WATER QUALITY OF THE MALHEUR LAKE SYSTEM AND MALHEUR RIVER, AND SIMULATED WATER-QUALITY EFFECTS OF ROUTING MALHEUR LAKE WATER INTO MALHEUR RIVER, OREGON, 1984-85

By L.A. Fuste' and S.W. McKenzie

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DONALD PAUL HODEL, Secretary

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Dallas L. Peck, Director

For additional information
write to:

Oregon Office Chief
U.S. Geological Survey
847 N.E. 19th Avenue, Suite 300
Portland, Oregon 97232

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CONTENTS

ILLUSTRATIONS

Page

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ILLUSTRATIONS--Continued

Page

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than inch-pound units used in this report, values may be converted by using the following factors.

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meters (m)
square foot (ft^2)	0.0929	square meters (m^2)
mile (mi)	1.609	kilometers (km)
square mile (mi^2)	2.590	square kilometers (km^2)
acre-foot (acre-ft)	1233.	cubic meters (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second m^3/s
degree Fahrenheit (°F)	°C=5/9(°F-32)	degrees Celsius (°C)
ton per acre-foot (ton/acre-ft)	735.3	milligrams per liter (mg/L)
pound/day (lb/d)	0.4536	kilograms per day (kg/d)

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ABSTRACT

Above average precipitation and runoff between 1980 and 1985 have raised the water-surface elevation of Harney, Mud, and Malheur Lakes in eastern Oregon to the highest levels recorded and have caused mixing and interflow of water among the three lakes. A 50-percent increase in specific conductance throughout Malheur Lake from 1984 to 1985 results from an increase in sodium and chloride concentrations, probably caused by the flow of saline water from Harney Lake into Malheur Lake and dissolution of evaporites in flooded areas around Malheur Lake. Arsenic and boron concentrations in Malheur Lake show a small increase during the two years. Algal productivity was highest towards the center of Malheur Lake, west of Cole Island Levee; productivity east of the levee is restricted by high turbidity due to wind-caused wave action.

Concentrations of major ions in the Malheur River during the 1985 irrigation season were dilute in upstream reaches because of flow releases from reservoirs; concentrations increased in a downstream direction because of irrigation-return flow. Concentrations also increased with time during the irrigation season, with the highest concentrations occurring in October after most diversions for irrigation were discontinued.

Mass-balance equations were used to simulate mixing of Malheur Lake with Malheur River water to estimate the water quality that would occur at different points along Malheur River. Simulations of sodium and chloride concentrations and specific conductance values based on August river-flows during irrigation season, show a gradual increase from the headwaters downstream to Hope and greater increases downstream of Hope. After irrigation ceases, the simulated water quality becomes uniform throughout the river, because proposed lake flows are then the principal source of Malheur River flows.

Arsenic and boron concentrations increase much more than expected between Namorf and Little Valley; thermal springs could be the source of arsenic and boron in this reach. Ground water coming in contact with arsenic rich soils may also contribute to the elevated arsenic levels found in the river. At the end of the irrigation season, arsenic concentrations were measured at 85 micrograms per liter in this 12-14 mile reach. Increasing inflows from Malheur Lake should reduce arsenic levels between Namorf and the mouth, especially after irrigation ceases.

INTRODUCTION

Above-normal precipitation and surface runoff between 1980 and 1985 have increased the water-surface elevation of Malheur Lake to record levels (from 4,095 to 4,102 feet above sea level), causing multimillion dollar damage to private property, range land, and irrigated land around the lake (pl. 1). The U.S. Army Corps of Engineers, Walla Walla District, has investigated the feasibility of constructing and operating a canal (Virginia Valley Canal) through the Malheur Gap, which crests at about 4,115 feet above sea level, into the South Fork Malheur River, to lower the water level of the lake to levels prior to 1980. The lowering of the water level in Malheur Lake could increase the hydraulic gradient from Harney Lake to Malheur Lake and induce poor quality water from Harney Lake to Malheur Lake, which would subsequently flow down the South Fork Malheur River into the Malheur River. However, the U.S. Army Corps of Engineers proposes that the Virginia Valley Canal alternative include construction of a one-directional flow gate in place of the existing roadway bridge between the two lakes to eliminate free flow of water from Harney Lake to Malheur Lake. The plan assumes that the water level of Harney Lake, which has minimal surface inflow, would decline from evaporation losses at a rate similar to that of Malheur Lake. Malheur Lake has much greater surface inflow and would have the canal to drain water to the South Fork Malheur River.

Water from Malheur Lake that enters Malheur River through the South Fork Malheur River could raise the mineral content of the Malheur River water destined for irrigation. An increase in mineral content in the river water used for irrigation could then cause reduced soil permeability in the irrigated fields. In response to the potential for such a water-quality problem, the U.S. Army Corps of Engineers requested that the U.S. Geological Survey conduct a study to examine the potential changes in water quality in Malheur River if the Virginia Valley Canal were constructed.

Objectives

The objectives of this report are: (1) to characterize the water quality in Harney, Mud, and Malheur Lakes, from 1984 to 1985, (2) to describe the current water-quality in the Malheur River, and (3) to develop a method for simulating the water-quality effects of mixing Malheur Lake water with Malheur River water.

Geographic and Geologic Setting

The area studied in Harney County covers Harney, Mud, and Malheur Lakes, and the lower reaches of major inflows to Malheur Lake within Harney Basin (pl. 1). The topographic drainage basin of the three lakes encompasses 5,125 square miles. Thirty percent of the 3,083 square mile area that drains into Malheur Lake does not contribute inflow (Johnson and others, 1984).

Harney, Mud, and Malheur Lakes currently occupy about 260 square miles of the lowest part of Harney Basin in southeastern Oregon; the lakes collect drainage water from Steens Mountain in the south and from the Snow, Strawberry, and Aldrich Mountains in the north. This area of Harney Basin consists of extensive alluvial plains underlain by shallow water-bearing beds and includes arable land irrigated by surface-water diversions and ground-water pumpage. Harney Valley and its tributary uplands to the east, north, and northwest constitute part of a closed basin draining into the playas forming these lakes (Leonard, 1970).

Malheur Lake represents a remnant of a much larger water body that existed during the Pleistocene Epoch, when precipitation was greater and evaporation was less. At its highest level, this pluvial lake is estimated to have been 900 square miles in surface area, with a maximum depth of 35 feet (Philips and Van Denburgh, 1971). It overflowed eastward into the Snake River by way of the Malheur River. Drainage was first through a channel near Princeton and later through a gap at Crane, when Pleistocene lava blocked the former channel. About 10,000 years ago, warmer and drier conditions caused the pluvial lake to shrink; the water no longer had an outlet to the sea. Much of this former lake bottom is now brush covered desert and seasonally flooded grass sedge meadowland, with Malheur and Harney Lakes existing as remnants of the former Pleistocene lake (Johnson and others, 1984). In at least four epochs, Malheur Lake has been stable long enough to form many typical beaches, which now are preserved in the high level beach ridges and in the three "islands" on the eastern part of the playa (Piper, Robinson, and Park, 1939).

The area studied in Malheur County (pl. 1) encompasses the headwaters of the Malheur River down to the mouth, near the city of Ontario, as well as two tributaries, Willow and Bully Creeks, and principal diversions along the irrigated areas of the basin. Malheur County is characterized by a semi-arid climate, intensive irrigated agriculture, and a complex irrigation distribution system. Most of the cropland is concentrated in the lower valley of the Malheur River basin. Water resources in the valley are managed by dams and irrigation delivery systems. Crops grown in the valley include sugar beets, onions, potatoes, corn, mint, grain, alfalfa seed, vegetable seeds, and hay.

Malheur River flows mostly through igneous rock terrain that is composed principally of volcanic rocks. Sedimentary rocks, mostly tuffaceous stream and lake deposits, occur in the Middle and North Fork Malheur River, Bully and Willow Creeks, and in the contributing area below Namorf. Some undifferentiated stream and lake deposits occur on the lower reaches of the river; undifferentiated sedimentary rocks occur in the headwaters of Willow Creek (Laird, 1964).

Generalized Hydrology and Historic Conditions

Harney Basin

The range of daily and seasonal air temperatures in Harney Basin is unusually wide. The humidity is low, and evaporation is high (40 inches per year); precipitation is less than 10 inches per year. Strong winds are common throughout the year, especially from March to June. Evaporation is greatest in July (9 inches) and least in October (3 inches), as shown by records (1914-1932) from the Harney Branch Experimental Station (Piper, Robinson, and Park, 1939). Hubbard (1975) has estimated that evapotranspiration losses from Malheur Lake for the years 1972 and 1973 amounted respectively to 80 and 96 percent of the inflow.

Most of the northern parts of Malheur Lake are considered ground-water discharge areas. These areas are marked by an alkali crust on the soil, caused by mineral salts that are carried to the surface and deposited as a result of evaporation (Leonard, 1970). These salts are thought to be trona, that consists mostly of sodium carbonate (Ivan Barnes, U.S. Geological Survey, written commun., 1986). Shallow permeable beds of the valley fill also are known to contain alkali. Confining beds prevent recharge of deep pervious beds by downward percolation of water. Ground water near Malheur Lake is unsuitable for irrigated crops or potable water uses, because of elevated boron, sodium, and dissolved-solids concentrations. Near the northern, western and eastern edges of Harney Valley, however, ground water is generally suitable for most uses (Piper, Robinson, and Park, 1939).

Data on the chemical character of ground water indicate that the concentration of dissolved constituents in ground water of shallow pervious beds increases steadily toward the southern part of the alluvial plain; the concentration of dissolved solids becomes large in the vicinity of Malheur and Harney Lakes. Generally, water from deep pervious beds contains smaller concentrations of dissolved constituents, especially near the playas (Piper, Robinson, and Park, 1939).

Malheur Lake receives water from four principal sources: surface runoff from Donner und Blitzen River and Silvies River, from direct precipitation, and from ground water, including Sodhouse Spring on the south side of the lake (pl. 1). During a typical year, the contribution of water into Malheur Lake from these sources is estimated to be 62, 25, 12, and 1 percent, respectively (Hubbard, 1975); the percent contribution varies yearly. Although it has a smaller drainage area, the Donner und Blitzen River has the highest annual surface discharge to Malheur Lake. Much of the surface discharge from the Silvies River is diverted for irrigation before entering Malheur Lake.

Historically, water flowed from Malheur Lake to Mud Lake and Harney Lake when Malheur Lake levels exceeded 4,093 feet. It was not uncommon for Harney Lake to dry up during the summer. Harney Lake acts as a sump for the entire Harney Basin and thus has become very alkaline, losing water by evaporation, whereas Malheur Lake is annually freshened by inflows from the Silvies and Donner und Blitzen Rivers.

Harney Lake usually has a surface-water elevation that is about 8 feet lower than that of Malheur Lake. Warm Springs and Silver Creeks contribute to the inflow of Harney Lake. Additional numerous springs, many of them thermal, occur in the southeastern part of Harney Lake. A sand dune separates Harney Lake from Mud Lake. During normal precipitation years, Mud Lake is merely a conduit through which water from Malheur Lake debouches through a small channel into Harney Lake.

The lakes exhibit an annual cycle of water-surface elevation fluctuations; the cycle usually reaches its yearly maximum elevation sometime during spring and reaches its minimum in October. Between 1932 and 1972, the highest lake level observed was 4,095.35 feet in 1952 (U.S. Fish and Wildlife Service, written commun., 1986). In the early 1980's a sequence of wet winters caused extensive flooding in the basin, with water of Malheur and Harney Lakes rising above their "normal" shorelines. Annual runoff in the Silvies River was 591 ft^3/s in 1983, the highest recorded. By April 1985, the lake level was 4,102.5 feet, 7 feet higher than the highest level that had been observed prior to 1980. Currently (1986), the three lakes are hydraulically connected at the Narrows (fig. 1) and have a total surface area of 172,900 acres, compared to a high of about 90,000 acres for the previous period of record.

Malheur River basin

Average precipitation is less than 10 inches in Malheur River basin. Precipitation results from short, intensive convection thunderstorms in the summer and from frontal storms in the winter and spring.

Much of the river flow in the Malheur River basin is controlled by reservoirs and by a complex system of diversions, canals, and siphons originating near Namorf and extending downstream to the mouth of Malheur River near Ontario (pl. 1). River flow also is augmented by inflow from the Owyhee Basin via the North Canal and the Ontario-Nyssa Canal downstream from Vale. Flow patterns along Malheur River are characterized by high flows in spring and low flows in summer.

Acknowledgments

This study was done in cooperation with the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington and with the Oregon Department of Environmental Quality (ODEQ). Andrew Schaedel of ODEQ provided historical water-quality data on Malheur River, and the laboratory personnel performed chemical analyses for selected water samples of Harney, Mud, and Malheur Lakes and Malheur River. Frank Elferling, Water Master of Malheur County, gave permission for access to continuous gaging stations operated by the State of Oregon in the Malheur River and in major irrigation canals and diversions. Benjamin Scales and Dave Jarrett, Oregon Water Resources Department, provided continual updates of stage-discharge relations at gaging stations in the Malheur River.

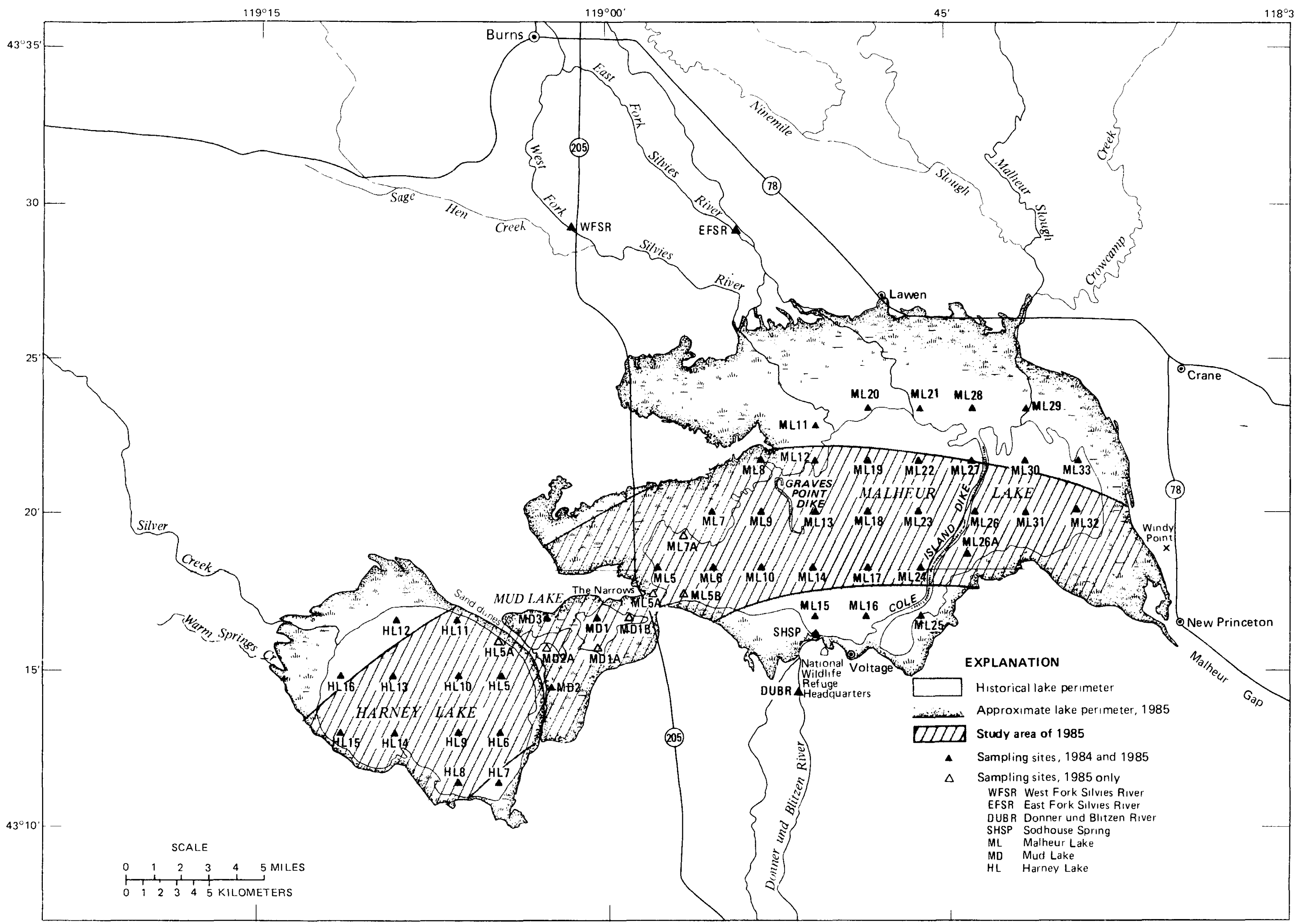

FIGURE 1.--Location of sampling sites in Harney, Mud, and Malheur Lakes, and major inflows to Malheur Lake during 1984 and 1985.

