0.057

† - non-certified value

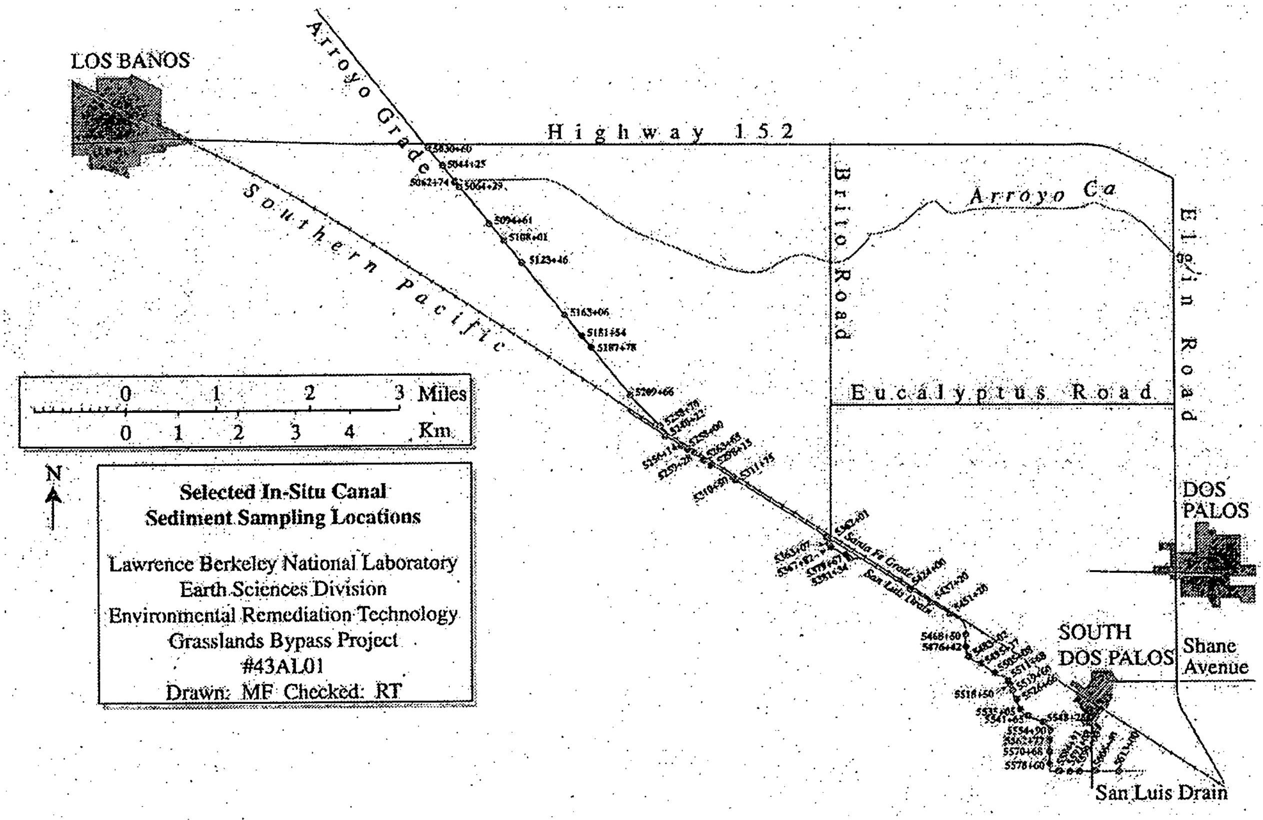


Figure 1: Location of LBNL sediment sampling points along the SLD.

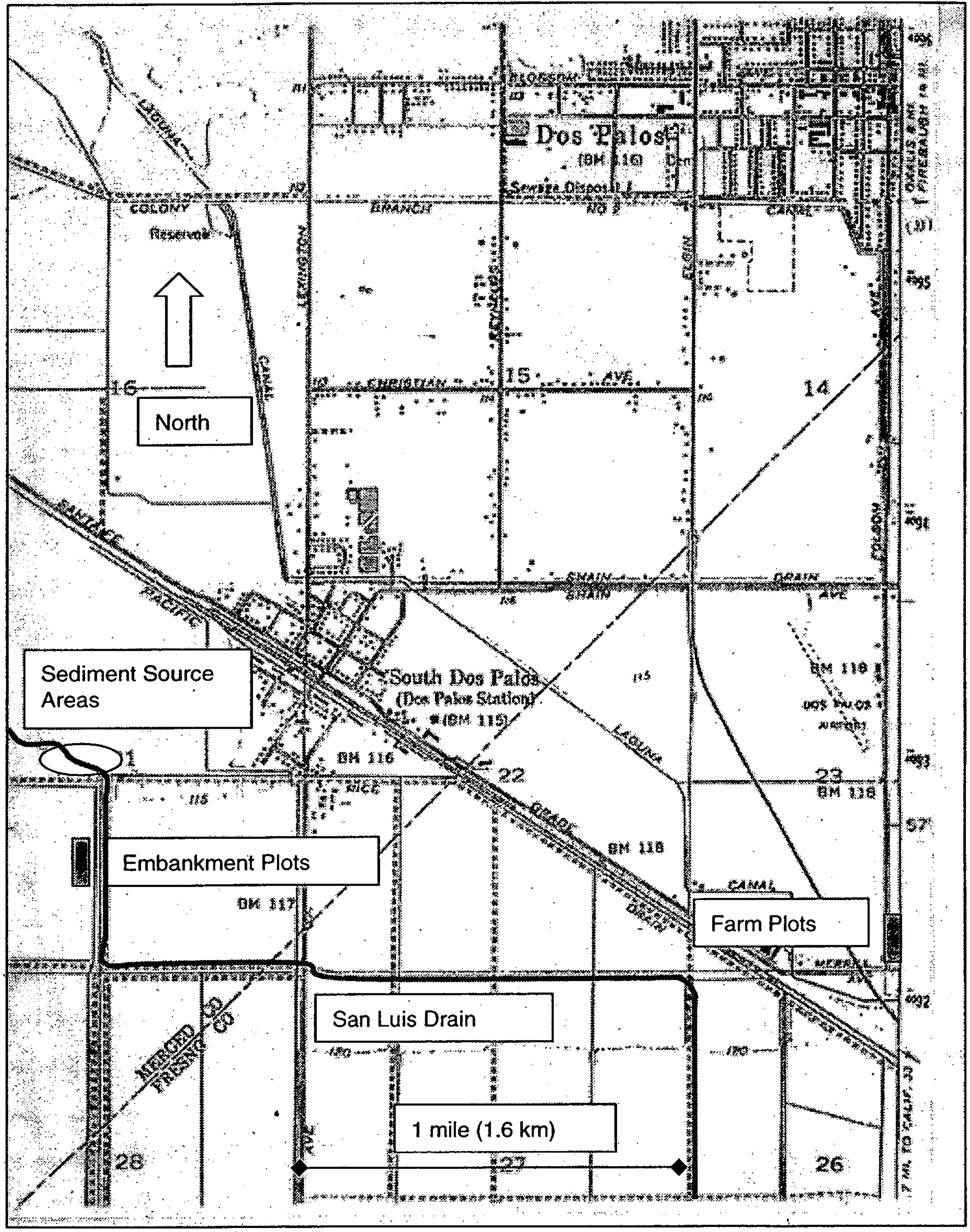


Figure 2: Locations of sediment source areas, embankment plots, and farm plots, relative to the SLD.

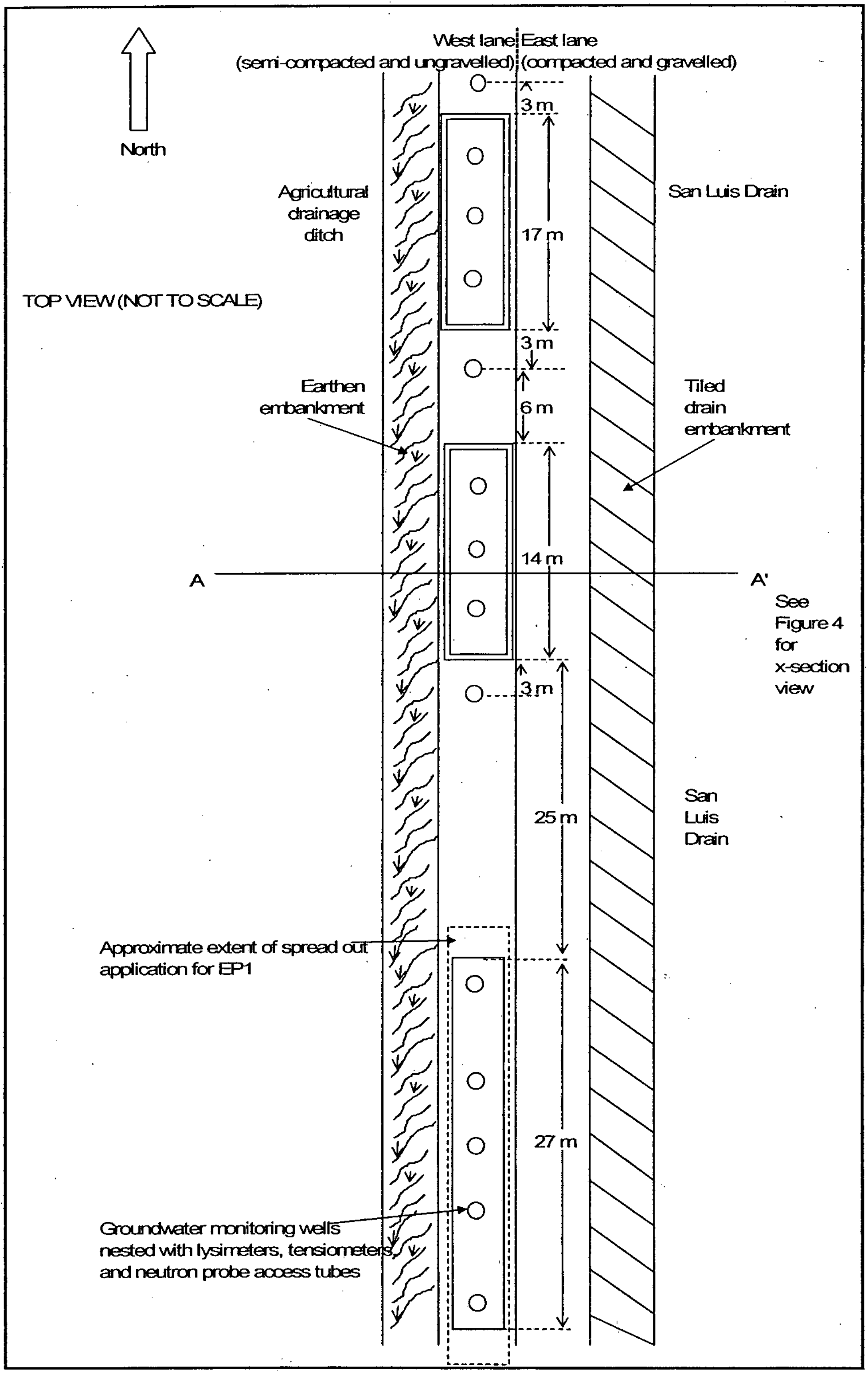


Figure 3: Layout of embankment plots and monitoring equipment.

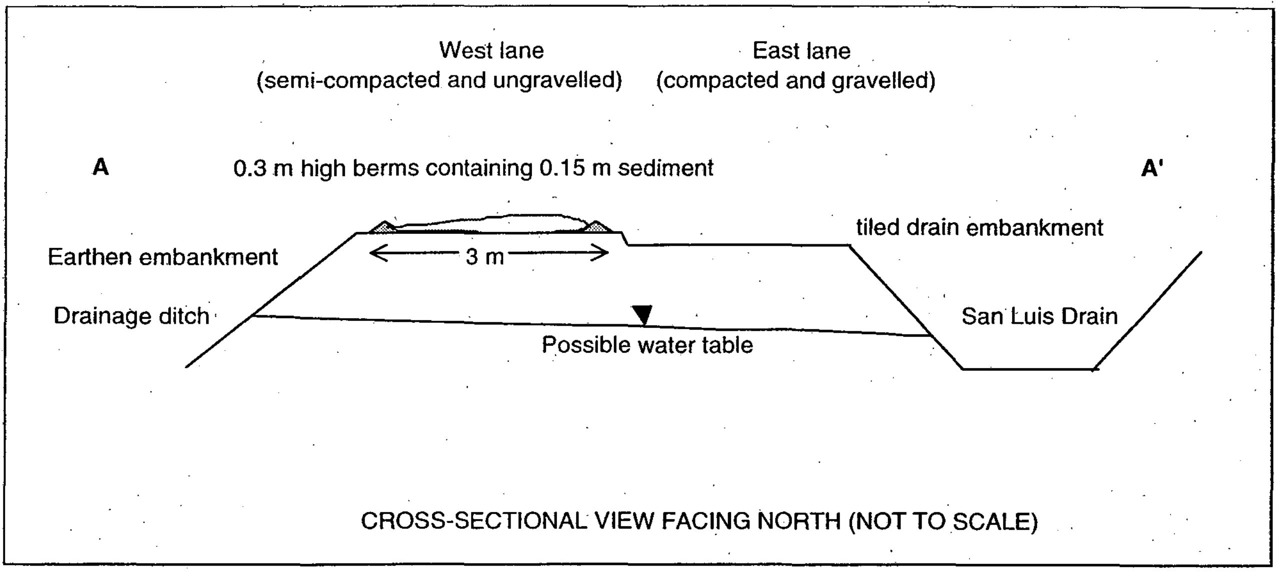


Figure 4: Cross-sectional view of embankment plots along Section A-A'.

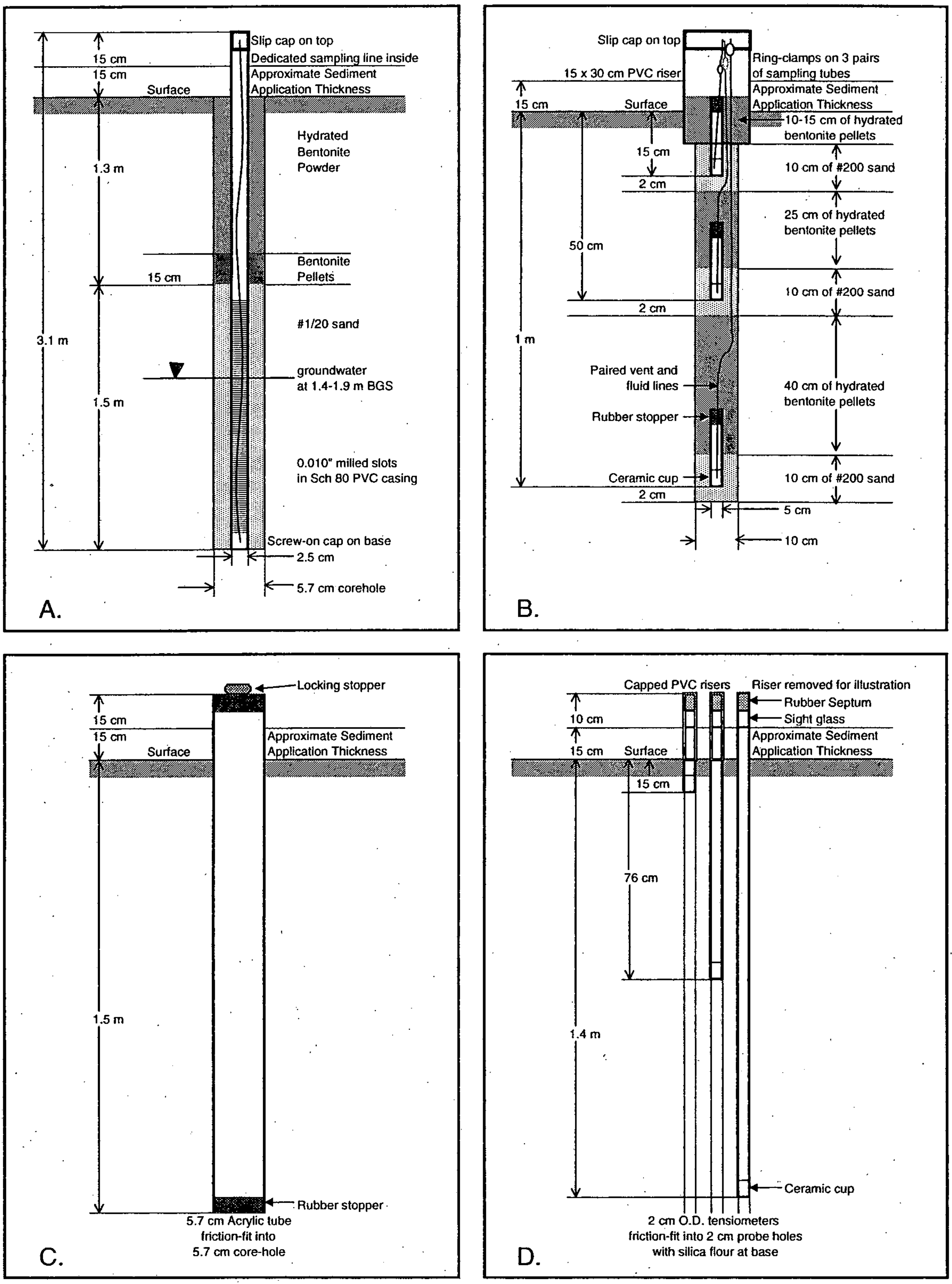


Figure 5: Construction detail of embankment plot instrumentation: a.) groundwater monitoring well; b.) suction lysimeter; c.) neutron probe access hole; and d.) tensiometer cluster.

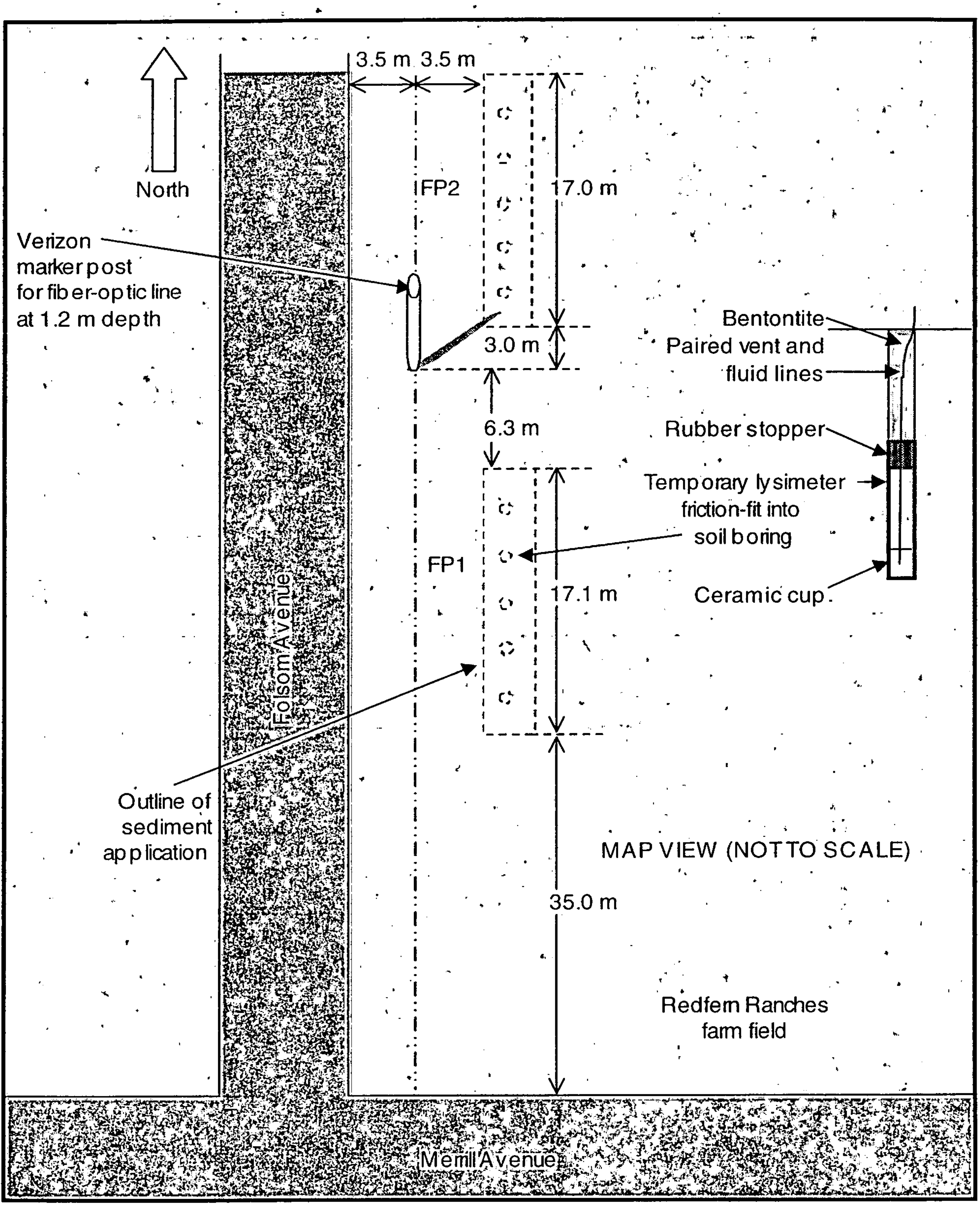


Figure 6: Layout of farm plots, locations of soil borings, and temporary lysimeter design.

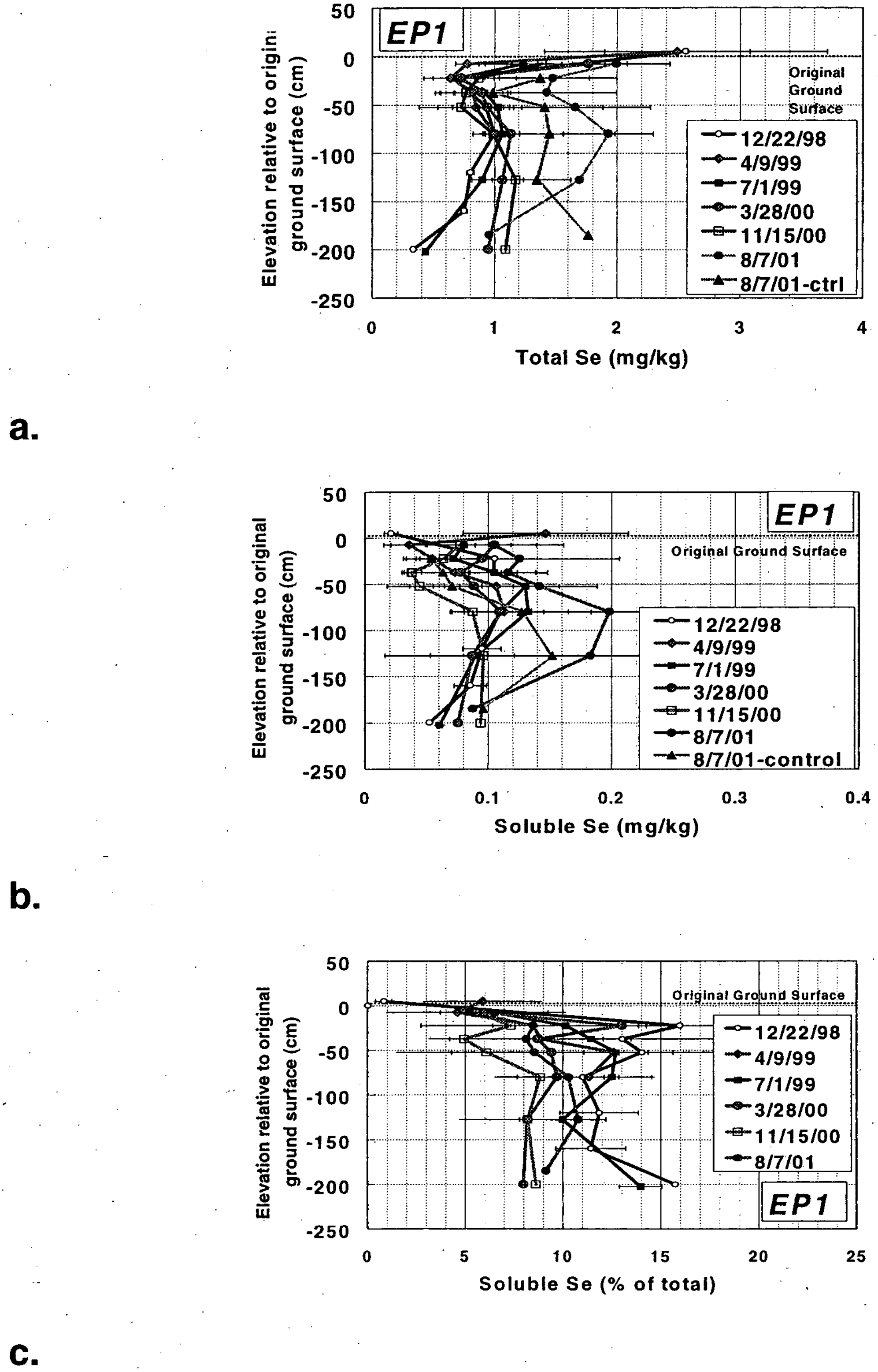


Figure 7: a.) Total, b.) water-soluble, and c.) percent water-soluble Se concentrations normalized to soil mass in EP-1. Error bars represent one standard deviation on either side of the mean.

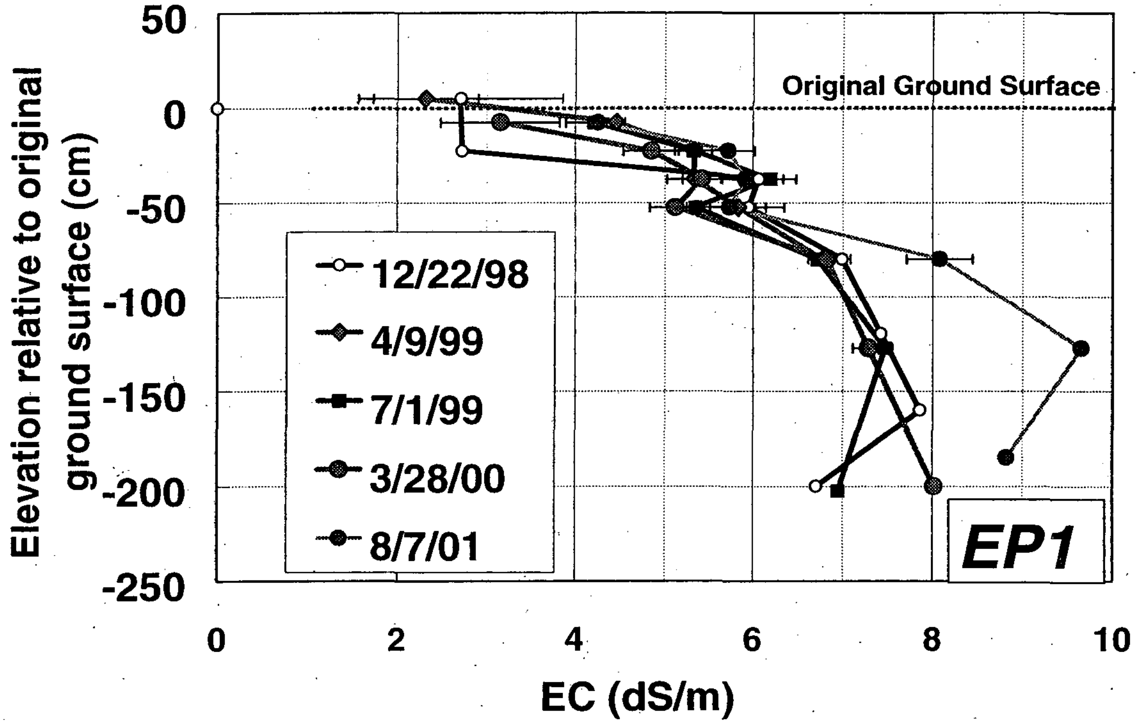


Figure 8: Electrical conductivity in water extracts of soils collected in EP-1. Error bars represent one standard deviation on either side of the mean.

