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Carolyn Wahl and Sally M. Benson
Earth Sciences Division

January 1996



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Update to Modeling Soil Selenium Concentrations in the Shallow Soil Profile at Kesterson Reservoir Merced County, California

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ABSTRACT

A mass balance model was developed to predict concentrations of water-extractable selenium in surface and subsurface soil by extrapolating the trend observed from 6 years of soil monitoring data collected at Kesterson Reservoir. Correlations between observed and calculated concentrations indicate that the major trends and year-to-year variations are well represented with the model. Results from this exercise were then used, under three climatic scenarios, to simulate the evolution of the soluble selenium inventory 25 years into the future. Based on these simulations, we expect that the availability of the soluble selenium inventory has most likely reached peak levels, and is now declining. However, year-to-year climatic variations may influence the rate of decline, and occasionally reverse this prevailing trend.

1.0 INTRODUCTION

This study was conducted at the request of the United States Bureau of Reclamation to assist in evaluating alternatives for continued management of the former Kesterson Reservoir, Merced County, California. From 1978 to 1986, Kesterson Reservoir was used for the disposal of subsurface agricultural drainage which contained high selenium concentrations. The estimated 9,000 kg of selenium delivered to Kesterson during this period accumulated largely in the upper-most 0.15 m of Reservoir bottom sediments (Weres *et al.*, 1989). By 1988, the Reservoir was dried out and low-lying areas were filled with approximately 25 cm of imported and local fill material.

Since 1987 the inventory and distribution of selenium in the soil profile has been monitored. Today, as in 1987, the majority of the inventory is largely insoluble and concentrated in the upper-most 0.15 m of the original soil profile. However, detailed monitoring of the distribution and speciation of the selenium inventory deeper in the soil profile indicates that a combination of remobilization, leaching and to lesser degree, volatilization is changing the speciation and spatial distribution of selenium in the soil profile.

This effort was prompted by the need to quantify these changes and predict their potential impact on wildlife. To accomplish this, a mass balance model for selenium and chloride was developed and used to estimate the rate of selenium leaching and remobilization that has occurred since 1987. This report describes the database available to support these projections, the methodology used to predict temporal trends, and the results of the predictions. This study expands upon work described in previous reports (Benson *et al.*, 1992; LBL, 1992).

2.0 OBJECTIVES

The objectives of this work are to:

- Analyze data gathered from ongoing monitoring and research efforts at Kesterson Reservoir regarding the evolution of the water-extractable soil selenium inventory.
- Calibrate a mass balance model for water-extractable soil selenium that can be used to extrapolate observed 1988–1993 time-trends into the future.
- Predict the distribution and average evolution of the current water-extractable soil selenium inventory under wet, dry, and average climatic scenarios spanning a 25-year period beginning in 1987.

3.0 KESTERSON RESERVOIR SOIL SELENIUM DATABASE

Since 1987, intensive soil and soil-water sampling has been conducted to determine selenium concentrations as part of monitoring and research activities at Kesterson Reservoir. These activities include:

- Soil selenium fractionation and speciation studies (Weres *et al.*, 1985 and 1989; Zawislanski, 1989 and 1990; Yee, 1990; Tokunaga *et al.*, 1991; Ita and Benson, 1992; Zawislanski and Zavarin, 1992; LBL, 1995).
- Long-term soil and soil-water selenium monitoring in former Ponds 5, 6, 7, 8, 9, 10, and 11 (LBL, 1988,; 1990a,b, 1995; Long, 1988; Zawislanski, 1989; Tokunaga *et al.*, 1991).
- Annual synoptic sampling of soil selenium at Kesterson (LBL 1990a,b and 1995; Wahl, 1992; Wahl *et al.*, 1994)
- Volatilization experiments in former Ponds 2, 4, and 11 (Doran and Alexander, 1977; Doran, 1982; Frankenberger and Karlson, 1988; Weres *et al.*, 1989; Frankenberger, 1990; Goldhammer and Alemi, 1990; Tokunaga, 1990; Terry *et al.*, 1990; Biggar *et al.*, 1990; Yee, 1990; ANR, 1992; LBL, 1995).
- Soil-Water-Vegetation management experiments in former Ponds 2, 5, and 7 (LBL, 1988, 1990a,b; Wu *et al.*, 1990).

This work builds on the scientific knowledge gained from these extensive studies of the environmental behavior of selenium at Kesterson Reservoir.

4.0 EXPECTED TRENDS IN SOIL SELENIUM AT KESTERSON RESERVOIR

Previous investigation results indicate that combination of remobilization, leaching, and volatilization are expected to produce the following changes in the Kesterson Reservoir soil selenium inventory and distribution over the next 25 years:

- The total inventory of soil selenium will decline at an annual rate of approximately 1 percent of the remaining inventory because of volatilization.
- Water-extractable selenium in surface soil (0 to 0.15 m depth) will be leached to deeper levels in the soil profile.
- Water-extractable soil selenium concentrations will initially increase in the root zone.
- The distribution of total selenium within the soil profile will change from being strongly concentrated near the soil surface to being more evenly distributed within the upper 2 m of the soil.

- As a result of redistribution, total selenium concentrations will decline in the 0 to 0.15 m depth interval and gradually increase at greater depths; total selenium concentrations are never expected to exceed the largest values previously observed at Kesterson.
- Significant quantities of water-extractable selenium will not be observed below 2 m due to the chemically reducing conditions below the water table which favor immobile forms of selenium. Flushing of water-extractable selenium below the water table, followed by subsequent reduction and immobilization, may contribute significantly to declines in the inventory of selenium in the vadose zone.

5.0 PREDICTED CHANGES IN THE SELENIUM INVENTORY AND DISTRIBUTION

To provide a more quantitative assessment of changes in the soluble selenium inventory, to illustrate the distribution in the soil profile, and to predict how these changes will continue into the future, a simple mathematical model was developed and applied to the soil selenium data collected during the past 6 years. The model tracks water-extractable selenium inventories in the top 2 m of soil and is used to interpret existing data as well as to predict the possible range of future selenium concentrations. A description of the approach, calibration, and application of this model follows. Extensive details are provided in Benson *et al.*, 1992, and LBL, 1992.

Approach and Model Description

A detailed description of the model used for these calculations is provided in Benson *et al.*, 1992. A brief description of the major features are provided below for the convenience of the reader.

The model tracks total and water extractable selenium concentration in the soil profile. To track these changes the top 2-m soil section is subdivided into the following intervals:

- Soil surface to a depth of 0.15 m.
- A depth of 0.15 to 1 m.
- A depth of 1 to 2 m.

The system was divided into these intervals because:

- The average depth to the water table at Kesterson Reservoir is about 2 m below the ground surface.
- A relatively large database is available to track changes in selenium concentrations in the top 0.15 m of soil.
- Selenium concentrations in the top 0.15 m of soil change dramatically in response to seasonal leaching and bare-soil evaporation.

- Below a depth of 1 m, the soil profile is less affected by seasonal changes in soil moisture content and by solute transport of solutes from surface soil. Consequently, it is not expected to undergo rapid changes in selenium concentrations.

The term “soil profile” is used to represent the top 2 m of soil at Kesterson Reservoir.

Three primary mechanisms that lead to changes in the selenium inventory are included in the model; volatilization, leaching, and remobilization. It should be noted that these mechanisms encompass a complicated interplay of physical, chemical, and microbial processes which vary in importance throughout the year. Because of the complexity of all these processes, a phenomenological approach has been taken in combining them into the 3 distinct mechanisms accounted for by the model. As used in the model, the role of each mechanism is described below.

Volatilization

A percentage of the selenium soil inventory will be transferred to the atmosphere by volatilization. For example, microbial volatilization is expected to remove selenium from the surface-most interval, while plant volatilization will remove selenium from the root zone. The rate of volatilization is expressed in terms of the fraction of the total selenium inventory removed from each soil interval per year. The quantity volatilized within a given year is calculated from

$$VOLI = VI * TII$$

where

VOLI is the mass of selenium volatilized from unit I.

VI is the volatilization rate for unit I.

TII is the total inventory of selenium in unit I.

Based on extensive field measurements of volatilization rates under a variety of conditions, volatilization rates are assigned a value of one percent per year from the surface-most interval (Benson *et al.*, 1992). Similarly, volatilization rate are assigned to be one percent per year from the 0.15-1 m interval.

