GEOCHEMISTRY OF SOILS AND SHALLOW GROUND WATER, WITH EMPHASIS ON ARSENIC AND SELENIUM, IN PART OF THE GARRISON DIVERSION UNIT, NORTH DAKOTA, 1985-87

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CONTENTS

CONTENTS, Continued

ILLUSTRATIONS

ILLUSTRATIONS, Continued

TABLES

TABLES, Continued

Page

TABLES, Continued

CONVERSION FACTORS

For those readers who may prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms used in this report are given below:

Multiply inch-pound unit	By	To obtain metric unit
Acre	0.4047	hectare (ha)
Acre-foot (acre-ft)	1,233	cubic meter (m^3)
Acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
Acre-foot per acre per year [(acre-ft/acre)/yr]	3,047	cubic meter per hectare per year [(m^3/ha)/yr]
Cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Foot (ft)	0.3048	meter (m)
Foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Inch (in.)	25.4	millimeter (mm)
	25,400	micrometer (µm)
Mile (mi)	1.609	kilometer (km)
Ounce, avoirdupois (oz)	28.35	gram (g)
Ounce, fluid (fl. oz)	29.57	milliliter (mL)
	0.02957	liter (L)
Square mile (mi^2)	2.590	square kilometer (km^2)
Ton, short	0.9072	ton, metric

To convert degrees Celsius (°C) to degrees Fahrenheit (°F), use the following formula: °F = 9/5(°C)+32.

Microsiemens per centimeter at 25 degrees Celsius (µS/cm) replaces micromhos per centimeter at 25 degrees Celsius used for specific conductance in older reports. The two units are equivalent.

Milligrams per kilogram (mg/kg) is a unit expressing the concentration of a chemical constituent in solid material as weight (milligrams) of a chemical constituent per weight (kilogram) of dry solid material; 1 mg/kg is approximately equal to 1 part per million (ppm).

Micrograms per liter (µg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (micrograms) of solute per unit volume (liter) of water.

Milligrams per liter (mg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water; 1 mg/L equals 1,000 micrograms per liter (µg/L).

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ABSTRACT

*The Garrison Diversion Unit is being constructed to transfer water from the Missouri River (Lake Sakakawea) to areas in east-central and southeastern North Dakota for expanded irrigation of agricultural lands. During initial investigations of irrigation return flows in 1969-76, the potential effects of toxic elements were considered, and the U.S. Bureau of Reclamation concluded these elements would have no adverse effects on streams receiving return flows. After the development of problems associated with selenium in irrigation return flows in the western San Joaquin Valley, Calif., in 1985, the U.S. Bureau of Reclamation initiated additional studies, including an investigation conducted in cooperation with the U.S. Geological Survey, to assist in collecting and evaluating trace-element data. Also, in 1986, with the passage of the Garrison Diversion Unit Reformulation Act, Congress mandated that soil surveys be conducted to determine if there are "*** soil characteristics which might result in toxic or hazardous irrigation return flows."*

In order to address this issue, an investigation was conducted during 1985-87 by the U.S. Geological Survey in cooperation with the U.S. Bureau of Reclamation to determine the occurrence and distribution of arsenic, selenium, and other trace elements in the soils of six potential irrigation areas along the Garrison Diversion Unit route and in the James River basin. A total of 165 soil samples were collected and analyzed for total concentrations of as many as 42 elements, including arsenic and selenium. In addition, 81 of the samples were analyzed for water-extractable concentrations of 14 elements, including arsenic and selenium, to aid in determining the extent to which they might be mobilized by the irrigation water. In a detailed phase of the investigation, 376 water samples were collected in one of the six potential irrigation areas, the west Oakes irrigation area. Most of these samples were analyzed for arsenic, selenium, and as many as 28 other elements.

Results of the investigation indicate that soils in the potential irrigation areas contain small concentrations of arsenic, selenium, and other trace elements. The geometric mean concentrations of total arsenic and selenium were 4.15 and 0.13 milligrams per kilogram, respectively, which *are considerably smaller than those measured in the western San Joaquin Valley, Calif., and soils from other areas in the western United States. Water-extractable concentrations of arsenic and selenium, determined on 1:5 soil to water extractions, generally were less than 10 percent of the total concentrations. The geometric mean water-extractable concentrations for both elements were 0.02 milligram per kilogram or less.*

The median and maximum concentrations of all constituents and properties indicative of irrigation drainage were tens to hundreds of times smaller in the Oakes test area drains than in western San Joaquin Valley drains. The maximum arsenic concentration in ground-water samples was 44 micrograms per liter, and the median concentration was 4 micrograms per liter. The maximum concentration in drain samples was 11 micrograms per liter, and the median concentration was 3 micrograms per liter.

Only 22 percent of the water samples collected from wells in the Oakes test area contained detectable concentrations (1 microgram per liter or more) of selenium. However, selenium was detected in 63 percent of the samples collected from sites on drains. The greater incidence of detection of selenium in the drain samples is interpreted as an effect of the more oxidizing environment of the drains, which are about 8 feet below land surface near the top of the water table. The median selenium concentration in the drain samples, however, was only 1 microgram per liter, and the maximum concentration in 63 drain samples was 4 micrograms per liter. For comparison, the median selenium concentrations reported for drains in the western San Joaquin Valley, Calif., ranged from 84 to 320 micrograms per liter. Water from two observation wells had the largest selenium concentrations (8 and 9 micrograms per liter) measured during the investigation. These were the only two samples that exceeded any of the water-quality regulations, standards, or criteria for selenium.

Mercury and boron were the only other trace elements that exceeded standards and criteria. The median concentration of mercury was less than 0.1 microgram per liter, and the maximum concentration was 0.8 microgram per liter. The chronic freshwater-aquatic-life criterion for mercury (0.012 microgram per liter) is about 10 times less than the laboratory detection limit and is derived from bioconcentration factors based on methylmercury. Two boron samples exceeded the irrigation criteria of 750 micrograms per liter. Comparisons with criteria and standards indicate that the concentrations of trace elements determined in samples from wells and drains in the Oakes test area during this investigation should not adversely affect human and aquatic life or irrigated crops.

The data collected indicate that the soils and ground water in the Garrison Diversion Unit contain small concentrations of trace elements, including arsenic and selenium. Based on a detailed study of soils and ground water in the west Oakes irrigation area, however, there is no evidence that expanded irrigation will mobilize these elements in concentrations large enough to adversely affect aquatic life in the James River ecosystem, based on current regulations, standards, and criteria. Data are not currently available to make definitive statements about selenium concentrations in ground water in Garrison Diversion Unit irrigation areas other than the west

Oakes irrigation area. Data available on total and water-extractable selenium concentrations in soils, however, indicate that concentrations in ground water would be similar to those determined in the west Oakes irrigation area. Plans have been developed to sample ground water in the additional areas.

INTRODUCTION

The Garrison Diversion Unit (GDU) in North Dakota (fig. 1) is part of the Pick-Sloan Missouri River Basin program. The purpose of the GDU project, referred to as GDU in this report, is to divert water from the Missouri River (Lake Sakakawea) to areas in east-central and southeastern North Dakota for irrigation, recreation, fish and wildlife, municipal, rural, and industrial uses. The GDU was authorized by Congress in 1944 (Public Law 78-534) and reauthorized in 1965 (Public Law 89-108). In 1984, Congress passed legislation (Public Law 98-360, Section 207) that recognized that the GDU, as authorized, raised significant issues of environmental, economic, and international concern. A special Garrison Commission was formed as a result of the 1984 legislation to review and evaluate these concerns and to make recommendations to Congress for the future development of the project. The Commission's recommendations were presented in a final report dated December 20, 1984, and were implemented in the GDU Reformulation Act (Public Law 99-294) in May 1986. One of the Commission's recommendations requires surveys of irrigation lands to "*** include an investigation of soil characteristics which might result in toxic or hazardous irrigation return flows."

Recent studies in the western United States have focused on important environmental problems associated with irrigating arid and semiarid lands underlain by soils that originated from sediments deposited in a marine environment (Gilliom and others, 1989). The natural accumulation of potentially toxic elements in the sedimentary rocks makes these lands important remobilization sources for trace elements such as selenium. Results of earlier investigations in the western San Joaquin Valley of California have demonstrated that under intensive irrigation, trace quantities of selenium have been mobilized, transported, and concentrated. This can create a major environmental problem. Changes in environmental conditions, such as those accompanying irrigation in the Garrison Diversion Unit, could result in increased concentrations or remobilization of potentially toxic elements. This in turn could limit water and soil uses and affect the ecological system dependent on the water resource.

Reconnaissance evaluations by the U.S. Department of the Interior's Irrigation Drainage Task Force indicated the probability of such effects at the Kesterson National Wildlife Refuge in the San Joaquin Valley of California (Presser and Ohlendorf, 1987), the Tulare Lake Bed area in California (Schroeder and others, 1988a), the Salton Sea in southern California (Schroeder and others, 1988b), and the Kendrick Irrigation Project in eastern Wyoming (Peterson and others, 1988). At many of these areas, marine shales of Cretaceous age were the original source of trace elements. Concentration of trace elements commonly was achieved through leaching processes, adsorption on fine-grained or organic-rich materials, evapotranspiration, or bioaccumulation.

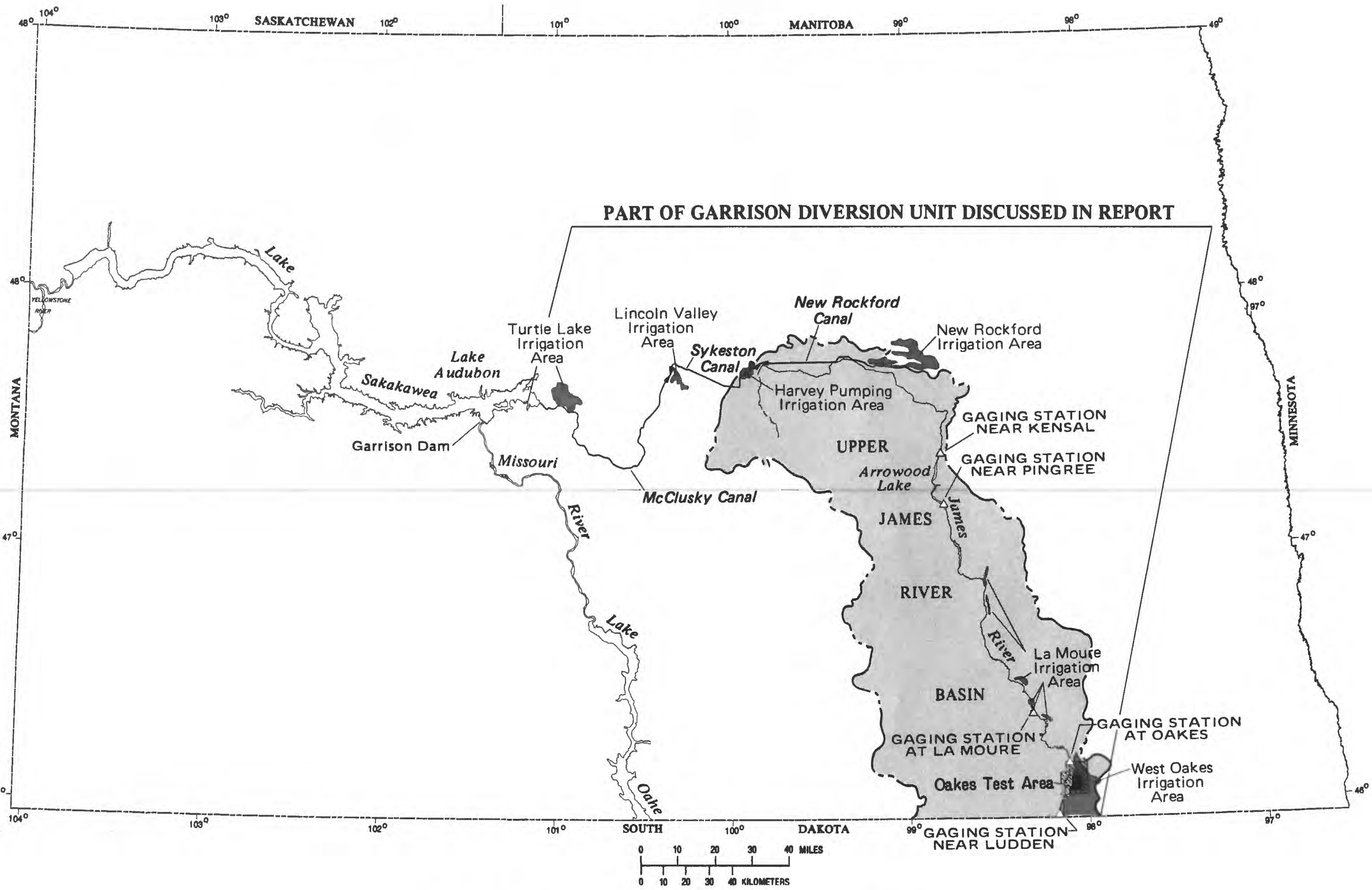

Figure 1.—Location of part of the Garrison Diversion Unit.

Expansion of irrigation in the James River basin of North Dakota is proposed as part of the GDU (fig. 1). Although there are no surface exposures of Cretaceous age shales within the irrigable areas of the GDU, a few outcrops occur in the walls of the James River valley, and Cretaceous age shale chips occasionally are found in the gravelly substratum of some soils in the GDU. During initial investigations of the potential effects of irrigation on mobilization of toxic trace elements from soils in the GDU, the U.S. Bureau of Reclamation concluded these elements would have no adverse effects on receiving streams (Harza Engineering Co., 1976). After the development of problems associated with selenium in irrigation return flows in the western San Joaquin Valley, Calif., the U.S. Bureau of Reclamation initiated additional investigations in the GDU to collect additional data on trace elements in soils and ground water and to reevaluate the effects trace elements, particularly arsenic and selenium, may have on receiving streams.

Purpose and Scope

In order to provide a basis for evaluating the potential for mobilization, transport, and concentration of trace elements during normal operation of the GDU, the U.S. Geological Survey in cooperation with the U.S. Bureau of Reclamation conducted an investigation during 1985-87 to obtain information on the natural occurrence and distribution of trace elements in soils and water in areas proposed for irrigation. The major emphasis of the investigation was to determine the total and water-extractable concentrations of arsenic and selenium in soils and dissolved concentrations of these elements in water and to evaluate the potential for mobilization of these elements as a result of irrigation with water from the GDU. The results of the investigation, including sample collection and analysis procedures, are summarized in this report. Additional results and data collected during the investigation are presented in reports by Severson and others (1988), Wald and others (1989), and Wilson and others (1989a, 1989b, 1989c).

Approach

This investigation was conducted in two phases--a reconnaissance phase and a detailed phase. The purpose of the reconnaissance phase was to review available data and define the occurrence and distribution of potentially toxic elements in soils in areas that are authorized to receive irrigation water from the GDU. The irrigation areas sampled and the number of soil and water samples collected are given in table 1. All samples were analyzed for total concentrations of 42 elements, including arsenic and selenium. In addition, 81 samples were analyzed for water-extractable concentrations of 14 elements, including three anions--chloride, fluoride, and sulfate.

The purpose of the detailed phase was to provide comprehensive information on potentially toxic elements in the soil profile, shallow ground water, and drains in the west Oakes irrigation area (fig. 1). These data would aid in defining conditions and processes that could mobilize potentially toxic elements. Soil samples were analyzed for total concentrations of 38 elements (Severson and others, 1988). Water samples were collected from 104 wells in a preliminary survey. Based on results from the survey, water samples

Table 1.--Garrison Diversion Unit irrigation areas and number of sampling sites and samples collected

[--, no samples collected]

Name of irrigation area	Size (acres)	Number of soil sites 1985-87	Number of soil samples 1985-87	Number of wells sampled 1986-87	Number of drain sites sampled 1986-87
		Reconnaissance study phase			
Turtle Lake irrigation area[1]	13,700	5	25	--	--
Lincoln Valley irrigation area[1]	6,515	4	19	--	--
Harvey pumping irrigation area	2,000	3	12	--	--
New Rockford irrigation area	20,935	7	37	--	--
LaMoure irrigation area	13,350	5	23	--	--
West Oakes irrigation area	23,660	10	49	--	--
Totals	80,160	34	165	--	--
		Detailed study phase			
West Oakes irrigation area	23,660	[2]32	[2]127	[3]120	[4]23

[1] Located outside James River basin; return flow waters from the Lincoln Valley irrigation area will be diverted into the James River basin; return flow waters from the Turtle Lake irrigation area will be diverted into the Missouri River basin.

[2] Excluding replicates.

[3] Total of 104 wells sampled during a preliminary survey; 63 wells sampled seasonally during detailed study, including 47 wells sampled during preliminary survey; total of 296 water samples collected.

[4] Total of 80 water samples collected.

were collected seasonally from 63 shallow wells and 23 sites on drains. The water samples were analyzed for major and trace elements (including arsenic, mercury, and selenium), nitrite plus nitrate-nitrogen, and total organic carbon. The number of samples collected is given in table 1.

RECONNAISSANCE EVALUATION OF THE GEOCHEMISTRY OF SOILS IN THE GARRISON DIVERSION UNIT

In the reconnaissance phase, soil samples were collected at six possible GDU irrigation areas. Four of these areas are within the James River basin and two areas are outside the basin along the diversion route (table 1, fig. 1). Within each proposed irrigation area, soil-sampling sites were selected in locations believed to represent conditions that might have lead to accumulations of potentially toxic trace elements, such as selenium. These sites, characterized by organic-rich soils, high water tables, temporary ponding of water subject to evapotranspiration, and topographic depressions, were selected to represent worst-case conditions.

Setting

The James River (fig. 1), a tributary to the Missouri River, occupies approximately 5,480 mi^2 in east-central North Dakota within the Central Lowland physiographic province (Fenneman, 1946). The James River valley, which is underlain predominantly by glacial lakebeds created when glacial sediments dammed parts of the glacial river channel, is several miles wide. Tributaries and drainage systems conveying precipitation runoff to the James River are incised into the gently rolling glacial drift, which is covered by prairie vegetation. Numerous depressions in the glacial drift, many of which are occupied by prairie-pothole wetlands or lakes, normally do not contribute runoff to the river. About 3,300 mi^2 of the basin area captures runoff internally and does not contribute it to the river system.

The James River has an extremely flat slope. The channel gradient decreases from about 2.5 ft/mi in the headwaters to about 0.05 ft/mi in the glacial Lake Dakota plain. Because of the slight gradient, the river channel tends to be stable and has minimal sediment-transport capacity.

Under the GDU Reformulation Act of 1986 (Public Law 99-294), 130,940 acres in the James River basin and adjacent areas were authorized for irrigation development. The six largest areas are shown in figure 1, and the authorized acreages are given in table 1. At the present time (1989), irrigation with water from the GDU has been limited to about 1,000 acres in the west Oakes irrigation area.

Methods for Collecting and Processing of Soil Samples

Collection of soil samples from potential irrigation areas for the reconnaissance-phase evaluation was done during two sampling periods--September 1985 and July 1987 (Wilson and others, 1989a, 1989c). During the first sampling period, 81 soil samples were collected and analyzed for total concentrations of 42 elements and water-extractable concentrations of 14 elements. During the second sampling period, 84 soil samples were collected and analyzed for only total element concentrations of 42 elements. The irrigation areas, number of sites sampled, and number of samples collected are given in table 1.

During both sampling periods, soil samples at each site were collected in continuous profiles to a depth of 18 ft. Soils collected from the unsaturated zone were obtained with a U.S. Bureau of Reclamation drilling apparatus. A soil tube that was 5 ft long and 4 in. in diameter was used to sample surface soils to a depth of 6 ft at most locations. Below a depth of 6 ft, samples were collected using a 6-in. continuous flight spiral auger. The surface of the core material from the soil tube and the auger flight then was scraped with a stainless steel blade to remove any contaminated material from the core. The collected soil material was laid out on plywood boards in the field. The soils were described, classified, and photographed by U.S. Bureau of Reclamation personnel. For each soil horizon, samples were collected from the interior of the core and placed in kraft paper bags. The samples then were frozen to minimize possible chemical alterations, packed in coolers, and shipped to the U.S. Geological Survey laboratories in Lakewood, Colo. The samples, once received and assigned a laboratory number, were dried in their original bags using forced air at ambient temperature. The dried samples then were disaggregated using a mechanical mortar and pestle and the less than 2-mm fraction was isolated for further processing. The less than 2-mm fraction was ground to pass through a 100-mesh sieve using a Bico[1] vertical grinder. Approximately 5 g of ground material then were placed in a 3-oz cardboard container, a paper mixing card was inserted, and the sample was mixed mechanically for 1 hour using a tumble mixer.

Methods for Determining Total Concentrations of Elements in Soils

The following discussion of analytical methods provides an overview of the methods used in this study. In addition to the references cited under each method, details for all procedures are given in Baedecker (1987). Soil samples submitted for total elemental analysis were analyzed using a combination of inductively-coupled argon plasma/optical emission spectroscopy (ICAP/OES), hydride generation/atomic absorption spectroscopy (HG/AAS), and, when requested, cold vapor/atomic absorption spectroscopy (CV/AAS) for mercury. A summary of each method follows.

Inductively-Coupled Argon Plasma/Optical Emission Spectroscopy

Samples were analyzed simultaneously for the total element concentrations of 39 elements using a Jarrell-Ash Model 1160 ICAP/OES system. Each sample (0.20 g) was dissolved using a low temperature digestion procedure using

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[1] The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or the U.S. Bureau of Reclamation.

concentrated hydrochloric, hydrofluoric, nitric, and perchloric acids (Crock and others, 1983). Lutetium was added at the start of the digestion to serve as an internal standard (5 mg/kg, final concentration). The acidic sample solution was taken to dryness and the residue was redissolved with 1 mL of aqua regia and then diluted to 10 g with 1-percent nitric acid. Reagent blanks, reference materials, and sample replicates all were digested by the same procedure and analyzed at the same time as the samples. Minimum detection limits are given in table 2. The percent relative standard deviation (RSD) for replicate determinations of most elements was about 5 percent.

Hydride Generation/Atomic Absorption Spectroscopy

Total arsenic and selenium concentrations were determined by HG/AAS (Briggs and Crock, 1986; Crock and Lichte, 1982). One gram of sample was digested with hydrofluoric, nitric, perchloric, and sulfuric acids. After digestion, the sample was diluted to 100 mL with 10-percent hydrochloric acid and allowed to sit overnight to ensure the conversion of selenium-VI to selenium-IV. The sample was reacted with sodium borohydride in a continuous flow system to generate the appropriate gaseous hydride compound. The hydride gas was separated from the aqueous phase using a specially designed phase separator and swept into a quartz atomization cell (Hatfield, 1987) positioned in the light path of the atomic absorption spectrometer. Arsenic was quantified using a series of external standards and the appropriate linear regression procedure. Selenium was quantified using the method of standard additions. The minimum detection limits for arsenic and selenium are given in table 2. The RSD for the determination of both elements is about 10 percent.

Cold Vapor/Atomic Absorption Spectroscopy

Total mercury was determined by CV/AAS (Kennedy and Crock, 1987). A 0.1-g sample was digested with nitric acid and a 25-percent (weight/volume) sodium dichromate solution in an aluminum heating block for 3 hours at 110 °C. The sample was allowed to cool (overnight) and the contents were quantitatively transferred to a 16-mm x 100-mm disposable glass test tube. The mass was adjusted to 12.00 g with deionized water. An aliquot of the sample was removed and combined with a solution of hydroxylamine hydrochloride followed by stannous chloride in a continuous flow system to produce a vapor of elemental mercury. The mercury vapor was separated from the aqueous phase using a specially designed phase separator, and the vapor was swept into a cold vapor cell positioned in the light path of the atomic absorption spectrometer. Quantification of mercury was obtained using a series of external aqueous standards and the appropriate linear regression procedures. The minimum detection limit is given in table 2. The RSD for the method is about 10 percent.

Methods for Determining Water-Extractable Concentrations of Elements in Soils

For the water-extraction analyses, a representative 5-g aliquot of ground soil was weighed into a tared 3-oz polyethylene bottle. Deionized water (25

Table 2.--Minimum detection limits for total element concentrations in Garrison Diversion Unit soils

[mg/kg, milligrams per kilogram; ICAP/OES, inductively-coupled argon plasma/optical emission spectroscopy; HG/AAS, hydride generation/atomic absorption spectroscopy; CV/AAS, cold vapor/atomic absorption spectroscopy]

Element	Unit of measure	Method of analysis	Minimum detection limit
Aluminum	Percent	ICAP/OES	0.05
Arsenic	mg/kg	HG/AAS	0.1
Barium	mg/kg	ICAP/OES	1
Beryllium	mg/kg	ICAP/OES	1
Bismuth	mg/kg	ICAP/OES	10
Cadmium	mg/kg	ICAP/OES	2
Calcium	Percent	ICAP/OES	0.05
Cerium	mg/kg	ICAP/OES	4
Chromium	mg/kg	ICAP/OES	1
Cobalt	mg/kg	ICAP/OES	1
Copper	mg/kg	ICAP/OES	1
Europium	mg/kg	ICAP/OES	2
Gallium	mg/kg	ICAP/OES	4
Gold	mg/kg	ICAP/OES	8
Holmium	mg/kg	ICAP/OES	4
Iron	Percent	ICAP/OES	0.05
Lanthanum	mg/kg	ICAP/OES	2
Lead	mg/kg	ICAP/OES	4
Lithium	mg/kg	ICAP/OES	2
Magnesium	Percent	ICAP/OES	0.005
Manganese	mg/kg	ICAP/OES	4
Mercury	mg/kg	CV/AAS	0.02
Molybdenum	mg/kg	ICAP/OES	2
Neodymium	mg/kg	ICAP/OES	4
Nickel	mg/kg	ICAP/OES	2
Niobium	mg/kg	ICAP/OES	4
Phosphorus	Percent	ICAP/OES	0.005
Potassium	Percent	ICAP/OES	0.05
Scandium	mg/kg	ICAP/OES	2
Selenium	mg/kg	HG/AAS	0.1

Table 2.--Minimum detection limits for total element concentrations in Garrison Diversion Unit soils--Continued

Element	Unit of measure	Method of analysis	Minimum detection limit
Silver	mg/kg	ICAP/OES	2
Sodium	Percent	ICAP/OES	0.005
Strontium	mg/kg	ICAP/OES	2
Tantalum	mg/kg	ICAP/OES	40
Thorium	mg/kg	ICAP/OES	4
Tin	mg/kg	ICAP/OES	10
Titanium	Percent	ICAP/OES	0.005
Uranium	mg/kg	ICAP/OES	100
Vanadium	mg/kg	ICAP/OES	2
Ytterbium	mg/kg	ICAP/OES	1
Yttrium	mg/kg	ICAP/OES	2
Zinc	mg/kg	ICAP/OES	2

mL) was added and the container was sealed producing a 1:5 soil to water mixture. The bottle then was placed on a Hembach horizontal shaker and the soil/water mixture was shaken overnight. The suspension was removed the next day, centrifuged, and filtered through a 0.45-µm filter. The solution was split into two parts, and one aliquot was acidified with concentrated nitric acid. Lutetium was added (5 mg/kg, final concentration) to the acidified aliquot and the solution was analyzed directly on the ICAP/OES system described above. Replicates and certified water standards also were analyzed.

Water-extractable arsenic and selenium were quantified after a persulfate digestion. In the persulfate digestion procedure, a 20-g aliquot of sample was pipetted into a 30-mL Teflon bomb. Two 2-mL aliquots of saturated potassium persulfate solution were added and the sample was allowed to sit for 1 hour. A 2-mL aliquot of concentrated hydrochloric acid then was added, the container covered with a watch glass, and the sample heated at 110 °C for 1 hour. The container then was uncovered and the solution heated until the volume was reduced to about 5 mL. About 4 mL of concentrated hydrochloric acid then was added, and the solution was heated at 110 °C for 1 hour. The solution then was quantitatively transferred to a 2-oz polyethylene bottle, and the tared mass was adjusted to 40 g using deionized water. The acidified solutions were analyzed using the HG/AAS method described above.

The extractable anions (chloride, fluoride, and sulfate) were determined by ion chromatography.

Total Concentrations of Arsenic, Selenium, and Other Elements in Soils

Results for total analyses made on 165 samples collected from the GDU during the reconnaissance phase are presented in Wilson and others (1989a, 1989c). The range in concentrations measured in these samples for 32 elements is given in table 3. An additional 10 elements were analyzed for, but the concentrations were smaller than the minimum detection limits (table 2). For comparison, the range in concentrations for these same 32 elements measured in northern Great Plains soils (Severson and others, 1978; Severson and Tidball, 1979) also is given in table 3. The maximum total arsenic concentration measured in GDU samples was 34 mg/kg. Only two of the 165 GDU samples analyzed, however, had total arsenic concentrations larger than 10 mg/kg (table 4), and, in 62 percent of the samples, the concentrations did not exceed 5 mg/kg. A comparison of the maximum, minimum, and geometric mean concentrations of total arsenic in GDU soil samples with soil samples analyzed in several other studies in the western United States is given in table 5. The geometric mean concentration of total arsenic in the GDU samples was 4.15 mg/kg compared with 7.1, 8.8, and 6.1 mg/kg, respectively, in soil samples from the northern Great Plains, Panoche Fan in the western San Joaquin Valley, and a study of soils in the western United States (table 5). On the basis of these data, it would appear that total arsenic concentrations in soil, which potentially could be mobilized by irrigation water from the GDU, are considerably smaller than those reported in soils from other regional studies.

Examination of the reconnaissance study data for total selenium shows that only five samples had concentrations larger than 1 mg/kg (table 4).