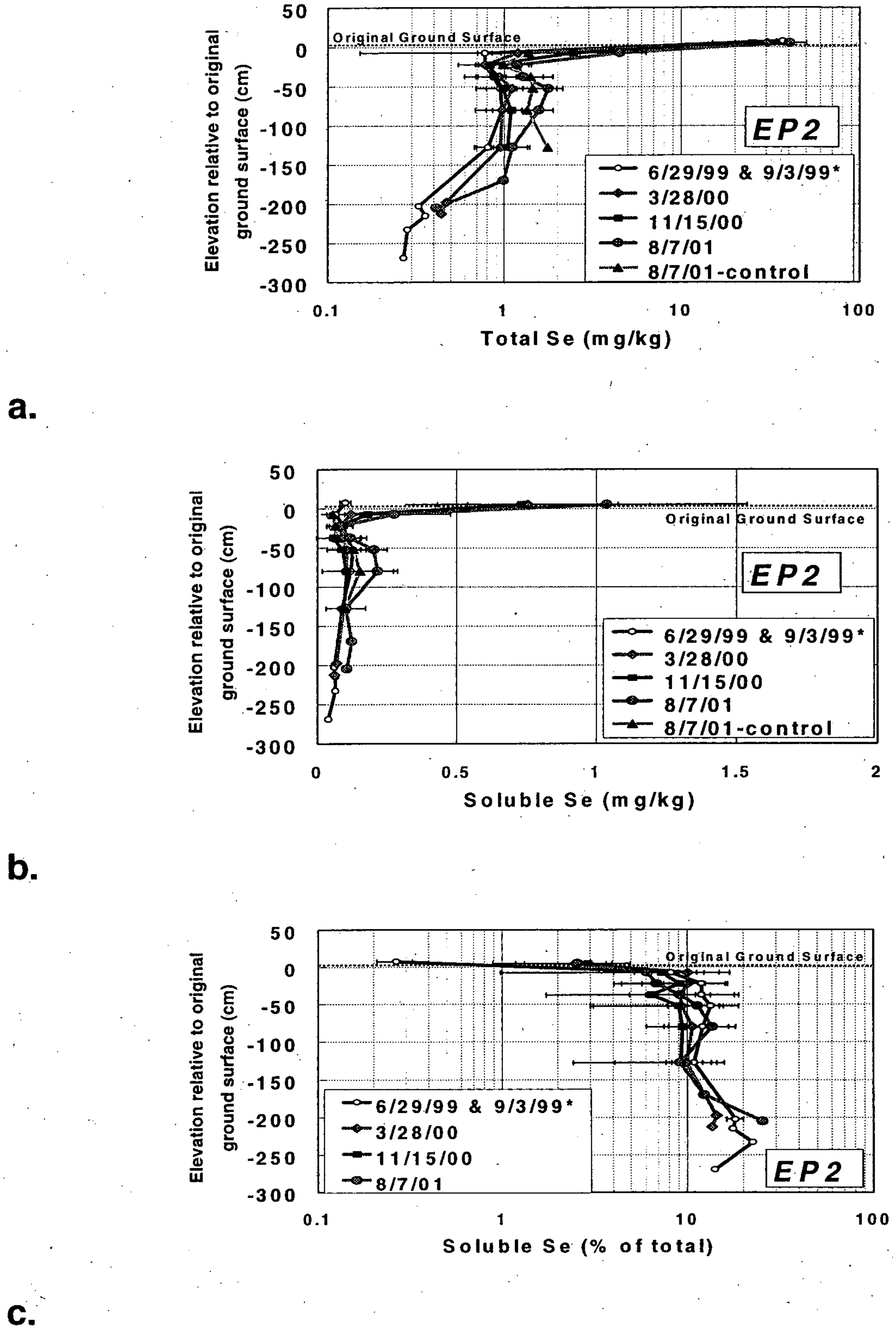


Figure 9: a.) Total, b.) water-soluble, and c.) percent water-soluble Se concentrations normalized to soil mass in EP -2. Error bars represent one standard deviation on either side of the mean.

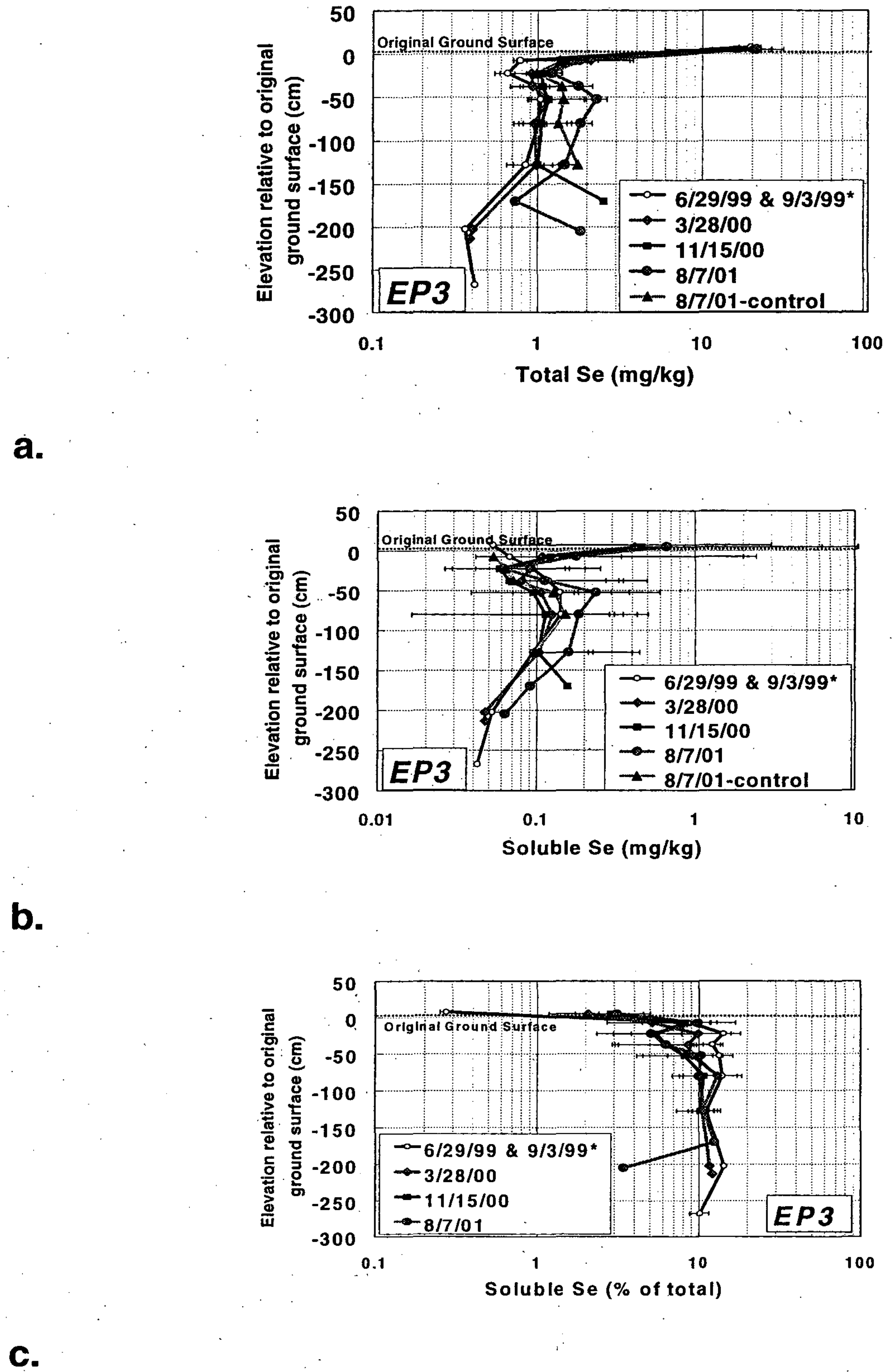


Figure 10: a.) Total, b.) water-soluble, and c.) percent water-soluble Se concentrations normalized to soil mass in EP-3. Error bars represent one standard deviation on either side of the mean.

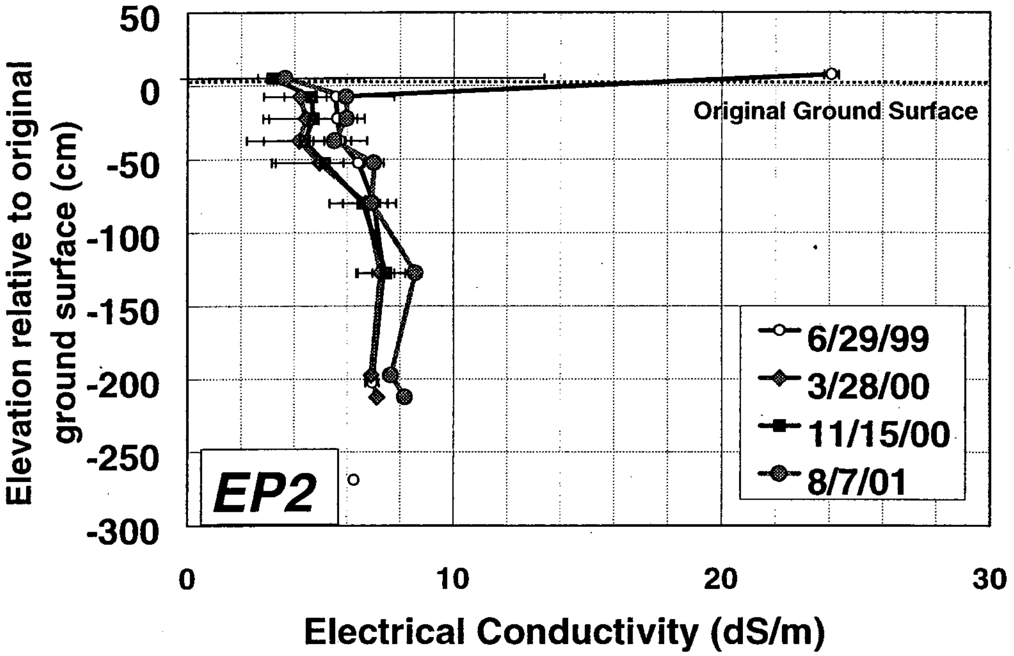


Figure 11: Electrical conductivity in water extracts of soils collected in EP-2. Error bars represent one standard deviation on either side of the mean.

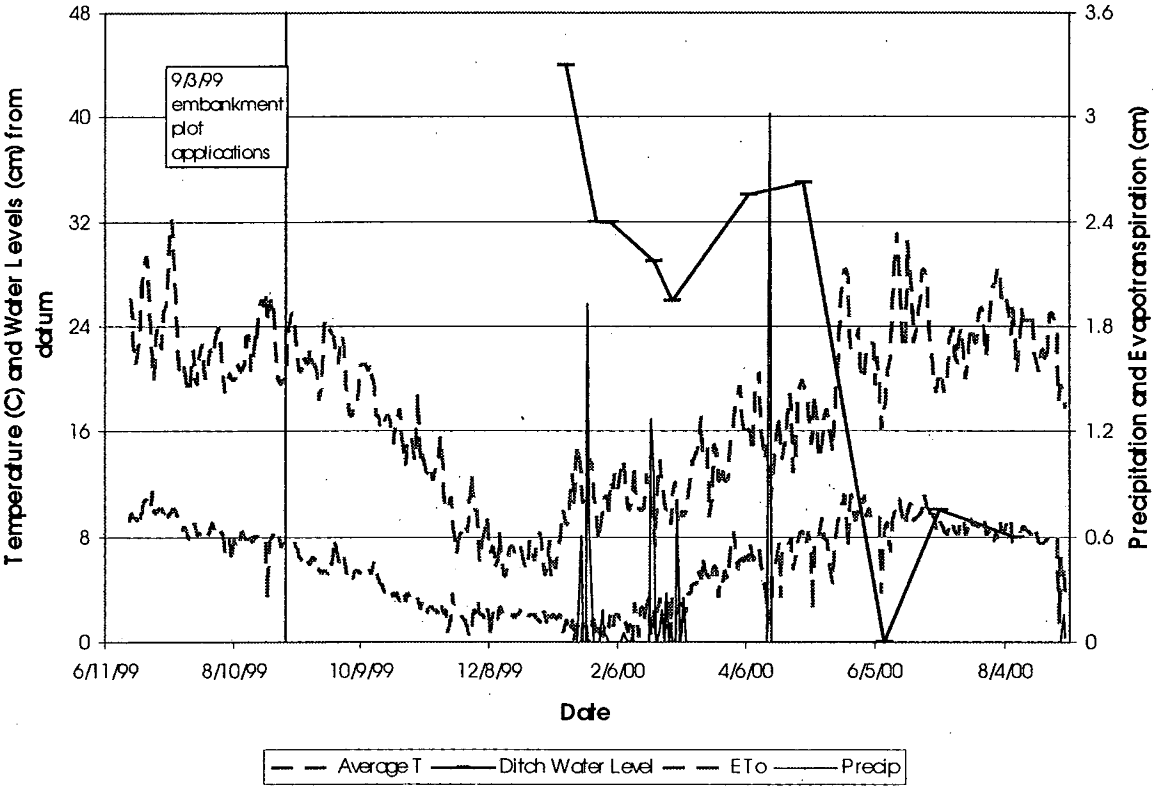


Figure 12: Daily weather records and ditch water levels at the embankment plots.

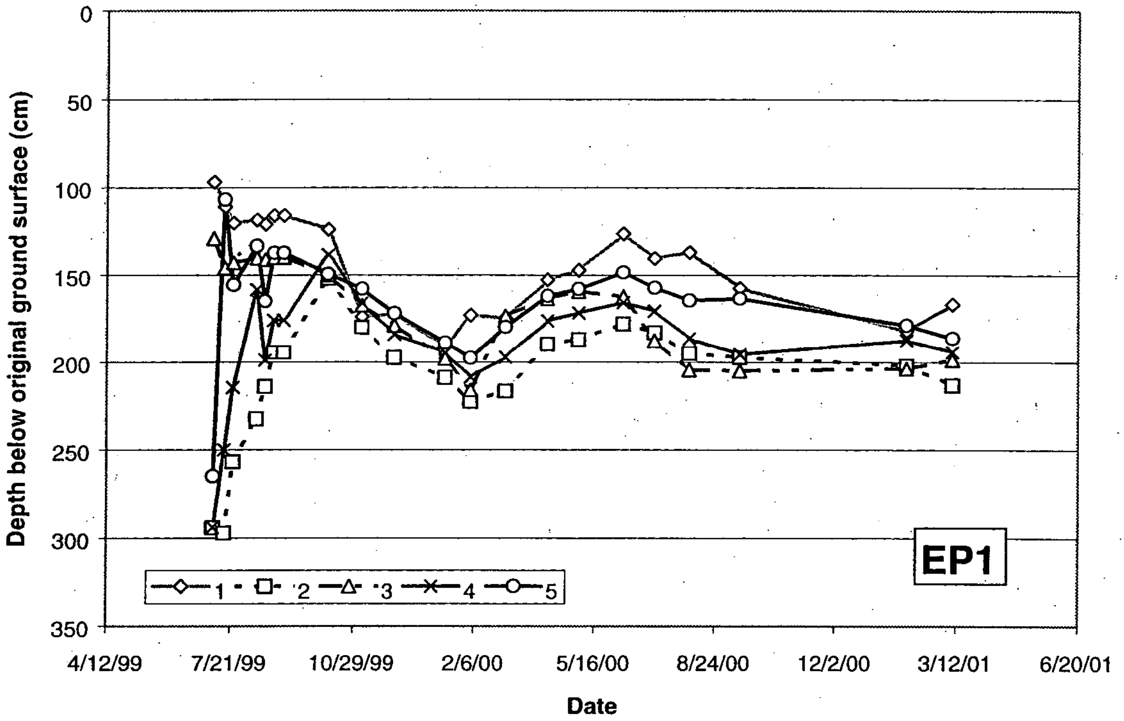


Figure 13: Depth to groundwater at EP-1.

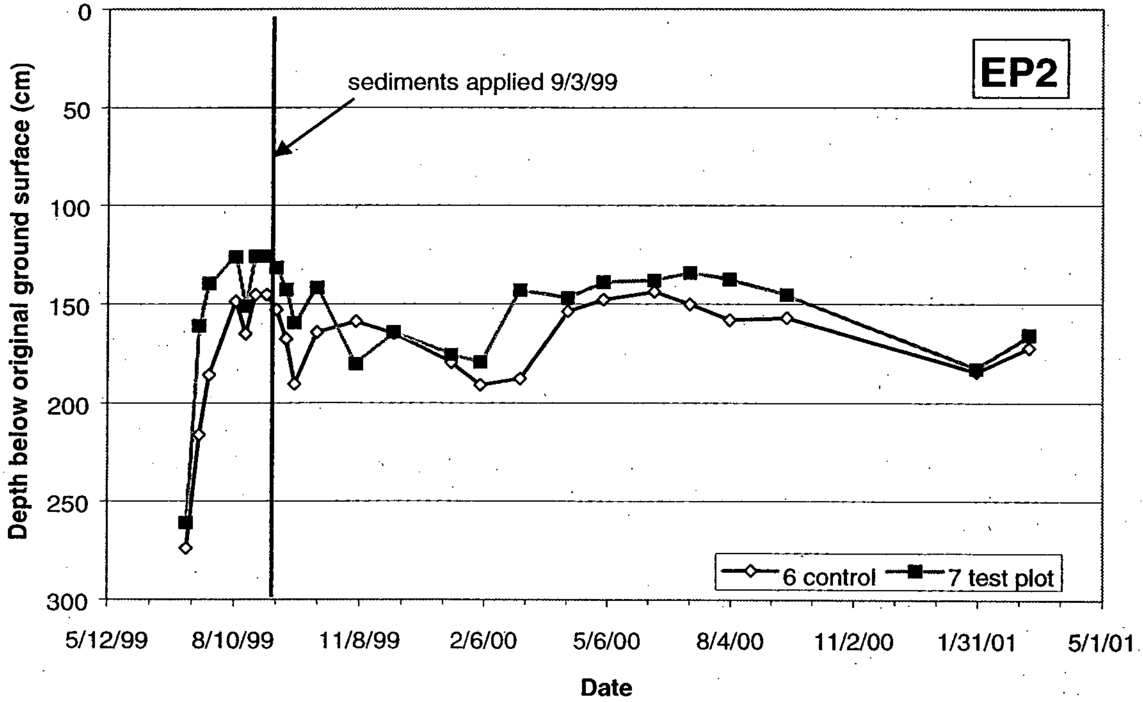


Figure 14: Depth to groundwater at EP-2.

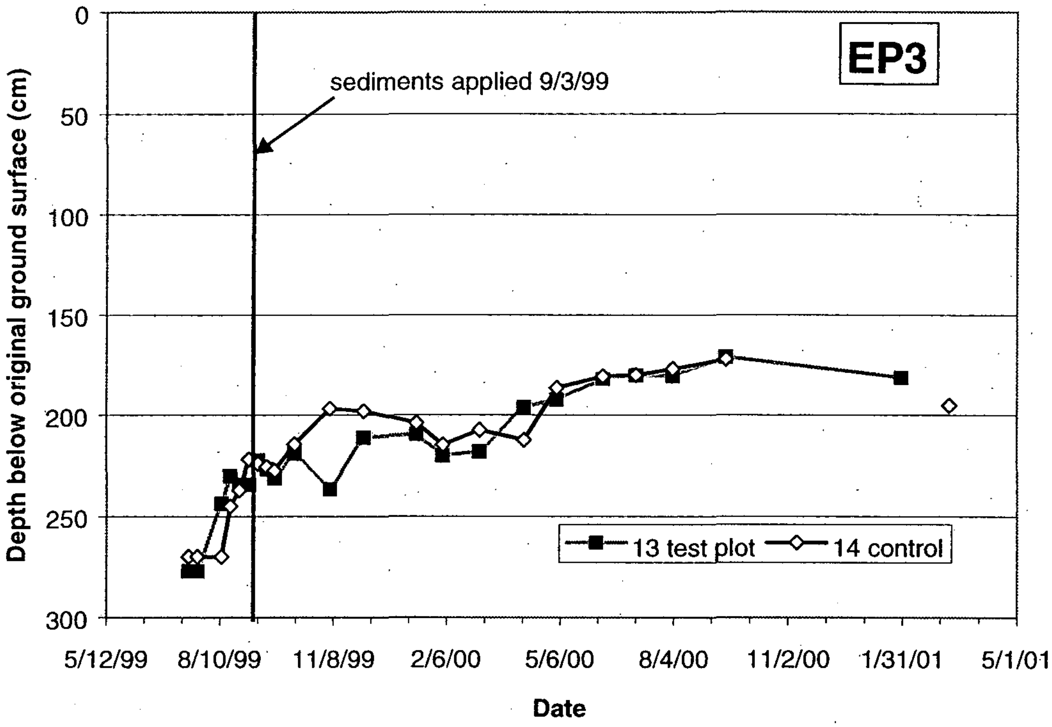


Figure 15: Depth to groundwater at EP-3.

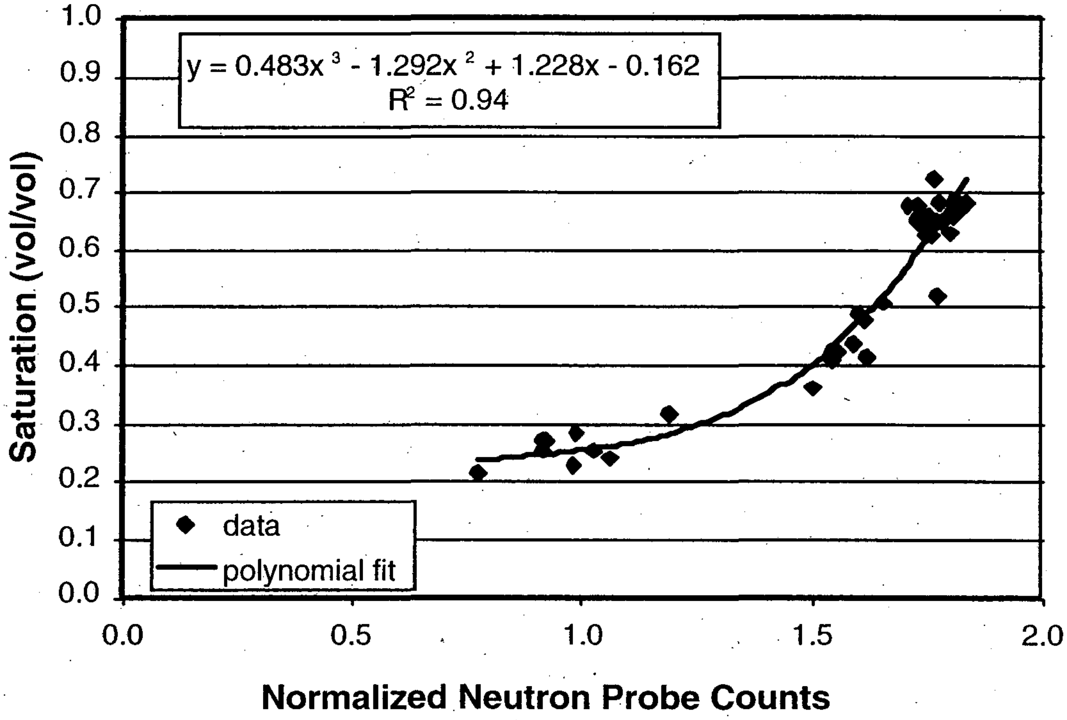


Figure 16: Calibration curve and equation for neutron probe counts in EP soil.

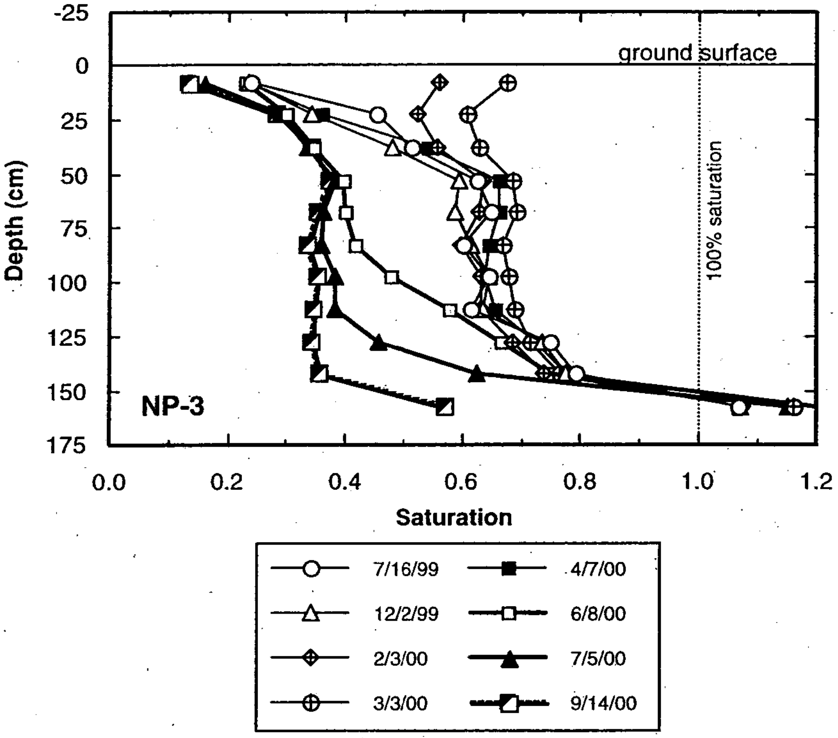


Figure 17: Sediment profile saturation at EP-1 (access hole NP-3) based on neutron probe measurements.

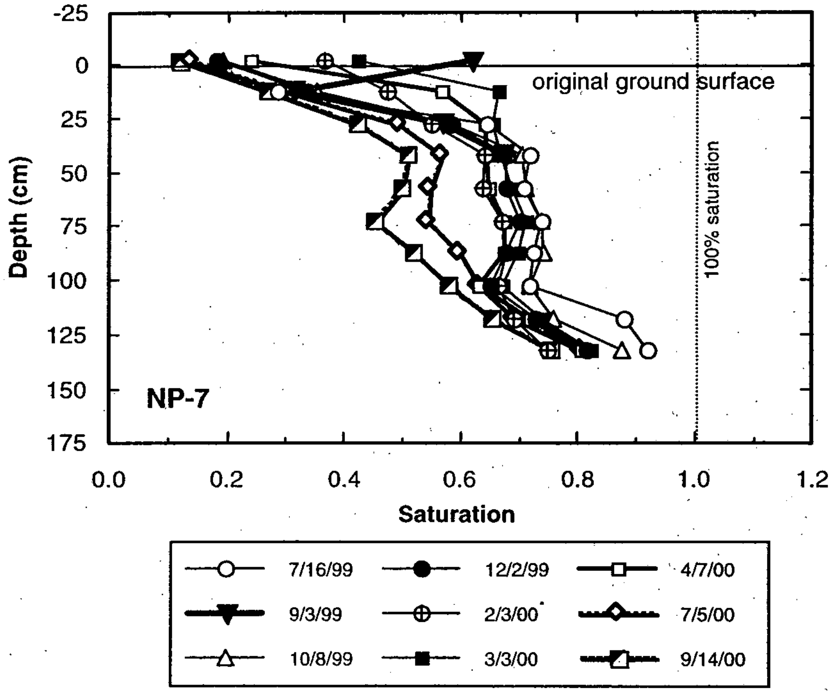


Figure 18: Sediment profile saturation at EP-2 (access hole NP-7) based on neutron probe measurements.

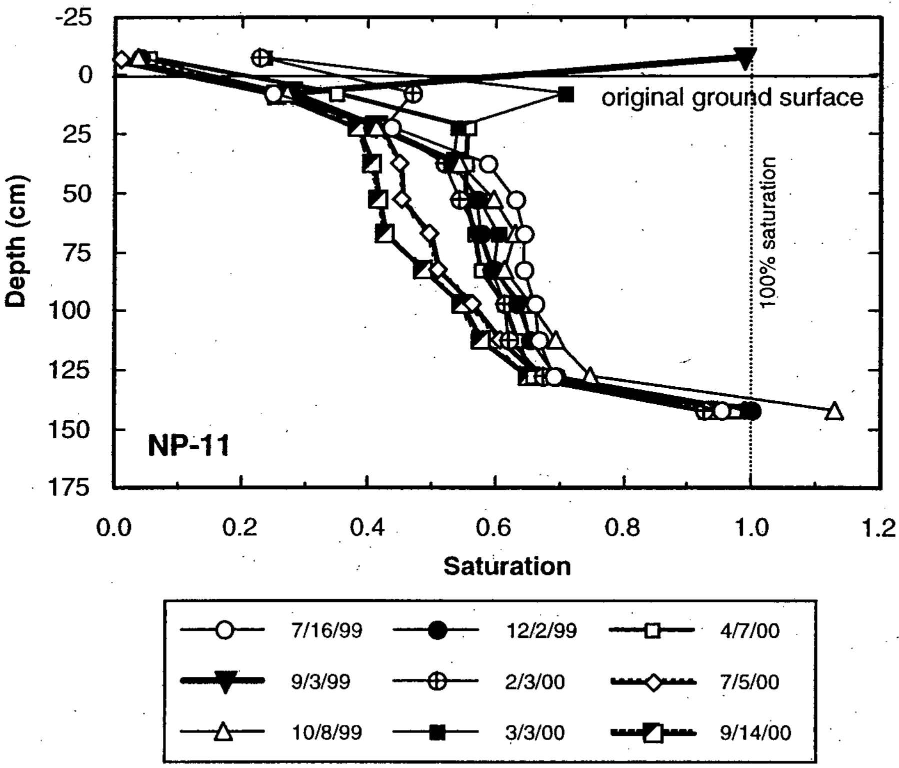


Figure 19: Sediment profile saturation at EP-3 (access hole NP-11) based on neutron probe measurements.

