UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Total and Extractable Selenium in Soils from the Lake Andes-Wagner Irrigation Area, South Dakota

by

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INTRODUCTION

In September of 1989 the Bureau of Reclamation (BOR) and the U.S. Geological Survey (USGS) entered into a cooperative agreement to study soils associated with the Lake Andes-Wagner (LAW) irrigation project. The LAW project is designed to bring irrigation waters to the Lake Andes area as part of a cooperative agreement between the Bureau of Reclamation and the LAW irrigation group. The study area consists of approximately 45,000 acres composed primarily of glacial till and alluvial soil types (Hedges, 1975). The project would include the installation of subsurface drains spaced between 50 and 200 feet apart. The drains are designed to remove excess ground and irrigation waters from the LAW area and transport them into Lake Andes or Choteau Creek, which both flow into the Missouri River.

Geologic Background

The study area, located in southeastern South Dakota (figure 1.) has bedrock material containing several geologic units, including Precambrian Sioux quartzite; the Dakota Formation; Graneros shale, Greenhorn limestone, Carlile shale, and Codell sandstone (Hedges, 1975).

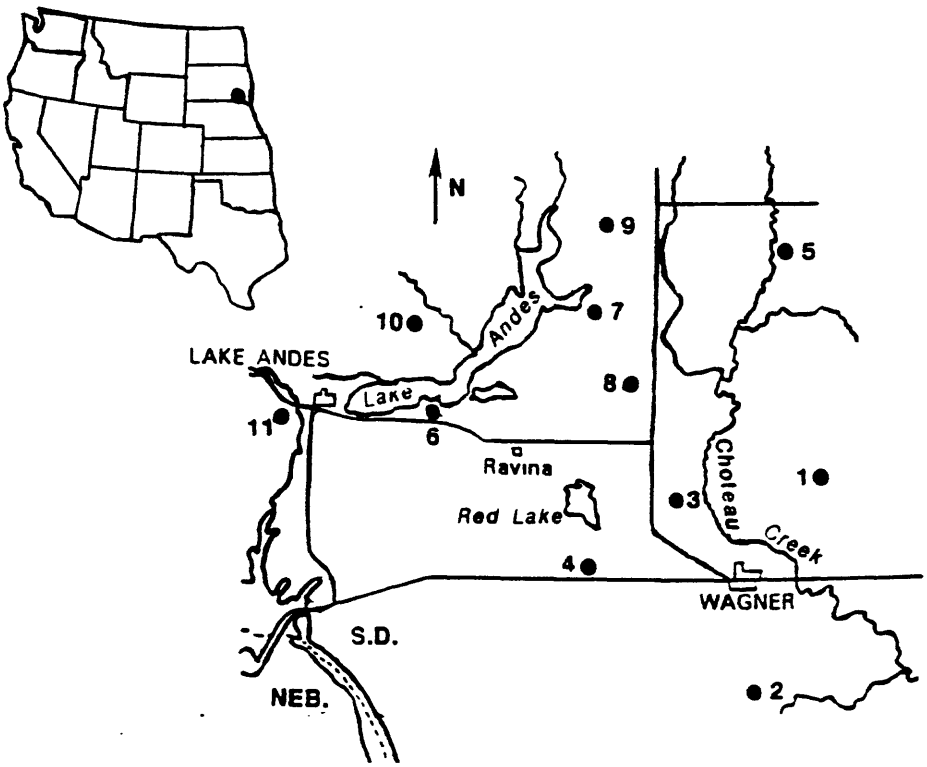

Figure 1. Location of study area and sample collection sites for Lake Andes-Wagner investigations

In addition, there are bedrock areas which include Niobrara Marl, Pierre Shale (Stevenson and Carlson, 1951; Walker, 1963 and, Tourtelot, 1962) and deposits of late Wisconsin age which consist of till, outwash, recent alluvium, colluvium and loess. In the following discussions only the Niobrara Marl and Pierre Shale are relevant to the Lake Andes-Wagner discussion, because they are the two formations which underlie the majority of the study area.

Other geologic deposits identified in the study area include Pleistocene till and outwash terrace deposits, loess of the late Wisconsin to Recent age, and alluvium and colluvium of late Wisconsin to Recent age. The occurrence of selenium is well documented in the Cretaceous bedrock of South Dakota (Pugsley and Cox, 1937; Moxon, and others, 1950; Anderson and others, 1961). It also appears that the soils derived from Pierre Shale, in particular the Mobridge, Sharon Springs, and Virgin Creek soil series may be the principal sources of selenium often found in this area (Pugsley and Cox, 1937). In an extensive soil survey (Moxon and others, 1939) over 500 samples were analyzed, mainly of soils developed from the Niobrara and Pierre formations, and found to have selenium concentrations ranging up to 113 ppm (mean 5.8 ppm). It was suspected that these formations had given rise to seleniferous vegetation in the area.

Previous soil selenium studies

The major areas of interest in this study were, 1) the degree of selenium migration under proposed irrigation conditions, 2) expected selenium concentrations in receiving waters during the initial irrigation period, and 3) the long term impact of selenium on local water systems. Due to lack of information on selenium mobility in terrain similar to LAW, other studies were consulted to see if they could provide some insight to these problems.

The western side of the San Joaquin valley of central California has received a great deal of attention due to problems encountered with the mobilization of selenium from soils under irrigation. Several investigators have examined the processes at work in valley and developed models which explain the mechanisms governing the transport of selenium. Even though the LAW and San Joaquin Valley (SJV) are composed of different geologic formations and soil types, it is believed that the models developed in the SJV studies may be useful in explaining the processes that govern the mobilization of selenium, in the LAW study area. While helpful in explaining the processes at work, the models are not designed to predict the absolute quantities of mobilized selenium in the LAW area.

USGS studies (Fujii,and others, 1982; Deveral and others, 1984; Deveral, Millard, 1986) in the SJV of California have detailed the short and long term effects of irrigation on the mobility of selenium from irrigate lands. Studies done on specially designed field sites in the SJV indicate that a major flux of selenium (Geometric Mean 2800 ppb) entered return flow waters over the first year of drainage. This high selenium flux was followed by a gradual decrease in selenium concentrations over the next 15 years of drainage. At the end of 15 years, average selenium concentrations in drain waters were reduced almost 25 fold (GM = 2800 ppb to 109 ppb). The process of selenium removal from the field over time is illustrated in figure 2 for the 1, 6, and 15 year fields.