WATER QUALITY OF MALHEUR LAKE SYSTEM AND MALHEUR RIVER BASIN

Malheur Lake System

Background

During "normal" precipitation years, Malheur Lake may be divided into three subbasins that differ substantially in ecological character (Duebert, 1969). The central basin, east of Graves Point Levee (fig. 1) and west of Cole Island Levee, is the deepest and receives the flow of the Donner und Blitzen and Silvies Rivers, making it relatively less saline. The eastern basin lies east of Cole Island Levee and has no exit, so that evaporation and lack of flushing, over time, cause the water to become considerably more saline. The western subbasin, west of Graves Point Levee, consists of interconnected channels and ponds with considerable growth of macrophytes.

The chemical quality of Malheur Lake differs greatly from point to point in the lake, as well as from time to time (Hubbard, 1975; Johnson and others, 1984). These differences in water quality are largely a result of the hydraulics of the lake and hydrologic events. The lake as a whole becomes appreciably more saline during dry periods and more dilute during wet periods.

Concentrations of most dissolved constituents are many times higher in Harney Lake than they are in Malheur Lake. This difference is due to repetitive lake drying cycles, which concentrate the salts in the bottom sediments of Harney Lake, and to mineral-rich springs in and near Harney Lake (Piper, Robinson, and Park, 1939).

Data-Collection Program

The lakes were visited two times, in September 1984 and July 1985. Lake elevation was approximately the same (4,102 feet above sea level) during both visits. Sampling sites were established in 1984 at equidistant points, approximately 1.75 miles apart, in all four cardinal directions and in all navigable areas of the three lakes (fig. 1). The area near the Narrows was sampled at more sites to get a better understanding of the mixing of water from Harney, Mud, and Malheur Lakes. Sampling sites on the lakes were located during both visits by using LORAN-C[1] navigational equipment with an accuracy of ±150 feet. Chlorophyll samples were obtained by filtering a known quantity of sample through a cellulose filter. The filter was placed in a glass vial with a measured quantity of acetone. The vials were chilled with dry ice and kept in darkness until analysis.

All analytical work on lake and river samples, except for trace elements, was done by the Oregon Department of Environmental Quality (ODEQ) laboratory in Portland, Oregon. Trace-element analyses were done by the U.S. Geological Survey Analytical Laboratory in Arvada, Colorado.

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[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Boron analyses in 1984 were also run by ODEQ. All methods for chemical analyses used by ODEQ are listed in an EPA publication (U.S. Environmental Protection Agency, 1979) with the exception of boron, which is listed as method 404A in Standard Methods (American Public Health Association and others, 1980). The collection of samples and secchi disk readings and the measurement of indicator bacteria were in accordance with Geological Survey Techniques of Water Resources Investigations (Skougstad and others, 1979; Greeson and others, 1977). All dissolved constituents were filtered with a 0.45-μm pore size filter. All nitrite plus nitrate samples were preserved with sulfuric acid.

In 1984 and 1985, the following water-quality data were collected at the lake sites :

1. Vertical profiles of water temperature, dissolved oxygen, pH, and specific conductance (using a multiparameter in-situ monitor)--in 1984 at 45 sites; specific conductance and water temperature--in 1985 at 38 sites;

2. Secchi disk readings for water transparency--in 1984 at 45 sites;

3. Color, suspended and total dissolved solids, turbidity, and total organic carbon--in 1984 at 30 sites;

4. Dissolved major ions, including Ca (calcium), Mg (magnesium), Na (sodium), K (potassium), Cl (chloride), SO_4 (sulfate), total alkalinity, HCO_3 (bicarbonate), CO_3 (carbonate), F (fluoride), and SiO_2 (silica)--in 1984, at 30 sites; Ca, Mg, Na, and Cl--in 1985 at 10 sites;

5. Nutrients, including dissolved ammonia, total ammonia, total nitrate plus nitrite, and total organic nitrogen plus ammonia as N; total phosphorus and dissolved orthophosphate as P--in 1984 at 30 sites;

6. Total-recoverable trace elements in water, including Al (aluminum), As (arsenic), B (boron), Ba (barium), Be (beryllium), Cd (cadmium), Co (cobalt), Cr (chromium), Cu (copper), Fe (iron), Hg (mercury), Li (lithium), Mo (molybdenum), Mn (manganese), Ni (nickel), Pb (lead), Se (selenium), Sb (antimony), and Zn (zinc)--in 1984 at 8 sites; As and B--in 1985 at 10 sites;

7. Dissolved trace elements in water, including B (boron), Br (bromide), I (iodide), and V (vanadium).

8. Fecal coliform and fecal streptococcal bacteria--in 1984 at 10 sites;

9. Phytoplankton, identified to genus and dominant species; chlorophyll a and pheophytin--in 1984. Water samples were collected with a Van Dorn sample bottle midway between the water surface and the 1-percent light transmittance depth at 21 sites in Malheur Lake, 5 sites in Harney Lake, and at 1 site in Mud Lake. Phytoplankton samples were preserved with formalin and sent to ODEQ for identification and qualitative assessment. The data collected during the study are available at the U.S. Geological Survey Office in Portland, Oregon.

During 1984, stream discharge, dissolved oxygen, water temperature, and specific conductance were measured and water samples of major ions and nutrients were collected on major inflows of Malheur Lake near the mouth of the Donner und Blitzen River and on both tributaries of the Silvies River. The Sodhouse Spring, west of the National Wildlife Refuge headquarters, was also sampled (fig. 1).

In 1985, water samples were collected from the three lakes to determine concentrations of only calcium, magnesium, sodium, chloride, arsenic, and boron. Emphasis was given to these constituents because of concern that saline water with moderate to large concentrations of arsenic and boron from Harney Lake would flow into Malheur Lake and subsequently into the Malheur River via the proposed Virginia Valley Canal.

The quality-assurance program consisted of samples of a "blank" of distilled-deionized water (1984 only), replicate samples, and spiked samples of known chemical concentrations (Victor Janzer, U.S. Geological Survey, written commun., 1984). This standard procedure is followed by the U.S. Geological Survey as part of every water-quality project and is intended to assess the accuracy and precision of the data. Results indicate good comparison between predetermined spiked trace elements sent to the U.S. Geological Survey Central Laboratory and known concentrations (blinds) and replicate water samples of major ions and nutrients sent to Oregon Department of Environmental Quality (tables 13 and 13, at back of report). No replicate sampling was done for trace elements other than arsenic and boron, due to the small number of samples and because of the high cost of sample analysis.

Results

A summary of the physical and chemical characteristics of Harney, Mud, and Malheur Lakes is presented in table 1. Selected water-quality data, including biological data, collected in 1984 and 1985 are tabulated in tables 14-18 (at back of the report).

Examination of the data in table 1 shows the following:

(1) The concentrations of sodium, potassium, chloride, sulfate, silica, and dissolved solids and measurements of specific conductance progressively increase from Malheur to Mud to Harney Lakes. Calcium and magnesium concentrations do not show the same increase, which explains the sharp increase in the sodium-adsorption ratio (SAR) values. The prevailing cation dominance in 1984 was in the form of Na>>Ca>K>Mg in Malheur Lake and Na>>K>Ca>Mg in Harney Lake.

(2) Sodium and chloride concentrations and SAR and specific conductance values increased from 1984 to 1985 in Malheur and Mud Lakes. No significant change was observed in Harney Lake.

(3) Relative to the range of values measured in Malheur Lake in 1972 and 1973 (Hubbard, 1975), the 1984 and 1985 data indicate the lake to be of a more homogeneous composition.

(4) Water quality of surface inflows to Malheur Lake remains essentially the same as in normal precipitation years.

Cole Island Levee in Malheur Lake is presently underwater and is rapidly deteriorating. This change was ascertained by a bathymetric study done in September 1984 by the U.S. Geological Survey. As this erosion process continues, the lake circulation patterns most likely will change and may cause more uniformly mixed conditions.

Water depths at Harney Lake were uniform and ranged between 16 and 20 feet, where sampled. Water depths at Mud and Malheur Laker were variable, ranging from 8 to 13 feet in Mud Lake and from 3 to 11 feet in Malheur Lake.

Mean vertical values of specific conductance in 1984 (fig. 2) show low values (505 to 554 µS/cm) near the center of Malheur Lake and towards the mouth of the Donner und Blitzen River that become increasingly higher from Mud Lake to Harney Lake. Variations of specific conductance with depth did not exceed 50 percent throughout Harney and Malheur Lakes. The sharp contrast in specific conductance between the north part of Mud Lake and Harney Lake suggest that there is little exchange of water between the lakes.

The dissolved oxygen concentration near the water surface was above 100-percent saturation west of Cole Island Levee, whereas east of the levee, dissolved oxygen was as low as 60 percent of saturation (fig. 3).

Table 1.--Summary of physical and chemical characteristics measured in Harney, Mud, and Malheur Lakes, and major inflows to Malheur Lake during September 1984 and July 1985.

[Concentrations are listed as minimum, median, (when available) maximum. Historical data of 1972-1973 (Hubbard, 1975) and Johnson and others (1984) are included for comparison]

Constituent /Characteristic	Year of sampling	Harney Lake	Mud Lake	Malheur Lake	Silvies River[a]	Donner und Blitzen River
Water temperature (degrees Celsius at surface)	1984	16/18/20	16/16/16	16/18/21	11.3/15.0	14.8
	1985	21/26/27	21/22/24	21/26/27	21.0/26.7	27.0
Dissolved oxygen (percent saturation at surface)	1984	96/97/103	87/90/100	11/116/160	-----	------
pH (units)	1972-73	------	------	7.5/7.9/8.9	7.6/7.7/8.0	7.5/7.7/8.2
	1982	9.5	------	-----	-----	------
	1984	8.8/8.9/9.0	8.5/8.6/8.7	7.9/8.4/8.6	8.0/8.1	8.0
Specific conductance (µS/cm at 25°C)	1972-73	-------	-------	279/613/6770	269/196/593	107/124/170
	1982	4275	-------	-----	-----	------
	1984	3150/3220/3250	1300/1360/1700	505/610/794	220/310	129
	1985	3270/3290/3360	1730/1780/2050	759/778/1210	------	------
Calcium, dissolved (mg/L)	1972-1973	------	------	11/43/61	26/29/50	9.3/11/16
	1982	9.8	------	-----	------	------
	1984	15/15/16	29	25/30/31	24/33	12
	1985	16	26/28/29	29/31/33	-----	-----

Table 1.--Summary of physical and chemical characteristics measured in Harney, Mud, and Malheur Lakes, and major inflows to Malheur Lake during September 1984 and July 1985.

Constituent /Characteristic	Year of sampling	Harney Lake	Mud Lake	Malheur Lake	Silvies River[a]	Donner und Blitzen River
Magnesium, dissolved (mg/L)	1972-1973	------	------	8.2/22/-55	7.7/8.2/16	3.8/4.8/6.9
	1982	6.9	------	------	-----	-----
	1984	9.1/9.6/11	17	9.5/15/20	5.9/8.6	4.6
	1985	9.8	16/17/17	19/19/20	-----	-----
Sodium, dissolved (mg/L)	1972-1973	------	------	14/54/1700	15/23/59	6.3/9.2/11
	1982	1045	------	-----	-----	-----
	1984	640/640/660	230	66/92/120	12.4/20.3	7.3
	1985	680	290/300/320	110/130/160	-----	-----
Potassium dissolved (mg/L)	1972-1973	------	------	3.5/12/130	3.4/4.9/8.8	1.3/1.6/1.9
	1982	57	------	-----	-----	-----
	1984	40/41/43	26	12.3/16.5/22	3.3/3.5	1.6
Chloride, dissolved (mg/L)	1972-1973	------	------	3.2/10/320	2.7/3.4/8.3	0.5/1.8/2.1
	1982	2205	------	-----	-----	-----
	1984	470/530/560	130	8.9/14/39	3.3/4.7	1.7
	1985	510	220/230/230	29/41/58	-----	-----
Sulfate, dissolved (mg/L)	1972-1973	------	------	4.0/20/600	12/18/32	3.7/4.9/8.7
	1982	------	------	------	-----	------
	1984	130/140/150	46	17/19/25	9.3-34	2.8
Bicarbonate, total (mg/L)	1972-1973	------	------	170/380/2740	149/165/206	58/73/102
	1984	700/730/760	750	300/365/410	-----	------
Nitrate + Nitrite (mg/L as N)	1972-1973	------	------	0.00/0.01/2.8	0.00/0.00/0.01	0.05/0.23/0.29
	1984	0.11/0.11/0.14	0.05	0.02/0.08/0.90	-----	------
Phosphorus, total (mg/L as P)	1972-1973	------	------	0.01/0.09/1.3	0.08/0.21/0.23	0.10/0.11/0.12
	1984	0.75/0.75/0.80	0.31	0.11-.18-.33	-----	------
Silica, dissolved (mg/L)	1972-1973	------	------	2.1/17/32	27/31/36	24/25/29
	1984	36/37/38	6.3	<0.5/2.0/15	35/39	28
Solids, dissolved (mg/L)	1972-1973	-------	-------	166/374/4620	178/206/377	82/98-120
	1984	1950/1960/1980	841	352-442-530	182-249	102
Sodium adsorption ratio (units)	1972-1973	------	------	0.6/1.9/65	0.80/0.80/1.9	0.4/0.6/0.7
	1984	30/32/33	8.4	2.5/3.2/4.2	0.59/0.81	0.45
	1985	33	11/11/12	3.8/4.3/5.6	-----	-----

a Includes East and West Fork Silvies River.