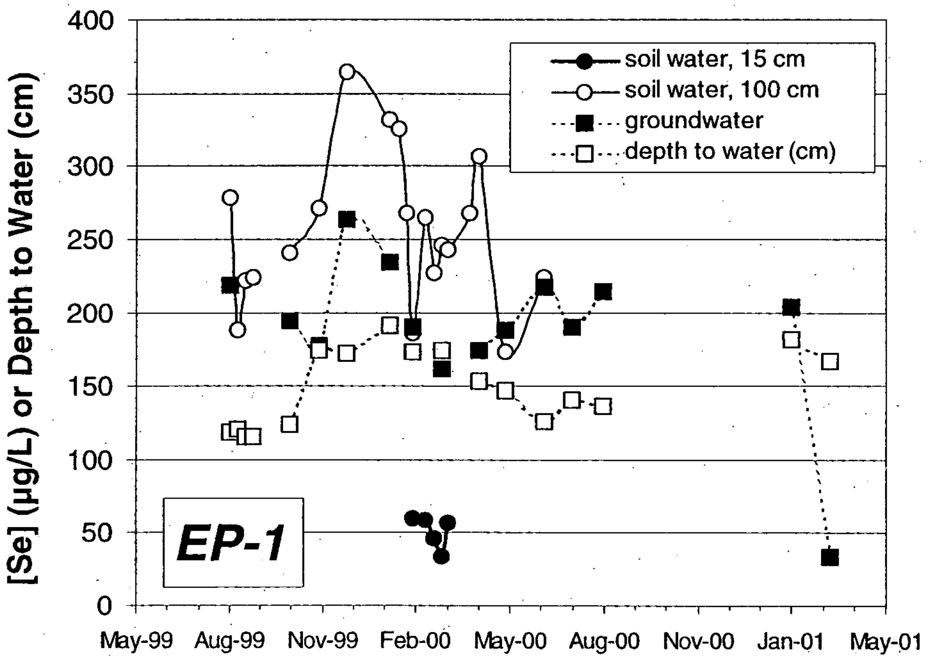


Figure 20: Soil water and groundwater Se and depth to water in EP-1.

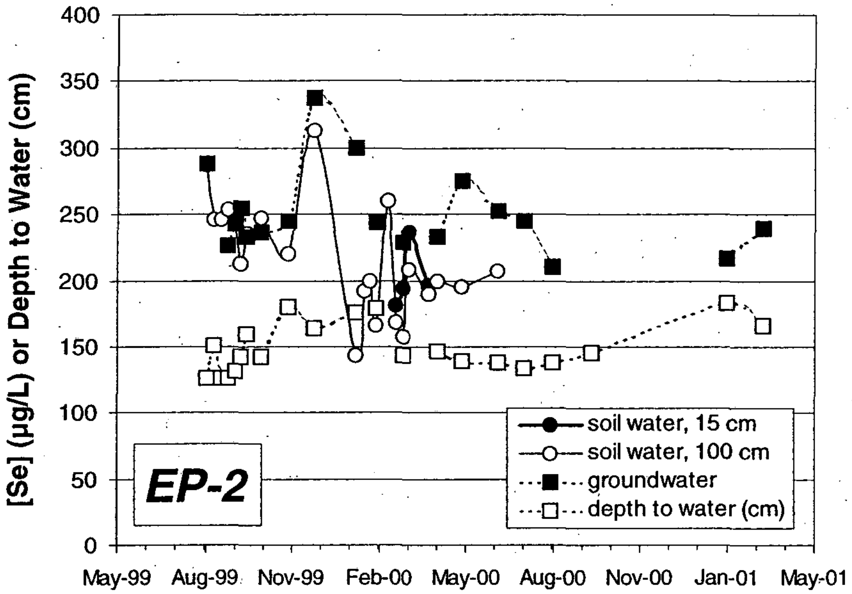


Figure 21: Soil water and groundwater Se and depth to water in EP-2.

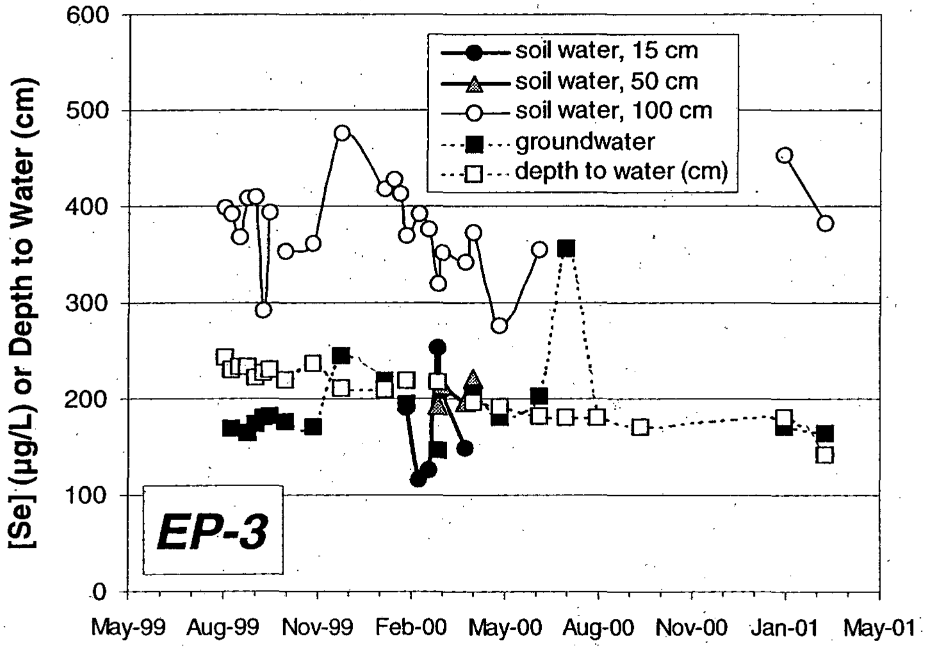


Figure 22: Soil water and groundwater Se and depth to water in EP-3.

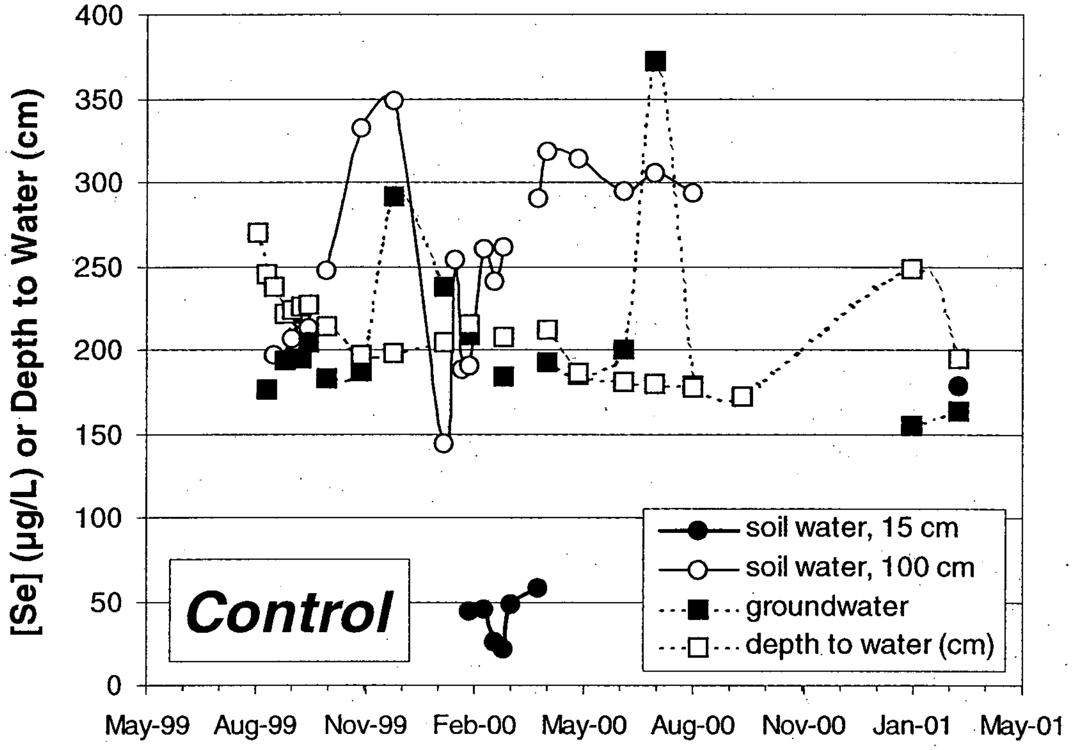


Figure 23: Soil water and groundwater Se and depth to water in the embankment control plot.

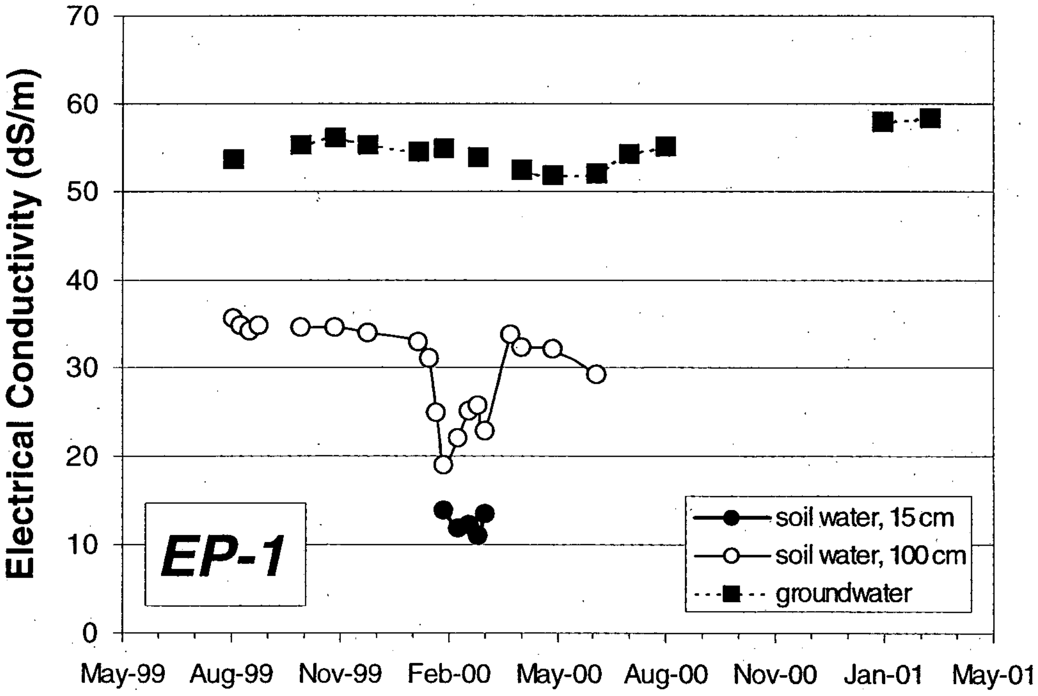


Figure 24: Soil water and groundwater electrical conductivity in EP-1.

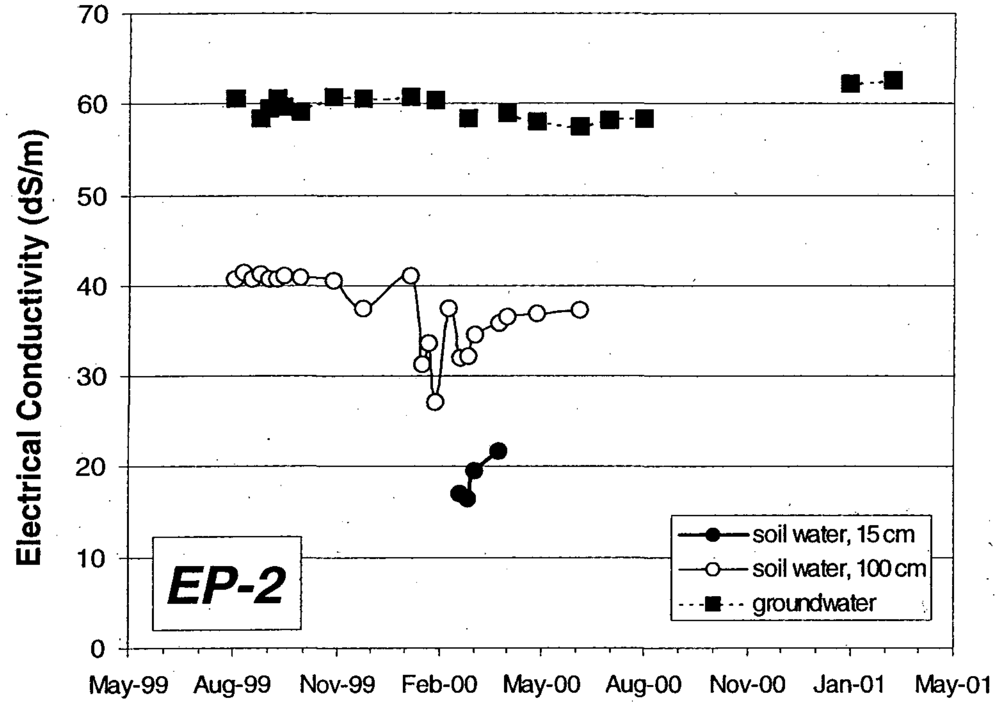


Figure 25: Soil water and groundwater electrical conductivity in EP-2.

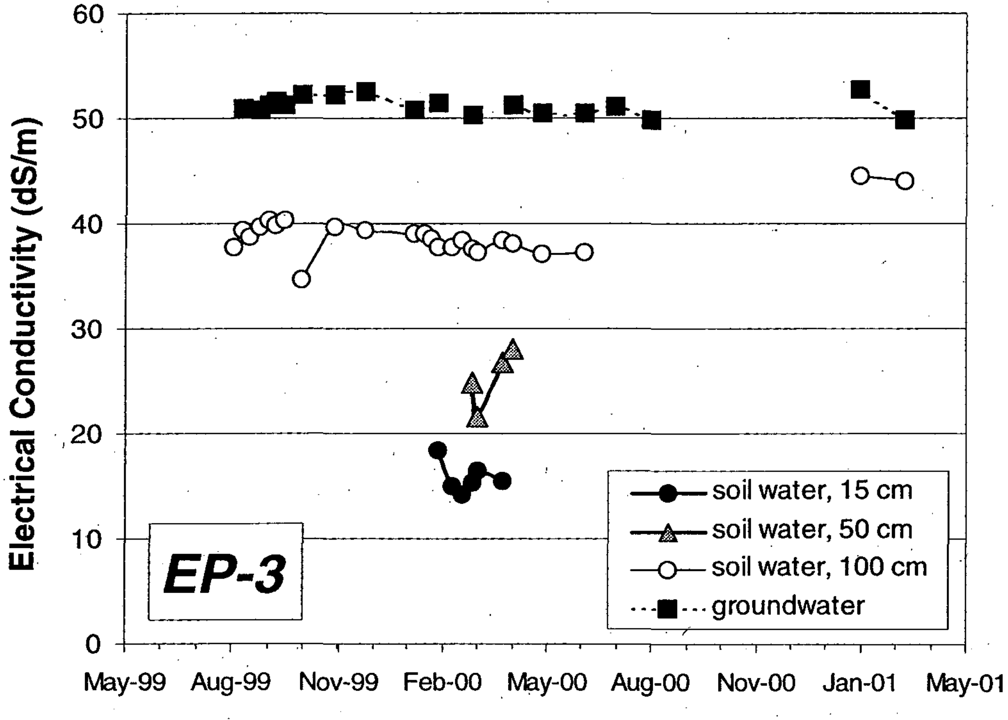


Figure 26: Soil water and groundwater electrical conductivity in EP-3.

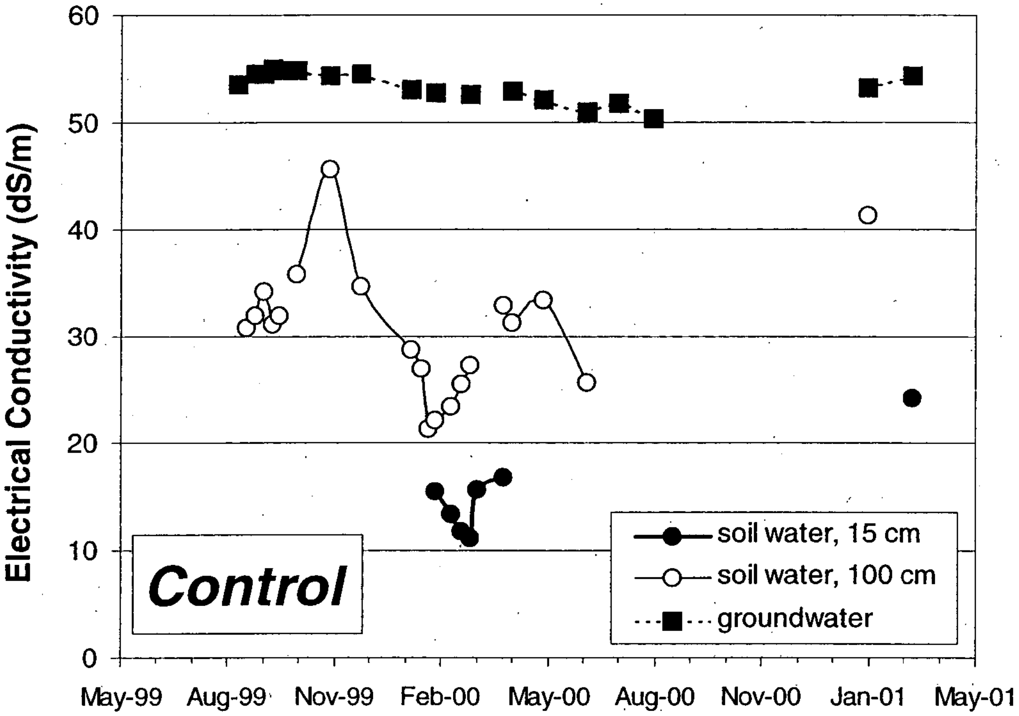


Figure 27: Soil water and groundwater electrical conductivity in the embankment control plot.

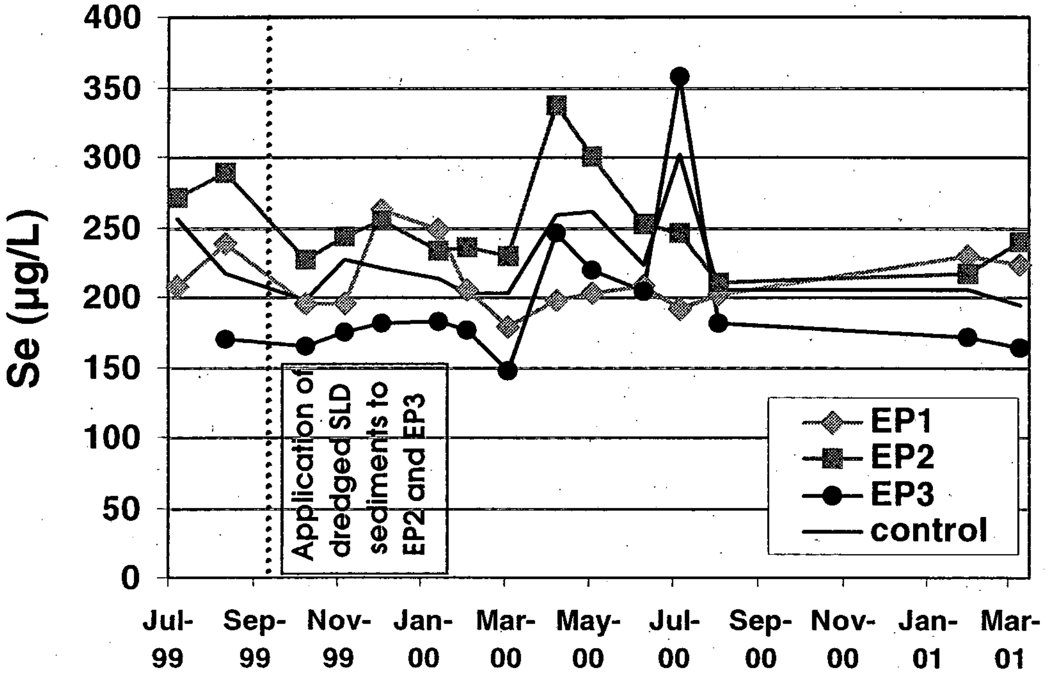


Figure 28: Groundwater Se in embankment test plot wells and in control wells.

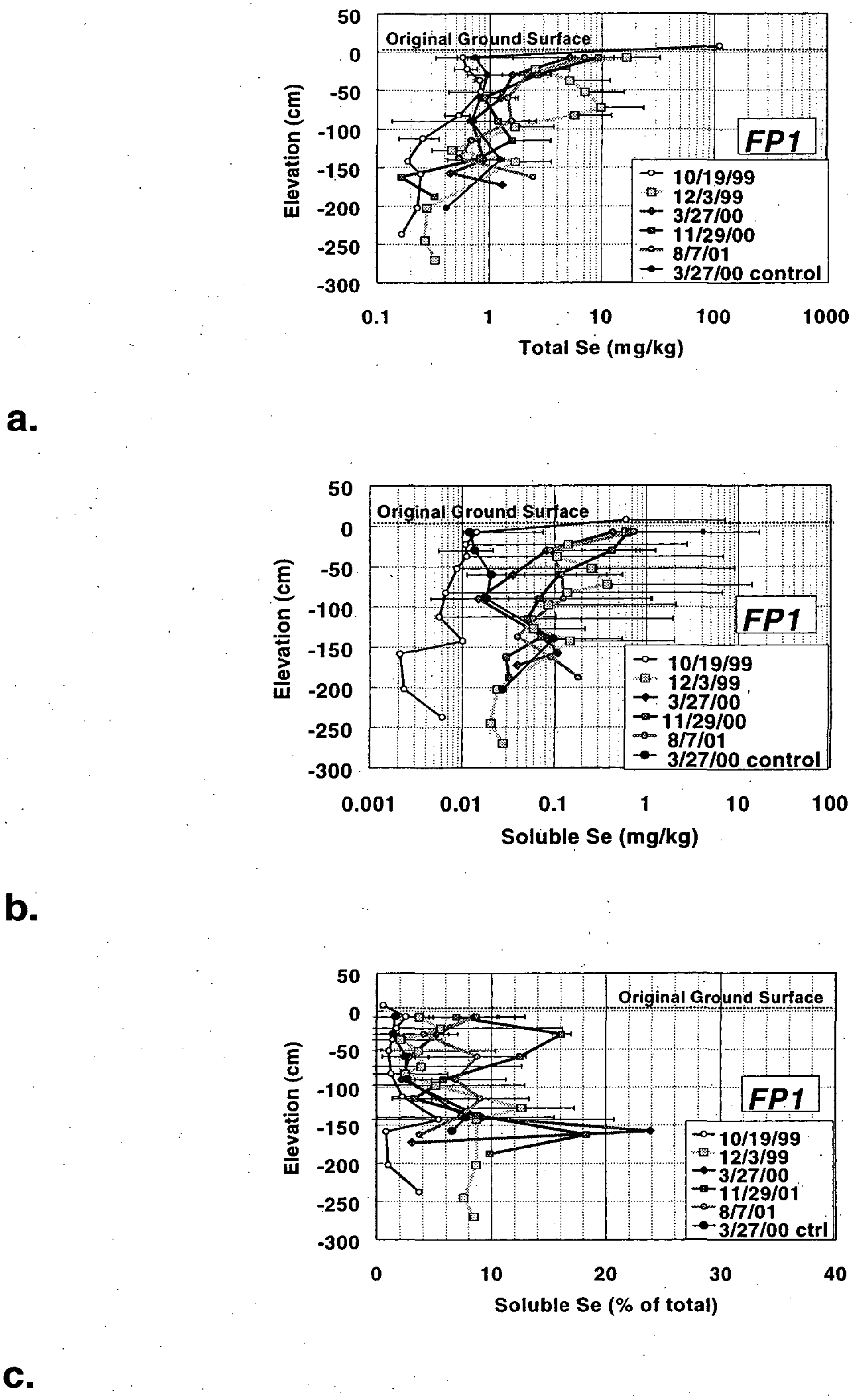


Figure 29: a.) Total, b.) water-soluble, and c.) percent water-soluble Se concentrations normalized to soil mass in FP-1. Error bars represent one standard deviation on either side of the mean.

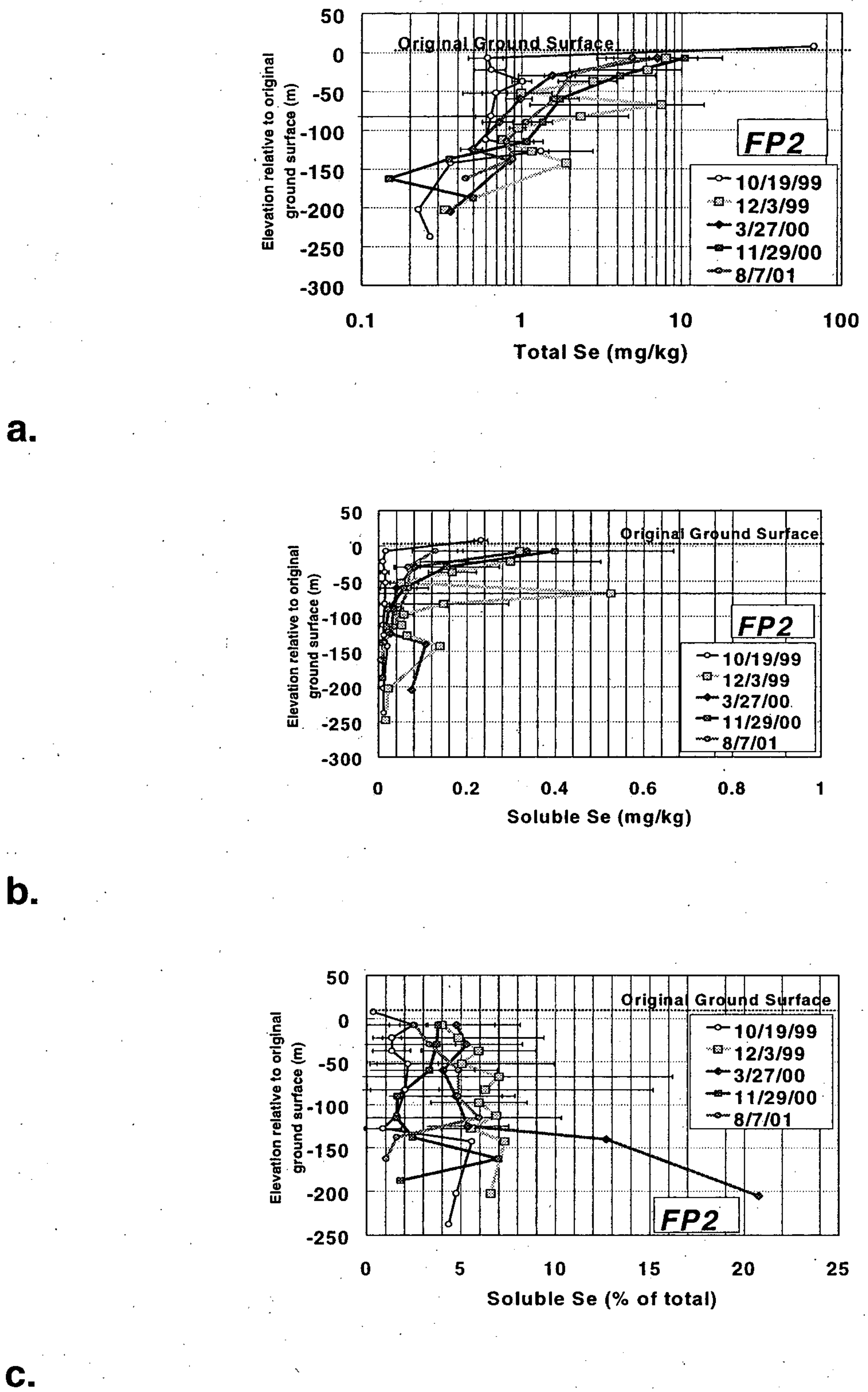


Figure 30: a.) Total, b.) water-soluble, and c.) percent water-soluble Se concentrations normalized to soil mass in FP-2. Error bars represent one standard deviation on either side of the mean.