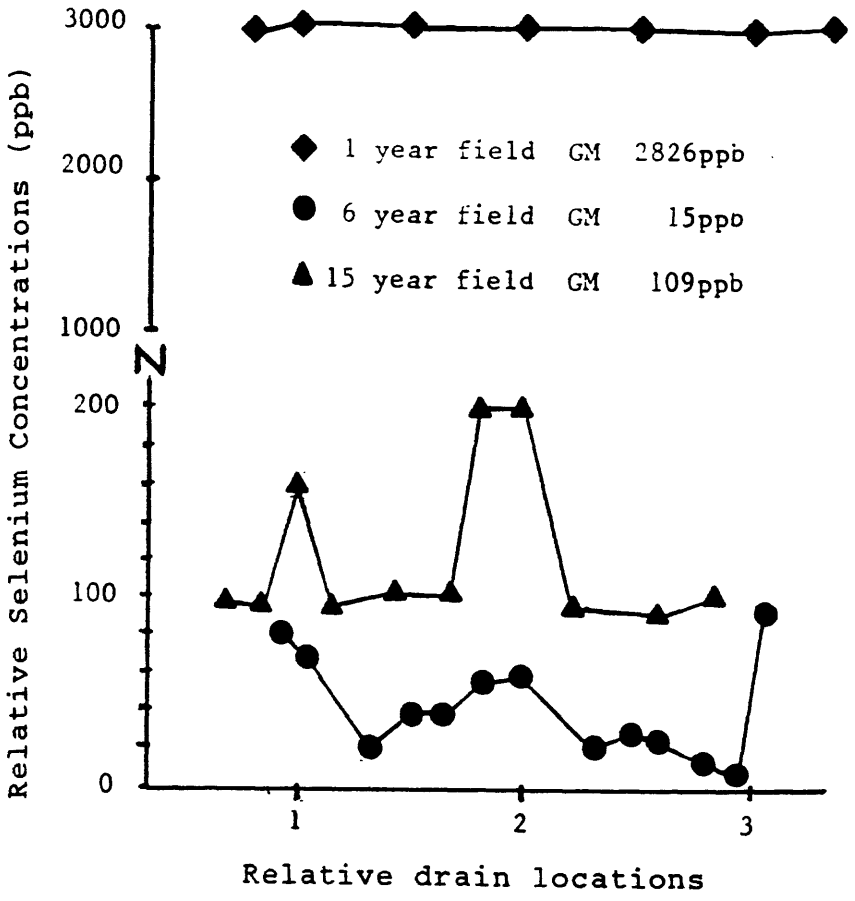

Figure 2 Relation of Selenium concentrations in ground water to drains for 1, 6, and 15 year fields

Figure 2 demonstrates that fields under irrigation for the first year show constant and elevated selenium levels across the study area (GM = 2800 ppb). In subsequent years as selenium deficient irrigation waters are applied to the fields, mobile selenium is displaced towards the drain. This results in lower selenium levels between the drains but persistently high levels at the inlets to the drain.

Additional studies in the San Joaquin Valley examined the time frame under which the hydrologic system responds to change. To evaluate the short and long term impact of surface and groundwater interaction, a series of water samples were collected and analyzed for tritium. The tritium data serves as an indicator of residence time for ground water in the system. These studies are schematically represented in figure 3 (Deveral, and Fujii, 1988)

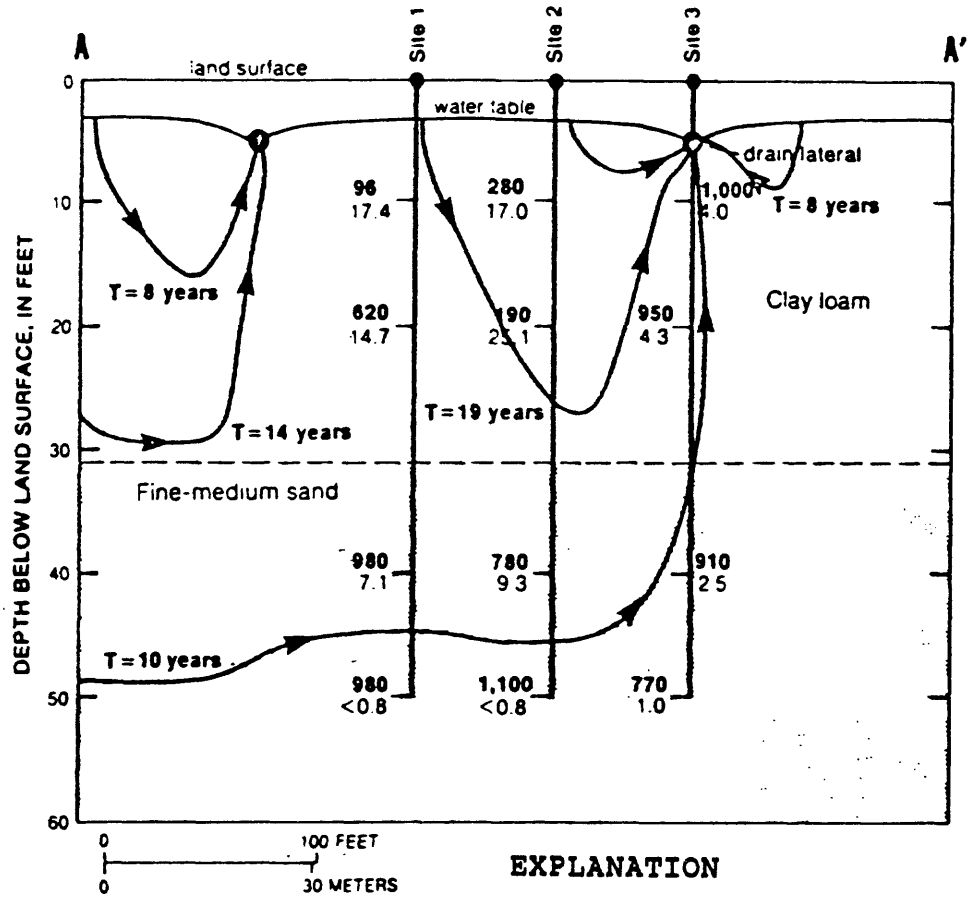

Figure 3 Selenium migration in soils of the San Joaquin Valley

It is apparent that irrigation waters added close to a drain have a residence time in the soil of approximately 8 years. Water added away from the drain, or to soils that are less porous will have longer residence time in the soils. Closer examination of figure 3 also reveals that groundwater originating in the sand or silt layers below the water table may have a shorter residence time than water added to soils above the water table. This shorter residence time is due to the greater permeability of the sand or silt material. The decrease in residence time for these waters may be significant for the LAW study area especially if the sand layer is shallower than that observed in the San Joaquin Valley.