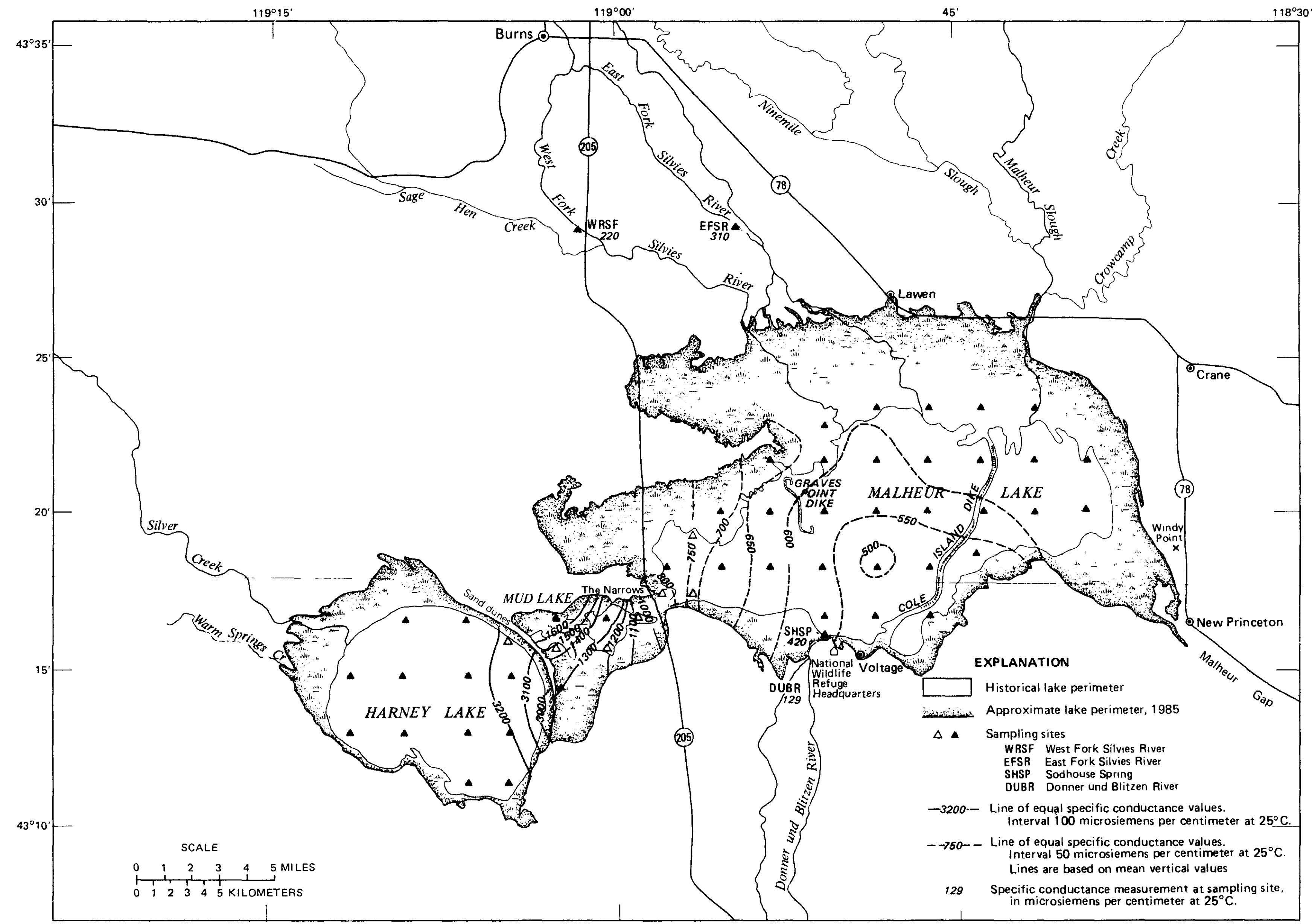


FIGURE 2.--Specific conductance values in Harney, Mud, and Malheur Lakes, and major inflows to Malheur Lake, September 1984.

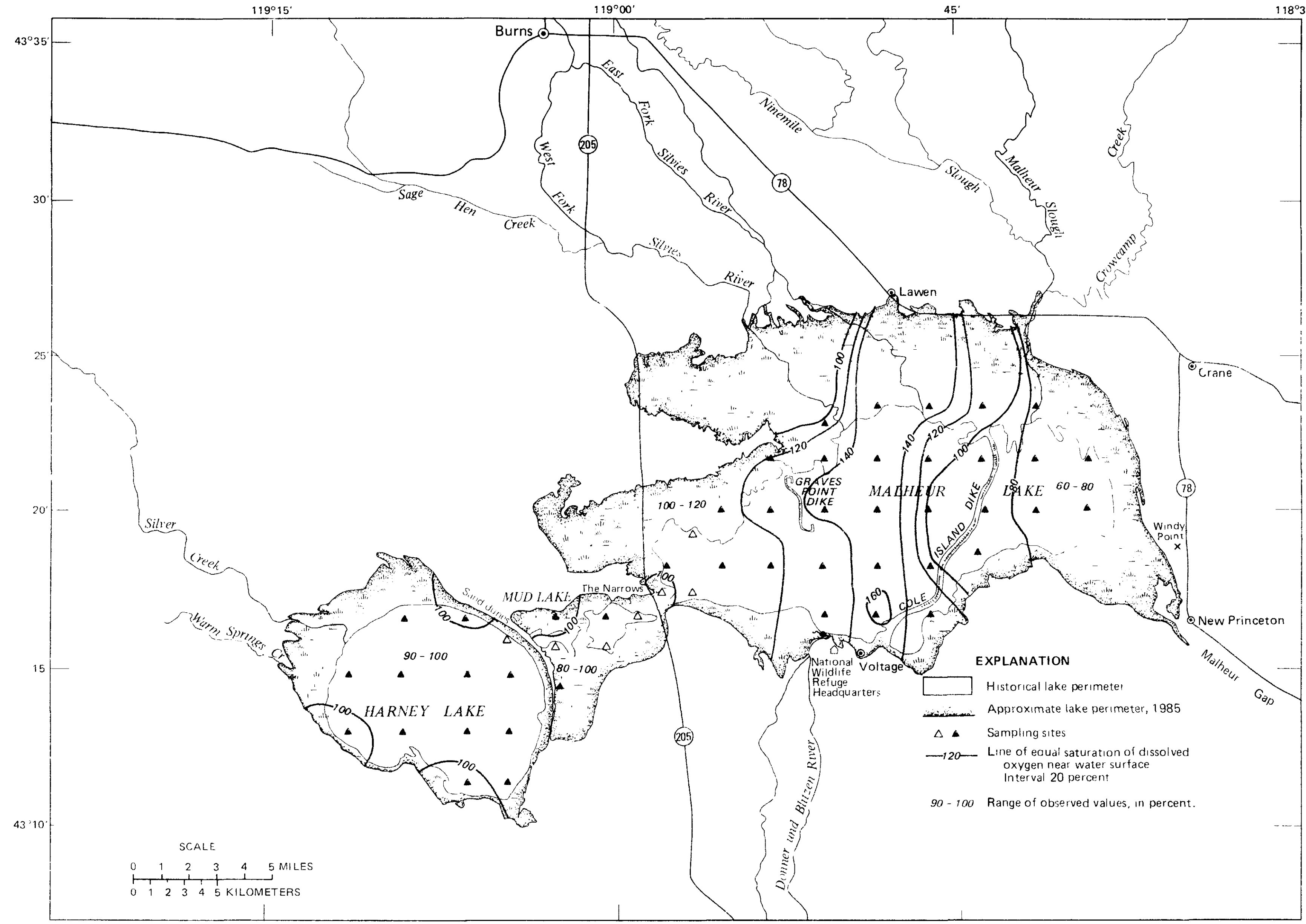


FIGURE 3.--Dissolved oxygen percent of saturation near water surface in Harney, Mud, and Malheur Lakes, September 1984.

Oxygen concentrations were highest near the surface but dropped sharply (20-70 percent) with depth in much of Malheur Lake. The change in concentration of dissolved oxygen with depth likely resulted from photosynthetic activity when the concentration was greater than 100 percent of saturation, and from respiration of algae and bacteria when less than 100 percent of saturation. Oxygen concentration in Harney and Mud Lakes was less variable vertically than in Malheur Lake.

Bicarbonate concentrations in Malheur Lake were smallest near the mouth of the Donner und Blitzen River (310-320 mg/L) and were almost twice as large in Harney and Mud Lakes (fig. 4). Carbonate concentrations were nonexistent throughout most of the eastern part of Malheur Lake, where pH of the water (see table 1) was consistently below 8.3 units. Carbonate concentrations in Mud Lake were comparable to those of Malheur Lake but increased rapidly towards Harney Lake.

Nitrate plus nitrite concentrations (as N) in Malheur Lake were largest (0.50-0.75 mg/L) east of Cole Island Levee (fig. 5). High turbidity, east of the levee, restricted photosynthetic activity and thus caused minimal nutrient uptake. West of the levee, concentrations were consistently small (0.05-0.25 mg/L). Algal productivity and macrophytic growth are probable causes for the nutrient depletion. At Harney Lake, concentrations were small 0.11 mg/L at each station sampled.

Chlorophyll a concentrations varied widely (10-80 mg/L) in Malheur Lake; the largest concentrations were observed in the southern part of the lake (fig. 6). Large concentrations of algae were observed throughout the lake west of Cole Island Levee, where water acquired at times a consistency of "pea soup," and had light transparency of less than 0.5 meters. Chlorophyll a concentrations were negligible in Mud and Harney Lakes. Phosphate concentrations do not appear to be the limiting growth factor in lake productivity in Harney and Mud Lakes, since phosphate concentrations were as much as five times higher than those in Malheur Lake.

Silica concentrations (fig. 7) in Malheur Lake were smallest (1.0 mg/L) near the mouth of Donner und Blitzen River and towards the center of the lake. This depletion of silica is probably caused by algal uptake. Concentrations in Mud Lake were somewhat intermediate (6.3 mg/L) to those found on the west side of Malheur Lake and were significantly larger in Harney Lake (35.7-37.3 mg/L).

Aluminum concentrations were elevated in some part of Malheur Lake (table 2); the largest concentration was detected east of Cole Island Levee (site 31, see fig. 1). Hubbard (1975) also found elevated concentrations of dissolved aluminum (200 μg/L) in this area in 1972. Arsenic and boron concentrations were largest (120 and 4,600 μg/L, respectively) in Harney Lake. In Malheur Lake, the concentrations of arsenic (9 μg/L) were below water-quality criteria for irrigation of crops (100 μg/L) and for domestic water supplies (50 μg/L). Boron concentrations were six to seven times lower in Malheur Lake than those in Harney Lake, where boron concentrations exceeded the criteria for crop irrigation of 750 μg/L (U.S. Environmental Protection Agency, 1976).

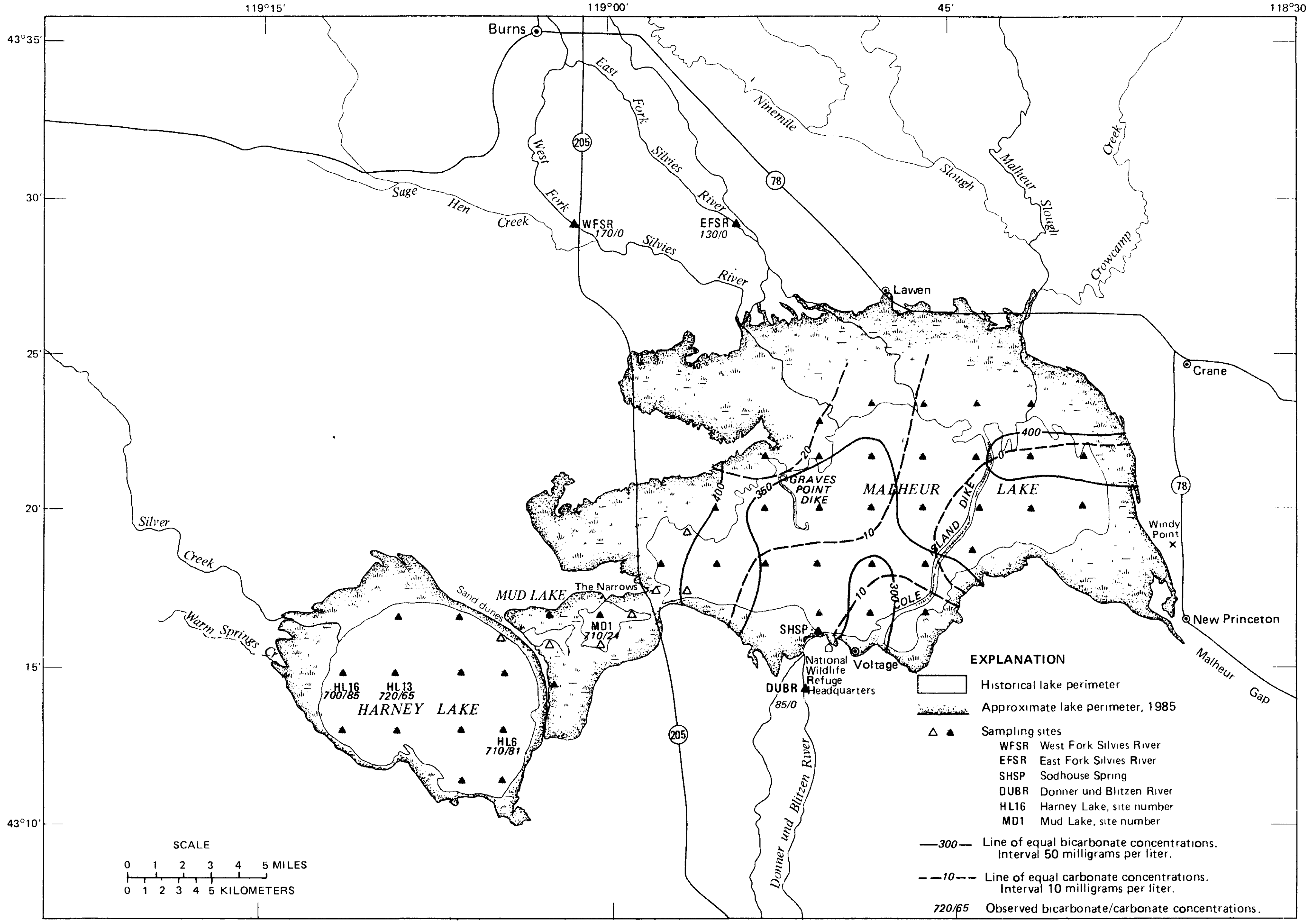


FIGURE 4.--Bicarbonate and carbonate concentrations in Harney, Mud, and Malheur Lakes, and major inflows to Malheur Lake, September 1984.

