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Land Disposal of San Luis Drain Sediments

Progress Report
October 1998–November 2000

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and S. E. Borglin

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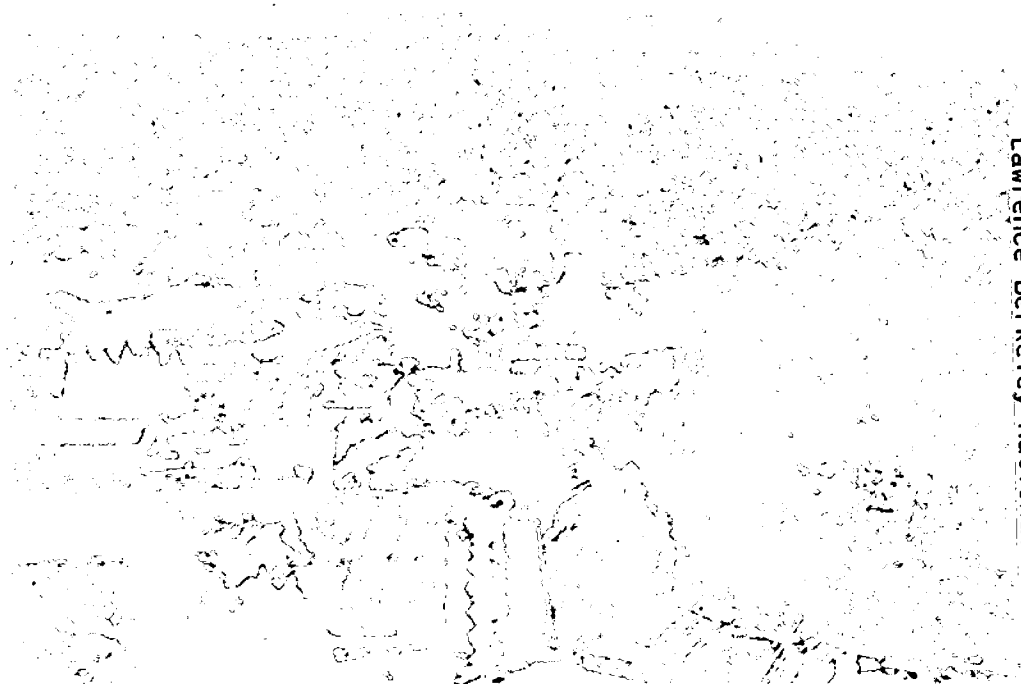

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DISCLAIMER

LBNL-47861

LAND DISPOSAL OF SAN LUIS DRAIN SEDIMENTS

Progress Report
October 1998 through November 2000

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EXECUTIVE SUMMARY

Since October 1998, Lawrence Berkeley National Laboratory (LBNL), in collaboration with the U.S. Bureau of Reclamation and the Panoche Water District, has been conducting a pilot-scale test of the viability of land application of selenium (Se)-enriched San Luis Drain (SLD) sediments. Agricultural drain water from surrounding areas in the Grasslands Water District is channeled via the San Luis Drain toward the San Francisco Bay Delta. The drain water carries with it and subsequently deposits Se-rich sediments, which 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 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, we performed detailed mapping of Se in SLD sediments (Chapter 2). Both total Se concentrations and sediment thickness are greatest immediately downstream of check structures in the San Luis Drain. Consequently, most of the Se in the SLD is deposited within 60 m (200 ft) downstream of these structures. Selenium concentrations in the regions further away from the check structures are typically in the range of 1 to 10 μg/g (dry weight). Concentrations increase generally downgradient, from the range of 1-2 μg/g near in the Grasslands Bypass Inlet (near check 18) to 4 to 10 μg/g near Check 10. Selenium concentrations near the check structures range from 10 to 186 μg/g. There is a general tendency for Se concentrations to increase with depth in the drain sediments. In order to assure compliance with environmental regulations, we reviewed and summarized land application permitting issues. The Total Threshold Limit Concentration (TTLC; California EPA) for Se is 100 mg Se/kg wet soil, while the Soluble Threshold Limit Concentration (STLC; California EPA) is 1 mg Se/L 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 (Chapter 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. 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 Drain. 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 Se concentrations averaged 2.56, 37.10, and 19.53 μg g^{-1}, in EP-1, EP-2, and EP-3, respectively (Chapter 4). Soluble Se comprised less than 1% of total. 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 5

cm (relative to the original ground surface). There was no significant effect on groundwater Se levels due to leaching during the test period. 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. Further oxidation of the Se inventory is anticipated, but the low permeability of the underlying sediments is a likely barrier to Se movement toward the water table.

In the farm plots, applied Se concentrations averaged 111.6 and 66.7 $\mu g\ g^{-1}$, in FP-1 and FP-2, respectively, with soluble Se comprising 0.35% to 0.55% of total. As part of the process of field preparation for cotton planting, the 10-cm-thick sediment application was mixed with the underlying soil via disking and deep plowing, down to a depth of 0.70 m. This resulted in the reduction of near-surface Se concentrations to around 10-15 $\mu g\ g^{-1}$, but also an increase of Se concentrations down to 0.70 m. Similarly, soluble Se concentrations increased in the soil profile due to physical mixing. There is some indication that rainfall and irrigation 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 plants was greater than anticipated. Bulk above-ground tissue concentrations in young plants were as high as 22.7 $\mu g\ g^{-1}$ (7/14/00). A more comprehensive sampling of cotton took place at full maturity (11/4/00), shortly after the application of exfoliant. Selenium concentrations in aboveground parts of mature plants (11/4/00) were lower than those measured on 7/14/00. Selenium in roots remained the same, between 0.5 and 3.5 $\mu g\ g^{-1}$. Seeds contained the highest Se concentrations, the highest being 16.6 $\mu g\ g^{-1}$ in FP-1. Selenium concentrations in lint were lowest, at or below 2 $\mu g\ g^{-1}$. Selenium levels were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C. Despite Se uptake, the cotton yield from the Se-amended part of the farm field was statistically equal to that from the unamended field. Therefore, the presence of high Se concentrations in the soil did not impede cotton growth or overall plant health.

Preliminary sequential extraction and x-ray spectroscopic results (Chapter 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. These results are preliminary and future sampling, extraction, and x-ray spectroscopic work will shed light on the oxidation reactions and their kinetics, providing important parameters in the prediction of long-term Se stability.

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 very 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. The results of the farm plot tests are less conclusive. Disposal of Se-enriched sediments onto a farm field may result in the movement of Se deeper into the soil profile and possibly to the groundwater, due to physical mixing and irrigation. However, the sediments which were applied to the farm plots contained some of the highest Se measured in the

SLD. These high-Se sediments comprise a very 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 1-10 μg g-1 range, which includes the majority of SLD sediments. We recommend at least one more year of monitoring at the established field sites. The relatively dry winter of 1999-2000 may not have been a good indication of future rainfall events, which may have more significant effects on Se leaching and mobility.

1 INTRODUCTION

Lawrence Berkeley National Laboratory (LBNL), in collaboration with the U.S. Bureau of Reclamation and the Panoche Water District, is conducting a pilot-scale test of the viability of land application of selenium (Se)-enriched San Luis Drain (SLD) sediments. 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 which 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 the groundwater; increased exposure to the biota; and reduced productivity of farm crops.

This report describes field and laboratory activities carried out from 1998 through November 2000, as well as the 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 down-stream of the check structures in the drain. Conveyance of Se-bearing drainage from the late 1970's to 1986, and more recently during the Grasslands Channel Bypass Project, have resulted in accumulation of Se in these sediments. Consequently, an estimated 98,000 cubic yards of sediments containing an average of 44 ppm (dry-weight) Se currently reside in the SLD between Check 30 and the terminus. These 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) has prepared a management plan for the SLD sediments which 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 STLC, Soluble Threshold Limit Concentration, does not exceed 1 mg/L). The sediments can however 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 (April 1997), the U.S. Bureau of Reclamation (April 1997), and the U.S. Geological Survey 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 more options;
- more effective demonstration that the selected option is the best choice;
- evaluation of the uptake of selenium by vegetation growing on the sediments;

- more detailed plans for sediment removal; and
- a long-term plan for management of the sediment after application (e.g. monitoring, planting and maintenance of vegetation, up-keep and limitation of access, erosion control, storm water management, etc..).

1.2 Purpose

The purpose of the pilot-scale test is to evaluate two options for removal and disposition of San Luis Drain (SLD) sediments. Several disposal options have been considered by the San Luis and Delta Mendota Water Authority:

- 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; and
- transport to and disposal at a Class II landfill.

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

- assessment of relevant regulations for land application of sediments
- analysis of the speciation of selenium 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 San Luis and Delta Mendota Water Authority and the U. S. Bureau of Reclamation to identify the best option for managing sediments from the SLD and other contaminated drainage ditches.

2 SITE SELECTION

2.1 Drain Surveys

During 1998 and 1999, sediments from the San Luis Drain (SLD) were systematically sampled along a length of approximately 18 km (11 miles), from the Grasslands Bypass Channel (GBC) Inlet to Check 10, due east of Los Baños. The sediments were analyzed for total selenium (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 Fig. 2.1.

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

2.2 Source Area and Experimental Plot Selection

The first source area was 180-240 m downstream of the GBC Inlet. This location was characterized as having relatively low Se concentrations. The drain survey described in section 2.1 found that most of the sediment in the canal ranged from 1 to 10 μg Se/g sediment (dry weight). For subsequent source areas, locations with elevated Se concentrations (Fig. 2.2, Table 2.1) 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 (Fig. 2.2). Sediment from Source Areas 1-3 was laid down on the adjacent or nearby embankment, west of the SLD, in embankment plots 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 a cultivated field, or farm plot, FP-1 and FP-2, respectively. This type of application is another candidate for large-scale disposal. It offers the advantage of incorporating the organic-rich sediment with top-soil. Furthermore, the available farmed area is far greater than that of drain embankments.

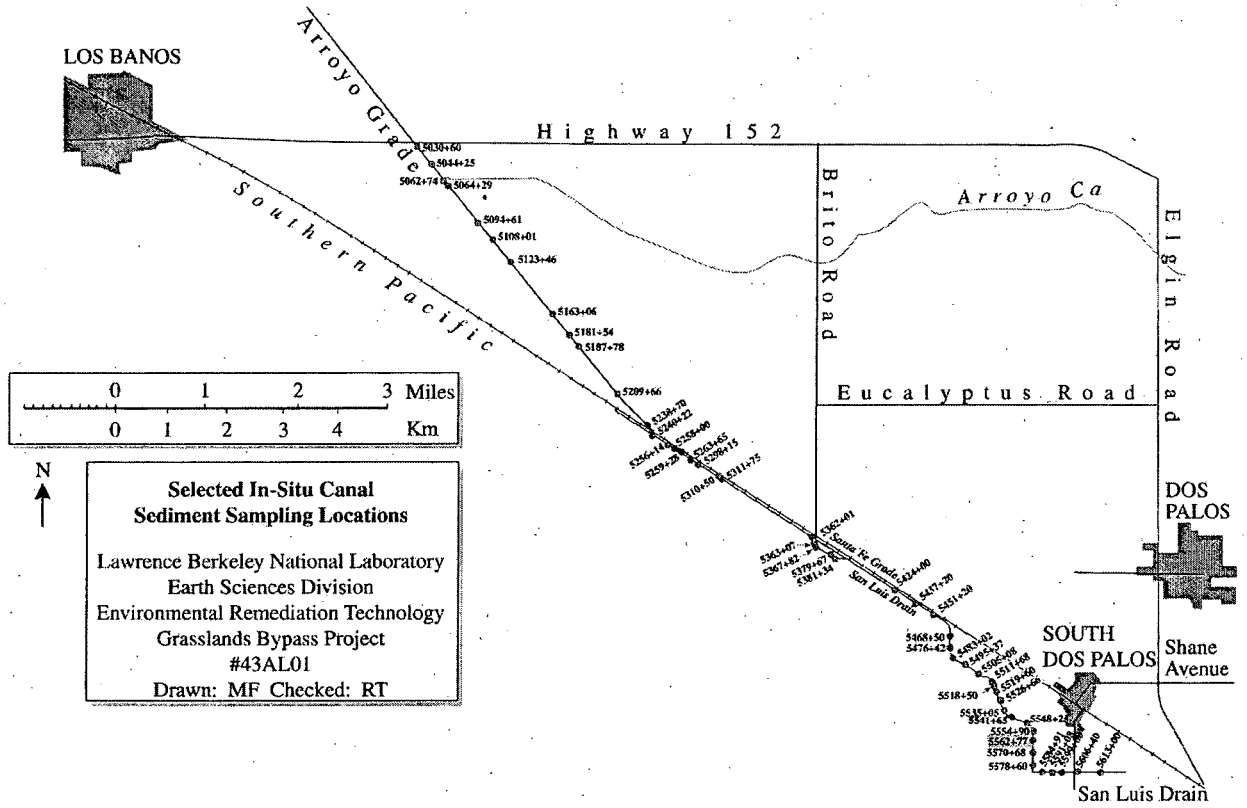


Figure 2.1. Location of LBNL sediment sampling points along the San Luis Drain.

Table 2.1. Locations of sediment sources and Se levels in nearest sediment core.

Source Area #	Distance up/down-stream 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

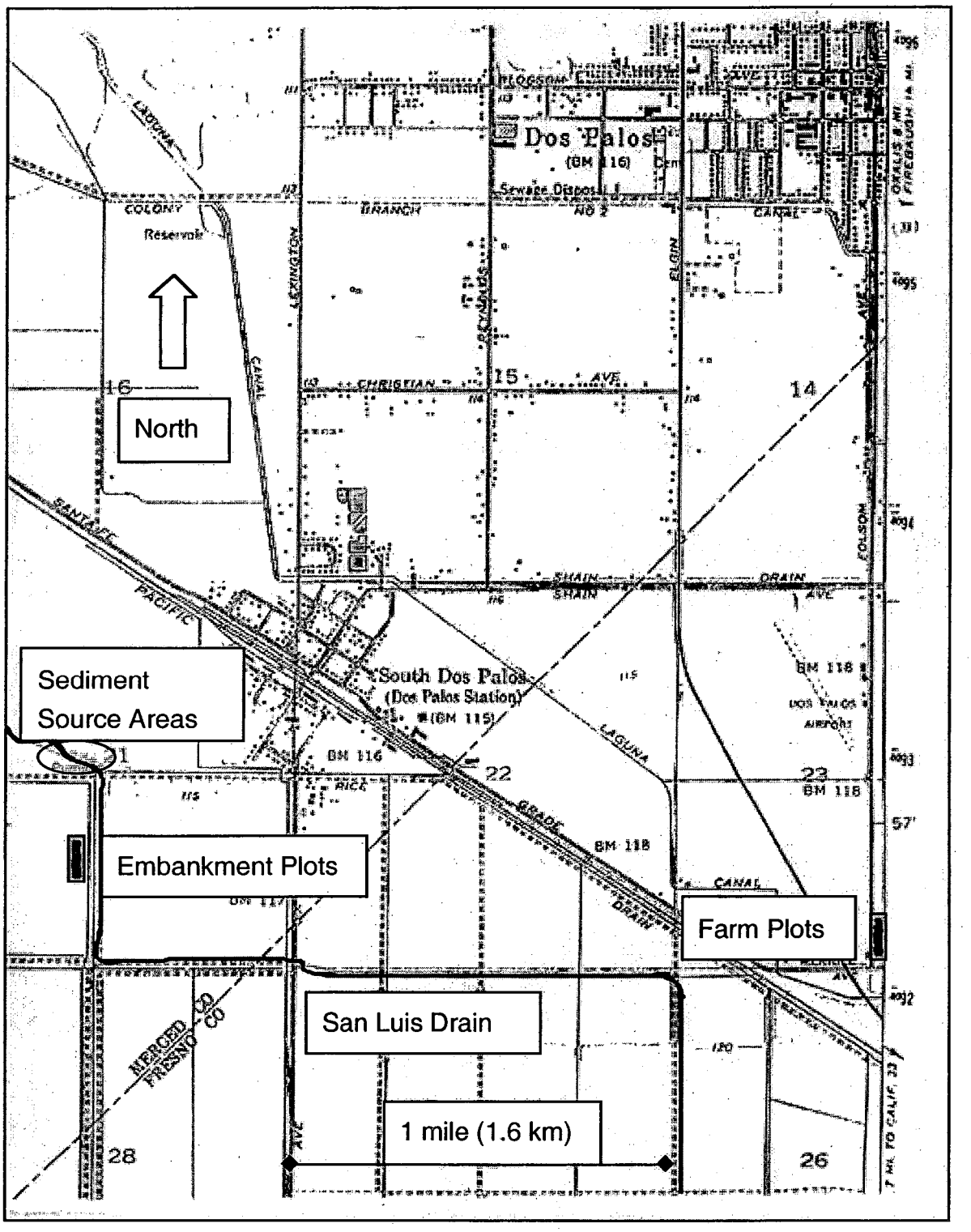


Figure 2.2. Locations of sediment source areas, embankment plots, and farm plots, relative to the San Luis Drain.

2.3 Permitting Issues

In late 1998, LBNL was granted a variance from the California State Water Quality Control Board (SWQCB) 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, they 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 in 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 selenium-enriched canal sediment. The following discussion is not intended to be all-inclusive or comprehensive.

<u>Chapter 3. Criteria for All Waste Management Units, Facilities, and Disposal Sites</u>

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

Subchapter 2 on Siting and Design, the waste is classified 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 SWQCB. 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 waste water

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 SWQCB 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 ANOVA 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 so as to minimize fluid losses to off the 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 CIWMB (California Integrated Waste Management Board) 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 SEDIMENT APPLICATION AND SAMPLING PROCEDURES

Sediment application to the embankment plots occurred in two stages. The sediment application procedure in plot EP-1 was initiated on 12/9/98 and completed on 1/14/99. Sediment was applied to Plots EP-2 and EP-3 on 9/3/99. Sediment application to the farm plots (FP-1 and FP-2) took place on 10/21/99. In each case, Lawrence Berkeley National Laboratory (LBNL), the Panoche W.D. and the Firebaugh W.D. collaborated on the removal and application of SLD sediments. 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. A pictorial account 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 12/9/98. A scoop was taken using a trackhoe from five locations spaced approximately 11.5 m apart, to 0.30-m depth into the roadbed. Sidewall samples were taken from the scooped hole, at 0-0.15 m, and 0.15-0.30 m. The sidewall samples were collected with a trowel, which was decontaminated between samples. The consecutive 0.15-m intervals were bagged into plastic freezer bags with as little air-space as possible.

On 12/22/98, five boreholes were drilled for pre-application soil sampling at EP-1. One hole was drilled to 2.2 m depth 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 0-0.15 m, dark olive brown clay with silt from 0.15-0.3 m, dark olive brown clay from 0.3-0.75, light olive brown clay from 0.75-1.5 m, and wet olive brown clay with minor silt from 1.5-2.2 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 San Luis Drain (SLD) (see Fig. 2.2). 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 12/9/98, SLD sediments were removed from a part of the Drain that was historically identified as having relatively high Se concentrations, and were applied to a 3 m by 59 m drying area. The area is immediately downstream of the Grasslands Bypass Channel Inlet (USBR ft markers 557068-557268). The sediments were removed from the Drain using a trackhoe. Sediment was placed laterally on the adjacent embankment roadway. The resulting stockpile was 3 m wide and 59 m long and allowed to air-dry with no liner underneath. 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 on the 3 m by 59 m drying area. Forty-three grab samples were collected from the stockpile along a paced grid of approximately

1.3 m intervals. Shortly after 1/14/99, the sediment stockpile was moved over and graded onto the embankment adjacent to the roadway (Figs. 3.1 and 3.2).

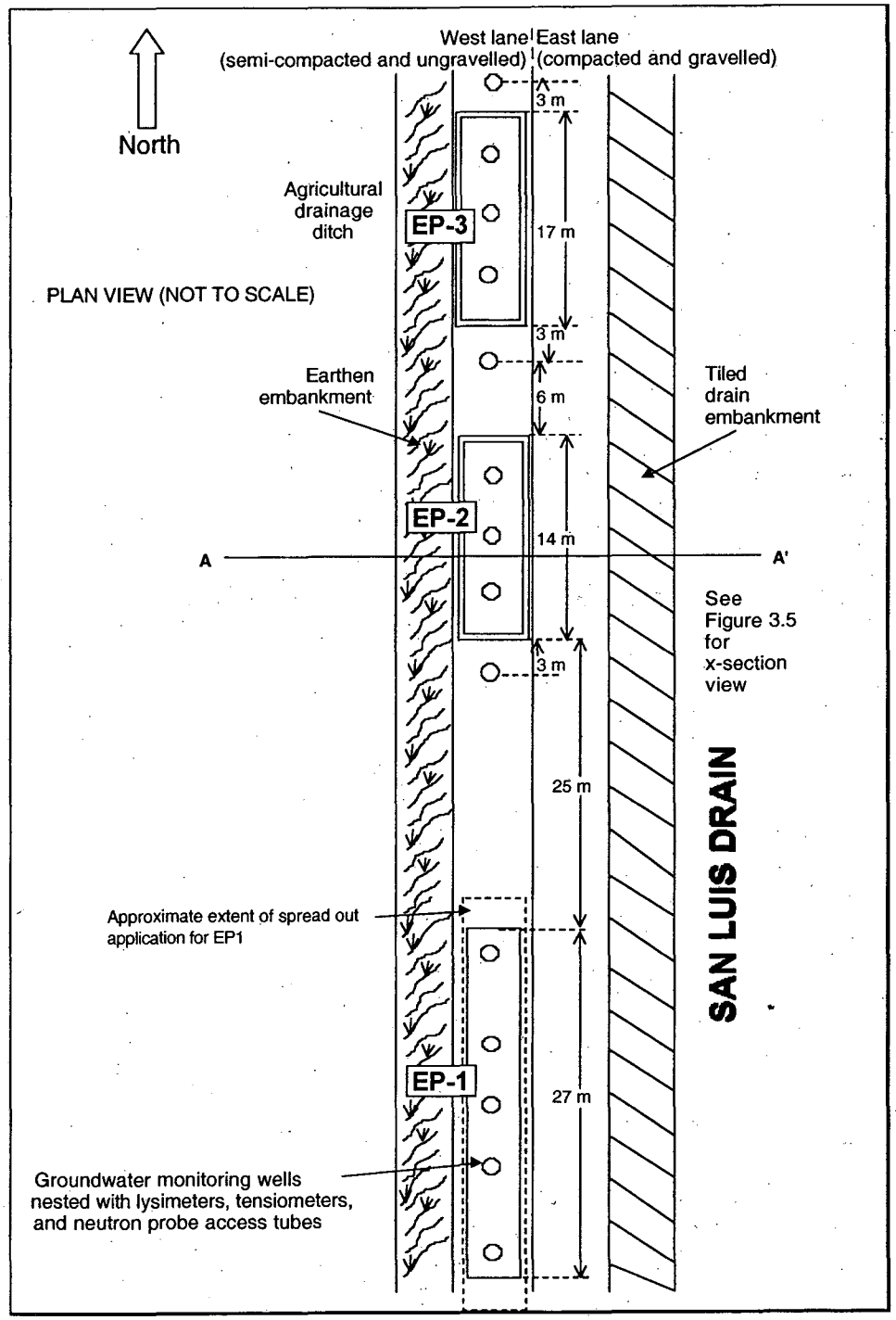


Figure 3.1. Layout of embankment plots and monitoring equipment.

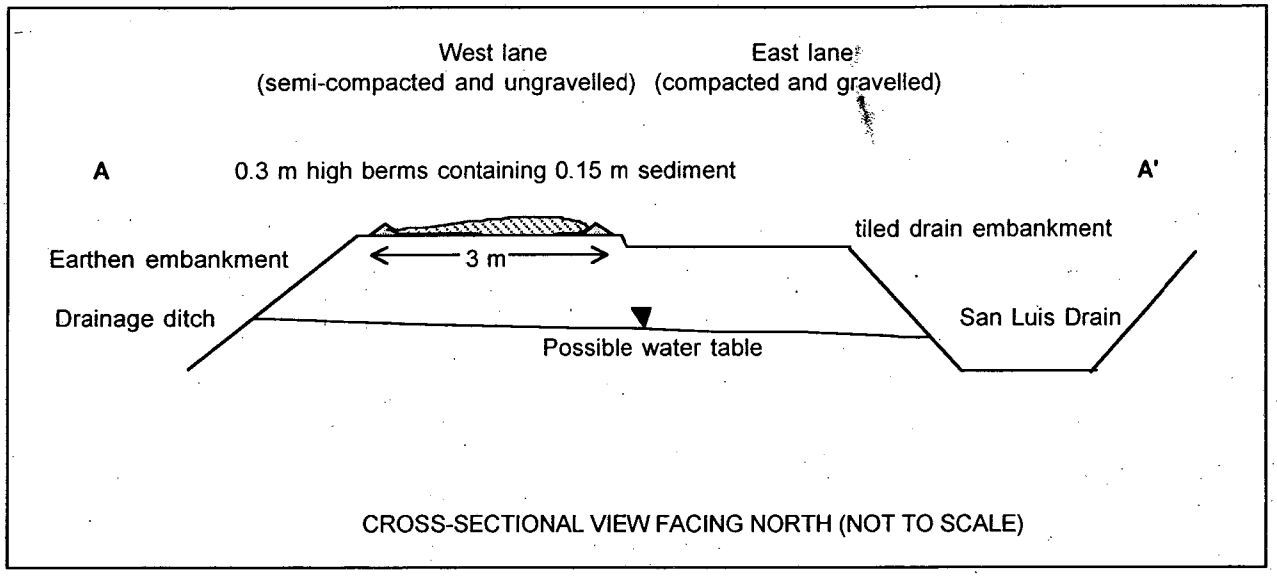


Figure 3.2. Cross-sectional view of embankment plots along section A-A'.

3.1.3 Post-Application Sampling

The first round of post-application soil sampling at EP-1 took place on 4/9/99. At that time, the application was visibly separable from underlying soil. The average thickness of applied sediment at that time was approximately 0.10 m. Drilling locations included five within test plot area, three outside of application area, and two in former location of drying pad. Five-cm-diameter cores were drilled to approximately 1.00-m depth at each location. All cores were sectioned into 0.15-m 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 0.15 m, which subsequently made it impossible to precisely separate the application from the embankment sediments.

From 6/22/99 to 7/6/99, 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 Fig. 3.3 and described in Table 3.1. Lysimeter were installed above the water table, complimentary 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 1.65-2.85 m intervals of the groundwater well boreholes. Subsequent neutron probe measurements were calibrated to the initial moisture contents obtained from cores at 0-1.65 m depth (calibration presented in Section 4.2). After installation, the instrumentation was monitored on a monthly basis.