Table 3.--Results of chemical analyses from Garrison Diversion Unit soils collected during the reconnaissance phase with northern Great Plains soils

[Does not include elements whose concentrations did not exceed the minimum detection limits; Data for northern Great Plains from Severson and others, 1978, and Severson and Tidball, 1979; mg/kg, milligrams per kilogram; <, less than]

Element	Unit of measure	Measured range, Garrison Diversion Unit	Measured range, northern Great Plains
Aluminum	Percent	2.1 - 7.3	3.4 - 12
Arsenic	mg/kg	1.0 - 34	<0.1 - 26
Barium	mg/kg	120 -1,300	420 -2,300
Beryllium	mg/kg	<1.0 - 2.0	<0.22 - 3.5
Calcium	Percent	0.68- 15	<0.014- 7.0
Cerium	mg/kg	18 - 61	<22 - 130
Chromium	mg/kg	9.0 - 83	11 - 160
Cobalt	mg/kg	3.0 - 16	<1.0 - 23
Copper	mg/kg	<1.0 - 29	4.3 - 110
Gallium	mg/kg	5.0 - 15	4.2 - 29
Iron	Percent	0.52- 4.6	0.26 - 6.5
Lanthanum	mg/kg	10 - 36	<10 - 49
Lead	mg/kg	6.0 - 22	5.1 - 41
Lithium	mg/kg	6.0 - 37	7.0 - 40
Magnesium	Percent	0.21- 4.7	0.18 - 2.7
Manganese	mg/kg	110 -2,800	<200 -3,800
Mercury	mg/kg	<0.02- 0.12	0.01 - 0.07
Molybdenum	mg/kg	<2.0 - 4.0	<1.0 - 12
Neodymium	mg/kg	6.0 - 33	<46 - 140
Nickel	mg/kg	6.0 - 38	4.3 - 64
Phosphorus	Percent	0.02- 0.13	<0.044- 0.13
Potassium	Percent	0.84- 2.5	1.3 - 2.7
Scandium	mg/kg	<2.0 - 10	<3.0 - 17
Selenium	mg/kg	<0.1 - 2.1	<0.1 - 20
Sodium	Percent	0.67- 2.3	0.22 - 1.6
Strontium	mg/kg	67 - 730	58 - 440
Thorium	mg/kg	<4.0 - 70	3.0 - 13
Titanium	Percent	0.05- 0.28	0.11 - 0.37
Vanadium	mg/kg	18 - 130	20 - 96
Ytterbium	mg/kg	<1.0 - 12	0.78 - 5.8
Yttrium	mg/kg	5.0 - 20	3.1 - 54
Zinc	mg/kg	15 - 95	14 - 170

Table 4.--Frequency distribution of arsenic and selenium concentrations in Garrison Diversion Unit soils collected during the reconnaissance phase

[mg/kg, milligrams per kilogram; >, greater than; <, less than]

Concentration (mg/kg)	Number of samples	Percentage of samples
	Total arsenic	
1.0- 3.0	41	25
3.1- 5.0	61	37
5.1-10	61	37
>10	2	1
	Total selenium	
<0.1	69	42
0.1-0.5	81	49
0.6-1.0	10	6
1.1-2.0	4	2.4
>2.0	1	0.6
	Water-extractable arsenic	
<0.02	21	26
0.02-0.03	29	36
0.04-0.06	24	30
0.07-0.08	5	6
>0.08	2	2
	Water-extractable selenium	
<0.02	41	50.5
0.02-0.03	34	42
0.04-0.06	2	2.5
0.07-0.08	2	2.5
>0.08	2	2.5

Table 5.--Summary of statistics for total arsenic and selenium concentrations in Garrison Diversion Unit soils collected during the reconnaissance phase and in soils from other areas in the western United States

[mg/kg, milligrams per kilogram; <, less than; --, not available]

Study area	Element	Number of samples	Maximum (mg/kg)	Minimum (mg/kg)	Geometric mean (mg/kg)	Arithmetic mean (mg/kg)	Median (mg/kg)
Garrison Diversion Unit, N.Dak. (This study)	Arsenic	165	34	1.0	4.15	4.7	4.2
	Selenium	165	2.1	<.1	[1].13	[1].23	.10
Northern Great Plains (Shacklette and Boerngen, 1984)	Arsenic	136	26	<0.1	7.1	--	--
	Selenium	136	20	<.1	.45	--	--
Panoche Fan, San Joaquin Valley, Calif. (Severson and others, 1986)	Arsenic	721	21	3.4	8.8	--	--
	Selenium	721	4.5	<.1	.68	--	--
Western United States (Connor and Shacklette, 1975)	Arsenic	490	97	<0.2	6.1	--	--
	Selenium	492	4.3	<.1	.25	--	--
Agricultural fields, western San Joaquin Valley, Calif. (Fujii and others, 1987)	Selenium	170	5.9	0.4	--	--	0.6-1.2

[1] Concentrations less than the detection limits were changed to one-half the detection limit for calculation of geometric and arithmetic means.

Of these, two were in the Turtle Lake irrigation area, one was in the Lincoln Valley irrigation area, and three were in the west Oakes irrigation area (fig. 1). Out of the 165 samples analyzed, 69 (42 percent) had concentrations that were less than the minimum detection limits (0.1 mg/kg), and 150 (91 percent) had concentrations of 0.5 mg/kg or less (table 4). A comparison of the maximum, minimum, and geometric mean concentrations of total selenium measured in GDU soils with concentrations determined in soils in other studies in the western United States is given in table 5. The maximum total selenium measured in GDU soils (2.1 mg/kg) was one-half to one-tenth the maximum concentrations reported in the other studies, and the geometric mean in the GDU soils (0.13 mg/kg) was one-half to one-fifth the geometric mean reported in the other studies (table 5). The maximum and minimum selenium concentrations reported for 170 soil samples from three agricultural fields in the western San Joaquin Valley were 5.9 and 0.4 mg/kg, respectively (Fujii and others, 1987). Median concentrations in each of the three agricultural fields ranged from 0.6 to 1.2 mg/kg. These medians were six to 12 times larger than the median of 0.10 mg/kg determined for GDU soils (table 5). On the basis of these data, it would appear that total selenium concentrations in soil, which potentially could be mobilized by irrigation water from the GDU, are several times smaller than concentrations measured in the western San Joaquin Valley and other areas in the western United States.

In general, the total concentrations of other elements in soils from the study area are within the typical range of element concentrations (table 3) determined in previous studies (Severson and Tidball, 1979). There were eight elements, however, whose range exceeded those previously measured. These elements were calcium, magnesium, mercury, sodium, strontium, thorium, vanadium, and ytterbium (table 3). In most cases, this difference was less than a factor of two and may reflect differences in analytical techniques, normal statistical error, or the presence of a single sample with anomalously large concentrations of elements.

Concentrations of Water-Extractable Elements in Soils

Extraction of soil samples using a 1:5 soil to water extraction procedure has been used to identify and compare concentrations of elements that may be leached from soil as a result of irrigation. The results of the 1:5 water-extraction analyses made on 81 of the 165 soil samples collected from the GDU during the reconnaissance phase are presented in Wilson and others (1989a) and are given in table 6. Water-extractable arsenic concentrations ranged from less than 0.02 to 0.20 mg/kg. The median, arithmetic mean, and geometric mean concentrations were all 0.03 mg/kg. A frequency distribution for water-extractable arsenic concentrations (table 4) shows that only two samples out of the 81 samples analyzed had concentrations larger than 0.08 mg/kg. One of these samples was from the New Rockford irrigation area (0.13 mg/kg), and the other was from the west Oakes irrigation area (0.20 mg/kg).

For water-extractable selenium, the concentrations measured in 81 samples ranged from less than the detection limit of 0.02 mg/kg to 0.16 mg/kg (table 6). The median, arithmetic mean, and geometric mean concentrations were <0.02 mg/kg, 0.02 mg/kg, and <0.02 mg/kg, respectively. A frequency

Table 6.--Summary of chemical analyses for 1:5 soil to water extraction analyses

[mg/kg, milligrams per kilogram; HG/AAS, hydride generation/atomic absorption spectroscopy; ICAP/OES, inductively-coupled argon plasma/optical emission spectroscopy; IC, ion chromatography; <, less than]

Element or anion	Method of analysis	Minimum detection limit	Number of analyses	Maximum (mg/kg)	Minimum (mg/kg)	Median (mg/kg)	Geometric mean[1] (mg/kg)	Arithmetic mean[1] (mg/kg)
Arsenic	HG/AAS	0.02	81	0.20	<0.02	0.03	0.03	0.03
Barium	ICAP/OES	0.01	81	0.59	0.10	0.23	0.23	0.24
Calcium	ICAP/OES	1	81	1,260	9	57	51	80
Chloride	IC	0.1	81	280	4.8	18	19	28
Fluoride	IC	0.1	68	10	1	3.6	3.6	3.9
Lithium	ICAP/OES	0.010	81	0.70	0.017	0.094	0.096	0.124
Magnesium	ICAP/OES	1	81	366	4	22	23	34
Manganese	ICAP/OES	0.01	81	0.57	<0.01	0.034	0.040	0.092
Molybdenum	ICAP/OES	0.01	81	0.87	0.01	0.036	0.045	0.091
Selenium	HG/AAS	0.02	81	0.16	<0.02	<0.02	<0.02	0.02
Silicon	ICAP/OES	10	81	102	22	52	52	55
Sodium	ICAP/OES	10	81	960	10	30	41	101
Strontium	ICAP/OES	0.05	81	19.4	<0.05	0.17	0.19	0.527
Sulfate	IC	1	81	7,500	9	30	52	317

[1] Concentrations less than the detection limits were changed to one-half the detection limit for calculation of geometric and arithmetic means.

distribution for selenium (table 4) shows that only two samples had concentrations larger than 0.08 mg/kg. One of these was in the New Rockford irrigation area (0.16 mg/kg); the other was in the west Oakes irrigation area (0.16 mg/kg). These were the same areas that had the two largest arsenic concentrations; however, they were not the same samples.

The water-extraction data show that, for most elements, the extractable ion concentrations are quite small. Developing accurate models to predict the concentrations of elements that may be leached by irrigation water based on water-extraction analyses is difficult, at this time, due to the general lack of reliable information on extractable elements, especially selenium. Five locations in the GDU had total selenium concentrations larger than 1 mg/kg. Samples from one of these locations were analyzed for water-extractable concentrations of selenium. The water-extraction analyses showed that 10 to 15 percent of the selenium was extractable using the 1:5 soil to water extraction analysis. This compares with 10- to 45-percent water-extractable selenium in several western San Joaquin Valley soil samples (Wilson and others, 1989a). It should be noted that, on the basis of internal experimentation (K. C. Stewart and S. A. Wilson, U.S. Geological Survey, written commun., 1989), the 1:5 extraction analysis generally removes more selenium than more traditional saturation-paste analyses. Based on the experiments and the samples analyzed to date, it appears that the soils analyzed during the reconnaissance phase of the investigation do not contain anomalously large trace-element concentrations, especially regarding arsenic and selenium.

DETAILED EVALUATION OF THE GEOCHEMISTRY OF SOILS AND SHALLOW GROUND WATER IN THE WEST OAKES IRRIGATION AREA

A detailed evaluation of trace-element distributions in soils and shallow ground water in a part of the west Oakes irrigation area referred to as the Oakes test area was conducted during 1986-87. The purpose of the evaluation was to obtain detailed information on the occurrence of potentially toxic elements in soils and shallow ground water in the area, to statistically describe the distribution of these elements, and to determine conditions and processes that could result in the mobilization and transport of these elements. The two elements of primary concern in the evaluation were arsenic and selenium.

Description of the West Oakes Irrigation Area

The west Oakes irrigation area is located in the James River valley north of the North Dakota-South Dakota State line (fig. 1). The area includes 23,660 acres, most of which is situated on lacustrine and deltaic deposits of ancestral glacial Lake Dakota. The Oakes test area (fig. 1) is a 5,000-acre feature within the west Oakes irrigation area established by the U.S. Bureau of Reclamation as a prototype to evaluate the effectiveness and environmental consequences of proposed irrigation techniques. At the present time (1989), the Oakes test area is the only area that has been irrigated with water provided by the GDU. Because of the limited water available from reservoirs on the James River, irrigation with surface water is limited to about 1,000 acres. An additional 1,300 acres in the area are being irrigated with ground water from private wells (U.S. Bureau of Reclamation, written commun., 1989).

Climate

The following discussion of climate is synthesized from Schuh and Shaver (1988) and the U.S. Bureau of Reclamation (written commun., 1989). The climate of the area is arid to subhumid. The average annual precipitation is about 19 in. but has ranged from 9.14 in. in 1936 to 29.64 in. in 1960. Annual precipitation at the Oakes test area for the period 1979-88 is shown in figure 2. One of the wettest years during the period of record occurred in 1986, the first year of the detailed evaluation.

Hydrogeology

The Oakes aquifer, which underlies the west Oakes irrigation area, is about 8 mi wide and 16 mi long (Armstrong, 1980). Aquifer materials consist of deltaic sand and gravel, lacustrine sand, channel-fill sand and gravel, and eolian sand (Schuh and Shaver, 1988). The composition of these materials ranges from fine sand to coarse gravel interbedded with silt and clay. The thickness of the aquifer ranges from a few feet to nearly 100 ft (Armstrong, 1980). At the Oakes test area, the thickness of the aquifer averages about 25 ft but varies from about 8 ft on the west side to 50 ft on the east side (Arden Mathison, U.S. Bureau of Reclamation, oral commun., June 1989).

The aquifer is unconfined and, at the Oakes test area, water-table depth ranges from less than 7 ft below land surface at low altitudes to more than 19 ft below land surface at high altitudes (Wald and others, 1989). The average water-table depth is about 12 ft below land surface. The normal water-level fluctuation is about 3 ft, and the water table is highest in May and lowest in March (U.S. Bureau of Reclamation, written commun., 1989). The regional pattern of ground-water flow in the Oakes test area is from east to west (fig. 3). The water-table gradient in the Oakes test area is 3 to 4 ft/mi.

Recharge to the Oakes aquifer is primarily from direct infiltration of precipitation and snowmelt (Armstrong, 1980). Natural discharge from the aquifer is primarily due to evapotranspiration (Schuh and Shaver, 1988) and is greatest in low-lying areas and depressions where the water table is closest to the land surface. Estimates of evapotranspiration made by the U.S. Bureau of Reclamation for the period 1980-88 indicate that evapotranspiration ranged from 13.7 in. during 1987 to 21.8 in. during 1983 (U.S. Bureau of Reclamation, written commun., 1989). The discharge of ground water through evapotranspiration has a significant effect on ground-water quality. This will be discussed in a later section of the report.

Ground-Water Drains

An extensive network of subsurface pipe drains was installed in the Oakes test area during 1983-85 to provide a means to control the water table. The subsurface drains consisted of perforated, corrugated plastic pipe and were placed about 8 ft below land surface. The drain discharge accumulates into three open outlet collector drains that discharge water from the Oakes test area into the James River. The drainage network and areas drained by the three major open outlet drains are shown in figure 4. The north drain (J.R. 12.6-0.7) discharges to the James River about 3 mi south of Oakes. The middle

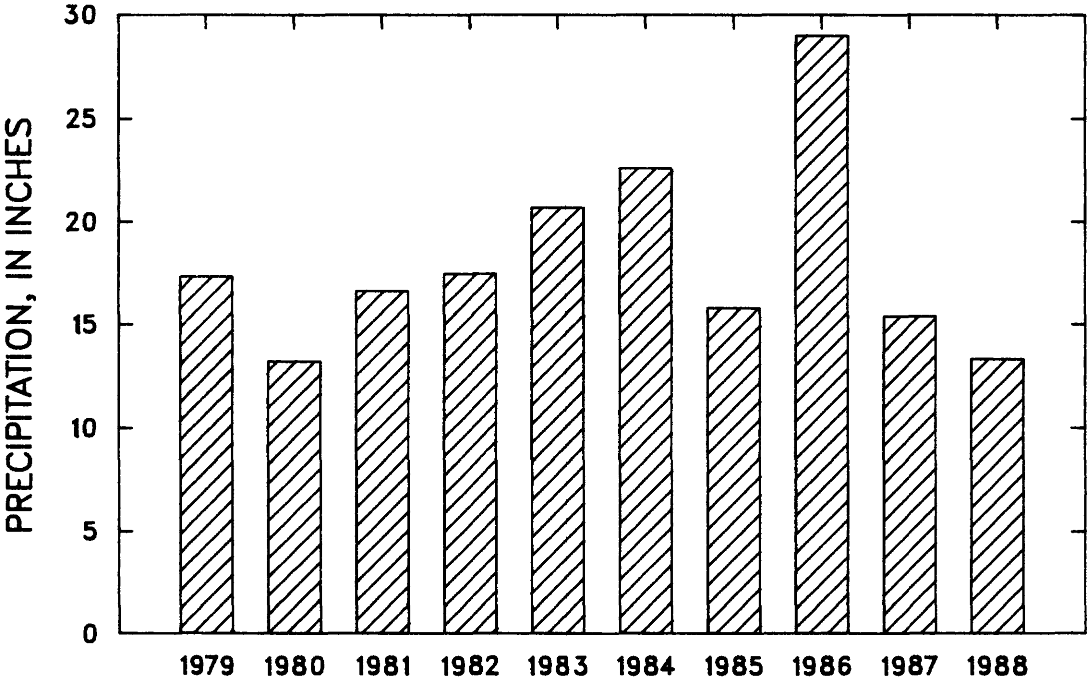
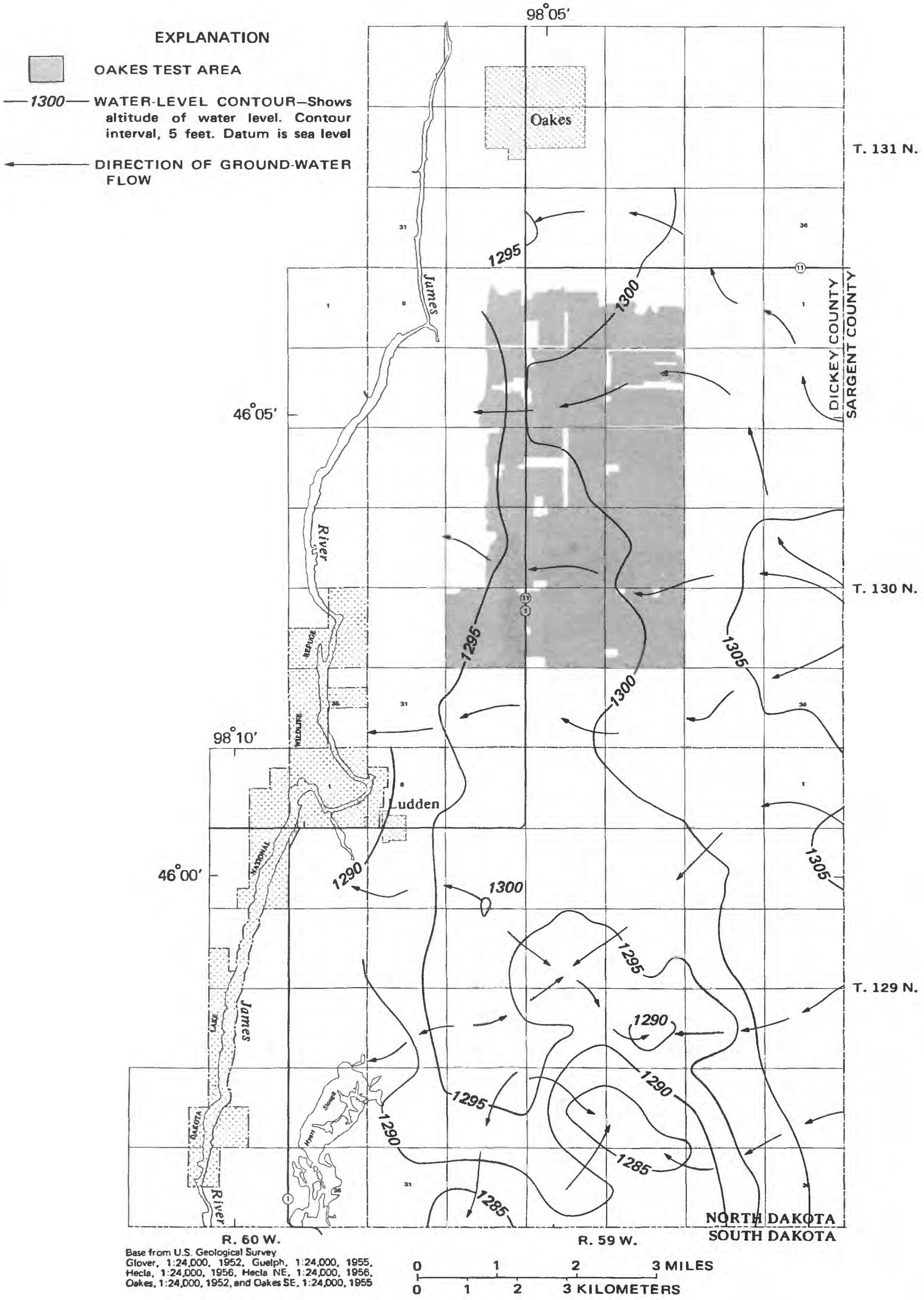
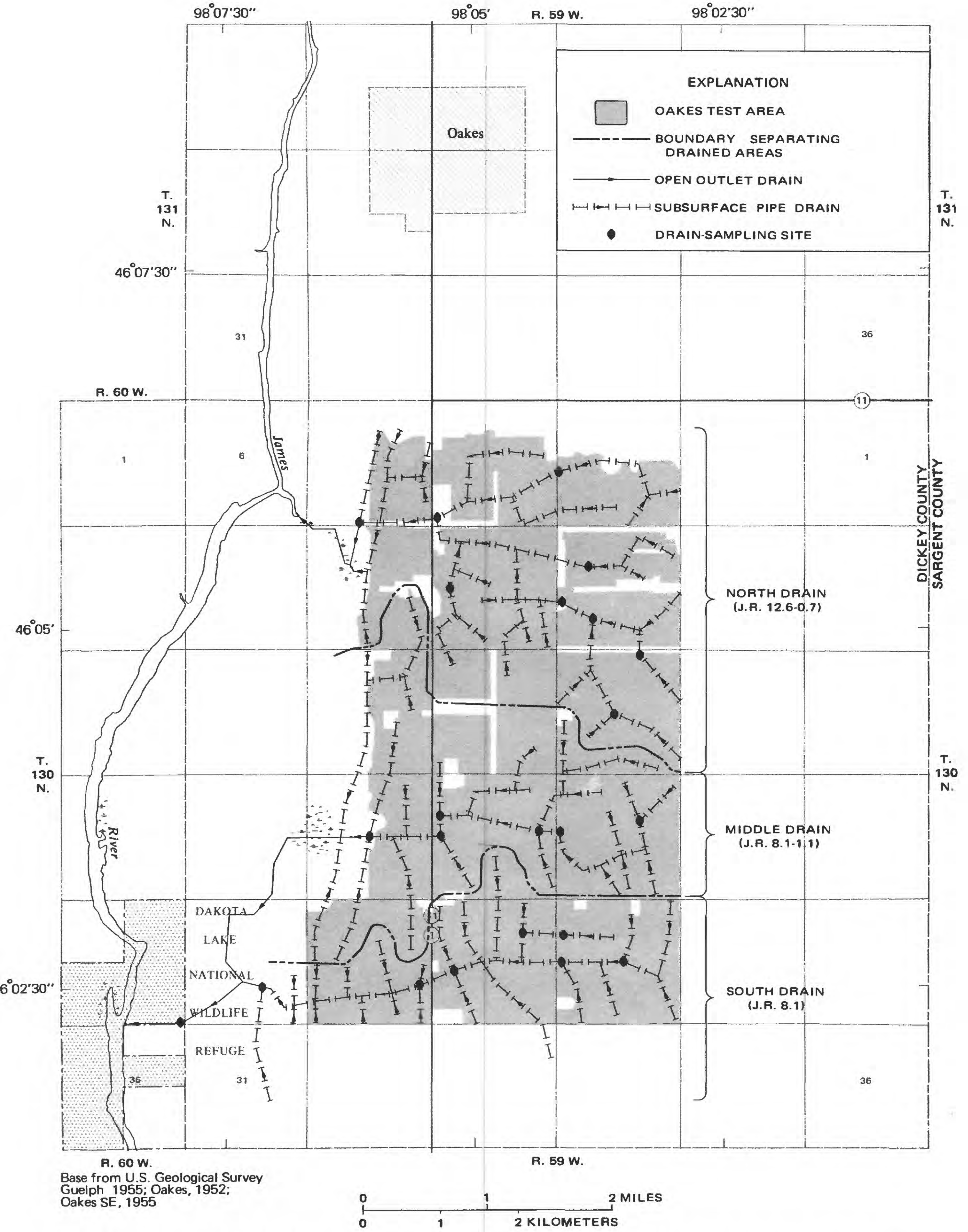


Figure 2.—Annual precipitation at the Oakes test area. [U.S. Bureau of Reclamation, written commun., 1989.]



Base from U.S. Geological Survey Glover, 1:24,000, 1952, Guelph, 1:24,000, 1955, Hecla, 1:24,000, 1956, Hecla NE, 1:24,000, 1956, Oakes, 1:24,000, 1952, and Oakes SE, 1:24,000, 1955

Figure 3.—Altitude of water table of the Oakes aquifer in the west Oakes irrigation area, October 1987. [U.S. Bureau of Reclamation, written commun., 1989.]



Base from U.S. Geological Survey
Guelph 1955; Oakes, 1952;
Oakes SE, 1955

Figure 4.—Location of drains and sampling sites in the Oakes test area (U.S. Bureau of Reclamation, written commun., 1989).

drain (J.R. 8.1-1.1) and the south drain (J.R. 8.1) join together and discharge to the James River at the southern boundary of the Oakes test area (fig. 4). The measured discharge from this drainage network reflects return flow from about 87 percent of the Oakes test area (Arden Mathison, U.S. Bureau of Reclamation, oral commun., 1989).

The individual and combined ground-water discharges from the three collector drains for 1984-88 are shown in figure 5. The combined annual discharge, in acre-feet, is summarized as follows:

Year	Discharge (acre-feet)
1983	262
1984	2,263
1985	2,645
1986	3,661
1987	1,616
1988	449

The U.S. Bureau of Reclamation has estimated that, when the west Oakes irrigation area receives Missouri River water and is in full operation, ground-water discharge from the drains will average about 0.5 (acre-ft/acre)/yr (U.S. Bureau of Reclamation, written commun., 1989). About one-half of this discharge would be derived from precipitation recharge in the area; the other one-half would be derived from diverted irrigation water applied to the area. For the Oakes test area, ground-water discharge from the drains would average about 3,500 acre-ft/yr. For the entire 23,660-acre west Oakes irrigation area, ground-water discharge from the drains would average about 12,000 acre-ft/yr.

Geochemistry of Soils

Thirty-two soil-sampling sites (fig. 6) were selected adjacent to observation wells previously installed by the U.S. Bureau of Reclamation and the U.S. Geological Survey. These sampling sites were located to define a 0.5-mi^2 grid in the 18-mi^2 Oakes test area. Soil samples were collected and analyzed according to procedures described in Severson and others (1988). Descriptive and analytical data for each soil profile are given in Severson and others (1988, table 10).

Site and Analytical Variability

Site variability was evaluated by comparing the chemical properties of soil samples collected adjacent to one another from two randomly selected profiles located at sites KW147A and KW153A, and KW222AC and KW230A (fig. 6). In each of the four profiles, four depth zones were identified comprising various combinations of soil horizons. A one-way analysis of variance was used to partition the variation among soil horizons from all profiles and between paired soil horizons (table 7). The variance components indicate that elements commonly redistributed within a profile by soil-forming processes (calcium, iron, magnesium, and manganese) are most variable between soil

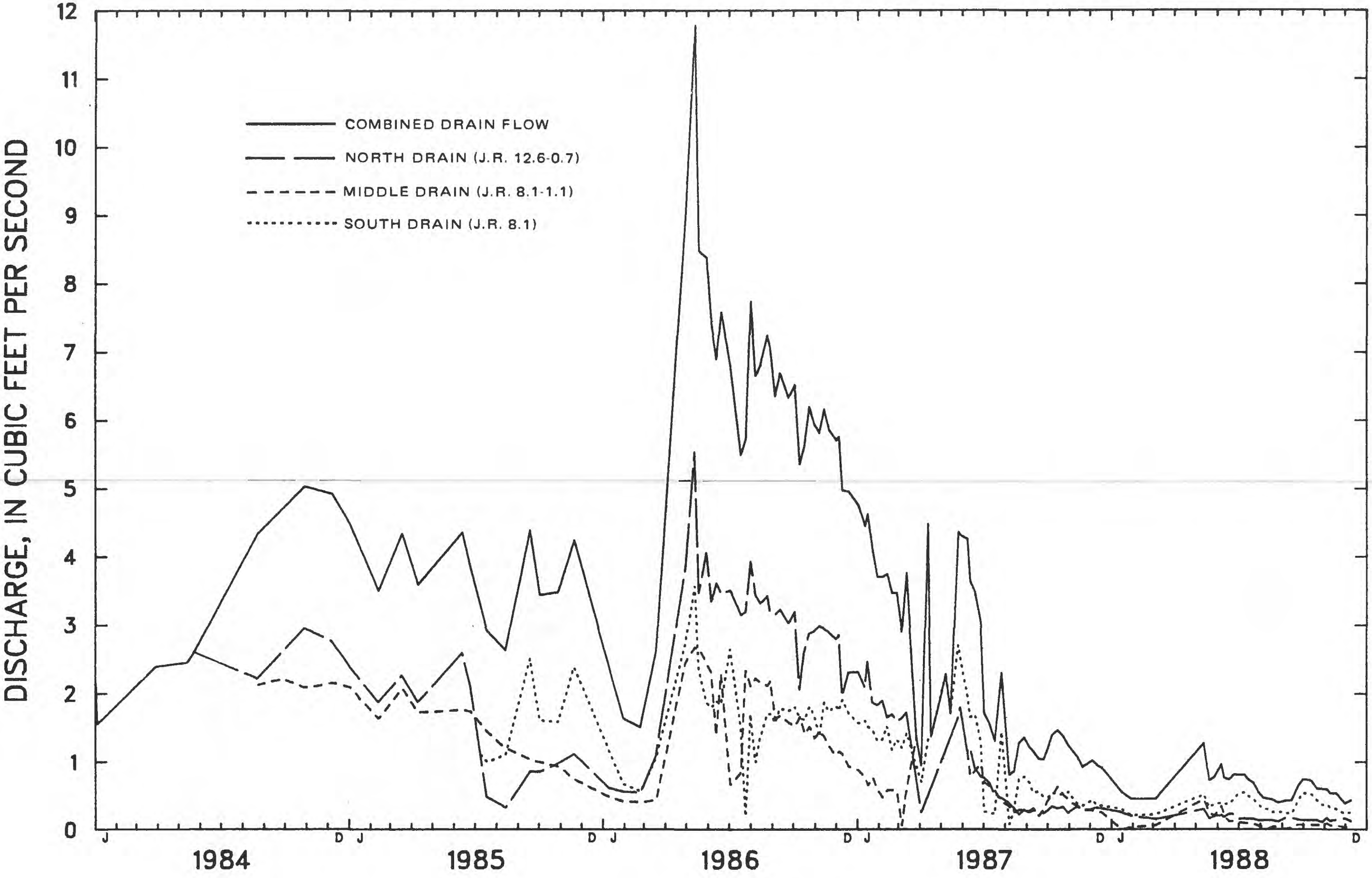
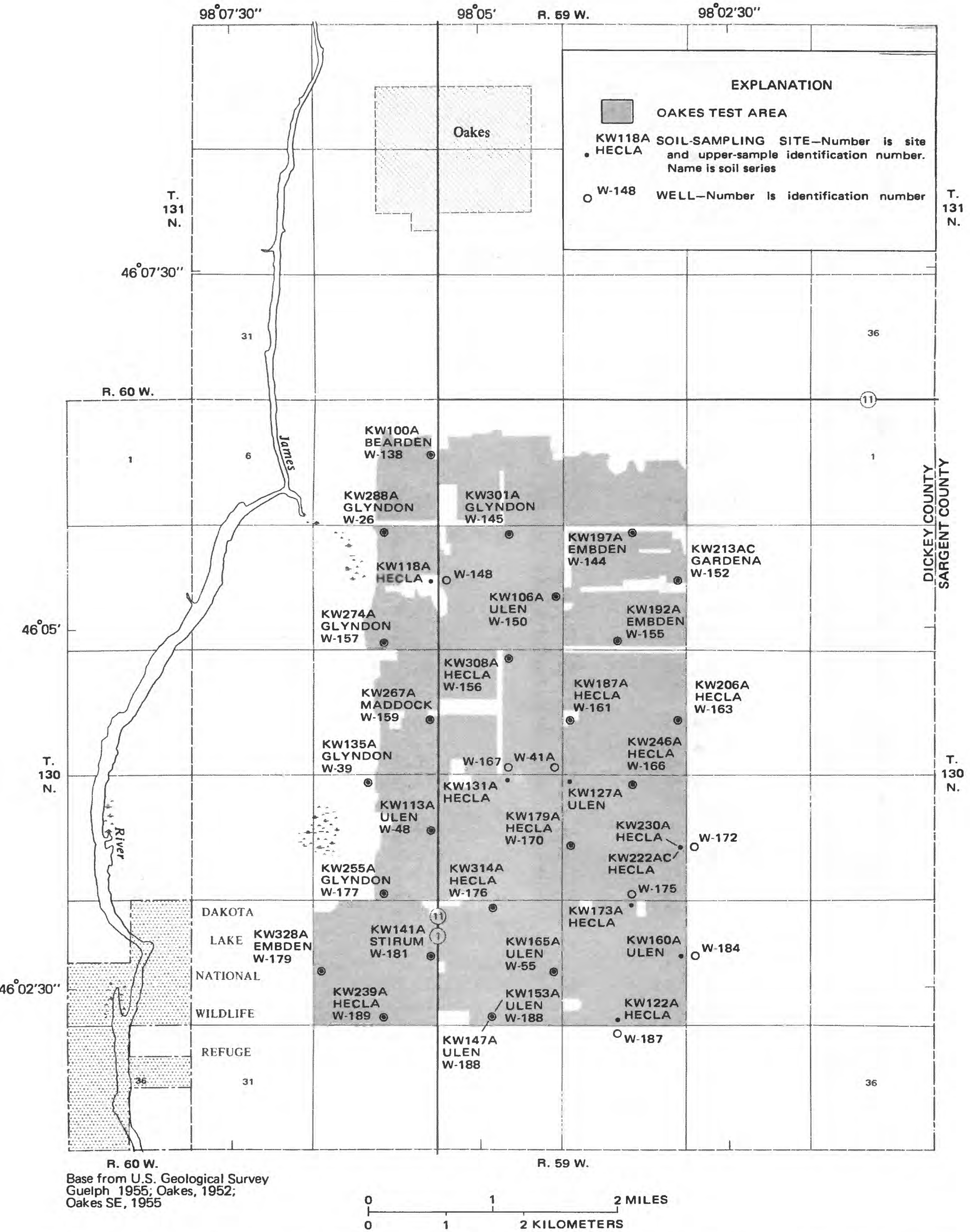


Figure 5.–Discharge from major collector drains in the Oakes test area. [U.S. Bureau of Reclamation, written commun., 1989.]