Leaching

Leaching provides the mechanism for transporting solutes from the surface to deeper into the profile. The leaching rate is expressed in terms of the percent of the solute inventory transported from one depth interval to another over a 1-year period. Note, this is the net leaching which occurs over a 1-year period, not the maximum leaching observed immediately following the rainy season. The model is not capable of simulating evapotranspiration or diffusive fluxes which may carry solutes from deeper in the profile to near surface soils. The mass of solute transported from unit I to unit J in a given year (LEACHIJ) is calculated by

$$LEACHIJ = LIJ * EII$$

where

L_{IJ} is the leaching rate from unit I to unit J.

E_{II} is the inventory of water-extractable selenium in unit I.

Remobilization

The remobilization term accounts for increases in water-extractable soil selenium due to oxidation or desorption of reduced forms of selenium, dissolution of selenium-bearing salts, and decomposition of organic-matter-associated selenium forms. In addition, the model can mimic decreases in the water-extractable inventory due to chemical reduction, and the consequent immobilization through precipitation or adsorption. Again, over the seasonal cycle, simultaneous or cyclical oxidation and reduction of selenium is expected to occur. Therefore, as with the leaching component, the rate constant associated with this process reflects the net effect of these competing processes over a year. The quantity remobilized within a given year is given by

$$\text{REMOBI} = \text{RI} * (\text{TII} - \text{EII})$$

where

REMOBI is the mass of selenium remobilized from unit I.

RI is the remobilization rate for unit I.

E_{II} is the inventory of water-extractable selenium in unit I.

T_{II} is the total inventory of selenium in unit I.

Computational Procedure

The model uses an explicit algorithm to calculate yearly changes in the selenium distribution and inventory in the soil profile. Further details on the initialization and calculation procedures used by the model are provided in Benson *et al.*, 1992.

Beginning with the initial (1988) inventory of selenium, the model calculates the amount of selenium leached and remobilized within each depth interval over a 1-year period. After completing these calculations, the model updates the inventories of water-extractable soil selenium in the three depth intervals. Having updated the selenium inventories, the model repeats these calculations for the desired number of annual intervals.

Model Calibration Procedure

The following procedure was utilized for the calibration of this model. First, yearly leaching rates were determined for each depth interval by matching the model results with the measured chloride concentration data. During this step, remobilization and volatilization rates were set to zero. If leaching for a year was negligible (e.g., a dry year), the rate constant was set to zero. Having determined the leaching rates for each year during the calibration period, the yearly

remobilization rate for each depth interval was then determined by increasing/decreasing the remobilization rate from zero to the value required to approximately match the observed changes in its water-extractable inventory. Changes in the water extractable selenium inventory attributable to oxidation was assigned a positive value (0 to 1). Changes in the water-extractable inventory chemical attributable to reduction were assigned a negative value (0 to -1).

6.0 HISTORY MATCHING AND MODEL CALIBRATION

Leaching Rates

History matching of data and calibration coefficients from two experimental plots, 8EP and 9BE, are presented here. Figures 1-8 illustrate the history matches used to determine the leaching rate constants shown in Table 1. For the surface-most interval, leaching rates range from 0-1. A similar range is also observed for the deeper intervals.

Observe that the matches between the observed and calculated chloride concentration are not equally good. The poor matches obtained for some years illustrate that in some cases the simple model used here requires further refinement. However, the overall quality of the matches is sufficiently good to indicate the model adequately captures the leaching process observed in this environment. Therefore, it is deemed satisfactory for the purpose of these calculations.

Selenium Remobilization Rates Determined from Plot 8EP

Measured water-extractable soil selenium concentrations in plot 8EP are provided in Table 2. Rate constants were obtained by the calibration procedure previously described and are summarized in Table 3. Matches between observed and calculated concentrations of water-extractable soil selenium in the 3 depth intervals are shown on Figures 9, 10, and 11. Figure 12 illustrates the correlation between observed and calculated mass of the entire inventory of water-extractable soil selenium in the top 2 m of soil.

Table 1. Leaching Rate Constants Determined for Plot 8EP and Plot 9BE

Depth (m)	1988	1989	1990	1991	1992
Plot 8EP					
0.0-0.15	0.16	0.6	0.5	0.9	1
0.15-1	0.1	0	0	0.5	0.3
1-2	0	0	0	0.8	0.4
Plot 9BE					
0.0-0.15	0	0.1	0.2	1	0.5
0.15-1	0	0	0.5	1	0.2
1-2	0	0	0.55	1	0.2

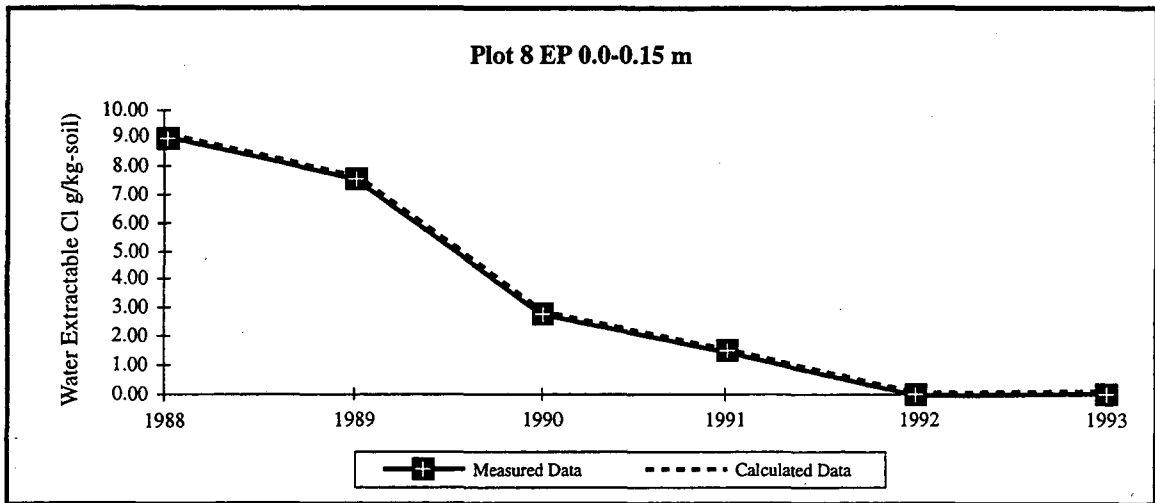


Figure 1. Comparison between measured and calculated chloride concentrations in the top 0.15 m of soil at Plot 8EP.

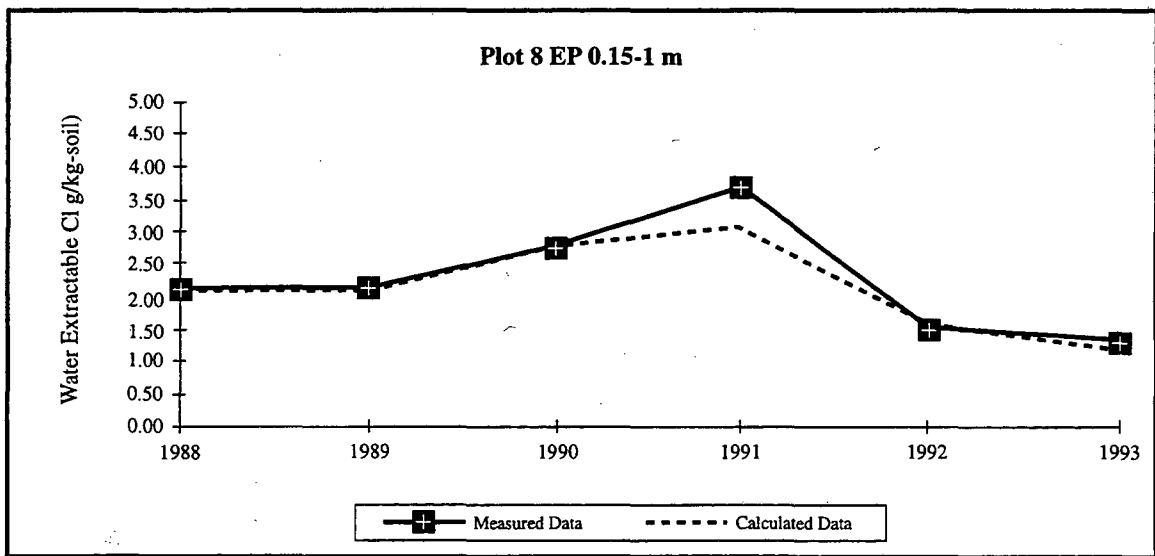


Figure 2. Comparison between measured and calculated chloride concentrations in the depth interval of 0.15 to 1 m of soil at Plot 8EP.