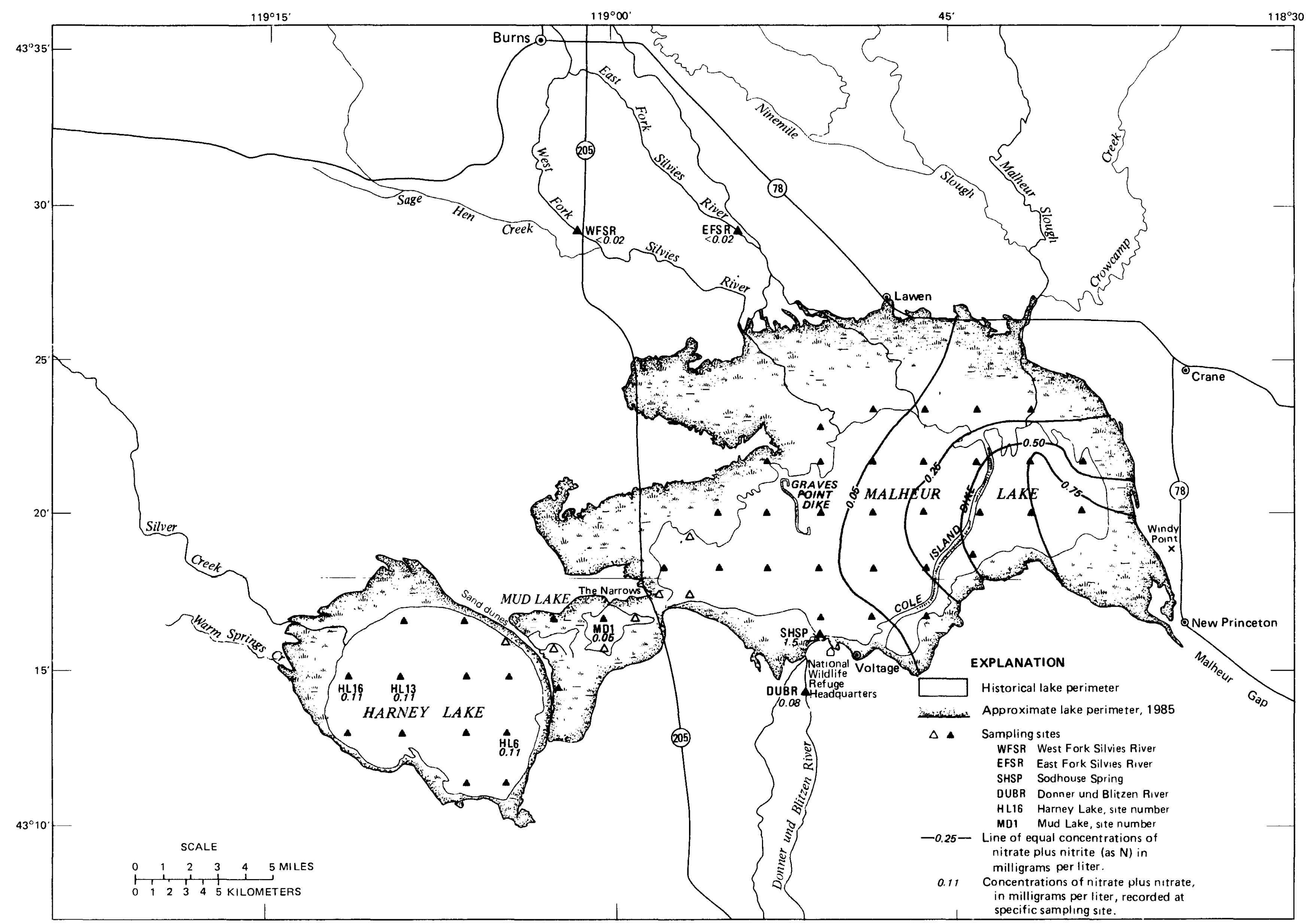


FIGURE 5.--Nitrate plus nitrite concentrations in Harney, Mud, and Malheur Lakes, September 1984.

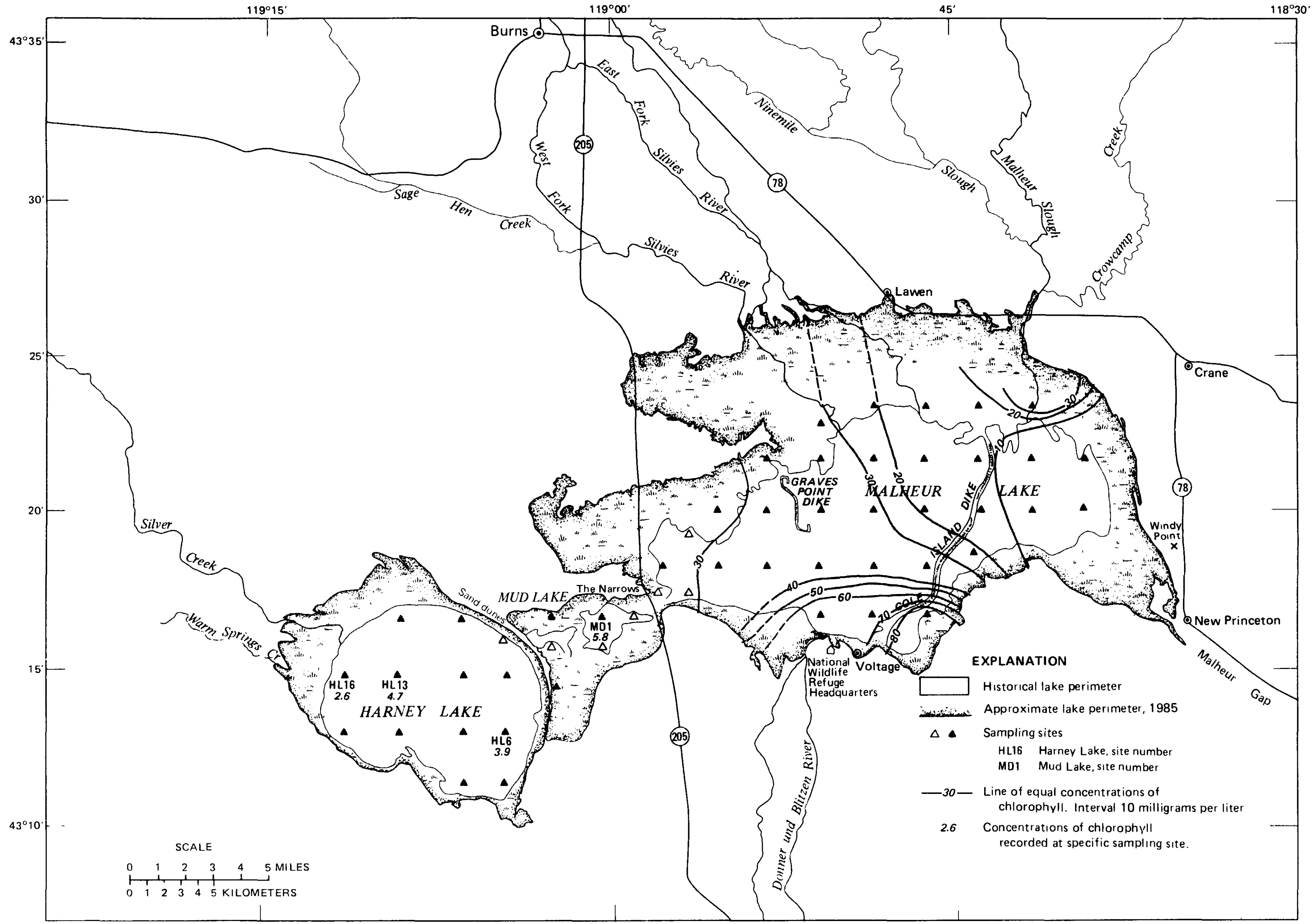


FIGURE 6.--Chlorophyll concentrations in Harney, Mud, and Malheur Lakes, September 1984.

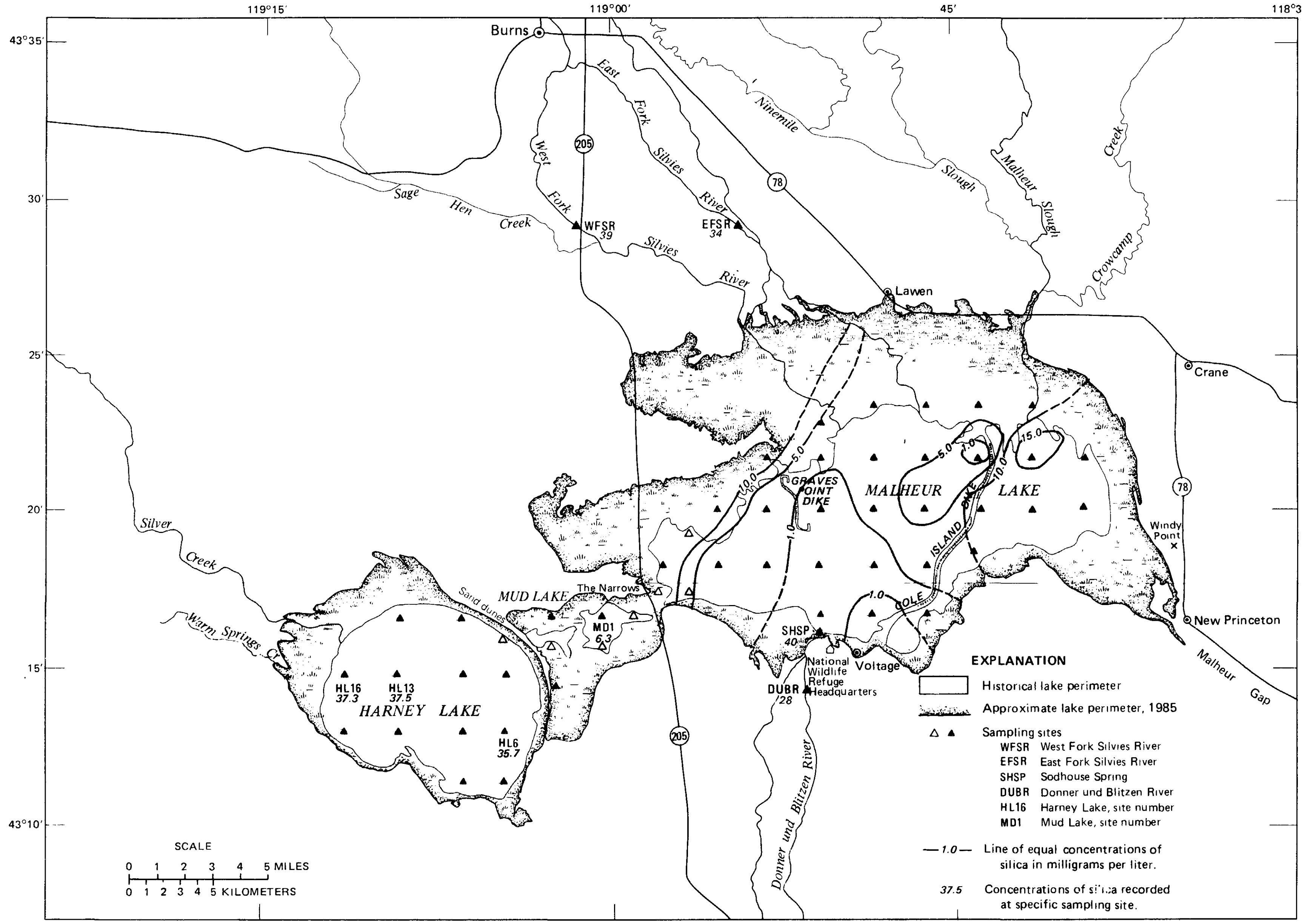


FIGURE 7.--Silica concentrations in Harney, Mud, and Malheur Lakes, and major inflows to Malheur Lake, September 1984.

Table 2.--Concentrations of trace elements in water samples from Harney, Mud, and Malheur Lakes, and major inflows during September 1984 and July 1985

[All analyses are total recoverable with the exception of arsenic which is total. Concentrations are listed as minimum, median (when available), maximum. Concentrations in micrograms per liter. Historical data of 1972-73 (Hubbard, 1975) are included for comparison]

Trace element	Year of sampling	Harney Lake	Mud Lake	Malheur Lake
Aluminum	1972-1973	----	----	0/20/200
	1984	30/50/60	----	100/150/410
Arsenic	1972-1973	----	----	0/8/9
	1984	120/120/120	----	4/9/9
	1985	140	63/70/81	11/15/22
Beryllium	1984	10/10/20	----	<1/1/1
Boron	1984	3600/4600/6700	1100	500/700/1200
	1985	4000	1800/1800/2100	510/575/800
Bromide	1984	<10/150/180	----	17/29/41
Iodide	1984	72/97/240	----	11/17/21
Lead	1972-1973	----	----	0/2/3
	1984	<5/<5/<5	----	<5/<5/9
Molybdenum	1984	24/26/28	----	<1/1/2
Nickel	1972-1973	----	----	2/3/4
	1984	<1/1/2	----	2/4/6
Vanadium	1984	24/27/27	----	5.4/7.4/8.8
Zinc	1972-73	----	----	20/130/160
	1984	<10/<10/<10	----	9-10-15

Moderately large concentrations of beryllium, bromide, iodide, molybdenum, and vanadium were found in Harney Lake; probable sources are the large number of thermal springs in this lake and the concentrating effect of evaporation. Lead concentrations were largest near the Narrows in Malheur Lake; vehicular traffic through the Narrows is a probable source of this lead. Concentrations of all other trace metals (antimony, barium, cadmium, chromium, cobalt, copper, iron, mercury, nickel, selenium, and zinc) were either below detection limits or the concentrations were very small. None of these concentrations exceeded the water-quality criteria for irrigation, water supplies, or protection of aquatic life.

Water temperatures decreased with depth at all sites for both years. Temperature changes were greatest within the first meter of depth throughout all three lakes. At all sites, inclusive of the inflows, water temperatures were 5 to 10 degrees cooler on the days of measurement in September 1984 than they were in July 1985.

Significant differences in specific conductance values for 1984 and 1985 were observed in Mud and Malheur Lakes. Values in Malheur Lake during 1985 were more uniform east of Graves Point Levee, and significantly higher in Mud Lake and the western portion of Malheur Lake (figs. 2 and 8). Mud Lake had larger specific conductance values in the southern part, where most of the water exchange between Harney and Malheur Lakes seems to occur. The hydraulic connection through the sand dune separating Harney from Mud Lake appears to be poor. Specific conductance values measured in Harney Lake in 1984 were similar to those measured in 1985 (see table 1). Specific conductance values varied little (<10 percent) with depth.

A 50-percent increase in specific conductance throughout Malheur Lake from 1984 to 1985 results from an increase in sodium and chloride concentrations. Between September 1984 and July of 1985, median concentrations of sodium and chloride increased in Malheur Lake by 40 and 190 percent, respectively (table 1). Most of the increase in sodium and chloride occurred on the west part of Malheur Lake and is thought to result from wind-caused mixing of water between Harney and Malheur Lakes. Dissolution of alkali encrustations (evaporites) found in the presently flooded areas north of Malheur Lake may have contributed a small amount of sodium and chloride. Arsenic and boron concentrations between 1984 and 1985 were relatively unchanged in Harney Lake, whereas arsenic concentrations in Malheur Lake increased by about 70 percent and boron concentrations remained relatively unchanged (table 2).