Base from U.S. Geological Survey
Guelph 1955; Oakes, 1952;
Oakes SE, 1955

Figure 6.—Location of soil-sampling sites and adjacent wells in the Oakes test area. [Modified from Severson and others, 1988.]

Table 7.---Site and analytical variance of elements in soils from sampling locations in the Oakes test area

[mg/kg, milligrams per kilogram; --, no value determined]

		Percentage of variance		Percentage of variance	
Element	Unit of measure	Among all soil horizons	Between pairs of soil horizons	Among samples	Between analyses
Aluminum	Percent	14.6	85.4	97.5	2.5
Arsenic	mg/kg	21.8	78.2	59.2	40.8
Barium	mg/kg	24.2	75.8	97.2	2.8
Beryllium	mg/kg	--	--	--	--
Calcium	Percent	70.3	29.7	99.0	1.0
Cerium	mg/kg	59.1	40.9	96.3	3.7
Chromium	mg/kg	75.0	25.0	98.9	1.1
Cobalt	mg/kg	77.4	22.6	96.5	3.5
Copper	mg/kg	0	100.0	98.8	1.2
Gallium	mg/kg	28.8	17.2	97.6	2.4
Iron	Percent	80.6	19.4	99.1	0.9
Lanthanum	mg/kg	56.6	43.2	95.2	4.8
Lead	mg/kg	13.0	87.0	95.5	4.5
Lithium	mg/kg	83.9	16.1	99.0	1.0
Magnesium	Percent	75.5	25.4	99.0	1.0
Manganese	mg/kg	79.5	20.5	99.6	0.4
Molybdenum	mg/kg	--	--	--	--
Neodymium	mg/kg	41.8	58.2	95.5	5.5
Nickel	mg/kg	28.6	71.4	98.7	1.3
Niobium	mg/kg	--	--	--	--
Phosphorus	Percent	54.5	45.5	95.4	4.6
Potassium	Percent	0	100.0	81.1	18.9
Scandium	mg/kg	51.3	48.7	97.4	2.6
Selenium	mg/kg	36.0	64.0	88.7	11.3
Sodium	Percent	0	100.0	96.0	4.0
Strontium	mg/kg	77.2	22.8	91.2	8.8
Thorium	mg/kg	--	--	--	--
Titanium	Percent	67.1	32.9	98.2	1.8
Vanadium	mg/kg	41.4	58.6	98.9	1.1
Ytterbium	mg/kg	--	--	--	--
Yttrium	mg/kg	77.3	22.7	96.4	3.6
Zinc	mg/kg	51.5	48.5	99.0	1.0

horizons and the differences between soil horizon pairs is small. This relation indicates that soils are relatively uniform in soil formation across small distance intervals as indicated by element composition. For other elements that are more indicative of exchange, sorption, or precipitation reactions (arsenic, copper, lead, nickel, selenium, and sodium), the greatest variation is between pairs of soil horizons. This relation indicates a lack of uniformity between soil profiles within short distances and may reflect the effects of mobilizing processes. These interpretations are considered to be tentative because of the limited number of samples evaluated and because analyzed samples represented composites of different soil horizons from profile to profile.

Laboratory variation was estimated by selecting 12 samples at random and analyzing them in duplicate. Variation partitioned among samples and between analyses (table 7) indicates that, for most elements, the laboratory error represents less than 5 percent of the total variation. The largest error is for arsenic, and an examination of the data indicates that this error is due to a large difference for a single pair of samples from site KW113A (Severson and others, 1988, table 10). Laboratory precision for all elements is sufficient so that trends in natural variation will not be obscured by laboratory error.

Soil-Series Variability

Eight soil series, or variants of a soil series, were identified by the field soil scientist logging the core. The soil series sampled, with number of profiles of each in parentheses, are: Bearden (1), Embden (3), Gardena (1), Glyndon (5), Hecla (13), Maddock (1), Stirum (1), and Ulen (7). Sampling locations for each soil series are shown in figure 6. Samples were not analyzed from each soil horizon individually, so differences within and among soil series could not be made on a horizon-by-horizon basis. Instead, samples were evaluated for each of three soil zones--oxidized, mottled (varying oxidized and reduced conditions, and transition zones), and reduced. The measured range, arithmetic mean, and standard deviation for the concentrations of all elements in each of these three soil zones are given in table 8. This summary indicates that the mean concentrations for most elements is the same in each soil zone. A few elements have a tendency to increase (cobalt, magnesium, manganese, and selenium) or decrease (barium and strontium) in concentration with depth, but these trends probably are not statistically significant.

In comparison to typical soil compositions for northern Great Plains surface or A-horizon soils (table 9, geometric mean) as determined by Severson and Tidball (1979), Oakes test area soils from the oxidized soil zone (table 8, arithmetic mean) tend to have less-than-average concentrations of most trace elements. This comparison of geometric and arithmetic means is conservative. Typically, trace-element data exhibit a positively skewed distribution and, therefore, geometric means are smaller than arithmetic means for the same distribution. The soils in the Oakes test area generally are more sandy than average soils from the northern Great Plains, and the smaller trace-element concentrations probably reflect the lesser quantity of clay-size minerals present in these soils. A few individual samples from the Oakes test

Table 8.--Detection ratio and measured range for all samples, and arithmetic mean and standard deviation for elements in three soil zones in the Oakes test area

[Detection ratio, number of samples in which element was detected and total number of samples; mg/kg, milligrams per kilogram; <, less than; --, no value determined]

		This study, all data		Oxidized soil zone		Mottled soil zone		Reduced soil zone	
Element	Unit of measure	Detection ratio	Measured range	Arithmetic mean	Standard deviation	Arithmetic mean	Standard deviation	Arithmetic mean	Standard deviation
Aluminum	Percent	139:139	2.8 - 6.6	4.2	0.534	3.8	0.535	3.8	0.529
Arsenic	mg/kg	139:139	1.3 - 46	4.5	3.78	4.5	2.45	4.5	3.41
Barium	mg/kg	139:139	380 -1,000	630	48.3	600	132	550	91.0
Beryllium	mg/kg	10:139	<1.0 - 1.0	--	--	--	--	--	--
Calcium	Percent	139:139	0.80- 19	3.2	3.17	2.4	1.11	2.9	0.761
Cerium	mg/kg	139:139	16 - 55	32	6.56	27	8.06	27	8.11
Chromium	mg/kg	139:139	15 - 79	30	10.1	26	8.13	28	10.8
Cobalt	mg/kg	139:139	4.0 - 18	6.1	1.81	6.6	0.877	6.9	2.32
Copper	mg/kg	139:139	3.0 - 26	6.4	3.75	5.4	1.47	6.6	4.49
Gallium	mg/kg	139:139	6.0 - 15	8.0	1.49	7.4	1.18	7.8	1.17
Iron	Percent	139:139	0.61- 3.0	1.2	0.366	1.1	0.210	1.1	0.325
Lanthanum	mg/kg	139:139	9.0 - 30	17	3.57	15	4.44	15	4.26
Lead	mg/kg	139:139	6.0 - 48	10	1.53	12	8.38	10	2.04
Lithium	mg/kg	139:139	6.0 - 38	12	4.44	10	1.86	12	4.33
Magnesium	Percent	139:139	0.20- 2.3	0.67	0.464	0.72	3.21	0.85	0.281
Manganese	mg/kg	139:139	130 -3,400	540	256	1,000	707	960	355
Molybdenum	mg/kg	4:139	<2.0 - 7.0	--	--	--	--	--	--
Neodymium	mg/kg	139:139	6.0 - 27	15	3.68	12	4.60	13	4.35
Nickel	mg/kg	139:139	8.0 - 58	14	5.38	14	3.18	17	6.67
Niobium	mg/kg	9:139	<4.0 - 8.0	--	--	--	--	--	--

Table 8.--Detection ratio and measured range for all samples, and arithmetic mean and standard deviation for elements in three soil zones in the Oakes test area--Continued

		This study, all data		Oxidized soil zone		Mottled soil zone		Reduced soil zone	
Element	Unit of measure	Detection ratio	Measured range	Arithmetic mean	Standard deviation	Arithmetic mean	Standard deviation	Arithmetic mean	Standard deviation
Phosphorus	Percent	139:139	0.02- 0.09	0.044	0.0130	0.034	0.0118	0.034	0.00342
Potassium	Percent	139:139	0.77- 1.8	1.3	0.139	1.3	0.141	1.3	0.124
Scandium	mg/kg	139:139	2.0 - 10	3.5	1.35	2.9	0.995	3.2	1.40
Selenium	mg/kg	114:139	<0.01- 3.0	0.28	0.181	0.32	0.514	0.53	0.330
Sodium	Percent	139:139	0.53- 1.6	1.2	0.134	1.2	0.169	1.1	0.151
Strontium	mg/kg	139:139	120 - 340	230	38.6	200	31.8	190	26.8
Thorium	mg/kg	65:139	<4.0 - 9.0	--	--	--	--	--	--
Titanium	Percent	139:139	0.05- 0.28	0.13	0.0360	0.096	0.0359	0.10	0.0430
Vanadium	mg/kg	139:139	18 - 140	39	17.8	37	8.77	43	19.9
Ytterbium	mg/kg	63:139	<1.0 - 2.0	--	--	--	--	--	--
Yttrium	mg/kg	139:139	5.0 - 18	9.7	2.19	8.2	2.37	8.5	2.82
Zinc	mg/kg	139:139	15 - 80	32	10.9	25	5.45	30	13.4

Table 9.--Geochemical baselines for northern Great Plains soils

[Modified from Severson and others, 1988; Detection ratio, number of samples in which element was detected and number of samples analyzed; Baseline, expected 95-percent range; mg/kg, milligrams per kilogram; <, less than; --, no value determined]

Element	Unit of measure	Detection ratio	Geometric mean	Geometric deviation	Baseline	Measured range, northern Great Plains
Aluminum	Percent	136:136	5.6	1.19	4.0 - 7.9	3.4 - 12
Arsenic	mg/kg	135:136	7.1	1.69	2.5 - 20	<0.1 - 26
Barium	mg/kg	136:136	1,100	1.33	620 -1,950	420 -2,300
Beryllium	mg/kg	135:136	1.6	1.42	0.79 - 3.2	<0.22 - 3.5
Boron	mg/kg	135:136	41	1.59	16 - 100	<2.2 - 990
Calcium	Percent	135:136	0.97	2.30	0.18 - 5.1	<0.014- 7.0
Cerium	mg/kg	99:136	38	2.08	8.8 - 164	<22 - 130
Chromium	mg/kg	136:136	45	1.56	18 - 110	11 - 160
Cobalt	mg/kg	135:136	6.4	1.48	2.9 - 14	<1.0 - 23
Copper	mg/kg	136:136	19	1.64	7.1 - 51	4.3 - 110
Gallium	mg/kg	136:136	11	1.44	5.3 - 23	4.2 - 29
Iron	Percent	136:136	2.1	1.41	1.1 - 4.2	0.26 - 6.5
Lanthanum	mg/kg	128:136	23	1.47	11 - 50	<10 - 49
Lead	mg/kg	136:136	16	1.54	6.7 - 38	5.1 - 41
Lithium	mg/kg	136:136	19	1.40	9.7 - 37	7.0 - 40
Magnesium	Percent	136:136	0.66	1.67	0.24 - 1.8	0.18 - 2.7
Manganese	mg/kg	109:136	460	2.38	81 -2,600	<200 -3,800
Mercury	mg/kg	135:136	0.023	1.68	0.0082- 0.065	<0.01 - 0.07
Molybdenum	mg/kg	118:136	3.8	1.68	1.3 - 11	<1.0 - 12
Neodymium	mg/kg	11:136	--	--	--	<46 - 140

See footnote at end of table.

Table 9.--Geochemical baselines for northern Great Plains soils--Continued

Element	Unit of measure	Detection ratio	Geometric mean	Geometric deviation	Baseline	Measured range, northern Great Plains
Nickel	mg/kg	136:136	18	1.46	8.4 - 38	4.3 - 64
Phosphorus	Percent	107:136	0.074	1.37	0.039 - 0.14	<0.044- 0.13
Potassium	Percent	136:136	1.8	1.13	1.4 - 2.3	1.3 - 2.7
Scandium	mg/kg	114:136	5.4	1.67	1.9 - 15	<3.0 - 17
Selenium	mg/kg	104:136	0.45	2.72	0.061 - 3.3	<0.1 - 20
Silver	mg/kg	22:136	0.14	1.58	0.056 - 0.35	<0.22 - 0.49
Sodium	Percent	136:136	[1]0.83	[1]0.36	0.11 - 1.6	0.22 - 1.6
Strontium	mg/kg	136:136	160	1.47	74 - 350	58 - 440
Thorium	mg/kg	136:136	8.4	1.23	5.6 - 13	3.0 - 13
Titanium	Percent	136:136	[1]0.2	[1]0.023	0.15 - 0.25	0.11 - 0.37
Uranium	mg/kg	136:136	2.3	1.25	1.5 - 3.6	1.1 - 4.9
Vanadium	mg/kg	136:136	54	1.35	30 - 98	20 - 96
Ytterbium	mg/kg	136:136	2.4	1.41	1.2 - 4.8	0.78 - 5.8
Yttrium	mg/kg	136:136	18	1.46	8.4 - 38	3.1 - 54
Zinc	mg/kg	136:136	[1]63	[1]20	23 - 100	14 - 170

[1] Arithmetic means or standard deviations.

area have element concentrations exceeding the upper concentration limit of average northern Great Plains soils. As summarized in Severson and others (1988, table 10), the following samples collected at sites shown in figure 6 contain element concentrations that substantially exceed the upper concentration limits for northern Great Plains soils (site numbers in fig. 6 shown in parentheses after sample number):

Arsenic--sample KW116A (site KW113A);

Calcium--samples KW100A (site KW100A), KW161A (site KW160A), KW225A (site KW222AC), KW256A (site KW255A), and KW288A (site KW288A);

Lead--sample KW314A (site KW314A);

Magnesium--sample KW255A (site KW255A);

Manganese--sample KW308A (site KW308A);

Nickel--sample KW116A (site KW113A); and

Vanadium--samples KW101A (site KW100A), KW117A (site KW113A), and KW139A (site KW135A).

All samples containing anomalously large calcium concentrations were associated with soil horizons characterized by carbonate-mineral accumulation. Several of the Oakes test area soil samples that were characterized by anomalously large element concentrations (samples KW116A, KW117A, KW225A, and KW314A in table 10 of Severson and others, 1988) came from soil profiles in which lignite was present in one or more soil horizons; however, other soil profiles that contained lignite did not have anomalously large element contents. Many samples containing anomalously large element concentrations also were from soil horizons characterized by fine-grained soils (silt loam or silty clay loam); however, several other samples from other fine-grained soil horizons did not contain anomalously large element concentrations.

For purposes of statistical analysis, a weighted-average value was computed for each element in each of the three soil zones (oxidized, mottled, and reduced) by multiplying the concentration by the depth increment represented by the sample and summing these values for the soil zone. The sum then was divided by the total depth of the soil zone to determine an average concentration for the soil zone. Where certain soil horizons or depth zones were not analyzed, the soil horizons above and below were averaged. This average concentration then was used for the missing depth increment. The oxidized soil zone was identified from field notes as the soil zone that is freely drained and not saturated with water. The mottled soil zone was identified as the soil zone that is saturated occasionally with water. The reduced soil zone was defined as the saturated soil zone below the permanent water table. The permanent water table ranged in depth from less than 7 to more than 19 ft within the study area.

Only soil series where more than one profile was sampled were included in the analysis of variance to estimate relative variation among and within soil series. The results of this analysis for the four soil series (Embden, Hecla, Glyndon, and Ulen) and the three soil zones (oxidized, mottled, and reduced) are given in table 10. A separate, one-way analysis-of-variance computation was used for each of the three soil zones. Differences among soil series generally are smaller than between samples from within the same soil series, except for lithium, magnesium, phosphorus, and scandium in the oxidized soil zone; lanthanum, phosphorus, scandium, titanium, and yttrium in the mottled

Table 10.--Partitioning of variation among soil series and between samples within soil series for three soil zones in the Oakes test area

[mg/kg, milligrams per kilogram]

Element	Unit of measure	Percentage of variance					
		Oxidized soil zone		Mottled soil zone		Reduced soil zone	
		Among soil series	Between samples	Among soil series	Between samples	Among soil series	Between samples
Aluminum	Percent	0	100.0	35.0	65.0	44.1	55.9
Arsenic	mg/kg	0	100.0	12.1	87.9	0	100.0
Barium	mg/kg	14.1	85.9	28.2	71.8	36.9	63.1
Calcium	Percent	35.6	64.4	0	100.0	16.6	83.4
Cerium	mg/kg	10.6	89.4	38.2	61.8	37.5	62.5
Chromium	mg/kg	35.6	64.4	32.7	67.3	41.8	58.2
Cobalt	mg/kg	21.3	78.7	32.7	67.3	33.9	66.1
Copper	mg/kg	38.9	61.1	3.9	96.1	13.8	86.2
Gallium	mg/kg	0	100.0	0	100.0	33.4	66.6
Iron	Percent	28.7	71.3	0	100.0	32.8	67.2
Lanthanum	mg/kg	12.2	87.8	50.7	49.3	37.3	62.7
Lead	mg/kg	8.3	91.7	0	100.0	35.6	64.4
Lithium	mg/kg	61.3	38.4	26.2	73.8	32.1	67.9
Magnesium	Percent	72.7	27.3	0	100.0	31.0	69.0
Manganese	mg/kg	0	100.0	0	100.0	0	100.0
Neodymium	mg/kg	10.5	89.5	47.7	52.3	40.5	59.5
Nickel	mg/kg	5.6	94.4	22.2	77.8	7.0	93.0
Phosphorus	Percent	68.1	31.9	52.5	47.5	51.7	48.3
Potassium	Percent	0	100.0	36.1	63.9	25.2	74.8
Scandium	mg/kg	59.1	40.1	50.3	49.7	31.4	68.6
Selenium	mg/kg	33.4	66.6	43.7	56.3	0	100.0
Sodium	Percent	0.6	99.4	47.1	52.9	0	100.0
Strontium	mg/kg	45.2	54.8	34.5	65.5	24.9	75.1
Titanium	Percent	26.0	74.0	52.9	47.1	32.6	67.5
Vanadium	mg/kg	25.9	74.1	0	100.0	18.7	81.3
Yttrium	mg/kg	21.8	78.2	52.3	47.7	37.0	63.0
Zinc	mg/kg	44.2	55.8	0	100.0	5.7	94.3

soil zone; and phosphorus in the reduced soil zone. This relation indicates that soil taxonomy reflects differences in total element concentrations among taxonomic units for only those elements listed above in each soil zone. The differences in total element concentrations within a soil series generally are greater than among soil series for most elements in each of the three soil zones. Therefore, extrapolations for chemical composition of a soil series, or the oxidized, mottled, or reduced soil zones from a soil series, cannot be made across the study area where this same soil series is present.

Element Associations

R-mode factor analysis (Jöreskog and others, 1976) of the weighted-average values for the oxidized, mottled, and reduced soil zones was performed using an oblique solution with extreme variables as the reference axis. Correlations between the sample scores and the variables are given in tables 11 through 13 for the three soil zones. Correlation coefficients quantify the relation between an element and a factor. Positive coefficients indicate element enrichment for a factor, whereas negative coefficients indicate element depletion. Because an oblique solution was used, an element can be associated with more than one factor. Factor analysis is used as an aid in interpreting the relation among a large number of variables by grouping them into a few factors. These element associations then are interpreted as processes.

Optimum models for the oxidized soil zone (table 11) and the reduced soil zone (table 13) each had six factors. The optimum model for the mottled soil zone (table 12) had five factors. The soil matrix is represented by factor 1 for the oxidized and mottled soil zones and by factor 2 for the reduced soil zone. Calcium and magnesium carbonate minerals are represented by factor 2 for the oxidized and mottled soil zones and by factor 3 for the reduced soil zone. In the oxidized soil zone, the carbonate minerals are associated positively with phosphorus and strontium and negatively with manganese. In contrast, manganese forms a positive association with the carbonate factor in the mottled soil zone, but there are no associations with the carbonate factor in the reduced soil zone. Factor 4 in the oxidized soil zone contains arsenic associated with titanium. No apparent explanation exists for this association. Arsenic associates mainly with transition metals in the mottled soil zone (factor 4) and in the reduced soil zone (factor 4). Factor 5 in the oxidized soil zone and factor 4 in the mottled soil zone represent metals associated with manganese oxides, whereas the manganese factor in the reduced soil zone (factor 5) does not indicate these same associations. In the reduced soil zone, these same metals are associated with iron on the arsenic factor (factor 4). A sodium factor (factor 3) in the oxidized soil zone has no counterparts in either of the other two soil zones. Factor 6 in the oxidized soil zone appears to be related inversely to factor 3; elements that relate positively with factor 3 relate negatively with factor 6 and vice versa. Factor 6 in the oxidized soil zone (the selenium factor) has factor 5 in the mottled soil zone and factor 6 in the reduced soil zone as counterparts. However, selenium is associated with different elements in the three soil zones. In the oxidized soil zone, selenium is associated with calcium and magnesium phosphates and probably carbonates; in the mottled soil zone,

Table 11.--Factor compositions, expressed as correlation coefficients, for the oxidized soil zone in the Oakes test area

[Elements having a correlation coefficient (Cc) less than 0.50 are not listed]

Factor 1		Factor 2		Factor 3		Factor 4		Factor 5		Factor 6	
Element	Cc	Element	Cc	Element	Cc	Element	Cc	Element	Cc	Element	Cc
Lanthanum	0.99	Strontium	0.98	Sodium	0.98	Arsenic	0.99	Manganese	0.98	Selenium	0.95
Neodymium	.98	Calcium	.70			Titanium	.55	Cobalt	.65	Phosphorus	.70
Yttrium	.98	Magnesium	.58					Nickel	.65	Magnesium	.58
Cerium	.97	Phosphorus	.51					Iron	.57	Calcium	.54
Titanium	.94							Gallium	.56		
Chromium	.91							Zinc	.55		
Aluminum	.89							Lead	.53		
Scandium	.84							Vanadium	.53		
Iron	.83							Copper	.51		
Gallium	.81										
Zinc	.80										
Vanadium	.77										
Barium	.75										
Lithium	.75			Selenium	-.50						
Nickel	.74			Vanadium	-.50						
Cobalt	.73			Scandium	-.52						
Copper	.72			Lithium	-.56						
Lead	.72			Calcium	-.62						
Potassium	.57			Magnesium	-.62						
Phosphorus	.51	Manganese	-.50	Copper	-.63			Strontium	-.50	Sodium	-.51
Percentage of total variance explained by each factor											
59.9		15.8		9.9		4.3		2.9		1.9	

Table 12.--Factor compositions, expressed as correlation coefficients, for the mottled soil zone in the Oakes test area

[Elements having a correlation coefficient (Cc) less than 0.50 are not listed]

Factor 1		Factor 2		Factor 3		Factor 4		Factor 5	
Element	Cc	Element	Cc	Element	Cc	Element	Cc	Element	Cc
Sodium	0.96	Magnesium	0.95	Vanadium	0.97	Manganese	0.95	Selenium	0.91
Strontium	.94	Calcium	.90	Lithium	.89	Magnesium	.71	Scandium	.62
Phosphorus	.92	Manganese	.71	Zinc	.80	Calcium	.69	Cobalt	.53
Titanium	.92	Gallium	.51	Chromium	.66	Gallium	.55		
Yttrium	.90	Lead	.51	Scandium	.62	Nickel	.55		
Lanthanum	.89			Aluminum	.59	Arsenic	.51		
Neodymium	.89			Potassium	.59	Cobalt	.51		
Aluminum	.87			Copper	.50				
Barium	.87								
Cerium	.87								
Scandium	.75								
Chromium	.71								
Potassium	.67								
Gallium	.62								
Zinc	.52								
Cobalt	.51								
Copper	.51			Arsenic	-.70				
Percentage of total variance explained by each factor									
50.9		15.4		8.9		5.6		5.2	

Table 13.--Factor compositions, expressed as correlation coefficients, for the reduced soil zone in the Oakes test area

[Elements having a correlation coefficient (Cc) less than 0.50 are not listed]

Factor 1		Factor 2		Factor 3		Factor 4		Factor 5		Factor 6	
Element	Cc	Element	Cc	Element	Cc	Element	Cc	Element	Cc	Element	Cc
Scandium	0.92	Potassium	0.93	Calcium	0.99	Arsenic	0.96	Manganese	0.96	Selenium	0.94
Vanadium	.92	Aluminum	.90	Magnesium	.86	Nickel	.73	Calcium	.50	Nickel	.64
Chromium	.91	Barium	.87			Zinc	.62			Zinc	.60
Iron	.91	Yttrium	.71			Cobalt	.59			Arsenic	.54
Lithium	.88	Gallium	.70			Iron	.56				
Zinc	.86	Lanthanum	.70			Lithium	.55				
Nickel	.85	Titanium	.70			Gallium	.54				
Copper	.83	Cerium	.69			Scandium	.54				
Yttrium	.83	Phosphorus	.69			Selenium	.53				
Gallium	.81	Neodymium	.68			Vanadium	.53				
Titanium	.80	Lithium	.65			Yttrium	.50				
Cobalt	.78	Strontium	.65								
Cerium	.77	Chromium	.59								
Neodymium	.76	Scandium	.58								
Lanthanum	.75	Zinc	.52								
Lead	.71	Iron	.50								
Aluminum	.65										
Phosphorus	.54							Barium	-.50		
Arsenic	.51							Sodium	-.56		
Magnesium	.51							Strontium	-.57	Sodium	-.58
Percentage of variance explained by each factor											
57.9		17.2		8.0		3.7		3.6		2.3	

selenium is associated with cobalt and scandium; and in the reduced soil zone, selenium is associated with arsenic, nickel, and zinc. These differences in selenium associations probably reflect differences in selenium chemistry under oxidizing and reducing conditions.

Factor scores for the selenium factor from the oxidized, mottled, and reduced soil zones, are shown in figures 7 through 9. Factor scores indicate how close the composition of each sample is to the factor's assigned theoretical end-member composition (Jöreskog and others, 1976); a sample with a large positive score on any factor indicates that the end-member composition of that factor represents the sample composition fairly well. A score near zero for a sample factor indicates that the sample composition is not similar to the end-member composition. A large negative score indicates that the composition of the sample opposes that of the end member, indicating depletion of the element rather than enrichment. Each sample has as many factor scores as there are factors. Thus, the combined scores define the mixture of end-member compositions that compose the sample. The same general patterns are shown in figures 7 through 9 with selenium and associated elements increasing in enrichment from east to west-northwest across the study area.

The factor analysis indicates that element associations in the oxidized soil zone differ from those in the mottled and reduced soil zones. These differences reflect the way in which elements react to oxidizing or reducing chemical conditions. If the natural water table is altered by irrigation and drainage practices, then the element associations will be altered to reflect the changes. If the changes are toward more oxidizing conditions (lowered water table), then increased mobility of arsenic, selenium, and associated elements and decreased mobility of cadmium, copper, lead, zinc, and associated elements can be expected. If the changes are toward more reducing conditions (raised water table), then the opposite trends in element mobility can be expected. Changes could be expected to be greatest in the west-northwest part of the study area, especially for selenium, as reflected in factor scores. This trend seems reasonable because the ground-water gradient is from east to west, and the northwest part of the area contains finer textured soils and smaller depths to impermeable materials.

These interpretations of factor analysis and predictions of increased or decreased element mobility, resulting from changes in oxidation-reduction reactions, are qualitative. Quantitative predictions of increases or decreases in actual element concentrations are not feasible from the existing data. However, results of water-extraction analyses on soils collected in the reconnaissance phase of this study suggest that, under oxidizing conditions, only small amounts of arsenic and selenium will be mobilized. On the basis of these results, the soils of the west Oakes irrigation area should react similarly to increases in oxidation potential and release only small quantities of selenium or arsenic.