The San Joaquin drainage problem was compounded by the creation of twelve evaporation ponds which were designed to receive drainage waters. These ponds were eventually incorporated into the Kesterson National Wildlife Refuge (KNWR). Under the intensive evaporation conditions occurring in the SJV, selenium and other salts reached elevated concentrations at the KNWR. Studies done at KNWR and the adjacent Volta NWR, (operated using a different water source) had 300 and 1 ppb selenium in receiving waters respectively (Ohlendorf and Hothem, 1989). Bioaccumulation of the elevated aqueous selenium by algae at KNWR allowed selenium to enter the food chain, which had an adverse effect on resident wildlife. Analysis of algae material at KNWR revealed a concentration range of selenium between 12-330 ppm (Ohlendorf, 1986). In submerged rooted aquatic plants (widgeon grass) typically eaten by ducks, selenium concentrations ranged between 18 and 390 ppm (GM = 73 ppm). Finally in adult coot livers average selenium concentrations reached 43ppm (baseline levels 4.4ppm). The situation at KNWR may represent an extreme, but still serves as a measure of how significant selenium contamination can be.

In light of SJV and other studies, water quality standards have evolved to limit the amount of selenium that can be tolerated in different water types Table 1.

Table 1 Water quality standards for selenium in selected water systems

Material	Water Quality Standard
Freshwater Aquatic Life	5 ppb (chronic) 20 ppb (acute)
Irrigation Waters	20 ppb
North Dakota Class I Streams	10 ppb

In a preliminary (1985, BOR Lake Andes-Wagner Environmental Impact Statement) study of LAW soils using a private laboratory, it was determined that project soils contained low total selenium concentrations (avg. 2 ppb). Due to concern about the incongruities with geologic information, the original 11 sites were reexamined in 1989, by drilling new cores to an average depth of eight feet. Core segments were isolated based on specific soil characteristics and representative splits sent to the USGS laboratory for total and water extractable selenium analyses

SAMPLE PREPARATION

Total selenium

Soil samples were received at the laboratory and dried at room temperature for a period of three days. The samples were crushed and a representative split obtained. The split material was then ground to pass 100 mesh. The ground samples (<100 mesh) were placed in a three ounce container and mixed for a minimum of one hour. The samples were then submitted to the laboratory for total element analysis.

Water extractable selenium

Extractable selenium investigations utilized a saturation paste procedure to obtain the water soluble selenium fraction. In the saturation procedure performed by BOR, air dried soil is ground to pass through a 2-mm sieve. The sieved material is added to 800 mL plastic cups filling them two thirds to three fourth full and the weight recorded. Distilled water is added to the soils until the mixture's surface glistens, flows slightly when the cup is tipped, and slide cleanly off the mixing spatula. The beaker is then covered with a watch glass and allowed to sit overnight. The next day an eight inch diameter porcelain buchner funnel equipped with a Whatman #42 filter paper is prepared and the sample transferred. Vacuum is applied to the filtration system and allowed to operate until a minimum of 10 mL of solution is obtained. The aqueous sample is transferred to a disposable plastic container, sealed and stored for analysis. Percent saturation is calculated by weighing a 5 to 10 gram aliquot of saturated material, drying it in an oven over night and reweighing. The weight of the water lost is divided by the dry weight and a percent saturation calculated.

ANALYTICAL TECHNIQUES

Total selenium in soils

Total selenium was determined using Hydride Generation Atomic Absorption Spectroscopy (HG-AAS) (Briggs and Crock, 1986: Crock and Lichte 1982). In this procedure an aliquot (0.2500 g) of sample is placed in a 30 mL teflon bomb and predigested for one hour at room temperature using a 2 mL aliquot of saturated potassium persulfate solution. Following this, the sample is subjected to a rigorous multi-acid digestion using a combination of concentrated nitric, perchloric, sulfuric and hydrofluoric acids. After the digestion is complete the sample is transferred to a 2 ounce polyethylene bottle and diluted to 50 mL (55 g) with 6 M hydrochloric acid and allowed to sit overnight. The 6 M hydrochloric acid assures the conversion of Se(VI) to Se(IV), an important prerequisite to reliable selenium analyses by HGAAS. In the HG-AAS procedure the sample is reacted with 0.1 M sodium borohydride solution, and the hydride gas separated from the aqueous phase using a specially designed phase separator. The hydride gas is passed into a quartz atomization cell positioned in the light path of an atomic absorption spectrometer. Selenium is quantified using a series of external standards, and a linear regression analysis. The RSD for the procedure is approximately 10 %, with a detection limit of 0.1 ppm in sample

Water extractable selenium in soils

The preparation of aqueous samples for hydride analysis starts with a persulfate digestion of the solution. In this digestion 10 mL of sample is transferred to a 30 mL teflon bomb. A 1 mL aliquot of a saturated potassium persulfate solution is added, the teflon bomb covered with a watch glass and allowed to sit for one hour at room temperature. At the end of an hour a 1 mL aliquot of concentrated hydrochloric acid is added and the bomb heated for one hour at 110 C. After this heating interval, the bomb is uncovered and heated until the volume is reduced to approximately 5 mL. Two milliliters of concentrated hydrochloric acid are then added, the bomb covered and the solution heated for an additional hour. Following this the solution is transferred to a two ounce polyethylene bottle and brought to a final mass of 20 g with deionized water.

RESULTS AND DISCUSSION

Total selenium in soils

Total selenium data for soils from the eleven collection sites is presented in Appendix A. Selenium concentrations in soil ranged between 100 and 3,100 ppb, with an average value of 930 ppb. To determine if an areal pattern of elevated selenium concentrations existed, each site was examined for its average selenium concentration. Results are seen in table 2.