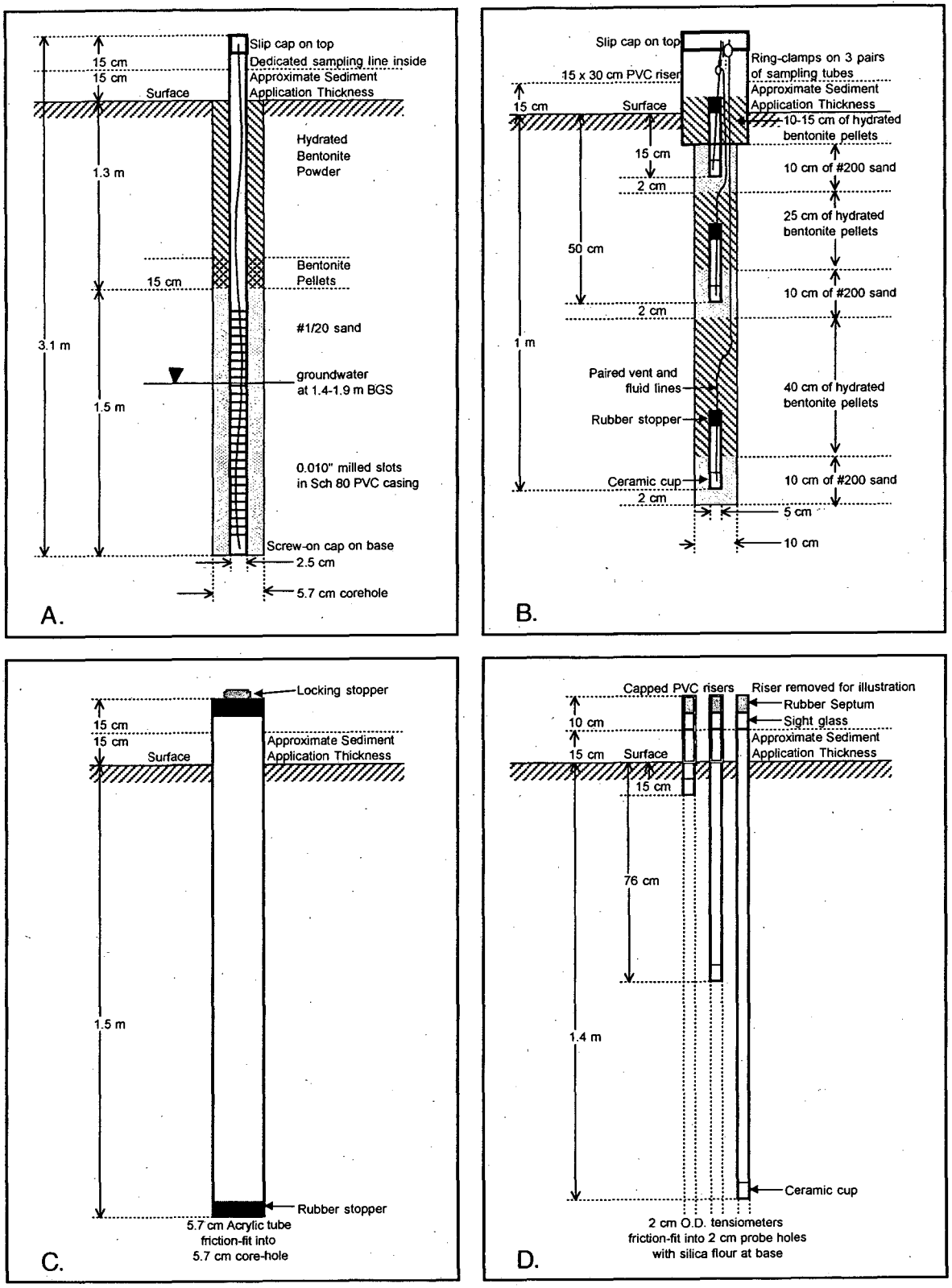


Figure 3.3. Construction detail of embankment plot instrumentation: a.) Groundwater monitoring well, b.) Suction lysimeter, c.) Neutron probe access hole, and d.) Tensiometer cluster.

Table 3.1: 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 cu	**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 Installat 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

As part of the continuing monitoring program, six borings were drilled in the EP-1 area on 3/29/00.

- 5-cm-diameter cores were drilled for each boring
- One core was drilled to 2.4 m depth and 4 cores were drilled to 1.2 m
- All cores were retained and sectioned into 0.15-m intervals for subsequent processing and analysis

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

3.2.1 Pre-Application Sampling

Prior to sediment application, two plots were set up end to end in a north-south alignment, with 9 m of space separating them (Fig. 3.1). On 6/29/99, four soil cores down to a depth of 1.50 m were sampled from each site. A fifth core down to 2.75 m was also collected. From 6/22/99 to 7/6/99, nine clusters of lysimeters, tensiometers, and neutron probe access tubes were installed in EP-2 and EP-3 (Fig. 3.3 and Tables 3.2 and 3.3). Of the nine clusters described, there were three

inside each of the two test plots, and three clusters used as control points (Fig. 3.1). Cores were collected from the 0-1.65 m depth of the neutron probe access boreholes and from the 1.65-2.85 m intervals of the groundwater well boreholes. Subsequent neutron probe measurements were calibrated to the initial moisture contents assessed on the cores from 0-1.65 m depth. Geological conditions were uniform across the plots with minor variations in color: olive gray sandy clay from 0-0.15 m, dark olive gray clay from 0.15-0.45 m, dark olive brown clay from 0.45-0.75, light olive brown clay from 0.75-1.5 m, and wet olive brown clay with minor silt from 1.5-2.85 m. The instrumentation was monitored on a weekly basis for 6 weeks before the 9/3/99 application.

Table 3.2: 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 lysimet	**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	**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 Install 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 3.3: 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	L14-S, -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 lysimet	**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 c	**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 Installa 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

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) which 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 (operated by private contractor, Wayne Gillet). 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 cubic yards (6.9 and 8.4 m^3) of sediment/water mixture were removed from the Source Areas 2 and 3, respectively. Each load was mixed thoroughly (about 100 turns of the

mixer between filling and application) and transported to their respective application sites. 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 0.15 m using a cement rake. 6.9 m^3 filled a 3 m by 14 m space to 0.15 m depth, while 8.4 m^3 filled a 3 m by 17 m space to 0.15 m 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 of Check 18, approximately 300 ft (90 m) downstream of Source Area 2 and 380 ft (116 m) downstream of 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 9/3/99 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 3/28/00.

- Five 5-cm-diameter cores were drilled into each plot.
- For each plot, one core was drilled to 2.2 m depth and four cores were drilled to 1.2-1.3 m.
- All cores were retained and sectioned into 0.15-m intervals for subsequent processing and analysis.

Dominant plants in each test plot were periodically identified. Plant samples were collected on 1/13/00 and 6/30/00, 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 (Fig. 3.4).

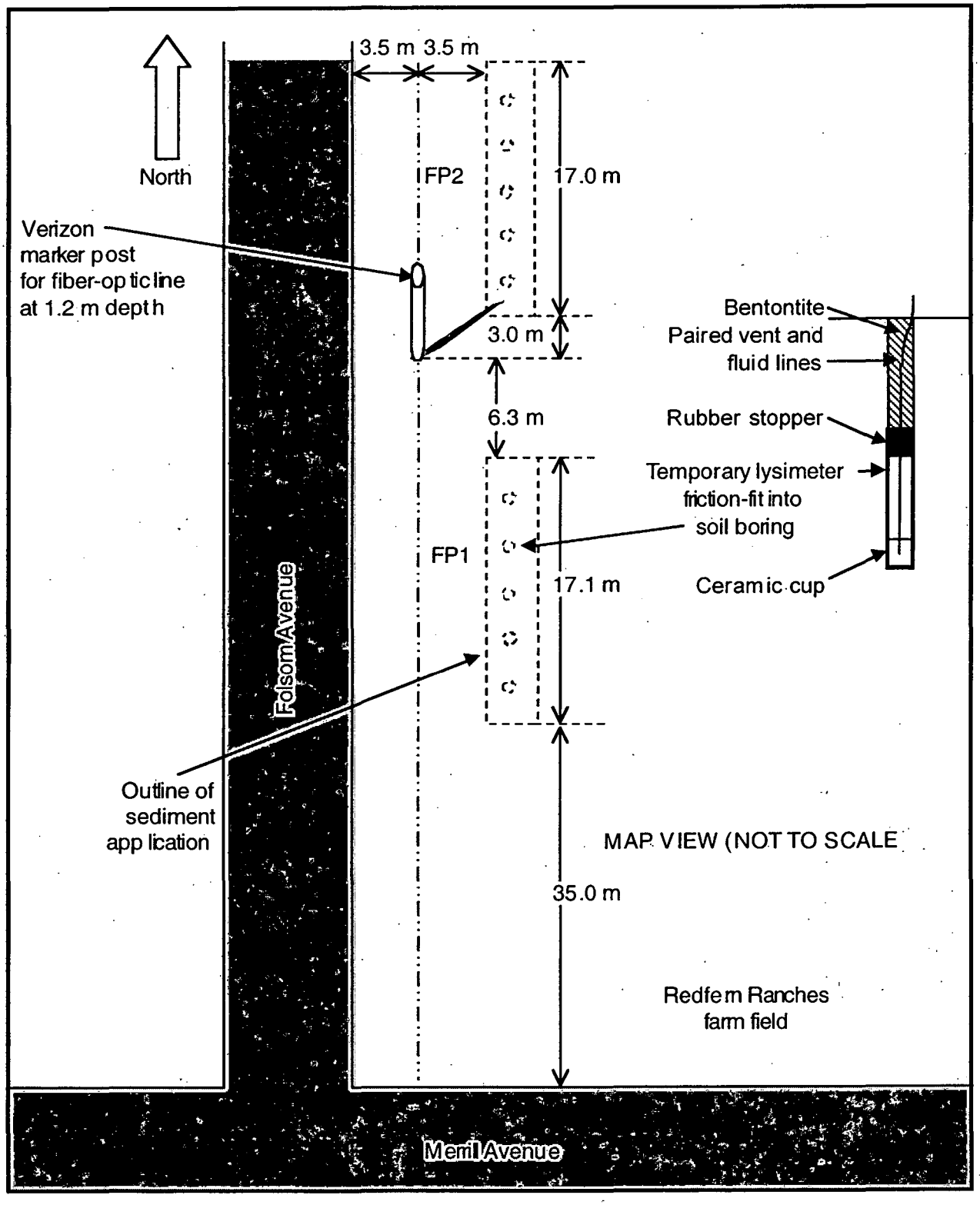


Figure 3.4. Layout of farm plots, location of soil borings, and temporary lysimeter design.

Pre-application drilling and sampling was performed on 10/19/99:

- Five 5-cm-diameter cores were drilled into each plot.
- For each plot, one core was drilled to 2.4-m depth 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 0.15-m-intervals for subsequent processing and analysis.
- Geological conditions were uniform across both plots: dark gray silty clay from 0-0.45 m, medium olive brown clay from 0.45-1.5 m, medium brown clay with sand (5-15 %) from 1.5-2.4 m.
- Temporary lysimeters (4.7-cm diameter) were installed in 2.4 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 later retrieval. The lysimeters were evacuated to 80 cbar.

On 10/20/99, groundwater samples were collected from the lysimeters buried at 2.4 m depth. Lysimeters buried at 1.5 m did not accumulate water. Three of 4 lysimeters were then retrieved. All drill holes were backfilled with bentonite pellets up to the water table (1.5 m depth) and dry fine grained bentonite chips to 0.15 m below the surface. The upper 0.15 m was covered with loose soil.

3.3.2 Sediment Dredging and Application

The SLD sediments were removed from two segments of the drain (Source Areas 4 and 5) as described in Section 2.1. The sediments were removed from the drain using a trackhoe, as described in Section 3.2. Eleven cubic yards (8.4 m^3) of sediment/water mixture were 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 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 0.15 m using a cement rake. The plot outlines were referenced by distances from the Merrill and Folsom Ave. pavement boundaries. No enclosures, flags, or instrumentation 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 of Check 18, approximately 320 ft (100 m) downstream of Source Area 1 and 400 ft (120 m) downstream of 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 10/28/99, the farm plot applications had become gray and fissured with drying cracks. There had been no record of rain at the test site up to 11/5/99. On 11/15/99 the farm plots were plowed by shanks that cut to 0.45-0.50 m depth, with 0.45 m lateral separation. On 11/19/99, the plots

were disked to 0.15-0.20 m depth. Disks are 0.15-0.20 m apart. On 11/29/99, the plots were plowed by a deep chisel with shanks that cut to 0.70-0.75 cm depth, with 0.45 m 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 1/12/00-3/8/00. On 3/27/00, the plots were again plowed by a deep chisel. By 4/7/00, the field had been disked twice again and set with north-south furrows. On 4/16/00, sprinkler irrigation had been started on a 10 day cycle through the summer. An isolated 3 cm rainfall event, recorded on 4/17/00 at Panoche W.D. (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 12/3/99 and 3/27/00. The 12/3/99 sampling occurred after several soil reworking procedures described in section 3.3.2, and before the beginning the 99/00 rainy season. The 3/27/00 event took place after the 99/00 rainy season and between plowing and planting of the field.

Post-application drilling was performed on 12/3/99:

- Five 5-cm-diameter cores were drilled into FP1 and 4 into FP2;
- For each plot, one core was drilled to 2.5 m depth 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 in FP1 (the apparent water table);
- Cores were sectioned into 0.15-m intervals for subsequent processing and analysis;
- Temporary lysimeters (4.7 cm diameter) were installed in the 2.5 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 0.10-0.20 m of each borehole was backfilled with native soil.

On 12/8/99, the three lysimeters were evacuated, but only the deepest (2.5 m deep) lysimeters produced water samples. On 12/17/99, two additional lysimeters were installed to 0.5 m depth, one in each farm plot. No rainfall of record had occurred between lysimeter installation and the application. On 1/5/00, 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 January 12-March 8, 2000. Water recoveries from the 1.8-m- and 0.5-m-deep lysimeters commenced on 2/24/00. On 3/13/00, the last round of water samples was collected from the lysimeters. In anticipation of spring plowing and planting, the shallow lysimeters were removed.

A drilling and sampling event took place on 3/27/00, between plowing and 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 FP1 and FP2 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 0.10-0.20 m of each borehole was backfilled with native soil.

After the furrows had been set, four temporary lysimeters were reinstalled on 4/14/00.

- Drilling locations were chosen to coincide with selected soil boring locations from 3/27/00;
- For each plot, one core was drilled to 2.2 m depth and one lysimeter was installed to 2 m depth;
- For each plot, one core was drilled to 1.8 m depth and one lysimeter was installed to 1.5 m depth
- Cores from below 1.2 m depth were sectioned into 0.15-m intervals for subsequent processing and analysis.

On 5/2/00, two additional lysimeters were installed to 0.5 m depth, one in each farm plot. On 5/3/00 the four deeper lysimeters were repaired from planting activities and sampled. The shallow lysimeters did not produce water. The farm plot lysimeters were subsequently sampled on a monthly basis.

On 5/1/00, 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 chile pepper seed. As of 5/31/00, sprouting crop was observed on furrow ridges. Tractor-drawn implements were used once, after the crop had grown to 15-cm height, to remove weeds from the furrow valleys. As of 9/13/00, The cotton started to bloom on 9/13/00 and was picked during the week of 11/6/00.

Three complete cotton plants were collected on 7/14/00 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 11/4/00, 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 m^2), permitting the calculation of biomass and cotton yield.

4 SAMPLING AND MONITORING RESULTS

The following data presentation contains results from the initial application of SLD sediment and subsequent monitoring through August 2000.

4.1 Initial Sediment Application

4.1.1 Drain Sediment Selenium

San Luis Drain sediments dredged for emplacement on embankment plot 1 (EP-1) were sampled from a bulk pile after dredging on 12/9/98. Forty-three samples were collected. Total and water-soluble Se data, along with gravimetric moisture content are shown in Table 4.1. The average total Se concentration was 2.56 µg/g on a dry weight basis and 1.45 µg/g on a wet weight basis. The wet weight concentration is well below the Cal EHS threshold for hazardous waste of 100 µg/g. Average total soluble Se was 0.021 µg/g, 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). Selenite comprised about 15% of total soluble Se. The average gravimetric moisture content of these sediments was 0.76.

San Luis Drain sediments applied to embankment plots 2 and 3 (EP-2, EP-3) were sampled shortly after dredging and spreading onto the designated area (9/3/99). Total Se, soluble Se, and moisture content for EP-2 and EP-3 are shown in Tables 4.2 and 4.3, respectively. The average total Se dry-weight concentrations were 37.1 µg/g in EP-2 and 19.53 µg/g in EP-3. Considering moisture content, the corresponding average wet-weight concentrations were 18.13 µg/g in EP-2 and 10.79 in EP-3, both below the Cal EHS threshold. Compared to the EP-1 sediments, soluble Se comprised an even smaller fraction of total Se, around 0.25%. Selenite comprised about 12% of total soluble Se. The average gravimetric moisture content was 1.05 and 0.81 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 10/21/99. Total Se, soluble Se, and gravimetric moisture content are shown in Tables 4.4 and 4.5. The average total Se was 111.6 µg/g in FP-1 and 66.7 µg/g in FP-2, on a dry-weight basis. On a wet-weight basis these concentrations (42.22 µg/g and 25.46 µg/g) do not exceed the Cal EHS threshold. 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 µg/kg. Soluble selenite comprised 12% and 16% of total in FP-1 and FP-2 soils, respectively.

Table 4.1 Total and soluble Se in SLD sediments applied to embankment plot 1 (EP-1).

Sample	Location (m†)	$[Se]_{total}$ dry weight (µg/g)	Moisture Content (g/g)	$[Se]_{total}$ wet weight (µg/g)	$[Se^{+4}]_{soluble}$ dry weight (µg/g)	$[Se]_{soluble}$ 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 4.2 Total and soluble Se in SLD sediments applied to embankment plot 2 (EP-2).

Sample	$[Se]_{total}$ dry weight (µg/g)	Moisture Content (g/g)	$[Se]_{total}$ wet weight (µg/g)	$[Se^{+4}]_{soluble}$ dry weight (µg/g)	$[Se]_{soluble}$ 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 4.3 Total and soluble Se in SLD sediments applied to embankment plot 3 (EP-3).

Sample	$[Se]_{total}$ dry weight (µg/g)	Moisture Content (g/g)	$[Se]_{total}$ wet weight (µg/g)	$[Se^{+4}]_{soluble}$ dry weight (µg/g)	$[Se]_{soluble}$ 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 4.4 Total and soluble Se in SLD sediments applied to farm plot 1 (FP-1).

Sample	$[Se]_{total}$ dry weight (µg/g)	Moisture Content (g/g)	$[Se]_{total}$ wet weight (µg/g)	$[Se^{+4}]_{soluble}$ dry weight (µg/g)	$[Se]_{soluble}$ 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 4.5 Total and soluble Se in SLD sediments applied to farm plot 2(FP-2).

Sample	$[Se]_{total}$ dry weight (µg/g)	Moisture Content (g/g)	$[Se]_{total}$ wet weight (µg/g)	$[Se^{+4}]_{soluble}$ dry weight (µg/g)	$[Se]_{soluble}$ 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		

4.1.2 Drain Water Selenium

Drain 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 4.6. The average total soluble Se was 68.6 µg/L, suggesting that the dredging operation was not enough of a disturbance to cause a significant increase in downstream Se levels, since Se 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 Cal EHS standard for wastewater.

Similar sampling occurred during the dredging for EP-2 and EP-3, and FP-1 and FP-2. The results are shown in Tables 4.7 and 4.8, 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.

Table 4.6 Selenium in San Luis Drain water collected downstream of 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 4.7 Selenium in San Luis Drain water collected downstream of 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 of 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 4.8 Selenium in San Luis Drain water collected downstream of the FP-1 and FP-2 dredging operation.

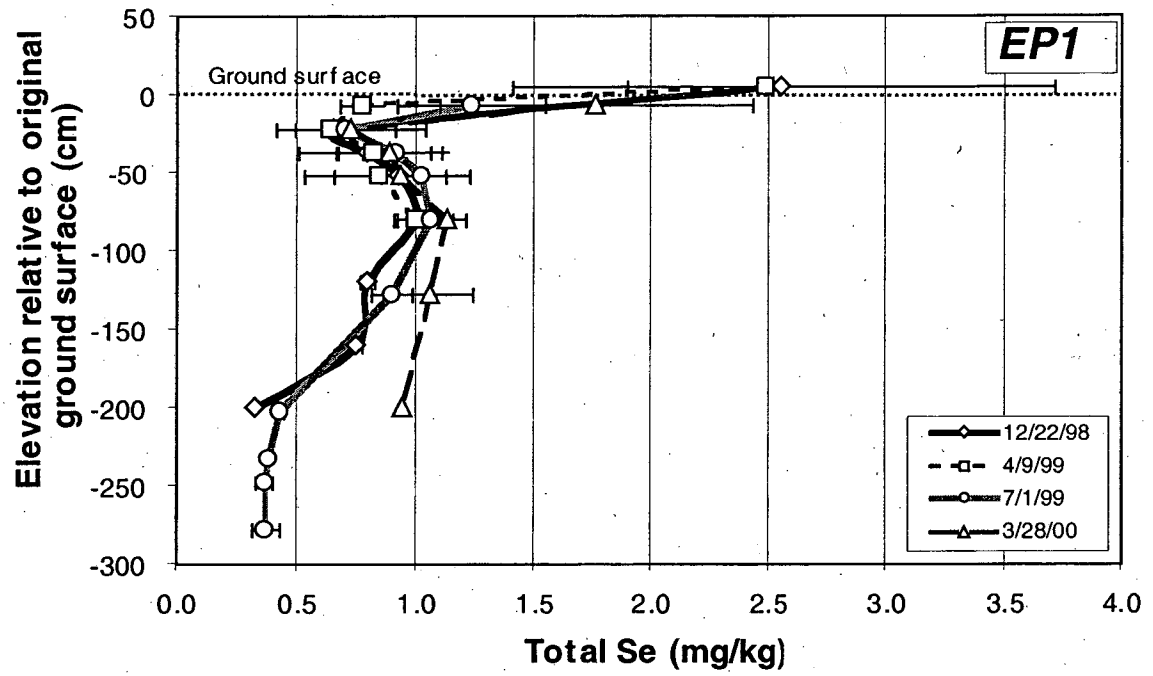
Sample location	Time	$[Se^{+4}]$ (µg/L)	[Se] (µg/L)
100 m downstream of sediment removal, 200 m downstream of Check 18	8:31	1.81	69.30
	8:40	1.87	63.84
	8:47	1.50	64.68
	8:55	1.84	70.98
	9:05	1.72	72.24
	9:21	1.76	66.99
	10:46	1.92	61.95
	10:56	2.01	72.03
	11:12	2.09	64.89
	11:26	1.73	67.83
	11:36	1.52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

4.2 Embankment Plots

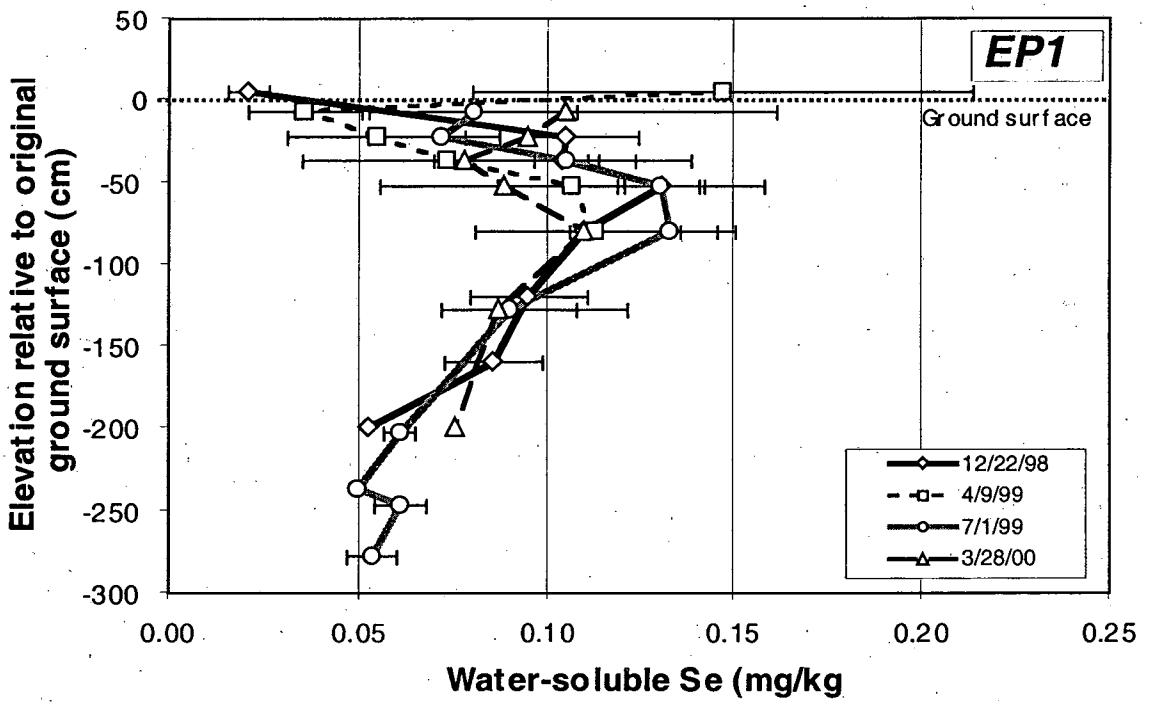
4.2.1 Sediment Selenium

4.2.1.1 Embankment Plot 1 (EP-1)

The soil profile under the future EP-1 plot was cored on 12/22/98 and after SLD sediment application on 4/9/99, 7/1/99, and 3/28/00. The results of this sampling and the subsequent Se analysis are shown in Fig. 4.1a and 4.1b, for total and soluble Se, respectively. The initial application of sediments containing on average 2.5 µg g^{-1} Se, is apparent in data from 12/22/98 and 4/9/99. Since the plot was disked in May of 1999, the applied sediment was not distinguishable during later sampling, and the near surface concentrations were somewhat lower (1.25 µg g^{-1} on 7/1/99 and 1.75 µg g^{-1} on 3/28/00). Nonetheless, there is overlap in this data, as shown by the standard deviations, signifying a lack of profile-wide changes in Se concentrations. It is also clear that Se did not move deeper into the profile, as evidenced by the static concentration profiles, in both total and water-soluble Se, below a depth of 0.25 m. The increase in water-soluble Se between 12/22/98 and 4/9/99 at +5 cm is due to the oxidation of Se in the applied sediments. The difference of approximately 0.13 µg g^{-1} 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 (7/1/99, at -5 cm). Although future increases in soluble Se concentrations near the soil surface can be anticipated, they will surely 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.



a.



b.

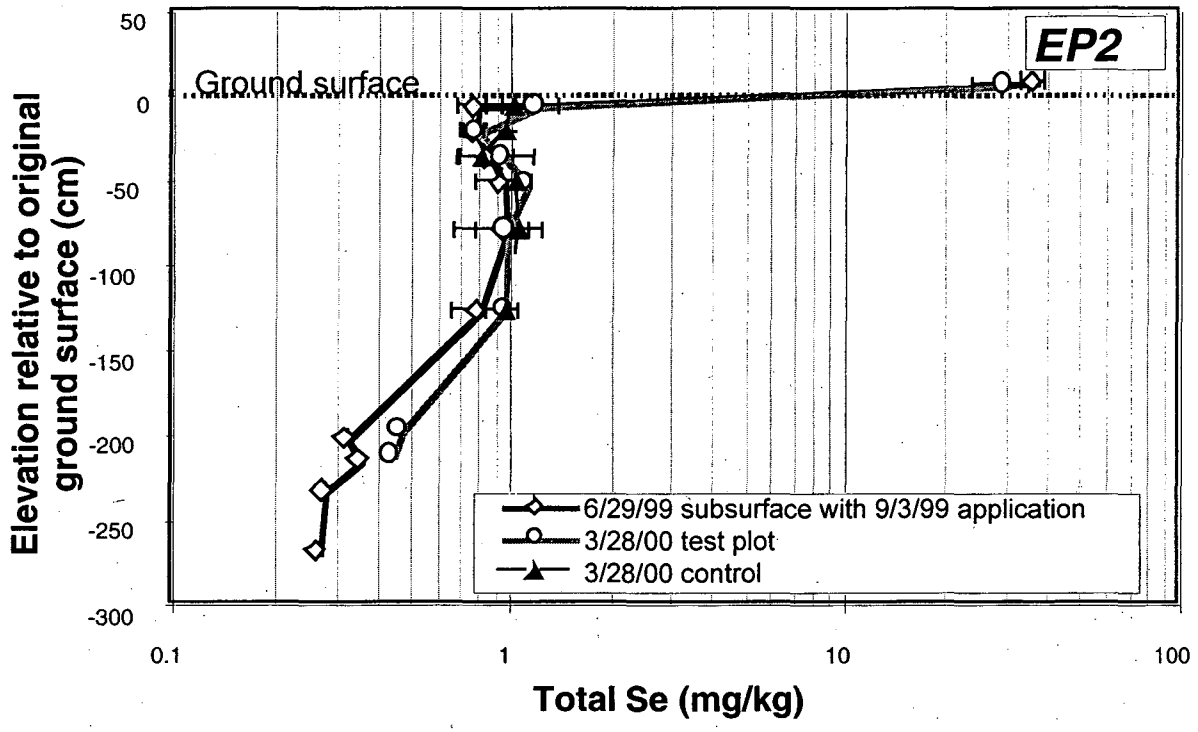
Figure 4.1. Total (a) and water-soluble (b) selenium concentrations normalized to soil mass in plot EP-1. Error bars represent one standard deviation on either side of the mean.