Geochemistry of Shallow Ground Water

To evaluate the occurrence and distribution of trace elements in shallow ground water in the Oakes test area, water samples were collected

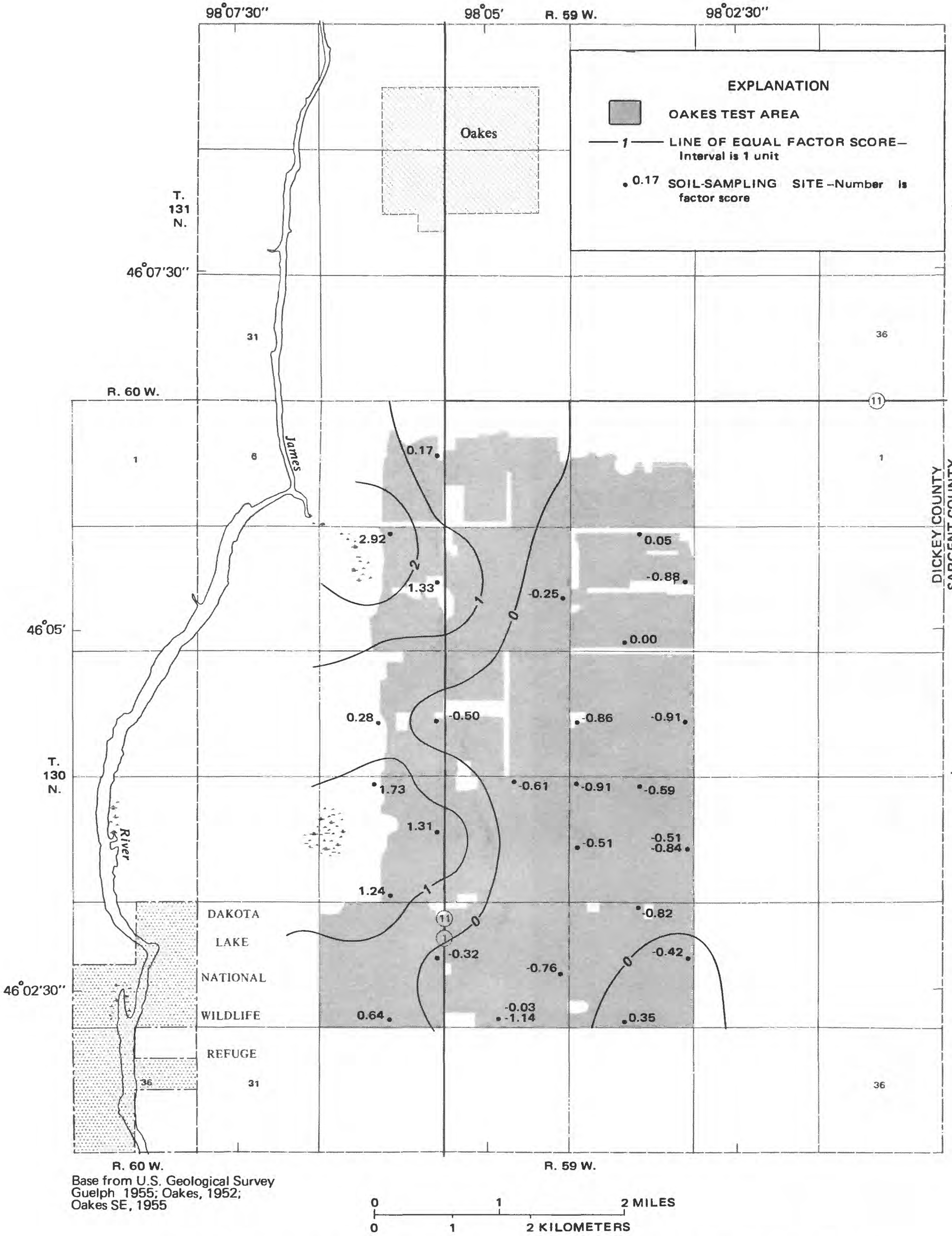


Figure 7.—Factor scores for the selenium factor from the oxidized soil zone in the Oakes test area. [Modified from Severson and others, 1988.]

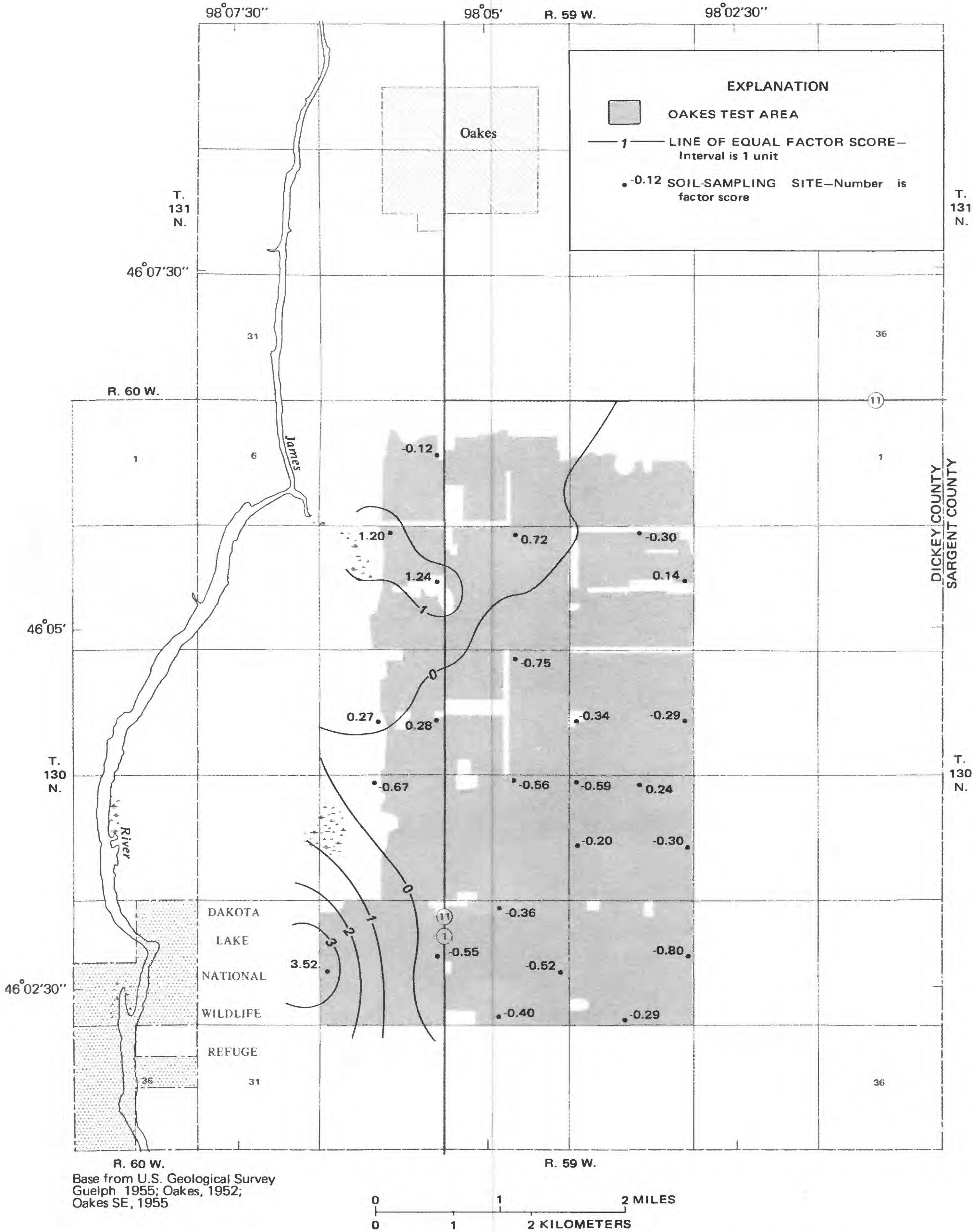
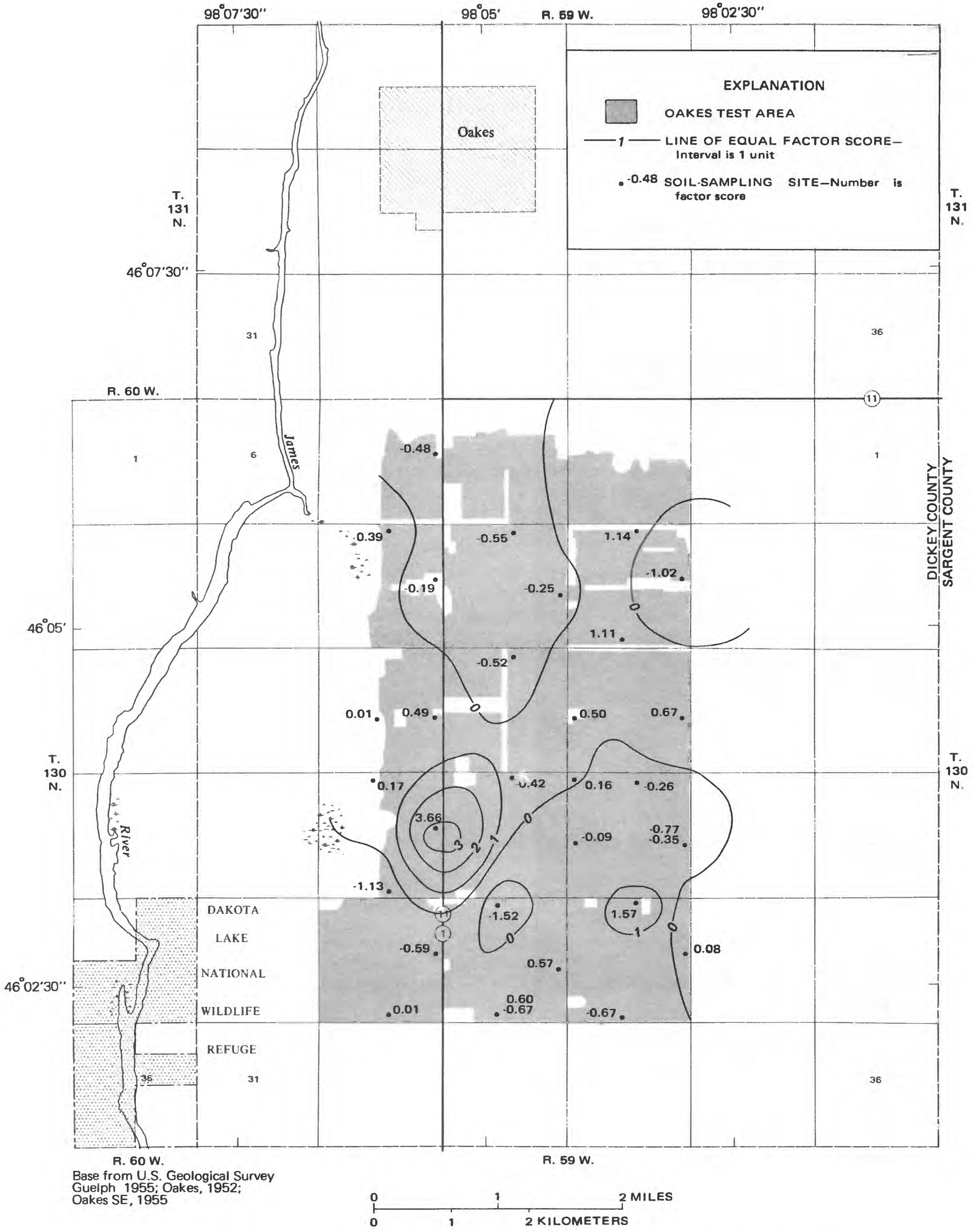


Figure 8.—Factor scores for the selenium factor from the mottled soil zone in the Oakes test area. [Modified from Severson and others, 1988.]



Base from U.S. Geological Survey
Guelph 1955; Oakes, 1952;
Oakes SE, 1955

Figure 9.—Factor scores for the selenium factor from the reduced soil zone in the Oakes test area. [Modified from Severson and others, 1988.]

from wells and drains for chemical analysis. In a preliminary survey, 104 U.S. Bureau of Reclamation observation wells were sampled during January 1986 and analyzed for 30 chemical constituents to determine which constituents should be included in the detailed evaluation. Observation wells sampled in the preliminary survey were distributed throughout the entire west Oakes irrigation area (fig. 10). Analytical results for these samples are presented in Wilson and others (1989b). A statistical summary of these data is given in table 14. On the basis of these results, a decision was made to include arsenic, boron, cadmium, iron, manganese, mercury, molybdenum, and selenium in future sampling that would be limited to the Oakes test area.

Detailed sampling of observation wells and drains was conducted in the Oakes test area from December 1986 to September 1987. Samples were collected quarterly from 33 observation wells and 16 subsurface drain sites and analyzed for 21 chemical constituents, including the trace elements discussed above. An additional 30 wells and seven drains were sampled at least two times during this period and were analyzed for 11 chemical constituents but no trace elements (Wald and others, 1989). The locations of the observation wells are shown in figure 10; locations of drain-sample collection sites are shown in figure 4. Analytical results for samples collected are presented in Wald and others (1989). A statistical summary of these data is given in tables 15 and 16.

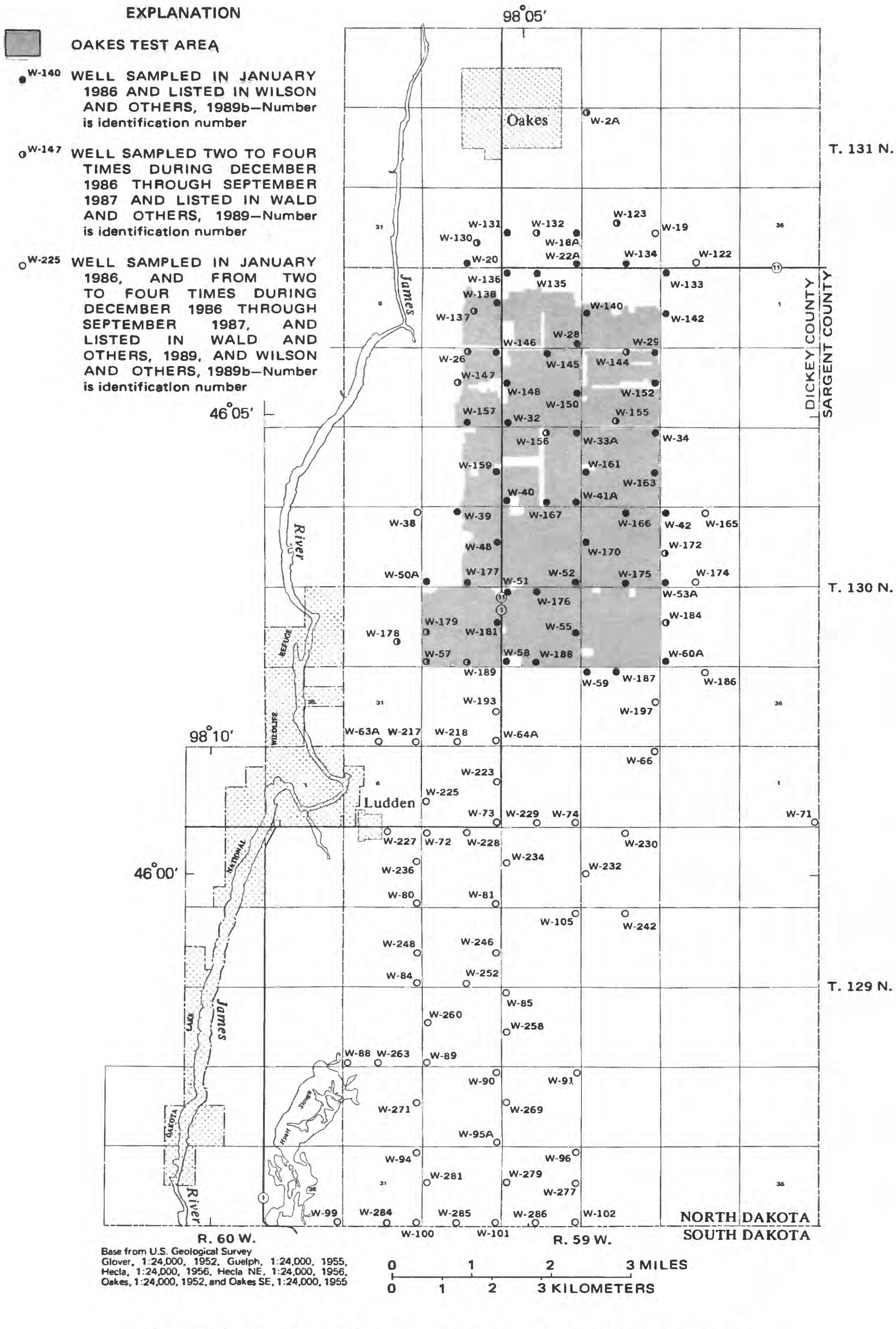
The James River is the only significant surface-water feature in or adjacent to the west Oakes irrigation area. The river was not a subject of this investigation, but its chemical characteristics have been discussed in a separate report (Briel, 1988). Since the chemical characteristics of the James River are important in evaluating potential effects of expanded irrigation in the GDU, a statistical summary of chemical data from five gaging stations on the James River from north of Arrowwood Lake to the North Dakota-South Dakota State line (fig. 1) is given in table 31 at the end of this report.

Water-Sample Collection, Processing, and Analytical Methods

The following discussion of water-sample collection, processing, and analytical methods is synthesized from Wald and others (1989) and Wilson and others (1989b).

Ground-water observation well construction.--Wells were constructed by the U.S. Bureau of Reclamation. Casing material was 2-in. diameter polyvinyl chloride (PVC) and had about 2 ft of 10-slot screen at the bottom. Casing joints were glued. The annular area around the screen was filled with pea-size gravel from a local source. A bentonite seal was constructed 1 to 2 ft below land surface (Richard Lunde, U.S. Bureau of Reclamation, oral commun., 1989).

Water-sample collection methods.--Water levels in the wells were measured using nonmetallic tapes as described by Garber and Koopman (1969). The wells were bailed using PVC bailers until 2.5 times the volume of standing water was removed. After the wells were bailed, the water level was allowed to recover for 24 hours or until water levels returned to within 5 percent of their


EXPLANATION

▨ OAKES TEST AREA

● W-140 WELL SAMPLED IN JANUARY 1986 AND LISTED IN WILSON AND OTHERS, 1989b—Number is identification number

○ W-147 WELL SAMPLED TWO TO FOUR TIMES DURING DECEMBER 1986 THROUGH SEPTEMBER 1987 AND LISTED IN WALD AND OTHERS, 1989—Number is identification number

○ W-225 WELL SAMPLED IN JANUARY 1986, AND FROM TWO TO FOUR TIMES DURING DECEMBER 1986 THROUGH SEPTEMBER 1987, AND LISTED IN WALD AND OTHERS, 1989, AND WILSON AND OTHERS, 1989b—Number is identification number

Base from U.S. Geological Survey Glover, 1:24,000, 1952, Guelph, 1:24,000, 1955, Hecla, 1:24,000, 1956, Hecla NE, 1:24,000, 1956, Oakes, 1:24,000, 1952, and Oakes SE, 1:24,000, 1955

Figure 10.—Location of data-collection sites in the west Oakes irrigation area.

Table 14.--Statistical summary of selected well, chemical-property, and chemical-constituent data collected from 104 wells in the west Oakes irrigation area during January 1986

[Samples collected by the U.S. Bureau of Reclamation and analyzed by the U.S. Geological Survey; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; >, greater than; <, less than; --, no data]

	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Well									
Depth of well (feet)	103	30	12	20	25	21	21	19	15
Altitude of land surface (feet above sea level)	104	1,317	1,288	1,306	1,314	1,311	1,306	1,302	1,294
Chemical property									
Specific conductance (µS/cm)	104	17,000	500	1,410	5,290	1,015	795	650	535
pH (standard units)	104	7.6	6.8	7.3	7.6	7.4	7.4	7.3	7.0
Temperature, water (°C)	104	9.5	5.5	7.4	8.8	8.0	7.0	7.0	6.0
Chemical constituent									
Oxygen, dissolved (mg/L)	102	6.0	0	2.0	4.9	2.8	1.8	1.0	0.1
Calcium, dissolved (mg/L as Ca)	104	>500	41	130	380	130	100	81	62

See footnote at end of table.

Table 14.--Statistical summary of selected well, chemical-property, and chemical-constituent data collected from 104 wells in the west Oakes irrigation area during January 1986--Continued

Type of data	Sample size	Descriptive statistics: Maximum	Minimum	Mean	Percentage of samples in which values were less than or equal to those shown: 95	75	Median 50	25	5
Chemical constituent, Continued									
Magnesium, dissolved (mg/L as Mg)	104	>500	17	63	270	50	37	29	22
Sodium, dissolved (mg/L as Na)	104	>500	3.9	80	>500	54	26	15	5.8
Sodium-adsorption ratio	96	4.0	.1	.8	4.0	.8	.6	.3	.1
Potassium, dissolved (mg/L as K)	104	64	1.4	7.6	20	8.9	5.4	3.8	2.1
Sulfate, dissolved (mg/L as SO_4)	104	6,800	6.1	330	2,200	160	81	49	18
Chloride, dissolved (mg/L as Cl)	104	970	.6	33	160	18	8.0	4.4	1.4
Fluoride, dissolved (mg/L as F)	103	4.5	.1	.6	2.6	.6	.4	.2	.2
Silica, dissolved (mg/L as SiO_2)	104	17	12	15	16	16	15	14	12
Nitrate, dissolved (mg/L as N)	99	140	<.2	[1]2.4	[1]7.2	[1].36	[1].18	[1].07	[1].01
Phosphate, ortho, dissolved (mg/L as PO_4)	95	1.0	.01	[1].13	[1].42	[1].20	[1].08	[1].04	[1].02
Aluminum, dissolved (µg/L as Al)	104	9,900	<100	[1]300	[1]1,100	[1]100	[1]40	[1]10	[1]0
Arsenic, dissolved (µg/L as As)	104	44	<2	[1]6	[1]18	[1]7	[1]3	[1]2	[1]1
Barium, dissolved (µg/L as Ba)	104	570	4	180	440	270	170	70	20
Beryllium, dissolved (µg/L as Be)	104	<1	--	--	--	--	--	--	--
Bismuth, dissolved (µg/L as Bi)	104	<10	--	--	--	--	--	--	--
Boron, dissolved (µg/L as B)	104	3,000	<10	130	280	90	60	30	20
Cadmium, dissolved (µg/L as Cd)	104	<1	--	--	--	--	--	--	--

See footnote at end of table.

Table 14.--Statistical summary of selected well, chemical-property, and chemical-constituent data collected from 104 wells in the west Oakes irrigation area during January 1986--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Chemical constituent, Continued									
Chromium, dissolved (µg/L as Cr)	104	2	<1	[1]0.28	[1]1	[1]0.3	[1]0.1	[1]0.1	[1]0.02
Cobalt, dissolved (µg/L as Co)	104	10	<3	[1]1.1	[1]5.5	[1]1.2	[1].5	[1].2	[1].1
Copper, dissolved (µg/L as Cu)	104	<10	--	--	--	--	--	--	--
Gallium, dissolved (µg/L as Ga)	104	<5	--	--	--	--	--	--	--
Iron, dissolved (µg/L as Fe)	104	8,700	<10	[1]270	[1]1,200	[1]190	[1]60	[1]14	[1]2
Lead, dissolved (µg/L as Pb)	104	<10	--	--	--	--	--	--	--
Lithium, dissolved (µg/L as Li)	104	5,000	<4	140	480	80	40	20	10
Manganese, dissolved (µg/L as Mn)	104	5,600	21	820	2,000	1,000	740	460	62
Selenium, dissolved (µg/L as Se)	104	9	<2	[1].7	[1]3	[1].7	[1].3	[1].1	[1].03
Silver, dissolved (µg/L as Ag)	104	<2	--	--	--	--	--	--	--
Strontium, dissolved (µg/L as Sr)	104	6,400	130	570	1,900	550	380	250	140
Zinc, dissolved (µg/L as Zn)	104	240	4	20	46	17	12	8	5

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[1] Concentration is estimated by using a log-probability regression to predict the values of data less than the detection limit.

Table 15.--Statistical summary of selected well, chemical-property, and chemical-constituent data collected from 63 wells in the Oakes test area during December 1986 through September 1987

[Samples collected and analyzed by the U.S. Bureau of Reclamation; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data]

	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Well									
Water level (feet below land surface)	131	19.20	7.60	12.54	18.02	13.80	11.90	10.90	8.88
Depth of well (feet)	192	30	9.6	20	28	21	20	19	17
Altitude of land surface (feet above sea level)	192	1,317	1,297	1,309	1,314	1,312	1,310	1,306	1,302
Chemical property									
Specific conductance (µS/cm)	192	6,800	445	1,050	5,150	920	782	611	528
pH (standard units)	192	8.2	6.9	7.5	7.7	7.5	7.5	7.4	7.3
Temperature, water (°C)	192	15.0	6.0	9.8	13.0	11.0	9.8	8.5	7.0
Chemical constituent									
Oxygen, dissolved (mg/L)	131	4.3	0.4	1.4	2.8	1.7	1.3	0.9	0.5
Calcium, dissolved (mg/L as Ca)	192	600	47	110	220	120	98	80	68

See footnote at end of table.

Table 15.--Statistical summary of selected well, chemical-property, and chemical-constituent data collected from 63 wells in the Oakes test area during December 1986 through September 1987--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Chemical constituent, Continued									
Magnesium, dissolved (mg/L as Mg)	192	360	16	51	300	42	33	27	23
Sodium, dissolved (mg/L as Na)	192	1,400	1.1	73	550	41	22	10	4.0
Sodium-adsorption ratio	192	15	<.1	1.0	5.0	.9	.5	.2	.1
Potassium, dissolved (mg/L as K)	192	23	.3	5.6	14	6.7	4.6	3.1	1.8
Bicarbonate (mg/L as HCO_3)	192	1,260	170	416	624	498	390	320	263
Sulfate, dissolved (mg/L as SO_4)	192	3,400	11	260	3,040	120	76	54	29
Chloride, dissolved (mg/L as Cl)	192	190	1.0	21	100	20	11	5.9	1.9
Nitrite plus nitrate, dissolved (mg/L as N)	192	32	<.01	.76	4.7	.13	.04	.02	.01
Nitrogen, nitrite, dissolved (mg/L as N)	192	.15	.01	--	--	--	--	--	--
Nitrogen, ammonia, dissolved (mg/L as N)	192	1.6	<.01	.30	.83	.37	.26	.12	.01
Phosphate, ortho, dissolved (mg/L as PO_4)	192	.40	<.01	.02	.08	.02	.01	<.01	<.01
Arsenic, dissolved (µg/L as As)	132	41	<1	[1]6	[1]19	[1]8	[1]4	[1]2	[1].6
Boron, dissolved (µg/L as B)	132	400	40	100	220	120	90	60	40
Cadmium, dissolved (µg/L as Cd)	132	3	<1	[1].6	[1]2	[1].7	[1].4	[1].3	[1].1
Iron, dissolved (µg/L as Fe)	132	5,500	10	650	3,100	620	270	60	20

See footnote at end of table.

Table 15.--Statistical summary of selected well, chemical-property, and chemical-constituent data collected from 63 wells in the Oakes test area during December 1986 through September 1987--Continued

	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Chemical constituent, Continued									
Manganese, dissolved (µg/L as Mn)	132	5,000	13	840	1,800	1,000	720	560	100
Mercury, dissolved (µg/L as Hg)	130	.8	<.1	[1].1	[1].4	[1].2	[1].1	[1].04	[1].01
Molybdenum, dissolved (µg/L as Mo)	132	9	1	3	6	4	3	3	1
Selenium, dissolved (µg/L as Se)	132	5	<1	[1].6	[1]3	[1].7	[1].3	[1].1	[1].03
Carbon, organic, total (mg/L as C)	129	110	2.1	7.9	22	7.7	5.4	4.1	2.4

[1] Concentration is estimated by using a log-probability regression to predict the values of data less than the detection limit.

Table 16.--Statistical summary of selected chemical-property and chemical-constituent data collected from 23 drains in the Oakes test area during December 1986 through September 1987

[Samples collected and analyzed by the U.S. Bureau of Reclamation; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data]

		Descriptive statistics			Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Chemical property									
Specific conductance (µS/cm)	80	1,300	612	823	1,060	889	800	758	637
pH (standard units)	80	7.8	7.3	7.4	7.6	7.4	7.4	7.4	7.3
Temperature, water (°C)	80	22.0	2.5	9.5	13.0	11.4	9.5	8.0	5.5
Chemical constituent									
Oxygen, dissolved (mg/L)	63	9.4	0.3	4.0	8.7	6.3	4.3	0.8	0.4
Calcium, dissolved (mg/L as Ca)	80	120	81	100	120	110	100	96	84
Magnesium, dissolved (mg/L as Mg)	80	52	24	37	47	41	36	34	26
Sodium, dissolved (mg/L as Na)	80	140	9.9	30	60	34	24	18	10
Sodium-adsorption ratio	80	3.0	.2	.7	1.0	.8	.5	.4	.2
Potassium, dissolved (mg/L as K)	80	22	3.2	5.8	8.4	6.4	5.6	4.7	3.4
Bicarbonate (mg/L as HCO_3)	80	560	300	406	500	440	390	380	330
Sulfate, dissolved (mg/L as SO_4)	80	260	40	100	170	110	100	82	47
Chloride, dissolved (mg/L as Cl)	80	25	4.5	12	22	15	12	8.7	4.7
Nitrite plus nitrate, dissolved (mg/L as N)	80	3.8	<.01	1.6	3.1	2.0	1.5	.97	.41

See footnote at end of table.

Table 16.--Statistical summary of selected chemical-property and chemical-constituent data collected from 23 drains in the Oakes test area during December 1986 through September 1987--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Chemical constituent, Continued									
Nitrogen, nitrite, dissolved (mg/L as N)	80	0.03	<0.01	--	--	--	--	--	--
Nitrogen, ammonia, dissolved (mg/L as N)	80	.68	<.01	0.18	0.33	0.25	0.17	0.09	0.02
Phosphate, ortho, dissolved (mg/L as PO_4)	80	.18	<.01	.02	.05	.02	.01	.01	0
Arsenic, dissolved (µg/L as As)	63	11	1	4	9	4	3	2	1
Boron, dissolved (µg/L as B)	63	120	40	70	100	90	70	60	50
Cadmium, dissolved (µg/L as Cd)	63	<1	--	--	--	--	--	--	--
Iron, dissolved (µg/L as Fe)	63	590	10	140	430	200	90	50	20
Manganese, dissolved (µg/L as Mn)	63	1,400	52	550	690	710	510	400	200
Mercury, dissolved (µg/L as Hg)	63	.2	<.1	[1].08	[1].2	[1].1	[1].06	[1].04	[1].01
Molybdenum, dissolved (µg/L as Mo)	63	6	1	4	6	4	3	3	2
Selenium, dissolved (µg/L as Se)	63	4	<1	[1]1.4	[1]3	[1]2	[1]1	[1].8	[1].5
Carbon, organic, total (mg/L as C)	61	16	1.5	4.1	7.9	4.7	3.7	3.0	2.1

[1] Concentration is estimated by using a log-probability regression to predict the values of data less than the detection limit.

original level. Prior to further disturbance, the downhole water temperature and dissolved oxygen concentration were measured using calibrated Yellow Springs Instruments Models 57 and 58 dissolved oxygen/temperature meters. The dissolved oxygen meters were calibrated in the morning and in the evening. The meters, which were not shut off during the day, were determined to have remained in calibration.

After the downhole measurements, ground-water samples were collected by U.S. Bureau of Reclamation personnel. Five liters of ground water was collected with a PVC bailer and placed in polyethylene containers that had been rinsed previously with sample water. All samples were returned to the U.S. Bureau of Reclamation headquarters in Oakes within 1 hour after collection for processing.

Concurrent with ground-water sampling, water samples were collected from drains at selected drain access sites. Samples were collected from the centroid of drain flow using a teflon sampler. Water samples collected from the drain sites were handled, processed, and analyzed in the same manner as described for ground-water samples.

Water-sample processing methods.--Sample processing and preparation for laboratory analysis were completed by U.S. Bureau of Reclamation chemistry technicians and a U.S. Geological Survey hydrologic technician at the U.S. Bureau of Reclamation headquarters in Oakes. Specific conductance and pH were measured on sample aliquots using a Markson Electromark conductance meter and an Orion Model 811 pH meter. Each sample then was composited (if necessary) in a 6-L Teflon churn splitter for sample splitting. A 250-mL aliquot was drawn from the churn into a sample-rinsed 250-mL polyethylene bottle for laboratory determination of pH, specific conductance, and carbonate and bicarbonate concentrations. An additional 100-mL aliquot was drawn from the churn into a sample-rinsed glass bottle for determination of total organic carbon concentration.