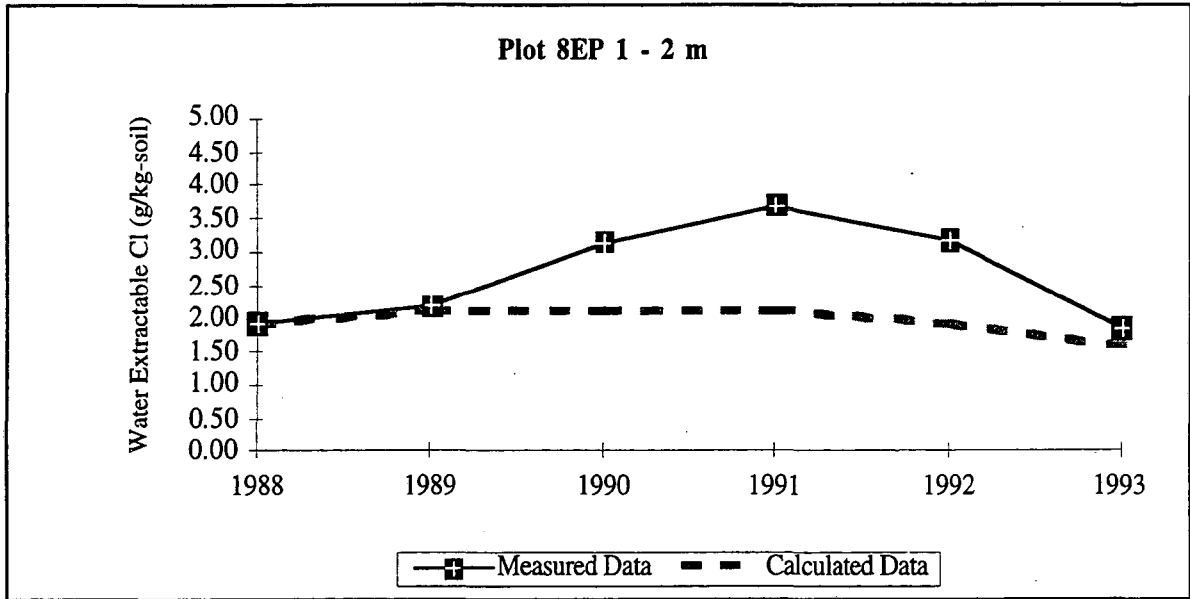


Figure 3. Comparison between measured and calculated chloride concentrations in the depth interval of 1 to 2 m of soil at Plot 8EP.

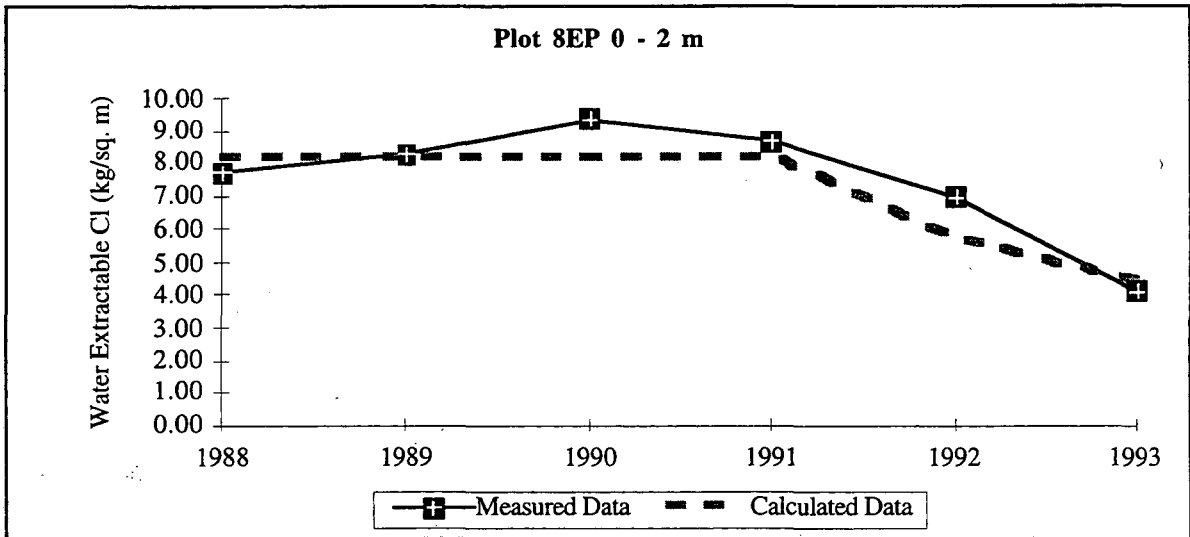


Figure 4. Comparison between measured and calculated inventories of chloride in the top 2 m of soil in Plot 8EP.

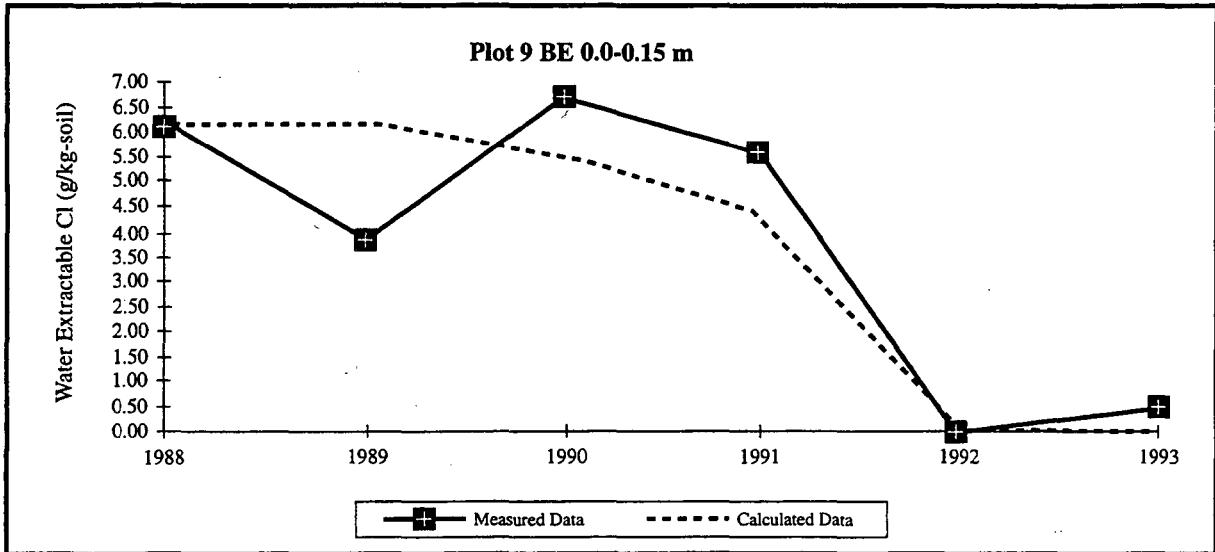


Figure 5. Comparison between measured and calculated chloride in the top 0.15 m of soil at Plot 9BE.

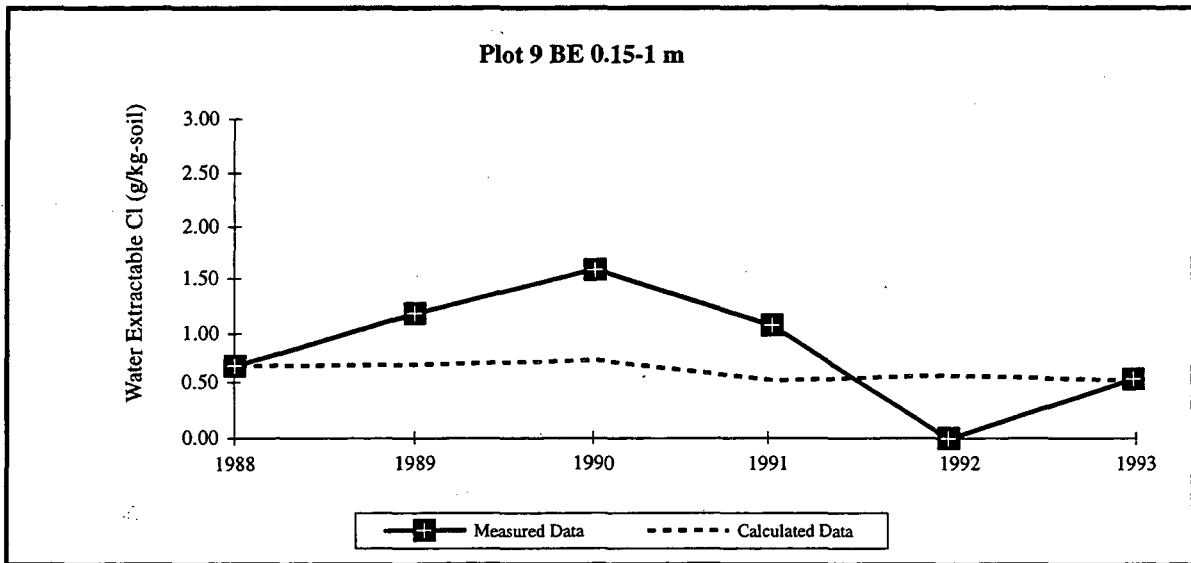


Figure 6. Comparison between measured and calculated chloride concentrations in the depth interval of 0.15 to 1 m of soil at Plot 9BE.