Table 2 Average total selenium concentrations by site at the Lake Andes-Wagner study area

Conc. Range (ppb)	+1500	1500-750	750-500	<500
Site No.	1,8	6,7,11	3,9,5,2	10,4

There is a continuous distribution of average selenium concentrations across the study area. The concentration range with the greatest number of data points (7) is between 500 and 1,500 ppb selenium. Closer examination of table 2 and figure 1 shows that no spatial pattern is apparent when one compares the distribution of selenium concentrations versus site locations. This suggests that the sampling was not sufficient to describe the hetrogeniety of selenium distribution in the soil and therefore a map of selenium would require more sampling.

Total selenium concentration was examined with respect to average sample collection depth (figure 4). Regression analysis reveals a very weak correlation ($r = 0.2$) between depth and total selenium concentration when all the data are considered. There are selected sites however (1 and 8), where the vertical profile demonstrates a definite increase in total selenium concentration with depth (figure 5). At these sites, the higher selenium concentrations with depth may be due to the presence of selenium source material (shale), the intrusion of selenium containing ground water, or the leaching of selenium from soils above. It should also be pointed out, that these two sites are not close together, reinforcing the speculation that there is no center of elevated selenium levels.

A comparison of total selenium concentrations in soils for three selected studies from across the western United States is presented in table 3. The data are from previous U.S. Geological Survey investigations in California, North Dakota, and Wyoming. The data in Table 3 show that the average concentration of

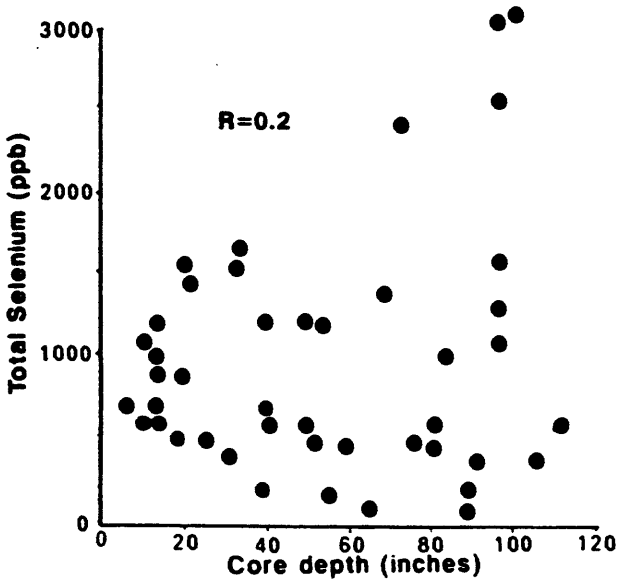

Figure 4 Total selenium concentrations in soils versus collection depth for Lake Andes Wagner study

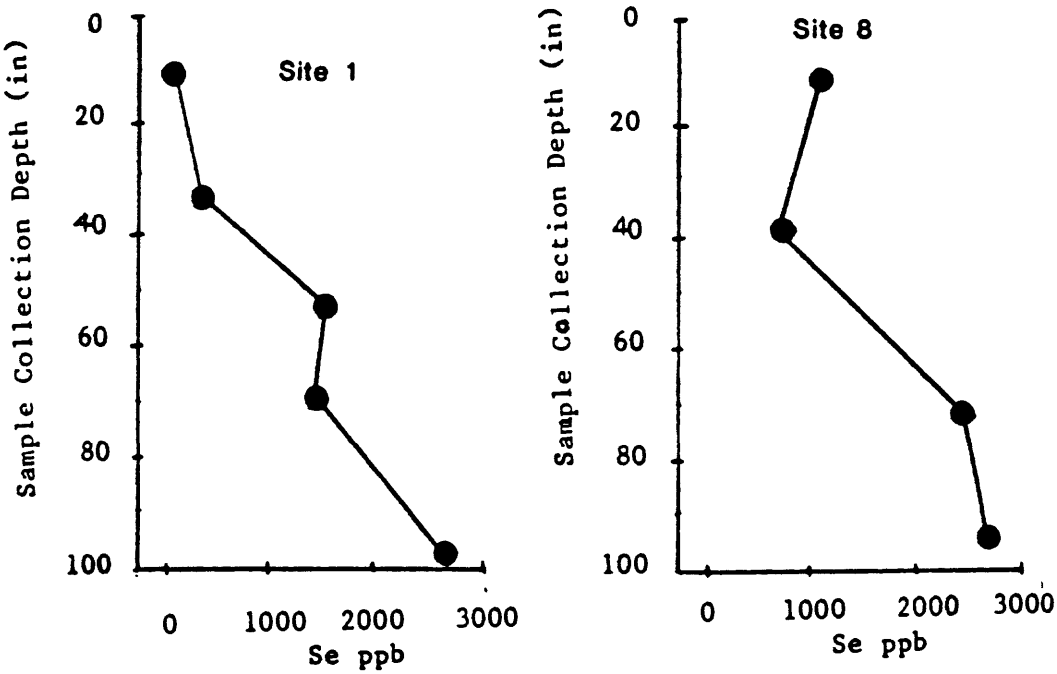

Figure 5 Total selenium concentration versus depth for sites 1 and 8, Lake Andes-Wagner study

Table 3 Total Selenium Concentrations in Soils From Selected Studies in the western United States

Location	Min. Se Content ppb	Max. Se Content ppb	Avg. Se Content* ppb	Reference
San Joaquin Valley, Ca.	<100	2800	240	Wilson and others 1989
Panoche Fan Ca.	<100	4500	820	Ryder, and others 1989
Oakes Irrig. Area, N.D.	<100	2100	130	Goolsby and others 1989
Kendrick Wyo.	<100	3800	450	Severson, and others 1989
Lake Andes Wagner S.D.	100	3100	630	This study

* Geometric Mean

selenium in soils from the LAW site falls in a range similar to that found in the San Joaquin Valley of central California, and the Kendrick, Wyoming study area located in north central Wyoming. Both areas have been recognized as having a selenium contamination problem (personal communication) brought on by the movement of soil selenium during irrigation and drainage. In the SJV and Kendrick studies numerous instances of waterfowl death and deformities have been observed.