Chemical quality of ground water in a few wells around Malheur Lake was assessed in 1985 for dissolved nitrate plus nitrite and total arsenic by Harney County Health Department (table 3). Most nitrate plus nitrite concentrations in ground water were larger than those found in Malheur Lake; the highest concentration (21 mg/L as N) was at a well near Lawen (T.24 S., R.32 E., sec.32). All measured arsenic concentrations in ground water were the same as or less than those measured in Malheur Lake. One well, in Voltage, had an arsenic concentration that exceeded the EPA drinking water standard of 50 μg/L (U.S. Environmental Protection Agency, 1976).

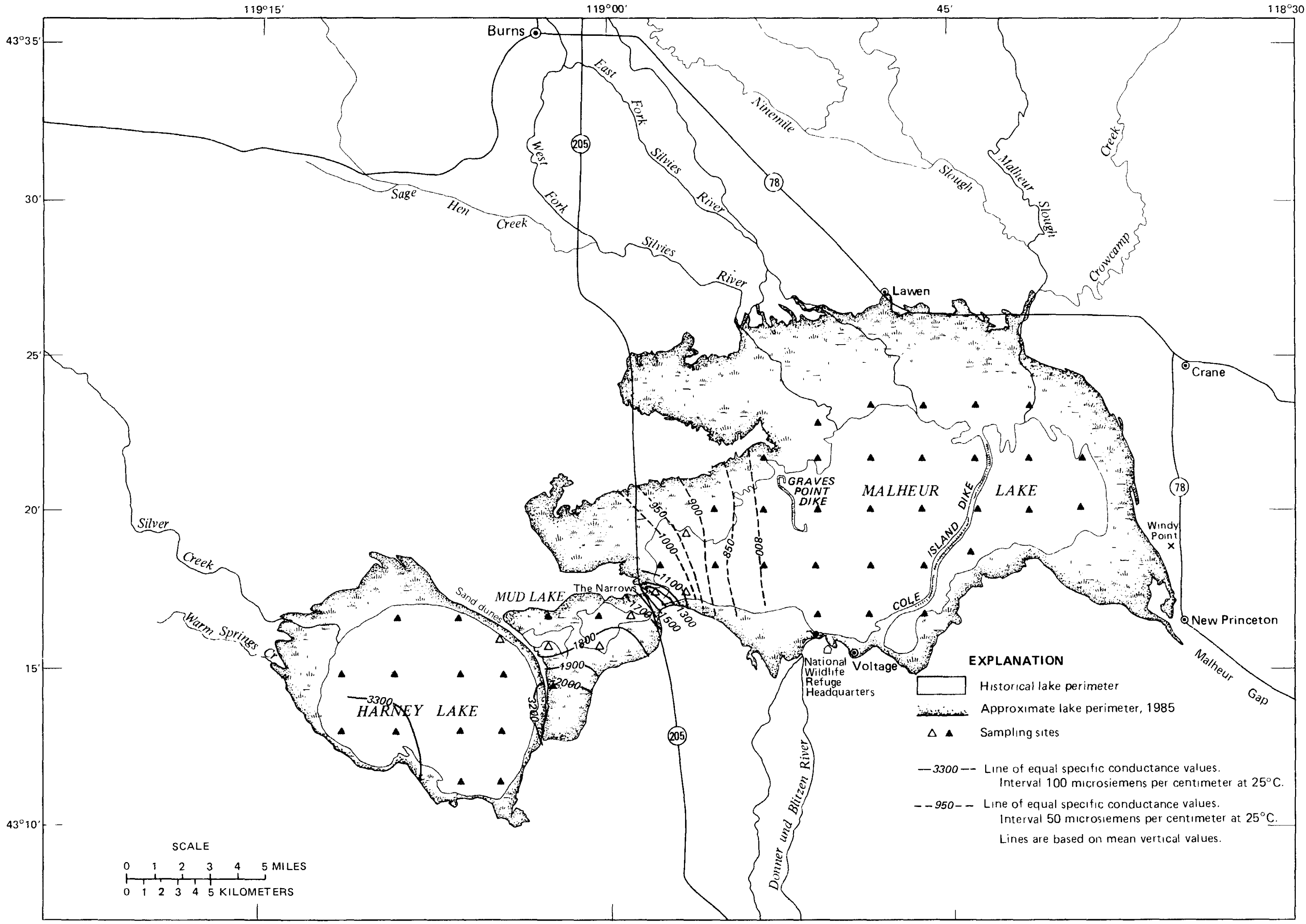


FIGURE 8.--Specific conductance values in Harney, Mud, and Malheur Lakes, July 1985.

Table 3.--Concentrations of total arsenic and nitrate plus nitrite (as N) in wells around the periphery of Malheur Lake

[Samples collected on July 23, 1985 by Harney County Health Department and analyzed by Oregon Department of Environmental Quality. Concentrations in milligrams per liter]

Site ID	Location	Total nitrate + nitrite as N	Total arsenic	Remarks
A	T26S R30E sec. 26	3.3	0.008	Near the Narrows.
B	T26S R30E sec. 35	1.8	.005	National Wildlife Refuge Headquarters.
C	T26S R32E sec. 31	1.9	.090	In Voltage, east of Refuge headquarters, south of Malheur Lake.
D	T26S R33E sec. 25	0.05	.015	Princeton Post Office, New Princeton southeast of Malheur Lake.
E	T26S R33E sec. 12	3.2	.010	East of Malheur Lake, at Windy Point.
F	T24S R32.5E sec. 32	21	.010	North of Malheur Lake, at Lawen.
G	T24S R32.5E sec. 31	0.13	<.005	North of Malheur Lake, northwest from Lawen.
H	T25S R32.5E sec. 6	0.04	<.005	North of Malheur Lake, south of Lawen.
I	T24S R32E sec. 23	5.0	<.005	1.4 miles northwest of Lawen, north of Malheur Lake.

Malheur River basin

Background

Two principal reservoirs, Warm Springs and Beulah Reservoirs (pl. 1), were built to supply water to irrigation districts in the Malheur River basin. Warm Springs Reservoir began operations in 1919. Water flow is completely regulated and used to irrigate about 13,000 acres. Reservoir gates are closed at the end of the irrigation season, usually by mid-October. Thereafter, the only flow is about 1 ft^3/s that leaks through the gates. Beulah Reservoir was put into operation in 1935. Water is regulated for irrigation of about 2,400 acres. As with the Warm Springs Reservoir, gates are closed at the end of irrigation season in mid-October and are not reopened until the following spring. Flow below these two reservoirs down to the Vale-Oregon Canal near Namorf is managed according to irrigation-water demand in the lower agricultural valley during irrigation season.

The Warm Springs Irrigation District operates numerous diversions for irrigation above Namorf. Vale-Oregon Canal, a few miles upstream from Namorf, was put into operation in 1930 and is one of the principal diversions in the Malheur River basin. The canal water from the river is used for irrigation within the Vale-Oregon Irrigation District or, alternatively, is diverted for storage in Bully Creek Reservoir. At times, the Vale-Oregon canal diverts more than 75 percent of the total river flow.

Many of the diversions downstream of Namorf have continuous gaging stations operated by the State (table 4). Farmers Ditch near Hope diverts water to irrigate 1,700 acres within the Warm Springs Irrigation District. Farmlands west of Vale are irrigated by Harper Southside Canal, Vines Ditch and the J-H Canal near Hope. The Gellerman-Froman Canal diverts water from Malheur River for irrigation within the Warm Springs Irrigation District near Vale. Lands east of Vale are irrigated by the Nevada Canal.

Table 4.--Mean and maximum discharge data available for gaged sites in the Malheur River basin

[Gaging stations other than 13215000 and 13217500 are operated by Oregon Water Resources Department. Discharge is in cubic feet per second, UD = undetermined]

Site name	Station ID	Mean discharge	Maximum discharge	Period of record
Malheur River below Warm Springs Reservoir near Riverside	[a]13215000	180	2,610	1920-1982 (continuous)
North Fork Malheur River at Beulah	[a]13217500	142	7,000	1936-1982 (continuous)
Vale-Oregon Canal near Namorf	[b]13219100	182	676	1930-1977 (discontinuous)
Malheur River near Namorf	[b]13219200	198	UD	1970-1977 (continuous)
Farmers Ditch near Hope	[b]13222000	UD	54	1938-1977 (discontinuous)
J-H Canal near Hope	[b]13223000	31	126	1968-1977 (discontinuous)
Gellerman-Froman Canal near Hope	[b]13224000	UD	261	1937-1977 (discontinuous)
Malheur River below Nevada Canal near Vale	[b]13233000	275	21,000	1967-1976 (continuous)
Nevada Canal near Vale	[b]13233200	53	252	1970-1977 (discontinuous)

a From Friday and Miller, 1984.

b From Oregon Water Resources Department, written commun., 1985.

Bully and Willow Creeks are two tributaries of Malheur River through which a large portion of irrigation waters from the Vale-Oregon Canal, North Canal (Owyhee River basin), and Gellerman-Froman Canal are returned to the main stem. Flow fluctuates widely in Bully Creek owing to occasional releases from the Vale-Oregon Canal. During dry years, the Vale-Oregon Canal contributes water to Bully Creek Reservoir. This transfer of water has not occurred for several years (Frank Elferling, Watermaster, Malheur County, oral commun., 1985).

The quality of water at the mouth of the South Fork Malheur River (dissolved solids of 250 to 558 mg/L) is similar to that of Malheur Lake (dissolved solids of 352 to 530 mg/L), based on water-quality data collected from 1984 to 1985 by the Oregon Department of Environmental Quality (table 5). Warm Springs and Beulah Reservoirs provide water with small concentrations of dissolved solids (133 to 229 mg/L). Between Juntura and Vale, nearly a three-fold increase in dissolved solids concentrations (168 to 450 mg/L) occurred in the river.

Table 5.--Summary of selected water-quality data from Harney, Mud, and Malheur Lakes; lake inflows; and Malheur River, 1984-85

[Lakes and inflows data collected by U.S. Geological Survey personnel. River data collected by Oregon Department of Environmental Quality. Concentrations are listed as minimum, median (when available), maximum and reported in milligrams per liter (mg/L). Specific conductance values reported in microsiemens per centimeter at 25 degrees Celsius]

Site Name	Specific conductance (µS/cm at 25°C)	Solids, dissolved (mg/L)	Sodium, dissolved (mg/L)	Sodium adsorption ratio (units)	Boron, total (mg/L)
LAKES (Harney Basin)					
Harney Lake	3,100/3,140/3,200	1,950/1,960/1,980	640/640/660	30/32/33	3.6/4.6/6.7
Mud Lake	1,300/1,360/1,700	841	230	8.4	1.1
Malheur Lake	505/610/794	352/442/530	66/92/120	2.5/3.2/4.2	0.5/0.7/1.2
MALHEUR LAKE INFLOWS (rivers and springs)					
Donner und Blitzen River	129	102	7.3	0.45	0.3
Silvies River	220/310	182/249	12.4/20.3	0.59/0.81	0.3
Sodhouse Spring	420	270	40	1.8	0.4
RIVER (Malheur River basin)					
South Fork Malheur River at Venator	350/393	250/275/293	44/45/49	1.7/2.2	0.2/0.3/0.4
South Fork Malheur River at mouth	570/571	387/420/558	68/82/122	2.4/2.9/2.7	0.6/0.6/0.9
Malheur River at Riverside Bridge	153/183	173/174/229	12/12/32	0.6/0.7//1.6	<0.1/<0.1/0.2
North Fork Malheur River at mouth	163	133/149	8	0.5	<0.1
Malheur River east of Juntura	175/187	153/168/182	13/14/15	0.7/0.8/0.8	<0.1/0.1/<0.1
Malheur River at Namorf	192	156/175	13/15	0.8	<0.1
Malheur River at Harper Bridge	186	173	16	0.9	0.1
Malheur River at Little Valley	445	237/267	35/41	1.7/1.8	0.2/0.3
Malheur River at Vale	624	430/462	81/83	2.4/2.9	0.3/0.3
Bully Creek at mouth	583	442/443	73/77	2.4/2.5	0.3/0.3
Malheur River at Ontario	520/864	380/574	63/124	2.4/3.9	0.3/0.4

Previous water-quality studies (Funk, 1972, 1976; Laird, 1964; Malheur County Planning Office, 1981) of the Malheur River show increasing concentration of dissolved constituents as water flows through the system. The increase is caused primarily by evapotranspiration of water diverted for irrigation, which returns as more "mineralized" wastewater to the main stem and, to a lesser extent, by mineral dissolution as irrigation waters come into contact with poorly unconsolidated lake-bed sediments making up the lower Malheur Basin (Laird, 1964) and natural ground-water seepage and springs. The increase in dissolved-constituent concentrations is reduced to some extent by excess release of water from Warm Springs and Beulah Reservoirs. Insufficient ground-water quality data are available to establish a relation with surface water quality. Agriculture use of ground water is limited in the valley.

Data Collection Program

Twenty-one sampling sites were visited between July and October 1985 (fig. 9). Water-quality and discharge measurements were made at 13 stations: 9 stations on the main stem of the Malheur River and on 4 tributaries--South Fork Malheur River (site 1), North Fork Malheur River (site 4), Bully Creek (site 16), and Willow Creek (site 17). Bully and Willow Creeks are primary contributors of irrigation return waters in the lower valley. Eight stations on major irrigation canals and ditches were monitored for discharge only. Of the 21 sites, 9 had continuous gaging stations operated by Oregon Water Resources Department. Station names, numbers, and locations of all sampling sites are shown in table 6. Typical river reaches at the headwaters, mid-basin, and near the mouth of the Malheur River for July 1985 are shown in figure 10.

Site visits generally were made biweekly from July to September 1985 (during the irrigation season) and once in October 1985 after irrigation ceased. On-site measurements of water temperature and specific conductance were made. Water samples were taken for determination of dissolved calcium, magnesium, sodium, chloride, and boron and total arsenic.

A whole-water sample (suspended plus dissolved) was collected during and after irrigation season for analyses of total-recoverable trace metals near the mouth of the Malheur River (site 20). At the same time, a bottom-sediment sample was collected. This bottom-sediment sample was sieved and less-than-62-micron sized particles retained, oven dried, and analysed for total metals. Water samples were also collected to assess the concentration of suspended sediment.

The quality-assurance program consisted of the following: (1) blind standards containing known concentrations of calcium, magnesium, sodium, chloride, arsenic, and boron; and (2) replicate samples collected from different locations on every field trip. During August and October, "blind" standards for total-recoverable trace metals in water also were sent for analysis. Results of the quality-assurance program are shown in tables 19 and 20 (at the back of report). Results of "blind" standards for trace-metal analyses are shown in table 21 (at the back of report).