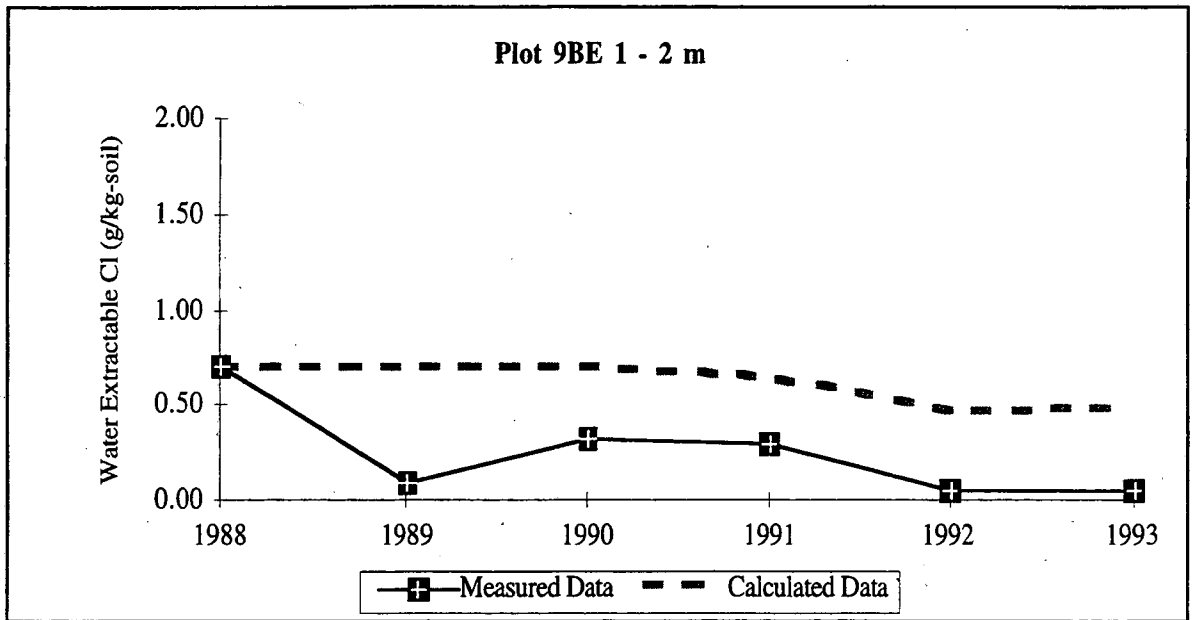


Figure 7. Comparison between measured and calculated chloride concentrations in the depth interval of 1 to 2 m of soil at Plot 9BE.

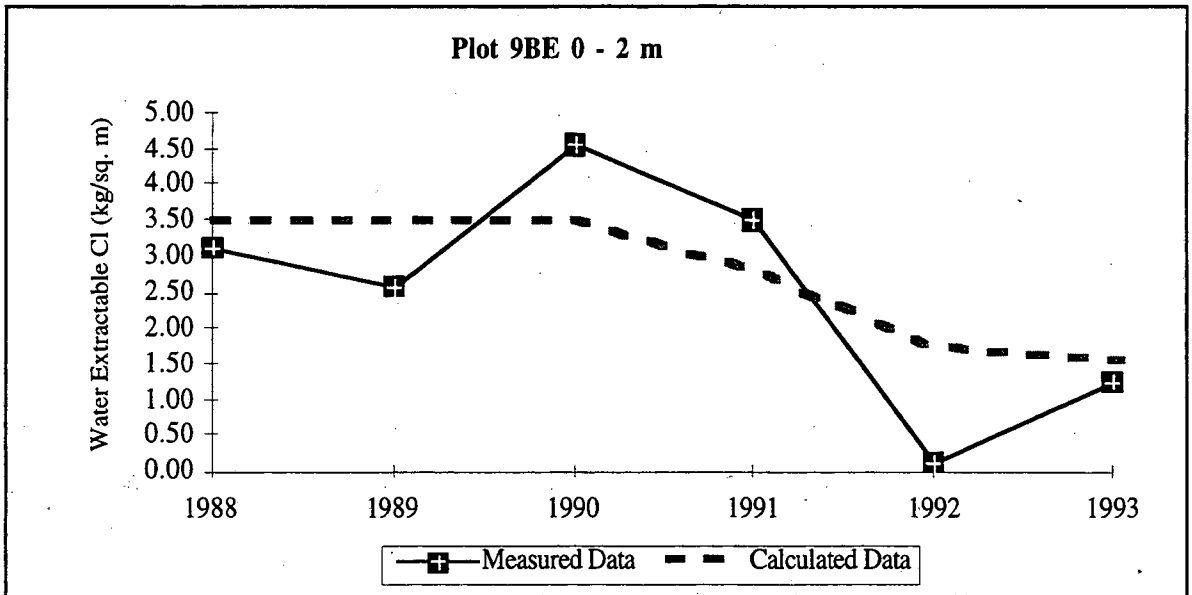


Figure 8. Comparison between measured and calculated inventories of chloride in the top 2 m of soil in Plot 9BE.

Table 2. Summary of Water-Extractable Soil Selenium Concentrations in Plot 8EP from 1988 to 1993.*

Depth (m)	1988	1989	1990	1991	1992	1993
0.0–0.15	0.49	0.93	0.71	0.37	0.45	0.36
0.15–1	0.06	0.09	0.18	0.17	0.13	0.21
1–2	0.01	0.02	0.02	0.06	0.08	0.09
Cumulative Se: (0–2 m)	0.23 g/m²	0.38 g/m²	0.46 g/m²	0.37 g/m²	0.42 g/m²	0.49 g/m²

Notes: *Values expressed as mg/kg-soil unless otherwise specified.

Table 3. Summary of Leaching and Remobilization Rate Constants Determined for Plot 8EP

Year	Rainfall (m)	Leaching Rate			Remobilization Rate		
		0.0–0.15 m	0.15–1 m	1–2 m	0.0–0.15 m	0.15–1 m	1–2 m
1988–89	0.17	0.16	0.1	0	0.12	0.05	0.12
1989–90	0.24	0.6	0	0	0.10	0.01	0
1990–91	0.21	0.5	0	0	0.02	–0.06	1
1991–92	0.32	0.9	0.5	0.8	0.13	0.02	0
1992–93	0.42	1	0.3	0.4	0.13	0.08	0.02

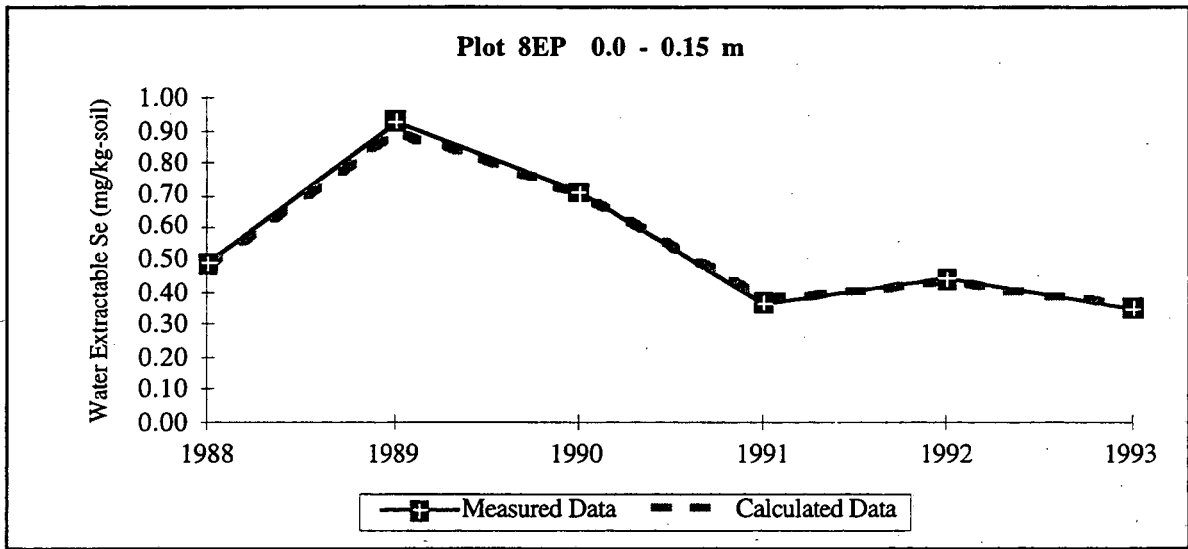


Figure 9. Comparison between measured and calculated water-extractable selenium concentrations in the top 0.15 m of soil at Plot 8EP.