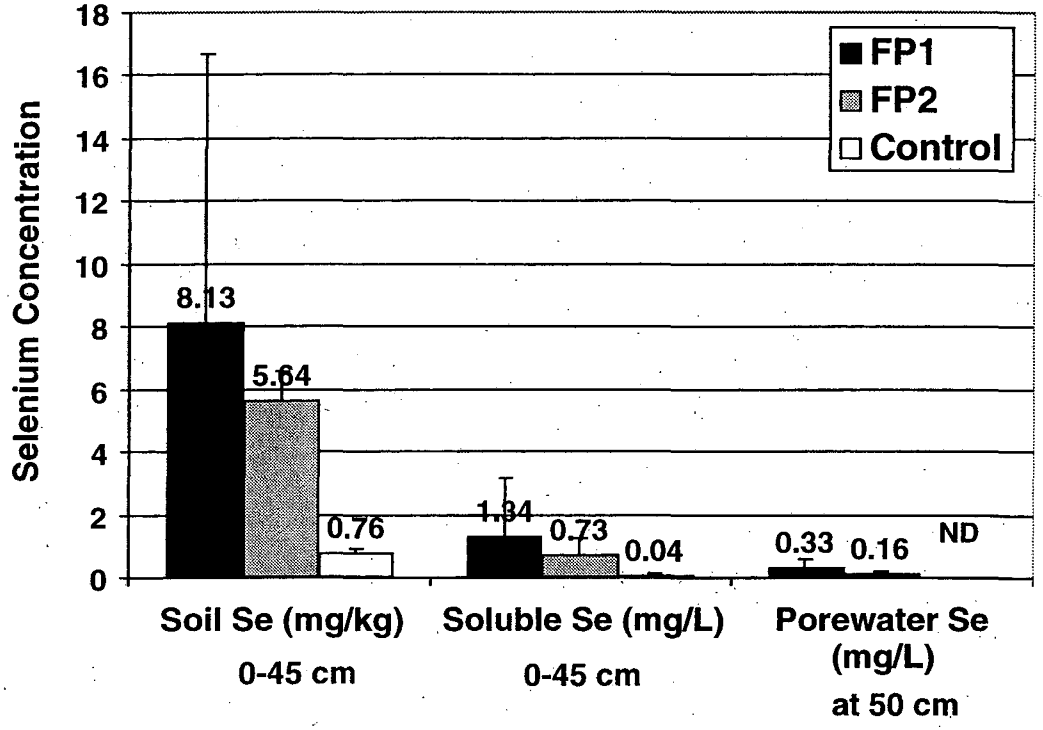


Figure 31: Total, water-soluble, and soil water Se in the Top 45 cm of FP-1, FP-2, and FP-C (control). Error bars represent one standard deviation on either side of the mean.

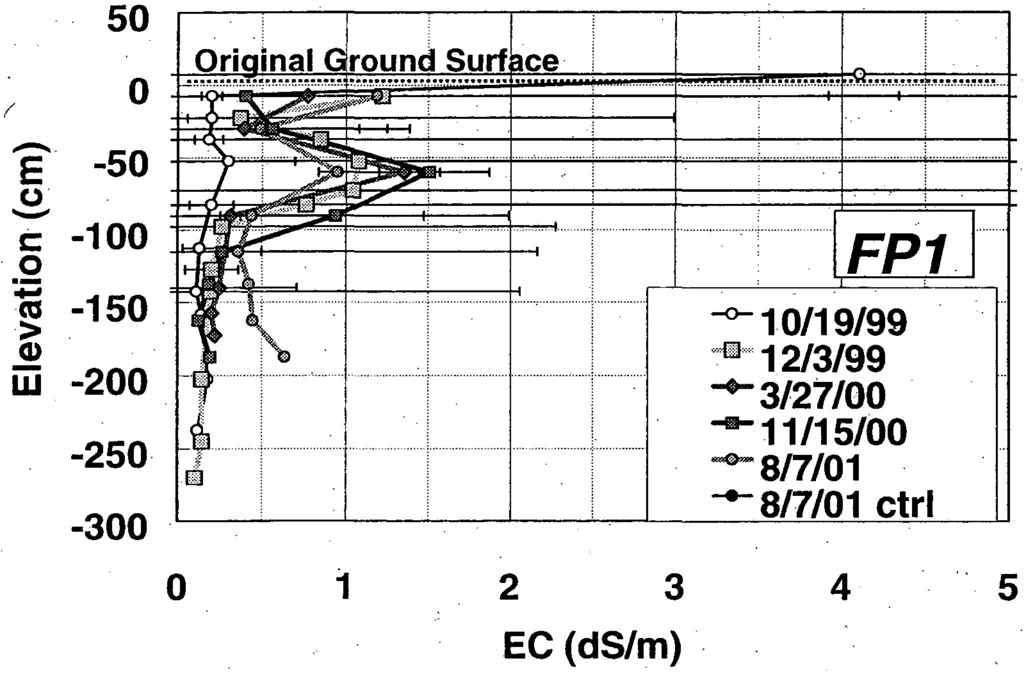


Figure 32: Electrical conductivity in water extracts of soils collected in FP-1. Error bars represent one standard deviation on either side of the mean.

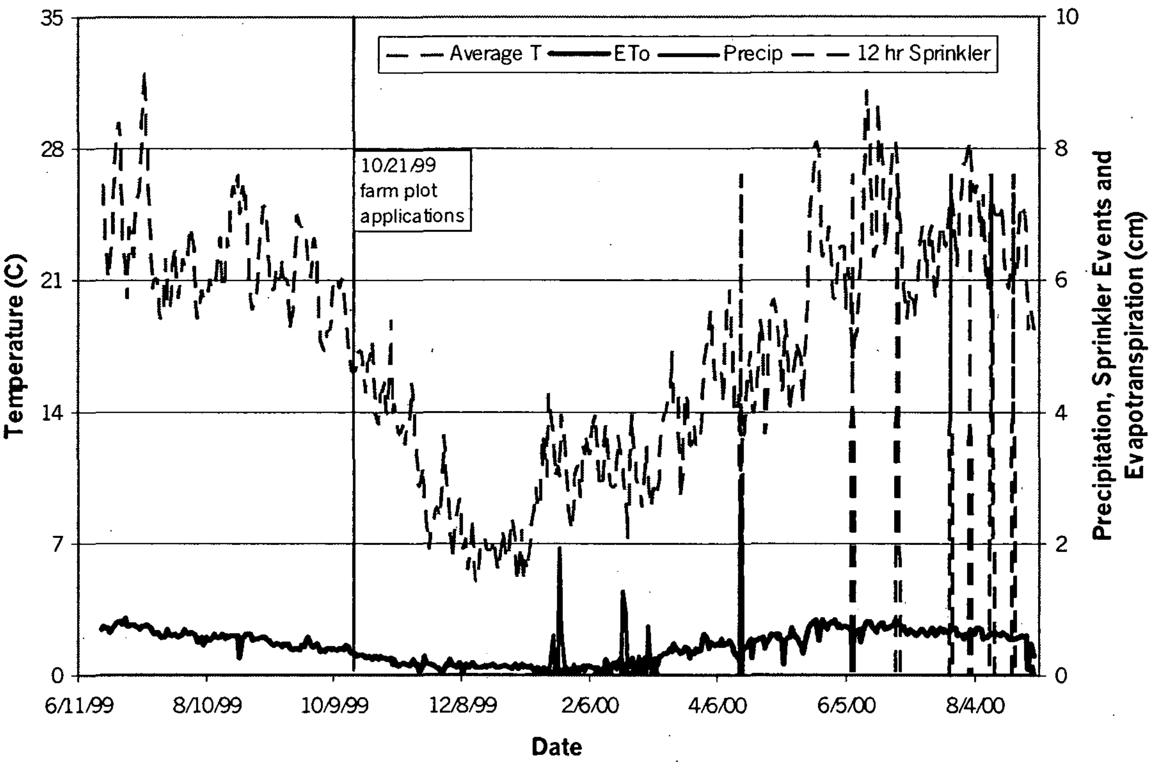


Figure 33: Daily weather records and irrigation events for farm plots.

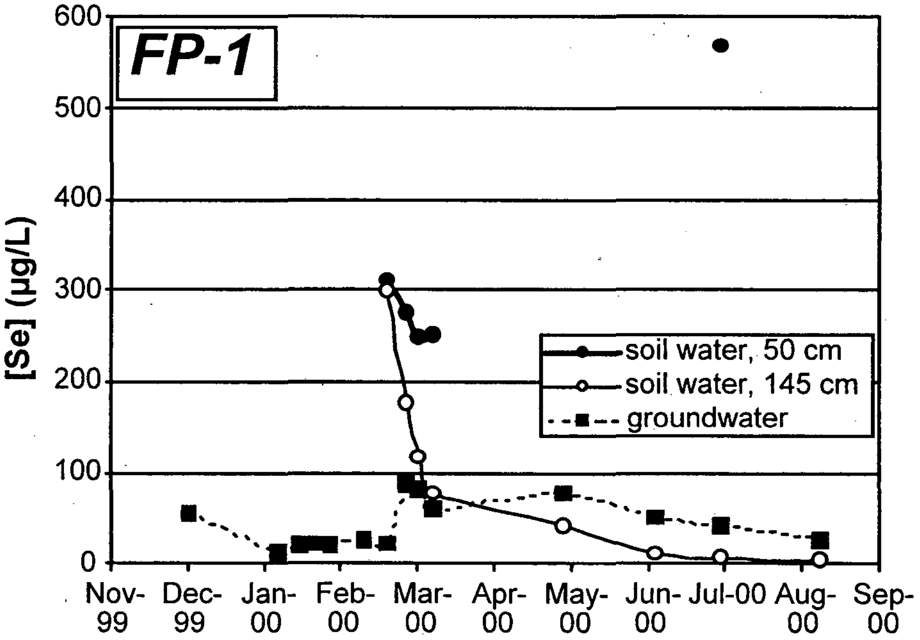


Figure 34: Soil water and groundwater Se in FP-1.

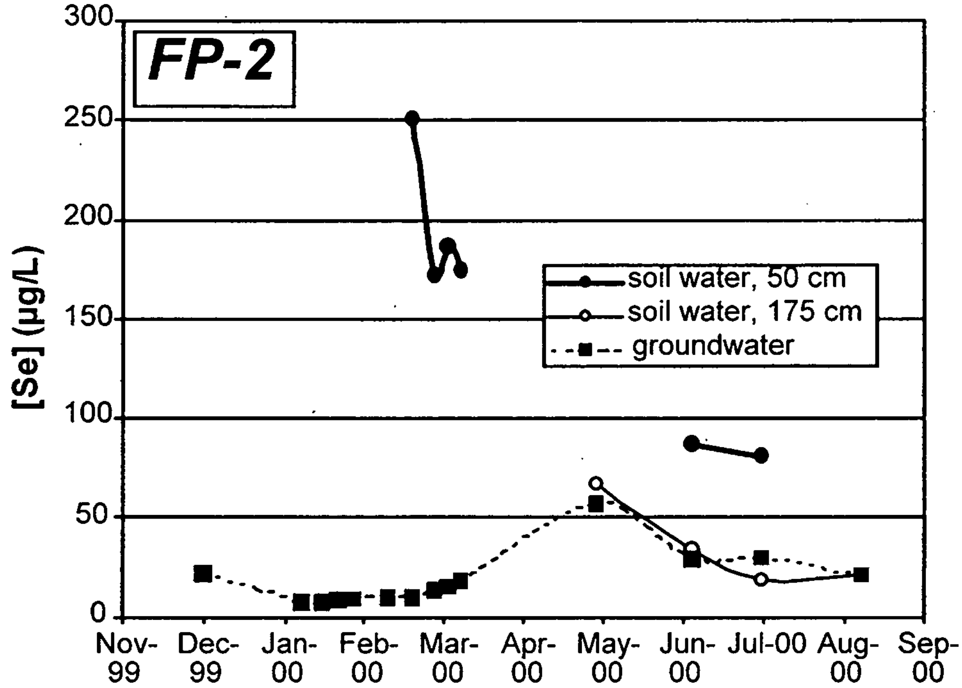


Figure 35: Soil water and groundwater Se in FP-2.

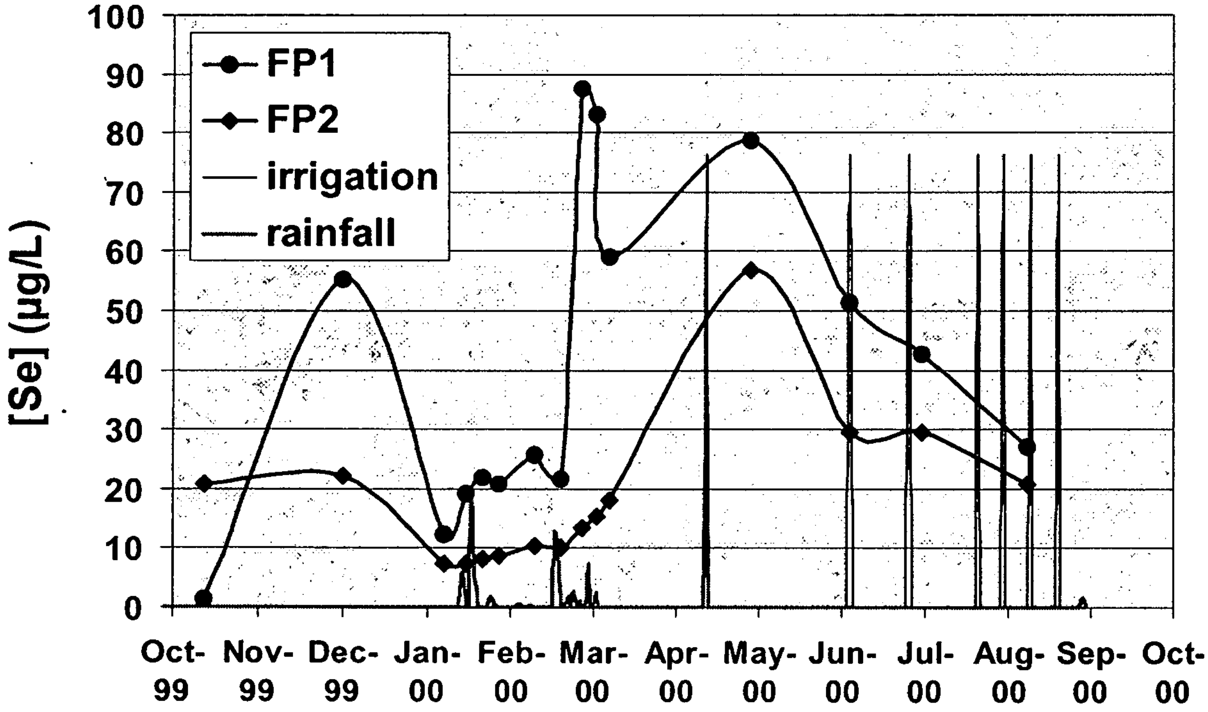


Figure 36: Groundwater Se and irrigation and rainfall events (mm) at farm plot.

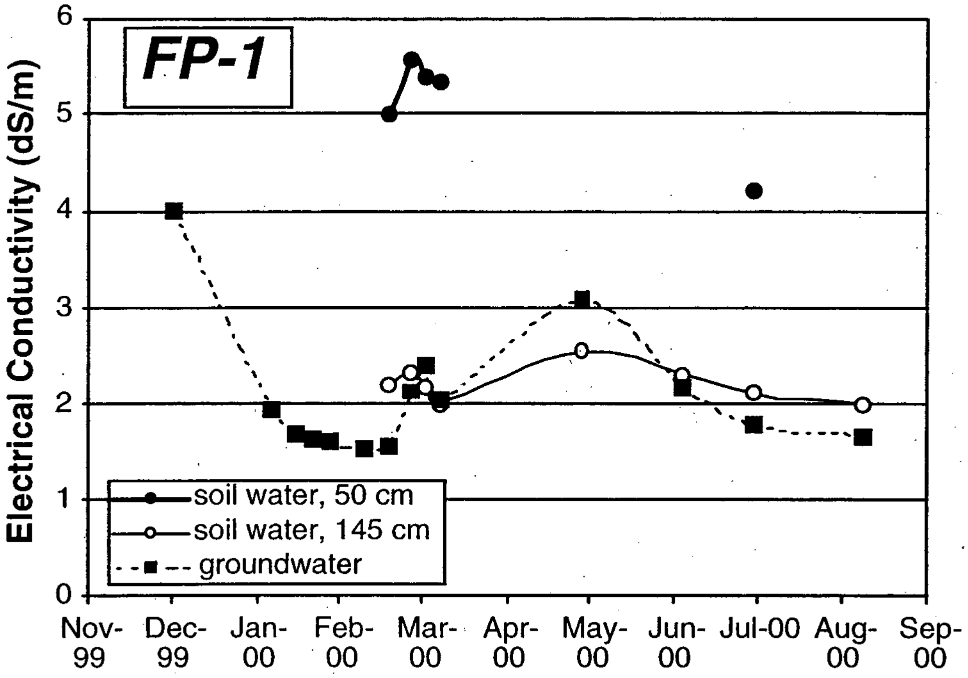


Figure 37: Soil water and groundwater electrical conductivity in FP-1.

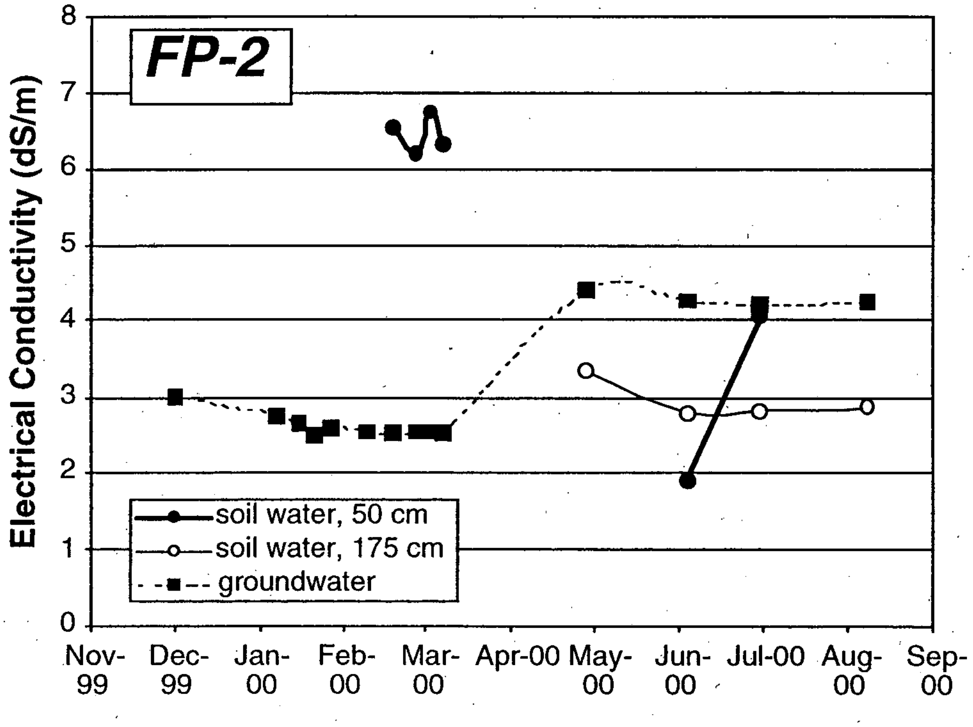


Figure 38: Soil water and groundwater electrical conductivity in FP-2.

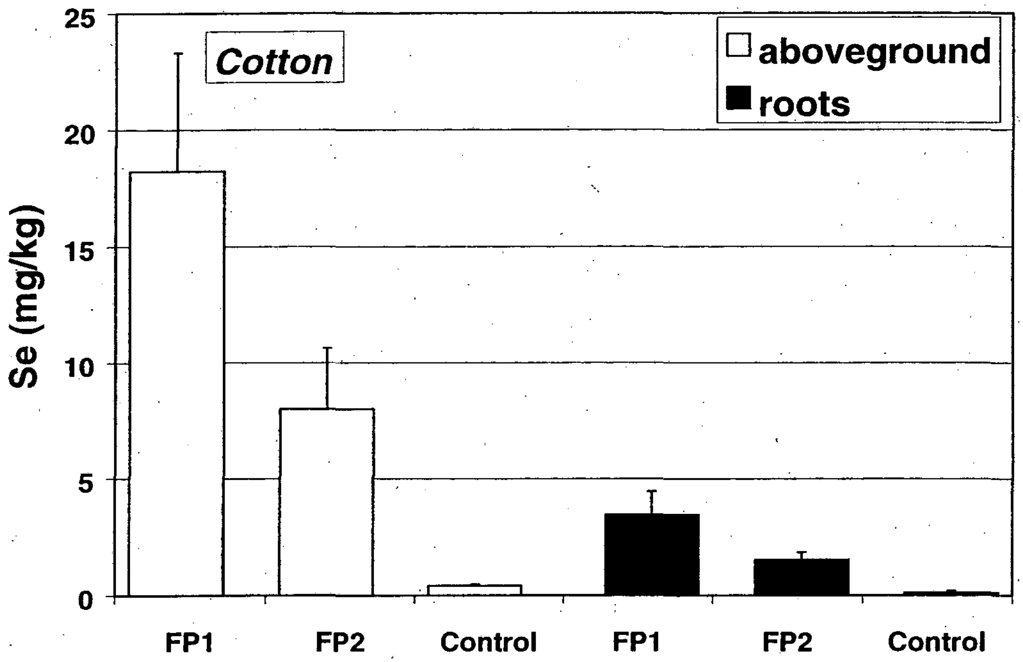


Figure 39: Average Se concentrations (±1s.d.) in cotton tissue from FP-1, FP-2, and a control area, 7/14/00.

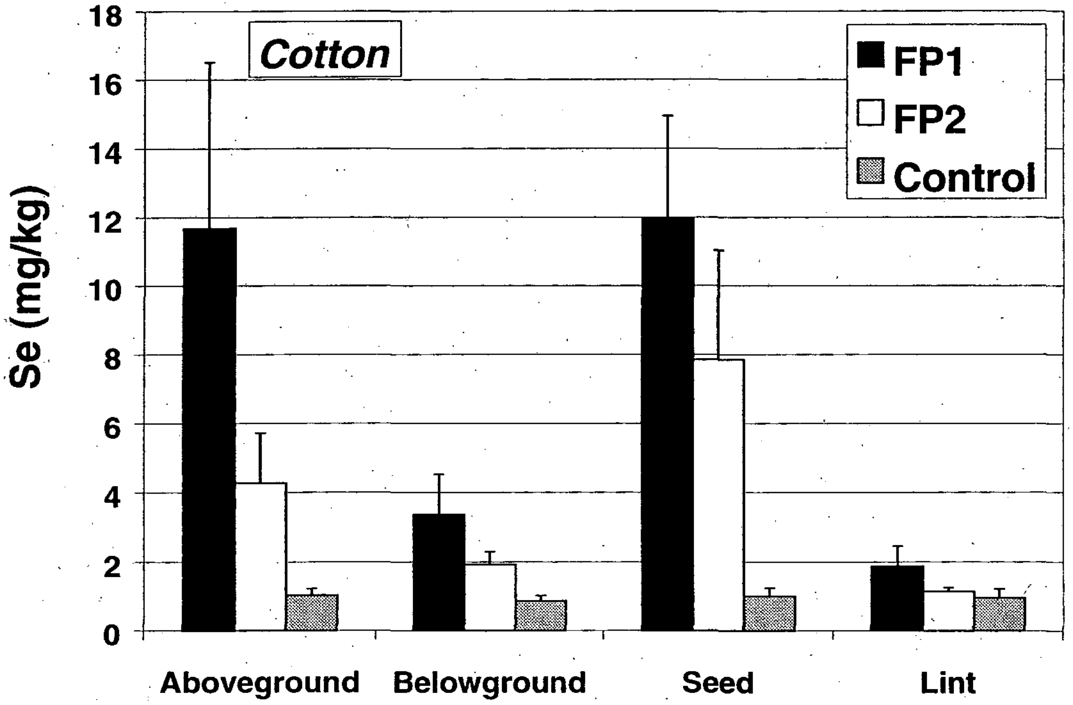


Figure 40: Average Se concentration (±1 s.d.) in aboveground parts (stems and leaves), belowground parts (roots), seeds, and lint of cotton plants from FP-1, FP-2, and a control area, 11/4/00.

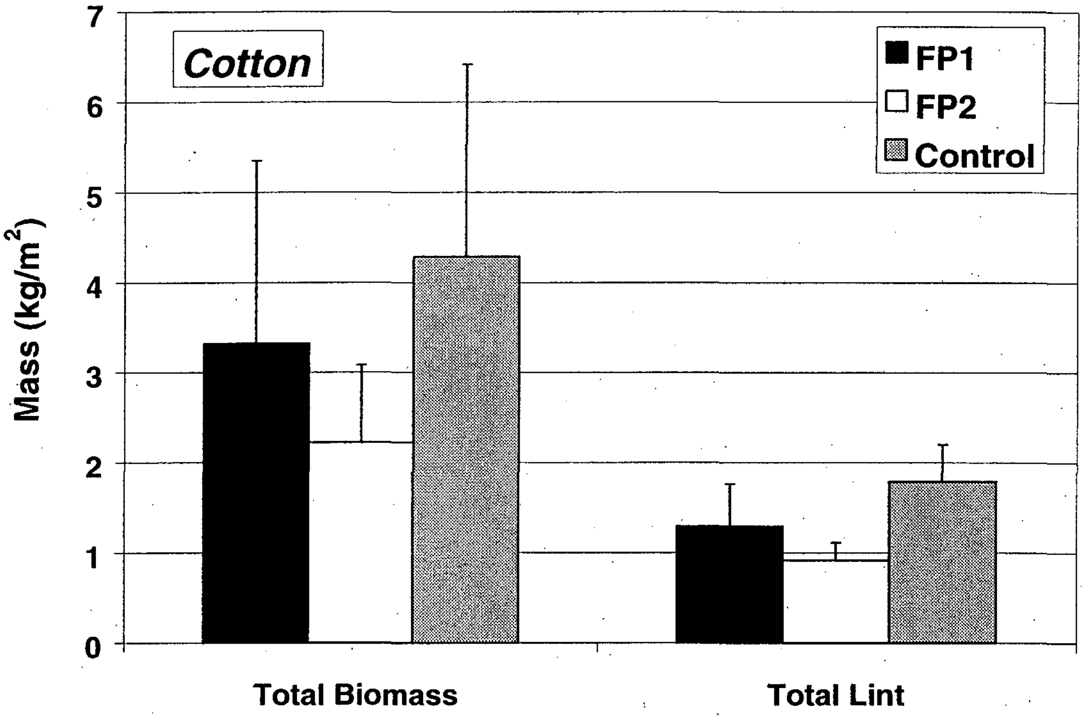


Figure 41: Average cotton biomass and cotton lint yield (±1 s.d.) in FP-1, FP-2, and a control area, 11/4/00.