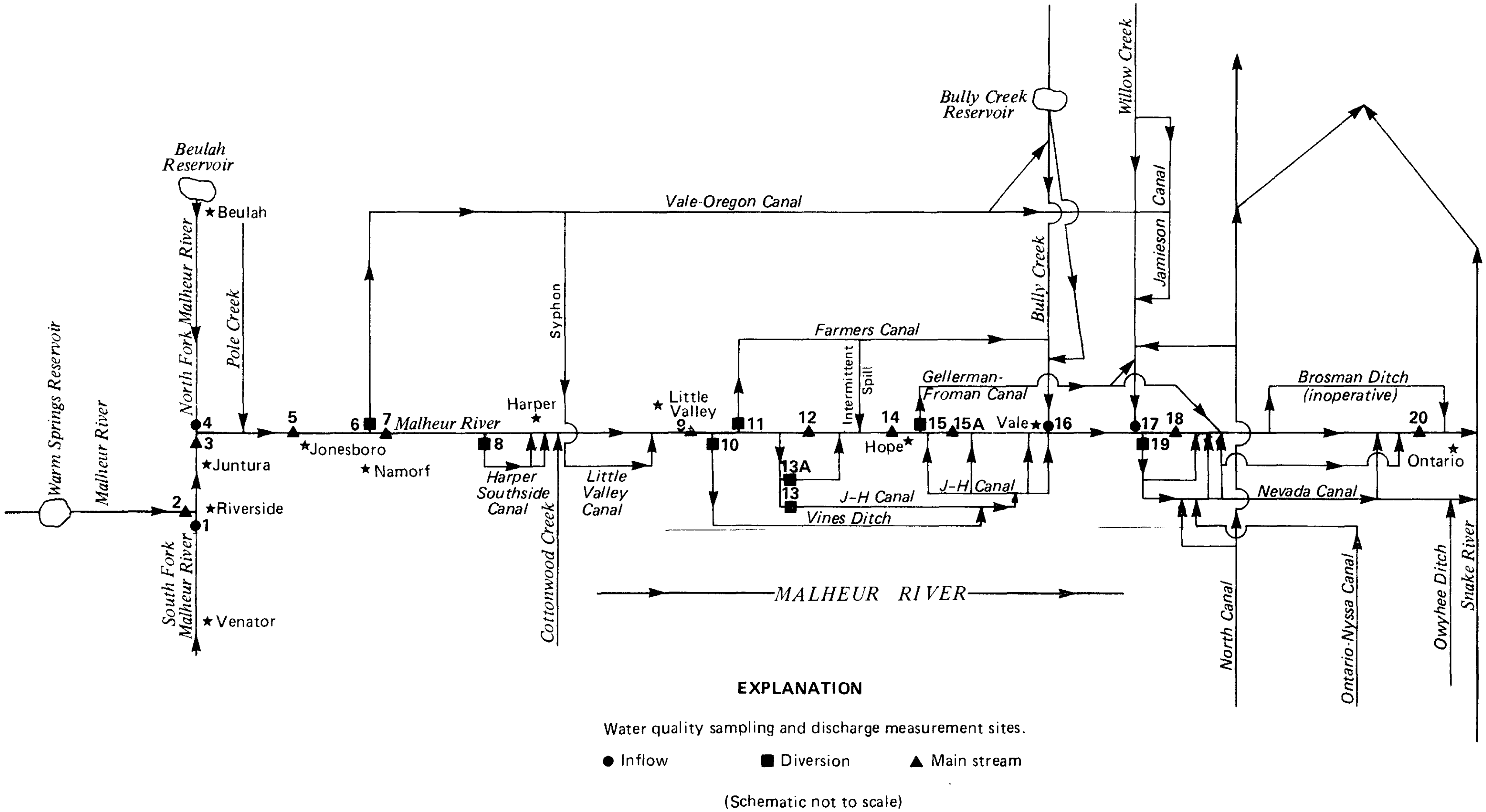


FIGURE 9.--Water-quality sampling and discharge measurement sites in Malheur River basin from Riverside to Ontario.

Table 6.--Station name, number, latitude, and longitude for sampling sites in the Malheur River basin

Station name	Site number	Latitude	Longitude
South Fork Malheur River at Riverside	1	433315	1181001
Malheur River below Warm Springs Reservoir near Riverside	2	433429	1181231
Malheur River at Juntura	3	434320	1180423
North Fork Malheur River at Beulah	4	435428	1180908
Malheur River near Jonesboro	5	434804	1175550
Vale-Oregon Canal near Namorf	6	434715	1174333
Malheur River near Namorf	7	434713	1174324
Harper Southside Canal near Harper	8	434930	1173827
Malheur River at Little Valley	9	435350	1173022
Vines Ditch near inflow of J-H Canal near Hope	10	435718	1172720
Farmers Ditch near Hope	11	435720	1172705
Malheur River below J-H Canal near Hope	12	435721	1172657
J-H Canal near Hope	13	435650	1172630
Diversion from J-H Canal near Hope	13A	435655	1172627
Malheur River near Hope	14	435634	1172206
Gellerman-Froman Canal near Hope	15	435520	1171927
Malheur River below Gellerman-Froman Canal near Hope	15A	435513	1171818
Bully Cr near mouth at Vale	16	435901	1171445
Willow Cr near mouth at Vale	17	435917	1171347
Malheur River below Nevada Canal near Vale	18	435917	1171304
Nevada Canal near Vale	19	435915	1171300
Malheur River near mouth near Ontario	20	440223	1170103

A. South Fork Malheur River at Riverside.

B. Malheur River near Riverside.

C. Malheur River near mouth at Ontario.

FIGURE 10.--Representative sampling sites in Malheur River basin.

Results

Comparisons of instantaneous discharge along the Malheur River above Juntura (site 3) to near the mouth (site 20) for the period of study are shown in figure 11. A large portion of the river is diverted into Vale-Oregon Canal (site 6), while smaller diversions downstream cause water to be reused many times between Namorf (site 7) and the mouth. In addition to the sampling sites near the mouth of Bully Creek (site 16) and Willow Creek (site 17) near Vale, return flows enter the river at many unsampled points. Towards the end of irrigation season less water is released from the reservoirs and diverted for irrigation; flows from Warm Springs and Beulah Reservoirs are reduced to less than 0.5 ft^3/s after the irrigation season. Consequently, return flows in October consist mostly of ground-water seepage from irrigated areas. Data on streamflow and water-quality measurements are presented in tables 22 and 23 (at back of report).

Concentrations of dissolved sodium (fig. 12) and chloride (fig. 13) increased progressively with time and in a downstream direction. Specific conductance, dissolved calcium, magnesium, and sodium adsorption ratios have similar trends. During the three later trips, progressively less water from Warm Springs and Beulah Reservoirs is mixed with ground-water seepage and results in increased concentrations. The lower concentrations at sites 18 and 20 during trip 4 are thought to be the result of a recent rainfall, when diverted water was not used for irrigation, but returned to the river with a quality similar to that when diverted.

Based on the cations (calcium, magnesium, sodium) and anion (chloride) studied, the Malheur River can be divided into three distinct areas in terms of water quality. The first area extends from the South Fork Malheur River (site 1) to site 7 on the main stem near Namorf (see fig. 9). Here, water from the reservoirs dilutes the South Fork Malheur River and the small return flows from irrigated land below Beulah Reservoir, resulting in relatively low concentrations.

The second area lies between Namorf and Hope (site 7 and site 14). A larger number of return flows, with higher concentrations of dissolved solids, enter the main stem in this reach and result in a gradual increase in constituent concentrations in the river.

The third area lies near the mouth of Malheur River and extends from Vale to Ontario, between site 14 and site 20. This reach receives the largest volume of return flows, including Bully Creek and Willow Creek, as well as water from the North Canal and Ontario-Nyssa Canal. The net result is an increase in discharge near the mouth of Malheur River, with a concurrent increase in dissolved-solids concentrations.

The process of cation exchange can affect the physical properties of soil. When exchange sites on clay minerals are occupied by calcium and magnesium, soil properties are optimal for plant growth and cultivation. Using water with a high sodium-adsorption ratio (SAR) may cause sodium to replace the calcium and magnesium, and the soil will tend to deflocculate and become impermeable to water.

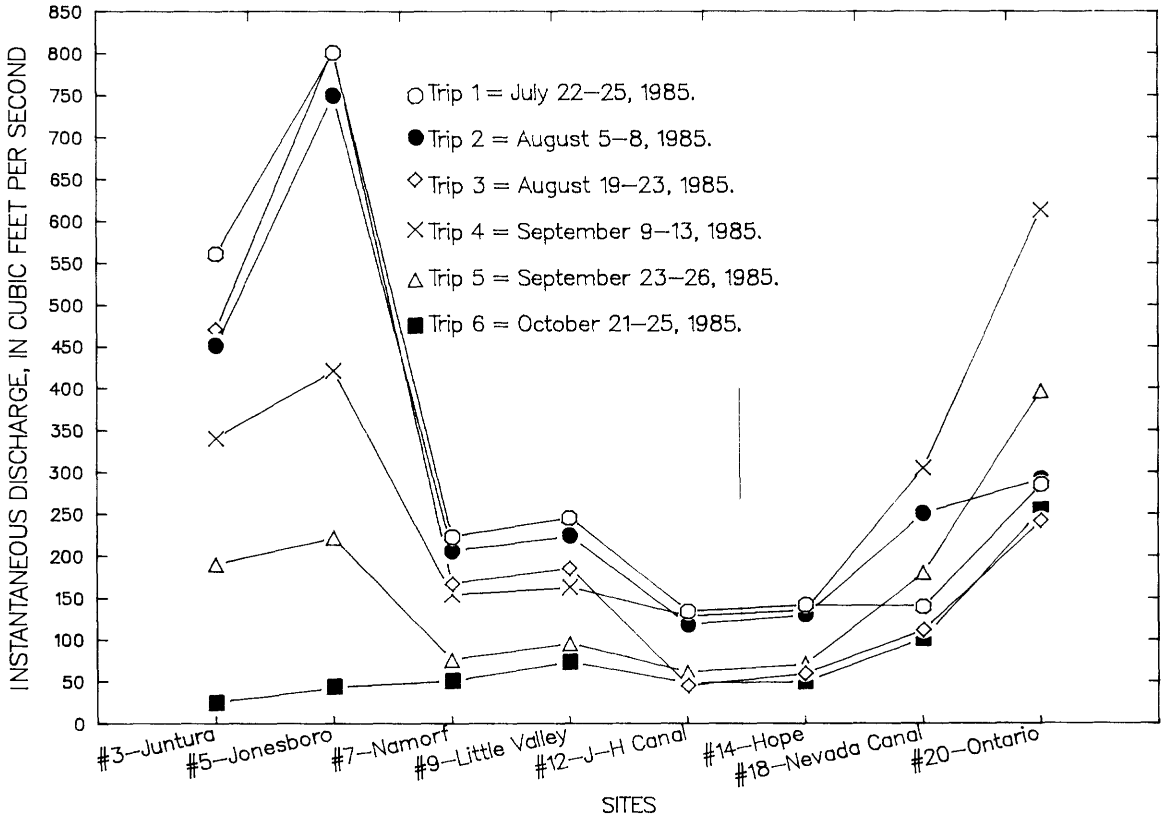


FIGURE 11.--Instantaneous discharge measured along the Malheur River, July-October, 1985.

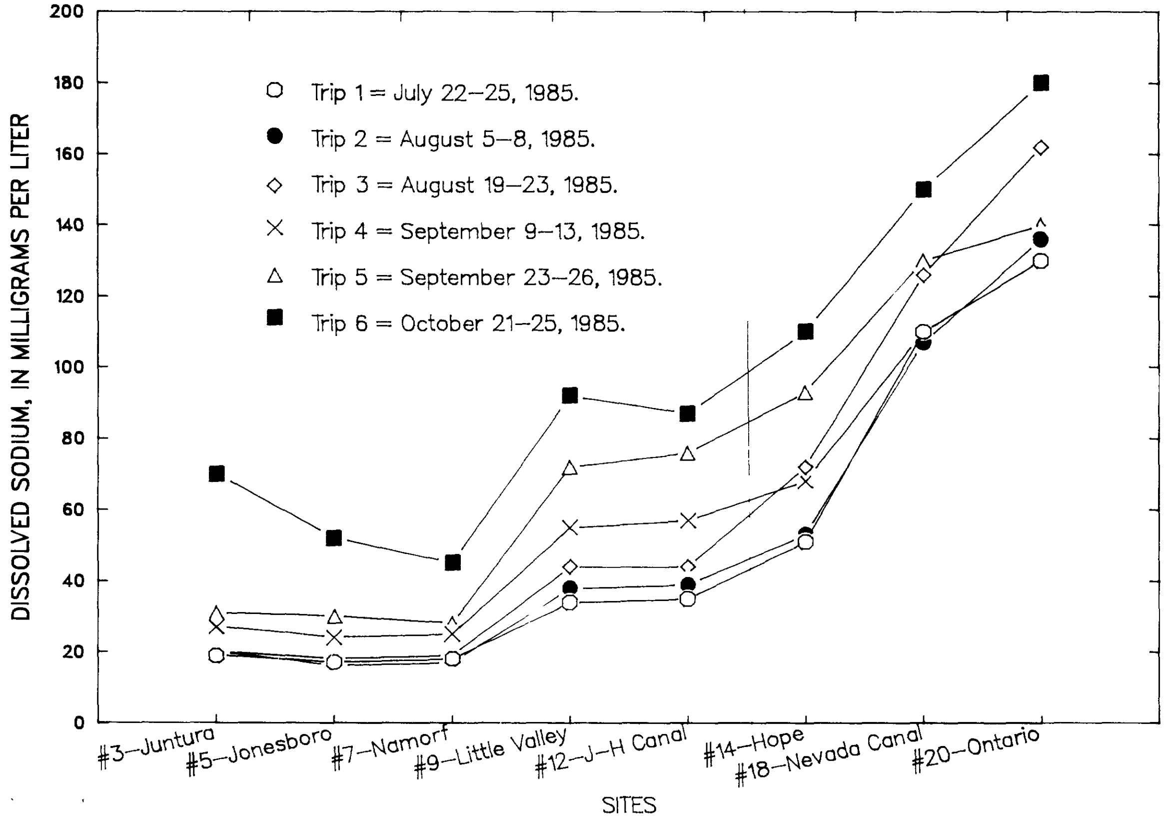


FIGURE 12.--Measured concentrations of dissolved sodium in the Malheur River, July-October, 1985.