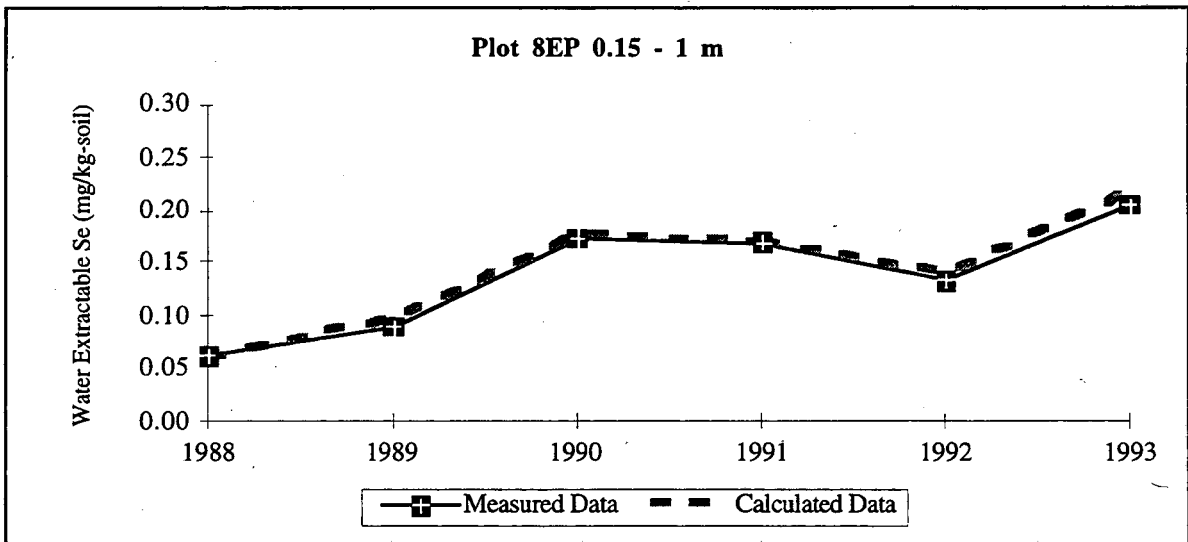


Figure 10. Comparison between measured and calculated water-extractable selenium concentrations in the depth interval of 0.15 to 1 m of soil at Plot 8EP.

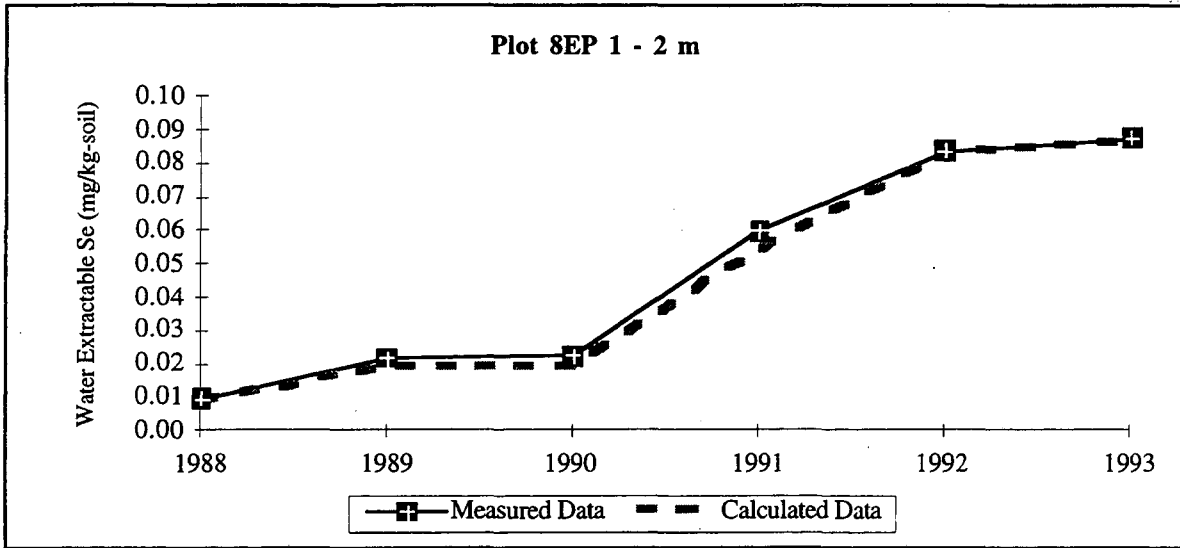


Figure 11. Comparison between measured and calculated water-extractable selenium concentrations in the depth interval of 1 to 2 m of soil at Plot 8EP.

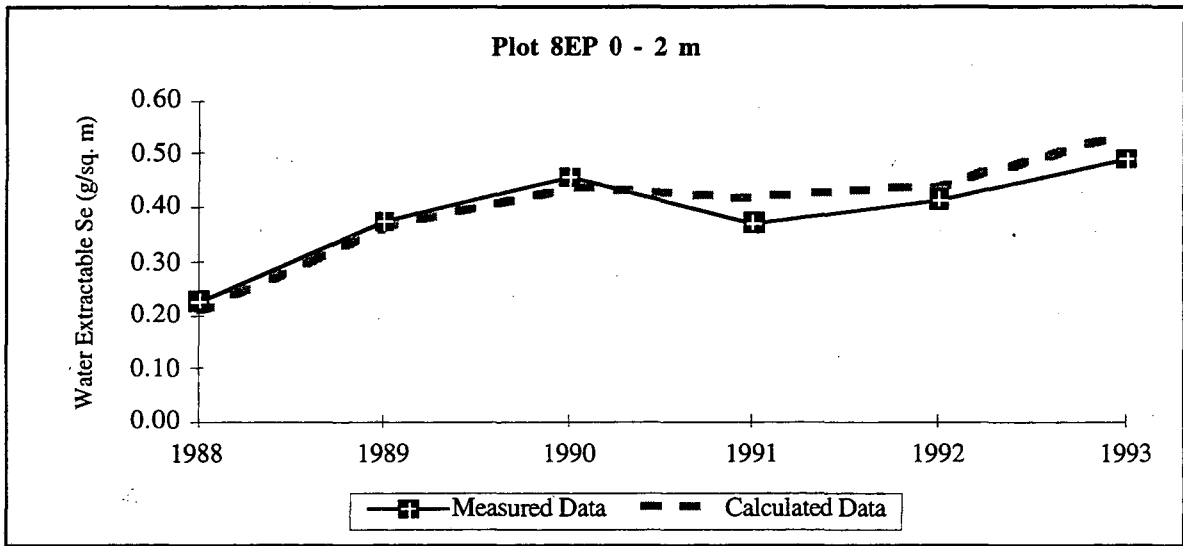


Figure 12. Comparison between measured and calculated inventories of water-extractable selenium in the top 2 m of soil in Plot 8EP.

Selenium Remobilization Rates Determined from Plot 9BE

Measured water-extractable soil selenium concentrations in plot 9BE are shown in Table 4. Rate constants were obtained by the calibration procedure described previously and summarized in Table 5. Matches between measured and calculated data for water-extractable soil selenium in the 3 depth intervals are shown on Figures 13, 14, and 15. Figure 16 shows the correlation between measured and calculated mass of the entire inventory of water-extractable soil selenium in the top 2 m of soil.

Table 4. Summary of Water-Extractable Soil Selenium Concentrations in Plot 9BE from 1988 to 1993 ⁽¹⁾

Depth (m)	1988	1989	1990	1991	1992	1993
0.0-0.15	1.13	0.93	2.15	1.40	0.86	0.47
0.15-1	0.01	0.09	0.14	0.10	0.02	0.10
1-2	0.01	0.02	0.03	0.01	0.04	0.16
Cumulative Se: (0-2 m)	0.22 g/m ²	0.41 g/m ²	0.61 g/m ²	0.41 g/m ²	0.22 g/m ²	0.26 g/m ²

Notes: ⁽¹⁾ Values expressed as mg/kg-soil unless otherwise specified.