Water extractable selenium

In order to evaluate the mobility of selenium in the LAW study area, water extraction tests were performed on collected soils. Extractable selenium results are presented in Appendix B along with the percent extractable selenium. Examination of the data reveal that extractable selenium concentrations ranged from <0.6 to 2,600 ppb, with an average (geometric) selenium concentration of 27 ppb. For comparison purposes, results from the LAW study and other USGS investigations are presented in Table 4.

Table 4 Extractable selenium concentrations in soils from selected sites in the western United States

Study Area	Max. ppb	Min. ppb	Mean* ppb	Reference
Oakes, N.D.	0.16	<0.02	0.02	Goolsby and others, 1989
San Joaquin Valley, Ca.	2800	3	60	Deveral and others, 1984
Kendrick** Wy.	2700	<0.02	31	Crock, 1989
Lake Andes Wagner, S.D.	2600	<0.6	27	This Study

* Geometric Mean
** 1:5 (Soil/water) extractions

Levels of water soluble selenium in the LAW study approximate those found in the San Joaquin and Kendrick studies (table 4). It should be pointed out, however, that soil properties and geochemical processes of the San Joaquin, Kendrick and LAW areas may be sufficiently different to preclude direct comparisons. Conditions such as an established water table, geology, surface terrain and permeability of the soil may all have an effect on the mobility of selenium through the soil profile.

Extractable selenium concentrations versus average sample collection depth were examined to see if a relationship existed between these parameters (figure 6). Figure 6, shows a weak correlation ($r = 0.4$) between average sample collection depth and extractable selenium concentrations. There are selected sites however (1, 8, and 7), which demonstrate a strong trend of increasing extractable selenium concentrations with depth (figure 7).

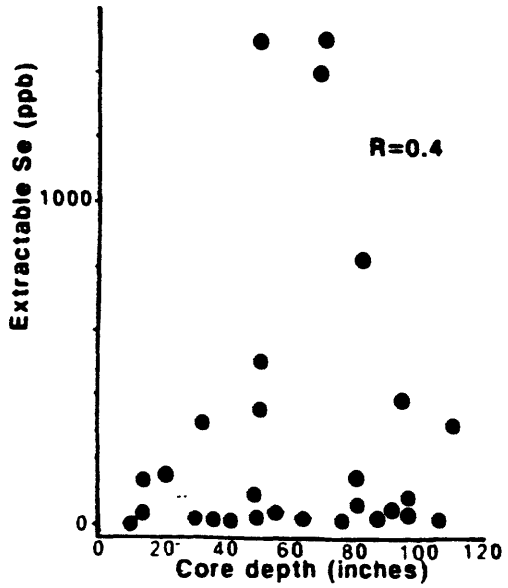

Figure 6 Extractable selenium concentrations in soils versus collection depth for Lake Andes-Wagner study

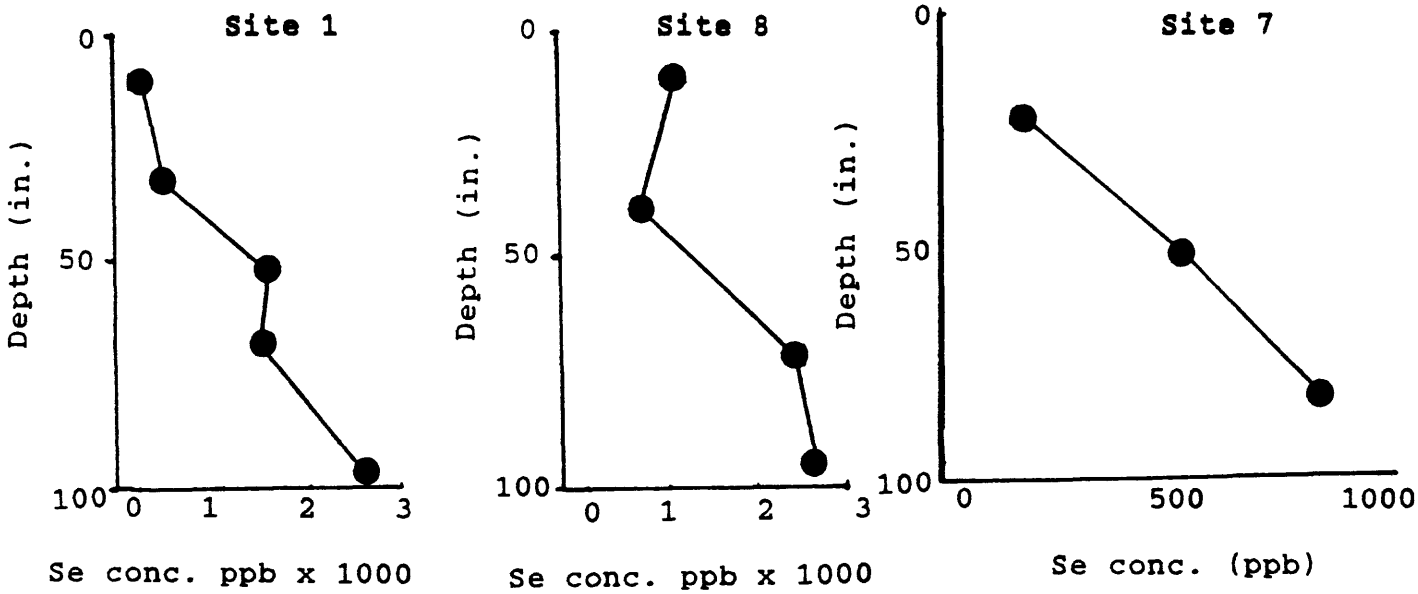

Figure 7 Extractable selenium concentrations versus collection depth for sites 1, 8, and 7 Lake Andes-Wagner study

Percent extractable selenium

Examination of the data in Appendix B reveals that several samples had moderate (20 %) to high (100 %) levels of percent extractable selenium, (average = 20 %) especially in deeper sections of the core. Regression analysis of percent extractable selenium versus average sample collection depth (figure 8) for the entire data set however, resulted in a low correlation coefficient (r = 0.45) for the study area.