Remaining sample water was filtered and separated into different aliquots for chemical analysis. A peristaltic pump equipped with sample-rinsed silicone rubber tubing was used to deliver sample water from the churn splitter through a Geotech Plate filter apparatus containing a 142-mm diameter, 0.45-µm pore size membrane filter. Filtered water was collected directly in sample bottles of appropriate size and preserved according to the analysis to be performed on that sample aliquot. A 250-mL sample aliquot was filtered into an acid-rinsed polyethylene bottle and was preserved with 2 mL of concentrated nitric acid to a pH of less than two for analysis of major cations. A 250-mL sample aliquot was filtered into a sample-rinsed polyethylene bottle for analysis of major anions. A 500-mL sample aliquot was filtered into an acid-rinsed polyethylene bottle for analysis of most trace elements. A 200-mL sample aliquot was filtered into an acid-rinsed glass bottle and was preserved with a mixture of nitric acid and potassium dichromate for analysis of mercury. A 250-mL sample aliquot was filtered into a sample-rinsed brown polyethylene bottle and was preserved with mercuric chloride for analysis of nutrients (nitrogen and phosphorus). Nutrient samples were not processed until after all mercury samples had been processed and stored in a sealed cooler. Once processing was complete, samples were placed in iced coolers for shipment to the appropriate analytical laboratory.

Analytical methods.--Water samples collected for the preliminary survey in January 1986 were analyzed by the U.S. Geological Survey geochemistry laboratory in Lakewood, Colo. Samples collected during the detailed study (December 1986 through September 1987) were analyzed by the U.S. Bureau of Reclamation laboratory in Bismarck, N.Dak., for all constituents except total organic carbon. This constituent was analyzed by the U.S. Geological Survey water-quality laboratory in Arvada, Colo. Analysis of nutrient and organic-carbon samples normally was begun within 10 days of collection. Analysis of the remaining constituents normally was completed within 100 days of collection. The analytical methods and detection limits for determination of chemical constituents are given in table 17.

Quality assurance.--Processed distilled-water blanks and duplicate samples were analyzed by the U.S. Bureau of Reclamation and the U.S. Geological Survey laboratories. All sample blanks indicated that constituent concentrations were below detection limits. Values for 24 duplicate samples analyzed by both laboratories (Wald and others, 1989) indicated no particular laboratory biases or contamination. Analytical results for arsenic by the two laboratories show that only five of the 24 analyses differed by more than 1 μg/L and only two analyses differed by more than 2 μg/L. For selenium, only two of the 24 duplicate analyses differed by more than 1 μg/L.

Variability and Chemical Composition

The following discussion is based on ground-water-quality data from 376 water samples collected from wells and drains in the west Oakes irrigation area (Wald and others, 1989; Wilson and others, 1989b). Table 14 gives a statistical summary of data from wells that generally are distributed throughout the entire 23,660-acre west Oakes irrigation area (fig. 10). Data from wells and drains distributed over the 5,000-acre Oakes test area (fig. 10) are given in tables 15 and 16. The statistics include maximum, minimum, and mean values, and several percentiles, including the median. For samples that had values less than the analytical detection limits (table 17), a log-probability regression was used to estimate the mean and percentiles (Helsel and Cohn, 1988).

The chemical composition and ground-water type was determined using trilinear diagrams (Piper, 1944; Back, 1966).

Areal variability.--The concentrations of major cations and anions in ground water are extremely variable within the west Oakes irrigation area. The most variable ions are magnesium, sodium, sulfate, and chloride. Concentrations of these ions determined on samples from 120 wells (fig. 10) varied by factors of 20 to more than 200 (see statistics in tables 14 and 15.)

The areal variability in major ion and dissolved-solids concentrations is indicated by the map of specific conductance (fig. 11). The correlation between specific conductance and all major ions is significant at the 0.001 probability level. Dissolved-solids concentration, which was not determined for the samples, can be estimated by multiplying specific conductance by a factor ranging from about 0.55 to 0.75 (Hem, 1985). The median specific conductance of ground water in the area is about 790 μS/cm. By using a factor

Table 17.--Laboratory analytical methods and detection limits for determination of chemical constituents in water

[Modified from Wald and others, 1989, and Wilson and others, 1989b; ICAP/OES, inductively-coupled argon plasma/optical emission spectroscopy; IC, ion chromatography; HG/AAS, hydride generation/atomic absorption spectroscopy; mg/L, milligrams per liter; µg/L, micrograms per liter; None, detection limit not given]

U.S. Geological Survey geochemistry laboratory, Lakewood, Colo.

Constituent determined	Analytical method	Detection limit
Calcium	ICAP/OES.	0.2 mg/L
Magnesium	ICAP/OES.	0.01 mg/L
Sodium	ICAP/OES.	0.2 mg/L
Potassium	ICAP/OES.	1 mg/L
Sulfate	IC.	1 mg/L
Chloride	IC.	0.1 mg/L
Fluoride	IC.	0.1 mg/L
Silica	ICAP/OES.	0.01 mg/L
Nitrate-nitrogen	IC.	0.1 mg/L
Orthophosphate	IC.	0.2 mg/L
Aluminum	ICAP/OES.	0.1 mg/L
Arsenic	HG/AAS.	2 µg/L
Barium	ICAP/OES.	10 µg/L
Beryllium	ICAP/OES.	1 µg/L
Bismuth	ICAP/OES.	10 µg/L
Boron	ICAP/OES.	0.1 µg/L
Cadmium	ICAP/OES.	1 µg/L
Chromium	ICAP/OES.	1 µg/L
Cobalt	ICAP/OES.	3 µg/L
Copper	ICAP/OES.	10 µg/L
Gallium	ICAP/OES.	5 µg/L
Iron	ICAP/OES.	3 µg/L
Lead	ICAP/OES.	10 µg/L
Lithium	ICAP/OES.	4 µg/L
Manganese	ICAP/OES.	1 µg/L
Selenium	HG/AAS.	2 µg/L
Silver	ICAP/OES.	2 µg/L
Strontium	ICAP/OES.	0.5 µg/L
Zinc	ICAP/OES.	3 µg/L

See footnote at end of table.

Table 17.--Laboratory analytical methods and detection limits for determination of chemical constituents in water--Continued

U.S. Bureau of Reclamation water-quality laboratory, Bismarck, N.Dak.

Constituent determined	Analytical method	Detection limit
Calcium	Atomic absorption, direct.	0.1 mg/L
Magnesium	Atomic absorption, direct.	0.1 mg/L
Sodium	Atomic absorption, direct.	0.1 mg/L
Potassium	Atomic absorption, direct.	0.05 mg/L
Carbonate	Titration.	None
Bicarbonate	Titration.	None
Chloride	Titration, $AgNO_3$.	0.1 mg/L
Sulfate	Colorimetry, automatic.	2 mg/L
Nitrate-nitrogen	Colorimetry, automatic.	0.01 mg/L
Nitrite-nitrogen	Colorimetry, automatic.	0.01 mg/L
Ammonia-nitrogen	Colorimetry, automatic.	0.05 mg/L
Orthophosphate	Colorimetry, automatic.	0.01 mg/L
Arsenic	Atomic absorption, furnace.	1 µg/L
Boron	Colorimetry, automatic.	40 µg/L
Cadmium	Atomic absorption, furnace.	1 µg/L
Iron	Atomic absorption, direct.	10 µg/L
Manganese	Atomic absorption, direct.	2 µg/L
Mercury	Atomic absorption, flameless.	0.1 µg/L
Molybdenum	Atomic absorption, furnace.	1 µg/L
Selenium	Atomic absorption, hydride, and furnace.[1]	1 µg/L

See footnote at end of table.

Table 17.--Laboratory analytical methods and detection limits for determination of chemical constituents in water--Continued

U.S. Geological Survey water-quality laboratory, Arvada, Colo.

Constituent determined	Analytical method	Detection limit
Calcium	Atomic absorption, direct.	0.1 mg/L
Magnesium	Atomic absorption, direct.	0.1 mg/L
Sodium	Atomic absorption, direct.	0.1 mg/L
Potassium	Atomic absorption, direct.	0.1 mg/L
Carbonate	Titration.	None
Bicarbonate	Titration.	None
Chloride	Colorimetry, discrete analyzer, automatic.	0.1 mg/L
Sulfate	Turbidimetry, automatic.	0.2 mg/L
Nitrate-nitrogen	IC.	0.01 mg/L
Nitrite-nitrogen	Colorimetry, diazotization, automatic.	0.01 mg/L
Ammonia-nitrogen	Colorimetry, automatic.	0.01 mg/L
Orthophosphate	Colorimetry, phosphomolybdate, automatic.	0.01 mg/L
Arsenic	Atomic absorption, hydride, automatic.	1 µg/L
Boron	Atomic emission, DC plasma.	10 µg/L
Cadmium	Atomic absorption, chel-extraction.	1 µg/L
Iron	Atomic absorption, direct.	10 µg/L
Manganese	Atomic absorption, direct.	10 µg/L
Mercury	Atomic absorption, flameless, automatic.	0.1 µg/L
Molybdenum	Atomic absorption, chel-extraction.	1 µg/L
Selenium	Atomic absorption, hydride, automatic.	1 µg/L
Total organic carbon	Combustion, infrared.	0.1 mg/L

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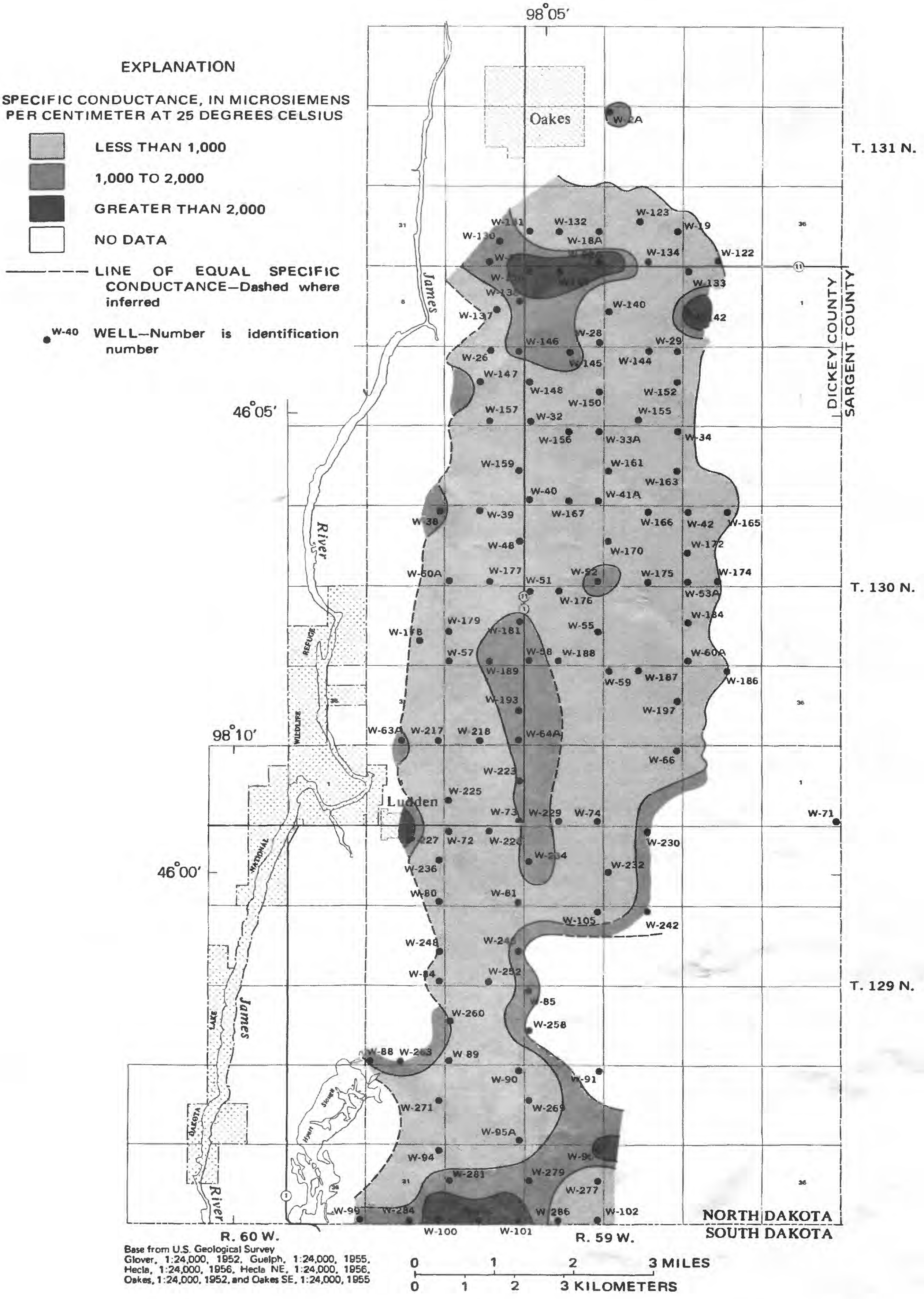
[1] Samples collected during December 1986 and March 1987 were analyzed by atomic absorption/hydride generation. Samples collected during June and September 1987 were analyzed by atomic absorption/graphite furnace (U.S. Bureau of Reclamation, written commun., 1989).



Base from U.S. Geological Survey
Glover, 1:24,000, 1952, Guelph, 1:24,000, 1955,
Hecla, 1:24,000, 1956, Hecla NE, 1:24,000, 1956,
Oakes, 1:24,000, 1952, and Oakes SE, 1:24,000, 1955

Figure 11.—Specific conductance of ground water in the west Oakes irrigation area, 1986-87.

of 0.65, this specific-conductance value equates to a median dissolved-solids concentration of about 515 mg/L. Throughout most of the area, the specific conductance is less than 1,000 µS/cm (fig. 11). In a few areas, specific conductance exceeds 2,000 µS/cm (fig. 11). The large specific-conductance values and dissolved ion concentrations tend to occur in areas where the water table is nearest the surface. In these areas, some of which are depressions, ground water is being discharged by evapotranspiration (Schuh and Shaver, 1988), which results in increased concentration of dissolved ions. This is particularly evident in the southern part of the west Oakes irrigation area where ground water discharges to shallow depressions (figs. 3 and 11), which also contain finer textured soils. Other locations where specific-conductance values are large are in the northern part of the west Oakes irrigation area where the water-table depth generally is 2 to 6 ft below land surface (U.S. Bureau of Reclamation, unpublished map, 1981).

Additional evidence of evaporative concentration is indicated by the water-extractable ion concentrations in soil-profile samples collected adjacent to three wells in the west Oakes irrigation area (Wilson and others, 1989a). Water-chemistry data for the wells (W-41A, W-218, and W-285 in fig. 10) and water-extractable ion concentrations in the adjacent soil profiles are given in table 18. Large concentrations of constituents in both soil and water occur at well W-285 in the southern part of the area, where ground-water flow patterns (fig. 3) suggest ground-water discharge by evapotranspiration. Also, in this soil profile, water-extractable concentrations of calcium, magnesium, and sulfate were considerably larger in the upper 3 ft of the profile than at lower depths in the profile. Concentrations of water-extractable constituents in the soil and dissolved ions in the water are much smaller at the other two well locations, where discharge by evapotranspiration is not occurring or is occurring to a much lesser extent.

The median concentrations of major ions and specific conductance in water from drains in the Oakes test area are almost the same as in water from wells (tables 15 and 16). However, major ion concentrations in water from the drains were much less variable than in water from wells. The drains, which consist of perforated, corrugated plastic pipe, are installed about 8 ft below land surface and into the saturated zone to collect water from near the water table. Concentrations of major ions in samples collected from 23 drain locations in three major drain basins (fig. 4) varied by factors of two to about 15. Statistically significant differences ($p = 0.05$) between the three drain basins were noted for concentrations of calcium, magnesium, bicarbonate, and sulfate. Tukey's multiple comparison test (SAS Institute, Inc., 1985) on rank transformations of the data indicated that calcium and magnesium concentrations were slightly larger in water from drain sites in the south drain (J.R. 8.1) basin than in the middle drain (J.R. 8.1-1.1) and north drain (J.R. 12.6-0.7) basins. Bicarbonate concentrations in water from the south drain basin were larger than those in the north drain basin, and sulfate concentrations in both the north and south drain basins were larger than those in the middle drain basin. Reasons for these small but statistically significant differences are not readily apparent, but they probably include agricultural practices, irrigation practices, discharge of ground water by evapotranspiration, and geochemistry of soils in the unsaturated zone. All of these could affect the chemistry of infiltrating and shallow ground water.

Table 18.--Water-extractable ion concentrations in soil-profile samples and dissolved ion concentrations and specific conductance in water samples collected from adjacent wells

[Units shown for values in second and third columns also apply to values in remaining columns; mg/kg, milligrams per kilogram; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; --, not applicable]

Ion or property	Soil profile at well W-41A	Well W-41A	Soil profile at well W-218	Well W-218	Soil profile at well W-285	Well W-285
Calcium	20-38 mg/kg	58 mg/L	29-74	100	126-456	406
Magnesium	18-64 mg/kg	25 mg/L	8-23	32	37-105	204
Sodium	10-30 mg/kg	22 mg/L	10-30	44	40-720	255
Potassium	20-38 mg/kg	7.5 mg/L	27-52	6.6	23-74	11
Chloride	6.5-30 mg/kg	5.9 mg/L	7.5-25	13	12-280	180
Sulfate	10-19 mg/kg	51 mg/L	18-30	75	890-2,200	1,500
Arsenic	0.01-0.06 mg/kg	<2 µg/L	0.01-0.08	13	0.01-0.04	3
Selenium	0.01-0.16 mg/kg	<2 µg/L	0.01-0.02	<2	0.01-0.02	<2
Molybdenum	0.018-0.064 mg/kg	<10 µg/L	0.001-0.220	<10	0.025-0.100	<10
Specific conductance	--	550 µS/cm	--	820	--	3,490

Concentrations of arsenic and selenium showed definite patterns in areal variability. Arsenic concentrations were largest in the middle part of the west Oakes irrigation area and smallest in the northern and southern parts of the area. Conversely, selenium concentrations were largest in the extreme northern and southern parts of the area and smallest in the middle part. The chemistry, concentrations, and distribution of arsenic and selenium will be discussed in detail in a later section of the report.

Seasonal variability.--Water samples collected at quarterly intervals from wells and drains in the Oakes test area were statistically analyzed for seasonal differences in concentrations of chemical constituents. Samples were collected in December (winter), March (spring), June (summer), and September (fall). The statistical analysis (tables 15 and 16) was done by using analysis of variance on rank transformations of the data from Wald and others (1989). For the purposes of this analysis, values equal to and less than the detection limit were assigned the same rank. For example, a value of 1 µg/L and a value of <1 µg/L were assigned the same rank.

Results of the analysis of data from 63 wells showed significant seasonal differences in concentrations ($p = 0.05$) for only three constituents--nitrite plus nitrate-nitrogen, mercury, and molybdenum. Nitrite plus nitrate-nitrogen concentrations (192 samples) were slightly larger in the fall than in the other three seasons (fig. 12). Mercury concentrations were slightly larger in the winter than in the other three seasons. It should be noted, however, that in 72 of the 130 mercury samples (55 percent), mercury concentrations were below the detection limit of 0.1 µg/L, and the maximum concentration measured was 0.8 µg/L (table 15). Molybdenum concentrations (132 samples) were smallest in the fall and largest in the spring.

Results of the analysis of data from 23 drains (63 samples) showed significant differences in concentrations ($p = 0.05$) for seven constituents--calcium, molybdenum, ammonia-nitrogen, orthophosphate, potassium, selenium, and total organic carbon. Because concentrations of ammonia-nitrogen and orthophosphate were small, they will not be discussed further. Calcium and total organic carbon concentrations were smaller in the summer than in the other three seasons. Potassium concentrations were smallest in the spring and largest in the fall, and selenium concentrations were smaller in the winter than in the other three seasons. Reasons for the measured seasonal differences have not been determined. It should be noted, however, that the near-record rainfall during 1986 and the resulting high water table that submerged many of the drains may have been a factor.

The median concentration of nitrite plus nitrate-nitrogen in drain samples was slightly larger in the summer than in the other three seasons (fig. 12). However, the differences between seasons were not statistically significant. Nitrite plus nitrate-nitrogen concentrations in the drains were much larger than in wells for all seasons. A possible explanation for this is that the drains collect water from the uppermost part of the saturated soil zone near the water table, which would contain the largest concentrations of nitrite plus nitrate-nitrogen from fertilizer application and aerobic oxidation of nitrogen-containing organic material from plants. The water from drains is well oxygenated (median dissolved oxygen concentration, 4.3

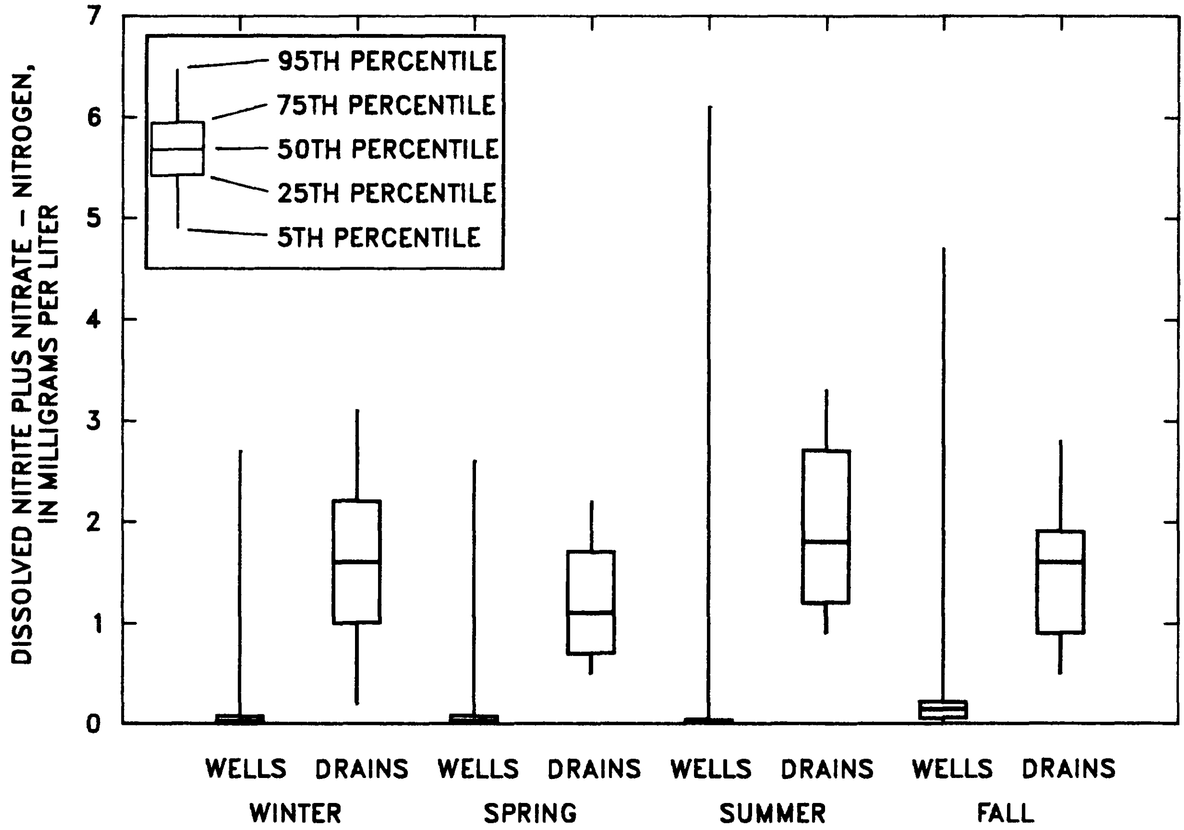


Figure 12.—Seasonal distribution of dissolved nitrite plus nitrate-nitrogen concentrations in water from wells and drains in the Oakes test area, 1986-87.

mg/L) and nitrite plus nitrate-nitrogen would be the stable form of nitrogen. The wells, in contrast, contained much lower concentrations of oxygen (median, 1.3 mg/L) and, in the presence of the abundant organic material, nitrate could be denitrified, converting it to nitrogen gas.

Chemical composition.--The chemical composition of ground water in the Oakes test area is shown in figure 13. The cations--calcium, magnesium, and sodium plus potassium--are plotted as their percentage of the milliequivalents of total cations. Similarly, bicarbonate, chloride, and sulfate are plotted as their percentage of the milliequivalents of total anions. The values plotted represent the mean concentrations in water from each well sampled in the Oakes test area.

The predominant ions in water from most wells are calcium and bicarbonate. As the total ion concentrations increase, the water type shifts from a calcium bicarbonate type toward a sodium calcium sulfate bicarbonate type (fig. 13). The most mineralized water is a calcium magnesium sodium sulfate type. Water of this type tends to coincide with the areas where specific-conductance values are large (fig. 11).

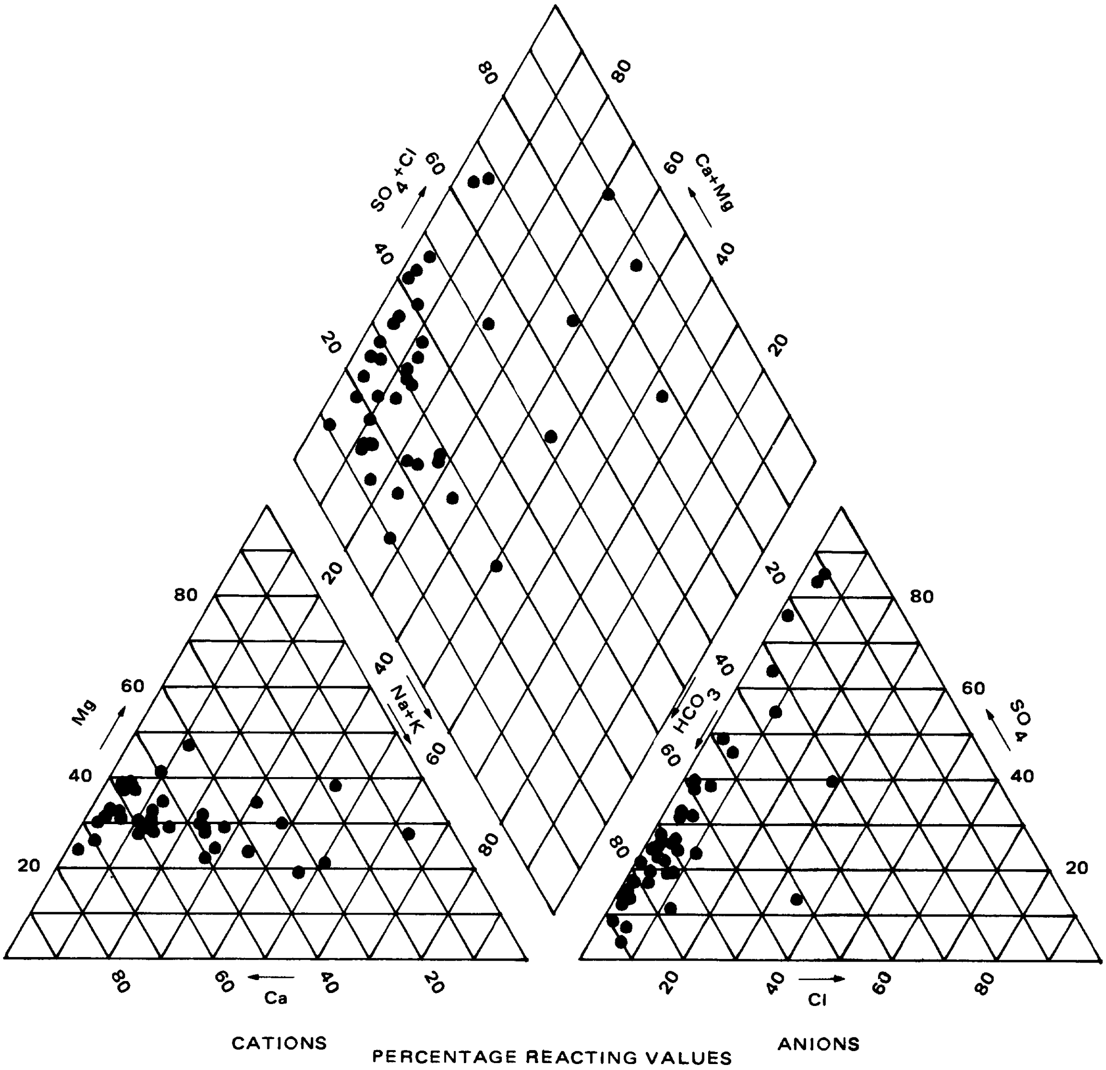
Analysis of the ground-water-quality data from the Oakes test area with the chemical equilibrium model WATEQF (Plummer and others, 1976) showed that water samples from wells and drains are saturated with respect to the carbonate minerals, aragonite and calcite, and, in most samples, dolomite. Water is considerably undersaturated with respect to gypsum except in a few wells where the water is most mineralized and sulfate concentrations are large. Most samples also were saturated with respect to iron-oxide minerals and, in some cases, siderite (ferrous carbonate).

Chemical reactions that govern the major ion chemistry of ground waters in the Oakes aquifer probably include dissolution and precipitation of calcite, dissolution of gypsum, and ion exchange with clay minerals. Evapotranspiration and precipitation of soluble minerals in the unsaturated zone followed by dissolution of these minerals during periods of recharge probably have a large effect on the chemical evolution of ground water in some parts of the aquifer. However, the extent and nature of these reactions were not determined in this investigation.

Arsenic and Selenium in Shallow Ground Water

Arsenic and selenium are two trace elements that were of primary concern in this investigation because of their potentially toxic effects on aquatic systems and the potential for mobilization of these elements in the GDU as a result of irrigation. Much of the concern about these elements, particularly selenium, is a result of documented effects of selenium from irrigation drainage in the western San Joaquin Valley, Calif. (Gilliom and others, 1989; Ohlendorf, 1989).

Geochemistry.--The geochemistry of arsenic and selenium has been described in considerable detail by Welch and others (1988) and Jacobs (1989). The following brief summary is derived largely from these two references.



EXPLANATION

Ca	CALCIUM
Mg	MAGNESIUM
Na	SODIUM
K	POTASSIUM
HCO_3	BICARBONATE
SO_4	SULFATE
Cl	CHLORIDE

Figure 13.—Chemical composition of ground water in the Oakes test area.

The chemistry of arsenic is similar to that of phosphorus. Arsenic can exist in oxidation states of -3, 0, +3, and +5, of which 0 and +3 are characteristic of reducing environments and +5 is characteristic of oxidizing environments (fig. 14). The oxyanions AsO_4^{-3}, $HAsO_4^{-2}$, and $H_2AsO_3^{-1}$ are the most mobile forms of arsenic. In oxidizing soil and aquatic environments, arsenic is strongly adsorbed on hydrous oxides and hydroxides of iron, particularly goethite. In environments having oxidation potentials small enough to reduce iron to the ferrous form, arsenic can be released from the iron minerals and become mobile.