Table 5. Summary of Leaching and Remobilization Rate Constants Determined for Plot 9BE

Year	Rainfall (m)	Leaching Rate			Remobilization Rate		
		0.0-15 m	0.15-1 m	1-2 m	0.0-0.15 m	0.15-1 m	1-2 m
1988-89	0.17	0	0	0	-0.05	0.1	0.4
1989-90	0.24	0.1	0	0	0.35	0.05	0.5
1990-91	0.21	0.2	0.5	0.55	-0.1	0	-1
1991-92	0.32	1	1	1	0.3	-0.2	-0.5
1992-93	0.42	0.5	0.2	0.2	0.05	0.01	1

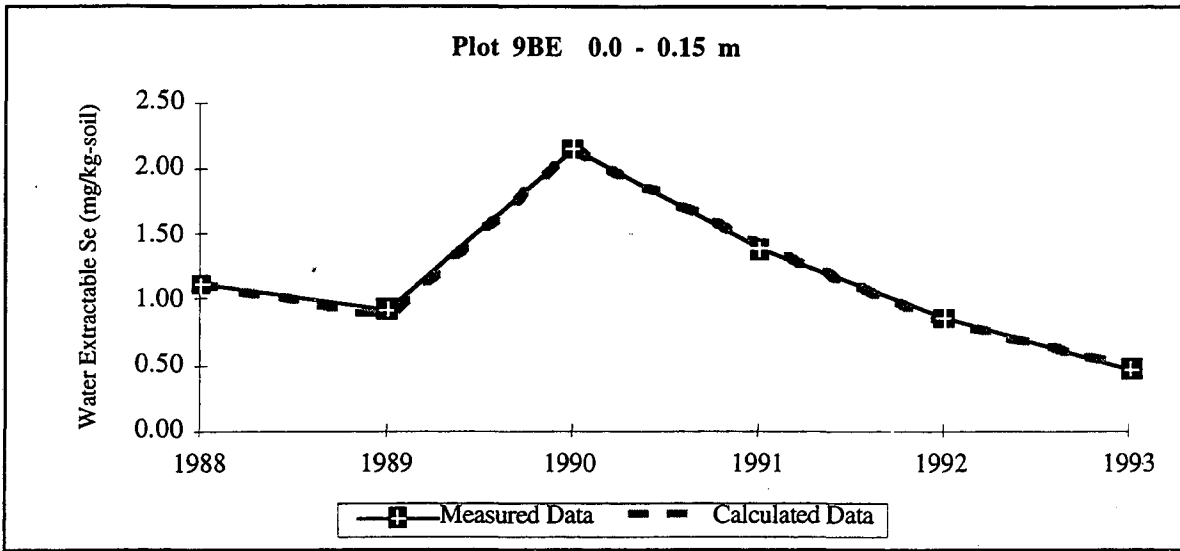


Figure 13. Comparison between measured and calculated water-extractable selenium concentrations in the top 0.15 m of soil at Plot 9BE.

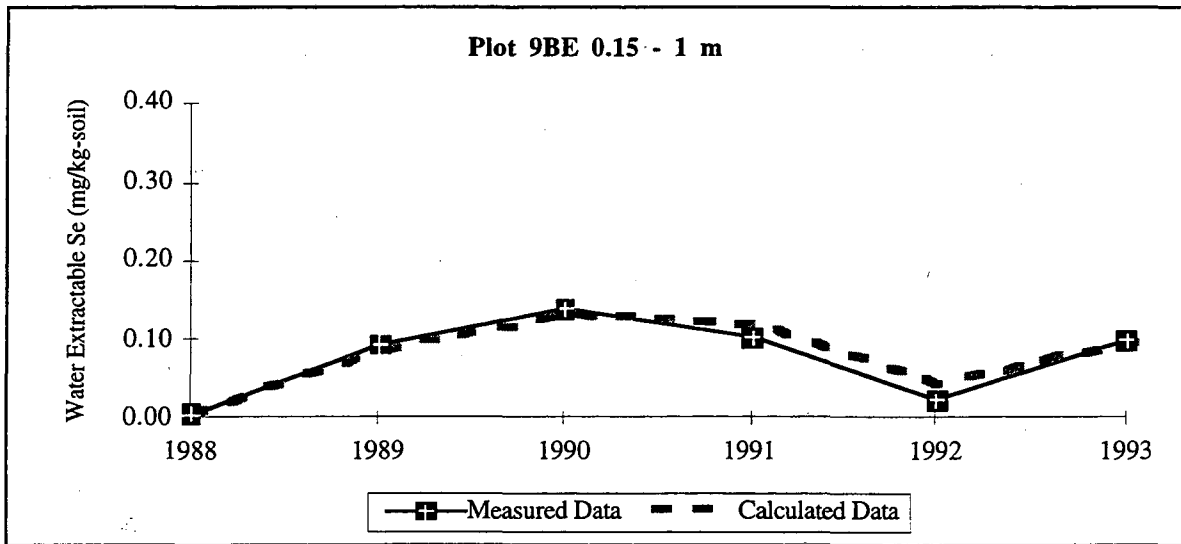


Figure 14. Comparison between measured and calculated water-extractable selenium concentrations in the depth interval of 0.15 to 1 m of soil at Plot 9BE.

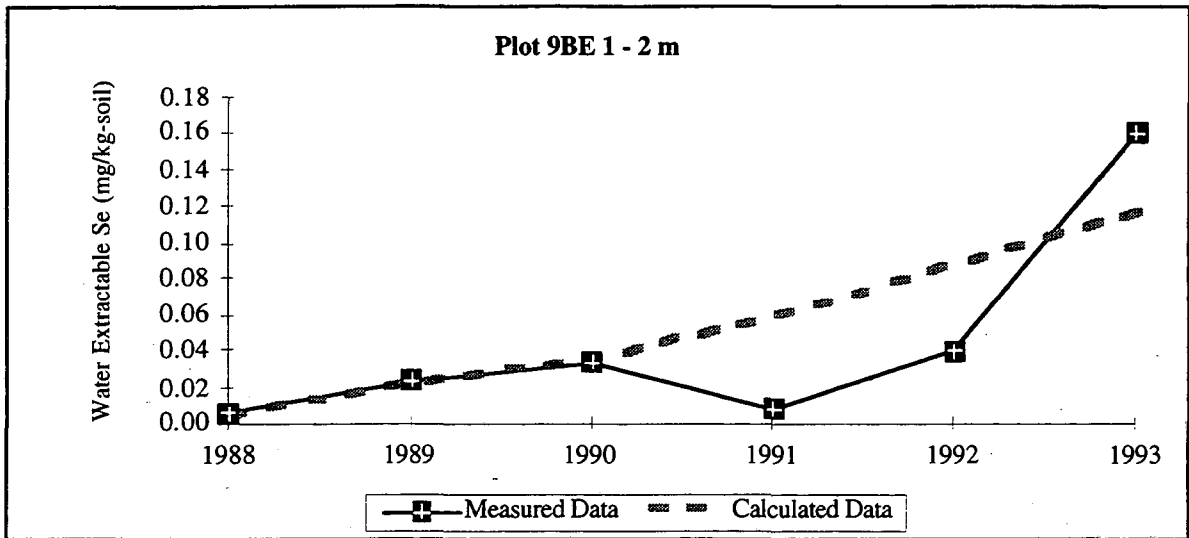


Figure 15. Comparison between measured and calculated water-extractable selenium concentrations in the depth interval of 1 to 2 m of soil at Plot 9BE.

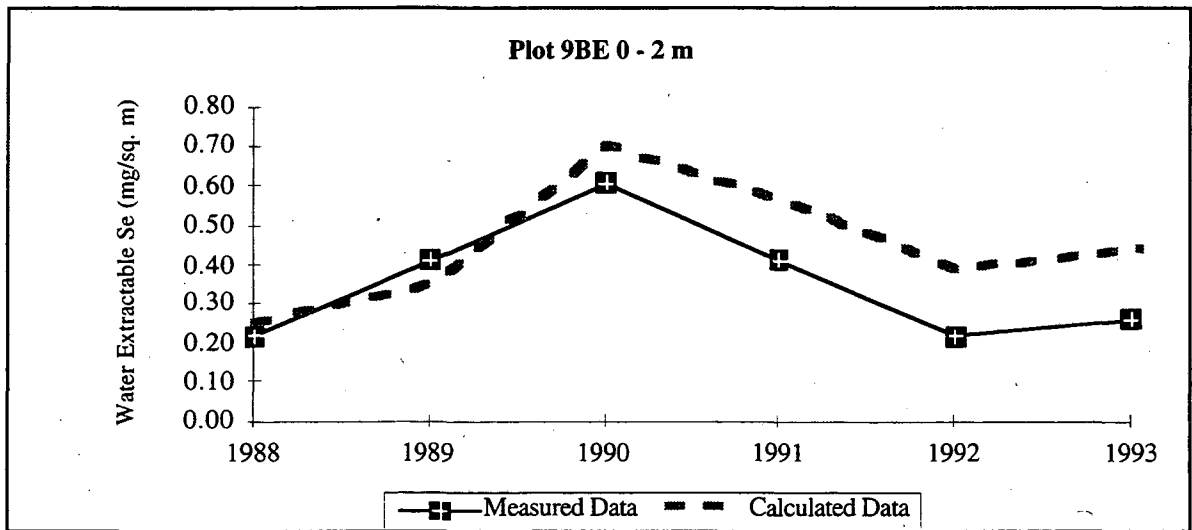


Figure 16. Comparison between measured and calculated inventories of water-extractable selenium in the top 2 m of soil in Plot 9BE.