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

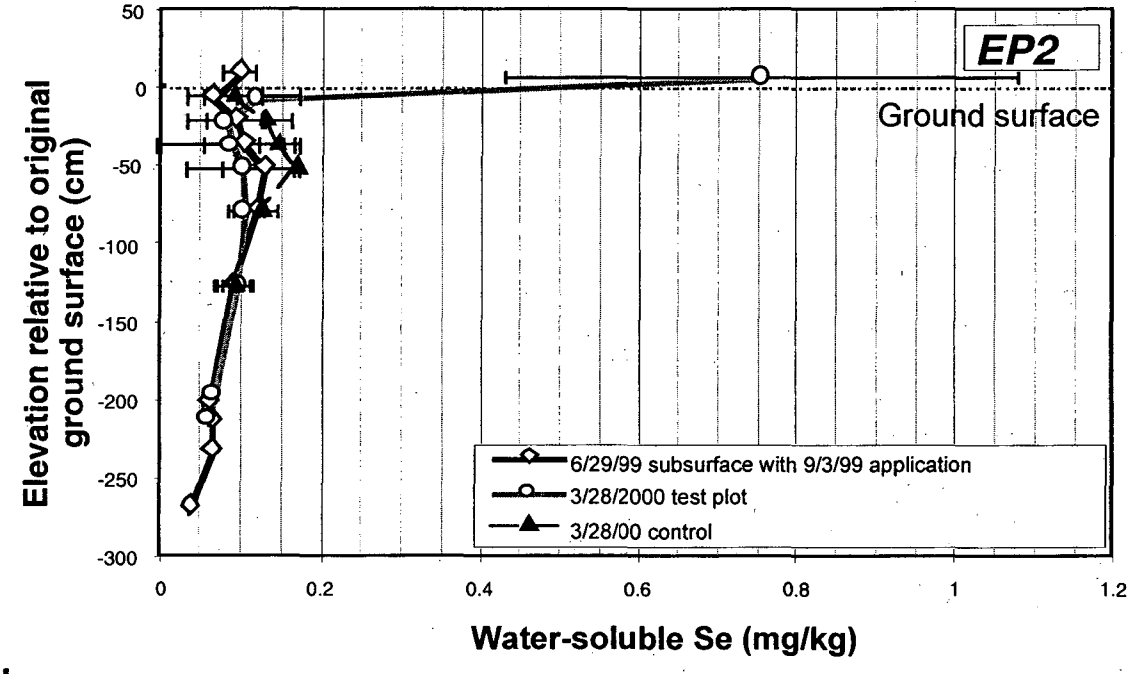
Similar to EP-1, the soil profile under the future EP-2 and EP-3 plots was cored prior to sediment application, on 6/29/99. Assuming that Se concentrations in the un-amended embankment sediments did not change over the following two months, the results of the 6/29/99 sampling and analysis are combined with the analysis of dredged sediments and presented in Figs. 4.2 and 4.3. These graphs also contain results from sediment cores collected on 3/28/00 from each of the test plots and a control area outside of the application. The results from EP-2 and EP-3 are similar. The applied sediments were not incorporated into the underlying sediment. Selenium concentrations did not change six months after application. Selenium concentrations in the 10 cm of applied sediment (shown above the original ground surface) were around 35 $\mu g\ g^{-1}$ and 20 $\mu g\ g^{-1}$, for EP-2 and EP-3, respectively (Figs. 4.2a and 4.3a). As in EP-1, no changes in Se concentrations at depth were observed. Although there is an apparent increase in total Se in EP-3 at the shallowest depth below the original ground surface (0-0.15 m), this is may be due to infiltration of SLD water from the applied sediments, immediately after application. Trends in soluble Se (Figs. 4.2b and 4.3b) are similar to those observed in EP-1, in that soluble Se concentrations in the applied sediments increase due to oxidation. These increases correspond to a net oxidation of 2% of the total Se inventory. 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 shown 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 San Luis Drain to the east (Fig. 3.1). The hydrologic parameters pertinent to the embankment plots are shown in Fig. 4.4. Rainfall, temperature, and evapotranspiration (ET_0) data came from the Panoche CIMIS Station (#124). The first cycle of post-application precipitation occurred from 1/19/00 to 3/8/00, with a significant event (3 cm) on 4/17/00. Cumulative rainfall during this period was 10.9 cm. ET_0 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 what one might expect at the embankment plot, and can only be interpreted qualitatively. Over any given year, cumulative ET_0 greatly exceeds cumulative rainfall. On the other hand, most of the rainfall occurs during periods of very low ET_0, thereby resulting in conditions more conducive to rainfall infiltration. Water levels in the unlined drainage ditch are also shown in Fig. 4.4. Apparently these levels are seasonally affected, as seen by peak flows in the winter and low flows in the summer.

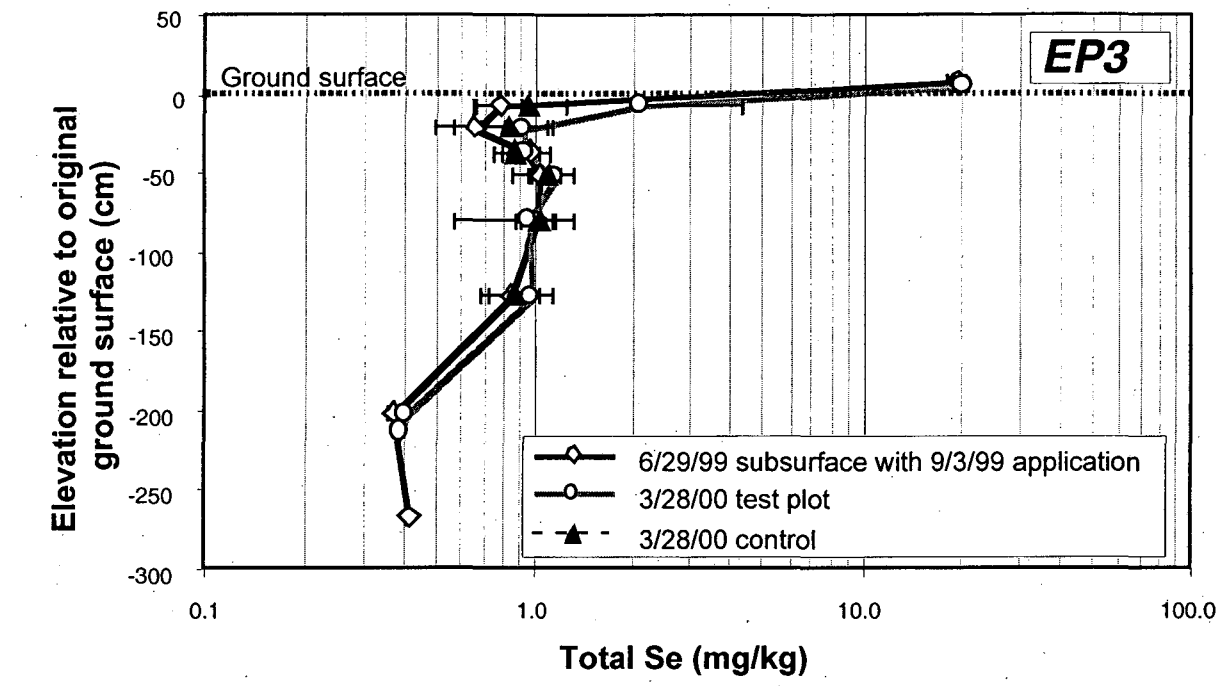


a.

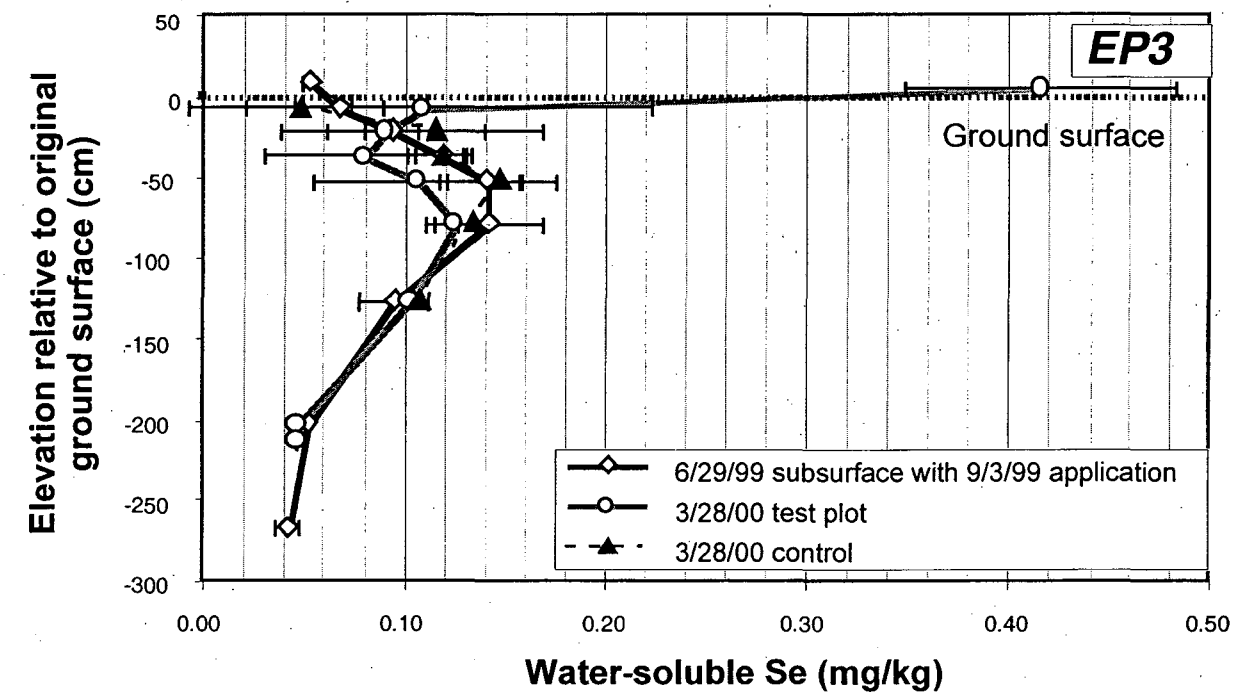


b.

Figure 4.2. Total (a) and water-soluble (b) selenium concentrations normalized to soil mass in plot EP-2. Error bars represent one standard deviation on either side of the mean.



a.



b.

Figure 4.3. Total (a) and water-soluble (b) selenium concentrations normalized to soil mass in plot EP-3. Error bars represent one standard deviation on either side of the mean.

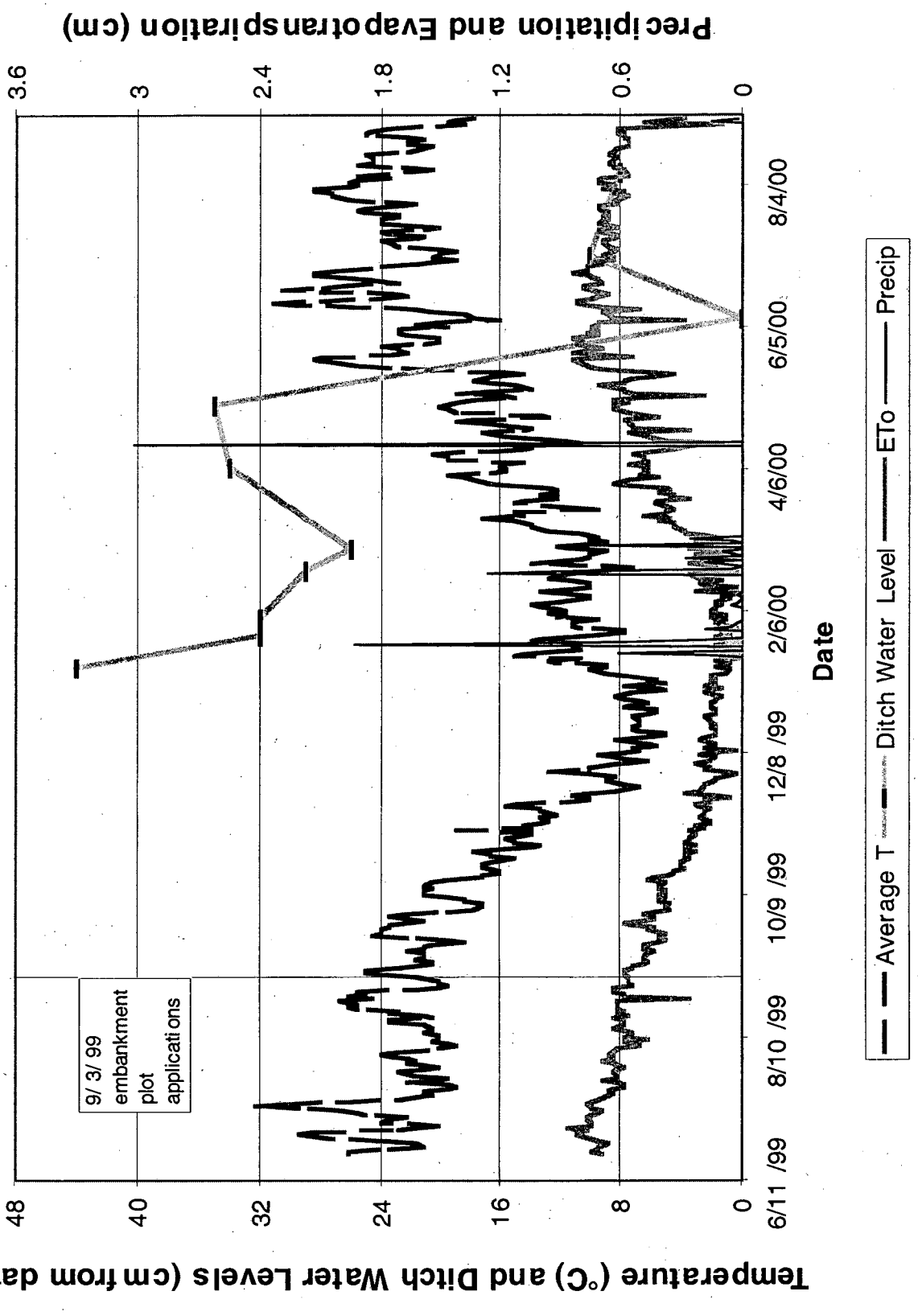


Figure 4.4. Daily weather records and ditch water levels at the embankment plots.

Wells distributed throughout the embankment plots (Fig. 3.1) are used to measure the groundwater level. The depth of the water table in EP-1, EP-2, and EP-3 is shown in Figs. 4.5, 4.6, and 4.7, 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. Groundwater levels fall during the summer and fall, and start rising following the first major rainfall. This behavior does not comply 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 Fig. 4.8. Representative results of moisture content (expressed as saturation) measurements from each of the embankment plots are shown in Figs. 4.9-4.11. Although there are some differences amongst the plots, the general trends are similar. Saturation increases in the winter, in particular at the sediment surface. Increases observed on 2/3/00 and 3/3/00 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 0.40 m 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 (7-9/00, between 0.50 m and 1.00 cm) are likely a result of evapotranspiration.

The effects of the application of SLD sediments on EP-2 and EP-3 are apparent in Figs. 4.10 and 4.11, respectively. Since the calibration curve shown in Fig. 4.8 was derived from embankment sediments and not SLD sediments, the saturation data for SLD sediments (above-ground values) is qualitative. Nevertheless, the original high moisture content of the applied sediments is clearly shown on 9/3/00 (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.

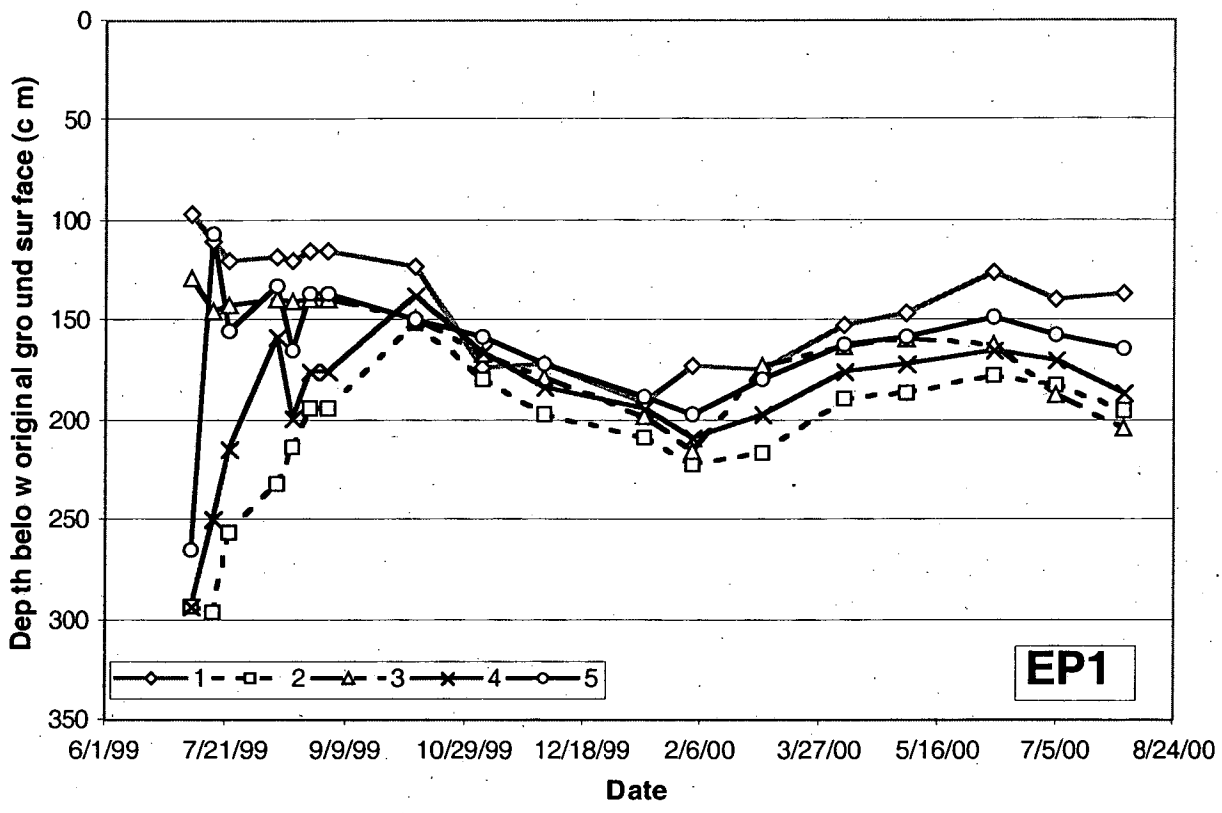


Figure 4.5. Depth to groundwater at EP-1.

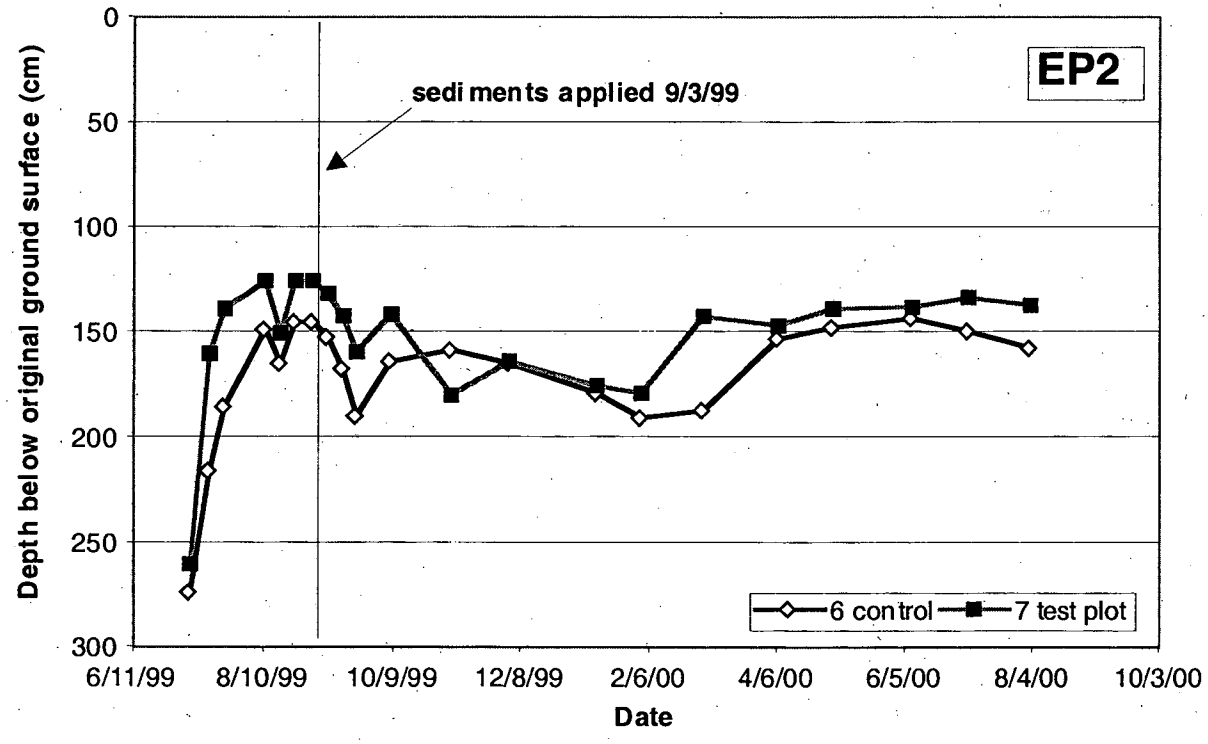


Figure 4.6. Depth to groundwater at EP-2.

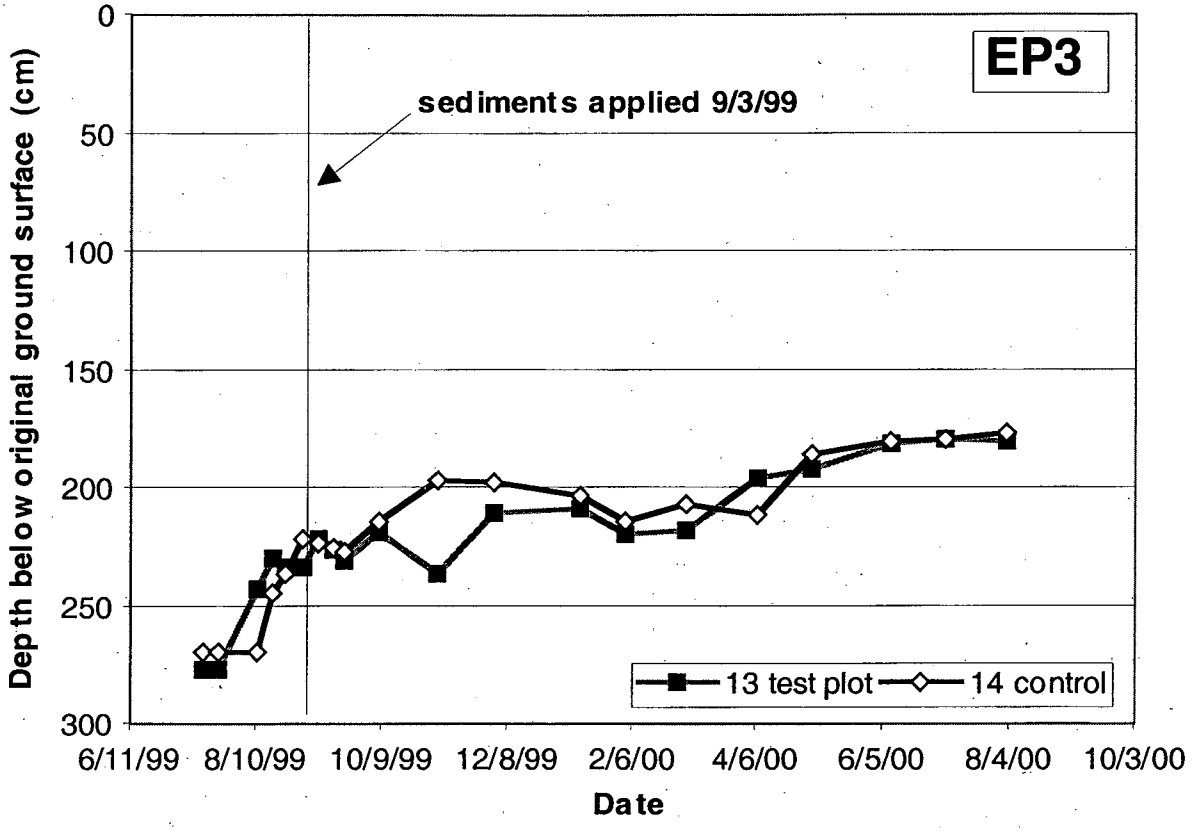


Figure 4.7. Depth to groundwater at EP-3.

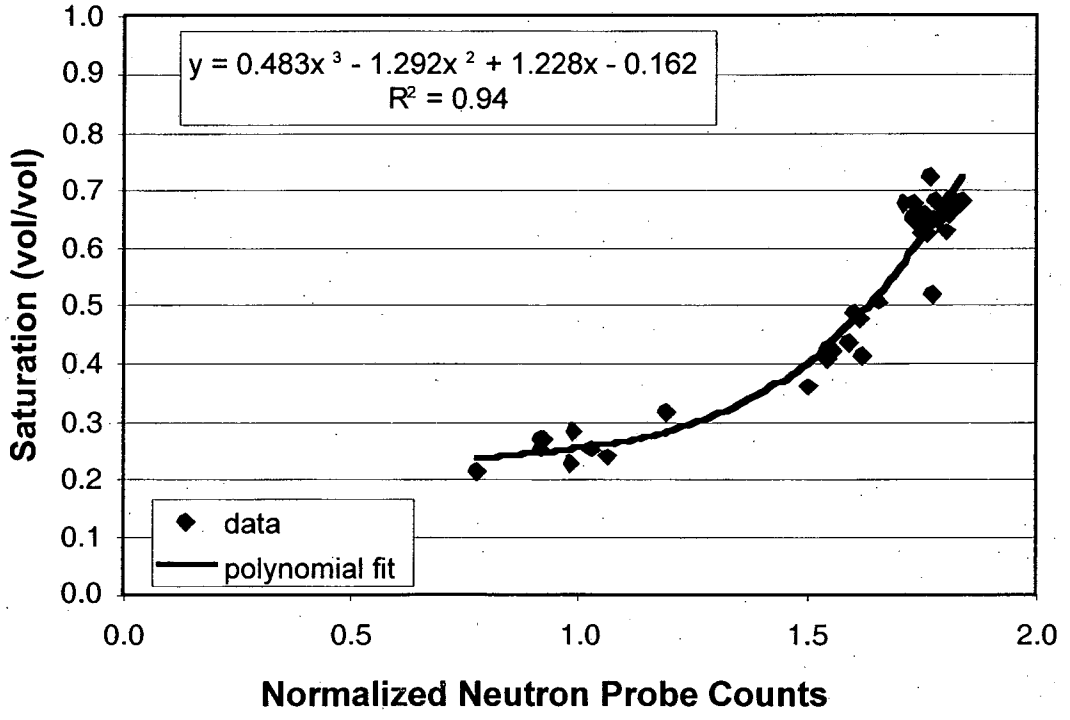


Figure 4.8. Calibration curve and equation for neutron probe counts in EP soil.