The chemistry of selenium is similar to that of sulfur. Selenium can exist in oxidation states of -2, 0, +4, and +6. Selenides (-2; Se^{-2}) and elemental selenium (0; Se^0) are stable in reducing environments; selenites (+4; SeO_3^{-2}) occur in mildly oxidizing environments, and selenates (+6; SeO_4^{-2}) occur in alkaline, strongly oxidizing environments. Selenides and elemental selenium are virtually insoluble in water and are, thus, immobile. Selenite compounds are relatively soluble, but selenite has a strong affinity for sorption, particularly on goethite and other iron oxides. As a result, selenite is relatively immobile. Other competing oxyanions, such as phosphates, can replace and, thus, mobilize selenite. Selenate compounds, like sulfates, are very soluble and quite mobile in soils and aquatic environments. An Eh-pH diagram for selenium species is shown in figure 15. Theoretically, in the pH range of 7 to 8, selenate would predominate only at oxidation potentials (Eh) larger than about 0.4 volt.

Occurrence and distribution.--Arsenic and selenium concentrations determined in 299 water samples collected from 120 wells (fig. 10) and 16 sites on drains (fig. 4) in the west Oakes irrigation area are given in tables 14 through 16. The median arsenic concentration was 4 µg/L, and less than 5 percent of the samples had concentrations exceeding 19 µg/L. The maximum concentration measured was 44 µg/L. For selenium, the median concentration was less than the analytical detection limits (2 µg/L for data given in table 14; 1 µg/L for data given in tables 15 and 16). The maximum selenium concentration measured was 9 µg/L, and only two samples had concentrations larger than 5 µg/L. Estimates based on a log-probability regression for censored data indicate that less than 5 percent of the samples had selenium concentrations larger than 3 µg/L.

The areal distribution of arsenic and selenium is shown in figures 16 and 17, respectively. For wells having more than one analysis, the maximum concentration was used. Small concentrations of arsenic, up to about 20 µg/L, were detected in water from most wells, and five wells yielded water that had concentrations larger than 20 µg/L. The largest concentration measured was 44 µg/L in well W-188 located in about the center of the west Oakes irrigation area. There was a general tendency for arsenic concentrations to be larger in the middle part of the area than in the northern and southern parts of the area.

In contrast to arsenic, the largest concentrations of selenium were detected in water from wells in the extreme northern and southern parts of the area (fig. 17). Selenium was detected in concentrations equal to or larger than 2 µg/L in water from 13 of the 120 wells sampled, and two wells yielded

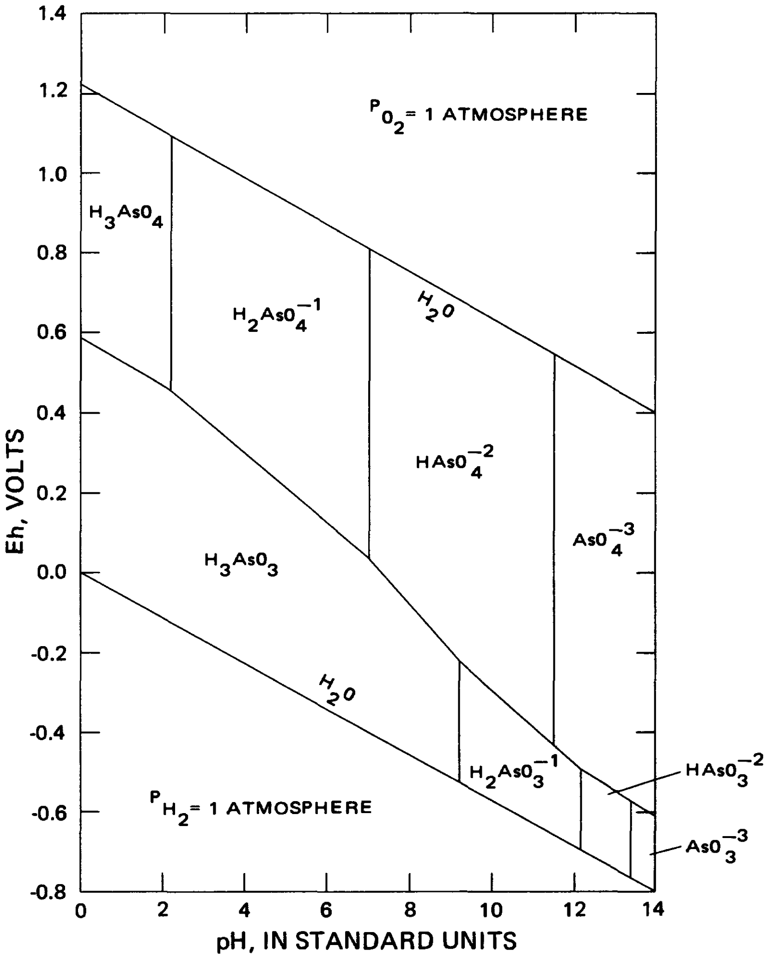


Figure 14.—Fields of stability for dissolved forms of arsenic as a function of Eh and pH. [Modified from Welch and others, 1988, Ground Water, v. 26, no. 3, p. 336.]

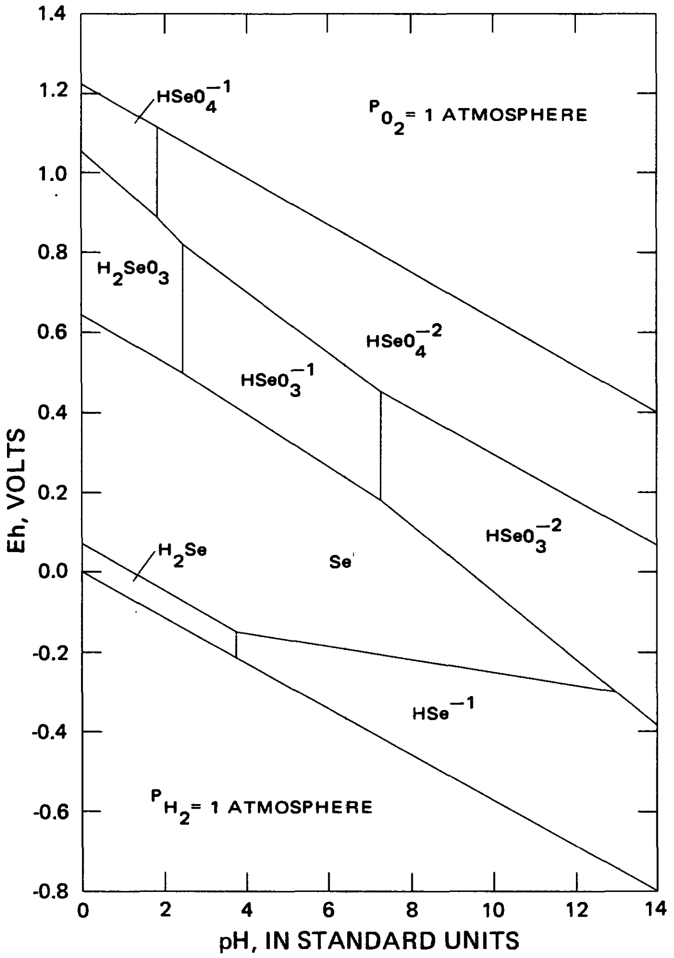


Figure 15.—Fields of stability for forms of selenium as a function of Eh and pH. [Modified from McNeal and Balestrieri, 1989.]

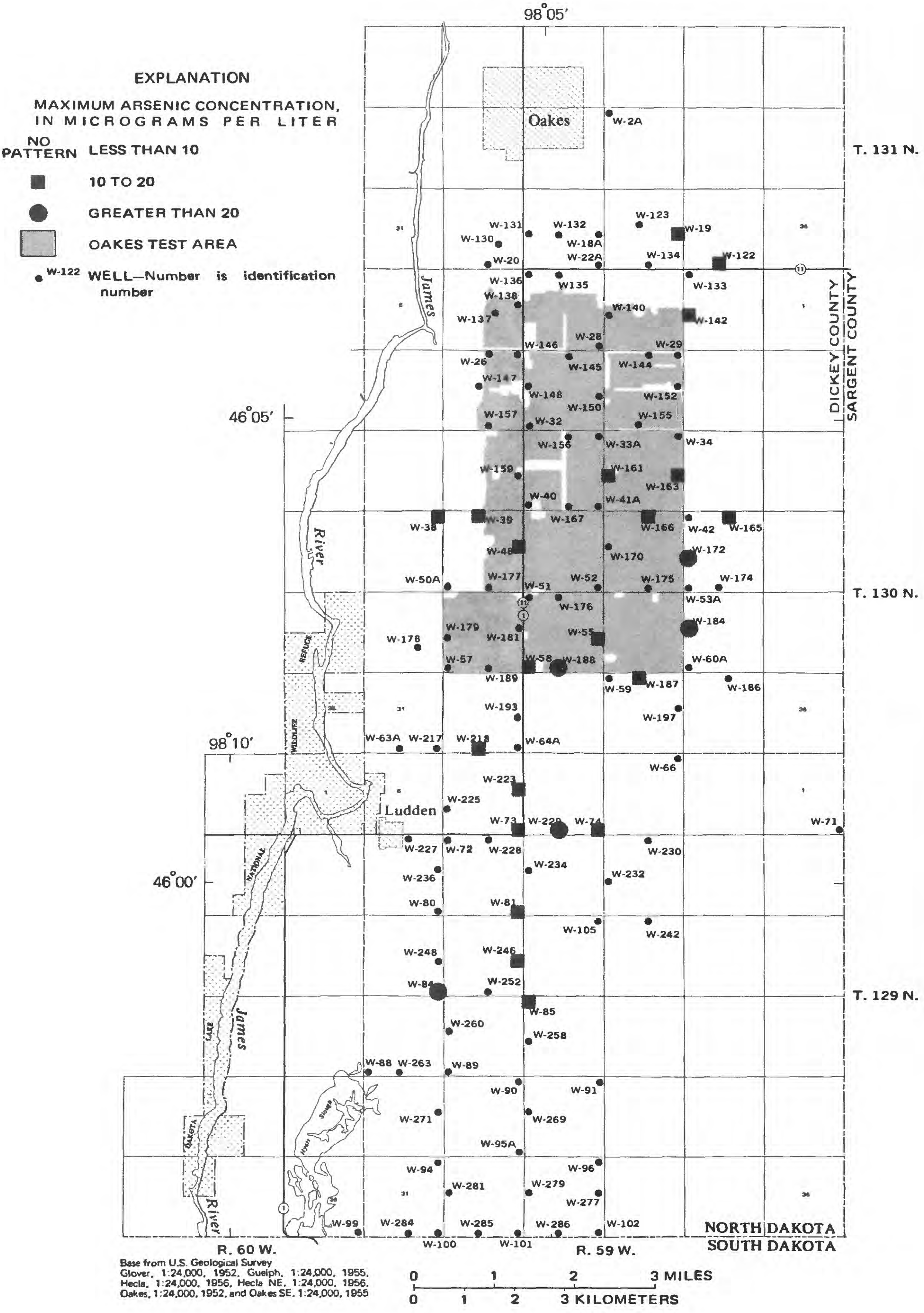
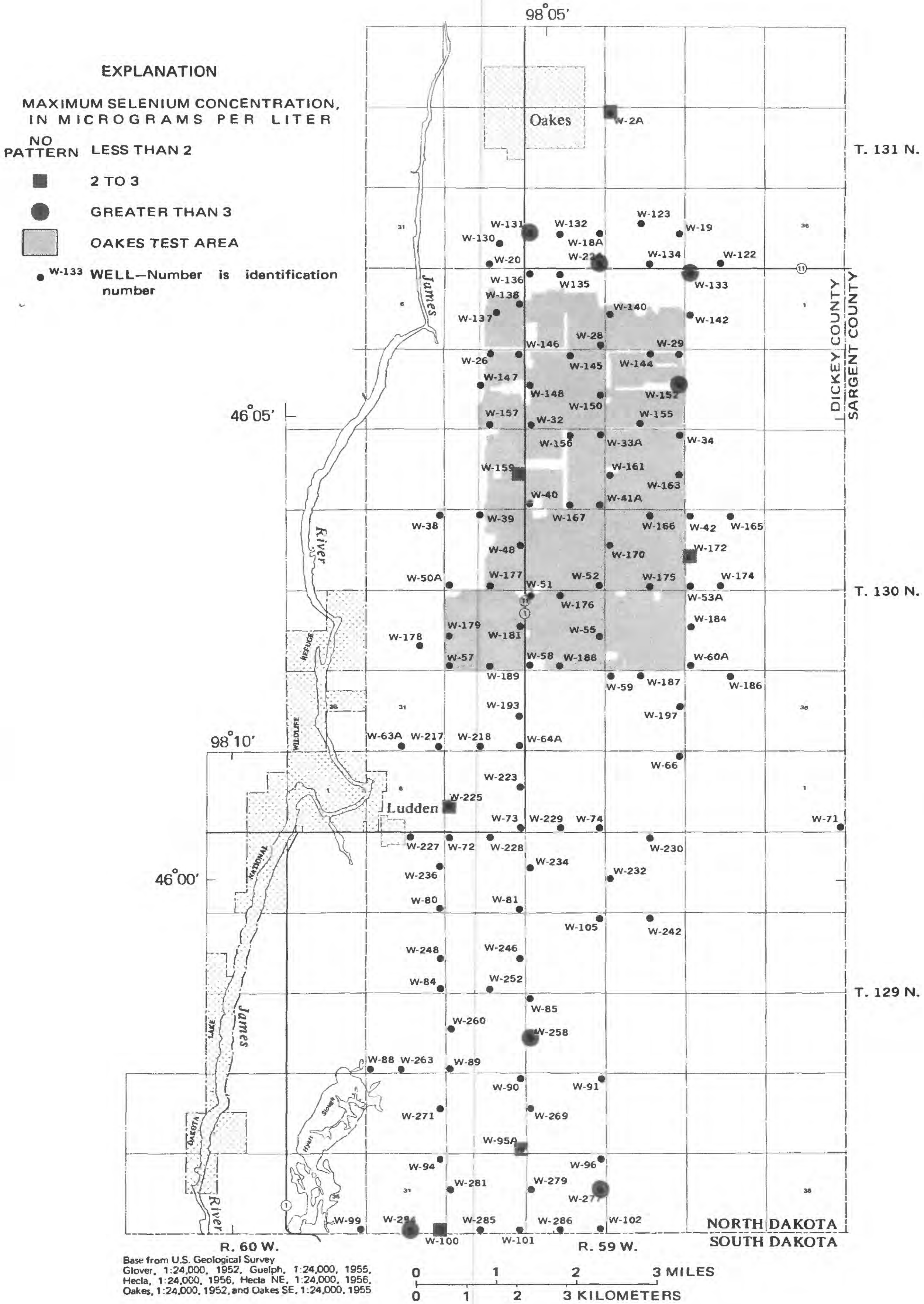


Figure 16.—Maximum arsenic concentrations in water from wells in the west Oakes irrigation area, 1986-87.



Base from U.S. Geological Survey
Glover, 1:24,000, 1952, Guelph, 1:24,000, 1955,
Hecla, 1:24,000, 1956, Hecla NE, 1:24,000, 1956,
Oakes, 1:24,000, 1952, and Oakes SE, 1:24,000, 1955

Figure 17.—Maximum selenium concentrations in water from wells in the west Oakes irrigation area, 1986-87.

water that had concentrations larger than 5 µg/L. These were wells W-133 (8 µg/L) and W-277 (9 µg/L), both of which are located at the extreme edges of the west Oakes irrigation area (fig. 17).

Of the 16 drain-sampling sites in the Oakes test area that were analyzed for arsenic and selenium, only water samples from two drains had arsenic concentrations larger than 10 µg/L. Both had maximum concentrations of 11 µg/L. Selenium, in contrast, was detected in small concentrations (2 to 3 µg/L) in water from 13 of the 16 drain sites, and the maximum measured in water from one drain site was 4 µg/L. A Wilcoxon-Mann-Whitney rank sum test indicated that the concentrations of arsenic in the samples from drains were statistically ($p = 0.05$) smaller than in samples from wells, and that concentrations of selenium were statistically larger in the samples from drains than in the samples from wells.

There appears to be a negative correlation between arsenic and selenium in that areas having the largest arsenic concentrations have the smallest selenium concentrations and vice versa. Also, constituents that are correlated positively with arsenic tend to be correlated negatively with selenium. The following is a summary of statistically significant ($p = 0.05$) rank correlations between arsenic and selenium and other variables for samples collected from 33 wells in the Oakes test area:

Correlated variable	Sign of correlation coefficient	
	Arsenic	Selenium
Water level	-	+
Well depth	+	NS[1]
Dissolved oxygen	NS	+
Magnesium	-	NS
Sodium	NS	-
Potassium	NS	-
Sulfate	NS	-
Nitrite plus nitrate-nitrogen	-	+
Arsenic	NA[2]	-
Boron	NS	-
Iron	NS	-
Manganese	NS	-
Molybdenum	+	-

[1] Not statistically significant.

[2] Not applicable.

The correlations indicate that oxidation-reduction (redox) potential may be an important factor affecting the mobility of these two elements. Arsenic is correlated negatively with nitrite plus nitrate-nitrogen concentrations, but the other factors with which arsenic is correlated are not direct redox indicators. The geochemistry of arsenic, however, indicates that arsenic, probably in the form of $HAsO_4^{-2}$ (fig. 14) would be strongly adsorbed on iron oxides in the oxidizing environment associated with the drains and would be less mobile than in the dissolved-oxygen-deficient environment associated with wells that produce water from deeper in the aquifer.

Selenium concentrations are correlated positively with dissolved oxygen and nitrite plus nitrate-nitrogen concentrations and negatively with iron and manganese concentrations. This is consistent with the geochemistry of selenium. Selenium is more mobile in an oxidizing environment (fig. 15) that is characterized by larger concentrations of dissolved oxygen and nitrite plus nitrate-nitrogen. Such an environment also would have much smaller concentrations of iron and manganese than a reducing environment. Also, the drain samples, which represent a more oxidizing environment than do the well samples, have a much greater frequency of occurrence of detectable, although small, concentrations of selenium than do the well samples. Unlike results of studies conducted in the western San Joaquin Valley, however, selenium is not correlated with salinity.

Element associations.--Factor analysis was used on the data from the 63 wells in the Oakes test area in an attempt to better understand the interrelation between the physical and water-quality variables. A brief description of factor analysis is given in the previous section of this report on soil geochemistry. The optimum model selected, with no rotation, included four factors (table 19). Factor 1 (principal factor) is a salinity or dissolved-solids factor that correlates with specific conductance, sodium-adsorption ratio, and many major cations and anions. Iron and manganese are correlated positively with this factor, and pH is correlated negatively with this factor. Factor 2 is a redox factor that correlates with water level, selenium, nitrite plus nitrate-nitrogen, altitude of land surface, dissolved oxygen, and orthophosphate. Although the correlation coefficients are small and probably not significant, arsenic (-0.26) and molybdenum (-0.33) are correlated negatively with factor 2. Factor 3 is a topography or land surface factor that is correlated positively with arsenic, depth of well, and molybdenum. Factor 4 is correlated negatively with calcium and manganese; however, the significance of this factor is not readily apparent.

Results of the factor analysis support the discussion presented earlier that larger concentrations of selenium are associated with the more oxygenated water, such as in the subsurface drains. Arsenic, in contrast, does not appear to be associated with the more oxygenated water.

Comparison of Water Quality in the West Oakes Irrigation Area with Water Quality in Other Areas in the Western United States

One of the major environmental concerns about the GDU is that arsenic, selenium, or other constituents in drainage from the irrigated areas will produce adverse effects on the James River ecosystem. To provide some insight

Table 19.--Factor compositions, expressed as correlation coefficients, for samples from 63 wells in the Oakes test area

[Variables having a correlation coefficient less than 0.40 are not listed]

Variable	Correlation coefficient for factor indicated			
	1	2	3	4
Specific conductance	0.97			
Sodium-adsorption ratio	.97			
Sodium	.96			
Magnesium	.96			
Potassium	.94			
Sulfate	.94			
Chloride	.91			
Boron	.90			
Calcium	.85			-0.42
Iron	.81			
Ammonia-nitrogen	.78			
Bicarbonate	.66			
Manganese	.51			-.54
pH	-.62			
Water level		0.75		
Selenium		.71		
Nitrite plus nitrate-nitrogen		.69		
Altitude of land surface		.47	0.61	
Dissolved oxygen		.43		
Orthophosphate		.40		
Arsenic			.52	
Depth of well			.46	
Molybdenum			.40	

into this concern, concentrations of arsenic, selenium, and several other constituents associated with irrigation drainage were compared with concentrations determined in other irrigation areas in the western United States, including the western San Joaquin Valley, Calif., and with ambient concentrations in the James River. Results of this comparison are given in tables 20 through 26 for arsenic, selenium, specific conductance, sulfate, nitrite plus nitrate-nitrogen, boron, and molybdenum. The median and maximum values for specific conductance and the median and maximum concentrations of all the constituents, except arsenic, were tens to hundreds of times smaller in the drain samples from the Oakes test area than in drain samples from the western San Joaquin Valley. The median arsenic concentrations in the Oakes test area were similar to concentrations measured in the western San Joaquin Valley. The median concentration of selenium in drain samples from the Oakes test area was 1 µg/L compared to medians of 84 to 320 µg/L reported for drain samples from the western San Joaquin Valley (table 21). Values of specific conductance and concentrations of all constituents in wells and drain samples from the Oakes test area were similar to or smaller than concentrations determined in other irrigation areas in the western United States. The median and maximum selenium concentrations in the drains were 1 and 4 µg/L, respectively, while the maximum concentrations in the James River generally were less than 1 µg/L. Median and maximum specific-conductance values and concentrations of arsenic, sulfate, and boron in the drain samples were similar to or smaller than those determined on James River samples. The median and maximum concentrations of nitrite plus nitrate-nitrogen in the drain samples were 1.42 and 3.82 mg/L, respectively, compared with median and maximum concentrations of about 0.5 and 1.9 mg/L, respectively, in the James River at Oakes. Insufficient data are available on molybdenum concentrations in the James River to permit comparison with samples from the drains.

A statistical summary of all inorganic water-quality data collected at five gaging stations on the James River (fig. 1) for the 1983 through 1988 water years is given in table 31 at the end of this report. These stations are located upstream and downstream of the inflow from the present drains in the Oakes test area. An analysis of these data shows no detectable effects of inflow during 1983-88 from the existing drains in the Oakes test area. All selenium concentrations determined at these stations were less than the detection limit of 1 µg/L except for one sample collected at Dakota Lake Dam (station 06470875 in table 31) in October 1988 that contained 2 µg/L. It is highly unlikely, however, that the selenium concentration for this sample can be attributed to the inflow from drains in the Oakes test area because the combined discharge from all drains at this time was less than 1 ft^3/s (fig. 5), and the discharge of the James River was about 175 ft^3/s (U.S. Geological Survey, 1988).

Comparison of Trace-Element Concentrations in the West Oakes Irrigation Area with Water-Quality Regulations, Standards, and Criteria

Concentrations of arsenic, selenium, and several other trace elements determined in samples from wells and drains in the west Oakes irrigation area were compared with national drinking-water regulations, North Dakota class I stream standards, acute and chronic criteria for freshwater aquatic life, and

Table 20.--Summary of dissolved arsenic concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States

[µg/L, micrograms per liter; <, less than; --, no data]

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
West Oakes irrigation area, N.Dak.							
104 wells sampled during January 1986	2	104	77	<2	3	44	(1)
33 wells sampled during December 1986 through September 1987	1	132	88	<1	4	41	(2)
16 drains sampled during December 1986 through September 1987	1	63	95	<1	3	11	(2)
Western San Joaquin Valley, Calif.							
Drains tributary to San Luis drain	1	7	28	<1	<1	2	(3)
Nontributary drains and canals	1	4	100	3	3	5	(3)
Background irrigation supply and return flow	--	0	--	--	--	--	(4)
Inflow to San Luis drain	--	0	--	--	--	--	(4)
Sumps and agricultural drains	--	0	--	--	--	--	(4)
Observation wells, sumps, and drains	1	130	76	<1	2	82	(5)

See footnotes at end of table.

Table 20.--Summary of dissolved arsenic concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
Reconnaissance irrigation drainage studies							
Bowdoin National Wildlife Refuge, Mont.	1	16	88	<1	2.5	47	(6)
Benton Lake National Wildlife Refuge, Mont.	1	6	67	<1	2	63	(7)
Freezout Lake National Wildlife Refuge, Mont.	1	4	100	2	9	22	(7)
Sun River irrigation project, Mont.							
Surface water	1	12	75	<1	1	2	(7)
Ground water	1	5	80	<1	1	2	(7)
Stewart Lake Wildfowl Management Area, Utah	1	13	69	<1	1	2	(8)
James River basin surface-water monitoring stations							
James River at LaMoure, N.Dak.	1	15	--	1	[9]2.6	5	(10)
James River at Oakes, N.Dak.	1	13	100	2	[9]3.0	5	(10)
Hyatt Slough Wildlife Management Area, N.Dak.	1	4	100	5.3	[9]6.2	7.5	(10)
James River near Hecla, S.Dak.	1	13	100	2	[9]2.7	4	(10)

See footnotes at end of table.

Table 20.--Summary of dissolved arsenic concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
James River basin surface-water monitoring stations--Continued							
Sand Lake National Wildlife Refuge, S.Dak.							
Mud Lake Pool	1	17	100	1.2	[9]4.0	10.2	(10)
Sand Lake Pool	1	17	100	1.5	[9]3.6	6.5	(10)
James River at Columbia, S.Dak.	1	35	--	1	[9]3.6	10	(10)

[1] Wilson and others, 1989b.

[2] Wald and others, 1989.

[3] Izbicki, 1984.

[4] Presser and Barnes, 1985.

[5] Deveral and others, 1984.

[6] Lambing and others, 1988.

[7] Knapton and others, 1988.

[8] Stephens and others, 1986.

[9] Mean value.

[10] Briel, 1988.

Table 21.--Summary of dissolved selenium concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States

[µg/L, micrograms per liter; <, less than; --, no data]

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
West Oakes irrigation area, N.Dak.							
104 wells sampled during January 1986	2	104	12	<2	<2	9.2	(1)
33 wells sampled during December 1986 through September 1987	1	132	22	<1	<1	5	(2)
16 drains sampled during December 1986 through September 1987	1	63	63	<1	1	4	(2)
Western San Joaquin Valley, Calif.							
Drains tributary to San Luis drain	1	7	100	145	320	870	(3)
Nontributary drains and canals	1	4	75	<1	2	23	(3)
Background irrigation supply and return flow	2	9	33	<2	<2	10	(4)
Inflow to San Luis drain	2	11	82	<2	200	1,400	(4)
Sumps and agricultural drains	2	17	100	8	84	4,200	(4)
Observation wells, sumps, and drains	1	130	74	<1	6	3,800	(5)

See footnotes at end of table.

Table 21.--Summary of dissolved selenium concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
Reconnaissance irrigation drainage studies							
Bowdoin National Wildlife Refuge, Mont.	1	16	6	<1	<1	1	(6)
Benton Lake National Wildlife Refuge, Mont.	1	6	83	<1	10	580	(7)
Freezout Lake National Wildlife Refuge, Mont.	1	4	75	<1	5	8	(7)
Sun River irrigation project, Mont.							
Surface water	1	12	58	<1	1	2	(7)
Ground water	1	5	80	<1	2	5	(7)
Stewart Lake Wildfowl Management Area, Utah	1	13	100	4	31	140	(8)
James River basin surface-water monitoring stations							
James River at LaMoure, N.Dak.	1	21	0	<1	<1	<1	(9)
James River at Oakes, N.Dak.	1	18	0	<1	<1	<1	(9)
Hyatt Slough Wildlife Management Area, N.Dak.	1	4	--	1	--	1.3	(9)
James River near Hecla, S.Dak.	1	20	0	<1	<1	<1	(9)

See footnotes at end of table.

Table 21.--Summary of dissolved selenium concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
James River basin surface-water monitoring stations--Continued							
Sand Lake National Wildlife Refuge, S.Dak.							
Mud Lake Pool	1	17	--	1	^{10}1.2	1.4	(9)
Sand Lake Pool	1	17	--	1.1	^{10}1.1	1.1	(9)
James River at Columbia, S.Dak.	1	40	--	--	--	1	(9)

[1] Wilson and others, 1989b.

[2] Wald and others, 1989.

[3] Izbicki, 1984.

[4] Presser and Barnes, 1985.

[5] Deveral and others, 1984.

[6] Lambing and others, 1988.

[7] Knapton and others, 1988.

[8] Stephens and others, 1986.

[9] Briel, 1988.

[10] Mean value.

Table 22.--Summary of specific conductance of water from the west Oakes irrigation area and specific conductance of water from other areas in the western United States

[μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Source of water samples	Number of samples	Minimum (μS/cm)	Median (μS/cm)	Maximum (μS/cm)	Reference
West Oakes irrigation area, N.Dak.					
104 wells sampled during January 1986	104	500	795	17,000	(1)
63 wells sampled during December 1986 through September 1987	192	445	782	6,800	(2)
23 drains sampled during December 1986 through September 1987	80	612	800	1,300	(2)
Western San Joaquin Valley, Calif.					
Drains tributary to San Luis drain	7	9,000	10,700	13,900	(3)
Nontributary drains and canals	4	1,890	3,100	8,130	(3)
Background irrigation supply and return flow	9	330	650	1,400	(4)
Inflow to San Luis drain	11	270	8,300	31,000	(4)
Sumps and agricultural drains	17	1,300	7,900	23,000	(4)
Observation wells, sumps, and drains	130	431	3,655	68,000	(5)

See footnotes at end of table.

Table 22.--Summary of specific conductance of water from the west Oakes irrigation area and specific conductance of water from other areas in the western United States--Continued

Source of water samples	Number of samples	Minimum (µS/cm)	Median (µS/cm)	Maximum (µS/cm)	Reference
Reconnaissance irrigation drainage studies					
Bowdoin National Wildlife Refuge, Mont.	16	550	1,580	9,200	(6)
Benton Lake National Wildlife Refuge, Mont.	5	860	3,550	12,000	(7)
Freezout Lake National Wildlife Refuge, Mont.	4	980	2,350	7,900	(7)
Sun River irrigation project, Mont.					
Surface water	12	220	660	755	(7)
Ground water	5	420	670	950	(7)
Stewart Lake Wildfowl Management Area, Utah	6	1,950	2,360	3,600	(8)
James River basin surface-water monitoring stations					
James River at LaMoure, N.Dak.	119	200	[9]779	1,600	(10)
James River at Oakes, N.Dak.	44	340	[9]842	2,250	(10)
Hyatt Slough Wildlife Management Area, N.Dak.	39	950	[9]1,360	1,790	(10)
James River near Hecla, S.Dak.	23	410	[9]847	1,780	(10)

See footnotes at end of table.

Table 22.--Summary of specific conductance of water from the west Oakes irrigation area and specific conductance of water from other areas in the western United States--Continued

Source of water samples	Number of samples	Minimum (µS/cm)	Median (µS/cm)	Maximum (µS/cm)	Reference
James River basin surface-water monitoring stations--Continued					
Sand Lake National Wildlife Refuge, S.Dak.					
Mud Lake Pool	156	350	[9]899	6,100	([10])
Sand Lake Pool	118	380	[9]753	1,800	([10])
James River at Columbia, S.Dak.	100	425	[9]827	2,100	([10])

[1] Wilson and others, 1989b.

[2] Wald and others, 1989.

[3] Izbicki, 1984.