Discussion of Leaching and Remobilization Rates

Two general trends in the soil profile data have been described in previous reports (LBL, 1995, 1992, 1990a,b, Benson et al., 1992) and are represented with the observed and modeled data presented in this report. The first trend is the influence of oxidation on the soil profile from dry conditions, and resultant increase of the water-extractable selenium inventory. The second trend observed in these data is the leaching of soluble selenium deeper into the soil profile.

While it remains clear that these are the two most significant processes leading to evolution of the selenium distribution in the soil profile, it is now clear that year-to-year variations in rainfall will strongly influence the overall trend. This is apparent in both the leaching and remobilization rate constants listed in Tables 3 and 5. For example, from 1988 to 1991, when the annual rainfall was less than 0.25 m, leaching rates for the surface-most unit were less than 0.6 for both sites and all depth intervals. From 1991 to 1993, when rainfall was higher (0.32 - 0.42 m/year) leaching rates in the surface-most interval increased to a range of 0.5 to 1. Moreover, during the drier years, leaching from all but the surface-most interval was nearly negligible, but during the wetter years deep leaching increased to a range of 0.2 to 1.

Less obvious but potentially important rainfall related trends are also apparent in the remobilization rates constants determined from Plot 9BE. In particular, deeper in the soil profile, remobilization rates are negative (indicating biogeochemical reduction of water-soluble selenium) or if positive, significantly smaller than during drier years. This trend is consistent with our understanding of the behavior of selenium in this environment. That is, during most years the soils will become fully saturated with a combination of rising ground water and infiltrating rain water. This will lead to creation of chemically reducing conditions, which then leads to microbially induced transformation of soluble selenium to less soluble forms.

The role of vegetation on the soil-moisture regime and transport of solutes may also contribute to annual variations in the rate constants. As an example, during the summer of 1989, no vegetation was allowed to grow in Plot 8EP and the soil was relatively moist (LBL, 1992). In the summer of 1990, *Bassia hyssopifolia* invaded the plot and transpired a large fraction of the soil moisture, resulting in the transpirative concentration of solutes in the root zone (LBL, 1992).

The relatively high values for the leaching rates (up to 1) and remobilization rates (up to 0.35) in the surface-most interval (0 - 0.15 m) indicate that the distribution and speciation of the selenium inventory will evolve relatively rapidly. In particular, we expect that remobilization and subsequent leaching will transport selenium deeper into the soil profile. In the following section of this report, the net effect of these processes over a 25 year period is evaluated.

7.0 PREDICTION OF SOIL SELENIUM CONCENTRATIONS FOR A 25-YEAR PERIOD

Using the rate constants determined from the calibration exercise described above, the model was used to forecast water-extractable soil-selenium concentrations over a 25-year period beginning in 1987. The calibration data presented in this report indicate leaching and remobilization rates vary from year to year. This is not surprising given the range of soil properties, variable meteorological conditions, hydrologic parameters, depth to water table, and vegetative cover. No one set of conditions will be representative of Kesterson Reservoir as a whole. Predicted concentrations of water-extractable selenium are therefore presented for three cases spanning the range of observed leaching and remobilization rates. The three cases include:

Case 1 – an average of the rate constants for each of the years for both experimental plots.

Case 2 – an average rate for the dry years (1988–1990) for both experimental plots.

Case 3 – an average rate for the wet years (1991–1993) for both experimental plots.

Initial conditions were based on the results of the Reservoir-wide sampling program (Wahl, 1992; Wahl *et al.*, 1994) and from supplemental information gathered elsewhere at Kesterson Reservoir (Benson *et al.*, 1992, LBL, 1992). For the surface interval, values for water-extractable selenium were taken directly from the 1989 Reservoir-wide sampling data (values were rounded to the nearest significant figure). It is assumed these values remained essentially unchanged from 1987 to 1989. This assumption is consistent with the reservoir-wide and profile monitoring investigations previously described.

For the depth intervals 0.15 to 1 m and 1 to 2 m, initial conditions are estimated based on profile sampling described by Long *et al.* (1990), Weres *et al.* (1989), Zawislanski (1990), and Tokunaga *et al.* (1991). An estimated 20 percent (1,800 kg) of the 9,000 kg of selenium delivered to Kesterson Reservoir from 1981 to 1986 is located in the 0.15 to 1 m depth interval. If this inventory is distributed uniformly over this interval, the average selenium concentration will be approximately 0.25 mg/kg-soil. Prior to 1989, limited information was available for assessing the fraction of this inventory that was water-extractable. However, based on information provided in LBL, 1990, Benson *et al.*, 1990 and Benson *et al.*, 1992, it is reasonable to assume approximately 20 percent of this inventory was water-extractable in 1987, the first year most of the Reservoir was dried out. The water-extractable selenium concentrations in the 1 to 2 m depth interval were assumed to be 20 percent of the values assigned to the 0.15 to 1 m depth interval.

The ratio between the leaching and remobilization rates is the primary factor governing temporal trends. Where this ratio is high (wet year–Case 3), water-extractable selenium concentrations will remain the same or decrease over time. Where this ratio is low (dry year–Case 2), water-extractable selenium concentrations will increase until the total selenium inventory is substantially decreased.

For the three cases listed in Table 6, predicted concentrations of water-extractable soil selenium in the 0 to 0.15 m depth interval are given in Figure 17. In all cases, water-extractable soil selenium concentrations showed an initial increase, followed by decreasing concentrations over the 25-year period. In Case 1 (average), water-extractable soil selenium concentrations increased to a maximum concentration of 0.34 mg/kg-soil in 1989 and then declined to 0.04 mg/kg-soil in 2012 (a decrease of 88 percent). In Case 2 (dry), water-extractable soil selenium concentrations increased to a maximum concentration of 0.38 mg/kg-soil in 1991 and then declined to 0.11 mg/kg-soil in 2012 (a decrease of 71 percent). In Case 3 (wet), water-extractable selenium concentrations increased to a maximum concentration of 0.35 mg/kg-soil in 1988 and then declined to near zero values by 2011.

Table 6. Initial Rate Constants used to Compute Changes in Soil Selenium Concentrations.

Case	Depth (m)	Unit	V1*	L1 [†]	R1 [‡]
Case 1 (average)	0-0.15	1	0.01	0.50	0.10
	0.15-1	2	0.01	0.26	0.01
	1-2	3	0	0.30	0.15
Case 2 (dry year)	0-0.15	1	0.01	0.26	0.07
	0.15-1	2	0.01	0.10	0.03
	1-2	3	0	0.09	0.17
Case 3 (wet year)	0-0.15	1	0.01	0.85	0.15
	0.15-1	2	0.01	0.50	-0.02
	1-2	3	0	0.60	0.13