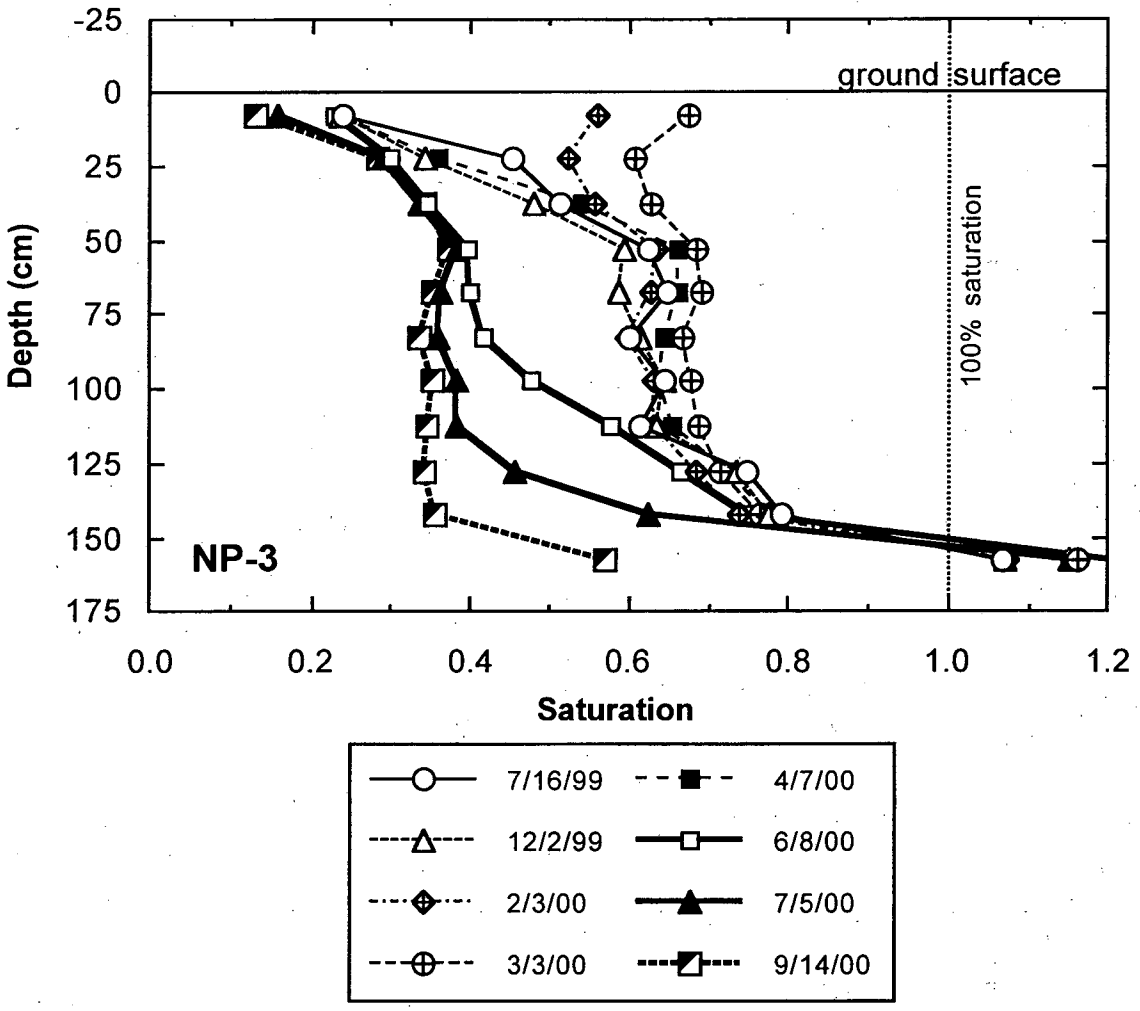


Figure 4.9. Sediment profile saturation at EP-1 (access hole NP-3) based on neutron probe measurements.

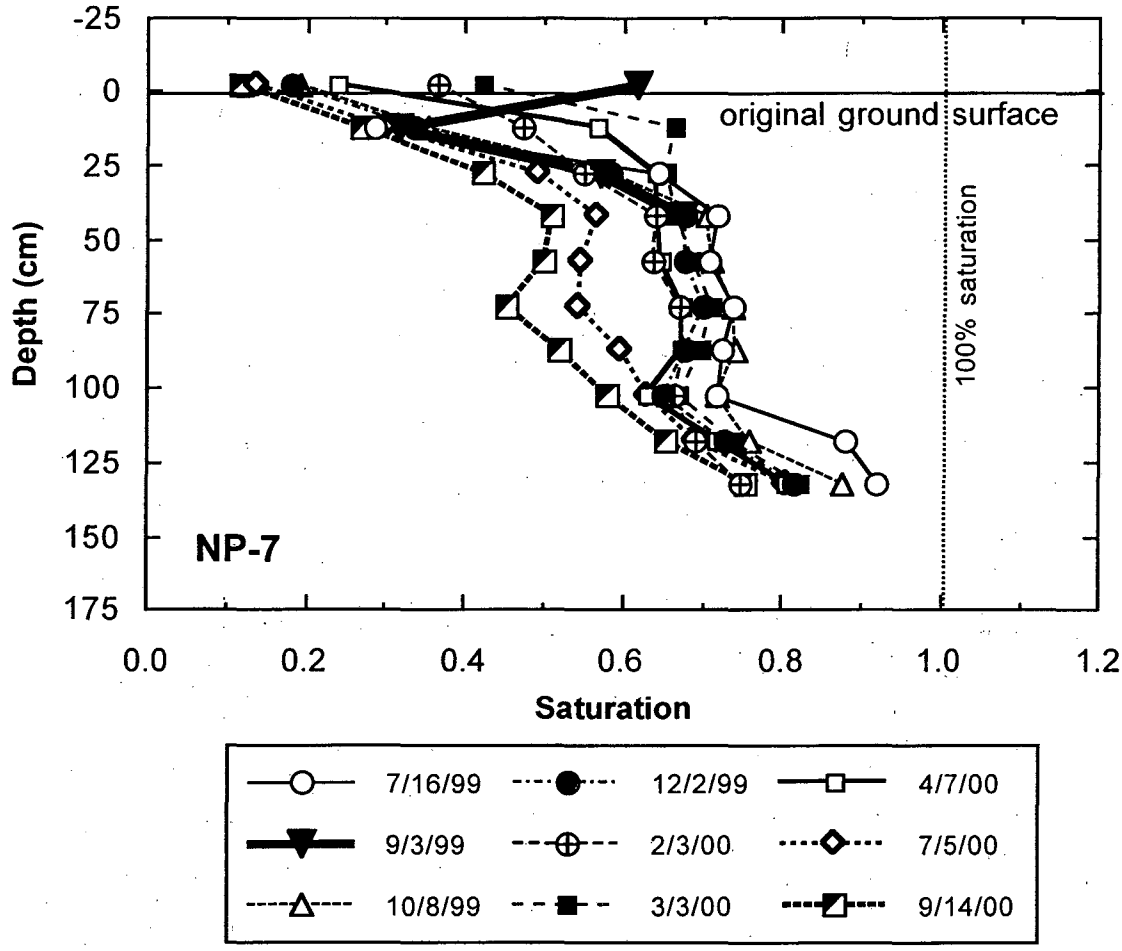


Figure 4.10. Sediment profile saturation at EP-2 (access hole NP-7) based on neutron probe measurements.

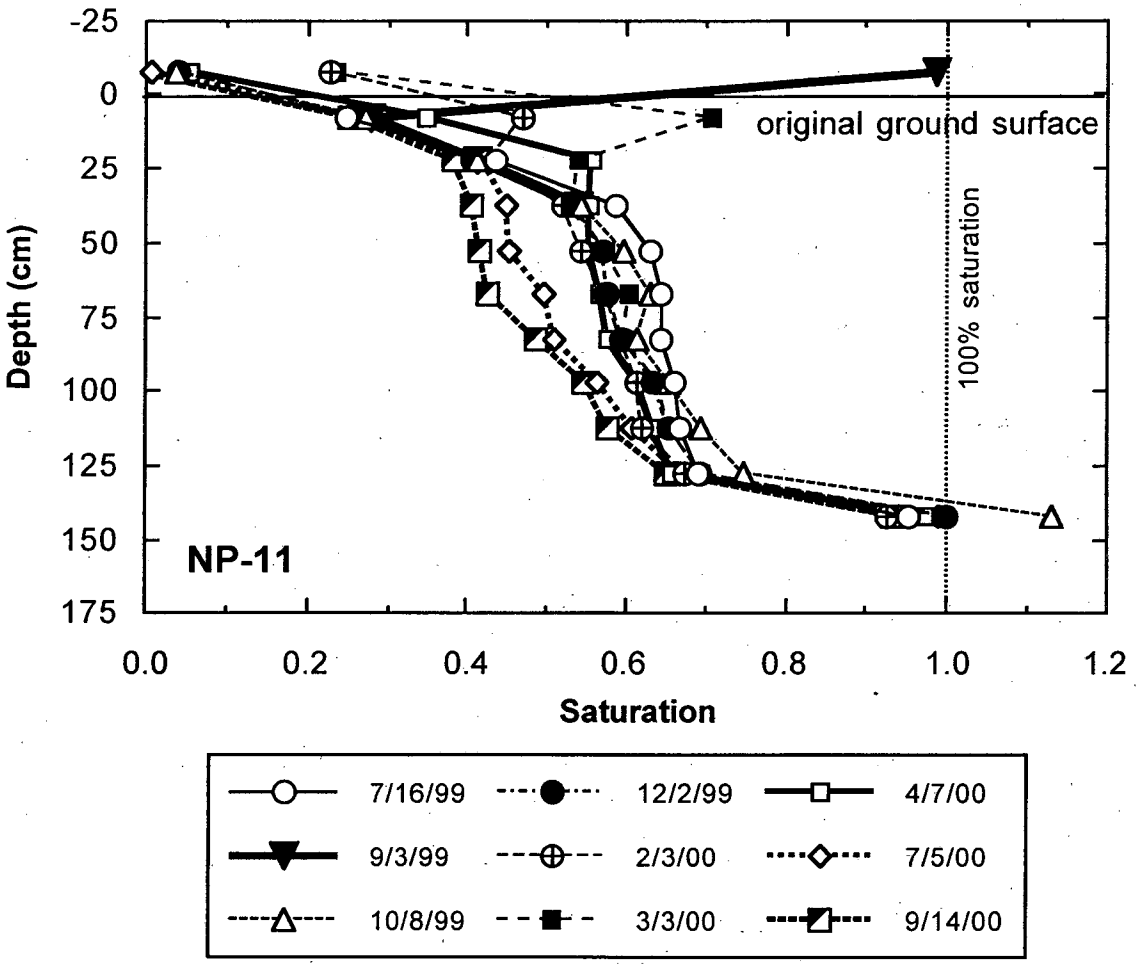


Figure 4.11. Sediment profile saturation at EP-3 (access hole NP-11) based on neutron probe measurements.

4.2.3 Soil water and groundwater selenium and salts

Soil water sampling in the embankment plots yielded nearly continuous data from the 1.00-m-deep samplers, intermittent data from the 0.15-m-deep samplers, and very rare data from the intermediate depth samplers at 0.50 m. This is due to limited rainfall infiltration, resulting in a matric potential close to or beyond the effective working range of vacuum lysimeters. The 1.00-m samplers were close enough to the water table, that they readily produced samples. The 0.15-m lysimeters produced samples following some of the larger rainfall events, specifically in February and March 2000. Samples from the 0.50-m 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, 2, and 3 are presented in Figs. 4.12-14. Also shown is the depth to the water table at each of these locations. Corresponding results from a control site are shown in Fig. 4.15.

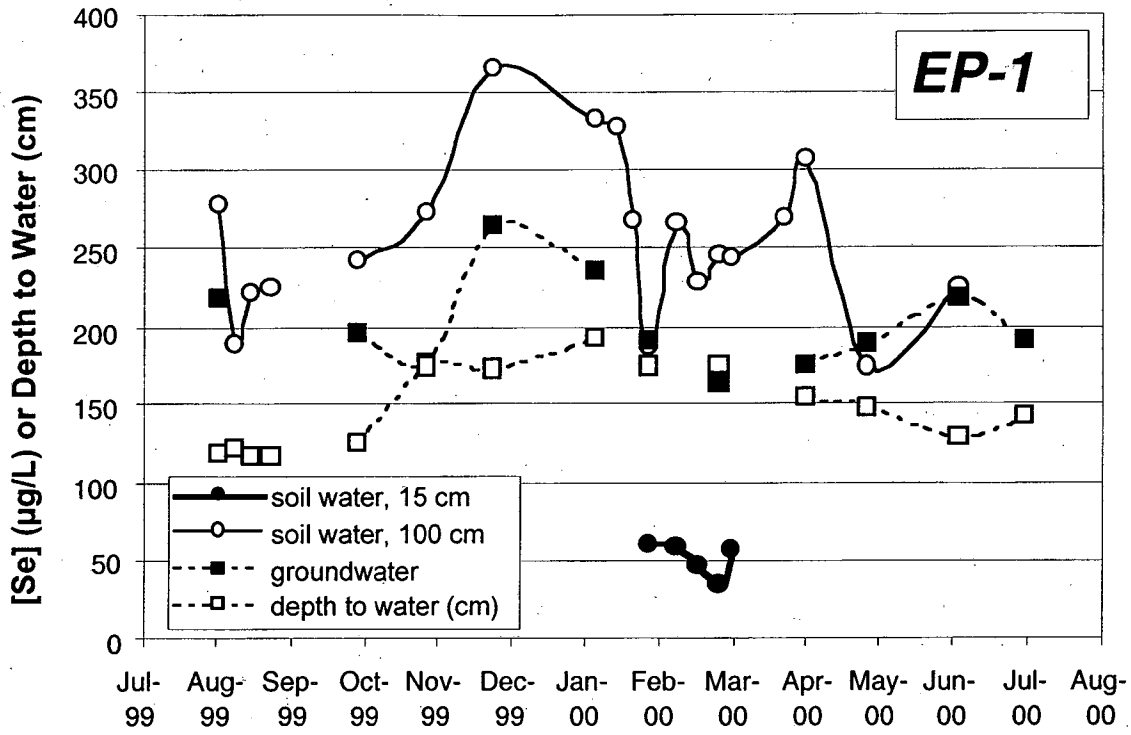


Figure 4.12. Soil water and groundwater Se and depth to water in EP-1.

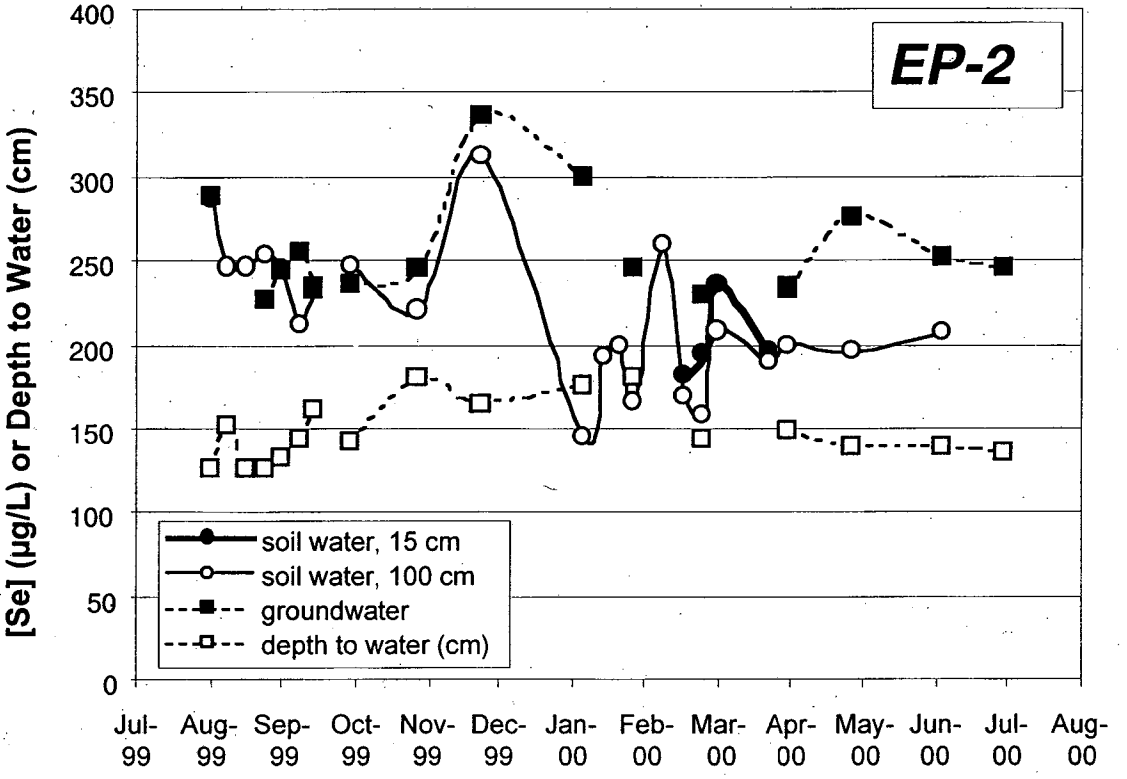


Figure 4.13. Soil water and groundwater Se and depth to water in EP-2.

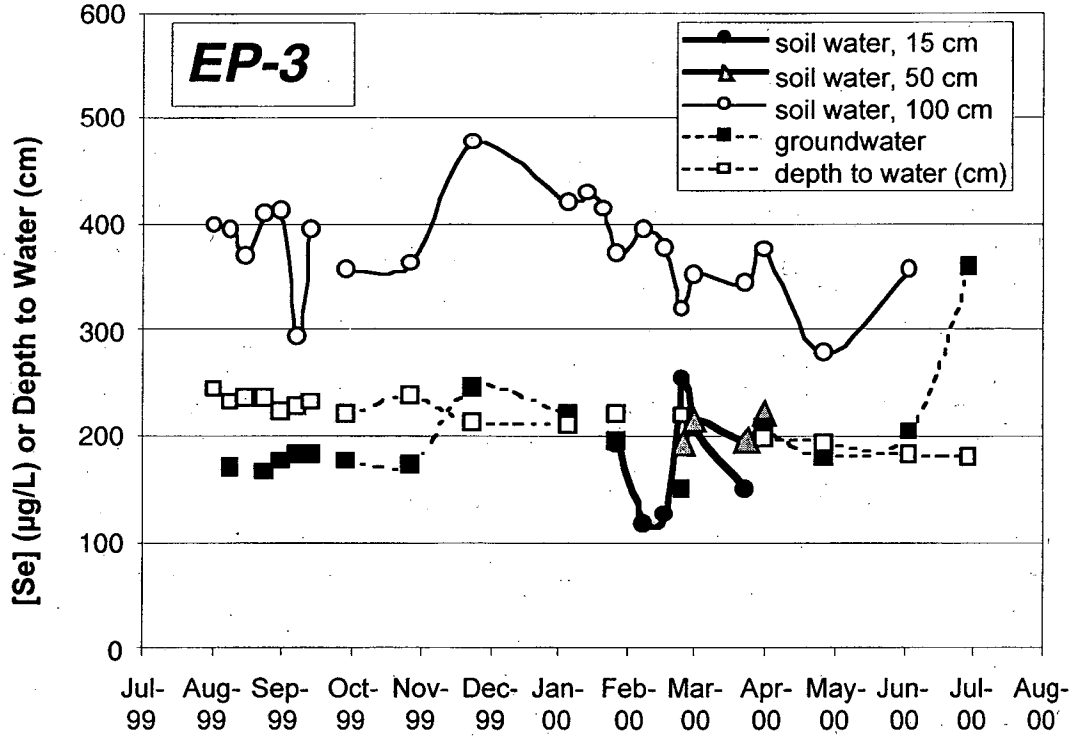


Figure 4.14. Soil water and groundwater Se and depth to water in EP-3.

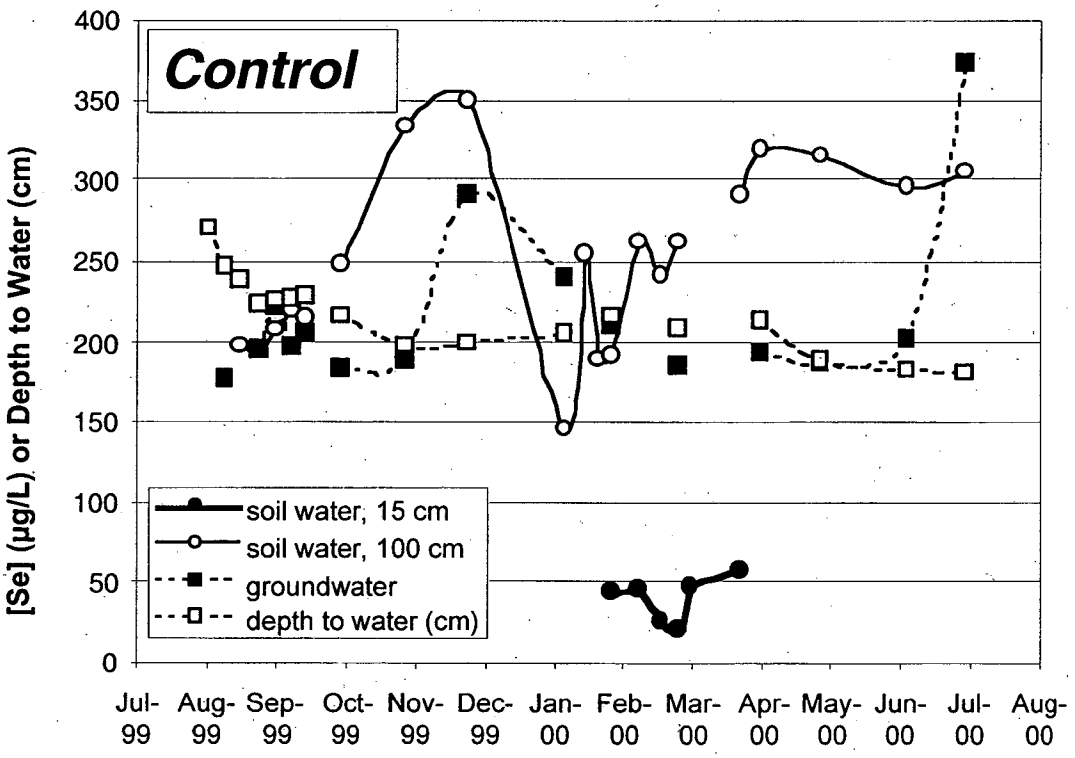


Figure 4.15. Soil water and groundwater Se and depth to water in the embankment control.

Selenium concentrations in the 1.00-m lysimeters fluctuate in a range from 150 to 400 $\mu g\ L^{-1}$, depending on the site. The fluctuations generally reflected those in the groundwater data, suggesting the dominance 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 likely enters into more seleniferous soil, resulting in higher Se concentrations. During a period between January and March 2000, Se concentrations at 1.00 m in EP-1, EP-2, and the control site drop suddenly and then rebound. This is not related to rainfall infiltration because the drop occurs before any major rainfall events and before any moisture breakthrough is observed in the 0.15-m and 0.50-m 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 (5-10 $\mu g\ L^{-1}$) and is at its highest point at this time. As mentioned above, soil water from the 0.15-m 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 $\mu g\ L^{-1}$, generally less than Se in deeper soil water and groundwater. Selenium levels observed at 0.15 m corresponded to the concentrations of Se in applied sediments. Shallow soil water Se was highest in EP-2, where sediments with 37 $\mu g\ g^{-1}$ Se were applied, somewhat lower in EP-3 (applied Se = 16 $\mu g\ g^{-1}$), significantly lower in EP-1 (applied Se = 2.5 $\mu g\ g^{-1}$), and similarly low in the control, where native Se levels are around 1 $\mu g\ g^{-1}$. No such correlation of concentrations was found in the 1.00-m data, with EP-3 containing the highest deep soil water Se and EP-2 the lowest. The limited intermediate soil water data is represented in EP-3 (Fig. 4.14). Selenium levels there are similar to those found at the 0.15-m level.

Dissolved salts are represented by measurements of electrical conductivity (EC). Data for EP-1, 2, 3 and a control site are shown in Figs. 4.16-19, respectively. Unlike Se, EC is consistently and substantially higher in groundwater than in overlying soil water, and ranges from 50 to 55 $dS\ m^{-1}$. Electrical conductivity trends in soil water at 1.00 m are very similar to Se trends, although observed changes have a smaller amplitude. The EC gradient with depth is representative of an un-vegetated site. Since the site has become vegetated during the Spring and Summer 2000, future redistribution of salts and Se can be anticipated. However, most of those changes will occur in the top 0.50 m of soil, where solute monitoring is impeded by low soil moisture content.

Selenium in groundwater data is summarized in Fig. 4.20. The EP-1 data are an average of Se measurements from five wells, whereas EP-2 and EP-3 are characterized by one groundwater well. 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, 2, and 3 are in agreement with changes in the control wells.

All of the results presented above indicate that for the test duration thus far, Se applied to the test plots does not influence Se concentrations in groundwater, or deeper soil water. Dissolved Se is being mobilized to a depth of 0.15 m, 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.

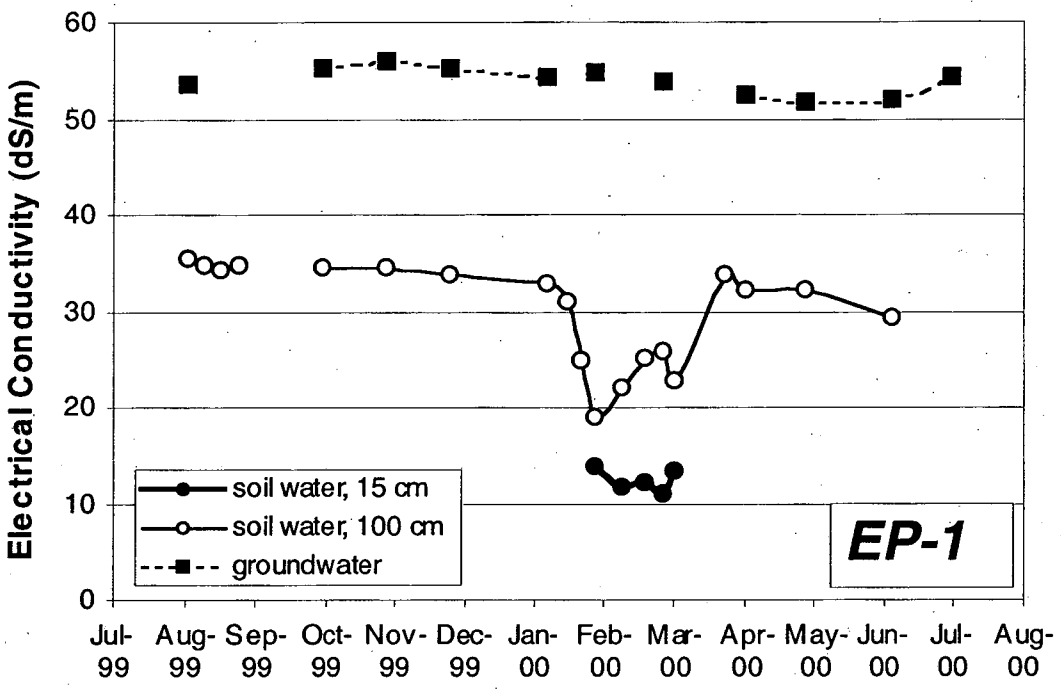


Figure 4.16. Soil water and groundwater EC in EP-1.