[4] Presser and Barnes, 1985.

[5] Deveral and others, 1984.

[6] Lambing and others, 1988.

[7] Knapton and others, 1988.

[8] Stephens and others, 1986.

[9] Mean value.

[10] Briel, 1988.

Table 23.--Summary of dissolved sulfate concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States

[mg/L, milligrams per liter; --, no data]

Source of water samples	Number of samples	Minimum (mg/L)	Median (mg/L)	Maximum (mg/L)	Reference
West Oakes irrigation area, N.Dak.					
104 wells sampled during January 1986	104	6.1	80	6,800	(1)
63 wells sampled during December 1986 through September 1987	192	11	75	3,400	(2)
23 drains sampled during December 1986 through September 1987	80	40	100	260	(2)
Western San Joaquin Valley, Calif.					
Drains tributary to San Luis drain	7	2,900	4,300	6,200	(3)
Nontributary drains and canals	4	220	440	850	(3)
Background irrigation supply and return flow	9	44	175	880	(4)
Inflow to San Luis drain	11	28	3,200	22,500	(4)
Sumps and agricultural drains	13	340	2,900	9,050	(4)
Observation wells, sumps, and drains	130	39	1,700	65,000	(5)

See footnotes at end of table.

Table 23.--Summary of dissolved sulfate concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Number of samples	Minimum (mg/L)	Median (mg/L)	Maximum (mg/L)	Reference
Reconnaissance irrigation drainage studies					
Bowdoin National Wildlife Refuge, Mont.	0	--	--	--	(6)
Benton Lake National Wildlife Refuge, Mont.	0	--	--	--	(7)
Freezout Lake National Wildlife Refuge, Mont.	0	--	--	--	(7)
Sun River irrigation project, Mont.					
Surface water	0	--	--	--	(7)
Ground water	0	--	--	--	(7)
Stewart Lake Wildfowl Management Area, Utah	13	367	1,063	2,145	(8)
James River basin surface-water monitoring stations					
James River at LaMoure, N.Dak.	77	35	[9]145	330	(10)
James River at Oakes, N.Dak.	30	61	[9]163	460	(10)
Hyatt Slough Wildlife Management Area, N.Dak.	39	190	[9]232	293	(10)
James River near Hecla, S.Dak.	20	57	[9]166	380	(10)

See footnotes at end of table.

Table 23.--Summary of dissolved sulfate concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Number of samples	Minimum (mg/L)	Median (mg/L)	Maximum (mg/L)	Reference
James River basin surface-water monitoring stations--Continued					
Sand Lake National Wildlife Refuge, S.Dak.					
Mud Lake Pool	158	50	[9]148	327	(10)
Sand Lake Pool	119	45	[9]108	159	(10)
James River at Columbia, S.Dak.	60	60	[9]142	310	(10)

[1] Wilson and others, 1989b.

[2] Wald and others, 1989.

[3] Izbicki, 1984.

[4] Presser and Barnes, 1985.

[5] Deveral and others, 1984.

[6] Lambing and others, 1988.

[7] Knapton and others, 1988.

[8] Stephens and others, 1986.

[9] Mean value.

[10] Briel, 1988.

Table 24.--Summary of dissolved nitrite plus nitrate-nitrogen concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States

[mg/L, milligrams per liter; <, less than; --, no data]

Source of water samples	Detection limit (mg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (mg/L)	Median (mg/L)	Maximum (mg/L)	Reference
			West Oakes irrigation area, N.Dak.				
104 wells sampled during January 1986[1]	0.2	99	88	<0.2	0.16	[2]135	(3)
63 wells sampled during December 1986 through September 1987	.01	192	96	<.01	.04	32	(4)
23 drains sampled during December 1986 through September 1987	.01	80	99	<.01	1.46	3.82	(4)
			Western San Joaquin Valley, Calif.				
Drains tributary to San Luis drain	0.1	7	100	40	55	68	(5)
Nontributary drains and canals	.1	4	75	<.1	1.4	6.2	(5)
Background irrigation supply and return flow	1	9	44	<1	<1	3.0	(6)
Inflow to San Luis drain[1]	1	11	82	<1	50	220	(6)
Sumps and agricultural drains[1]	1	11	100	5.1	25	280	(6)

See footnotes at end of table.

Table 24.--Summary of dissolved nitrite plus nitrate-nitrogen concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (mg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (mg/L)	Median (mg/L)	Maximum (mg/L)	Reference
Reconnaissance irrigation drainage studies							
Bowdoin National Wildlife Refuge, Mont.	0.1	6	17	<0.1	<0.1	0.45	(7)
Benton Lake National Wildlife Refuge, Mont.	--	0	--	--	--	--	(8)
Freezout Lake National Wildlife Refuge, Mont.	--	0	--	--	--	--	(8)
Sun River irrigation project, Mont.							
Surface water	--	0	--	--	--	--	(8)
Ground water	.1	5	100	.46	4.1	6.4	(8)
Stewart Lake Wildfowl Management Area, Utah	.1	9	100	2.5	5.2	6.6	(9)
James River basin surface-water monitoring stations							
James River at LaMoure, N.Dak.	0.1	75	--	<0.01	[10]0.33	1.8	(11)
James River at Oakes, N.Dak.	.1	30	100	.13	[10].53	1.9	(11)
Hyatt Slough Wildlife Management Area, N.Dak.[1]	.1	39	--	<.01	[10].02	.16	(11)
James River near Hecla, S.Dak.	.1	20	100	.12	[10].30	.73	(11)

See footnotes at end of table.

Table 24.--Summary of dissolved nitrite plus nitrate-nitrogen concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (mg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (mg/L)	Median (mg/L)	Maximum (mg/L)	Reference
James River basin surface-water monitoring stations--Continued							
Sand Lake National Wildlife Refuge, S.Dak.[1]							
Mud Lake Pool	0.1	156	--	<0.01	[10]0.01	0.18	(11)
Sand Lake Pool	.1	115	--	<.01	[10].08	1.44	(11)
James River at Columbia, S.Dak.	.1	56	--	<.01	[10].27	1.50	(11)

[1] Results are for nitrate-nitrogen only.

[2] Contamination suspected; well located in a barnyard; next largest value--41 milligrams per liter.

[3] Wilson and others, 1989b.

[4] Wald and others, 1989.

[5] Izbicki, 1984.

[6] Presser and Barnes, 1985.

[7] Lambing and others, 1988.

[8] Knapton and others, 1988.

[9] Stephens and others, 1986.

[10] Mean value.

[11] Briel, 1988.

Table 25.--Summary of dissolved boron concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States

[µg/L, micrograms per liter; <, less than; --, no data]

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
West Oakes irrigation area, N.Dak.							
104 wells sampled during January 1986	10	104	99	<10	60	[1]2,230	(2)
33 wells sampled during December 1986 through September 1987	40	132	98	<40	90	400	(3)
16 drains sampled during December 1986 through September 1987	40	63	98	<40	70	120	(3)
Western San Joaquin Valley, Calif.							
Drains tributary to San Luis drain	--	7	--	7,900	14,000	21,000	(4)
Nontributary drains and canals	--	4	--	1,800	3,500	6,400	(4)
Background irrigation supply and return flow	--	0	--	--	--	--	(5)
Inflow to San Luis drain	--	0	--	--	--	--	(5)
Sumps and agricultural drains	--	0	--	--	--	--	(5)
Observation wells, sumps and drains	--	130	--	140	3,100	120,000	(6)

See footnotes at end of table.

Table 25.--Summary of dissolved boron concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (μg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (μg/L)	Median (μg/L)	Maximum (μg/L)	Reference
Reconnaissance irrigation drainage studies							
Bowdoin National Wildlife Refuge, Mont.	10	16	88	<10	120	6,000	(7)
Benton Lake National Wildlife Refuge, Mont.	10	6	100	150	630	2,500	(8)
Freezout Lake National Wildlife Refuge, Mont.	10	4	100	160	445	890	(8)
Sun River irrigation project, Mont.							
Surface water	10	12	100	<10	120	140	(8)
Ground water	10	5	100	40	170	250	(8)
Stewart Lake Wildfowl Management Area, Utah	10	13	100	210	570	1,200	(9)
James River basin surface-water monitoring stations							
James River at LaMoure, N.Dak.	10	76	100	40	[10]215	650	(11)
James River at Oakes, N.Dak.	10	30	100	60	[10]206	720	(11)
Hyatt Slough Wildlife Management Area, N.Dak.	--	--	--	--	--	--	--
James River near Hecla, S.Dak.	10	20	100	60	[10]184	410	(11)

See footnotes at end of table.

Table 25.--Summary of dissolved boron concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
James River basin surface-water monitoring stations--Continued							
Sand Lake National Wildlife Refuge, S.Dak.							
Mud Lake Pool	--	--	--	--	--	--	--
Sand Lake Pool	--	--	--	--	--	--	--
James River at Columbia, S.Dak.	10	15	100	120	[10]175	250	(11)

[1] Contamination suspected; next largest value--500 micrograms per liter.

[2] Wilson and others, 1989b.

[3] Wald and others, 1989.

[4] Izbicki, 1984.

[5] Presser and Barnes, 1985.

[6] Deveral and others, 1984.

[7] Lambing and others, 1988.

[8] Knapton and others, 1988.

[9] Stephens and others, 1986.

[10] Mean value.

[11] Briel, 1988.

Table 26.--Summary of dissolved molybdenum concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States

[µg/L, micrograms per liter; <, less than; --, no data]

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
			West Oakes irrigation area, N.Dak.				
104 wells sampled during January 1986	10	104	5	<10	<10	30	(1)
33 wells sampled during December 1986 through September 1987	1	132	98	<1	3	9	(2)
16 drains sampled during December 1986 through September 1987	1	63	100	1	3	6	(2)
			Western San Joaquin Valley, Calif.				
Drains tributary to San Luis drain	1	7	100	26	63	190	(3)
Nontributary drains and canals	1	4	100	6	8	21	(3)
Background irrigation supply and return flow	--	0	--	--	--	--	(4)
Inflow to San Luis drain	--	0	--	--	--	--	(4)
Sumps and agricultural drains	--	0	--	--	--	--	(4)
Observation wells, sumps, and drains	1	130	96	<1	17	5,000	(5)

See footnotes at end of table.

Table 26.--Summary of dissolved molybdenum concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
Reconnaissance irrigation drainage studies							
Bowdoin National Wildlife Refuge, Mont.	1	16	81	<1	2	5	(6)
Benton Lake National Wildlife Refuge, Mont.	1	6	50	<1	1	5	(7)
Freezout Lake National Wildlife Refuge, Mont.	1	4	100	1	5	9	(7)
Sun River irrigation project, Mont.							
Surface water	1	12	75	<1	2	5	(7)
Ground water	1	5	100	3	3	8	(7)
Stewart Lake Wildfowl Management Area, Utah	1	13	92	<1	3	8	(8)
James River basin surface-water monitoring stations							
James River at LaMoure, N.Dak.	10	1	--	--	--	<10	(9)
James River at Oakes, N.Dak.	--	0	--	--	--	--	(9)
Hyatt Slough Wildlife Management Area, N.Dak.	--	0	--	--	--	--	(9)
James River near Hecla, S.Dak.	--	0	--	--	--	--	(9)

See footnotes at end of table.

Table 26.--Summary of dissolved molybdenum concentrations in water from the west Oakes irrigation area and concentrations in water from other areas in the western United States--Continued

Source of water samples	Detection limit (µg/L)	Number of samples	Percentage of samples having concentrations exceeding detection limit	Minimum (µg/L)	Median (µg/L)	Maximum (µg/L)	Reference
James River basin surface-water monitoring stations--Continued							
Sand Lake National Wildlife Refuge, S.Dak.							
Mud Lake Pool	--	0	--	--	--	--	(9)
Sand Lake Pool	--	0	--	--	--	--	(9)
James River at Columbia, S.Dak.	--	0	--	--	--	--	(9)

[1] Wilson and others, 1989b.

[2] Wald and others, 1989.

[3] Izbicki, 1984.

[4] Presser and Barnes, 1985.

[5] Deveral and others, 1984.

[6] Lambing and others, 1988.

[7] Knapton and others, 1988.

[8] Stephens and others, 1986.

[9] Briel, 1988.

criteria for irrigation. Results of the comparison are given in tables 27 and 28. None of the concentrations determined exceeded drinking-water regulations, North Dakota stream standards, or criteria for irrigation except for boron concentrations in wells W-101 and W-227, which had specific-conductance values exceeding 2,000 µS/cm (fig. 11). Selenium concentrations of 8 and 9 µg/L from two wells exceeded the recently revised chronic criteria for freshwater aquatic life of 5 µg/L (Federal Register, January 5, 1988). However, comparison of selenium concentrations in ground water with criteria for freshwater aquatic life in streams may be inappropriate. The maximum selenium concentrations measured in water from drains that could come into contact with freshwater aquatic life was 4 µg/L, and the median concentration was 1 µg/L. The following statement regarding the revised selenium criteria is a quote from the Federal Register (January 5, 1988):

> The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for Protection of Aquatic Organisms and their Uses" indicate that except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of selenium does not exceed 5 µg/L more than once every three years on the average and if the one-hour average does not exceed 20 µg/L more than once every three years on the average.

The chronic criterion for freshwater aquatic life for mercury is 0.012 µg/L, which is about 10 times smaller than the detection limit for the analytical method used in this investigation. This criterion is derived from bioaccumulation factors based on methylmercury. The median and maximum mercury concentrations measured in samples from drains were <0.1 and 0.2 µg/L, respectively; the median and maximum concentrations in samples from wells were <0.1 and 0.8 µg/L, respectively. It should be noted that these concentrations are smaller than median concentrations (0.2 µg/L) and maximum concentrations (1.4 µg/L) measured at five gaging stations on the James River (table 31).

The above comparison indicates that the concentrations of trace elements determined in water from wells and drains in the Oakes test area during this investigation should not adversely affect human and aquatic life or irrigated crops.

Examination of Relations Between Soil Chemistry and Water Chemistry

As many as seven samples were collected from soil profiles adjacent to wells at 30 sites in the Oakes test area (fig. 6) and analyzed for total concentrations of major and trace elements (Severson and others, 1988, table 10). The adjacent wells were sampled four times during December 1986 through September 1987 for major ions and trace elements (Wald and others, 1989). An examination of these data was made to determine if there were any discernible relations between concentrations of arsenic and selenium in the soil and concentrations in the ground water. The arsenic and selenium data from the soil and water samples are given in table 29. It should be noted, however, that measurements of total arsenic and selenium concentrations in soil are not necessarily an indication of the degree to which these elements can become mobile and be transported into ground water.

Table 27.--Summary of trace-element concentrations in ground water and drain water in the west Oakes irrigation area, national drinking-water regulations, and North Dakota class I stream standards

[Concentrations in micrograms per liter; <, less than; --, no data or no regulation or standard]

	Ground water				Drain water				Drinking-water regulations[1]	
Element	Number of measurements	Minimum	Median	Maximum	Number of measurements	Minimum	Median	Maximum	Maximum contaminant level	Class I stream standards[2]
Arsenic	[3]104	<2	3.0	44	--	--	--	--	50	50
	[4]132	<1	4	41	63	<1	3	11	50	50
Beryllium	[3]104	<1	<1	<1	--	--	--	--	--	--
Boron	[3]104	<10	60	2,230	--	--	--	--	--	750
	[4]132	<10	90	400	63	<10	70	120	--	750
Cadmium	[3]104	<1	<1	3	--	--	--	--	10	10
	[4]132	<1	<1	3	63	<1	<1	<1	10	10
Copper	[3]104	<10	<10	20	--	--	--	--	[5]1,000	50
Lead	[3]104	<10	<10	12	--	--	--	--	50	50
Mercury	[4]130	<.1	<.1	.8	63	<.1	<.1	.2	2	2

See footnotes at end of table.

Table 27.--Summary of trace-element concentrations in ground water and drain water in the west Oakes irrigation area, national drinking-water regulations, and North Dakota class I stream standards--Continued

Element	Ground water				Drain water				Drinking-water regulations[1]	
	Number of measurements	Minimum	Median	Maximum	Number of measurements	Minimum	Median	Maximum	Maximum contaminant level	Class I stream standards[2]
Molybdenum	[3]104	<10	<10	30	--	--	--	--	--	--
	[4]132	<1	3	9	63	1	3	6	--	--
Nickel	[3]104	<2	<2	43	--	--	--	--	--	--
Selenium	[3]104	<2	<2	9.2	--	--	--	--	10	10
	[4]132	<1	<1	5	63	<1	1	4	10	10

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[1] U.S. Environmental Protection Agency, 1987.

[2] Standards of water quality for North Dakota, rule 33-16-02, April 1, 1985.

[3] Wilson and others, 1989b.

[4] Wald and others, 1989.

[5] Secondary maximum contaminant level.

Table 28.--Summary of trace-element concentrations in ground water and drain water in the west Oakes irrigation area, criteria for freshwater aquatic life, and criteria for irrigation

[Concentrations in micrograms per liter; <, less than; --, no data or no criteria]

Element	Ground water				Drain water				Criteria for freshwater aquatic life[1]		Criteria for irrigation[2]
	Number of measurements	Minimum	Median	Maximum	Number of measurements	Minimum	Median	Maximum	Acute	Chronic	
Arsenic	[3]104	<2	3.0	44	--	--	--	--	--	--	100
	[4]132	<1	4	41	63	<1	3	11	--	--	100
Pentavalent	--	--	--	--	--	--	--	--	850	48	--
Trivalent	--	--	--	--	--	--	--	--	360	190	--
Beryllium	[3]104	<1	<1	<1	--	--	--	--	[5]130	[5]5	100
Boron	[3]104	<10	60	2,230	--	--	--	--	--	--	750
	[4]132	<10	90	400	63	<10	70	120	--	--	750
Cadmium	[3]104	<1	<1	3	--	--	--	--	[5]3.9	[5]1.1	10
	[4]132	<1	<1	3	63	<1	<1	<1	[5]3.9	[5]1.1	10
Copper	[3]104	<10	<10	20	--	--	--	--	[5]18	[5]12	200
Lead	[3]104	<10	<10	12	--	--	--	--	[5]82	[5]3.2	5,000
Mercury	[4]130	<.1	<.1	.8	63	<.1	<.1	.2	2.4	.012	--
Molybdenum	[3]104	<10	<10	30	--	--	--	--	--	--	--
	[4]132	<1	3	9	63	1	3	6	--	--	--
Nickel	[3]104	<2	<2	43	--	--	--	--	[5]1,400	[5]160	200

See footnotes at end of table.

Table 28.--Summary of trace-element concentrations in ground water and drain water in the west Oakes irrigation area, criteria for freshwater aquatic life, and criteria for irrigation--Continued

	Ground water				Drain water				Criteria for freshwater aquatic life[1]		
Element	Number of measurements	Minimum	Median	Maximum	Number of measurements	Minimum	Median	Maximum	Acute	Chronic	Criteria for irrigation[2]
Selenium	[3]104	<2	<2	9.2	--	--	--	--	[6]20	[6]5	20
	[4]132	<1	<1	5	63	<1	1	4	[6]20	[6]5	20

[1] U.S. Environmental Protection Agency, 1987.

[2] National Academy of Sciences, National Academy of Engineering, 1973.

[3] Wilson and others, 1989b.

[4] Wald and others, 1989.

[5] Hardness-dependent criteria; used 100 milligrams per liter hardness as calcium carbonate.

[6] Federal Register, January 5, 1988.

Table 29.--Summary of total arsenic and total selenium concentrations in soil profiles and dissolved arsenic and dissolved selenium concentrations in water from adjacent wells in the west Oakes irrigation area

[Values for total arsenic and total selenium in soil are modified from Severson and others, 1988; values for dissolved arsenic and dissolved selenium in water are from Wald and others, 1989; values for total arsenic and total selenium in soil are listed in order of depth from top to bottom of profile; values for dissolved arsenic and dissolved selenium in water are for quarterly samples collected during December 1986 through September 1987; mg/kg, milligrams per kilogram; µg/L, micrograms per liter; <, less than; --, no data]

Soil profile site number	Total arsenic in soil (mg/kg)	Total selenium in soil (mg/kg)	Well number	Dissolved arsenic in water (µg/L)	Dissolved selenium in water (µg/L)
KW100A	3.8, 8.9, 1.5, 3.7	0.50, 0.27, 0.20, 0.45	W-138	2, 2, <1, 2	<1, <1, <1, 3
KW288A	2.6, 2.8, 2.8, 14	0.80, 0.40, 0.20, 0.70	W-26	5, 7, 9, 5	<1, <1, <1, <1
KW301A	3.0, 3.1	0.60, 0.30	W-145	5, 5, 3, 3	<1, <1, <1, <1
KW197A	2.1, 3.7, 9.0, 2.2, 6.1, 2.2	0.20, 0.31, 0.40, 0.24, 1.6, 0.76	W-144	1, 2, <1, <1	<1, <1, <1, <1
KW118A	2.4, 5.2, 1.7	0.50, 0.80, 0.40	W-148	<1, 1, 2, 3	<1, <1, <1, <1
KW106A	1.6, 2.5, 1.3, 1.6	0.25, 0.40, 0.60, 0.30	W-150	4, 4, 4, 4	<1, <1, <1, <1
KW213AC	2.3, 2.4, 4.8, 2.4	0.40, <0.10, <0.10, 0.10	W-152	3, 2, 2, 2	4, 3, 2, 1
KW274A	3.3, 3.2, 3.7	0.30, 0.30, 0.50	W-157	<1, <1, <1, <1	<1, <1, <1, <1
KW308A	9.5, 2.0	0.30, 0.50	W-156	1, 3, 2, 2	<1, <1, <1, <1
KW192A	3.5, 6.5, 2.9, 1.6	0.38, <0.10, 0.40, 0.80	W-155	1, 2, 1, <1	<1, <1, <1, <1

Table 29.--Summary of total arsenic and total selenium concentrations in soil profiles and dissolved arsenic and dissolved selenium concentrations in water from adjacent wells in the west Oakes irrigation area--Continued

Soil profile site number	Total arsenic in soil (mg/kg)	Total selenium in soil (mg/kg)	Well number	Dissolved arsenic in water (µg/L)	Dissolved selenium in water (µg/L)
KW267A	3.8, 2.9, 4.8, 1.7	0.30, 0.21, 0.22, 0.70	W-159	<1, 1, 1, <1	1, 1, 1, 3
KW187A	2.0, 1.7, 4.5, 2.3	0.10, <0.10, <0.10, 0.70	W-161	12, 10, 9, 6	<1, <1, <1, <1
KW206A	1.5, 3.8, 3.0, 1.5, 1.8	0.10, <0.10, 0.10, 1.0, 0.70	W-163	20, 13, 14, 13	<1, <1, <1, 1
KW135A	12, 3.8, 5.5, 4.3, 4.5, 8.4	0.50, 0.10, 0.43, 0.60, 0.76, 0.90	W-39	6, 13, 9, 9	<1, <1, <1, 1
KW127A	3.2, 3.8, 3.5, 3.5	<0.10, <0.10, 0.90, 0.40	W-41A	--	--
KW131A	2.4, 4.0, 2.8	0.10, 0.23, 0.20	W-167	3, 3, 2, 2	<1, <1, <1, 1
KW246A	1.9, 3.6, 8.2, 5.2, 5.1	0.10, 0.25, <0.10, 0.50, 0.50	W-166	16, 7, 10, 10	<1, <1, <1, 1
KW113A	11, 4.0, 2.9, 46, 7.3	0.50, 0.32, 3.0, 2.1, 1.0	W-48	12, 8, 10, 12	1, 1, <1, 1
KW179A	10, 4.0, 2.8, 5.1	<0.10, <0.10, 0.35, 0.40	W-170	6, 6, 8, 6	<1, <1, <1, 1
KW222AC	6.4, 2.8, 10, 2.4	<0.10, 0.40, <0.10, 0.60	W-172	19, 14, 16, 22	<1, <1, 2, 2
KW255A	1.7, 5.0, 3.9, 3.9, 6.1, 3.0, 6.0	0.80, 0.40, <0.10, 0.50, 0.20, 0.50, 0.70	W-177	2, 3, 3, 2	<1, <1, <1, <1

Table 29.--Summary of total arsenic and total selenium concentrations in soil profiles and dissolved arsenic and dissolved selenium concentrations in water from adjacent wells in the west Oakes irrigation area--Continued

Soil profile site number	Total arsenic in soil (mg/kg)	Total selenium in soil (mg/kg)	Well number	Dissolved arsenic in water (µg/L)	Dissolved selenium in water (µg/L)
KW314A	2.2, 2.0	0.20, 0.30	W-176	4, 6, 5, 3	<1, <1, <1, 1
KW173A	1.8, 2.6, 6.6	0.10, 0.70, 1.0	W175	7, 7, 6, 7	<1, <1, <1, 1
KW328A	2.0, 3.1	2.6, 0.30	W179	--	--
KW141A	1.6, 3.0, 7.1, 9.5, 2.5, 2.8	0.30, <0.10, 0.24, 0.20, 0.48, 0.20	W181	<1, 2, 2, <1	<1, <1, <1, 1
KW165A	1.4, 2.0, 7.8, 5.0	0.31, <0.10, <0.10, 0.80	W55	8, 18, 13, 8	<1, <1, <1, <1
KW160A	1.7, 2.7, 4.2, 8.5	<0.10, 0.57, 0.10, 0.40	W184	<1, 32, 28, 24	<1, <1, <1, <1
KW239A	17, 13, 2.9, 2.5, 7.4	0.50, 0.50, <0.10, 0.65, 0.60	W189	4, 11, 8, 5	<1, <1, <1, 1
KW147A	1.8, 3.7, 11, 2.6	0.10, <0.10, 0.20, 0.50	W188	4, 14, 9, 6	<1, <1, <1, <1
KW122A	1.6, 4.9, 7.7	0.30, <0.10, <0.10	W187	7, 12, 7, 5	<1, <1, <1, <1

A contingency-table analysis (Inman and Conover, 1983) was used to test for the existence of relations between total arsenic concentrations in soil and dissolved arsenic concentrations in water. The same was done for selenium. The results (table 30) indicate there is no relation between either total arsenic or selenium concentrations in soil and dissolved arsenic or selenium concentrations in water for the data used in this analysis.

Water-extractable concentration data of arsenic and selenium for three soil profiles sampled during the reconnaissance phase of this investigation in the west Oakes irrigation area and on dissolved concentrations in water from three adjacent wells are given in table 18. These are the only locations in the GDU where data on both water-extractable ion concentrations and dissolved ion concentrations in water from adjacent wells were collected. The water-extractable selenium concentration (0.16 mg/kg) in the soil profile adjacent to well W-41A was the largest measured in 81 samples collected during the reconnaissance phase study (table 6). Selenium was not detected in a water sample collected from well W-41A. These three samples indicate no apparent relations between water-extractable and dissolved concentrations of arsenic and selenium. It should be noted, however, that the soil-profile samples and the water samples from adjacent wells were not collected at the same point in time. Soil samples were collected in September 1985 and water samples were collected in January 1986.

POTENTIAL FOR MOBILIZATION OF ARSENIC AND SELENIUM FROM SOILS IN THE GARRISON DIVERSION UNIT

Data for soil and water chemistry collected during the detailed study phase in the Oakes test area do not give any indications of potential problems related to the mobilization of arsenic or selenium. The total concentrations of these elements are within baselines determined for other soils in the northern Great Plains and smaller than concentrations measured in the western San Joaquin Valley. Concentrations of arsenic and selenium in water samples from drains are less than regulations for drinking water and criteria for freshwater aquatic life. Small concentrations of selenium (median, 1 µg/L) were detected in 63 percent of the samples collected from drains as compared with 22 percent in samples from wells. The absence of any large concentrations of selenium is an indication that source materials containing appreciable quantities of selenium are not present in the soils and unsaturated zone. The source of selenium determined in the drain samples is probably from oxidation, desorption, and exchange reactions involving organic and inorganic material in the zone above and near the water table. Small concentrations of selenium likely will continue to occur in the drain water as long as a source exists. Concentrations could potentially increase if irrigation or agricultural practices produce a more oxidizing environment. However, unlike the western San Joaquin Valley, Calif., soils in the proposed GDU irrigation areas do not contain large concentrations of soluble salts as shown by the water-extractable element data, and large concentrations of arsenic or selenium are unlikely to occur in the irrigation drains.

Table 30.--Contingency tables for total arsenic and total selenium concentrations in soils and dissolved arsenic and dissolved selenium concentrations in water from adjacent wells in the west Oakes irrigation area

[Top number is number of soil-water sample pairs; bottom number is expected number of sample pairs based on sample statistics; mg/kg, milligrams per kilogram; μg/L, micrograms per liter; <, less than; >, greater than; chi square, value of test statistic; critical value, critical value for test statistic]

Total arsenic concentration in soil (mg/kg)			Dissolved arsenic concentration in water (μg/L)	Row totals
<6	6-10	>10		
6 4.34	7 6.28	1 3.38	<6	14
1 1.55	2 2.24	2 1.21	6-10	5
2 2.96	4 4.44	4 2.59	>10	10
Column totals				
9	13	7		29

Chi square = 4.62; critical value = 9.49.

Total selenium concentration in soil (mg/kg)			Dissolved selenium concentration in water (μg/L)	Row totals
<0.5	0.5-1	>1		
1 3.10	13 10.86	1 1.03	<1	15
4 2.07	5 4.74	1 0.69	1	10
1 0.83	3 2.90	0 0.28	>1	4
Column totals				
6	21	2		29

Chi square = 4.80; critical value = 9.49.

An analysis of variance on rank transformations of the data available for total and water-extractable concentrations of arsenic and selenium collected during the reconnaissance phase of this investigation indicate statistical differences between concentrations in the six potential irrigation areas that were sampled. Because of the small number of samples available, no attempt was made to analyze these data for the different soil zones in the soil profile. All samples from all profiles in each irrigation area were combined and used in the analysis. Tukey's multiple comparison test on rank-transformed data indicated that total arsenic concentrations were larger in the Lincoln Valley and Harvey pumping irrigation areas than in the New Rockford and west Oakes irrigation areas. Extractable arsenic concentrations were larger in the New Rockford irrigation area than in the Harvey pumping irrigation area but not statistically different from the other four irrigation areas. Total selenium concentrations were statistically larger in the Lincoln Valley irrigation area than in the New Rockford and LaMoure irrigation areas. Water-extractable selenium concentrations were statistically the same in all areas.

The above results need to be used with caution because of the small number of samples available. Also, it should be restated that the reconnaissance phase soil samples were collected in areas expected to represent worst-case conditions. Thus, the samples may not be entirely representative of the irrigation areas from which they were collected.

During this investigation, no data on arsenic and selenium concentrations in ground water were collected in potential GDU irrigation areas other than the west Oakes irrigation area. In the 1970's, a number of ground-water samples were collected in the GDU and analyzed for these two elements (Harza Engineering Co., 1976), but the analytical detection limits were not low enough for the data to be useful in this investigation. Consequently, there currently is insufficient information on the occurrence of these elements in ground water in the other possible GDU irrigation areas to determine whether arsenic and selenium concentrations are likely to present a problem. Plans have been developed to collect water samples from shallow wells and drains in the other potential irrigation areas and analyze the samples for arsenic, selenium, and a number of other elements.