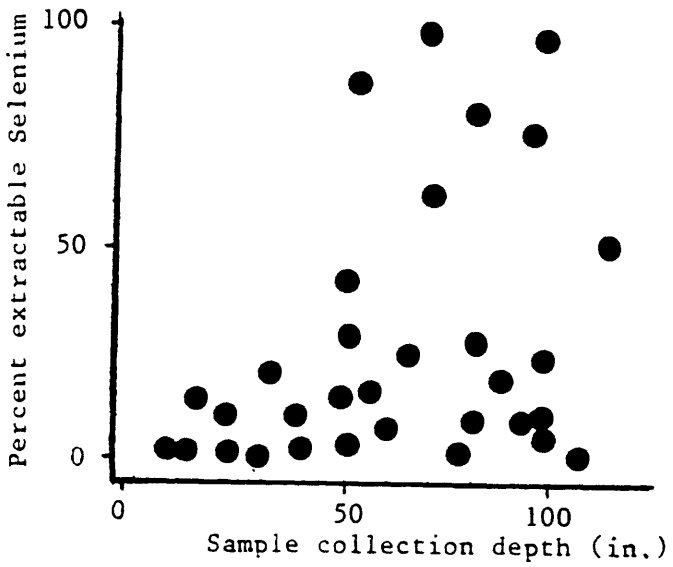

Figure 8 Percent extractable selenium versus core depth for Lake Andes-Wagner study

Analysis of percent extractability versus depth for the four most elevated sites (1, 3, 7, and 8) produced a regression coefficient of 0.75, significantly higher than that seen for the entire data set. The higher levels of percent extractable selenium at deeper core depths for these sites may reflect the presence of shales containing selenium, the intrusion of high selenium ground waters, or the migration of soluble selenium from surface soils. In addition, the elevated levels of percent extractable selenium indicate that the dominate form of selenium

in the LAW system is probably selenate. Based on earlier studies, selenate is the most mobile of all the selenium species. It is also the form of selenium which can be most readily incorporated into the food chain by algae or plants. In light of these observations it is likely that selenium will migrate under irrigation conditions scheduled for the LAW area. Uncertainties at this time are: 1) the magnitude of this mobilization, 2) the impact of selenium on the local environment, and 3) the rate of this migration.

A final comparison was made between total and extractable selenium concentrations. Regression analysis of total versus extractable selenium data produces a correlation coefficient of 0.86 (figure 9). This strong correlation was most evident at selenium concentrations above 300 ppb.

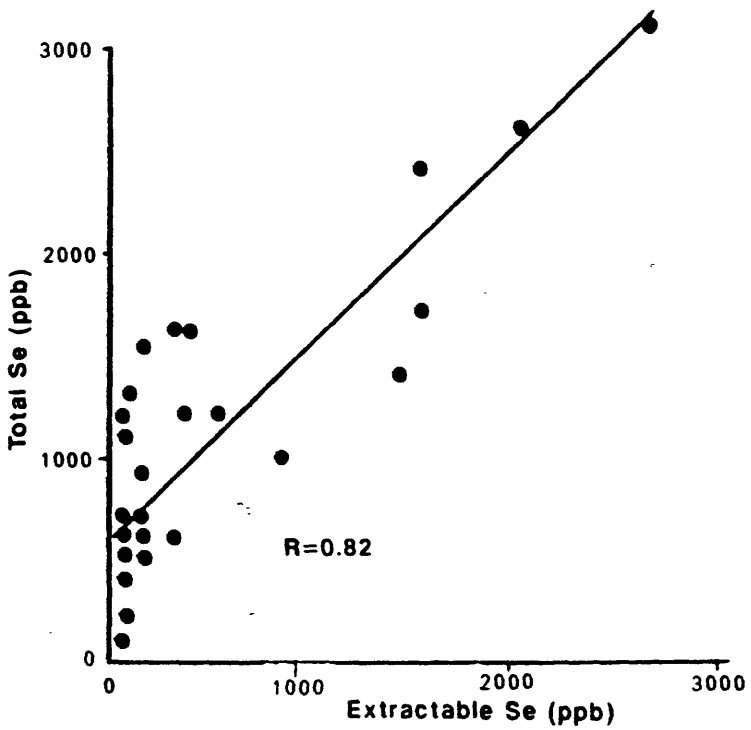

Figure 9 Total versus extractable selenium in soils from Lake Andes-Wagner study

Quality Control Data

Several duplicates and soil standards were included in the samples analyzed to monitor the quality of the data being produced. Table 5 outlines the results of these analyses. The maximum relative standard deviation for the soil duplicates analyzed in the study was 9% (rsd). Replicate analyses of water and soil reference materials produced relative standard deviations of 8% and <1% respectively. These results fall within established laboratory guidelines.

Table 5 Analysis of replicates and standards for Lake Andes-Wagner study

	Total Se ppb		Water Extractable Se ppb	
Sample I.D.	Analysis #1	Analysis #2	Analysis #1	Analysis #2
LAW 1	1200	1100		
LAW 7	600	500	<0.6	<0.1
LAW 14	500	600		
LAW 37	200	200		
LAW 40	1200	1200		
USGS Soil Standard*	1000	1000		
USGS Water Standard**	11	13		

* In-house standard determined value 1000 ppb

** WRD Reference standard 81 certified value (Long,K., 1989) 12 ppb

Summary

The geology of the LAW area suggests that there should be formations containing low to moderate levels of total selenium. Examination of eleven test sites for total selenium reveal an average concentration of 930 ppb (Geometric Mean). Similar concentrations have been observed in the San Joaquin Valley of central California (GM = 680 ppb), and Kendrick Wyoming (GM = 370 ppb). Extractable selenium concentrations in the LAW study (GM = 52

ppb) also approximate those seen in the San Joaquin Valley (GM = 60 ppb). Indications are that under irrigation conditions selenium will be mobilized.

At this time it is not possible to estimate the total amount of selenium that will be mobilized, because information is not available on the selenium concentration in ground water, the permeability of the soils in the area, or the distribution pattern of selenium in the study area. It is apparent, however that because of the similarities between LAW, Kendrick and SJV studies, the potential is there for significant mobilization of selenium at LAW under irrigation conditions. Data on selenium transport processes through glacial till in the north central United States is lacking.