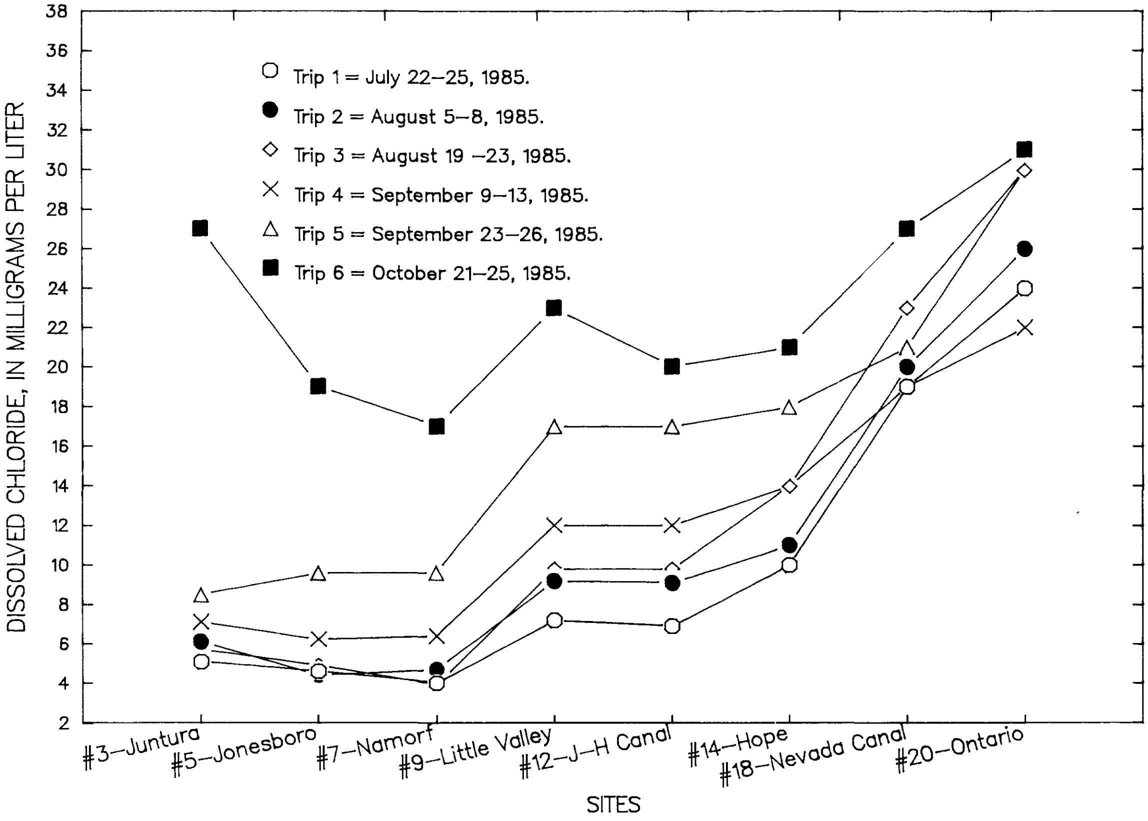


FIGURE 13.--Measured concentrations of dissolved chloride in the Malheur River, July-October, 1985.

The U.S. Salinity Laboratory experiments (1954) have shown that irrigation water with large SAR values may cause sodium to replace adsorbed calcium and magnesium and ultimately damage the soil structure. Figure 14 shows existing SAR values to be lower during the July and August trips than the September and October trips; SAR values tend to increase as water moves downstream in the Malheur River.

Total arsenic concentrations between Namorf (site 7) and Little Valley (site 9) showed a much greater increase than expected (fig. 15); two samples in September and five samples in October 1985 exceeded the drinking water standard of 50 μg/L. In October the concentration increased from 14 to 85 μg/L, representing an inflowing load of 31 pounds per day of arsenic (table 7). Probable sources of the arsenic are thermal springs along this reach. A rise in the water table, during irrigation season, that comes into contact with a soil zone rich in arsenic could explain the increase from July to October. This phenomenon has been observed and reported from saline seleniferous soils yielding selenium rich water (Presser and Barnes, 1984, 1985; Barnes, 1985). The chemistry of arsenic is very similar to that of selenium (Ivan Barnes, U.S. Geological Survey, oral commun., 1986). Arsenic concentrations were increasing in a downstream direction, during the first three trips, similar to concentrations of sodium and chloride. During September and October, arsenic concentrations remained equal or decreased progressively downstream because irrigation return flows downstream were more equal or dilute in arsenic than those in the main stem.

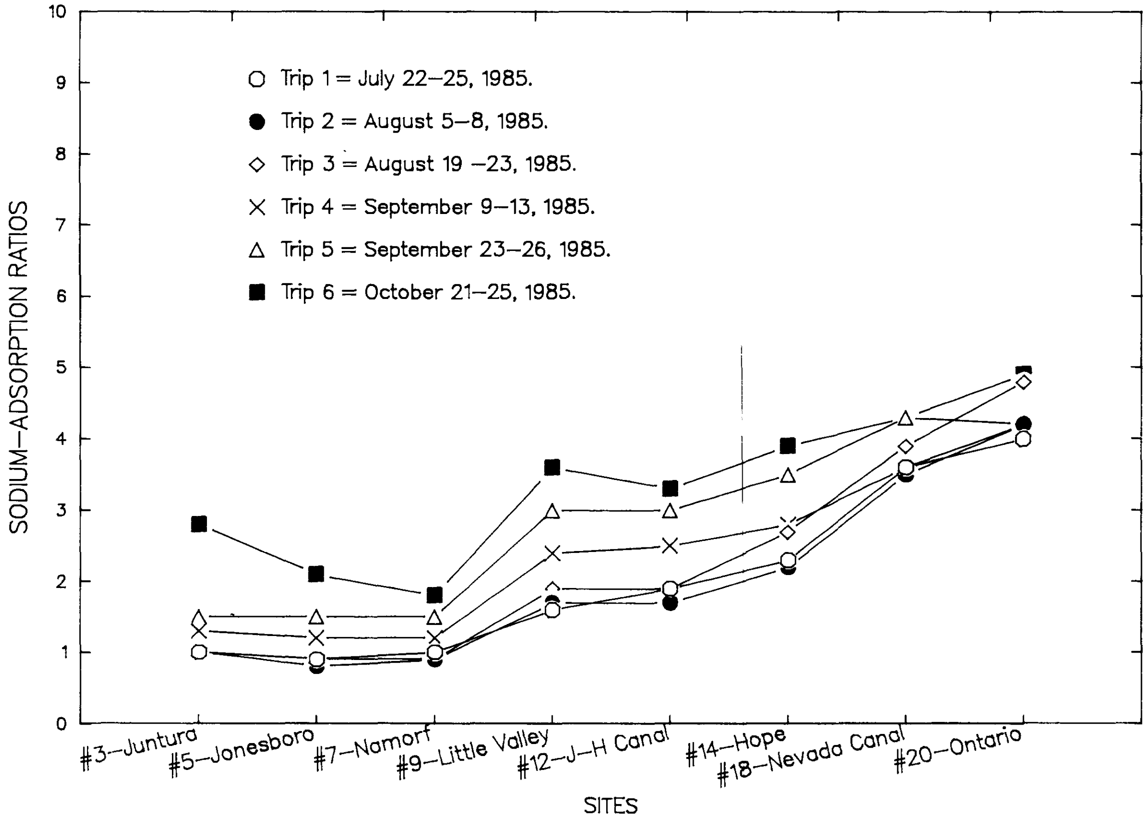


FIGURE 14.--Calculated sodium adsorption ratios in the Malheur River, July-October, 1985.

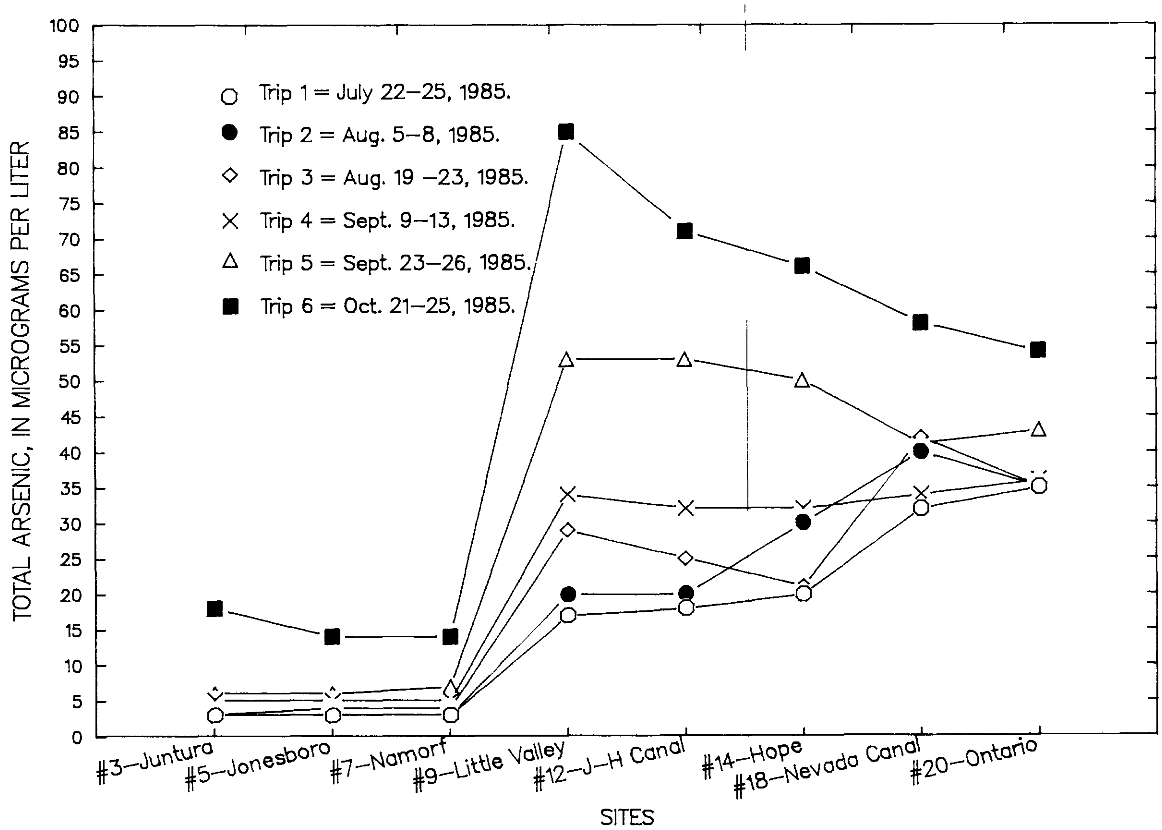


FIGURE 15.--Measured concentrations of total arsenic in the Malheur River, July-October, 1985.

Table 7.--Arsenic and boron loads entering Malheur River between Namorf (site 7) and Little Valley (site 9) during 1985

Date	Trip number	Pounds per day Arsenic, total	 Boron, dissolved
Jul 22-25	1	20	100
Aug 5-8	2	22	200
Aug 19-23	3	26	240
Sept 9-13	4	27	240
Sept 23-26	5	25	210
Oct 21-25	6	31	240

Concentrations of boron between Namorf (site 7) and Little Valley (site 9) also showed a high rate of increase during September and October 1985 (fig. 16). In October, the boron concentration at site 9 increased from 320 to 810 μg/L between Namorf and Little Valley, an estimated increase of 240 pounds per day (table 7). A previous study by the Malheur County Planning office (1981) indicates that boron concentrations along the Malheur River have been consistently below 1,000 μg/L (ranging from 330 to 780 μg/L). Probable sources of the boron are thermal springs along this reach.

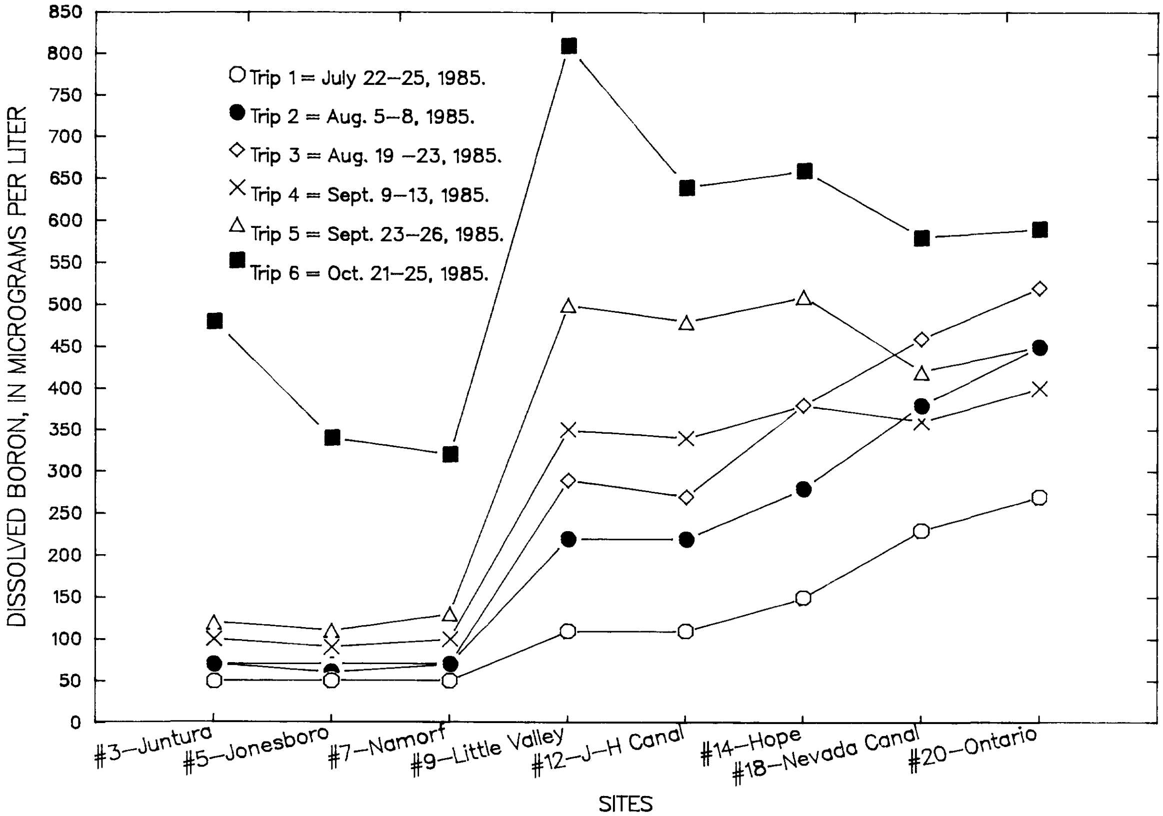


FIGURE 16.--Measured concentrations of dissolved boron in the Malheur River, July-October, 1985.

Concentrations of total-recoverable trace elements in water samples collected in August and October (table 8) were below toxicity criteria for freshwater aquatic life (Federal Register, 1985). The August sample, including algae, had a suspended-sediment concentration of 207 mg/L of which 86 percent by weight was less than 0.062 mm in diameter (silt and clay sizes).

Concentrations of trace elements in Malheur River bottom sediments are typical of soils found in and near Malheur River basin (table 9). Principal elements composing the fine sediments (<0.062 mm) were aluminum, calcium, iron, magnesium, potassium, sodium, and titanium. As much as 66 percent by weight of bottom sediments were composed of silts and clays. Based on available data from nine soil samples collected in and near Malheur River basin, the concentrations on soils and on bottom sediments are comparable in value (Boerngen and Schacklette, 1981).