Notes: *V1: Fraction of total inventory volatilized per year

†L1: Fraction of water-extractable inventory leached per year

‡R1: Fraction of immobile inventory remobilized per year

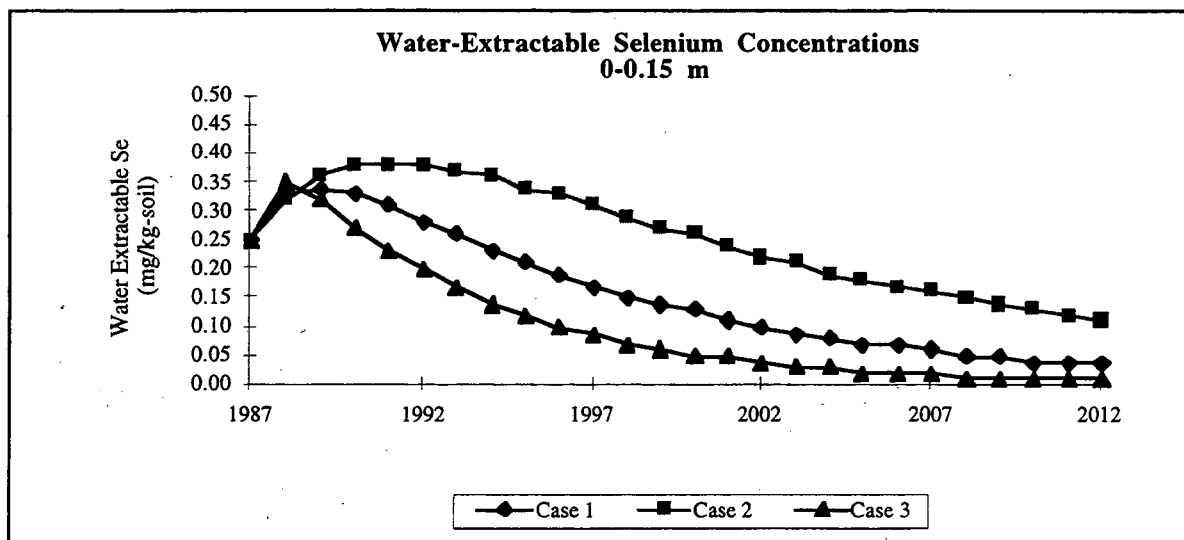


Figure 17. Predicted concentrations of water-extractable selenium in the top 0.15 m of soil at Kesterson Reservoir for the cases listed in Table 8.

Predicted concentrations of water-extractable soil selenium in the 0.15 to 1 m depth interval are shown on Figure 18. In Case 1 and Case 2, water-extractable soil selenium concentrations increased to a maximum concentration and then decreased slightly for the remainder of the 25-year period. After an initial decrease and stabilization, concentrations of water-extractable selenium for Case 3 declined to zero. In Case 1 (average), water-extractable soil selenium concentrations increased to a maximum concentration of 0.09 mg/kg-soil in 1991–1992 and then declined to 0.02 mg/kg-soil in 2012 (a decrease of 77 percent). In Case 2 (dry), water-extractable soil selenium concentrations increased to a maximum concentration of 0.15 mg/kg-soil in 1996–2001 and then decreased to a concentration of 0.10 mg/kg-soil in 2012 (a decrease of 33 percent). In Case 3 (wet), water-extractable soil selenium concentrations peaked in 1987 at 0.09 mg/kg-soil and declined to zero in 1997.

Predicted changes in the water-extractable soil selenium inventory within the top 2 m of soil are shown on Figure 19. In all cases, water-extractable soil selenium inventories show an initial increase followed by decreases over the modeling period. In Case 1 (average), water-extractable soil selenium inventory increased to a maximum of 0.30 g/m² in 1990 and then declined 83 percent to 0.05 g/m². In Case 2 (dry), water-extractable soil selenium inventory increased to a maximum concentration of 0.44 g/m² in 1999–2003 and then declined to 0.40 g/m² (a decrease of 9 percent). In Case 3 (wet), water-extractable soil selenium inventory peaked at 0.24 g/m² in 1988 and 1989 and then declined to near zero values by the year 2000.

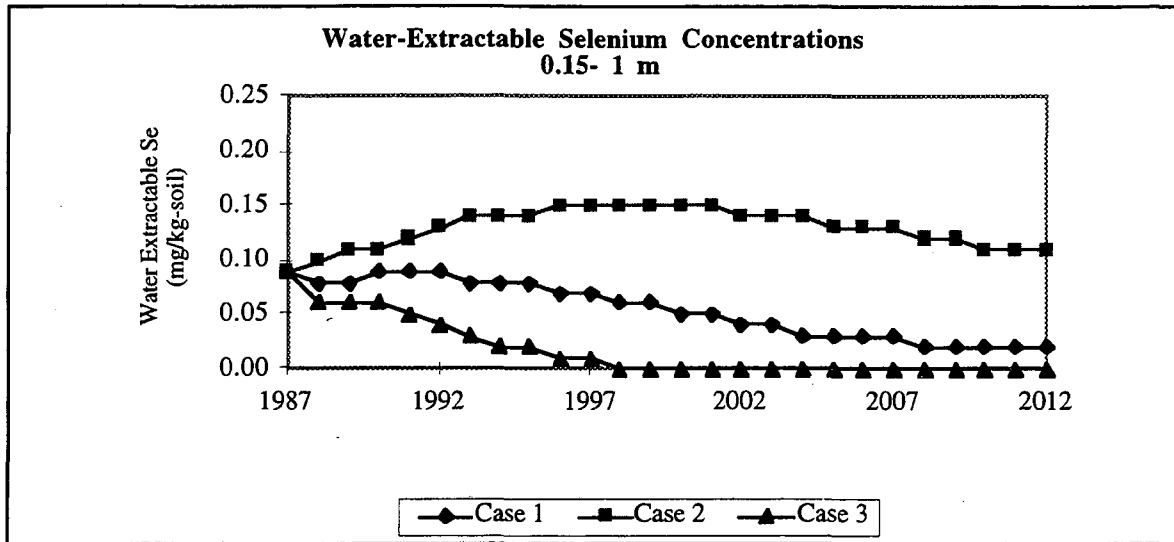


Figure 18. Predicted concentrations of water-extractable selenium in the depth interval from 0.15 to 1 m for the cases listed in Table 8.

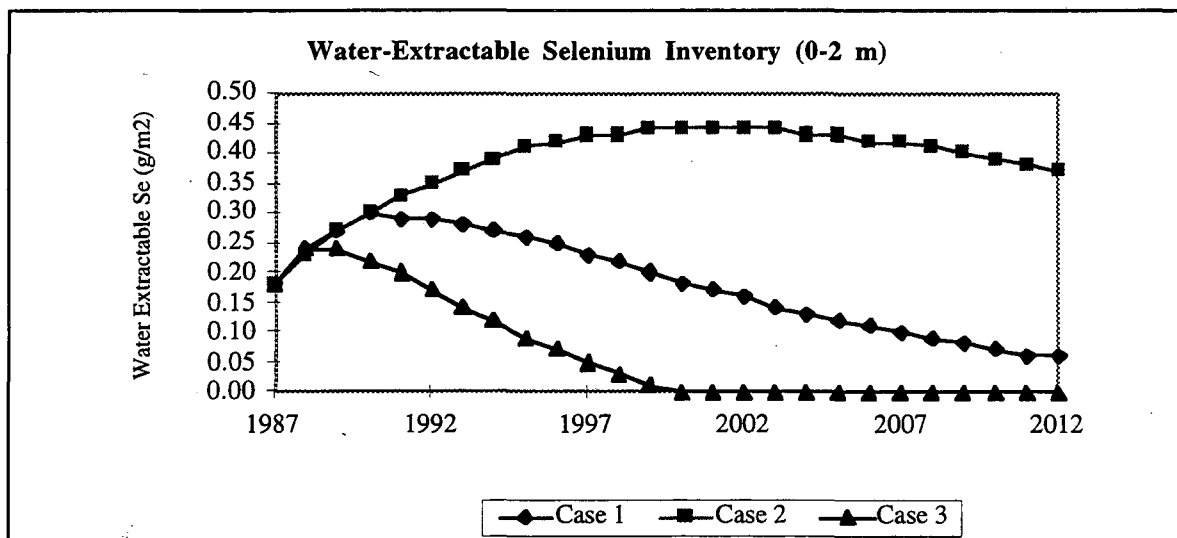


Figure 19. Predicted inventories of water-extractable selenium in the top 2 m of soil at Kesterson Reservoir for the cases listed in Table 8.

8.0 CONCLUSIONS

This paper has described efforts to model and predict the evolution of the water-extractable selenium inventory in the top 2 m of the soil profile at Kesterson Reservoir. Correlations between observed and calculated water-extractable soil selenium concentrations indicate that the major trends and year-to-year variations observed are represented with the model. Results from a series of calibration runs, extrapolated 25 years in the future, were used to predict the evolution and redistribution of selenium within the soil profile under three climatic scenarios. The three scenarios considered are average rainfall conditions as represented by the past 6 years, a sequence of drier than normal years, and a sequence of wetter than average years.

For all three scenarios, water-extractable selenium concentrations are expected to increase initially in the surface soil, but eventually begin to decline. The magnitude of the increase and duration of the period before the decline occurs depends on the specific climatic conditions. Deeper in the profile, water-extractable selenium concentrations are expected to gradually decline for normal and wetter than normal climatic conditions. A sequence of dry years will lead to gradual increases in water-extractable selenium concentrations deeper in the profile.

Based on these simulations, we expect that the availability of selenium has most likely reached peak levels, and is now declining. However, year-to-year climatic variations may influence the rate of decline and occasionally reverse this prevailing trend.

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