The LAW area could serve as a field laboratory to provide information on irrigation and drainage effects on selenium mobility. Selenium mobilization and transport models developed for the LAW area might then be applied to other potentially irrigable areas in glacial till soils.

REFERENCES

Anderson, M.S. Lakin, H.W. Beeson, K.C., Smith, F.F., and Thacker, E., 1961, Selenium in agriculture: U.S. Department of Agriculture Handbook no. 200, p. 1-64

Briggs, P.H. and Crock, J.G., 1986, Automated determination of total selenium in rocks, soils and plants: U.S. Geological Survey Open-file report 86-40, p. 1-20

Crock, J.G. and Lichte, F.E., 1982, An improved method for the determination of trace levels of arsenic and antimony in geologic materials by automated hydride generation atomic absorption spectroscopy: Analytica Chimica Acta, v. 144, p. 223-233

Crock, J.C., 1989, Extractable selenium from soil samples in the Kendrick Wyoming study area, Personal communication.

Deveral, S.J., Gilliom, Fujii, R., Izbicki, J.A., and Fields, J.C., 1984, Areal distribution of selenium and other inorganic constituents in shallow ground water of the San Luis Drain Service Area, San Joaquin Valley, California: A preliminary study, U.S.G.S. Water Resources Investigative Report, 84-4319, p. 1-66.

Deveral, S.J. and Fujii, R., 1988, Processes affecting the Distribution of Selenium in Shallow Groundwater of Agricultural Areas, Western San Joaquin Valley, California, Water Resources Research, 24, p. 516-524.

Deveral, S.J. Millard, S.P., 1986, Distribution and mobility of selenium and other trace elements in shallow ground water of the western San Joaquin Valley, California, U.S.G.S. Open File Report 86-538, p. 697-702.

Fujii, R., Deveral, S.J., and Hatfield, D.B., 1982, Distribution of selenium in soils of agricultural fields western San Joaquin Valley, California, U.S.G.S. Open File Report, 87-467, p. 1274-1283

Goolsby, D. A. Severson, R.C., Wilson, S.A., and Webber, K., 1989, Geochemistry of soils and shallow groundwater, with emphasis on arsenic and selenium, in part of the Garrison Diversion Unit, North Dakota, 1985-87, Water Resources Investigation Report 89-4104, 132 p.

Hedges, L.S., 1975, Geology and water resources of Charles Mix and Douglas Counties, South Dakota; Part I, Geology: South Dakota Geological Survey Bulletin 22, p. 1-43.

Lake Andes-Wagner unit planning report/final environmental statement, 1985, Bureau of Reclamation Upper Missouri Region Department of the Interior, 254 p.

Long, K., U.S. Geological Survey Water Resources Division Bureau of Quality Control, Certificate of Analysis.

Moxon, A.L., Olson, O.E. and Searight, W., W., 1950, Selenium in rocks soil and plants: Brookings, South Dakota, South Dakota State College of Agriculture and Mechanical Arts, Agricultural Experiment Station Technical Bulletin no. 2 (Revised May 1950), 32 p.

Moxon, A.L., Olson, O.E., Seawright, W.V. and Sandals, K.M., 1939, The stratigraphic distribution of selenium in the Cretaceous formations of South Dakota and the selenium content of some associated vegetation: American Journal of Botany, vol. 25, p. 794-809

Ohlendorf, H.M., 1986, Bioaccumulation and effects of selenium in wildlife, In, Jacobs, L.W., and others (eds.) Selenium in agriculture and the environment Soil Science Society of America, Special Publication #23, Madison Wi., p. 133-178.

Ohlendorf, H.M., and Hothem, R.L., 1989, Aquatic Birds and Selenium in the San Joaquin Valley and San Francisco Bay; In, Howard, A.Q., Selenium and Agricultural Drainage: Implications for San Francisco Bay and the California Environment, Proceedings Of The Third Selenium Symposium, Berkeley Ca., 1986, p. 21-33

Puglsley, C.W., and Cox, T.H., 1937, Selenium problems in South Dakota: Published by Central Office, South Dakota State Planning Board p. 1-30.

Ryder, J.L., Briggs, P.H., Gent, C.A., Kennedy,K.R., Severson, R.C., Tidball, R.R., and Wilson, S.A., 1989, Analysis of 721 soil samples from the Panoche Fan area of the San Joaquin Valley, California, U.S. Geological Survey Open File Report 89-298, p. 1-81.

Severson, R.C., Crock, J.G., Erdman, J.A., 1989, Lateral and depth variability in chemical composition of soil at the Kendrick Reclamation Project Area, Wyoming, U.S. Geological Survey Open File Report 89-470, p. 1-27.

Stevenson, R.E., and Carlson, L.A., 1951, Geology of the Lake Andes quadrangle, South Dakota: South Dakota Geological Survey map.

Tourtelot, H.A., 1962, Preliminary investigation of the geologic setting and chemical composition of the Pierre Shale Great Plains region, U.S. Geological Survey, Professional paper 390, p. 1-74.

Walker, I.R., 1963, Geology and ground water resources of the Wagner quadrangle, South Dakota: Unpublished M.A. thesis, State University of South Dakota, p. 1-225

Wilson, S.A., Kennedy, K.R., Gent, V.A., Briggs, P.H., Tidball, R.R., and McNeal, J.M., 1989, Analysis of soil samples from the San Joaquin Valley of California, U.S.G.S. Open File Report (in progress)