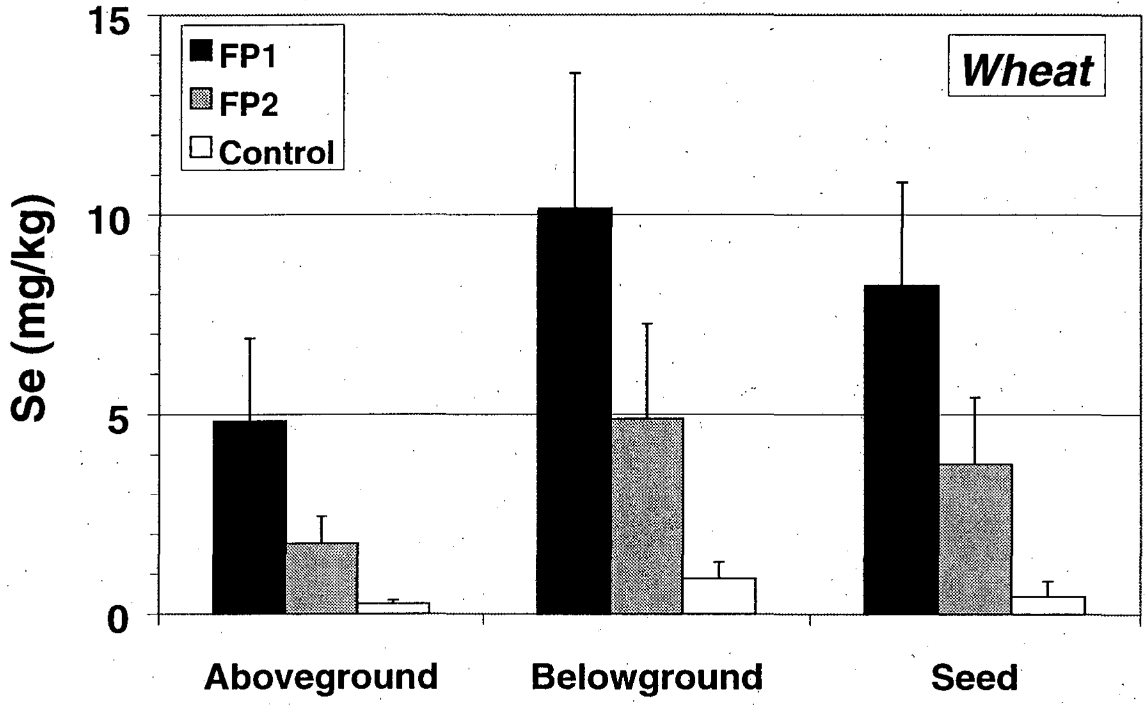


Figure 42: Se concentrations in wheat tissue in FP-1, FP-2, and a control area, 6/7/01.

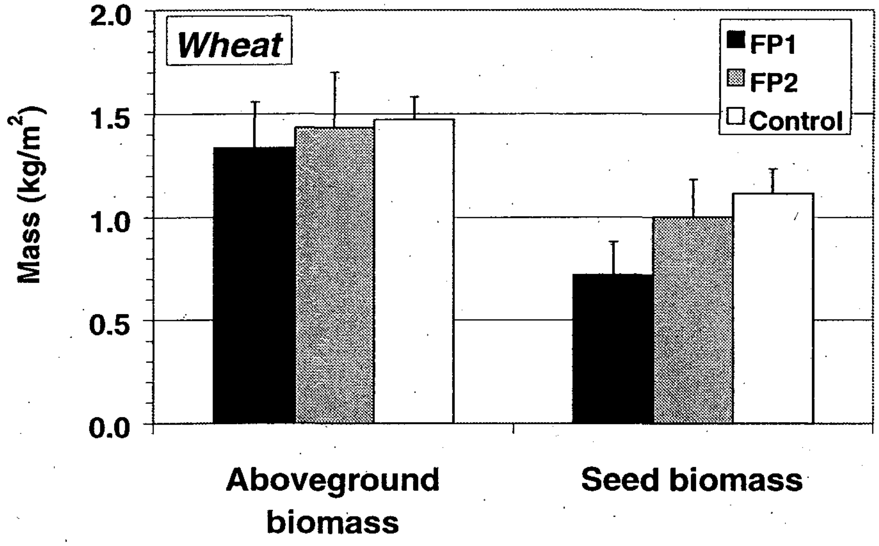


Figure 43: Average aboveground wheat and wheat seed yield (±1 s.d.) in FP-1, FP-2, and a control area, 6/7/01.

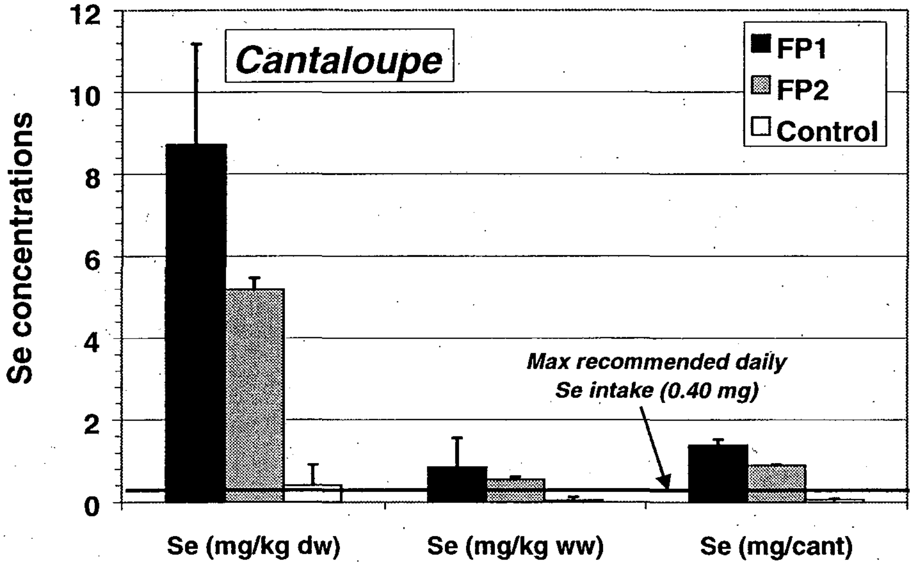


Figure 44: Average Se concentrations (±1 s.d.) in cantaloupe fruit in FP-1, FP-2, and a control area, 10/5/01. Expressed relative to dry weight (dw), wet weight (ww), and as a mass of Se per average cantaloupe.

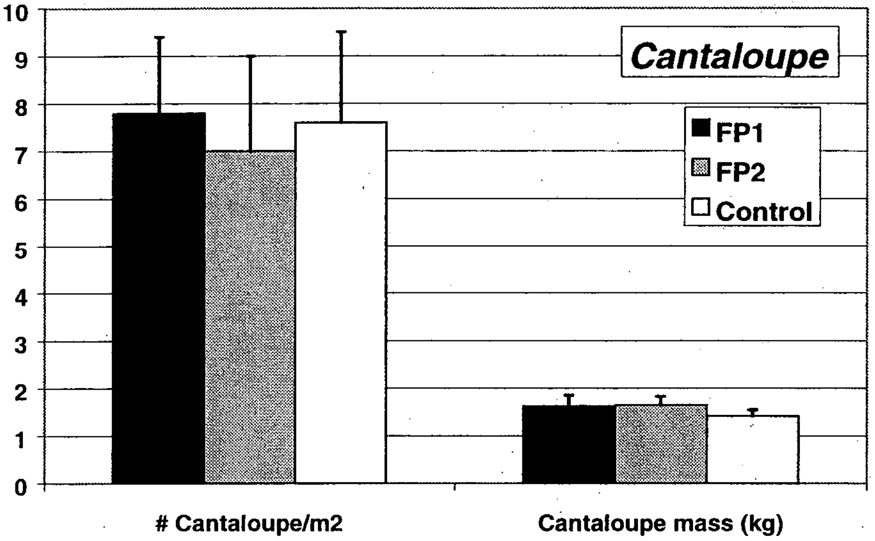


Figure 45: Average cantaloupe yield (±1 s.d.) in FP-1, FP-2, and a control area, 6/7/01. Expressed as the number of cantaloupe per m^2 and average cantaloupe mass.

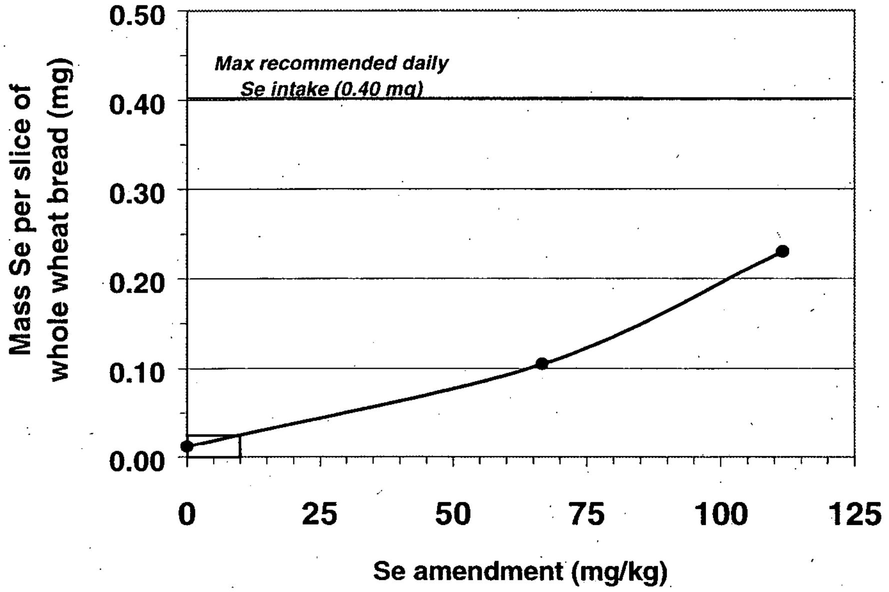


Figure 46: Mass of Se in hypothetical slice of whole wheat bread made from wheat seeds from FP-1, FP-2, and FP-C, compared with the maximum recommended daily Se intake. The box on the lower left indicates the Se concentration range of the majority of SLD sediments.

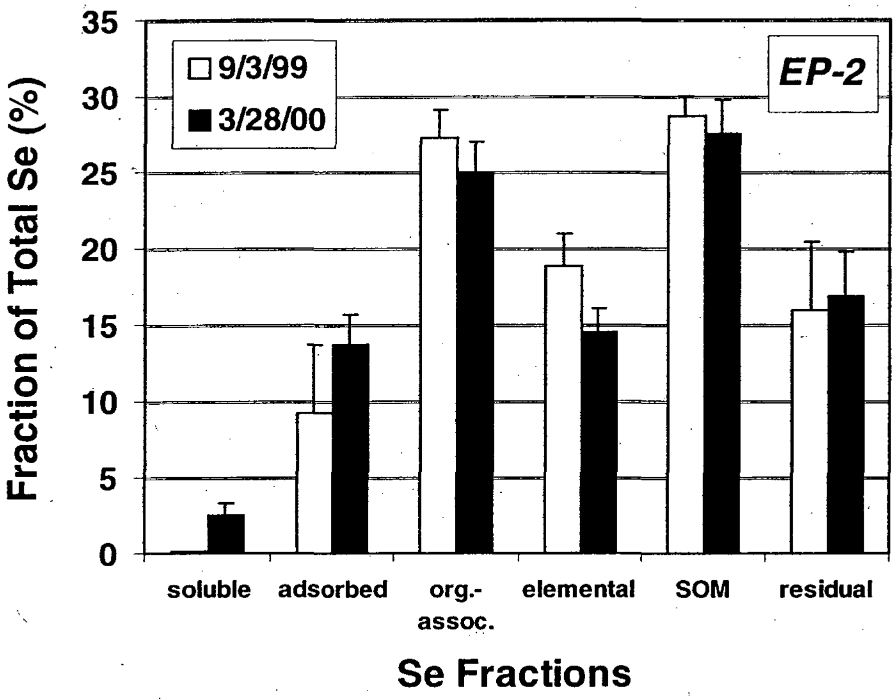


Figure 47: Se fractions in SLD sediment applied to EP-2.

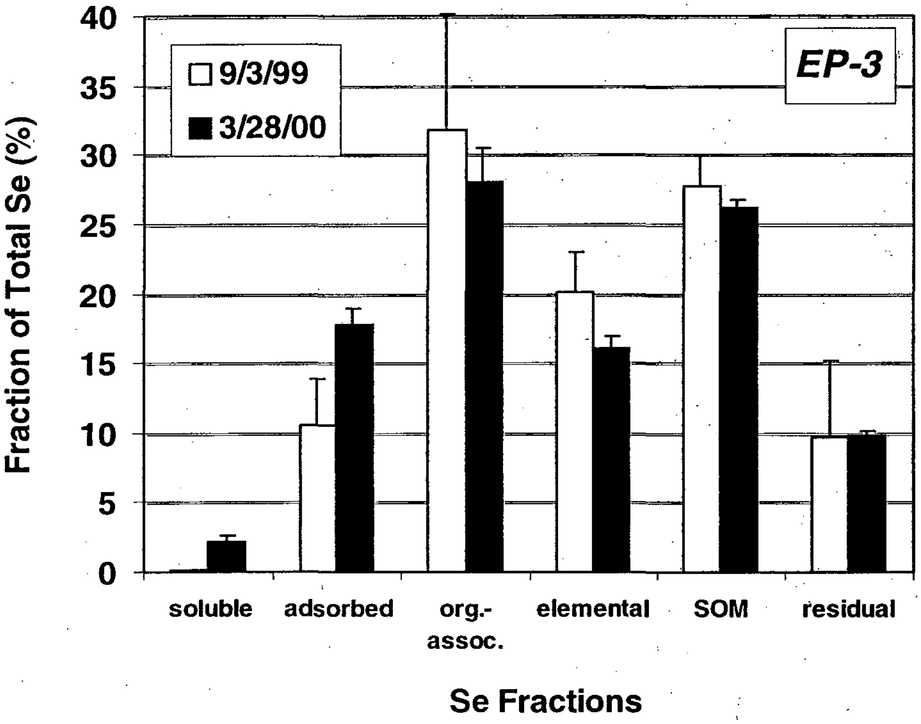


Figure 48: Se fractions in SLD sediment applied to EP-3.

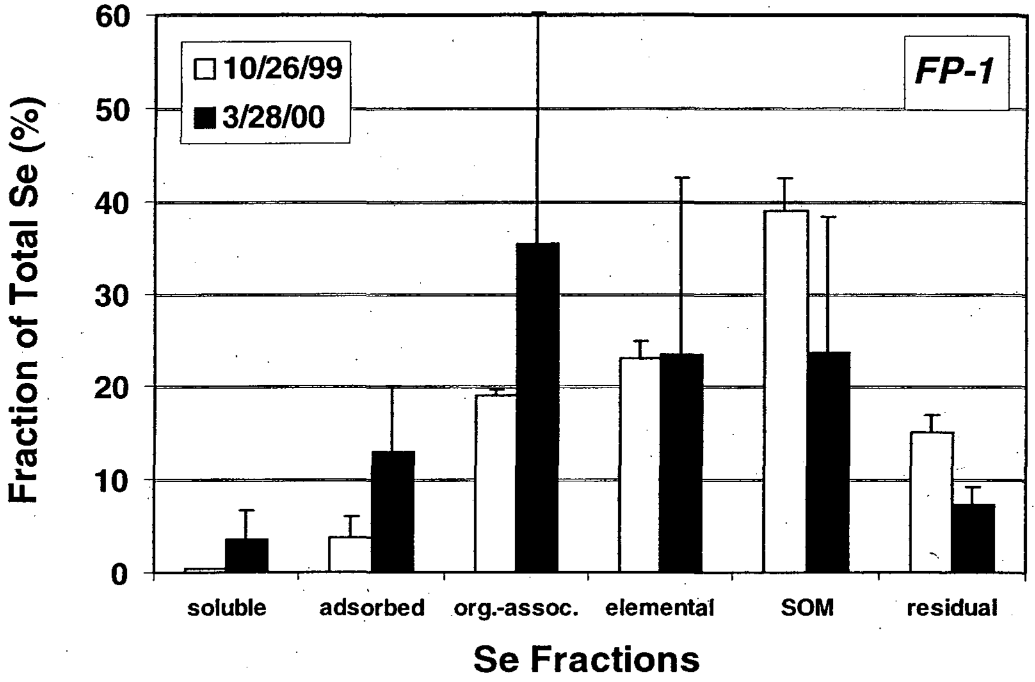


Figure 49: Se fractions in SLD sediment applied to FP-1.

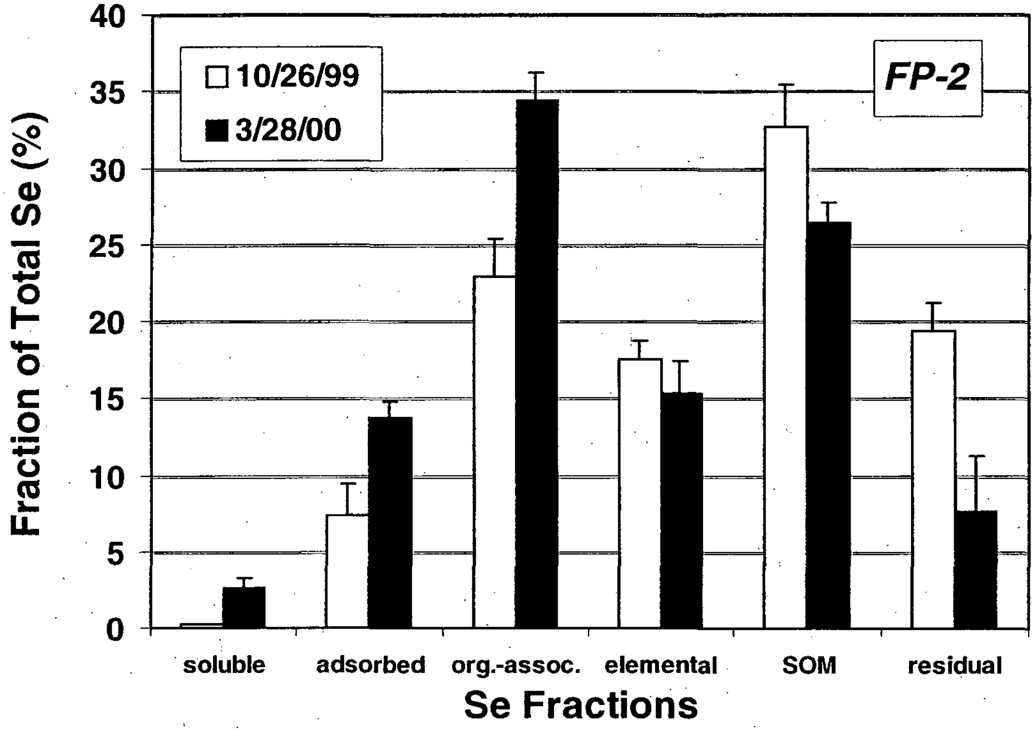


Figure 50: Se fractions in SLD sediment applied to FP-2.

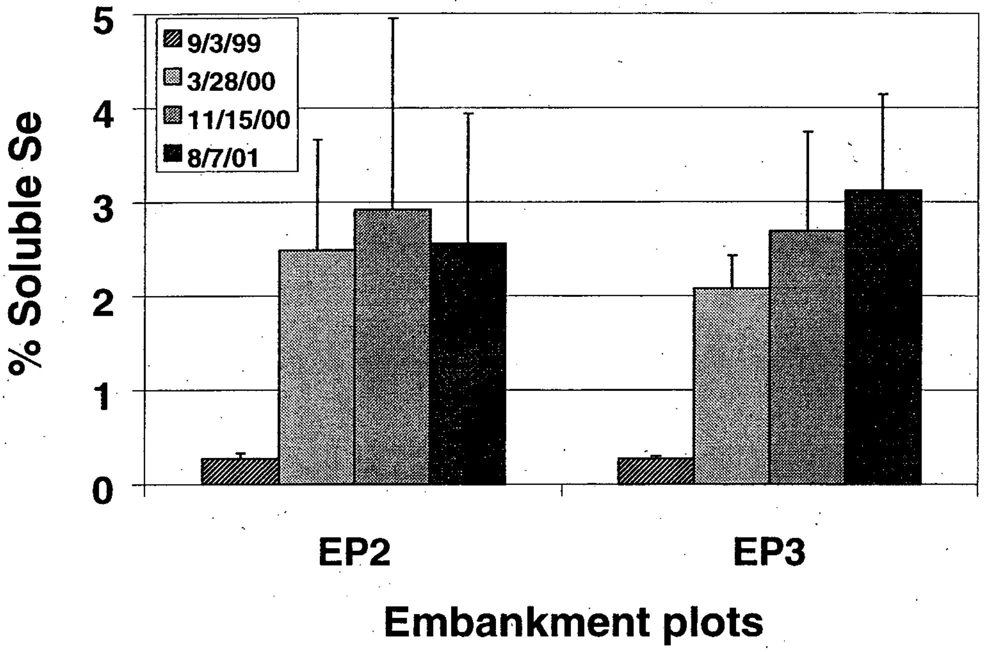


Figure 51: Se fractions in SLD sediment applied to EP-2 and EP-3.

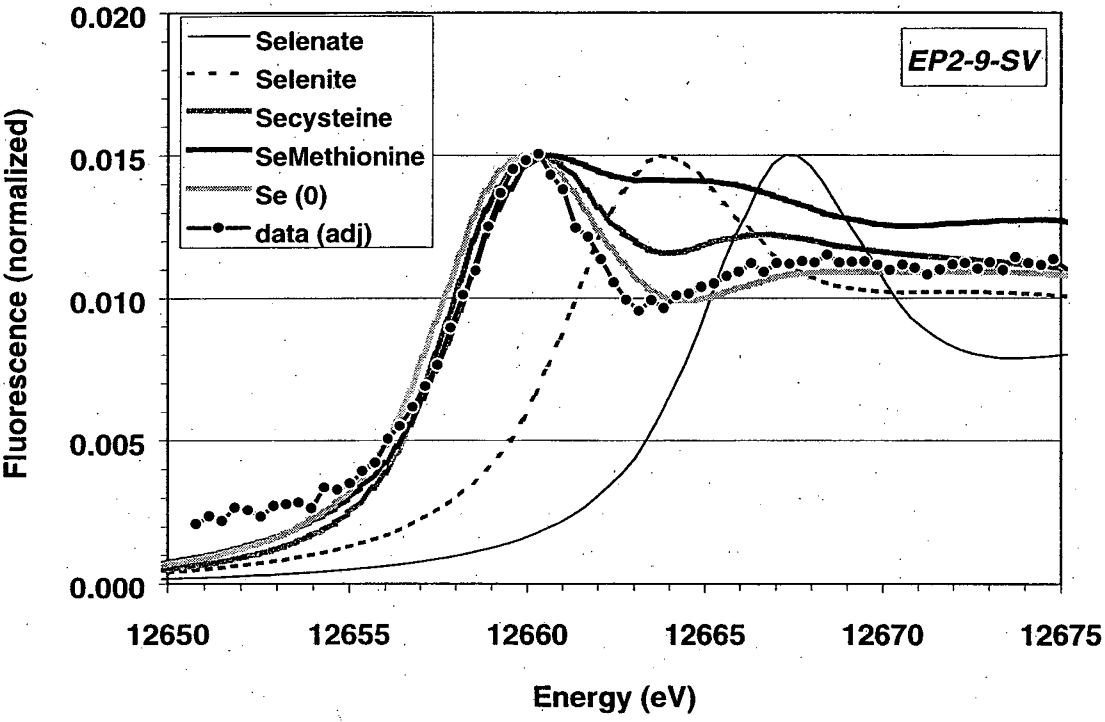


Figure 52: Se K-edge absorption spectra of Se standards and SLD sediment sample EP2-9-SV. Collected on 9/3/99, immediately after application.

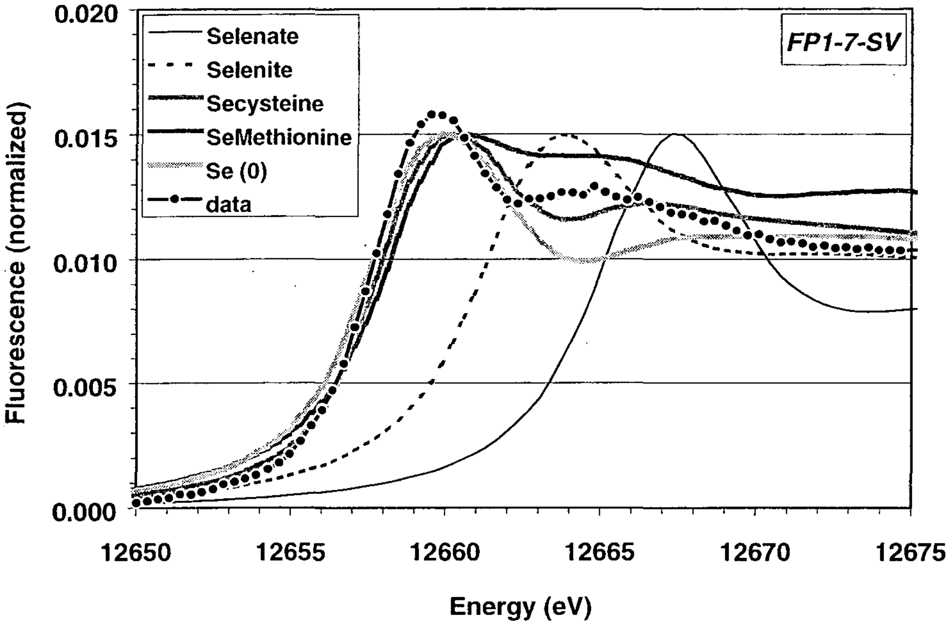


Figure 53: Selenium K-edge absorption spectra of Se standards and SLD sediment sample FP1-7-SV. Collected on 10/21/99, immediately after application.

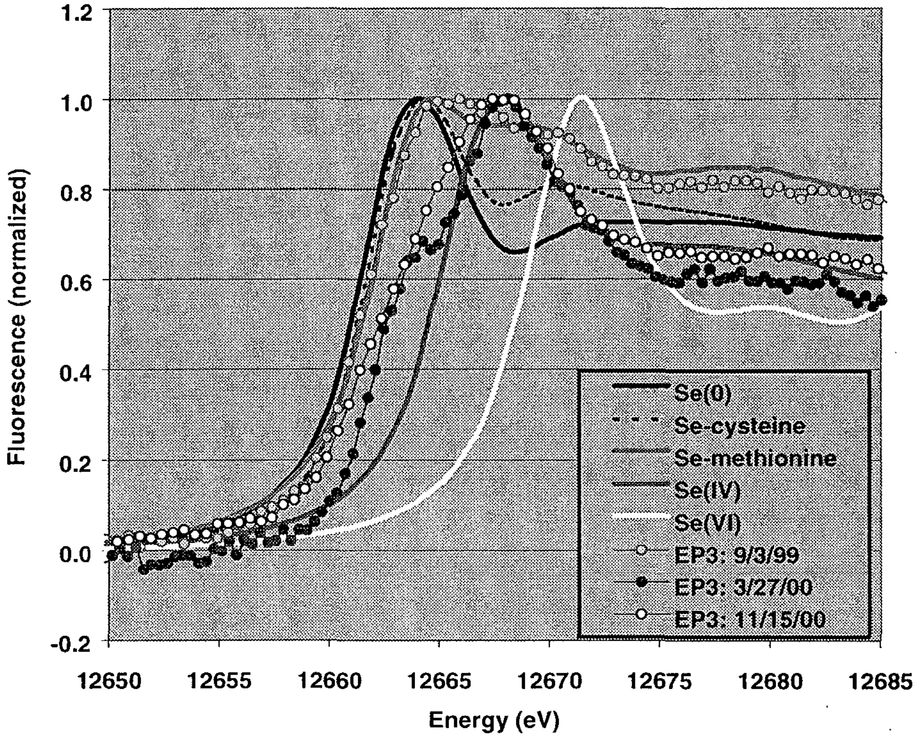


Figure 54: Se K-edge absorption spectra of Se standards and SLD sediment samples. Collected on 9/3/99, 3/27/00, and 11/15/00 from EP-3.

APPENDIX A -- SAN LUIS DRAIN SURVEYS

A.1 Sample Collection, Processing and Analysis

The locations of the samples collected for this analysis are shown in Figure A-1. Sampling began just downstream of the Grasslands Bypass Channel and continued northward toward the terminus of the SLD to Check 10. In each case, the sample was collected within 1 m of the access ladders located at 200-m (1/8-mile) intervals along the SLD, and subsequently at higher frequencies close to check structures. Two hundred and twenty samples were collected over 7 sampling events between 12/4/98 to 5/18/99.