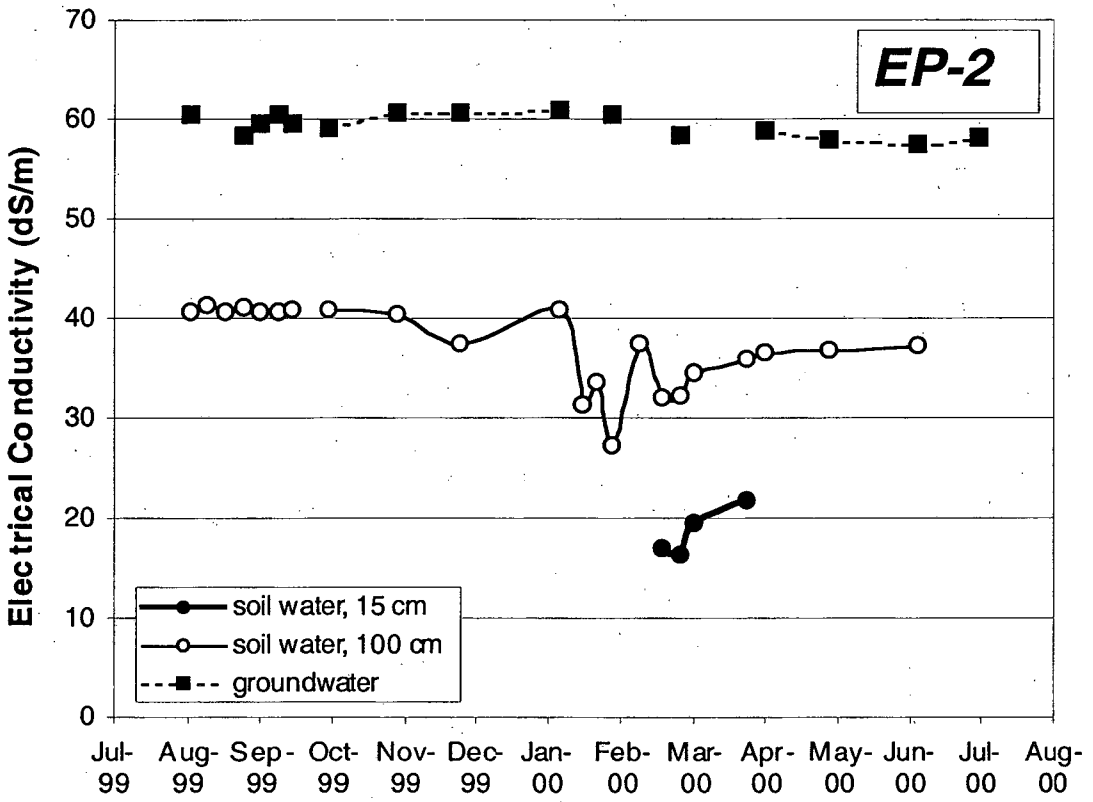


Figure 4.17. Soil water and groundwater EC in EP-2.

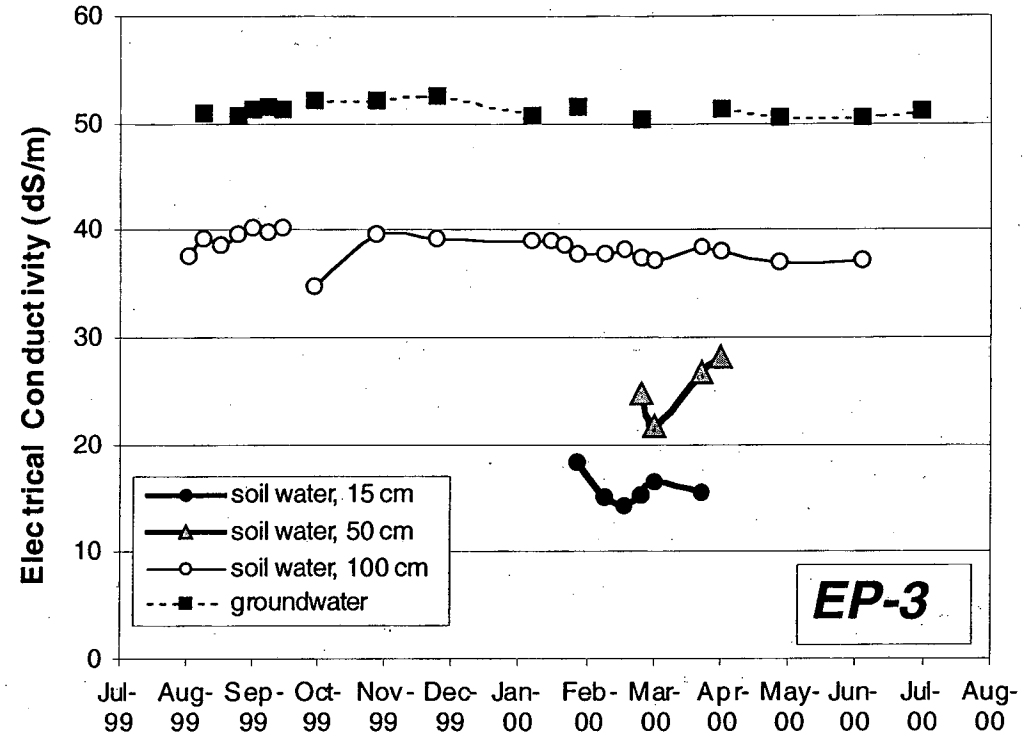


Figure 4.18. Soil water and groundwater EC in EP-3.

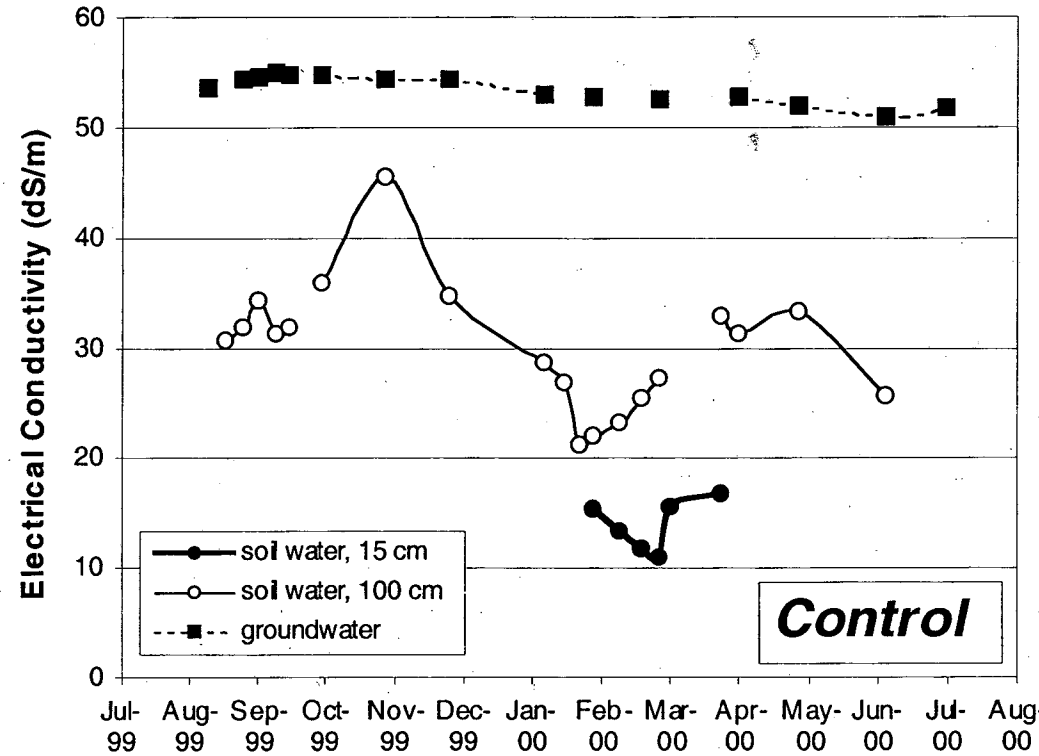


Figure 4.19. Soil water and groundwater EC in the embankment control plot.

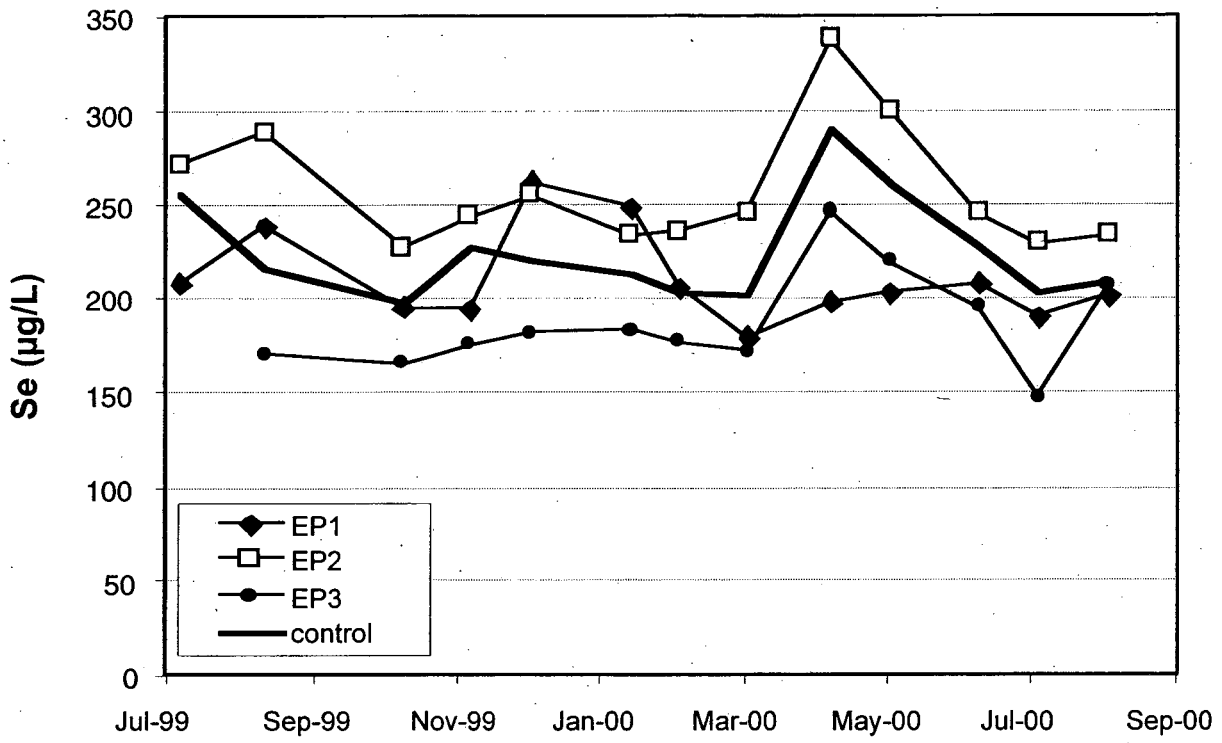


Figure 4.20. Groundwater Se in embankment test plot wells and in control wells.

4.2.4 Plants and Plant Selenium

Alkali mallow was the dominant plant species on 1/13/00 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 6/30/00, alkali mallow and russian knapweed dominated the embankment plot. At that time, as 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 4 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 4.9.

Table 4.9 Selenium concentrations in embankment plot plants.

Species (Date)	Mean aboveground Se, [std dev] ($\mu g\ g^{-1}$)	Mean belowground Se, [std dev] ($\mu g\ g^{-1}$)
alkali mallow (1/13/00)	1.63 [1.57]	–
alkali mallow (6/30/00)	1.00 [0.30]	2.78 [–]
russian knapweed (6/30/00)	0.87 [0.37]	0.58 [0.39]

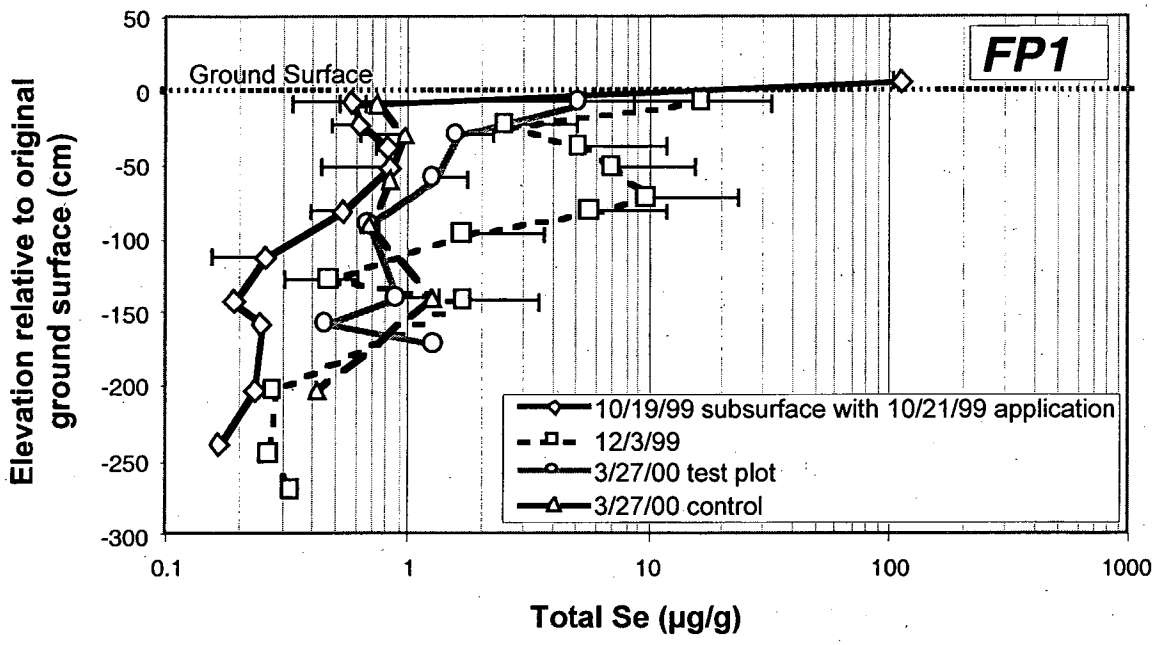
Aboveground Se concentrations fall in a low range, with means not exceeding 2 μg g^{-1}. Small differences in concentrations among the three treatments were not statistically significant. It appears that plant Se levels in the embankment plots are not of environmental concern.

4.3 Farm Plots

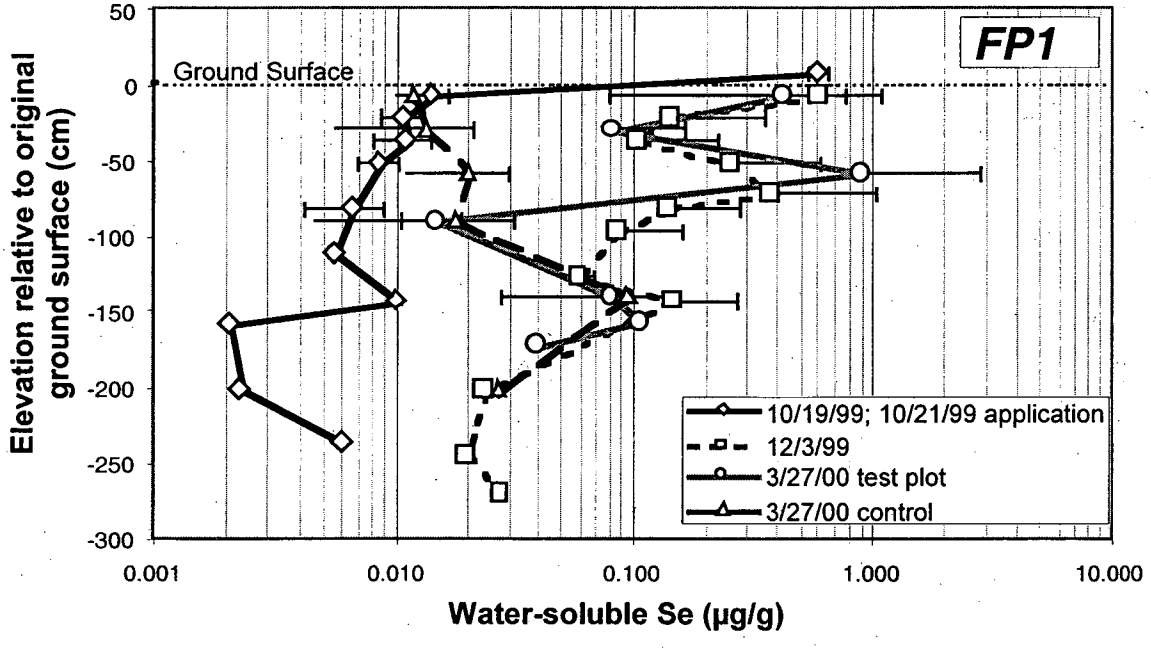
4.3.1 Sediment Selenium

The soil profile under the future farm plots was cored on 10/19/99, two days prior to the application of SLD sediment. Results of this sampling and the subsequent Se analysis are shown in Figs. 4.21 and 4.22, for FP-1 and FP-2, respectively. In FP-1, the initial application contained on average 112 μg g^{-1} total Se, as seen in Fig. 4.21a. After the application, several ripping and disking operations were performed, resulting in the mixing of sediments to a depth of approximately 0.75 m. This is apparent in the distribution of Se in the soil profile on 12/3/99, with Se concentrations exceeding 2 μg g^{-1} down to a depth of about 0.80 m. It is important to note the large spatial variability as expressed by the standard deviations around the means (n = 5). Data from a subsequent sample collection on 3/27/00, which followed additional soil disking, shows much less variability. In addition, Se concentrations on 3/27/00 are lower than on 12/3/99. 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 0.75 m of soil may result in lateral displacement of a certain fraction of Se-amended soil outside of the test plots and addition of non-amended soil from the adjacent area. Soluble Se in FP-1 soil (Fig. 4.21b) is also clearly higher in the 0-0.75 m 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 0.75 m on 12/3/99 and 3/27/00 are higher than pre-application levels, but they are not different from those measured in a control soil core, sampled outside of 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 μg g^{-1} was distributed over the top 0.75 m of soil and similar patterns of reduced spatial variability with time are observed. Although Se concentrations in samples taken on 3/27/00 are lower than on 12/3/99, they are not statistically different (Fig. 4.22a,b).

Future plowing and disking of the FP sites will likely result in further homogenization of Se concentrations. However, the relatively small standard deviations on 3/27/00 suggest that this data set will serve well as a reference for future soil profile analyses. Deep chiseling of the soil to a depth of 0.75 m may result in some further "dilution" of Se in the test plots.

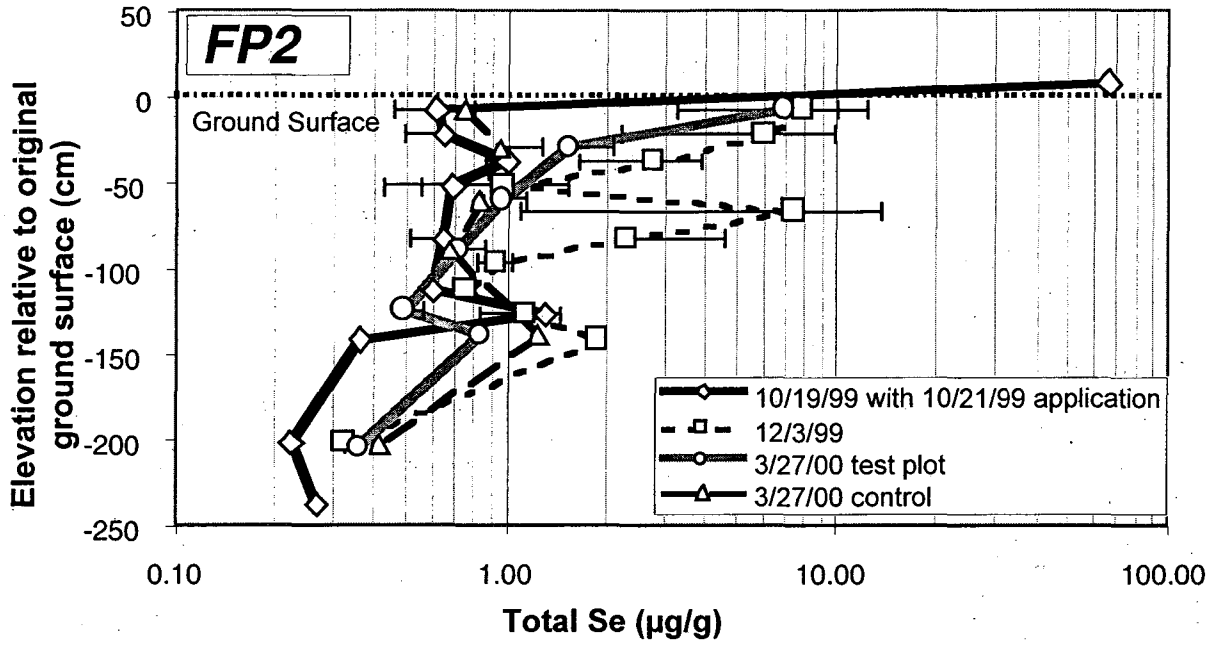


a.

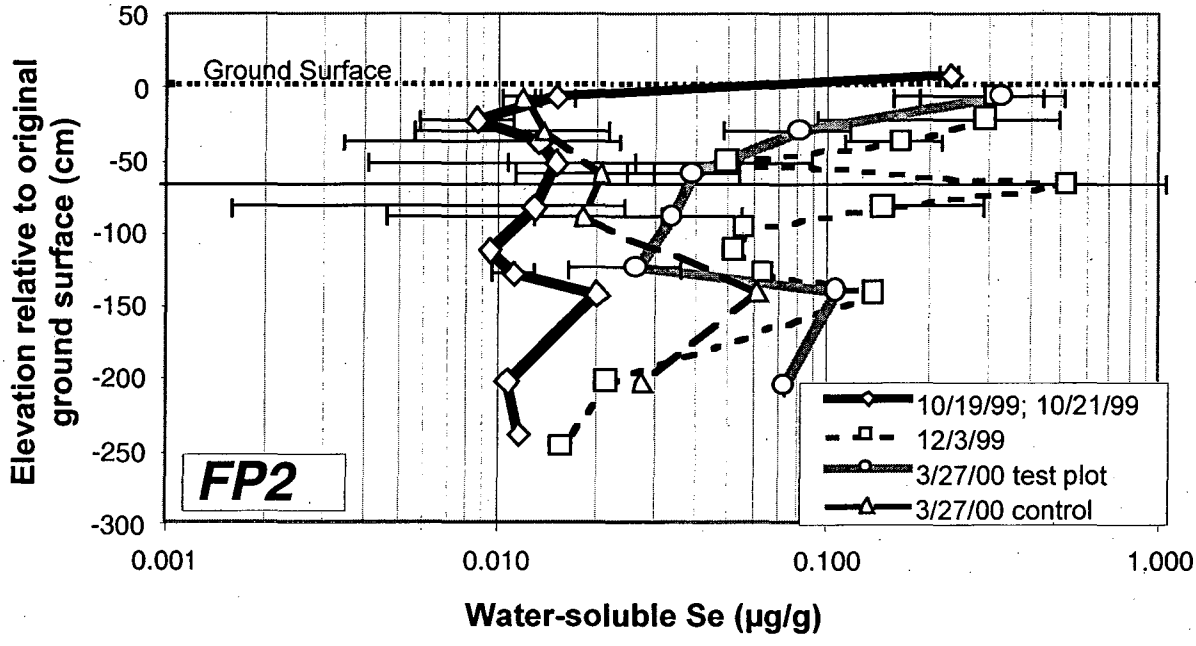


b.

Figure 4.21. Total (a) and water-soluble (b) selenium concentrations normalized to soil mass in plot FP-1. Error bars represent one standard deviation on either side of the mean.



a.



b.

Figure 4.22. Total (a) and water-soluble (b) selenium concentrations normalized to soil mass in plot FP-2. Error bars represent one standard deviation on either side of the mean.

4.3.2 Soil water and groundwater selenium and salts

Soil water sampling in the farm plots was limited due to periodic soil disking. 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 2/24/00 and continued to do so through August 2000. The shallow sampler in FP-1 (at 0.50 m) 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 1.75 m 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 (Fig. 4.23) and, due to much higher concurrent evapotranspiration, its effect on the soil water regime at 0.50 m 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 Figs. 4.24 and 4.25. Measurements of EC at the same locations are shown in Figs. 4.26 and 4.27.

Groundwater Se concentrations in FP-1 and FP-2 remained in the range of 10 to 100 $\mu g\ L^{-1}$. 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 differences in soil water Se at different depths in the soil profile. It is interesting to note that groundwater Se levels prior to any possible leaching of applied sediments were already in the 20 to 50 $\mu g\ L^{-1}$ range. In samples from intermediate lysimeters, Se levels are initially high, especially in FP-1 (Fig. 4.24), but quickly dissipate to less than 100 $\mu g\ L^{-1}$ and by June 2000 are less than 10 $\mu g\ L^{-1}$. Perhaps the initial higher concentrations are 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 supposition, but soil water at 0.50 m in FP-2 shows a similar pattern in soluble Se concentrations. Initial values in February 2000 were around 250 $\mu g\ L^{-1}$, but dropped by March to 175 $\mu g\ L^{-1}$ and by June to less than 100 $\mu g\ L^{-1}$. Patterns in EC (Figs. 4.26 and 4.27) 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 1.45 or 1.75 m. Therefore, the effect of rising groundwater also needs to be considered. The next crop in the rotation, winter wheat, does not require post-planting soil manipulation and both lysimeters and tensiometers will be installed. The latter will permit the measurement of the groundwater level.

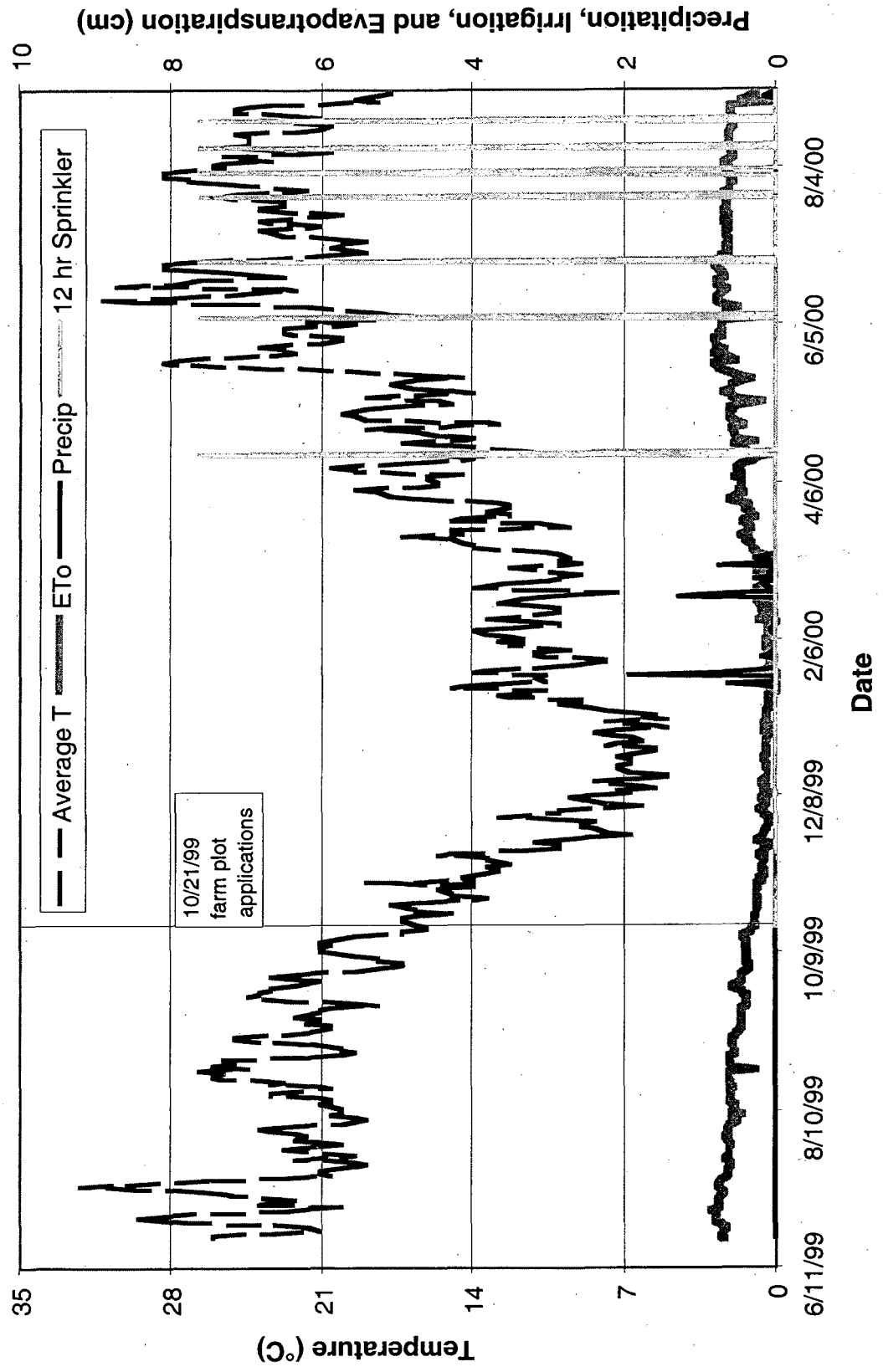


Figure 4.23. Daily weather records and irrigation events for farm plots.