Appendix A Total, selenium in soils from the Lake Andes-Wagner study area

Site No.	Field I.D.	Site Location Lat.	Site Location Long.	Collection interval inches	Avg. Depth of Collection inches	Total Se ppb
1	LAW 1	43 08' 08"	98 13' 58"	0 - 20	10	1200
	LAW 2	" "	" "	23 - 42	32	1600
	LAW 3	" "	" "	43 - 61	52	1700
	LAW 4	" "	" "	61 - 75	68	1400
	LAW 5	" "	" "	75 - 120	98	3100
2	LAW 6	43 01' 58"	98 16' 18"	0 - 23	12	700
	LAW 7	" "	" "	23 - 55	39	600
	LAW 8	" "	" "	55 - 120	88	200
3	LAW 9	43 06' 51"	98 19' 56"	0 - 35	17	900
	LAW 10	" "	" "	36 - 60	48	600
	LAW 11	" "	" "	61 - 98	78	500
	LAW 12	" "	" "	99 - 120	110	600
4	LAW 13	43 05' 14"	98 23' 07"	0 - 34	17	500
	LAW 14	" "	" "	35 - 66	51	500
	LAW 15	" "	" "	67 - 106	86	100
5	LAW 16	43 13' 28"	98 16' 16"	0 - 22	11	600
	LAW 17	" "	" "	23 - 54	38	200
	LAW 18	" "	" "	55 - 72	64	100
	LAW 19	" "	" "	73 - 86	80	600
	LAW 20	" "	" "	87 - 104	96	1300
6	LAW 21	43 08' 57"	98 28' 05"	0 - 27	14	900
	LAW 22	" "	" "	28 - 72	50	1200
	LAW 23	" "	" "	73 - 120	96	1600
7	LAW 24	43 11' 48"	98 23' 17"	0 - 39	20	1500
	LAW 25	" "	" "	40 - 60	50	1200
	LAW 26	" "	" "	61 - 104	82	1000
8	LAW 27	43 09' 56"	98 21' 34"	0 - 20	10	1100
	LAW 28	" "	" "	21 - 56	38	700
	LAW 29	" "	" "	57 - 84	70	2400
	LAW 30	" "	" "	85 - 102	94	2600

Appendix A (cont.)

Site No.	Field I.D.	Site Location Lat.	Site Location Long.	Collection Interval inches	Average Depth of Collection inches	Total Se ppb
9	LAW 31	43 13' 54"	98 22' 16"	0 - 25	12	600
	LAW 32	" "	" "	26 - 34	30	400
	LAW 33	" "	" "	35 - 80	58	500
	LAW 34	" "	" "	81 - 110	96	1100
10	LAW 35	43 11' 14"	98 29' 15"	0 - 10	5	700
	LAW 36	" "	" "	11 - 38	25	500
	LAW 37	" "	" "	39 - 68	54	200
	LAW 38	" "	" "	69 - 113	91	400
11	LAW 39	43 09' 10"	98 33' 39"	0 - 21	10	1000
	LAW 40	" "	" "	22 - 53	38	1200
	LAW 41	" "	" "	54 - 96	75	500
	LAW 42	" "	" "	97 - 113	105	400
	LAW 43	" "	" "	22 - 53	38	1200

Appendix B Total extractable, and percent extractable selenium in soils from Lake Andes-Wagner study area

Site No.	Field I.D.	Site Location Lat.	Site Location Long.	Depth of Collection inches	Percent Saturation	Extractable Se (ppb)	Percent Extractable
1	LAW 1	43 08' 08"	98 13' 58"	0 - 20	56.3	10	0.83
	LAW 2	" "	" "	23 - 42	63.7	320	20
	LAW 3	" "	" "	43 - 61	67.4	1500	88
	LAW 4	" "	" "	61 - 75	39.9	1400	100
	LAW 5	" "	" "	75 - 120	60.0	2600	100
2	LAW 6	43 01' 58"	98 16' 18"	0 - 23	61.0	5.6	0.6
	LAW 7	" "	" "	23 - 55	65.2	10	1.7
	LAW 8	" "	" "	55 - 120	59.2	2.5	1.2
3	LAW 9	43 06' 51"	98 19' 56"	0 - 35	61.6	5.2	0.6
	LAW 10	" "	" "	36 - 60	58.6	88	15
	LAW 11	" "	" "	61 - 98	66.0	140	28
	LAW 12	" "	" "	99 - 120	59.9	300	50
4	LAW 13	43 05' 14"	98 23' 07"	0 - 34	66.0	<1	<0.2
	LAW 14	" "	" "	35 - 66	72.8	18	3.6
	LAW 15	" "	" "	67 - 106	60.9	19	19
5	LAW 16	43 13' 28"	98 16' 16"	0 - 22	58.4	5.8	0.97
	LAW 17	" "	" "	23 - 54	80.6	16	8
	LAW 18	" "	" "	55 - 72	54.2	24	24
	LAW 19	" "	" "	73 - 86	40.3	56	9.3
	LAW 20	" "	" "	87 - 104	29.6	86	6.6
6	LAW 21	43 08' 57"	98 28' 05"	0 - 27	59.2	130	14
	LAW 22	" "	" "	28 - 72	60.2	350	29
	LAW 23	" "	" "	73 - 120	70.5	380	24
7	LAW 24	43 11' 48"	98 23' 17"	0 - 39	64.3	150	10
	LAW 25	" "	" "	40 - 60	64.9	510	43
	LAW 26	" "	" "	61 - 104	48.5	820	82
8	LAW 27	43 09' 56"	98 21' 34"	0 - 20	57.5	13	1.2
	LAW 28	" "	" "	21 - 56	59.3	29	4.1
	LAW 29	" "	" "	57 - 84	62.7	1500	62
	LAW 30	" "	" "	85 - 102	50.9	2000	77

Appendix B (cont.)

Site No.	Field I.D.	Site Location Lat.	Site Location Long.	Depth of Collection inches	Percent Saturation	Extractable Se (ppb)	Percent Extractable
9	LAW 31	43 13' 54"	98 22' 16"	0 - 25	54.1	4.4	0.73
	LAW 32	" "	" "	26 - 34	60.8	6.1	1.5
	LAW 33	" "	" "	35 - 80	59.1	30	6.0
	LAW 34	" "	" "	81 - 110	59.0	33	12
10	LAW 35	43 11' 14"	98 29' 15"	0 - 10	57.4	1.0	0.14
	LAW 36	" "	" "	11 - 38	64.6	<0.6	<0.1
	LAW 37	" "	" "	39 - 68	61.8	30	15
	LAW 38	" "	" "	69 - 113	53.0	36	9
11	LAW 39	43 09' 10"	98 33' 39"	0 - 21	63.1	0.8	0.8
	LAW 40	" "	" "	22 - 53	69.1	<0.6	<0.05
	LAW 41	" "	" "	54 - 96	45.8	0.8	0.16
	LAW 42	" "	" "	97 - 113	33.5	0.5	0.13
	LAW 43	" "	" "	22 - 53	65.0	<0.6	<0.05