Samples were taken from the middle of the channel, with access via inflatable raft. A custom-made coring tool designed specifically for this purpose was used to collect cores of the unconsolidated sediment (Quinn and Clyde, 1998). After the sample was collected it was divided into several segments, depending on the total sediment thickness (0-3 cm, 3-8 cm, 15 cm increments thereafter). Total recovered sediment depth never exceeded 36.5 cm. Actual sediment thickness may be greater due to compression during collection and by the 36.8-cm limitation of the sediment-coring tool. An estimate of total sediment thickness was made by measuring the mud-covered extent of the sampling tool wherever sediment thickness appeared to exceed 36.8 cm. After subdividing the samples in the field, they were stored in an ice chest for transportation back to the laboratory, where they were stored frozen. In the laboratory, subsamples were homogenized, dried, milled, and analyzed for total Se (procedures described in Appendix B).

A.2 Sampling Data and Charts

The following charts and tables summarize the data collected as part of this effort. For comparison we have included charts of Se concentration data collected by the USBR in 1987, 1988, 1994, 1997 and 1998.

A.3 Results

Chart 1 illustrates the distribution of Se in the SLD. The most notable feature is that the Se concentrations in the SLD sediments are highest immediately downgradient of check structures (and road crossings), and comparatively low in the large regions between the check structures. Selenium concentrations near the check structures range from 10 to 186 μg/g (dry weight). In comparison, concentrations range from <1 to 10 μg/g in the regions between them. For the between-check regions, Se concentrations generally increase downgradient from the range of 1-2 μg/g near in the Grasslands Channel Bypass (near check 18) to 4 to 10 μg/g near Check 10. In addition, as shown by Chart 2, Se concentrations generally increase with depth.

Chart 3 illustrates how the mass of Se per unit area varies along the length of the drain. The mass of Se takes into account both the Se concentration and the thickness of sediments. The mass of Se per unit area, shown in Chart 3, was calculated from the equation on the chart. This data is consistent with the information provided by charts 1 and 2, that is, Se accumulations are concentrated immediately downgradient of the check structures.

Charts 4 through 7 provide detailed profiles of the Se concentrations and sediment thickness near Checks 13, 16, 17 and 18. These again illustrate that Se concentrations are highest immediately downgradient of the check structure, but return to lower levels within about 60 m (200 ft.). They also illustrate that sediment thickness is usually large upgradient of the check structure, while Se concentrations tend to be higher downgradient of the check structure. The larger upgradient sediment thickness is an artifact of sampling only on the midline of the channel, as mentioned in the upcoming discussion.

It is interesting to compare these data with data collected in the past. The first survey we are aware of was conducted in 1987, followed shortly thereafter by a survey in 1988. These data, which are illustrated in Chart 8a, were collected at 1/2-mile increments along the length of the drain and were not located with any specific relationship to the check structures. These data indicated that the Se concentrations ranged from 30 to nearly 100 µg/g. At this time there was no apparent relationship between the location of the sample and the Se concentration.

In 1994, a limited survey was conducted at 4 locations. These data, shown in Chart 8a, are consistent with the data obtained in the earlier survey.

Beginning in 1997 the USBR began a regular sampling program in conjunction with the Grasslands Bypass Channel project. These data are provided in Charts 9a,b. Nine sites are sampled annually. Of these nine sites, five are located close to check structures. The remaining 4 are located midway between the checks. These data are consistent with our observations, that Se concentrations are highest near the check structures. However, because the majority of samples are collected near the check structures, they provide a biased representation about the amount of Se that has accumulated in the drain sediments. Additional sampling in the mid-check regions would provide a more accurate representation of the status of the SLD sediments.

A.4 Discussion

The explanation for high concentrations of Se observed immediately downstream of the check structures is not well understood. Two alternative hypotheses are that: (1) preferential accumulation of Se-rich sediment occurred during previous operations (e.g. late 1970's to 1987); or (2) the regions presently down-gradient of any check structure favor deposition of Se-rich sediments and/or and accumulation of Se through water/sediment/plant interactions.

In either case, the hydraulic regime associated with the check structure must be, in large part, responsible for these accumulations. The hydraulic regime in the upstream side of a flow check can be characterized by: constraint of flow and bed load, increased flow velocity for suspended solids, and no change in water aeration until the check is breached. The hydraulic regime in the downstream side can be characterized by: freshly aerated water, a high-velocity venturi-affected zone in the center of the channel, and significant eddying with sediment deposition at the sides of the channel. Our midline-channel survey confirmed relatively coarse bed load accumulation upstream of flow checks, and thinned or blown out clay and silt sedimentation downstream of flow checks. Field observations also found that algae, reeds, grass, and even bushes were supported by sedimentation on the channel margins directly downstream of check structures. No comparable types or amounts of sediment or vegetation were observed near the upstream side of any check structure.

Table A-1: Project Sampling Locations with USBR Mile Markers on San Luis Drain

Ft. from San Joaq. River	Miles from SJR	Depth Intvl (cm)	Total dry Se (ug Se/ g dry soil)	Moisture Content (g water/g soil)	Total Se (ug Se/ g wet soil)	Sampling Date (mm/dd/yy)	Comments
California EHS Total Threshold limit Concentration (TTLC)					100.00		
503060	94.76	0-3	7.11	2.65	1.95	2/22/99	30 ft south of Check 10 inlet (Highway 152/33)
503060	94.76	3-8	7.53	2.18	2.37	2/22/99	
503060	94.76	8-23	25.86	2.14	8.22	2/22/99	"
503060	94.76	23-32	2.32	1.37	0.98	2/22/99	"
504425	95.01	0-3	4.80	1.62	1.83	2/22/99	30 ft south of 95.01 farm road crossing
504425	95.01	3-8	6.10	1.46	2.48	2/22/99	"
504425	95.01	8-16	16.14	1.30	7.03	2/22/99	"
506274	95.36	0-3	8.85	0.52	5.81	3/26/99	85 ft north of 95.38 farm road crossing
506274	95.36	3-8	43.44	1.58	16.81	3/26/99	"
506274	95.36	8-20.5	52.43	1.62	20.04	3/26/99	"
506304	95.37	0-3	67.59	1.62	25.80	3/26/99	55 ft north of 95.38 farm road crossing
506304	95.37	3-8	31.50	1.36	13.37	3/26/99	"
506304	95.37	8-23	43.84	1.58	16.97	3/26/99	"
506304	95.37	23-36	125.08	1.50	50.13	3/26/99	"
506400	95.38	0-3	7.43	0.80	4.13	2/22/99	30 ft south of 95.38 farm road crossing
506400	95.38	3-8	34.26	1.66	12.88	2/22/99	"
506400	95.38	8-21.5	91.09	2.06	29.75	2/22/99	"
506429	95.39	0-3	10.13	1.64	3.84	3/26/99	60 ft south of 95.38 farm road crossing
506429	95.39	3-8	9.90	1.49	3.97	3/26/99	"
506429	95.39	8-16	28.22	1.74	10.29	3/26/99	"
509461	95.97	0-3	7.84	1.62	2.99	2/22/99	2 ladders north of Check 11
509461	95.97	3-8	8.77	1.21	3.96	2/22/99	"
509461	95.97	8-13	35.77	1.46	14.53	2/22/99	"
510801	96.22	0-3	5.11	2.33	1.53	2/22/99	20 ft south of Check 11 inlet (Mud Slough crossing)
510801	96.22	3-8	4.38	1.88	1.52	2/22/99	
510801	96.22	8-23	6.90	1.49	2.77	2/22/99	"
510801	96.22	23-28.5	4.88	2.02	1.62	2/22/99	"
512346	96.51	0-3	5.39	1.71	1.99	2/22/99	30 ft south of Gun Club Rd. crossing
512346	96.51	3-8	3.71	1.09	1.77	2/22/99	"
512346	96.51	8-23	5.96	1.66	2.24	2/22/99	"
512346	96.51	23-34	7.38	1.61	2.82	2/22/99	"
513900	96.81	0-3	3.52	1.52	1.40	5/5/99	2nd ladder south of Gun Club Rd. crossing
513900	96.81	3-8	3.03	1.33	1.30	5/5/99	"
513900	96.81	8-23	5.54	1.42	2.29	5/5/99	"

513900	96.81	23-28	21.79	1.24	9.73	5/5/99	"
516306	97.26	0-3	6.46	1.65	2.44	2/22/99	4th ladder north of 97.73 crossing
516306	97.26	3-8	6.09	1.65	2.30	2/22/99	"
516306	97.26	8-26	10.19	1.66	3.83	2/22/99	"
518154	97.61	0-3	6.67	1.94	2.27	2/22/99	1st ladder north of 97.73 crossing
518154	97.61	3-8	7.34	1.57	2.85	2/22/99	"
518154	97.61	8-26	11.58	1.78	4.17	2/22/99	"
518778	97.74	0-3	8.30	2.33	2.49	2/22/99	30 ft south of 97.73 farm road crossing
518778	97.74	3-8	35.77	2.27	10.94	2/22/99	"
518778	97.74	8-24	108.68	1.88	37.75	2/22/99	"
520966	98.16	0-3	6.85	2.58	1.91	2/22/99	4th ladder dwnstrm of rail crossing
520966	98.16	3-8	7.39	2.37	2.19	2/22/99	"
520966	98.16	8-19	13.60	1.88	4.73	2/22/99	"
523870	98.71	0-3	7.52	0.21	6.20	2/22/99	1st ladder dwnstrm of rail crossing
523870	98.71	3-8	9.66	1.17	4.45	2/22/99	"
523870	98.71	8-19	6.06	1.76	2.20	2/22/99	"
524022	98.73	0-3	4.59	2.17	1.45	2/22/99	60 ft south of Check 12 inlet
524022	98.73	3-8	4.28	1.68	1.60	2/22/99	(Southern Pacific Railroad crossing)
524022	98.73	8-23	6.54	1.66	2.46	2/22/99	"
524022	98.73	23-29.5	4.19	1.21	1.90	2/22/99	"
525614	99.04	0-3	6.86	2.53	1.94	2/22/99	1st ladder north of 99.09 crossing
525614	99.04	3-8	6.21	1.17	2.87	2/22/99	"
525614	99.04	8-24	20.93	0.76	11.88	2/22/99	"
525800	99.07	0-3	4.87	0.39	3.49	3/26/99	85 ft north of 99.09 drain crossing
525800	99.07	3-11.5	6.72	0.46	4.60	3/26/99	"
525830	99.08	0-3	24.37	0.57	15.52	3/26/99	55 ft north of 99.09 drain crossing
525830	99.08	3-8	45.61	2.09	14.76	3/26/99	"
525830	99.08	8-15.5	57.88	1.71	21.40	3/26/99	"
525928	99.10	0-3	6.52	0.68	3.88	2/22/99	50 ft south of 99.09 drain crossing
525928	99.10	3-8	7.72	1.74	2.82	2/22/99	"
525928	99.10	8-23.5	109.73	1.35	46.66	2/22/99	"
526230	99.16	0-3	14.90	0.62	9.18	3/26/99	90 ft north of Check 13 inlet
526230	99.16	3-10	31.17	1.11	14.78	3/26/99	"
526236	99.16	0-3	13.78	0.68	8.21	3/26/99	84 ft north of Check 13 inlet
526236	99.16	3-8	20.21	2.17	6.37	3/26/99	"
526236	99.16	8-11	59.59	2.22	18.51	3/26/99	"
526242	99.17	0-3	13.98	0.61	8.69	3/26/99	78 ft north of Check 13 inlet
526242	99.17	3-8	30.52	1.66	11.47	3/26/99	"
526242	99.17	8-11	66.28	1.77	23.93	3/26/99	"
526249	99.17	0-3	8.35	0.22	6.86	3/26/99	71 ft north of Check 13 inlet
526249	99.17	3-8	26.96	0.60	16.81	3/26/99	"
526249	99.17	8-14.5	61.82	1.12	29.18	3/26/99	"
526255	99.17	0-3	12.73	0.29	9.89	3/26/99	65 ft north of Check 13 inlet
526255	99.17	3-8	9.40	0.56	6.02	3/26/99	"
526255	99.17	8-24	72.84	1.43	30.01	3/26/99	"
526262	99.17	0-3	35.50	0.70	20.87	3/26/99	58 ft north of Check 13 inlet
526262	99.17	3-8	65.43	1.23	29.36	3/26/99	"
526262	99.17	8-23.5	68.64	1.25	30.57	3/26/99	"
526268	99.17	0-3	58.01	1.44	23.73	3/26/99	52 ft north of Check 13 inlet
526268	99.17	3-8	66.68	1.56	26.02	3/26/99	"
526268	99.17	8-15.5	80.33	1.04	39.32	3/26/99	"
526274	99.17	0-3.5	29.53	0.51	19.52	3/26/99	46 ft north of Check 13 inlet
526365	99.18	0-3	3.48	1.92	1.19	2/22/99	45 ft south of Check 13 inlet
526365	99.18	3-8	3.58	1.49	1.44	2/22/99	(Sierra Gun Club Rd. crossing)
526365	99.18	8-23	4.29	1.16	1.99	2/22/99	"
526365	99.18	23-31	5.67	1.03	2.79	2/22/99	"
527967	99.49	0-3	5.04	1.81	1.79	5/5/99	2nd ladder south of Check 13

527967	99.49	3-8	3.74	1.11	1.77	5/5/99	"
527967	99.49	8-22	9.54	1.26	4.22	5/5/99	"
529815	99.84	0-3	4.58	1.58	1.78	2/22/99	2nd ladder north of Check 14
529815	99.84	3-8	6.27	0.55	4.05	2/22/99	"
529815	99.84	8-21	21.98	0.63	13.52	2/22/99	"
531050	100.07	0-3	26.91	1.50	10.77	3/26/99	85 ft north of Check 14 inlet
531050	100.07	3-8	43.44	1.44	17.78	3/26/99	"
531050	100.07	8-23	71.79	1.67	26.92	3/26/99	"
531050	100.07	23-27	117.08	1.12	55.11	3/26/99	"
531080	100.08	0-3	10.55	0.23	8.61	3/26/99	55 ft north of Check 14 inlet
531080	100.08	3-8	29.40	0.78	16.55	3/26/99	"
531080	100.08	8-23	30.32	1.37	12.80	3/26/99	"
531080	100.08	23-28.5	55.26	1.16	25.61	3/26/99	"
531175	100.09	0-3	3.66	1.48	1.48	2/22/99	40 ft south of Check 14 inlet
531175	100.09	3-8	4.79	1.45	1.95	2/22/99	(farm road crossing)
531175	100.09	8-27	5.50	1.56	2.15	2/22/99	"
531195	100.10	0-3	4.31	1.85	1.51	3/26/99	60 ft south of Check 14 inlet
531195	100.10	3-8	3.37	1.58	1.31	3/26/99	"
531195	100.10	8-20	3.57	1.29	1.56	3/26/99	"
533775	100.59	0-3	4.61	1.75	1.67	5/5/99	overhead wire crossing
533775	100.59	3-8	4.08	1.56	1.60	5/5/99	"
533775	100.59	8-23	4.97	1.34	2.12	5/5/99	"
533775	100.59	23-31	8.30	1.45	3.39	5/5/99	"
536201	101.07	0-3	3.70	1.74	1.35	2/22/99	1st ladder north of Agatha Canal crossing
536201	101.07	3-8	3.27	1.62	1.25	2/22/99	"
536201	101.07	8-23	4.53	1.37	1.91	2/22/99	"
536201	101.07	23-33	5.09	1.60	1.96	2/22/99	"
536307	101.09	0-3	4.96	1.66	1.86	2/22/99	21 ft south of Agatha Canal crossing
536307	101.09	3-8	4.28	1.53	1.69	2/22/99	"
536307	101.09	8-22	4.03	1.40	1.68	2/22/99	"
536782	101.18	0-3	5.28	1.92	1.81	2/22/99	2nd ladder north of Check 15
536782	101.18	3-8	3.14	1.77	1.13	2/22/99	"
536782	101.18	8-19	35.57	4.39	6.60	2/22/99	"
537967	101.41	0-3	7.35	1.65	2.78	3/26/99	107 ft north of Check 15 inlet
537967	101.41	3-8	26.51	2.16	8.39	3/26/99	"
537967	101.41	8-22.5	38.46	1.96	12.98	3/26/99	"
537997	101.42	0-3	30.32	0.85	16.35	3/26/99	77 ft north of Check 15 inlet
537997	101.42	3-8	65.30	1.89	22.60	3/26/99	"
537997	101.42	8-23	109.99	2.12	35.22	3/26/99	"
537997	101.42	23-29	119.70	1.83	42.27	3/26/99	"
538103	101.44	0-3	8.23	1.39	3.45	2/22/99	30 ft south of Check 15 inlet
538103	101.44	3-8	25.00	2.04	8.23	2/22/99	(Torchiana Grade crossing)
538103	101.44	8-23	97.65	2.60	27.12	2/22/99	"
538134	101.44	0-3	3.58	1.32	1.54	3/26/99	60 ft south of Check 15 inlet
538134	101.44	3-8	1.27	1.23	0.57	3/26/99	"
538134	101.44	8-15.5	7.32	1.56	2.86	3/26/99	"
540420	101.89	0-3	3.99	1.54	1.57	5/5/99	0.5 miles north of Check 16
540420	101.89	3-8	5.07	1.46	2.06	5/5/99	"
540420	101.89	8-23	3.85	1.13	1.80	5/5/99	"
540420	101.89	23-32	6.98	1.24	3.11	5/5/99	"
542400	102.27	0-3	3.95	1.60	1.52	2/22/99	1st ladder north of Check 16 (102.39)
542400	102.27	3-8	4.74	1.56	1.85	2/22/99	"
542400	102.27	8-23	5.29	1.43	2.18	2/22/99	"
542818	102.34	0-3	7.81	1.73	2.86	5/5/99	242 ft north of Check 16 (102.39)
542818	102.34	3-8	11.63	1.70	4.31	5/5/99	"
542818	102.34	8-16	12.92	1.60	4.97	5/5/99	"

542918	102.36	0-3	12.94	2.07	4.21	5/5/99	142 ft north of Check 16 (102.39)
542918	102.36	3-8	22.71	0.89	12.04	5/5/99	"
542918	102.36	8-23	39.70	1.72	14.60	5/5/99	"
542968	102.37	0-3	26.12	0.44	18.13	5/5/99	92 ft north of Check 16 (102.39)
542968	102.37	3-8	36.16	1.43	14.88	5/5/99	"
542968	102.37	8-17.5	83.08	2.47	23.94	5/5/99	"
542998	102.38	0-3	47.12	1.16	21.84	5/5/99	62 ft north of Check 16 (102.39)
542998	102.38	3-8	79.93	2.04	26.29	5/5/99	"
542998	102.38	8-23	45.28	1.91	15.58	5/5/99	"
542998	102.38	23-28	72.98	2.55	20.57	5/5/99	"
543083	102.39	0-3	4.54	1.36	1.93	5/5/99	23 ft south of Check 16 (102.39)
543083	102.39	3-8	3.01	1.04	1.47	5/5/99	"
543083	102.39	8-23	3.68	1.02	1.82	5/5/99	"
543083	102.39	23-30	11.45	2.46	3.31	5/5/99	"
543113	102.40	0-3	3.47	1.29	1.51	5/5/99	53 ft south of Check 16 (102.39)
543113	102.40	3-8	4.45	1.38	1.87	5/5/99	"
543113	102.40	8-23	3.75	1.30	1.63	5/5/99	"
543113	102.40	23-31	4.83	1.26	2.14	5/5/99	"
543163	102.41	0-3	3.69	1.19	1.69	5/5/99	103 ft south of Check 16 (102.39)
543163	102.41	3-8	4.03	1.43	1.66	5/5/99	"
543163	102.41	8-23	3.35	1.14	1.56	5/5/99	"
543163	102.41	23-37	4.36	1.27	1.92	5/5/99	"
543720	102.53	0-3	3.19	0.96	1.63	2/4/99	700 ft south of Check 16 inlet
543720	102.53	3-8	3.77	1.40	1.57	2/4/99	"
543720	102.53	>8	2.55	0.75	1.46	2/4/99	"
545120	102.78	0-3	3.06	1.37	1.29	2/4/99	0.4 mile south of Check 16 (102.39)
545120	102.78	3-8	2.98	1.07	1.43	2/4/99	"
545120	102.78	>8	2.80	1.17	1.29	2/4/99	"
546972	103.13	0-3	2.49	0.69	1.47	2/4/99	0.7 mile south of Check 16 (102.39)
546972	103.13	3-8	2.91	0.94	1.50	2/4/99	"
546972	103.13	>8	3.53	1.35	1.50	2/4/99	"
547642	103.25	0-3	3.33	1.45	1.36	2/4/99	0.9 mile south of Check 16 (102.39)
547642	103.25	3-8	2.81	1.05	1.37	2/4/99	"
547642	103.25	>8	3.20	1.08	1.54	2/4/99	"
548302	103.38	0-11	3.53	1.26	1.56	1/6/99	1.0 mile south of Check 16 (102.39)
548302	103.38	0-3	3.37	1.50	1.35	2/4/99	"
548302	103.38	3-8	2.69	0.94	1.39	2/4/99	"
548302	103.38	>8	3.18	1.01	1.58	2/4/99	"
549537	103.61	0-6	4.08	1.64	1.55	1/6/99	1.2 miles south of Check 16 (102.39)
550508	103.80	N/A	4.00	1.49	1.61	1/6/99	2nd ladder north of Check 17
551168	103.92	0-7	4.24	1.51	1.69	1/6/99	1st ladder north of Check 17
551168	103.92	7-27	3.08	1.14	1.44	1/6/99	"
551747	104.03	0-3	40.56	1.96	13.68	5/5/99	213 ft north of Check 17 inlet
551747	104.03	3-11	186.90	2.20	58.40	5/5/99	"
551850	104.05	0-3	42.26	2.04	13.92	3/26/99	110 ft north of Check 17 inlet
551850	104.05	3-8	43.71	2.96	11.04	3/26/99	"
551850	104.05	8-19.5	83.74	2.64	23.04	3/26/99	"
551856	104.05	0-3	81.38	2.46	23.55	3/26/99	104 ft north of Check 17 inlet
551856	104.05	3-8	92.01	2.46	26.60	3/26/99	"
551856	104.05	8-23	107.76	2.34	32.30	3/26/99	"
551856	104.05	23-27	145.95	2.53	41.38	3/26/99	"
551862	104.05	0-3	39.90	1.76	14.45	3/26/99	98 ft north of Check 17 inlet
551862	104.05	3-8	57.23	2.53	16.20	3/26/99	"
551862	104.05	8-22	74.68	2.49	21.42	3/26/99	"

551920	104.06	0-3	15.82	0.31	12.06	2/4/99	40 ft north of Check 17 inlet
551920	104.06	3-8	43.05	1.32	18.53	2/4/99	"
551920	104.06	>8	54.99	2.25	16.94	2/4/99	"
551960	104.07	0-8	3.33	1.19	1.52	1/6/99	Check 17 inlet
551960	104.07	8-24	3.36	1.15	1.57	1/6/99	"
552666	104.20	0-12	2.93	1.20	1.33	1/6/99	4th ladder north of Check 18
553505	104.36	0-14	3.57	1.26	1.58	1/6/99	3rd ladder north of Check 18
554165	104.50	0-5	2.33	0.96	1.19	1/6/99	2nd ladder north of Check 18
554165	104.50	5-15	2.35	0.72	1.37	1/6/99	"
554825	104.62	0-10	2.92	0.93	1.51	1/6/99	1st ladder north of Check 18
554825	104.62	10-25	2.39	0.79	1.34	1/6/99	"
555204	104.70	0-3	3.79	0.91	1.98	5/18/99	280 ft north of Check 18 inlet
555204	104.70	3-8	22.12	1.53	8.74	5/18/99	"
555204	104.70	8-23	58.93	1.61	22.57	5/18/99	"
555204	104.70	23-32.5	113.66	1.71	41.88	5/18/99	"
555244	104.70	0-3	3.86	1.38	1.62	5/18/99	240 ft north of Check 18 inlet
555244	104.70	3-8	4.88	0.77	2.76	5/18/99	"
555244	104.70	8-17	59.85	1.29	26.10	5/18/99	"
555284	104.71	0-3	11.63	0.38	8.41	5/18/99	200 ft north of Check 18 inlet
555284	104.71	3-8	55.52	1.65	20.97	5/18/99	"
555284	104.71	8-23	123.90	1.80	44.25	5/18/99	"
555324	104.72	0-3	12.36	0.61	7.69	5/18/99	160 ft north of Check 18 inlet
555324	104.72	3-8	77.31	1.63	29.36	5/18/99	"
555324	104.72	8-23	160.91	1.95	54.48	5/18/99	"
555364	104.73	0-3	6.33	1.07	3.05	5/18/99	120 ft north of Check 18 inlet
555364	104.73	3-8	8.06	1.32	3.47	5/18/99	"
555364	104.73	8-23	28.81	1.04	14.11	5/18/99	"
555364	104.73	23-38	52.76	1.69	19.65	5/18/99	"
555490	104.75	0-5	3.49	1.44	1.43	12/4/98	7 ft south of Check 18 inlet
555490	104.75	5-10	12.81	1.32	5.53	12/4/98	(Aqua Vista Ave crossing is 80 ft wide)
555490	104.75	10-15	43.18	2.69	11.71	12/4/98	"
555490	104.75	15-20	45.54	2.71	12.29	12/4/98	"
555490	104.75	20-25	60.77	2.09	19.64	12/4/98	"
555490	104.75	25-28	114.71	1.81	40.79	12/4/98	"
555490	104.75	0-3	3.23	1.19	1.48	2/4/99	"
555490	104.75	3-8	21.72	1.79	7.80	2/4/99	"
555490	104.75	>8	47.51	2.64	13.06	2/4/99	"
555503	104.75	0-3	3.19	1.17	1.47	2/4/99	20 ft south of Check 18 inlet
555503	104.75	3-8	9.53	0.82	5.22	2/4/99	"
555503	104.75	>8	48.96	2.33	14.70	2/4/99	"
555523	104.76	0-3	2.14	0.70	1.25	2/4/99	40 ft south of Check 18 inlet
555523	104.76	3-8	1.84	0.59	1.16	2/4/99	"
555523	104.76	>8	4.42	0.76	2.51	2/4/99	"
555543	104.76	0-3	2.29	0.77	1.29	2/4/99	60 ft south of Check 18 inlet
555543	104.76	3-8	2.72	0.73	1.57	2/4/99	"
555543	104.76	>8	4.86	0.85	2.63	2/4/99	"
555563	104.76	0-3	3.92	0.84	2.13	2/4/99	80 ft south of Check 18 inlet
555563	104.76	3-8	2.33	0.68	1.39	2/4/99	"
555563	104.76	>8	6.04	1.11	2.86	2/4/99	"
555621	104.78	0-3	2.12	0.72	1.23	2/4/99	138 ft south of Check 18 inlet
555621	104.78	3-8	1.58	0.59	0.99	2/4/99	"
555621	104.78	>8	10.26	1.31	4.45	2/4/99	"
555700	104.79	0-3	2.56	0.73	1.48	2/4/99	217 ft south of Check 18 inlet
555700	104.79	3-8	2.74	0.85	1.48	2/4/99	"
555700	104.79	>8	2.66	0.79	1.49	2/4/99	"
556277	104.90	0-5	3.01	1.24	1.34	12/4/98	2nd ladder south of Check 18
556277	104.90	5-10	1.39	0.75	0.79	12/4/98	"
556277	104.90	10-15	1.51	0.63	0.93	12/4/98	"

556277	104.90	15-19	1.79	0.55	1.15	12/4/98	"
557068	105.05	0-5	2.07	0.81	1.15	12/4/98	3rd ladder south of Check 18
557068	105.05	5-10	1.49	0.59	0.93	12/4/98	"
557068	105.05	10-15	1.94	0.72	1.13	12/4/98	"
557068	105.05	15-18	1.37	0.56	0.87	12/4/98	"
557068	105.05	18-21.5	2.17	0.88	1.15	12/4/98	"
557860	105.20	0-5	1.27	0.58	0.80	12/4/98	30 ft dwnstrm of Grasslands channel inlet
557860	105.20	5-10	1.46	0.65	0.89	12/4/98	"
557860	105.20	10-15	1.60	0.72	0.93	12/4/98	"
557860	105.20	15-20	1.33	0.64	0.81	12/4/98	"
557860	105.20	20-25	1.38	0.66	0.83	12/4/98	"
557860	105.20	25-30	1.14	0.55	0.73	12/4/98	"
557860	105.20	30-36.5	0.88	0.42	0.62	12/4/98	"
558491	105.31	N/A	17.00	2.66	4.65	1/6/99	3rd ladder west of Check 19 inlet
559108	105.43	N/A	14.96	2.15	4.75	1/6/99	2nd ladder west of Check 19 inlet
559900	105.58	N/A	16.34	1.87	5.69	1/6/99	1st ladder west of Check 19 inlet
560640	105.72	0-8	15.23	2.92	3.89	1/6/99	60 ft east of Check 19 inlet
561300	105.85	0-3	29.73	3.60	6.46	2/4/99	1st ladder east of Check 19
561300	105.85	3-8	31.17	3.18	7.46	2/4/99	"
561300	105.85	>8	33.47	2.97	8.42	2/4/99	"

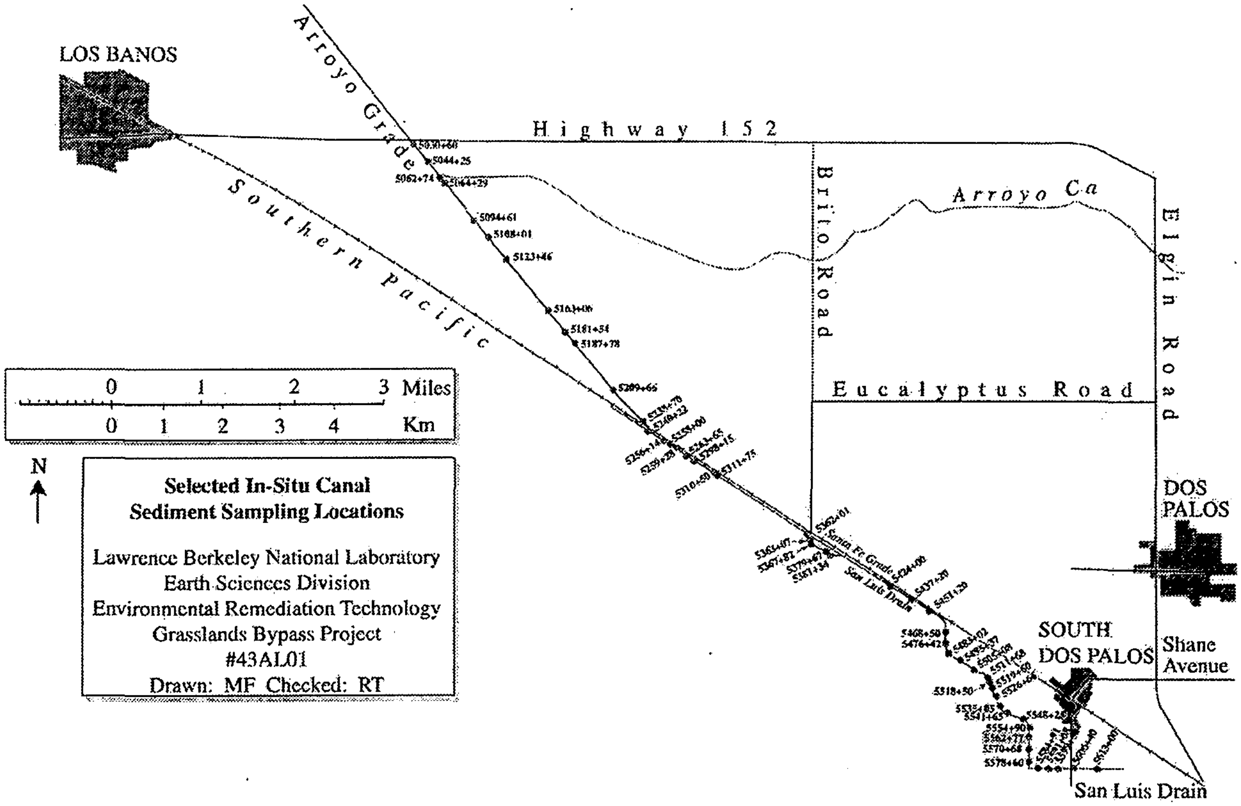


Figure A-1. Location of LBNL sediment sampling points along the San Luis Drain.