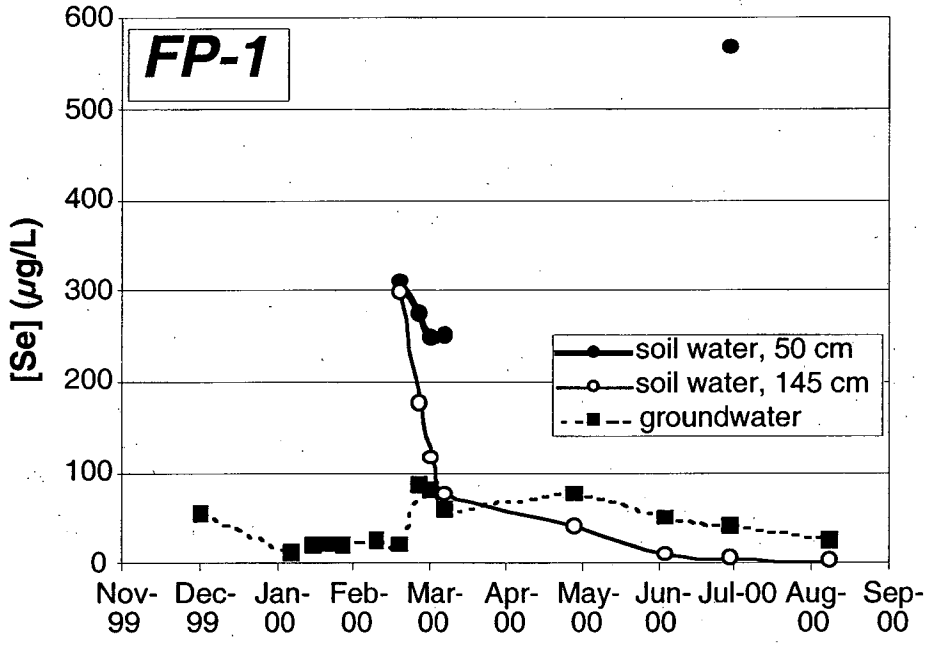


Figure 4.24. Soil water and groundwater Se in FP-1.

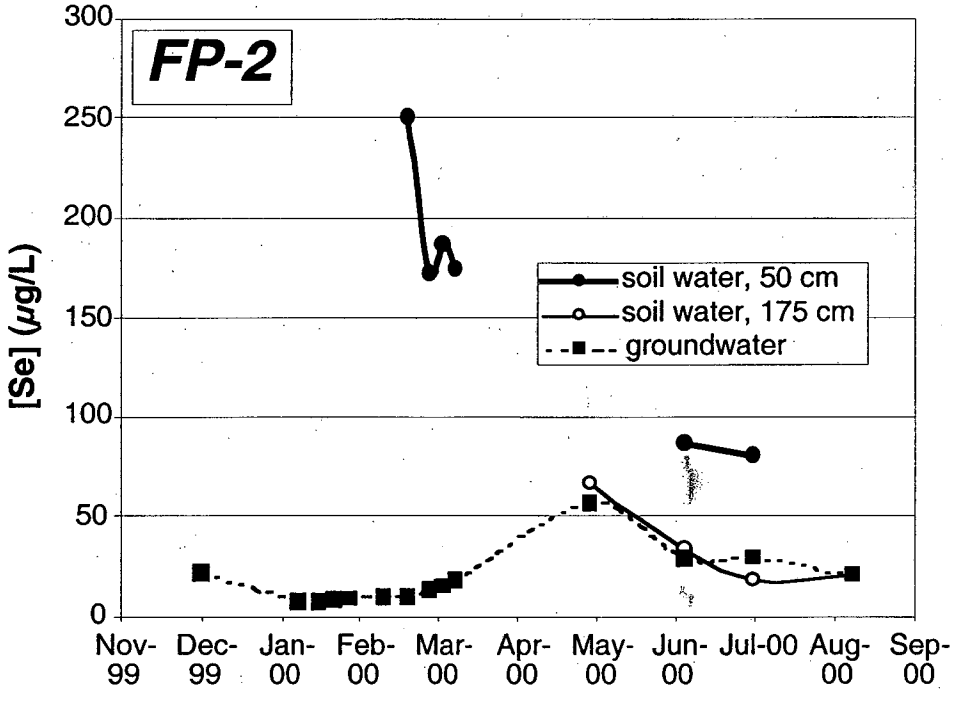


Figure 4.25. Soil water and groundwater Se in FP-2.

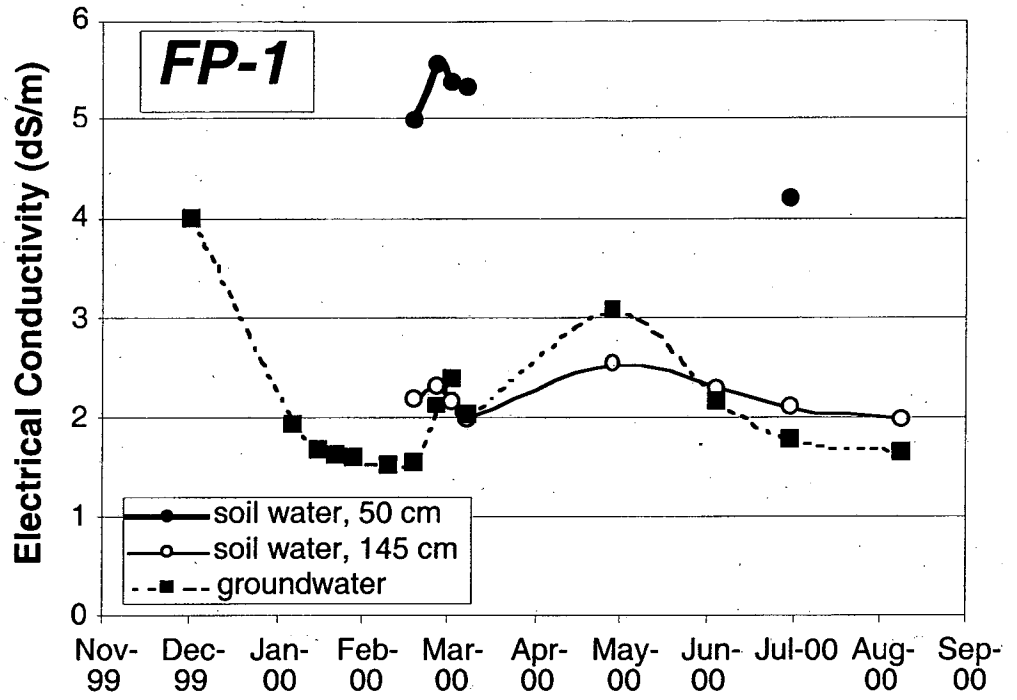


Figure 4.26. Soil water and groundwater electrical conductivity in FP-1.

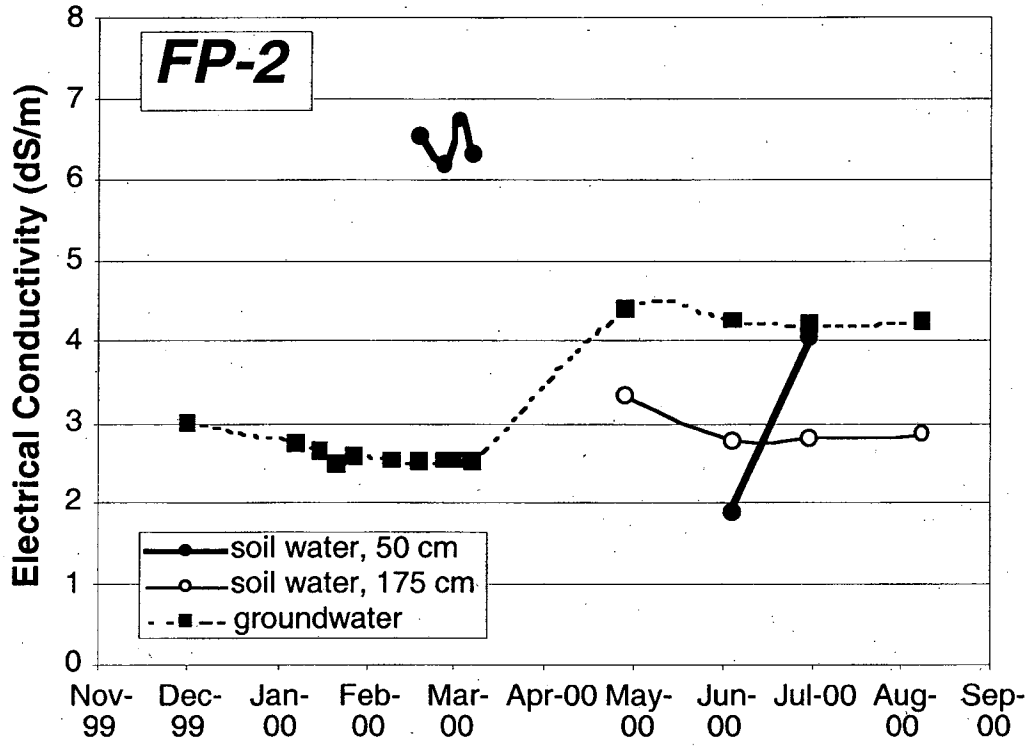


Figure 4.27. Soil water and groundwater electrical conductivity in FP-2.

4.3.3 Plants and Plant Selenium

Three complete cotton plants were collected on 7/14/00 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 Fig. 4.28. The data suggest that the 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 Se concentration was observed in FP-1 at 22.7 μg g^{-1}.

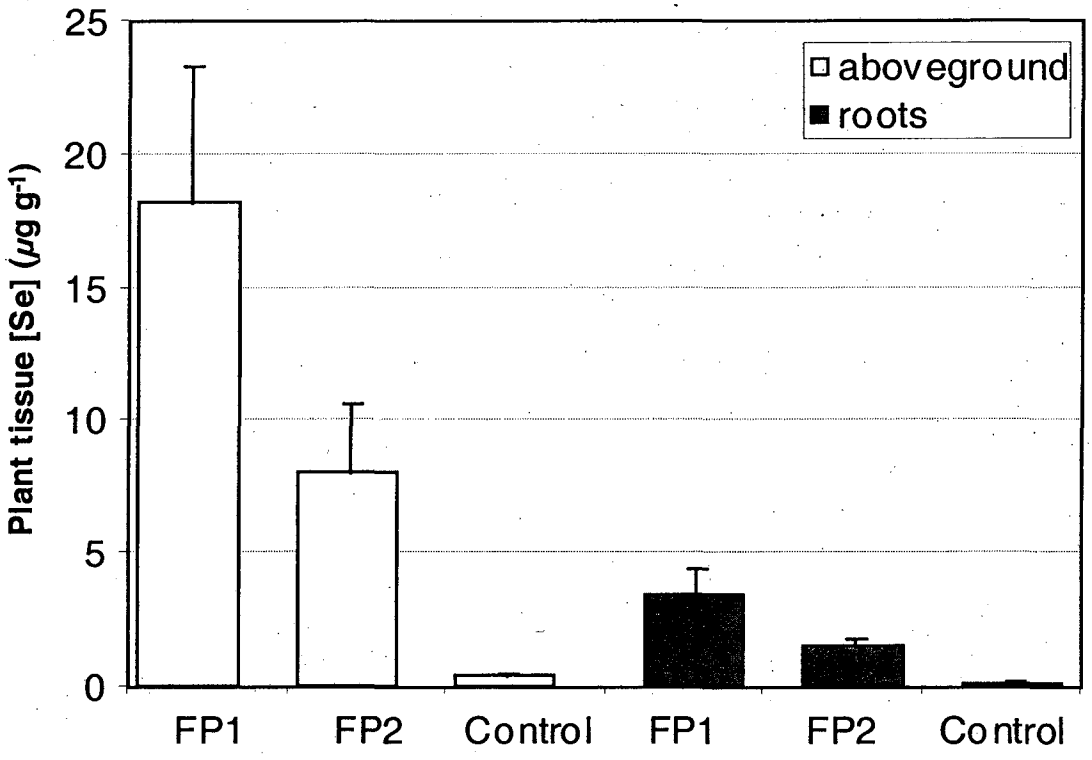


Figure 4.28. Average Se concentrations (±1s.d.) in cotton tissue from FP-1, FP-2, and a control area, 7/14/00.

A more comprehensive sampling of cotton took place at full maturity (11/4/00), shortly after the application of exfoliant. Five complete plants were 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 Fig. 4.29. Selenium concentrations in the aboveground parts were lower than those measured on 7/14/00. Selenium in roots remained the same, between 0.5 and 3.5 μg g^{-1}. Seeds contained the highest Se concentrations, the highest being 16.6 μg g^{-1} in FP-1. Selenium concentrations in lint were lowest, at or below 2 μg g^{-1}. In all plant parts Se levels were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C.

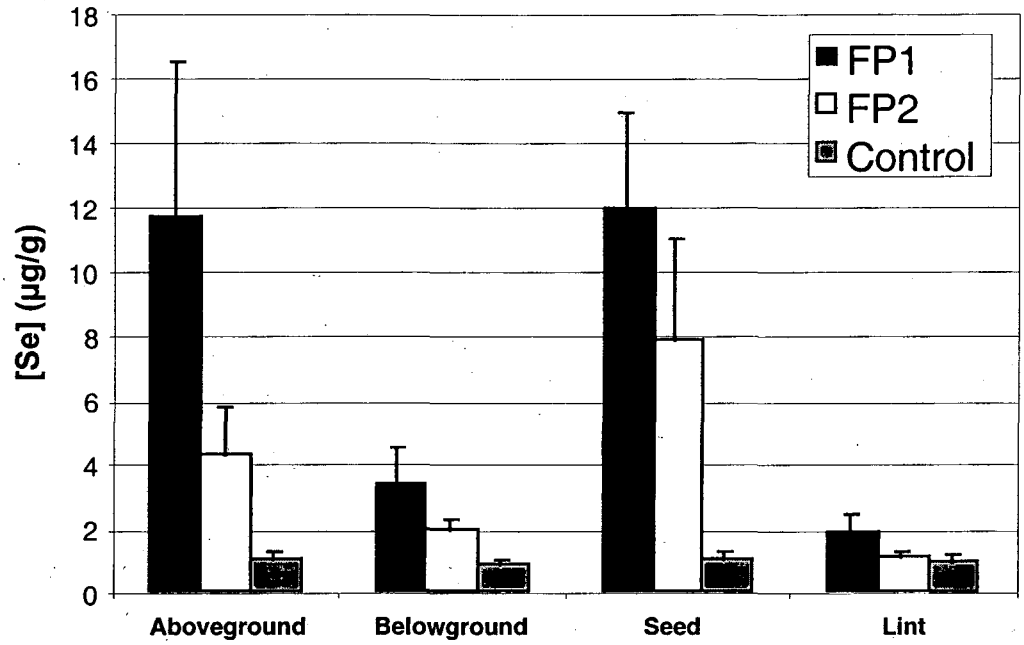


Figure 4.29. Average Se concentration (±1 s.d.) in aboveground parts (stems and leaves), belowground parts (roots), seeds, and lint of cotton plants in plots FP-1, FP-2, and a control area, 11/4/00.

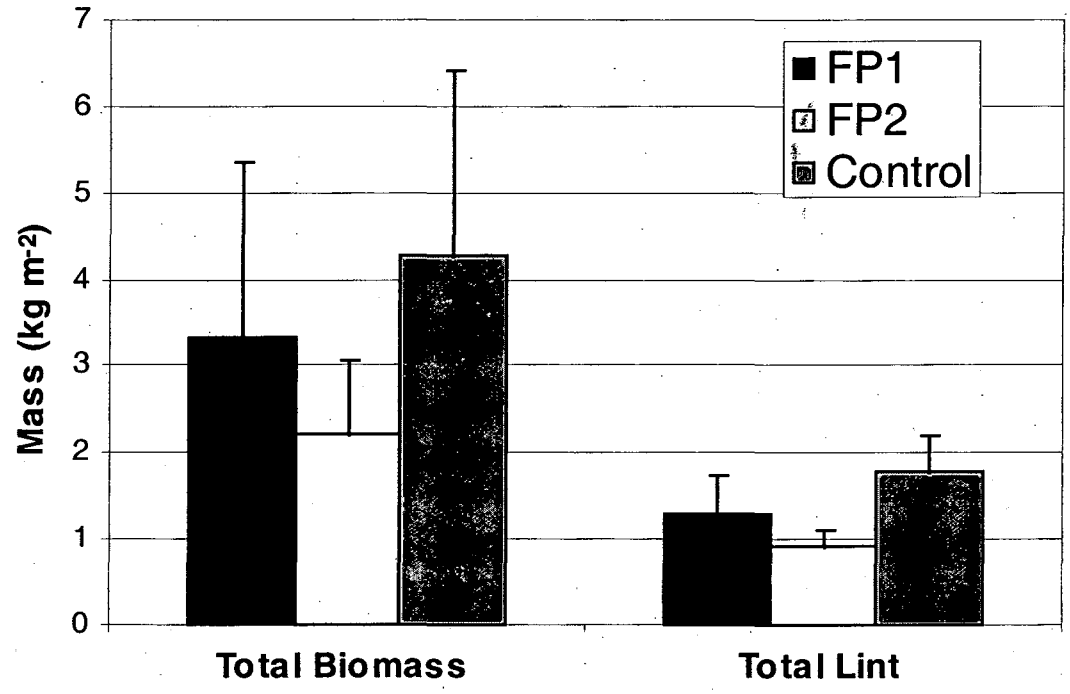


Figure 4.30. Average biomass and cotton lint yield (±1 s.d.) in plots FP-1, FP-2, and a control area, 11/4/00.

Total biomass and cotton (lint) mass are shown in Fig. 4.30. There are only small differences in both measures amongst 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 applied 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. Since 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.

5 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 on 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 on 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 amongst 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 amongst 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 on soils and sediments containing less than 10 $\mu g\ g^{-1}$ 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 which can directly determine the valence of elements, including Se. This method can distinguish amongst organic-Se, elemental Se, selenite, and selenate. The distinction amongst 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 10's of ppm are necessary for a quantitative measurement of their percentages. The advantages and limitations of this technique are summarized 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 and after several months. 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.

5.1 Sequential Extraction Procedure

5.1.1 Lab Methods

A sequential extraction procedure was developed from previous techniques used for Se fractionation and speciation (Weres et al., 1989a,b; Velinsky and Cutter, 1990; Lipton, 1991; Tokunaga et al., 1991). Table 5.1 contains the sequence of extractions and the target species each extraction is designed to remove. Samples were extracted without drying, after removal of porewater 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-μm nitrocellulose filter immediately after extraction. A discussion on 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).

Table 5.1. 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.

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°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 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 5.2). 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).

Table 5.2. 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

5.1.2 Sample Collection

Sediments for the sequential extraction were chosen from the initial application at the embankment plots (9/3/99) and the farm plots (10/21/99), and from soil cores collected on 3/27/00 and 3/28/00 at these two locations. The samples were stored frozen prior to sequential extraction. Another set of sediment samples from the same locations took place in November 2000. The results of the analysis of this recent collection will be presented in a future report.

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 5.1-5.4. 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 sediment. Although the soluble and adsorbed Se fractions increased significantly, so did the organically-assoc. 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 are expected to decrease as readily oxidizable Se is depleted (Zawislanski and Zavarin, 1996). 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 3/28/00. 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.

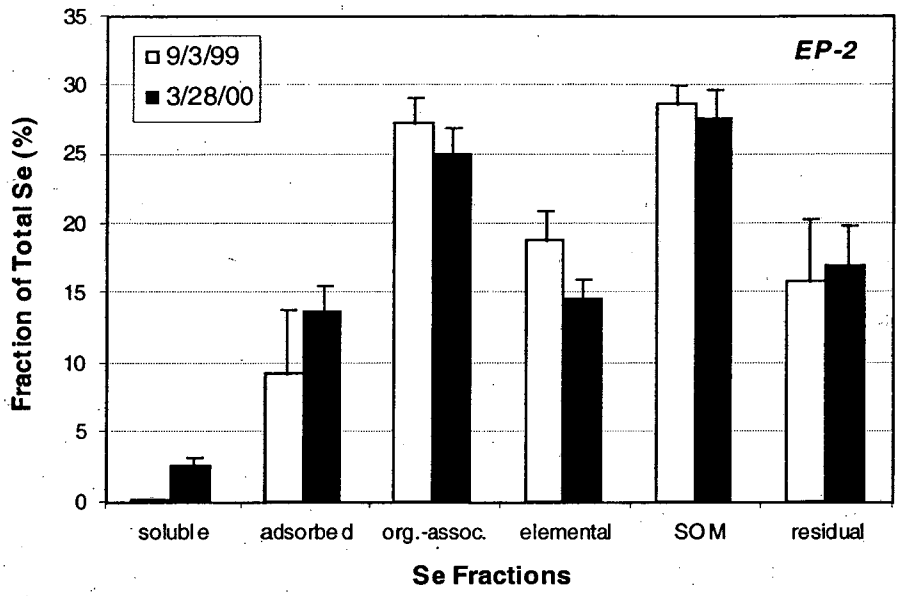


Figure 5.1. Selenium fractions in SLD sediment applied to EP-2.

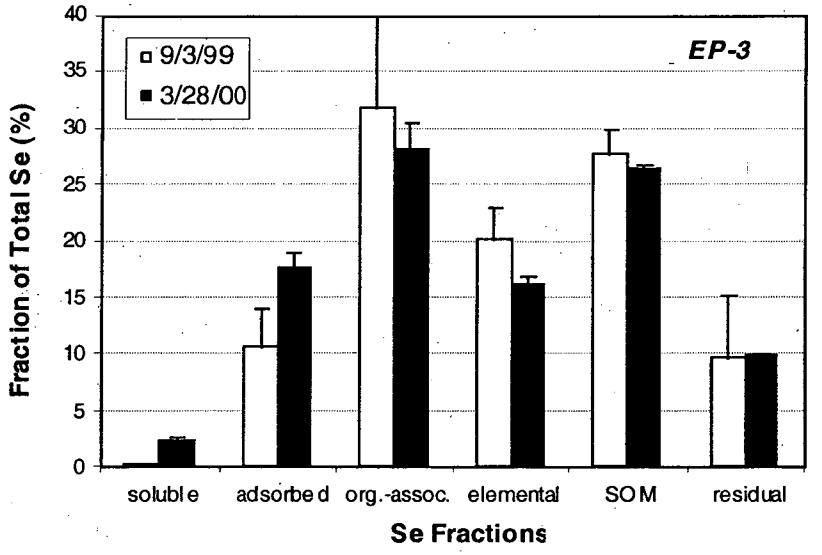


Figure 5.2. Selenium fractions in SLD sediment applied to EP-3.

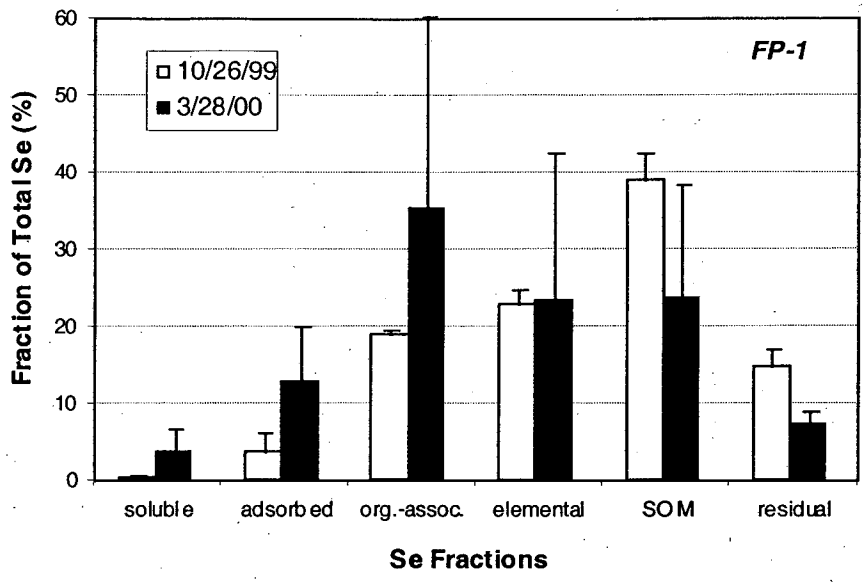


Figure 5.3. Selenium fractions in SLD sediment applied to FP-1.

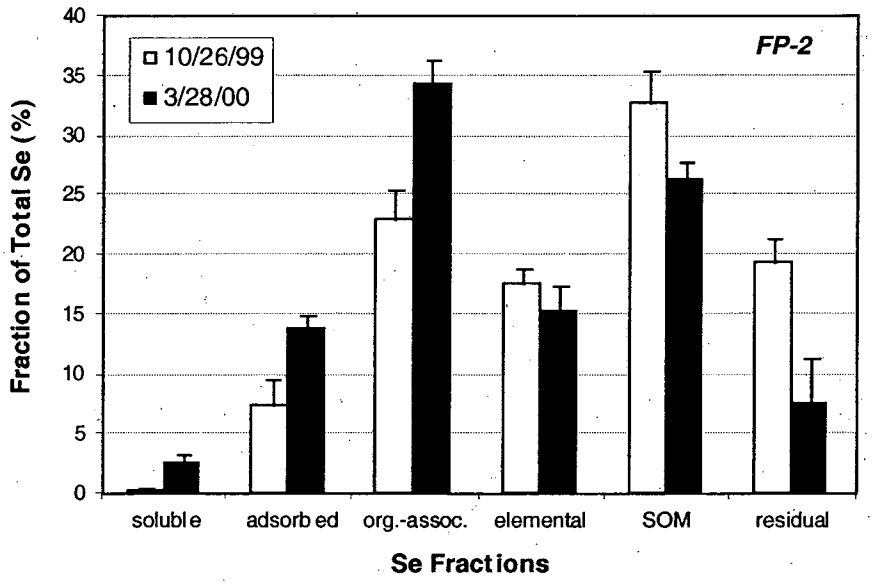


Figure 5.4. Selenium fractions in SLD sediment applied to FP-2.

5.2 X-Ray Spectroscopy

Selenium K-edge XAS data was collected at the Stanford Synchrotron Radiation Laboratory (SSRL) on Beam Line 4-1. X-rays were passed through a Si (220) double crystal monochromater and detuned to 50% to remove higher-order harmonics. The samples were packed in a holder with dimension 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 selenium 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 was processed by averaging multiple scans and subtracting a

background function which was fit from the pre-edge spectra. The data was then fit from the sum of the edges from standard materials allowing a scale factor and an edge shift.