SUMMARY AND CONCLUSIONS

Examination of soil-analysis data collected during the reconnaissance phase of this investigation indicates concentrations for total arsenic and selenium were less than concentrations determined in baseline studies conducted in the northern Great Plains and at the Panoche Fan, western San Joaquin Valley, Calif. The maximum, minimum, and geometric mean concentrations of total arsenic measured in the GDU were 34, 1.0, and 4.15 mg/kg, respectively. In comparison, the maximum, minimum, and geometric mean concentrations of total arsenic measured in the northern Great Plains were 20, <0.1, and 7.1 mg/kg, respectively; and, in the Panoche Fan, they were 21, 3.4, and 8.8 mg/kg, respectively. For total selenium, the maximum, minimum, and geometric mean concentrations measured in the GDU were 2.1, <0.1, and 0.13 mg/kg, respectively. In comparison, the maximum, minimum, and geometric mean concentrations of total selenium were 20, <0.1, and 0.45 mg/kg, respectively, in the northern Great Plains, and 4.5, <0.1, and 0.68 mg/kg, respectively, in the Panoche Fan. The median total selenium concentration determined in soils in the GDU reconnaissance phase (0.1 mg/kg) was six to 12 times smaller than those measured in agricultural fields in the western San Joaquin Valley.

In addition to the less than baseline concentrations of total selenium, water-extraction analyses made on samples from the Turtle Lake, Lincoln Valley, Harvey pumping, New Rockford, LaMoure, and west Oakes irrigation areas indicate that only minor quantities, typically less than 10 percent, of the total selenium were extracted from most samples using the 1:5 (soil to water) extraction procedure. Only two samples had water-extractable selenium concentrations that accounted for more than 10 percent of the total selenium. This compares to a 10- to 45-percent water-extractable concentration determined in several western San Joaquin Valley soil samples.

In the detailed study phase conducted in the Oakes test area, soil chemistry was determined for samples after separating the soil-profile samples into three soil zones--the oxidized soil zone, which comprises the upper, well-drained, well-aerated soil horizons; the mottled soil zone, which represents the soil zone where the water table has fluctuated over the years causing various degrees of mottling; and the reduced soil zone, which is relatively oxygen free due to a permanently saturated condition. In most soil profiles, the oxidized soil zone was 3 to 4 ft thick and the mottled soil zone was 3 to 5 ft thick. The reduced soil zone most generally was located at a depth of about 9 ft and continued to the base of the drill holes (about 18 ft). The arithmetic mean concentration of total selenium in the oxidized soil zone samples was 0.28 mg/kg; in the mottled soil zone samples, it was 0.32 mg/kg; and, in the reduced soil zone samples, it was 0.53 mg/kg. The minimum and maximum concentrations were <0.1 mg/kg and 3.0 mg/kg, respectively. These concentrations are smaller than those measured in the northern Great Plains study and in the Panoche Fan.

During 1986-87, 296 ground-water samples from 120 wells and 80 drain-water samples from 23 drains were collected in the west Oakes irrigation area. Most samples were analyzed for arsenic, selenium, and a number of other trace elements. The maximum arsenic concentration measured in 236 ground-water samples was 44 µg/L, and the median concentration was 4 µg/L. The maximum and median arsenic concentrations in 63 drain water samples were 11 and 3 µg/L, respectively. The median selenium concentration measured in the ground-water samples was less than the laboratory analytical detection limits. Only 17 percent of the 236 samples from wells in the west Oakes irrigation area analyzed for selenium had detectable concentrations, and only two samples had concentrations greater than 5 µg/L. These two samples were from well W-133 (8 µg/L) and well W-277 (9 µg/L), which are located at the extreme edges of the west Oakes irrigation area. The maximum selenium concentration in 63 drain-water samples from drains was 4 µg/L, and the median was 1 µg/L. Small concentrations of selenium were detected in 63 percent of the drain samples analyzed and at 14 of the 16 drain locations sampled. The larger incidence of detection of selenium in the drains is indicative of the greater mobility of selenium in the more oxidizing environment of the drains than in the less oxidizing environment deeper in the aquifer.

Arsenic concentrations in wells are largest in areas where selenium concentrations are smallest and are correlated negatively with variables that are correlated positively with selenium. Arsenic concentrations are smallest in the more oxidizing environments, whereas selenium concentrations are largest in these environments.

Concentrations of arsenic, selenium, and a number of other trace elements were compared with national drinking-water regulations, North Dakota class I stream standards, acute and chronic criteria for freshwater aquatic life, and criteria for irrigation. Except for selenium in samples from two wells and mercury at several locations, none of the above regulations, standards, or criteria were exceeded in any of the well or drain samples. Selenium concentrations of 8 and 9 µg/L in two wells exceeded the chronic criteria for freshwater aquatic life. Comparison of selenium concentrations in ground water with criteria for freshwater aquatic life in streams, however, may be inappropriate. The chronic criterion for mercury in freshwater aquatic life is 0.012 µg/L and is much less than the laboratory analytical detection limit of 0.1 µg/L. The maximum mercury concentrations detected were 0.8 µg/L in samples from wells and 0.2 µg/L in samples from drains. Median concentrations of mercury were less than detection limits in samples from both wells and drains.

Because of concern about the potential for selenium contamination resulting from irrigation return flow to the James River, a comparison was made between selenium concentrations measured in 63 samples from drains in the Oakes test area with samples from other irrigation areas in the western United States, including the western San Joaquin Valley. The median selenium concentrations in drain samples from the western San Joaquin Valley ranged from 84 to 320 µg/L. The median concentration measured in drain samples from the Oakes test area was 1 µg/L. Selenium concentrations in drain samples from the Oakes test area generally were comparable to, or smaller than, concentrations measured in irrigation areas in Montana and Utah.

Comparisons also were made between drain samples from the Oakes test area and other irrigation areas in the western United States for arsenic, specific conductance, sulfate, nitrite plus nitrate-nitrogen, boron, and molybdenum. Median values of specific conductance and median concentrations of these constituents generally were smaller in the west Oakes irrigation area than in the western San Joaquin Valley and other irrigation areas.

Based on data from soil samples analyzed for both total and water-extractable concentrations of selenium in the reconnaissance phase of this investigation and on data from the soil and water samples analyzed for total selenium during the detailed phase, the conclusion was made that the areas under consideration for irrigation in the GDU project contain small concentrations of total and water-extractable selenium. This conclusion is supported by comparing the North Dakota data to data from other areas in the western United States, such as the northern Great Plains and the Panoche Fan. Additional data in support of this conclusion are the small concentrations of selenium measured in 299 water samples from wells and drains in the west Oakes irrigation area. The median selenium concentration was 1 µg/L or less, and the maximum concentration measured (except in two wells) was less than acute and chronic criteria for freshwater aquatic life, national drinking-water regulations, North Dakota class I stream standards, and criteria for irrigation.

Data are not currently available to make definitive statements about selenium concentrations in ground water in GDU irrigation areas other than the west Oakes irrigation area. Data available on total and water-extractable concentrations of selenium in soil, however, indicate that concentrations in ground water would be similar to those determined in the west Oakes irrigation area. Plans have been developed to sample the ground water in these areas. If expanded irrigation and associated agricultural practices result in an environment that is considerably more oxidizing than the present environment, it is possible that larger quantities of selenium than were measured during the detailed study phase of this investigation could be mobilized and transported into the irrigation drains. Unlike soils in the western San Joaquin Valley, however, the soils in the proposed GDU irrigation areas do not contain large concentrations of soluble salts that contain selenium, and large concentrations of selenium are unlikely to be present in the discharge from the irrigation drains.

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Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River

[Samples collected and analyzed by the U.S. Geological Survey; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data]

	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468250, James River above Arrowwood Lake near Kensal, N.Dak. June 1985 to May 1988									
Discharge									
Discharge, instantaneous, stream (ft^3/s)	19	773	0.24	55	773	16	1.8	0.60	0.24
Chemical property									
Specific conductance (µS/cm)	19	1,720	322	947	1,720	1,020	890	720	322
pH (standard units)	18	8.9	7.6	8.2	8.9	8.5	8.2	7.7	7.6
Temperature, water (°C)	19	23.0	0	10.8	23.0	19.0	12.0	1.0	0
Turbidity (NTU)	18	15	2.3	7.9	15	13	6.2	4.7	2.3
Hardness (mg/L as $CaCO_3$)	18	600	160	320	600	350	300	220	160
Alkalinity, total (mg/L as $CaCO_3$)	15	570	160	330	570	360	330	260	160

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468250, James River above Arrowwood Lake near Kensal, N.Dak.--Continued June 1985 to May 1988									
Chemical constituent									
Oxygen, dissolved (mg/L)	16	13.0	2.3	8.0	13.0	11.2	7.5	5.7	2.3
Calcium, dissolved (mg/L as Ca)	18	110	24	57	110	64	56	41	24
Magnesium, dissolved (mg/L as Mg)	18	79	18	43	79	48	40	30	18
Sodium, dissolved (mg/L as Na)	18	210	38	100	210	110	90	74	38
Sodium-adsorption ratio	18	4.0	1.0	2.4	4.0	3.0	2.0	2.0	1.0
Potassium, dissolved (mg/L as K)	18	21	7.7	15	21	16	15	12	7.7
Sulfate, dissolved (mg/L as SO_4)	18	350	70	160	350	200	140	120	70
Chloride, dissolved (mg/L as Cl)	18	59	11	24	59	27	20	15	11
Silica, dissolved (mg/L as SiO_2)	12	45	13	25	45	31	26	16	13
Dissolved solids, residue at 180 °C (mg/L)	18	1,140	280	648	1,140	691	600	510	280
Dissolved solids, calculated, sum of constituents (mg/L)	18	1,200	274	583	1,200	627	541	456	274
Nitrite plus nitrate, dissolved (mg/L as N)	18	<.01	--	--	--	--	--	--	--
Nitrogen, ammonia, dissolved (mg/L as N)	6	.36	.02	.08	.36	.12	.04	.02	.02

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468250, James River above Arrowwood Lake near Kensal, N.Dak.--Continued June 1985 to May 1988									
Chemical constituent, Continued									
Phosphorus, total (mg/L as P)	7	0.41	0.09	0.18	0.41	0.18	0.16	0.12	0.09
Phosphorus, dissolved orthophosphate (mg/L as P)	17	.16	<.01	[1].06	[1].16	[1].07	[1].04	[1].01	[1]<.01
Arsenic, total (µg/L as As)	7	7	2	3	7	4	2	2	2
Arsenic, dissolved (µg/L as As)	16	9	1	3	9	4	2	2	1
Barium, dissolved (µg/L as Ba)	10	130	46	82	130	92	77	70	46
Beryllium, dissolved (µg/L as Be)	10	<10	--	--	--	--	--	--	--
Boron, dissolved (µg/L as B)	18	290	70	190	290	210	180	160	70
Cadmium, dissolved (µg/L as Cd)	16	<1	--	--	--	--	--	--	--
Chromium, dissolved (µg/L as Cr)	10	<1	--	--	--	--	--	--	--
Copper, dissolved (µg/L as Cu)	18	3	<1	[1]1.3	[1]3	[1]2	[1]1	[1].7	[1].3
Iron, dissolved (µg/L as Fe)	18	60	10	20	60	30	20	10	10
Lead, dissolved (µg/L as Pb)	18	<5	--	--	--	--	--	--	--

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468250, James River above Arrowwood Lake near Kensal, N.Dak.--Continued June 1985 to May 1988									
Chemical constituent, Continued									
Manganese, dissolved (µg/L as Mn)	18	1,300	4	200	1,300	250	90	12	4
Mercury, dissolved (µg/L as Hg)	17	.7	<.1	.3	.7	.3	.2	.2	.1
Selenium, total (µg/L as Se)	6	<1	--	--	--	--	--	--	--
Selenium, dissolved (µg/L as Se)	18	<1	--	--	--	--	--	--	--
Zinc, dissolved (µg/L as Zn)	18	14	<10	[1]7	[1]14	[1]9	[1]6	[1]4	[1]2
Sediment									
Sediment, suspended, concentration (mg/L)	19	208	4	48	208	65	28	12	4
Sediment, suspended, sieve diameter, percent finer than 0.62 millimeter	18	100	53	90	100	97	96	88	53

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
				Station 06468500, James River near Pingree, N.Dak. October 1983 to May 1988					
Discharge									
Discharge, instantaneous, stream (ft^3/s)	7	770	1.5	118	770	25	2.5	1.5	1.5
Chemical property									
Specific conductance (µS/cm)	25	960	345	678	951	745	710	600	352
pH (standard units)	25	9.1	7.4	8.5	9.1	8.9	8.6	8.0	7.5
Temperature, water (°C)	26	23.0	1.0	10.9	22.6	17.9	10.0	3.0	1.0
Turbidity (NTU)	19	100	1.2	17	100	25	7.0	2.8	1.2
Hardness (mg/L as $CaCO_3$)	26	350	110	230	340	260	220	200	120
Alkalinity, total (mg/L as $CaCO_3$)	25	360	120	240	360	260	240	210	130
Chemical constituent									
Oxygen, dissolved (mg/L)	24	22.4	4.7	11.0	21.6	12.9	10.8	8.0	5.3

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468500, James River near Pingree, N.Dak.--Continued October 1983 to May 1988									
Chemical constituent, Continued									
Calcium, dissolved (mg/L as Ca)	26	65	24	41	63	49	40	32	25
Magnesium, dissolved (mg/L as Mg)	26	45	13	31	44	34	32	28	14
Sodium, dissolved (mg/L as Na)	26	82	23	57	81	70	56	50	23
Sodium-adsorption ratio	26	2.0	.9	1.7	2.0	2.0	2.0	1.0	.9
Potassium, dissolved (mg/L as K)	26	22	8.6	15	21	17	15	13	9.1
Sulfate, dissolved (mg/L as SO_4)	26	170	48	120	170	140	120	88	48
Chloride, dissolved (mg/L as Cl)	26	16	5.8	11	16	13	11	10	5.9
Fluoride, dissolved (mg/L as F)	24	.3	.1	.2	.3	.2	.2	.1	.1
Silica, dissolved (mg/L as SiO_2)	21	28	<.1	8.9	28	15	9.9	.5	<.1
Dissolved solids, residue at 180 °C (mg/L)	26	637	220	442	621	503	451	389	226
Dissolved solids, calculated, sum of constituents (mg/L)	26	617	207	416	601	459	434	370	219
Nitrite plus nitrate, dissolved (mg/L as N)	26	<.10	--	--	--	--	--	--	--

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468500, James River near Pingree, N.Dak.--Continued October 1983 to May 1988									
Chemical constituent, Continued									
Nitrogen, ammonia, dissolved (mg/L as N)	5	0.04	0.01	--	--	--	--	--	--
Phosphorus, total (mg/L as P)	8	.33	.08	0.19	0.33	0.27	0.16	0.14	0.08
Phosphorus, dissolved orthophosphate (mg/L as P)	15	.17	<.01	.04	.17	.04	.02	.01	<.01
Arsenic, total (μg/L as As)	8	8	1	3	8	5	2	1	1
Arsenic, dissolved (μg/L as As)	18	6	<1	[1]3	[1]6	[1]3	[1]2	[1]2	[1]1
Barium, dissolved (μg/L as Ba)	15	100	43	[1]71	[1]100	[1]82	[1]69	[1]59	[1]43
Beryllium, dissolved (μg/L as Be)	10	<10	--	--	--	--	--	--	--
Boron, dissolved (μg/L as B)	26	160	50	110	160	140	120	100	50
Cadmium, dissolved (μg/L as Cd)	18	<1	--	--	--	--	--	--	--
Chromium, dissolved (μg/L as Cr)	13	<1	--	--	--	--	--	--	--
Copper, dissolved (μg/L as Cu)	21	4	<1	[1]1	[1]4	[1]2	[1]1	[1]1	[1].3
Iron, dissolved (μg/L as Fe)	21	200	<10	[1]20	[1]190	[1]16	[1]10	[1]5	[1]1

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06468500, James River near Pingree, N.Dak.--Continued October 1983 to May 1988									
Chemical constituent, Continued									
Lead, dissolved (µg/L as Pb)	21	<5	--	--	--	--	--	--	--
Manganese, dissolved (µg/L as Mn)	21	1,600	4	200	1,500	160	37	10	4
Mercury, dissolved (µg/L as Hg)	19	1.0	<.1	.3	1.0	.3	.2	.1	.1
Selenium, total (µg/L as Se)	8	<1	--	--	--	--	--	--	--
Selenium, dissolved (µg/L as Se)	21	<1	--	--	--	--	--	--	--
Zinc, dissolved (µg/L as Zn)	21	20	1	^{1}7	^{1}18	^{1}10	^{1}6	^{1}3	^{1}1
Sediment									
Sediment, suspended, concentration (mg/L)	18	461	2	60	461	70	34	8	2
Sediment, suspended, sieve diameter, percent finer than 0.62 millimeter	15	100	40	89	100	98	94	88	40

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470500, James River at LaMoure, N.Dak. December 1983 to August 1988									
Discharge									
Discharge, instantaneous, stream (ft^3/s)	34	556	5.0	137	547	231	63	16	7.2
Chemical property									
Specific conductance (µS/cm)	34	1,550	440	877	1,540	1,080	852	595	508
pH (standard units)	33	9.2	7.5	8.2	8.9	8.5	8.3	7.8	7.6
Temperature, water (°C)	34	26.0	0	10.1	24.5	19.2	8.8	.9	0
Turbidity (NTU)	24	45	2.6	16	40	25	16	3.6	2.6
Hardness (mg/L as $CaCO_3$)	29	520	170	310	500	380	310	210	180
Alkalinity, total (mg/L as $CaCO_3$)	33	470	140	270	460	330	270	210	150
Chemical constituent									
Oxygen, dissolved (mg/L)	32	20.0	5.5	11.3	19.7	15.2	10.0	7.6	5.8

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470500, James River at LaMoure, N.Dak.--Continued December 1983 to August 1988									
Chemical constituent, Continued									
Calcium, dissolved (mg/L as Ca)	29	140	37	70	140	85	67	47	38
Magnesium, dissolved (mg/L as Mg)	29	48	18	32	48	37	32	23	19
Sodium, dissolved (mg/L as Na)	29	180	25	77	160	96	75	42	30
Sodium-adsorption ratio	29	4.0	.9	1.9	3.5	2.0	2.0	1.0	1.0
Potassium, dissolved (mg/L as K)	33	15	3.0	11	14	13	12	10	5.1
Sulfate, dissolved (mg/L as SO_4)	33	290	66	150	290	190	150	110	81
Chloride, dissolved (mg/L as Cl)	33	88	9.7	32	75	43	30	12	9.8
Fluoride, dissolved (mg/L as F)	32	.7	.1	.2	.5	.3	.2	.2	.1
Silica, dissolved (mg/L as SiO_2)	24	26	4.1	14	25	20	15	8.6	4.3
Dissolved solids, residue at 180 °C (mg/L)	29	1,030	280	572	1,010	708	564	364	305
Dissolved solids, calculated, sum of constituents (mg/L)	29	1,040	270	559	964	694	542	351	302
Nitrite plus nitrate, dissolved (mg/L as N)	30	.60	<.01	[1].22	[1].58	[1].34	[1].15	[1].09	[1].04

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470500, James River at LaMoure, N.Dak.--Continued December 1983 to August 1988									
Chemical constituent, Continued									
Nitrogen, ammonia, dissolved (mg/L as N)	5	<0.01	--	--	--	--	--	--	--
Phosphorus, total (mg/L as P)	9	.37	0.13	0.28	0.37	0.34	0.30	0.22	0.13
Phosphorus, dissolved orthophosphate (mg/L as P)	17	.41	<.01	[1].11	[1].41	[1].17	[1].08	[1].05	[1]<.05
Arsenic, total (μg/L as As)	9	6	2	4	6	4	4	2	2
Arsenic, dissolved (μg/L as As)	20	16	1	3	15	3	2	2	1
Barium, dissclved (μg/L as Ba)	11	92	48	65	92	82	63	50	48
Beryllium, dissolved (μg/L as Be)	11	<10	--	--	--	--	--	--	--
Boron, dissolved (μg/L as B)	30	550	60	230	480	300	220	110	70
Cadmium, dissolved (μg/L as Cd)	18	2	<1	[1].6	[1]2	[1]1	[1].5	[1].3	[1].2
Chromium, dissolved (μg/L as Cr)	13	<1	--	--	--	--	--	--	--
Copper, dissolved (μg/L as Cu)	26	7	<1	[1]1	[1]6	[1]2	[1]1	[1]1	[1].3
Iron, dissolved (μg/L as Fe)	24	120	<10	16	99	12	10	7	4

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470500, James River at LaMoure, N.Dak.--Continued December 1983 to August 1988									
Chemical constituent, Continued									
Lead, dissolved (µg/L as Pb)	26	<5	--	--	--	--	--	--	--
Manganese, dissolved (µg/L as Mn)	24	1,600	5	480	1,600	820	260	110	8
Mercury, dissolved (µg/L as Hg)	28	.7	<.1	[1].2	[1].7	[1].4	[1].2	[1].1	[1].04
Selenium, total (µg/L as Se)	9	<1	--	--	--	--	--	--	--
Selenium, dissolved (µg/L as Se)	24	<1	--	--	--	--	--	--	--
Zinc, dissolved (µg/L as Zn)	25	40	<10	[1]12	[1]35	[1]17	[1]10	[1]4	[1]2
Sediment									
Sediment, suspended, concentration (mg/L)	29	234	3	67	180	85	67	34	4
Sediment, suspended, sieve diameter, percent finer than 0.62 millimeter	22	100	13	80	100	99	98	56	13

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470830, James River at Oakes, N.Dak. December 1983 to May 1988									
Discharge									
Discharge, instantaneous, stream (ft^3/s)	16	618	5.0	161	618	226	85	22	5.0
Chemical property									
Specific conductance (µS/cm)	26	2,250	400	1,020	2,150	1,230	880	640	456
pH (standard units)	26	9.0	7.6	8.2	8.9	8.5	8.2	8.0	7.6
Temperature, water (°C)	26	23.5	0	8.4	23.5	15.2	7.0	0	0
Turbidity (NTU)	21	80	1.4	23	80	33	17	5.6	1.4
Hardness (mg/L as $CaCO_3$)	26	750	150	360	750	460	300	240	160
Alkalinity, total (mg/L as $CaCO_3$)	25	700	140	330	680	430	280	220	150
Chemical constituent									
Oxygen, dissolved (mg/L)	22	23.2	5.8	12.3	23.0	13.4	10.8	9.2	6.0

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470830, James River at Oakes, N.Dak.--Continued December 1983 to May 1988									
Chemical constituent, Continued									
Calcium, dissolved (mg/L as Ca)	26	170	35	80	170	100	64	53	37
Magnesium, dissolved (mg/L as Mg)	26	83	16	40	83	49	32	26	18
Sodium, dissolved (mg/L as Na)	26	240	23	88	220	100	75	49	29
Sodium-adsorption ratio	26	4.0	.8	1.9	3.6	2.0	2.0	1.0	.9
Potassium, dissolved (mg/L as K)	26	23	10	14	22	14	13	12	10
Sulfate, dissolved (mg/L as SO_4)	26	460	61	190	450	220	160	120	69
Chloride, dissolved (mg/L as Cl)	26	140	11	40	120	52	34	16	11
Fluoride, dissolved (mg/L as F)	26	.6	.1	.3	.6	.3	.3	.2	.1
Silica, dissolved (mg/L as SiO_2)	20	990	2.8	62	940	19	12	9.3	2.9
Dissolved solids, residue at 180 °C (mg/L)	21	1,560	261	660	1,540	696	550	414	269
Dissolved solids, calculated, sum of constituents (mg/L)	26	2,050	257	692	1,880	800	554	385	286
Nitrite plus nitrate, dissolved (mg/L as N)	26	.62	<.01	[1].14	[1].59	[1].15	[1].07	[1].03	[1].01

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470830, James River at Oakes, N.Dak.--Continued December 1983 to May 1988									
Chemical constituent, Continued									
Nitrogen, ammonia, dissolved (mg/L as N)	26	0.61	0.01	0.09	0.51	0.09	0.06	0.03	0.01
Phosphorus, total (mg/L as P)	5	.33	.12	--	--	--	--	--	--
Phosphorus, dissolved orthophosphate (mg/L as P)	26	.17	<.01	.07	.17	.11	.06	.03	<.03
Arsenic, total (µg/L as As)	6	4	2	3	4	4	3	2	2
Arsenic, dissolved (µg/L as As)	16	5	1	3	5	3	2	2	1
Barium, dissolved (µg/L as Ba)	10	100	43	69	100	85	64	56	43
Beryllium, dissolved (µg/L as Be)	10	<10	--	--	--	--	--	--	--
Boron, dissolved (µg/L as B)	26	720	60	240	650	310	200	140	70
Cadmium, dissolved (µg/L as Cd)	16	<1	--	--	--	--	--	--	--
Chromium, dissolved (µg/L as Cr)	10	<1	--	--	--	--	--	--	--
Copper, dissolved (µg/L as Cu)	21	3	<1	[1]2	[1]3	[1]2	[1]2	[1]1	[1]1
Iron, dissolved (µg/L as Fe)	26	130	3	20	100	20	10	10	<10

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470830, James River at Oakes, N.Dak.--Continued December 1983 to May 1988									
Chemical constituent, Continued									
Lead, dissolved (µg/L as Pb)	21	12	<1	[1]2	[1]11	[1]3	[1]1	[1]1	[1]0.3
Manganese, dissolved (µg/L as Mn)	26	890	10	180	860	200	120	40	13
Mercury, dissolved (µg/L as Hg)	19	1.4	<.1	[1].3	[1]1.4	[1].3	[1].2	[1].1	[1].03
Selenium, total (µg/L as Se)	6	<1	--	--	--	--	--	--	--
Selenium, dissolved (µg/L as Se)	21	<1	--	--	--	--	--	--	--
Zinc, dissolved (µg/L as Zn)	21	20	<10	[1]11	[1]21	[1]15	[1]10	[1]6	[1]4
Sediment									
Sediment, suspended, concentration (mg/L)	14	461	13	102	461	104	79	55	13
Sediment, suspended, sieve diameter, percent finer than 0.62 millimeter	15	99	10	77	99	99	97	59	10

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470875, James River at Dakota Lake Dam near Ludden, N.Dak. December 1983 to May 1988									
Discharge									
Discharge, instantaneous, stream (ft^3/s)	32	1,220	0.10	180	983	192	82	16	3.0
Chemical property									
Specific conductance (µS/cm)	32	2,300	425	930	2,300	1,120	805	620	526
pH (standard units)	30	9.1	7.8	8.4	9.1	8.7	8.6	8.0	7.8
Temperature, water (°C)	32	25.0	0	8.9	23.7	14.8	6.2	1.6	.6
Turbidity (NTU)	25	40	1.4	15	38	26	14	3.2	1.7
Hardness (mg/L as $CaCO_3$)	32	890	150	320	810	360	260	210	180
Alkalinity, total (mg/L as $CaCO_3$)	31	820	140	290	740	340	230	200	150
Chemical constituent									
Oxygen, dissolved (mg/L)	32	30.2	0.5	12.6	27.7	14.9	11.4	8.4	0.8

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Type of data	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470875, James River at Dakota Lake Dam near Ludden, N.Dak.--Continued December 1983 to May 1988									
Chemical constituent, Continued									
Calcium, dissolved (mg/L as Ca)	32	190	35	67	160	78	56	47	40
Magnesium, dissolved (mg/L as Mg)	32	100	16	37	100	42	32	24	18
Sodium, dissolved (mg/L as Na)	32	260	25	80	230	95	66	45	35
Sodium-adsorption ratio	32	4.0	.9	1.8	4.0	2.0	2.0	1.0	1.0
Potassium, dissolved (mg/L as K)	32	32	8.3	14	29	15	14	12	9.3
Sulfate, dissolved (mg/L as SO_4)	32	570	64	180	490	210	160	100	81
Chloride, dissolved (mg/L as Cl)	32	150	11	36	120	42	24	16	12
Fluoride, dissolved (mg/L as F)	32	.5	.1	.2	.4	.3	.2	.2	.1
Silica, dissolved (mg/L as SiO_2)	25	71	.9	14	62	17	13	5.6	.9
Dissolved solids, residue at 180 °C (mg/L)	25	1,630	282	590	1,510	708	516	386	304
Dissolved solids, calculated, sum of constituents (mg/L)	32	1,660	267	593	1,600	738	486	370	324
Nitrite plus nitrate, dissolved (mg/L as N)	32	.62	<.01	[1].06	[1].54	[1].05	[1].01	[1]<.01	[1]<.01

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470875, James River at Dakota Lake Dam near Ludden, N.Dak.--Continued December 1983 to May 1988									
Chemical constituent, Continued									
Nitrogen, ammonia, dissolved (mg/L as N)	32	2	<0.01	[1]0.18	[1]1.3	[1]0.12	[1]0.05	[1]0.02	[1]0.02
Phosphorus, total (mg/L as P)	7	.31	.11	.20	.31	.22	.19	.16	.11
Phosphorus, dissolved orthophosphate (mg/L as P)	32	.70	<.01	[1].06	[1].34	[1].06	[1].03	[1].01	[1]<.01
Arsenic, total (µg/L as As)	8	10	2	4	10	4	3	2	2
Arsenic, dissolved (µg/L as As)	19	6	<1	[1]2	[1]6	[1]3	[1]2	[1]1	[1]1
Barium, dissolved (µg/L as Ba)	12	140	40	72	140	86	66	54	40
Beryllium, dissolved (µg/L as Be)	12	<10	--	--	--	--	--	--	--
Boron, dissolved (µg/L as B)	32	4,200	60	320	1,800	240	160	120	90
Cadmium, dissolved (µg/L as Cd)	19	<1	--	--	--	--	--	--	--
Chromium, dissolved (µg/L as Cr)	12	<1	--	--	--	--	--	--	--
Copper, dissolved (µg/L as Cu)	25	3	<1	[1]1	[1]3	[1]2	[1]1	[1]1	[1].5
Iron, dissolved (µg/L as Fe)	32	80	<10	[1]18	[1]82	[1]27	[1]8	[1]5	[1]1

See footnote at end of table.

Table 31.--Statistical summary of instantaneous-discharge and water-quality data collected at five gaging stations along the James River--Continued

Type of data	Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
	Sample size	Maximum	Minimum	Mean	95	75	Median 50	25	5
Station 06470875, James River at Dakota Lake Dam near Ludden, N.Dak.--Continued December 1983 to May 1988									
Chemical constituent, Continued									
Lead, dissolved (µg/L as Pb)	25	8	<1	[1]2	[1]7	[1]3	[1]2	[1]1	[1]1
Manganese, dissolved (µg/L as Mn)	32	5,700	1	230	2,200	86	24	8	2
Mercury, dissolved (µg/L as Hg)	25	.5	<.1	[1].2	[1].3	[1].2	[1].2	[1].1	[1].1
Selenium, total (µg/L as Se)	8	<1	--	--	--	--	--	--	--
Selenium, dissolved (µg/L as Se)	25	<2	<1	--	--	--	--	--	--
Zinc, dissolved (µg/L as Zn)	25	30	<1	[1]7	[1]22	[1]9	[1]7	[1]4	[1]2
Sediment									
Sediment, suspended, concentration (mg/L)	23	101	4	52	101	73	45	31	5
Sediment, suspended, sieve diameter, percent finer than 0.62 millimeter	21	100	23	83	100	99	97	77	23

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[1] Concentration is estimated by using a log-probability regression to predict the values of data less than the detection limit.