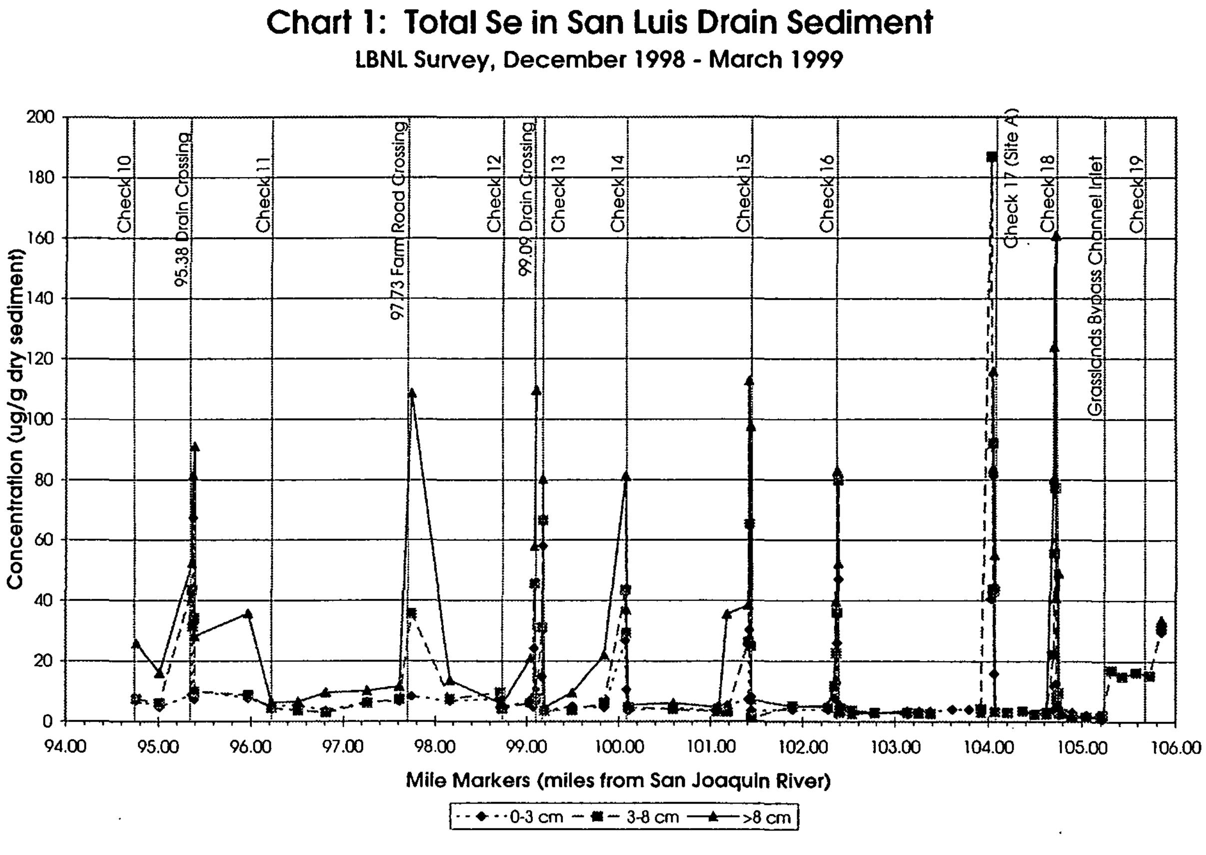


Chart 2: Histogram showing depth distribution of Total Se in San Luis Drain Sediment

LBNL Survey, December 1998 - March 1999

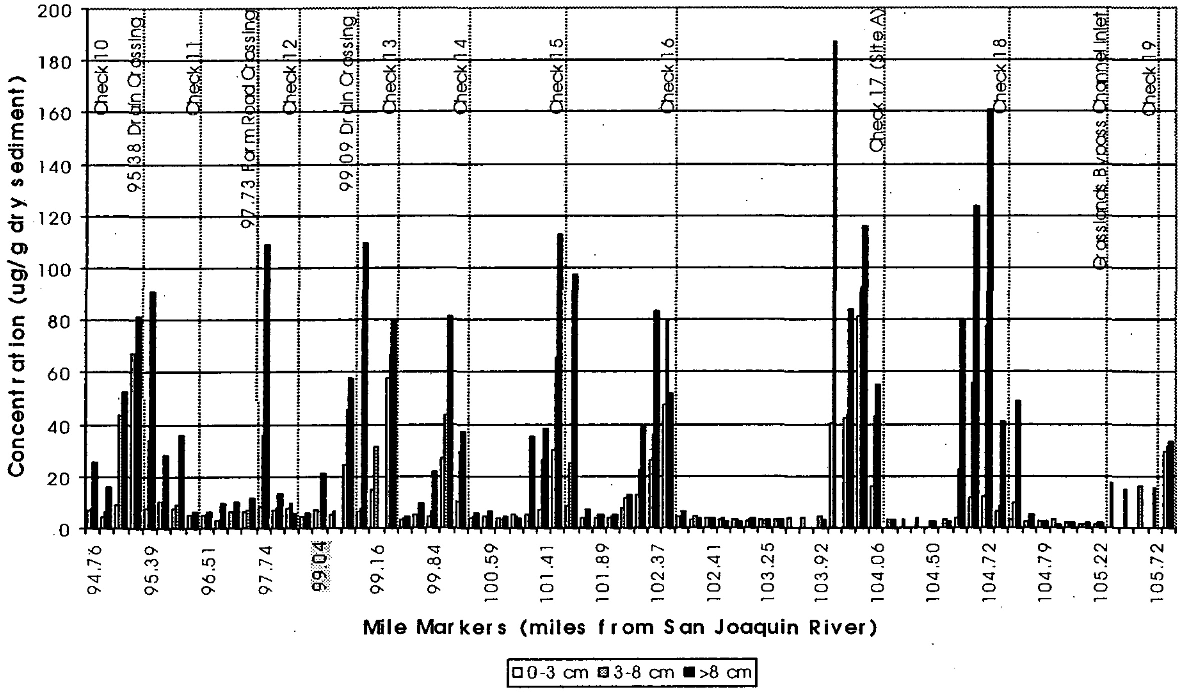
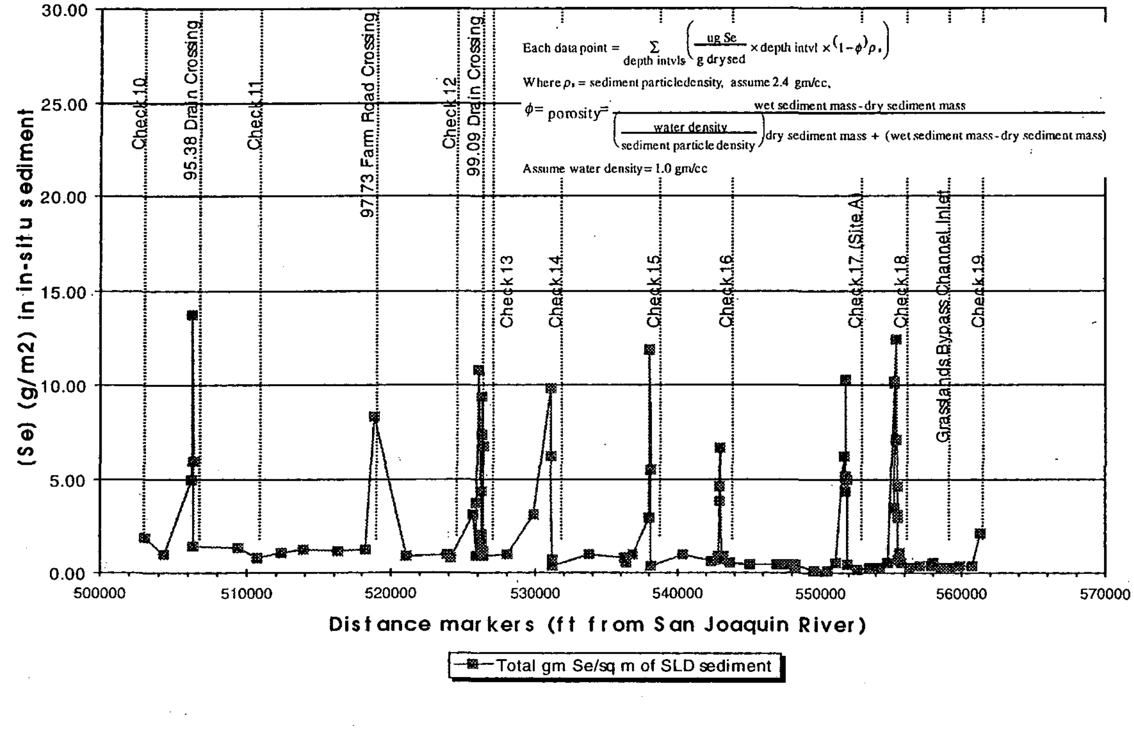


Chart 3: Distribution of the Mass of Se along the San Luis Drain

LBNL Survey, December 1998 - March 1999



Each data point = $\sum_{\text{depth intvls}}\left(\frac{\text{ug Se}}{\text{g dry sed}} \times \text{depth intvl} \times (1-\phi)\rho_s\right)$

Where ρ_s = sediment particledensity, assume 2.4 gm/cc.

$\phi = \text{porosity} = \frac{\text{wet sediment mass - dry sediment mass}}{\left(\frac{\text{water density}}{\text{sediment particle density}}\right)\text{dry sediment mass + (wet sediment mass - dry sediment mass)}}$

Assume water density = 1.0 gm/cc

Chart 4: Details of distribution of Se and sediments at Check 13
LBNL Survey, December 1998 - March 1999

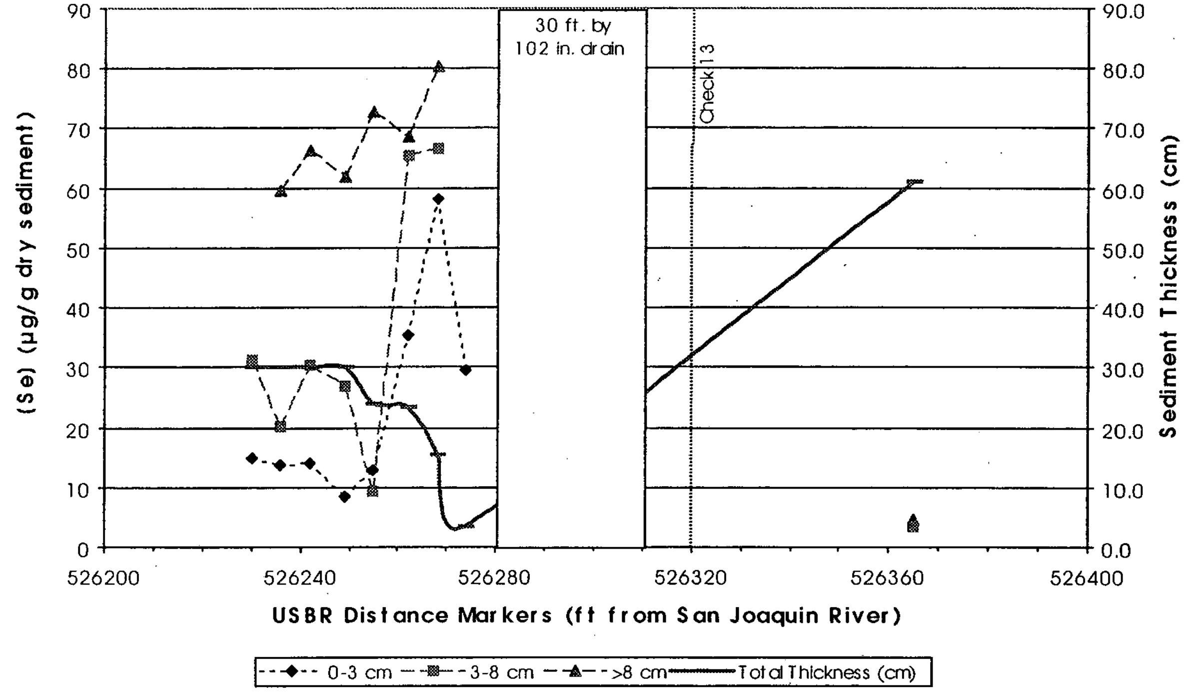


Chart 5: Details of distribution of Se and sediments at Check 16
LBNL Survey, December 1998 - March 1999

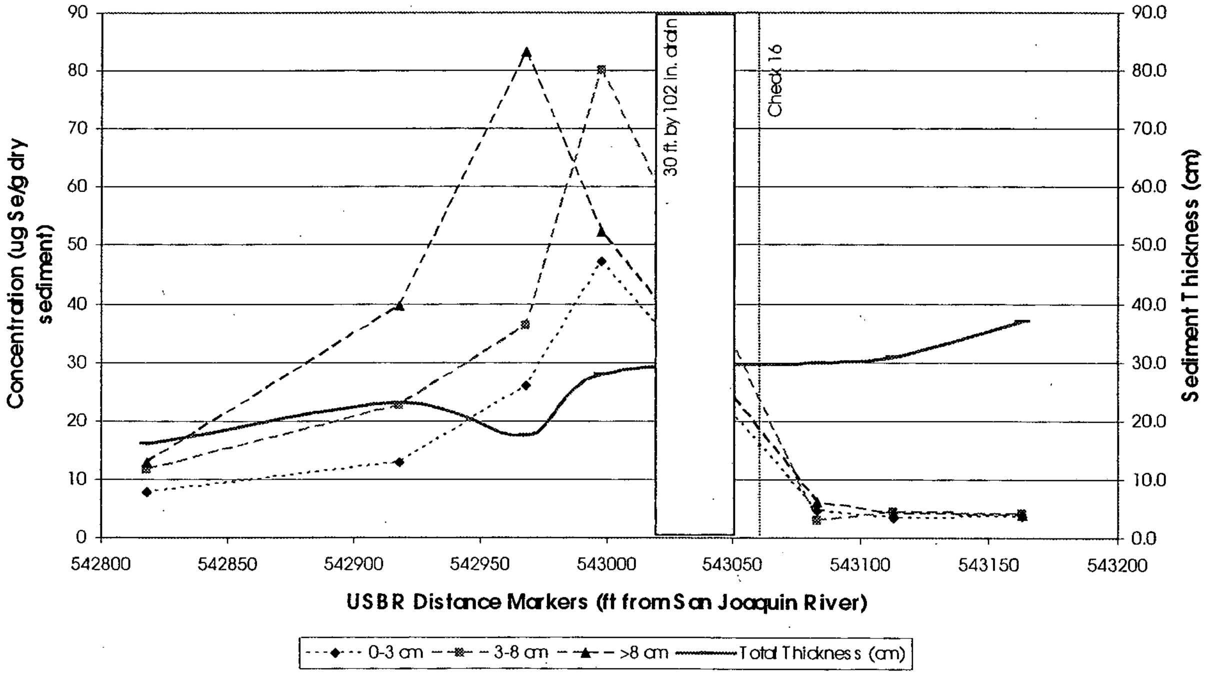


Chart 6: Details of distribution of Se and sediments at Check 17

LBNL Survey, December 1998 - March 1999

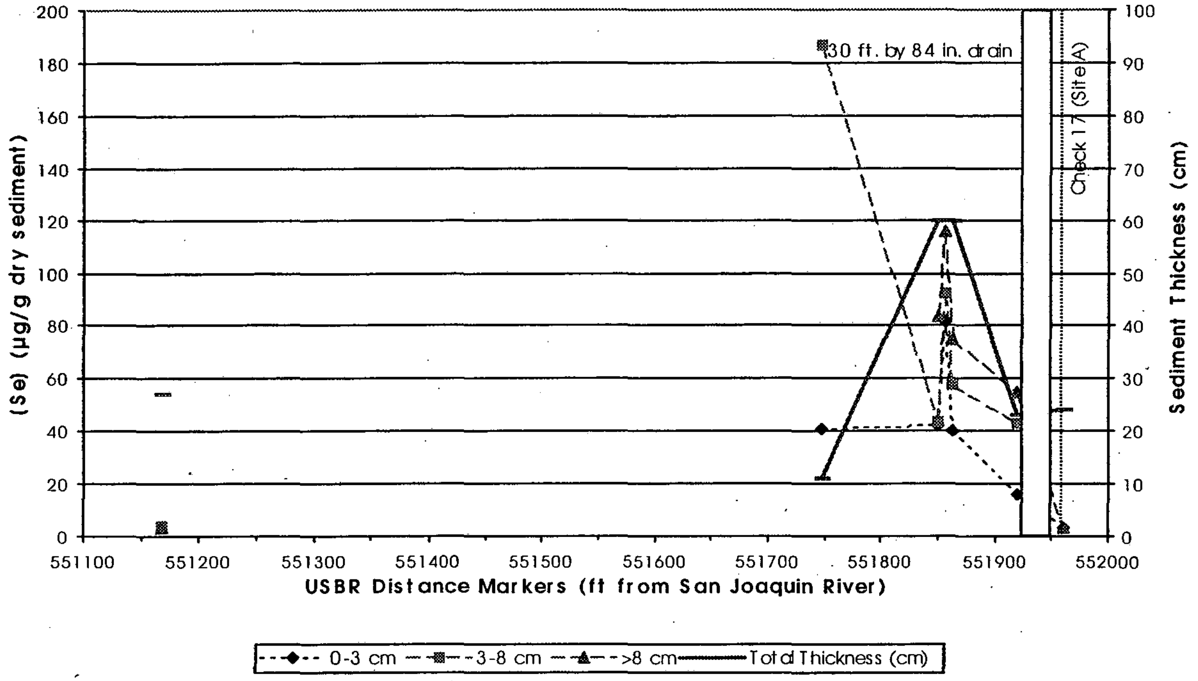


Chart 7: Details of distribution of Se and sediments at Check 18

LBNL Survey, December 1998 - March 1999

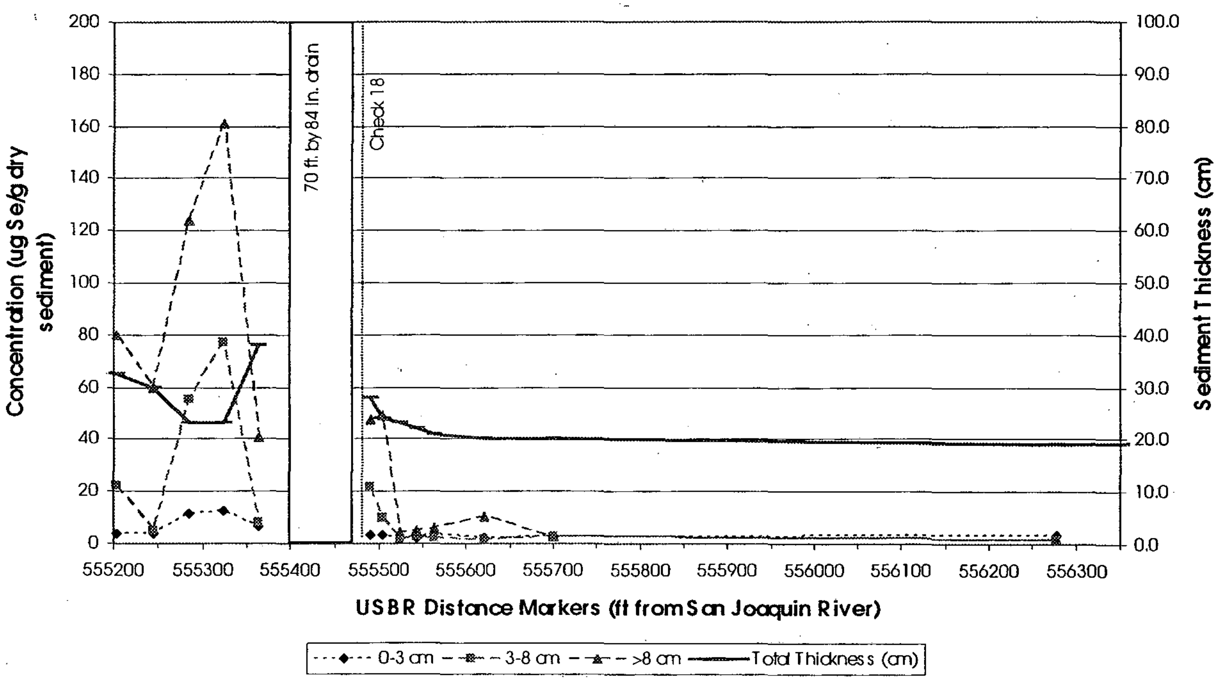


Chart 8a: USBR Surveys, 1987, 1988

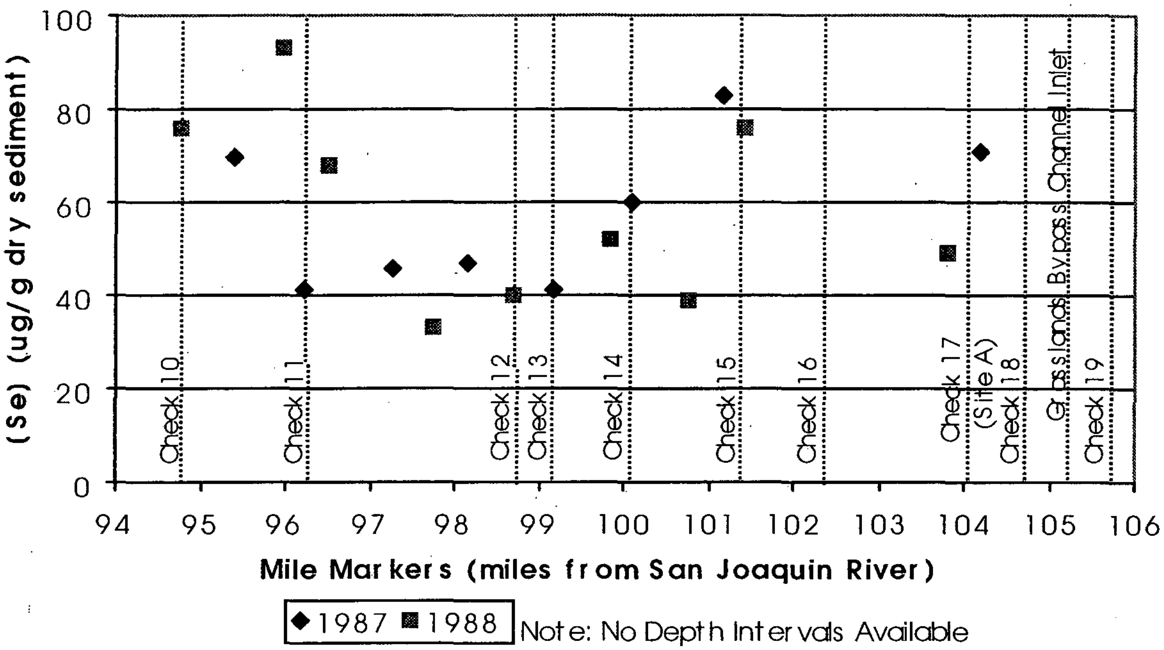
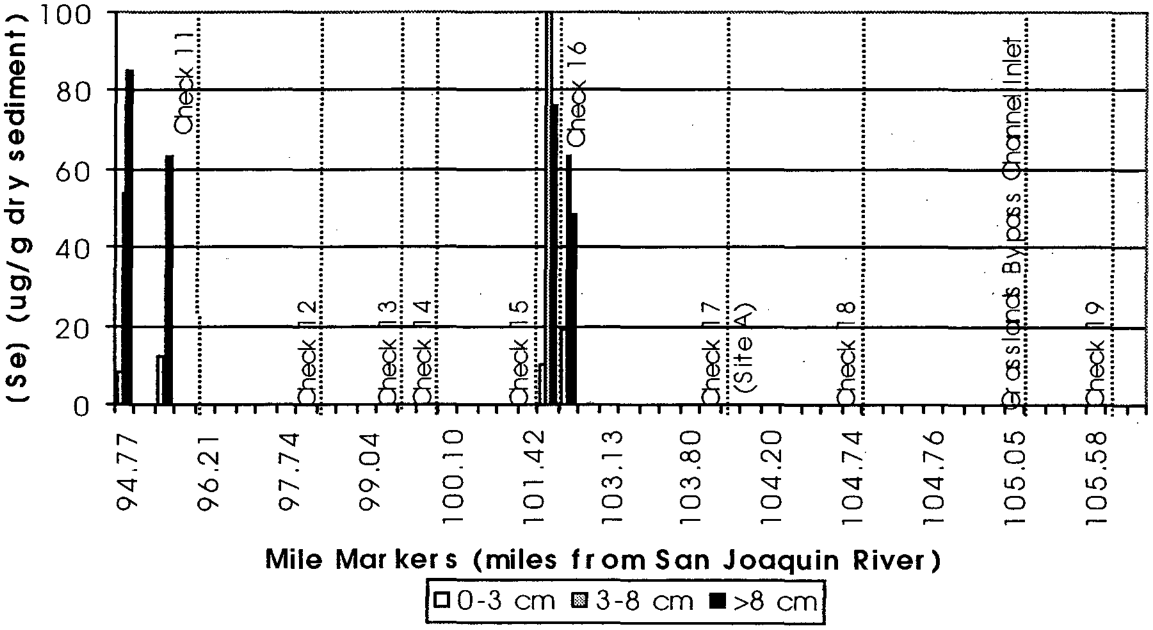
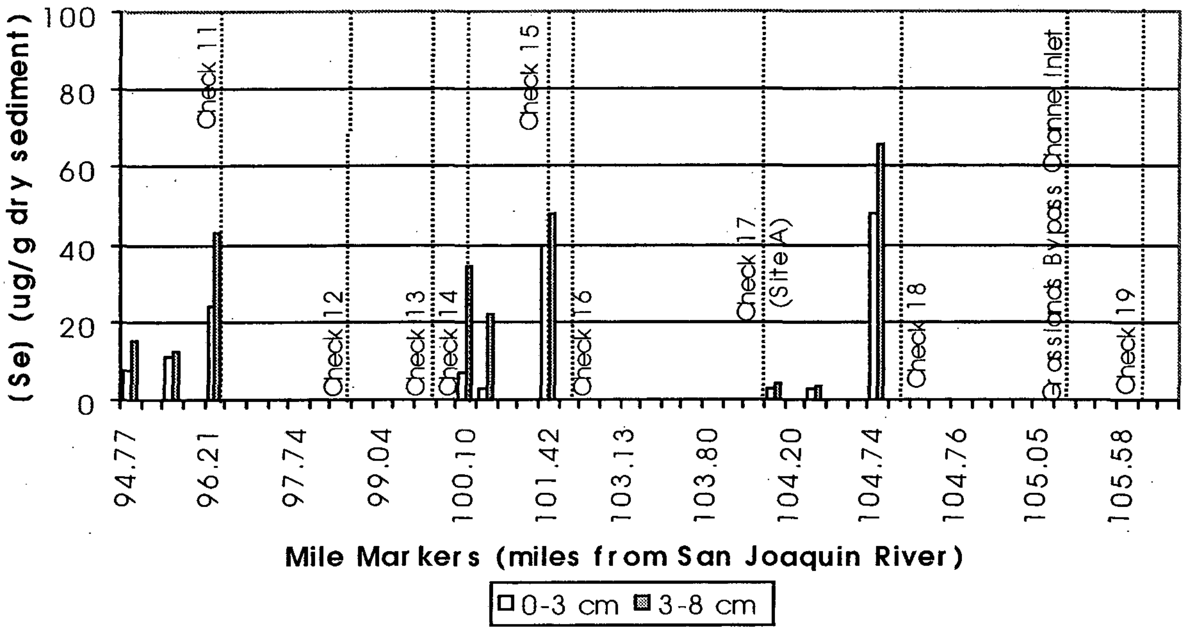