A number of samples were run in March and June 2000, but several of the results were compromised by beam instability and other experimental problems. Here we present two successful runs. The findings confirm the dominance of reduced Se species. In sample EP2-9-SV, (Fig. 5.5), which represents the initial sediment application to plot EP-2, and contained 37.7 $\mu g\ g^{-1}$ Se, the spectrum can best be fit with 100% elemental Se, although fits with 53% Se^0 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 farm plot 1 is represented by sample FP1-7 and is shown in Fig. 5.6. The shape of the data is more complex and suggests the presence of Se^{+4}. Both a 100% Se-cysteine fit and an 87% Se^0 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 peaks, 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 SLD sediment, with no detectable Se^{+6}. These findings agree qualitatively with results of sequential extractions. Additional x-ray runs were conducted in January 2001 and will be presented in a future report.

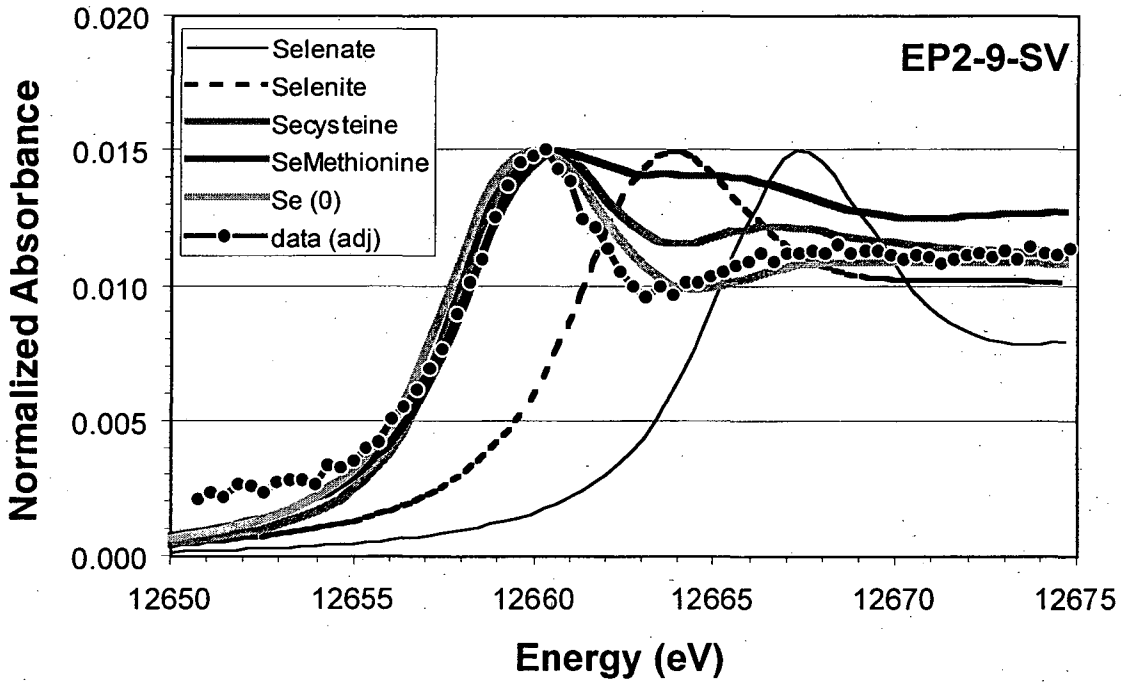


Figure 5.5. Selenium K-edge absorption spectra of Se standards and SLD sediment sample EP2-9-SV, collected on 9/3/99 immediately after application.

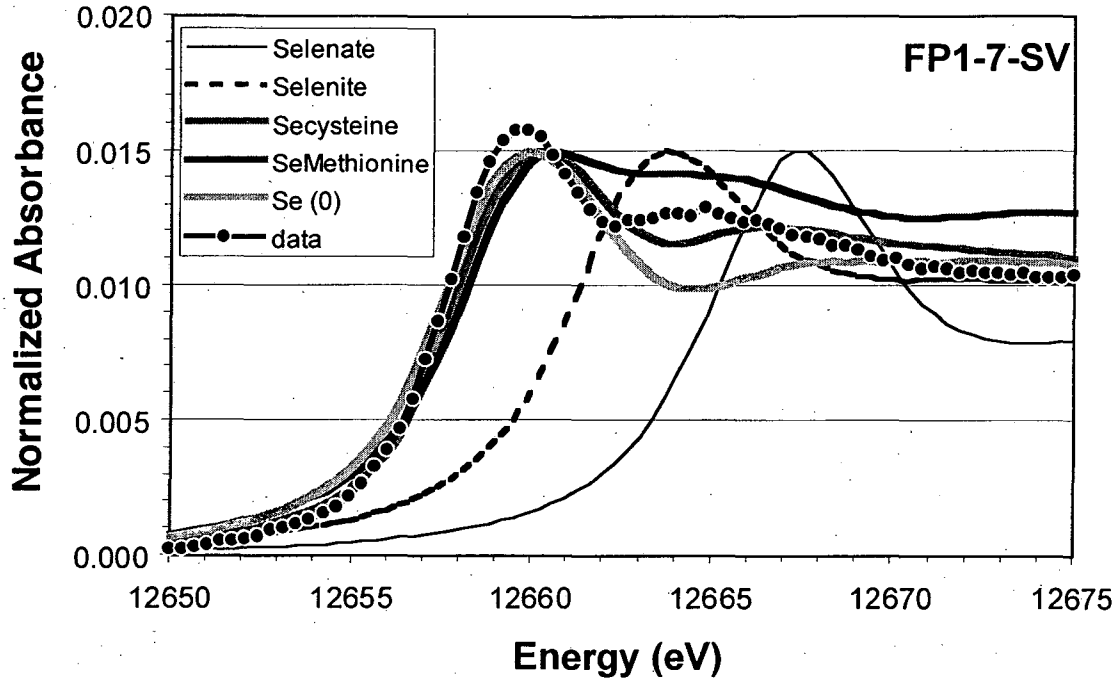


Figure 5.6. Selenium K-edge absorption spectra of Se standards and SLD sediment sample FP1-7-SV, collected on 10/21/99 immediately after application.

6 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 the amended soil was used to grow cotton during the Summer and Fall 2000. 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 Drain. 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 Se concentrations averaged 2.56, 37.10, and 19.53 $\mu g\ g^{-1}$, in EP-1, EP-2, and EP-3, respectively. Soluble Se comprised less than 1% of total. Although the initial gravimetric moisture content of the applied sediments was high (around 1), 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 5 cm (relative to the original ground surface). There was no significant effect on groundwater Se levels due to leaching during the test period. 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. Further oxidation of the Se inventory is anticipated, but the low permeability of the underlying sediments is a likely barrier to Se movement toward the water table.

In the farm plots, applied Se concentrations averaged 111.6 and 66.7 $\mu g\ g^{-1}$, in FP-1 and FP-2, respectively, with soluble Se comprising 0.35% to 0.55% of total. As part of the process of field preparation for cotton planting, the 10-cm-thick sediment application was mixed with the underlying soil via disking and deep plowing, down to a depth of 0.70 m. This resulted in the reduction of near-surface Se concentrations to around 10-15 $\mu g\ g^{-1}$, but also an increase of Se concentrations down to 0.70 m. Similarly, soluble Se concentrations increased in the soil profile due to physical mixing. There is some indication that rainfall and irrigation 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. Unfortunately, only a few temporary lysimeters were installed due to the periodic disking of the field.

Selenium uptake by cotton plants was greater than anticipated, with bulk above-ground tissue concentrations as high as 22.7 $\mu g\ g^{-1}$. This value was measured in a young plant in July of 2000. A more comprehensive sampling of cotton took place at full maturity (11/4/00), shortly after the application of exfoliant. Selenium concentrations in aboveground parts were lower than those measured on 7/14/00. Selenium in roots remained the same, between 0.5 and 3.5 $\mu g\ g^{-1}$. Seeds

contained the highest Se concentrations, the highest being 16.6 $\mu g\ g^{-1}$ in FP-1. Selenium concentrations in lint were lowest, at or below 2 $\mu g\ g^{-1}$. In all plant parts Se levels were proportional to soil Se in the given plot, i.e., FP-1 > FP-2 > FP-C. Despite such Se uptake, the cotton yield from the Se-amended part of the farm field was statistically equal to that from the unamended field. Therefore, the presence of high Se concentrations in the soil was not an impediment to cotton growth and overall health.

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. Selenium oxidation and partial solubilization took place within the first six months after application. These results are preliminary and future sampling, extraction, and x-ray spectroscopic work will shed light on the oxidation reactions and their kinetics, providing important parameters in the prediction of long-term Se stability.

6.2 Recommendations

Based on the findings summarized above, the following recommendations are made regarding the future monitoring and management of the land application sites.

• Quarterly monitoring of soil water and groundwater in the embankment plots is needed to confirm that soluble Se is not migrating toward the water table. The relatively dry winter of 1999-2000 may not have been a good indication of future rainfall events which may have more significant effects on Se leaching. At least one more year of monitoring is recommended.

• Twice-a-year soil sampling at the embankment sites needs to be continued to monitor Se displacement and solubility. Soil sampling provides more reliable results than lysimetry because dry conditions often prevent collection of soil water. In addition, soil core analysis provides a better overall Se mass balance.

• Plant sampling and analysis at the embankment sites should be conducted at least once a year to confirm that Se is not being accumulated to levels of concern. Selenium uptake may change as Se solubility increases.

• Monitoring of the farm plots needs to be expanded to measure soil water movement. This will be made possible during the winter wheat growing period, since no post-planting soil manipulation takes place. Installation of either neutron probe access pipes and/or tensiometers is recommended.

• Sequential fractionation and x-ray spectroscopic studies will yield important information on the future solubility of Se. Analysis of surface soils and sediments collected during soil coring is recommended.

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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.

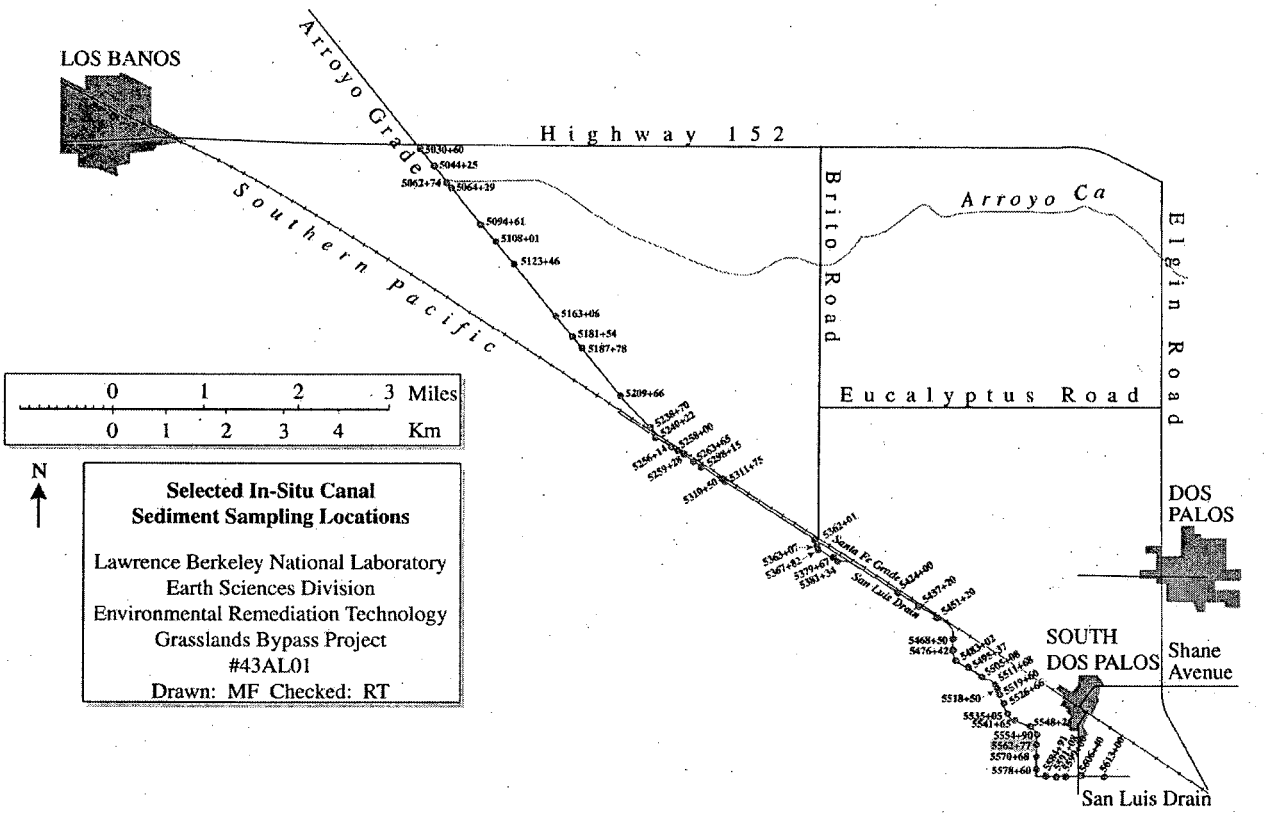


Figure A-1. Location of LBNL sediment sampling points along the San Luis Drain.

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.

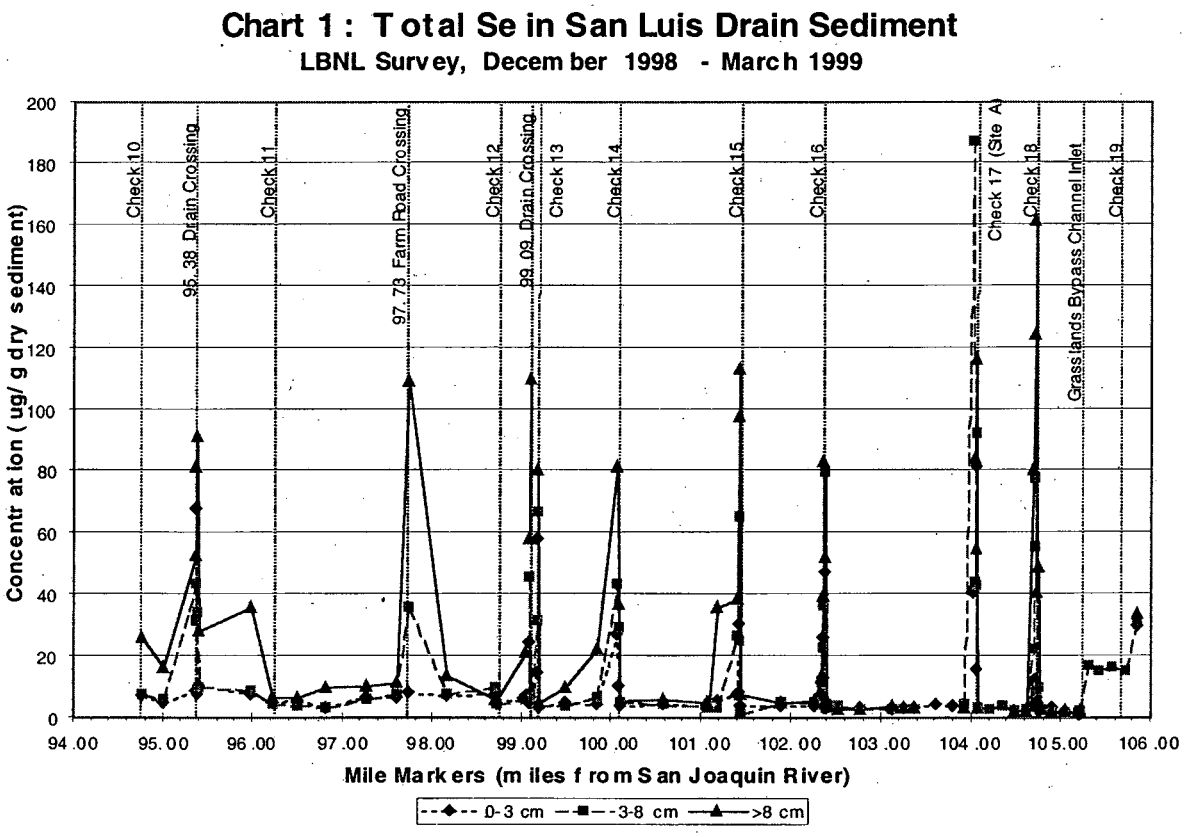


Chart 2: Histogram showing depth distribution of Total Se in San Luis Drain Sediment