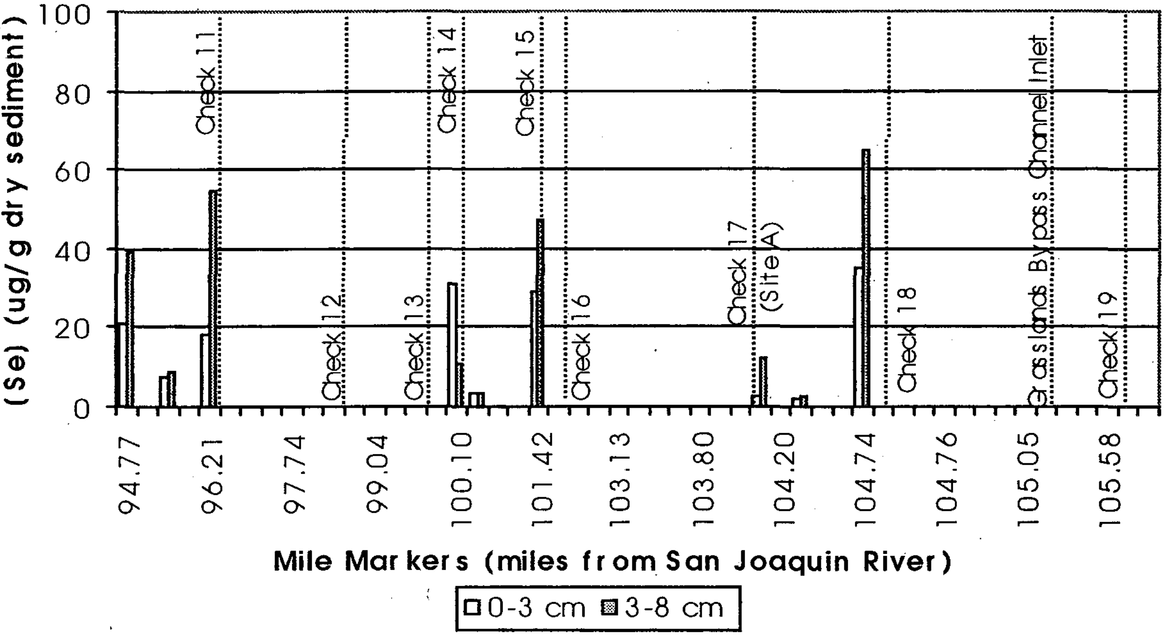
Chart 8b: USBR September 1994 Survey



9a: USBR June 1997 Survey



9b: USBR June 1998 Survey



APPENDIX B -- FIELD AND LABORATORY PROCEDURES

B.1 Field Procedures

Soil and sediment cores were collected using a hydraulic push rig (see Figures C.1 and C.20). Variable length soil cores were collected with minimal loss due to compression. The core barrel was rinsed in soapy water, then tap water, then sprayed with distilled water, and dried before each pass. Soil cores were collected in 15-60 cm intervals. Cores were then collected from the barrel in consecutive 15-cm intervals, and placed in plastic freezer bags with as little air-space as possible. The bagged samples were stored in a cooler. Samples of the top 10-15 cm corresponding to the applied SLD sediment, were frozen upon arrival in the laboratory. Boreholes were backfilled with bentonite pellets.

Surfaces of all water sampling apparatus, which contacted groundwater, were triple-rinsed with distilled water before sampling. Groundwater samples were collected in 60 ml HDPE bottles and stored in a cooler with ice. The filtration action of the ceramic cup in the lysimeter allowed sample collection without secondary filtration or acid preservation for metals from suspended solids. Water quality parameters of pH, temperature, and electrical conductivity were measured at the lab. The lysimeters were purged of standing water and set with a maximum sustainable vacuum (around 80 centibar). Soil water samples were collected a week later.

B.2 Soil/Sediment/Plant Processing

Soil and sediment samples were manually homogenized, using stainless steel blades. Subsamples were oven-dried to determine gravimetric moisture content. The same subsamples were subsequently ball-milled to a fine powder in preparation for acid-digestion. Another subsample from the field-moist soil was used in a water extract to determine water-soluble Se species. Approximately 10-20 g of the soil was shaken with water at a ratio of 1:5, for one hour. The extract was then centrifuged (10,000 rpm) and filtered. The filtered liquid was submitted for chemical analysis. Whole plants were removed from the soil. Plant tissue was separated into above-ground parts and roots, cut up using scissors and then mixed. Tissue was oven-dried at 50°C and a 10 to 20 g subsample was ground to a powder in an electric grinder. The powdered sample was subsequently acid-digested.

B.3 Soil/Sediment/Plant Digestion and Analysis Procedure

A strong acid digest procedure (Zawislanski and Zavarin, 1996) was used to extract total Se from soils and sediments. The sample was oven-dried (105°C) and powdered (425-µm mesh) in an agate ball-mill, then digested using hot, concentrated HNO_3 and 30% H_2O_2 for 24 h. The residue was then refluxed using 6 *M* HCl, and washed several times with HCl. Supernatant solutions were passed through a 0.45-µm, nitrocellulose filter immediately after extraction.

Plant tissue was digested using a procedure modified from Ganje and Page (1974) and described by Zawislanski et al. (in press). A powdered subsample (1 to 2 g) was digested in Teflon tubes, using concentrated HNO_3 at 60°C for 2 hr. After cooling, a 2:1 mixture of HNO_3:$HClO_4$ was added and the sample was refluxed at 110°C for 24 hr. Subsequently, 0.5 mL of 8 M urea was added to prevent nitrate interference during Se analysis.

Sediment digests, extracts and plant digests were analyzed for total dissolved Se using hydride generation atomic absorption spectrometry (HG-AAS; Perkin Elmer Model 3030) (Weres et al., 1989b). In the case of plant digests, prior to analysis, 5 mL of each sample was refluxed with 2.5 mL HCl and H_2O_2 was added to break up large organic molecules, which often interfere in HG-AAS analysis.

APPENDIX C -- PHOTO GALLERY

Figure C.1: Dredged SLD sediment (EP-1) drying on berm. Soil core sampling and instrument installation in progress (December 1998). View to the north.

Figure C.2: Sites EP-2 and EP-3, prepared for sediment application (9/3/99). View to the north.

Figure C.3: Instrument cluster 7 in EP-2. From left to right: tensiometers (covered with PVC pipe), neutron probe access pipe (clear acrylic), and soil water suction lysimeters (under large PVC cap).

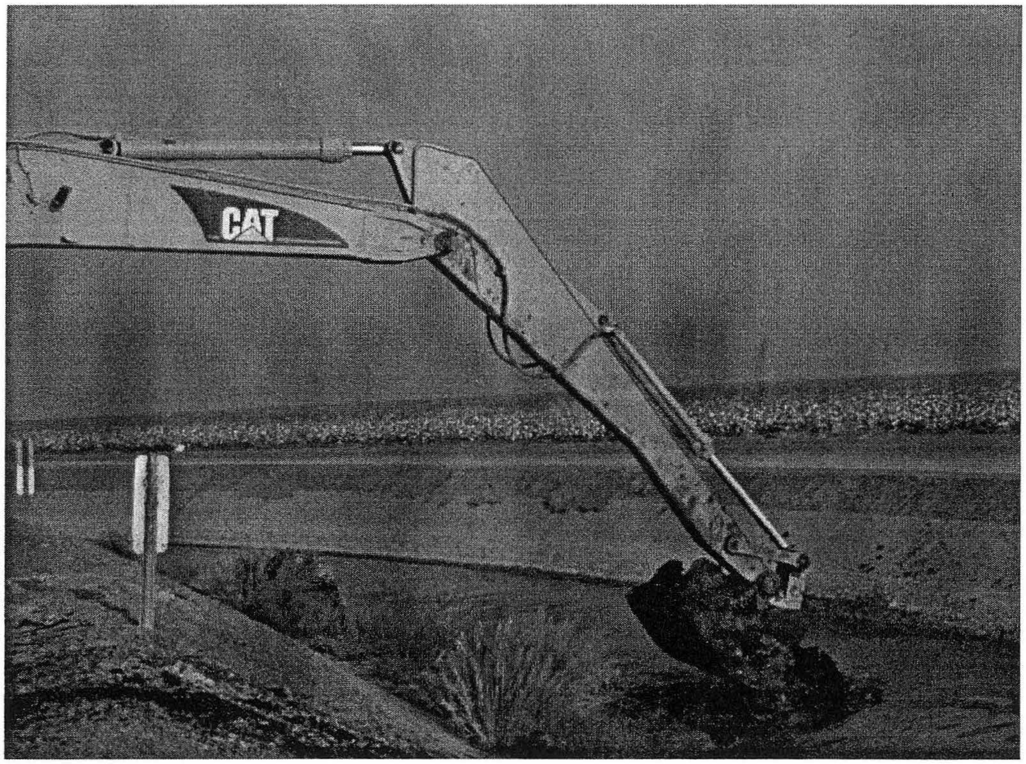


Figure C.4: Dredging of SLD sediment.

Figure C.5: SLD sediment being placed in cement truck via hopper.

Figure C.6: Sites EP-3 (foreground) and EP-2, immediately after sediment application (9/3/00).

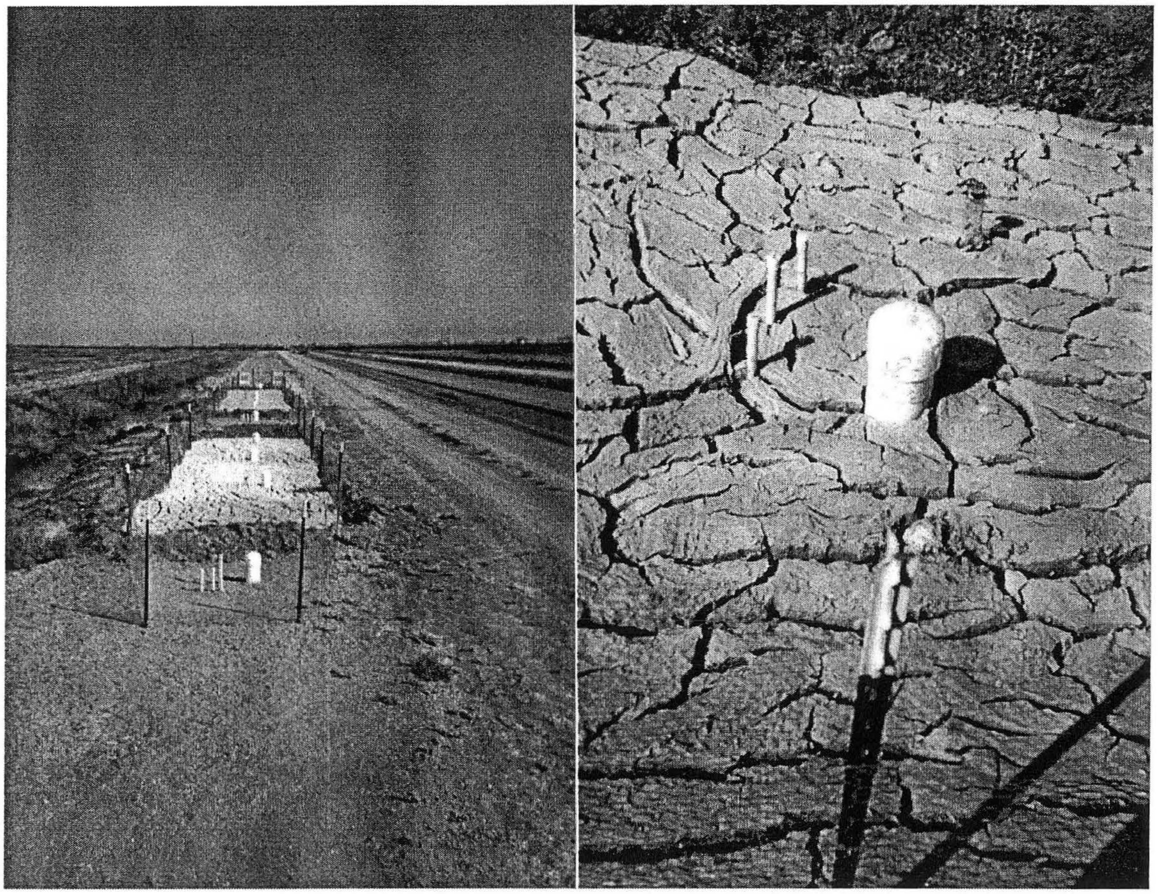


Figure C.7: Left: Sites EP-2 and EP3 after a few days of drying (9/9/99). Right: Close-up view of drying cracks around one of the monitoring cluster.

Figure C.8: Application of SLD sediments to FP-1 using cement-truck chute (10/21/99).

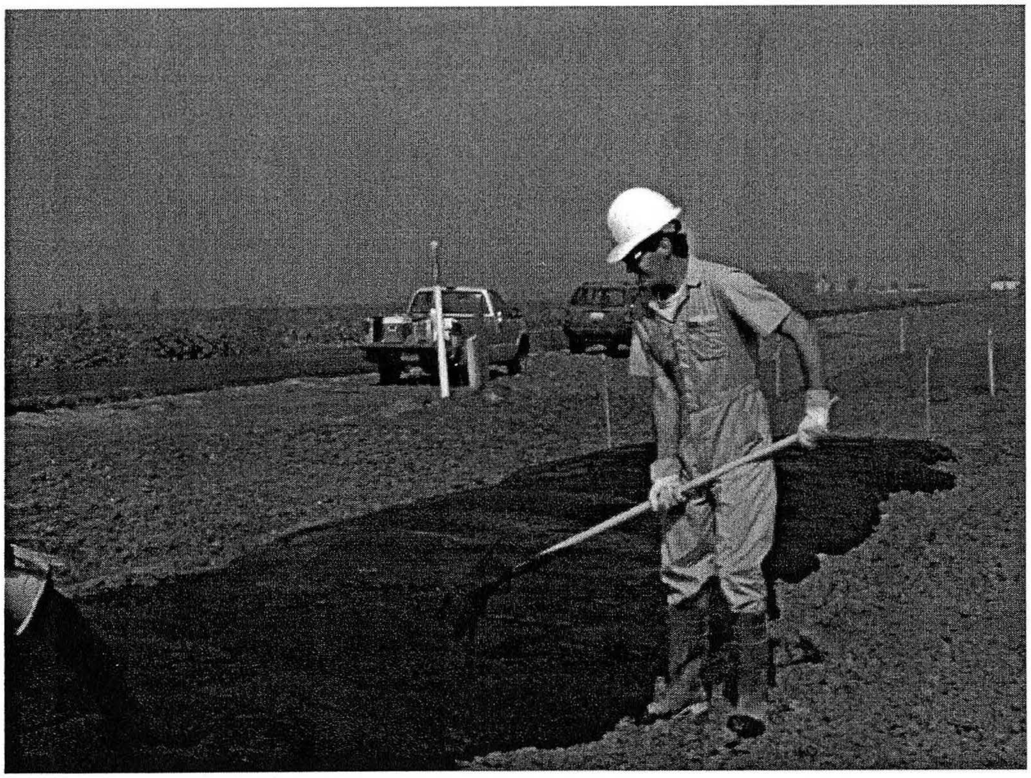


Figure C.9: Spreading of SLD sediments in FP-1 using cement rake (10/21/99).

Figure C.10: Sites FP-1 (foreground) and FP-2 after a few days of drying (10/28/99). View to the north.

Figure C.11: Sites FP-1 and FP-2 after plowing (11/19/00). View to the north.

Figure C.12: Site EP-2 on 2/14/00.

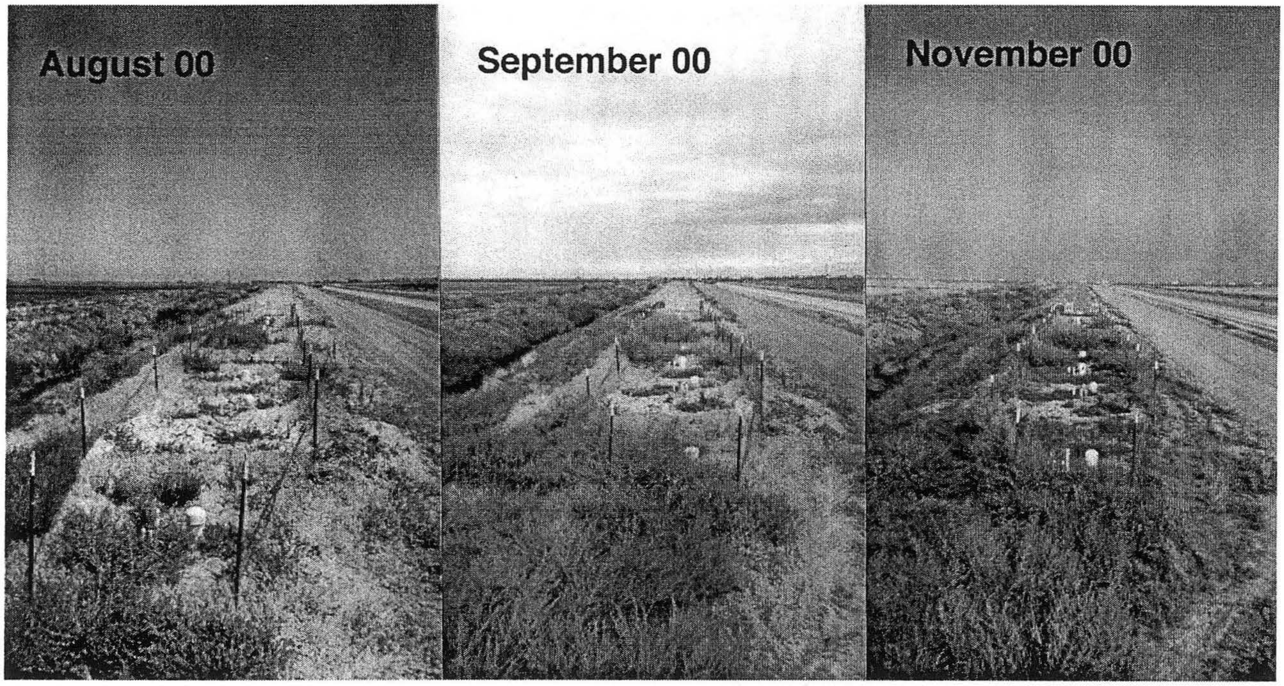


Figure C.13: Plant growth at EP-2 and EP-3 between August and November 2000.

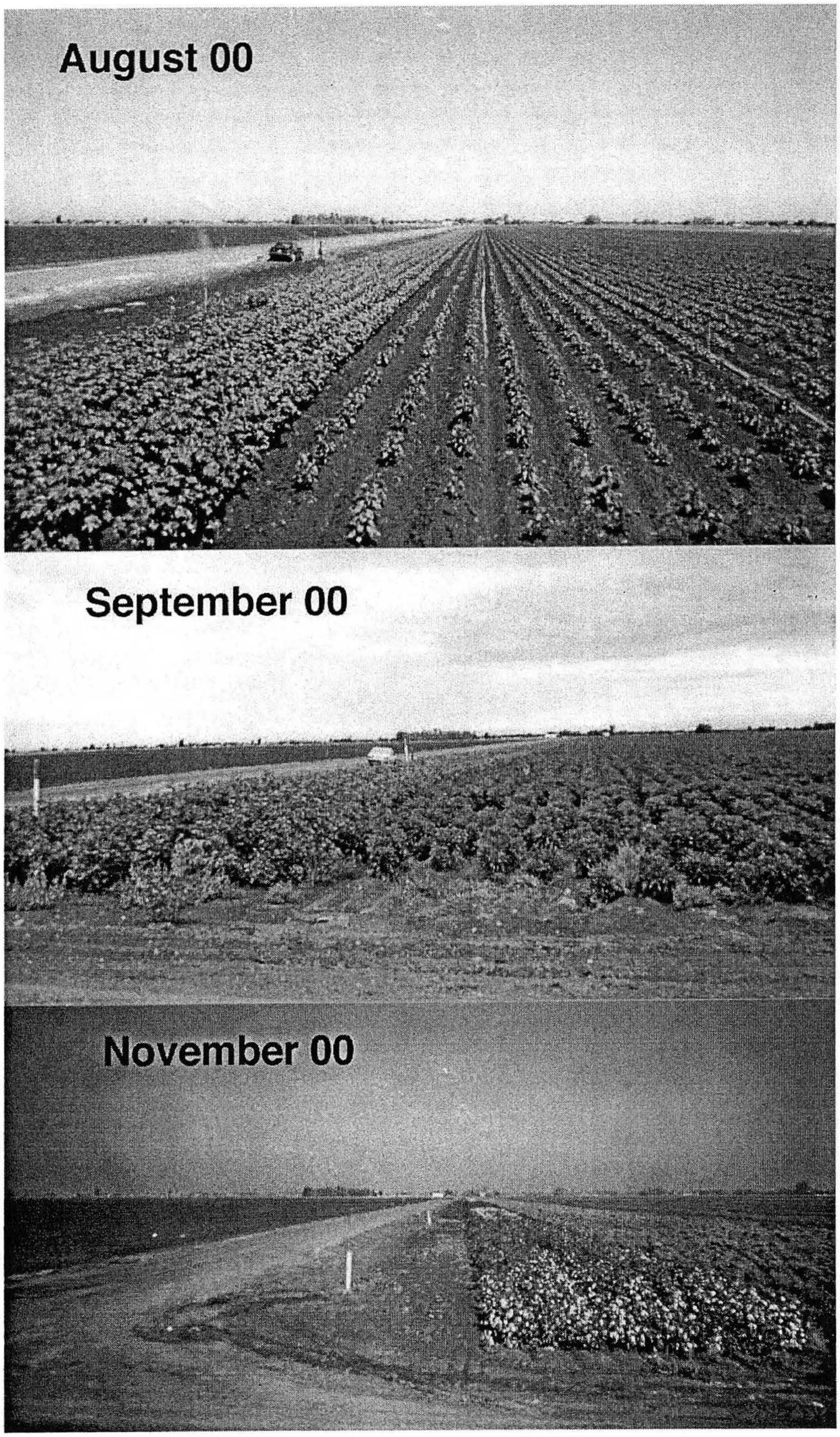


Figure C.14: Crop growth at the farm plot sites. Thicker vegetation on the left side is cotton, that to the right is chile pepper.

Figure C.15: Cotton plants in plots FP-1 (top) and FP-2 (bottom) in November 2000, shortly before picking.

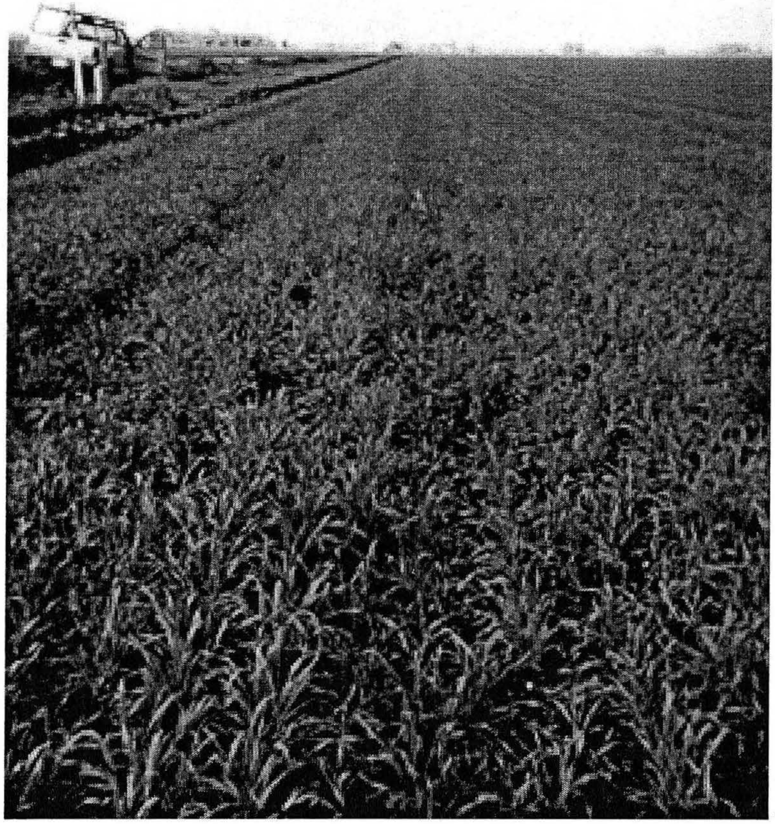


Figure C.16: Winter wheat in FP-1 and FP-2, Spring 2001.

Figure C.17: Winter wheat in FP-1 and FP-2, shortly before harvest, 6/7/01.

Figure C.18: Sample grid, randomly thrown over winter wheat, 6/7/01.

Figure C.19: Sample grid, after winter wheat sample collection, 6/7/01.

Figure C.20: Soil sample collection in FP-2, 8/7/01.

Figure C.21: Cantaloupe crop, FP-1 and FP-2, 10/5/01.

Figure C.22: Cantaloupe sampling 1, 10/5/01.

Figure C.23: Cantaloupe sampling 2, 10/5/01.

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