LBNL Survey, December 1998 - March 1999

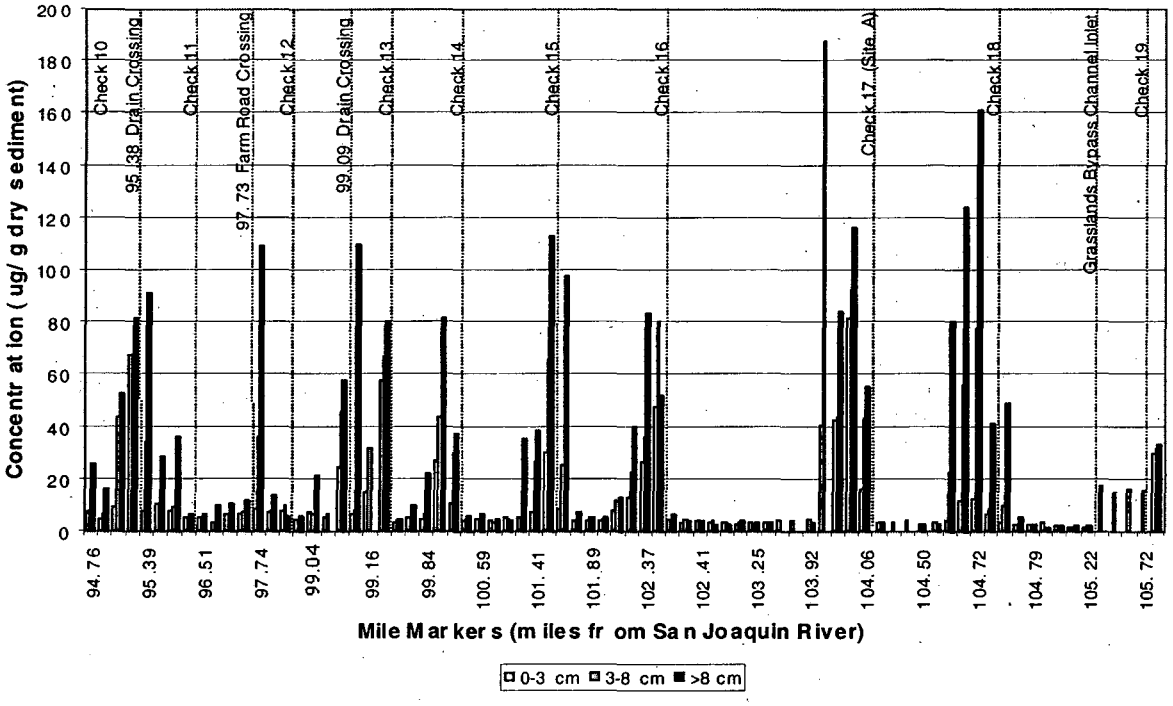


Chart 3: Distribution of the Mass of Se along the San Luis Drain

LBNL Survey, December 1998 - March 1999

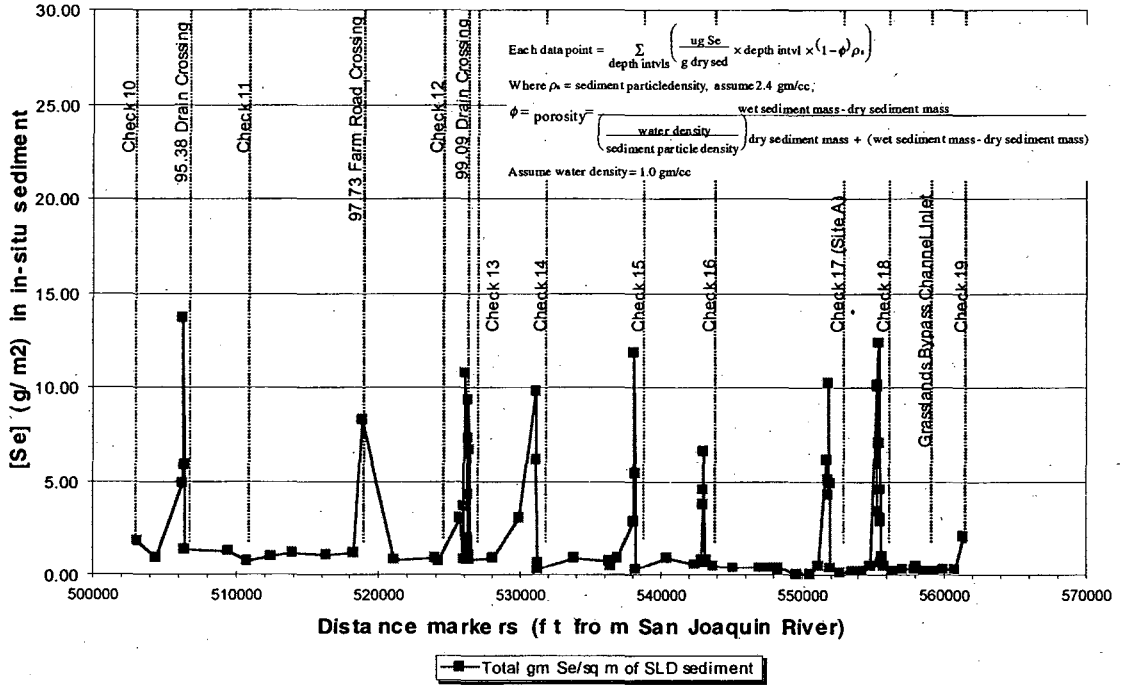


Chart 4: Details of distribution of Se and sediments at Check 13

LBNL Survey, December 1998 - March 1999

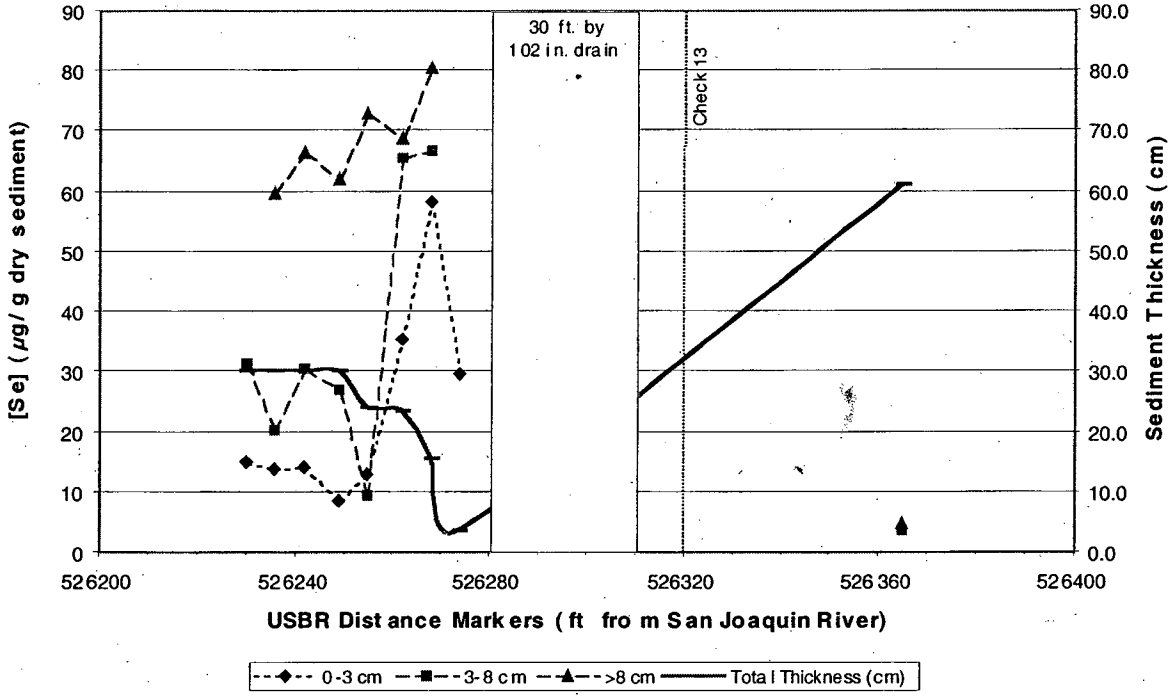


Chart 5: Details of distribution of Se and sediments at Check 16

LBNL Survey, December 1998 - March 1999

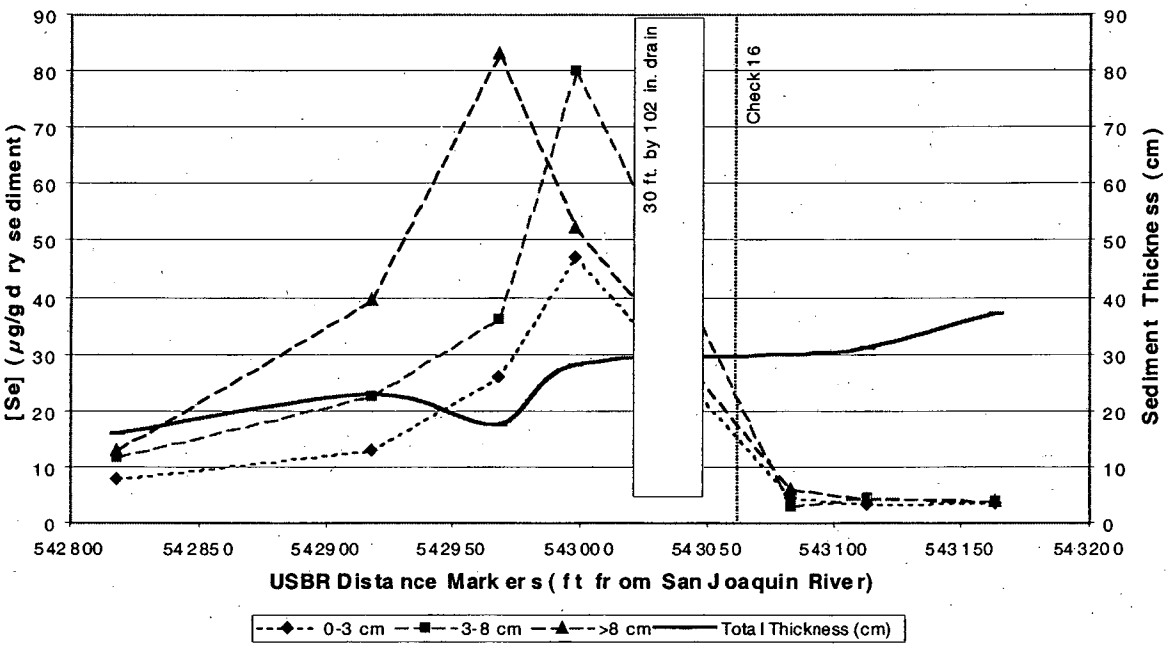


Chart 6: Details of distribution of Se and sediments at Check 17

LBNL Survey, December 1998 - March 1999

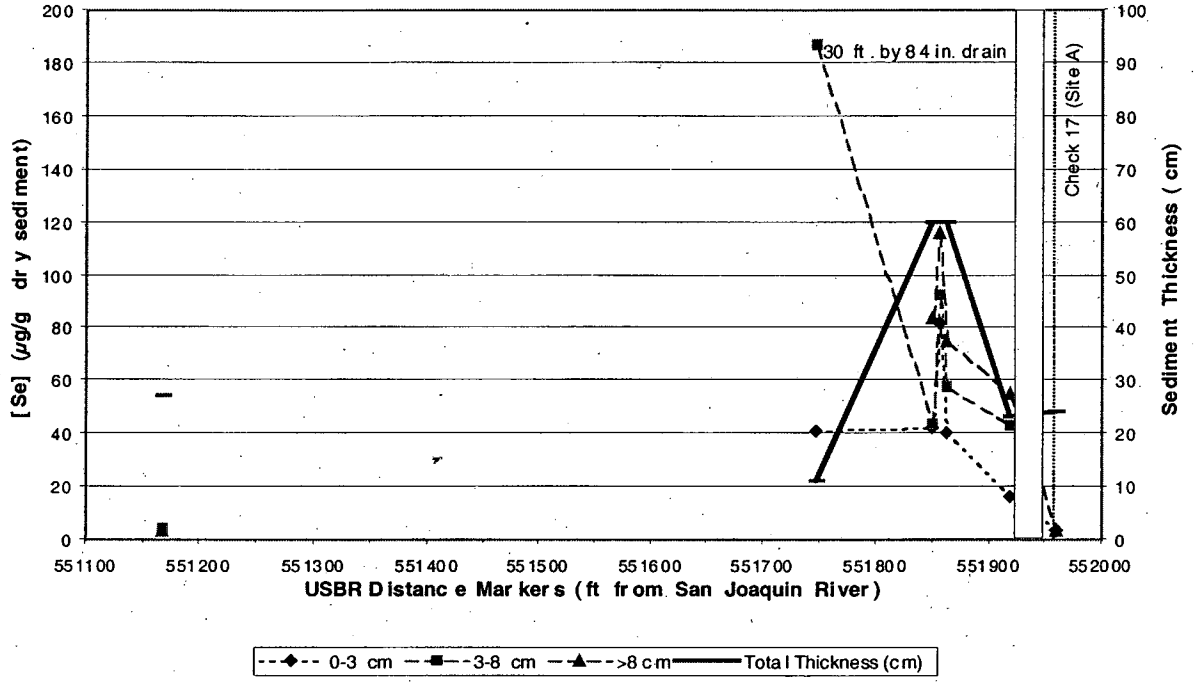


Chart 7: Details of distribution of Se and sediments at Check 18

LBNL Survey, December 1998 - March 1999

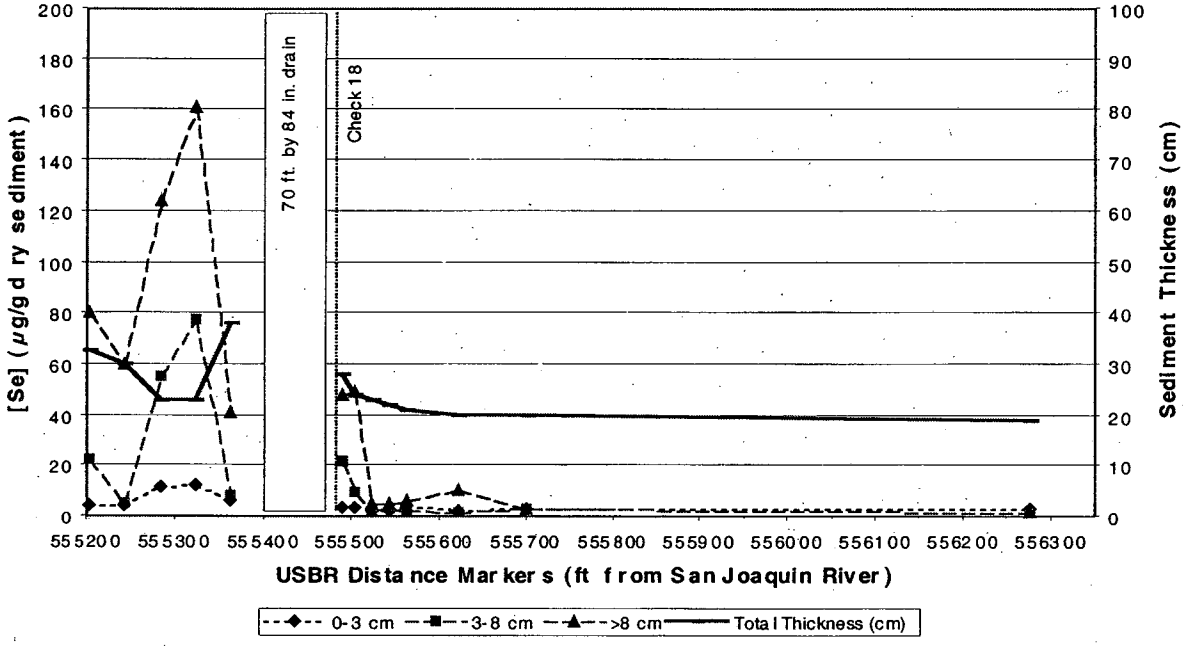


Chart 8a: USBR Surveys, 1987, 1988

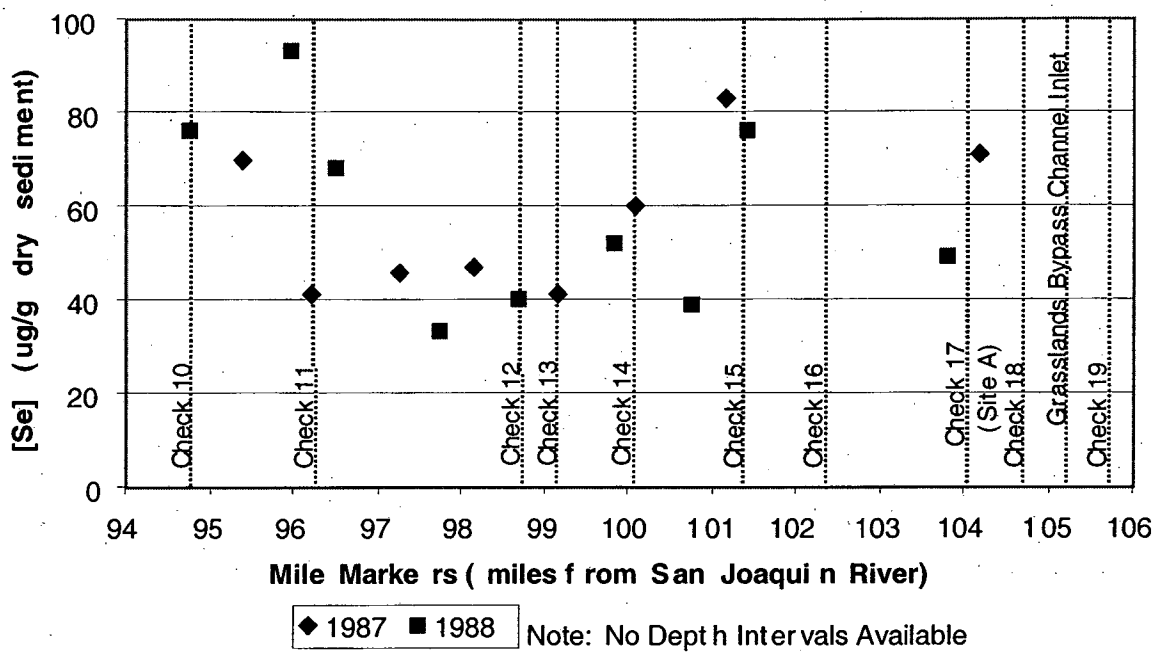
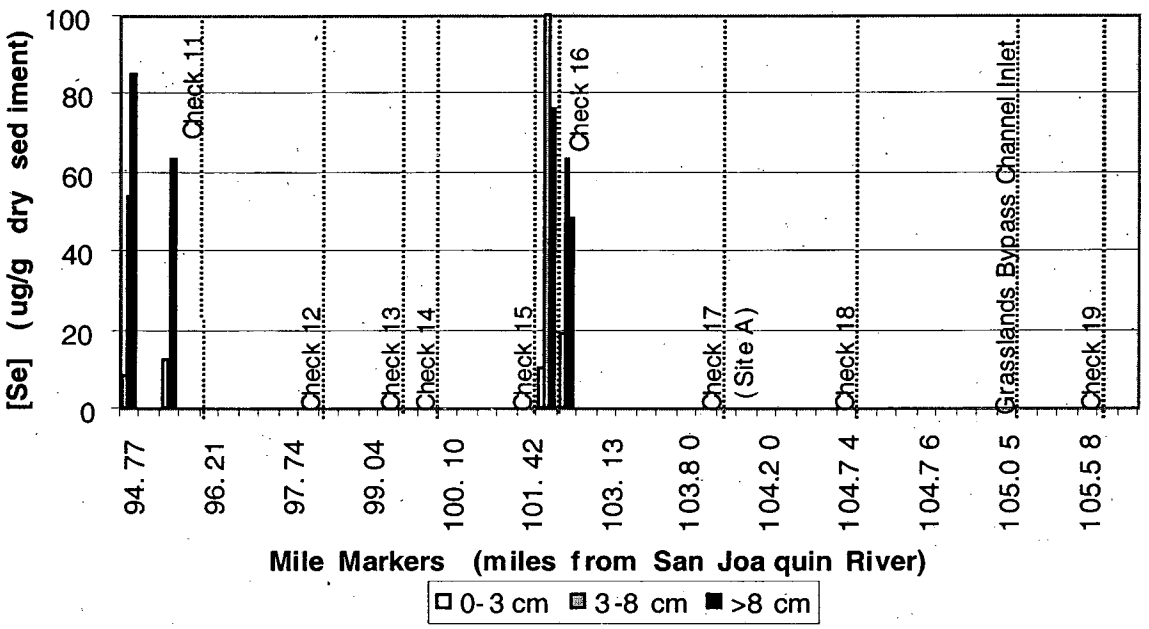
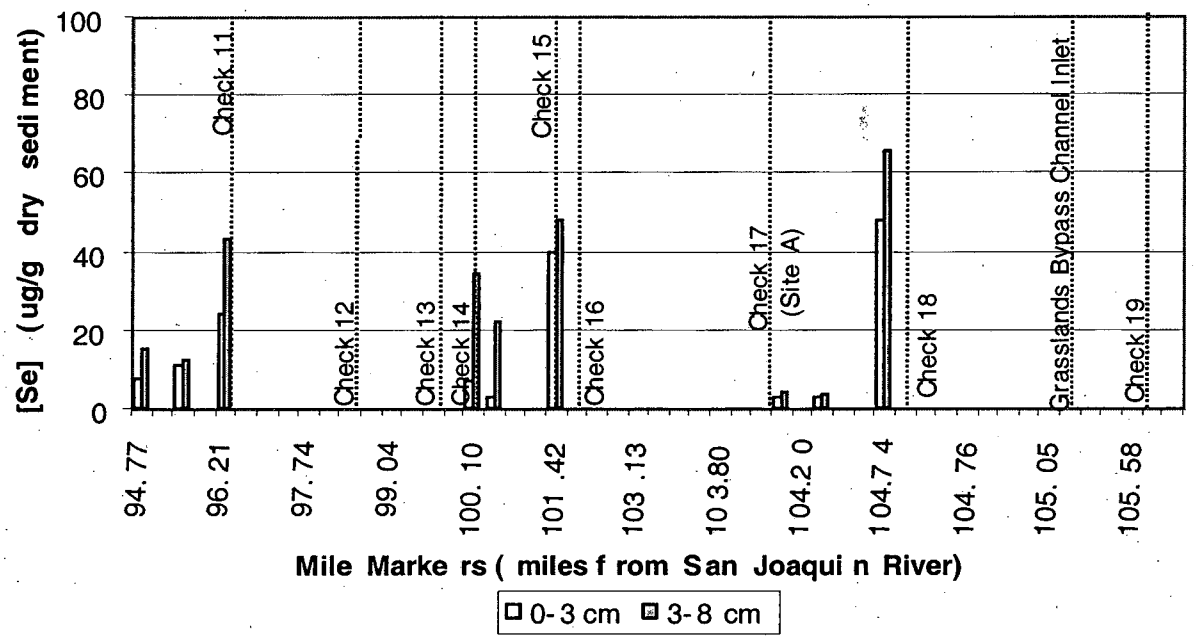


Chart 8b: USBR September 1994 Survey



9a: USBR June 1 99 7 Surv ey



9b: USBR June 19 98 S urv ey

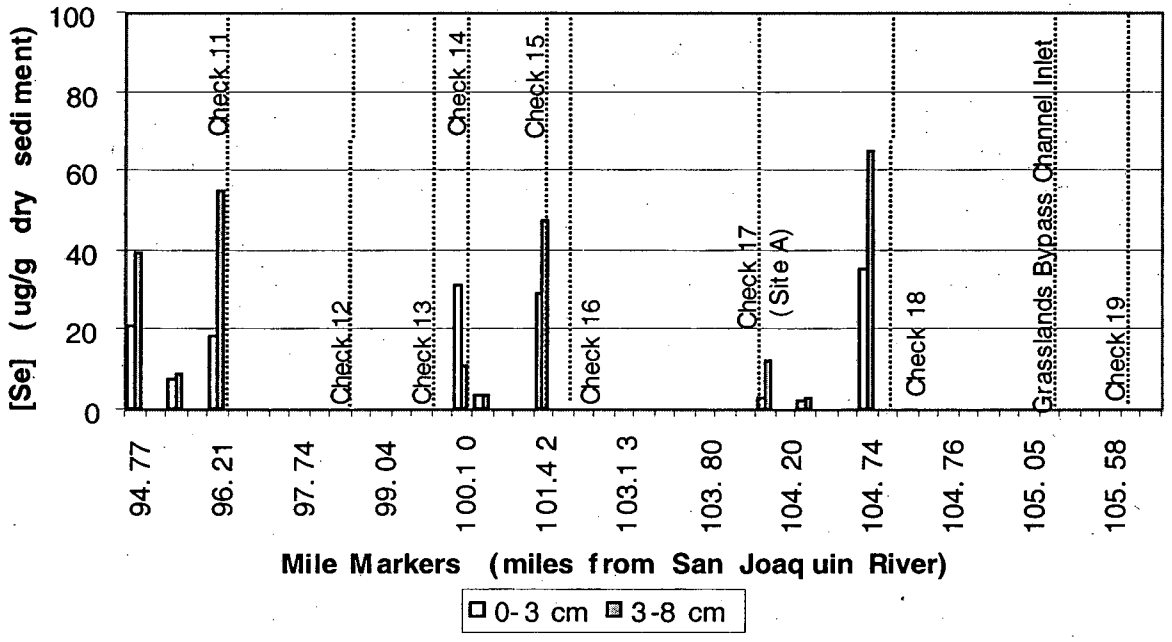


Table A.1. Project Sampling Locations with USBR mile markers on San Luis Drain

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
503060	94.76	3-8	7.53	2.18	2.37	2/22/99	(Highway 152/33)
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
510801	96.22	3-8	4.38	1.88	1.52	2/22/99	(Mud Slough crossing)
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	"

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.

APPENDIX B -- FIELD AND LABORATORY PROCEDURES

B.1 Field Procedures

Soil and sediment cores were collected using a Giddings hydraulic push rig (see Fig. C.1). Variable length soil cores were collected with minimal loss due to compression. The core barrel was rinsed in soapy water, then tapwater, then sprayed with distilled water, and dried before each pass. Soil cores were collected in 15-60 cm passes. Cores were then taken 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 then stored in a cooler. Samples of the top 10-15 cm corresponding to the applied SLD sediment, were frozen upon arrival in the laboratory. Holes created by the coring 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).

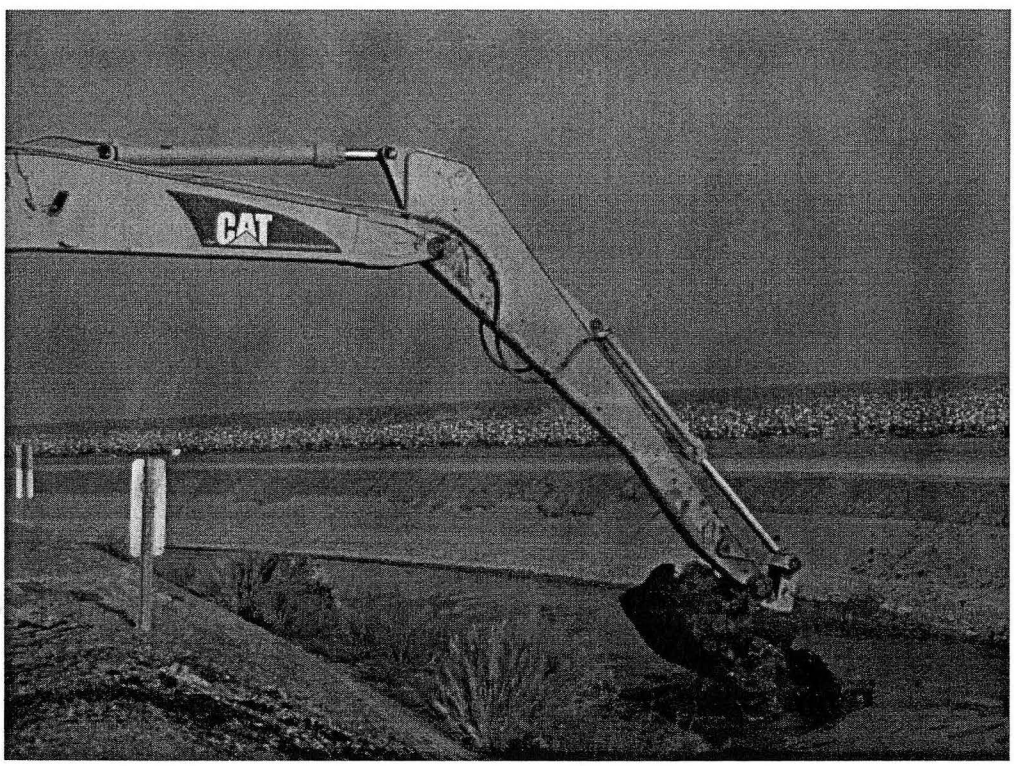


Figure C.4. Dredging of SLD sediment.

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).

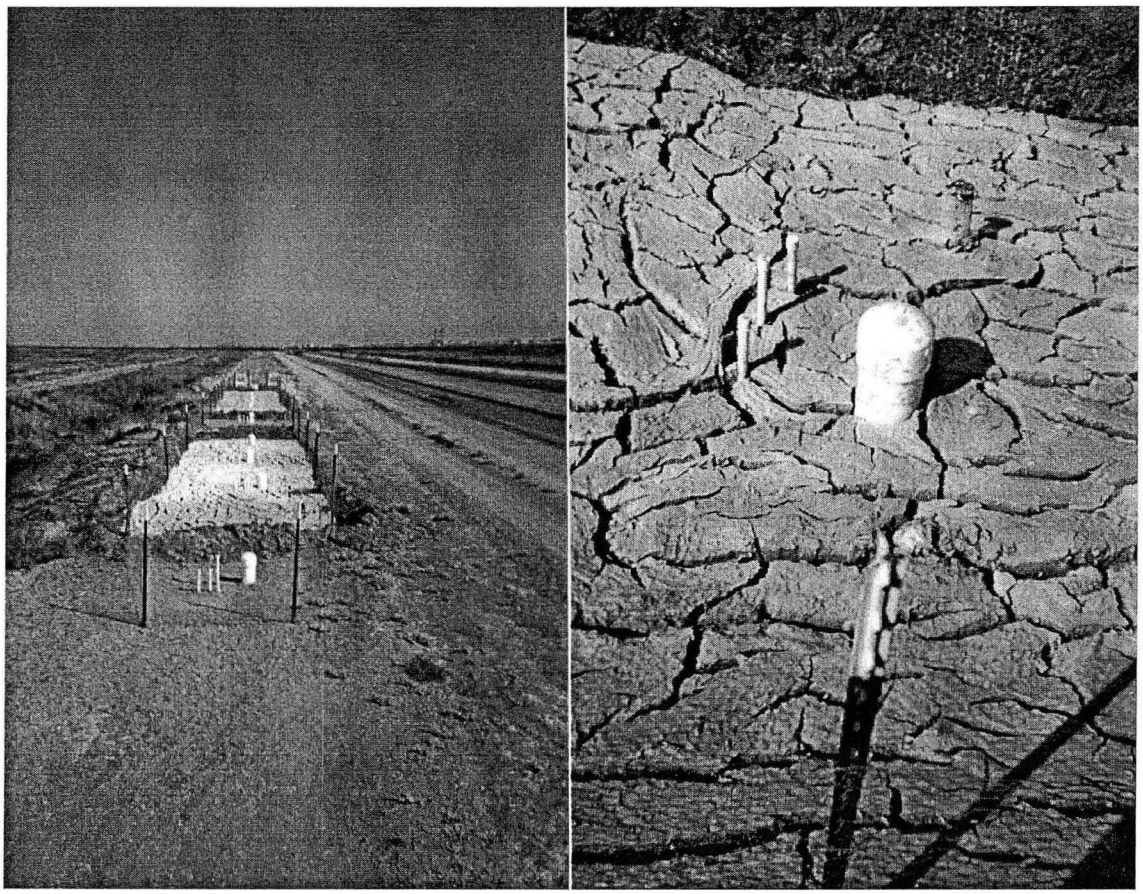


Figure C.7. Left: Sites EP-2 and EP3 after a few days of drying (9/9/99). Close-up view of drying cracks around one of the monitoring clusters (right).

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.

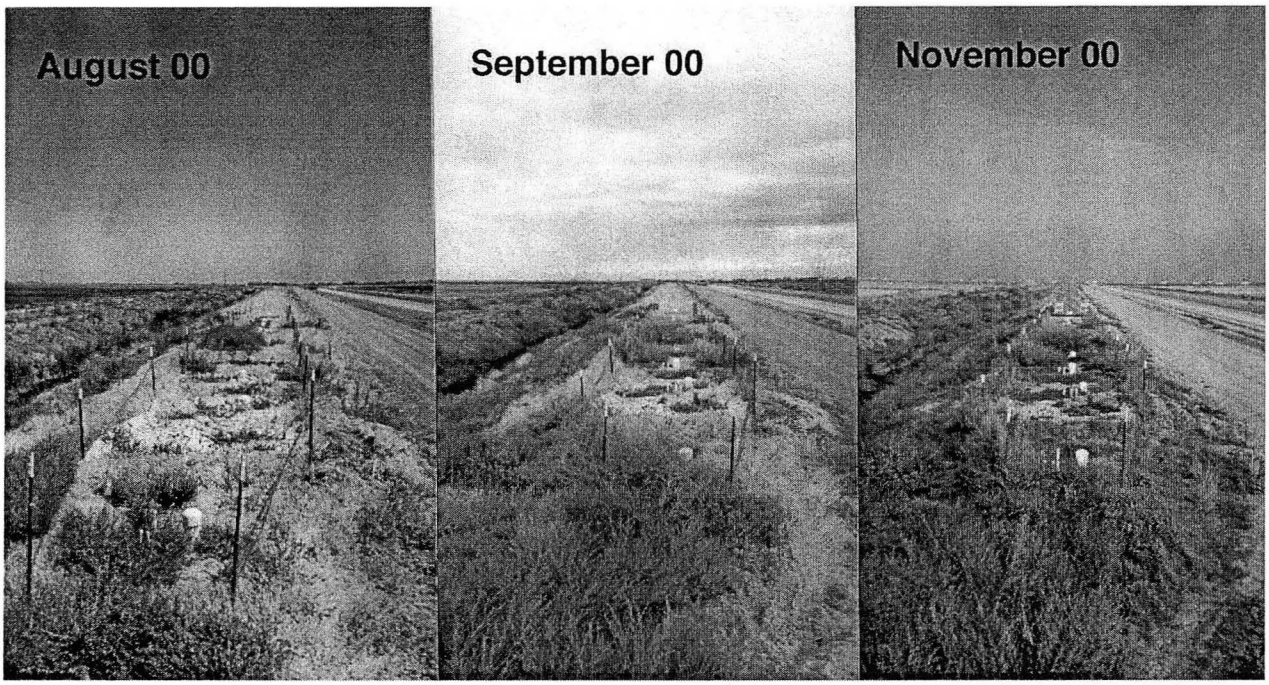


Figure C.13.Plant growth at EP-2 and EP-3 between August and November 2000.

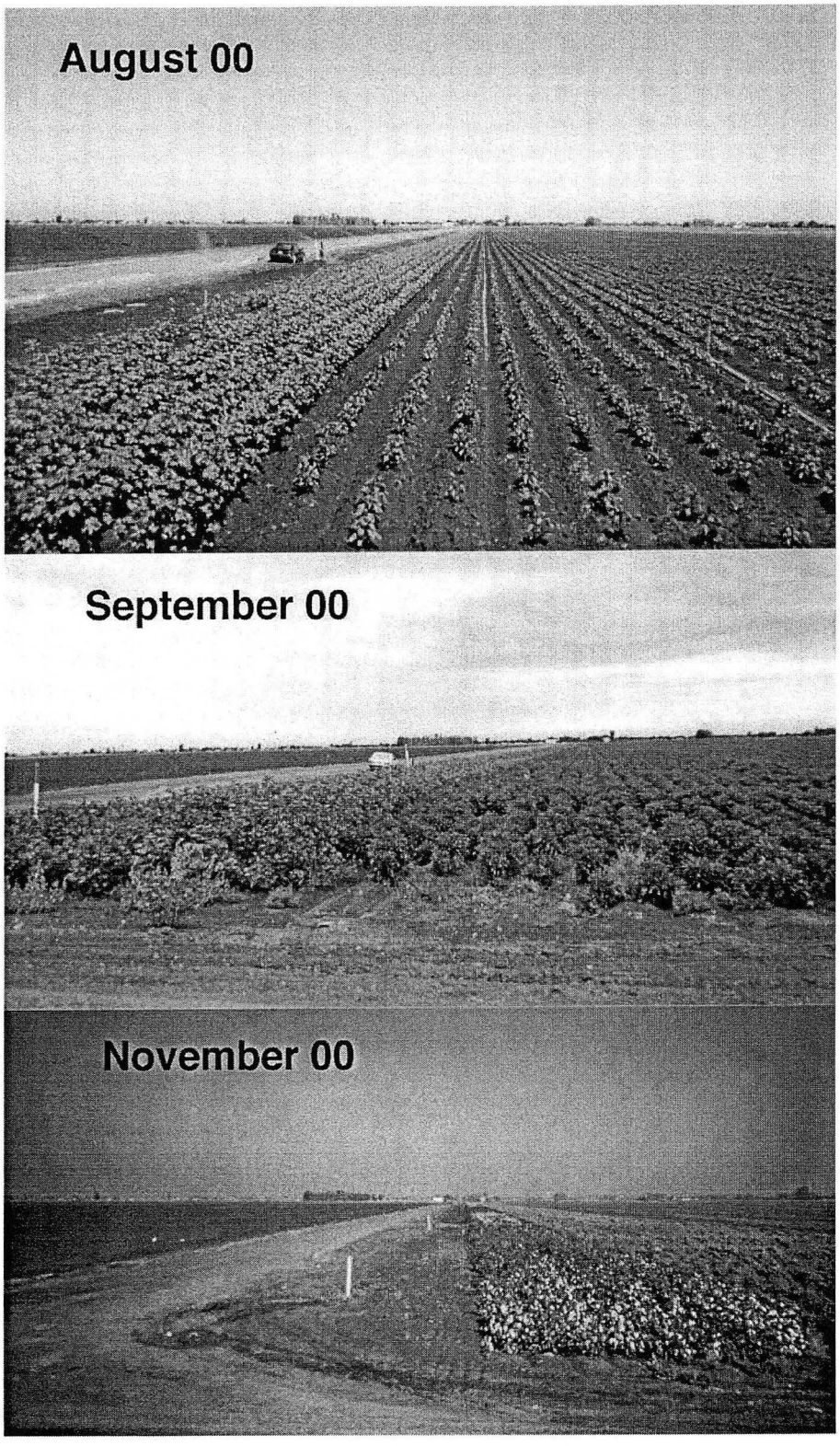


Figure C.14. Crop growth at the farm plot sites. Thicker vegetation on the left side is cotton, that to the right is chile pepper.

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

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