Table 8.--Concentrations of total-recoverable trace elements for water samples collected near mouth of Malheur River north of Ontario, in August and October, 1985

[Lead analysis in August done by different method with a higher detection level. Concentrations in micrograms per liter]

Element	Trip 3 August 23	Trip 6 October 26
Aluminum	1300	800
Lead	<100	<5
Manganese	80	70
Cadmium	1	<1
Chromium	15	10
Copper	6	6
Nickel	8	7
Selenium	3	3
Zinc	20	20

Table 9.--Concentrations of total trace elements in bottom sediments with size less than 0.062 mm in diameter near the mouth of Malheur River, August and October 1985

[All concentrations are in milligram per kilogram]

	Malheur River basin bottom sediments		Soils in and near the Malheur River basin	
Element	August	October	Median	Range[1]
Aluminum	74,000	74,000	>100,000	70,000->100,000
Arsenic	<10	8.6	4.3	3.6-12
Barium	610	630	700	500-1,000
Beryllium	2	1	1.0	<1.0-2.0
Bismuth	<10	<10	--	--
Cadmium	<2	<2	--	--
Calcium	31,000	34,000	24,000	16,000-102,000
Cerium	50	48	--	--
Cobalt	16	17	15	7-30
Chromium	70	67	30	15-70
Copper	35	36	30	7-150
Europium	<2	<2	--	--
Gallium	16	17	30	15-30
Gold	<8	<8	--	--
Holmium	<4	<4	--	--
Iron	38,000	39,000	50,000	15,000-70,000
Lanthanum	29	27	50	<30-70
Lead	17	21	15	10-30
Lithium	31	31	25	12-30
Magnesium	13,000	13,000	15,000	5,000-30,000
Manganese	700	840	700	500-1,000
Mercury	--	0.05	0.03	0.02-0.14
Molybdenum	<2	<2	<5	<5-7
Neodynium	28	26	<70	<70-70
Nickel	35	33	20	5-30
Phosphorus	1,100	1,100	3,000	1,600-10,500
Potassium	12,000	11,000	17,600	13,000-28,000
Scandium	13	14	15	7-30
Silver	<2	<2	--	--
Sodium	13,000	14,000	15,000	10,000-30,000
Strontium	290	310	500	300-1,000
Tantalum	<40	<40	--	--
Thorium	7	6	--	--
Tin	<20	<20	--	--
Titanium	4,900	4,900	5,000	2,000-10,000
Uranium	<100	<100	--	--
Vanadium	110	110	150	70-300
Yttrium	25	24	30	15-70
Ytterbium	3	2	3	1.5-7
Zinc	100	99	55	35-310

[1] Nine soil samples are from B soil horizon, (Boerngen, J. G and Schacklett, H.T, 1981)

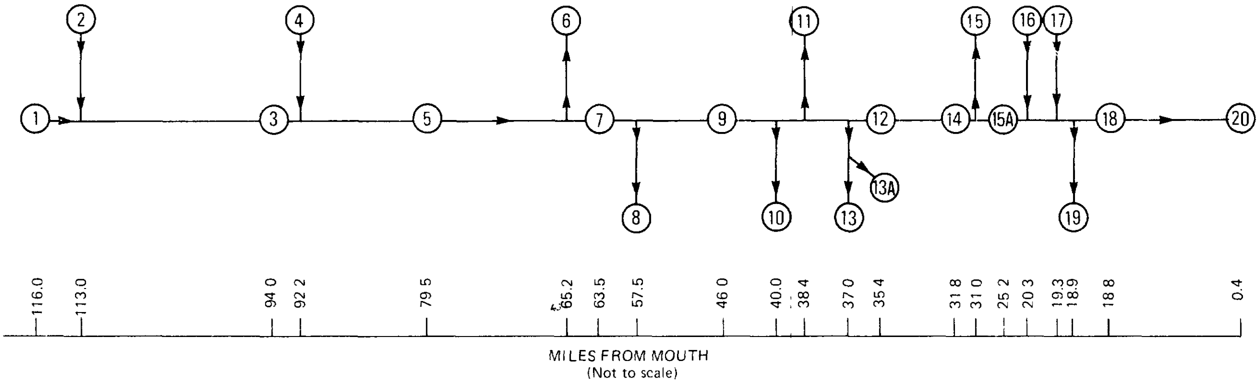
SIMULATION OF WATER QUALITY IN THE MALHEUR RIVER BASIN

Development of Simulation Method

A mass-balance calculation of chemicals for the collective irrigation systems in the Malheur River basin may not be very accurate because of the existence of multiple and overlapping diversions and return flows throughout the entire river length. Instead, discharge and constituent concentrations at each of 13 Malheur River basin sites, along with discharge at 8 diversion sites, were used to develop equations to calculate the change in loads of calcium, magnesium, sodium, chloride, arsenic, boron, specific conductance (dissolved solids), and SAR at 8 main-stem river reaches (fig. 17).

The 1985 water-quality data show increasing concentration in a downstream direction (see figs. 12 and 13). These increases in concentrations (used in developing the simulation methodology) are thought to be caused by the following two major geochemical processes:

o Evaporation and transpiration (evapotranspiration) -- Water lost to the atmosphere by these processes will cause the concentration of constituents to increase. Assuming similar irrigated acreages, irrigation methods, and crop types, the water loss and resulting increase in concentrations should be relatively constant between measured and simulated conditions for 1985. These processes should also be independent of the amount of water in the main stem.



INFLOW SAMPLING SITES:

1 South Fork Malheur River at Riverside
2 Malheur River at Juntura
4 North Fork Malheur River at Beulah
16 Bully Creek near mouth at Vale
17 Willow Creek near mouth at Vale

DIVERSION SAMPLING SITES:

6 Vale-Oregon Canal near Namorf
8 Harper Southside Canal near Harper
10 Vines Ditch near inflow of J-H Canal near Hope
11 Farmers Canal near Hope
13 J-H Canal near Hope
13A Diversion from J-H Canal near Hope
15 Gellerman Froman Canal near Hope
19 Nevada Canal near Vale

MAIN STEM SAMPLING SITES:

3 At Juntura
5 Near Jonesboro
7 Near Namorf
9 At Little Valley
12 Below J-H Canal near Hope
14 Near Hope
15A Below Gellerman Froman Canal near Hope
18 Below Nevada Canal near Vale
20 Near mouth near Ontario

FIGURE 17.--Location of sampling sites at inflows, diversions, and main stem in river miles from the mouth of Malheur River.

- Soil and rock dissolution -- The rate that soil and rock dissolve should remain fairly constant provided that

  (1) The method of irrigation and thus the amount of water infiltrating the unsaturated and saturated zones remains relatively constant. This condition should occur, assuming similar irrigated acreages, irrigation methods, and crop types; and

  (2) The concentrations of constituents in the irrigation water do not increase to the level where they approach saturation.

Processes of transporting chemicals include the following:

- Surface-water return flows -- This is the irrigation water which leaves the field as excess surface water or "tailwater." The quantity of surface-water runoff, in aggregate for individual reaches, should be relatively constant and independent of streamflow, assuming that the methods of irrigation, crop types, and irrigated acreage do not change. The change in the quality of water leaving irrigated fields should be directly affected by the quality of water being diverted for irrigation.

- Ground-water seepage -- The rate of ground-water seepage results from the amount of water applied to land which recharges the water table and determines the water level and gradient to the stream or velocity of ground-water flow. If farming and irrigation methods do not change, the fluctuations in the water table should not vary significantly from year to year. With increasing streamflow resulting from Malheur Lake inflow, it is likely that the ground-water gradient will be lower and the rate of seepage will be slightly decreased. Since the equations do not compensate for this change in gradient, the simulations may be slightly overestimating the amount of seepage. The quality of ground water should be directly affected by the quality of water being applied as irrigation water.

Assumptions and Limitations

The method selected to simulate constituent concentrations requires (1) knowing the load at nine selected points in the main stem and at four inflow points, (2) knowing the discharge at eight diversion points, and (3) calculating the change in load between any two main-stem sites. The change in load is calculated as (1) a coefficient of the upstream load (loading factor) or (2) a constant gain or loss of load in the reach (constant load factor). The loading-factor coefficients and the constant-load values within each reach were determined by comparing (for each constituent) the chemical load arriving at a downstream site to the chemical load leaving an upstream site. Mass-balance equations used to represent each reach are shown in tables 10 and 11. Use of the equations with the loading-factor coefficient assumes that the increase in load for a reach being simulated is proportional to the concentration at the start of the reach. Use of the equations with the constant-load value assumes that the difference in load for a reach being simulated is constant (equal to the 1985 measured difference in load). The data collected in 1985 do not allow the quantitative separation of these processes to determine which of the two processes was predominant on each reach. Since both processes are thought to occur, the long-term effect is likely to be some combination of the two sets of equations shown on tables 10 and 11.

Table 10.--Mass-balance equations that use a loading-factor coefficient to simulate the mixing of Malheur Lake water with Malheur River water

[Abbreviations are as follows: Q_n = instantaneous discharge at site n; C_n = concentration of chemical constituent at site n; Q_L = lake flow; C_L = concentration of chemical constituent in Malheur Lake water; lf = loading-factor coefficient; ΔL = constant loading value; see figure 1 for location of sites]

	Equation	Reach between sampling sites
(1)	$\left[\frac{Q_L C_L + Q_1 C_1 + Q_2 C_2}{Q_L + Q_1 + Q_2}\right] \left[(Q_1 + Q_2)(\mathrm{lf}_1) + Q_L\right] = (Q_3 + Q_L) C_3$	1 to 3
(2)	$(Q_3 C_3 + Q_4 C_4)(\mathrm{lf}_3) + Q_L C_3 = (Q_5 + Q_L) C_5$	3 to 5
(3)	$(Q_5 C_5)(\mathrm{lf}_5) + Q_L C_5 = (Q_6 + Q_7 + Q_L) C_7$	5 to 7
(4)	$(Q_7 - Q_8)(C_7)(\mathrm{lf}_7) + \Delta L + Q_L C_7 = (Q_9 + Q_L) C_9$	7 to 9
(5)	$(Q_9 C_9)(\mathrm{lf}_9) + Q_L C_9 = (Q_{10} + Q_{11} + Q_{12} + Q_{13} + Q_{13A} + Q_L) C_{12}$	9 to 12
(6)	$(Q_{12} C_{12})(\mathrm{lf}_{12}) + Q_L C_{12} = (Q_{14} + Q_L) C_{14}$	12 to 14
(7)	$(Q_5 C_5)(\mathrm{lf}_5) + \Delta L + Q_{16} C_{16} + Q_L C_5 = (Q_{18} + Q_{19} + Q_L) C_{18}$	5 to 18
(8)	$(Q_{18} C_{18})(\mathrm{lf}_{18}) + Q_L C_{18} = (Q_{20} + Q_L) C_{20}$	18 to 20

Table 11.--Mass-balance equations that use a constant-load value to simulate mixing of Malheur Lake water with Malheur River water

[Abbreviations are as follows: Q_n = instantaneous discharge at site n; C_n = concentration of chemical constituent at site n; Q_L = lake flow; C_L = concentration of chemical constituent in Malheur Lake water; ΔL = constant loading value; see figure 1 for location of sites]

	Equation	Reach between sampling sites
(1)	$Q_1 C_1 + Q_2 C_2 + Q_L C_L + \Delta L = (Q_3 + Q_L) C_3$	1 to 3
(2)	$(Q_3 + Q_L) C_3 + Q_4 C_4 + \Delta L = (Q_5 + Q_L) C_5$	3 to 5
(3)	$(Q_5 + Q_L) C_5 + \Delta L = (Q_6 + Q_7 + Q_L) C_7$	5 to 7
(4)	$(Q_7 - Q_8 + Q_L) C_7 + \Delta L = (Q_9 + Q_L) C_9$	7 to 9
(5)	$(Q_9 + Q_L) C_9 + \Delta L = (Q_{10} + Q_{11} + Q_{12} + Q_{13} + Q_{13A} + Q_L) C_{12}$	9 to 12
(6)	$(Q_{12} + Q_L) C_{12} + \Delta L = (Q_{14} + Q_L) C_{14}$	12 to 14
(7)	$(Q_5 + Q_L) C_5 + Q_{16} C_{16} + \Delta L = (Q_{18} + Q_{19} + Q_L) C_{18}$	5 to 18
(8)	$(Q_{18} + Q_L) C_{18} + \Delta L = (Q_{20} + Q_L) C_{20}$	18 to 20

In equations shown in table 10 and 11, diversions could be shown on the left or right side of the equation. The authors placed the diversions (see fig. 17) on the left side if nearest the start of the reach (equation 4) and on the right side of the equation if nearest the end of the reach (equation 3) in order to simulate the water traversing the reach as representatively as possible. The first term of equation 1 in table 10 calculates a flow-weighted concentration considering flows from Malheur Lake, South Fork Malheur, and Malheur Rivers. Loading-factor coefficients and constant-loading values for equations shown were calculated by using values of discharge and concentrations shown in table 23.

Loading-factor coefficients and constant-load values were calculated for specific conductance (dissolved solids), and for concentrations of calcium, magnesium, sodium, chloride, arsenic, and boron for each of the river reaches (tables 24 and 25, at the back of report). Generally, the loading-factor coefficients and constant-load values within a river reach for a specific constituent were found to exhibit a similar range of values over all visits.

Application of Simulation Method

Simulations include two hypothetical flow regimes of 300 and 500 ft^3/s from Malheur Lake and observed flows from Warm Springs and Beulah Reservoirs. Malheur River flows measured during the second week of August 1985 (trip 2) were selected as representative of typical irrigation flows (Friday and Miller, 1984) during irrigation season, while flows measured in late October (trip 6) represent flows occurring after irrigation ceases. Median 1985 Malheur Lake concentrations of calcium, magnesium, sodium, chloride, arsenic, boron, and values of specific conductance were used when simulating the effect of placing lake water in the Malheur River basin.

The equations in tables 10 and 11 include four terms (Q_n, C_n, lf_n and ΔL_n), which are used in the mixing simulations of Malheur Lake and Malheur River water. Equation 2 in table 10 uses the inflowing load from site 3 (Q_3C_3) plus the load from site 4 (Q_4C_4), all multiplied by a loading-factor coefficient (lf_3) plus an additional flow from Malheur Lake times the concentration at site 3 (Q_LC_3) to predict the load arriving at site 5 $(Q_5 + Q_L)C_5$. Equation 2 indicates that any increase in load at site 3 due to an increase in concentration at site 3 will cause an increase in load at site 5. This form of the equation best simulates evapotranspiration as a dominant process. The additional load due to the added water from Malheur Lake and concentration at the upstream end of the reach is not multiplied by the loading factor since the major processes have been accounted for and the additional loss of water or change in concentration is thought to be insignificant. Equation 2 in table 11 is for the same reach. This form of the equation uses a constant-load value, which means that the difference in measured load between sites 3 and 5 will remain constant from year to year for this time period, regardless of flow and concentration inflowing to the reach. This form of the equation best simulates a constant rate of dissolution or a constant source, such as a deep spring that is not affected by ground-water levels. The equations in tables 10 and 11 simulate the concentrations on one reach at a time to allow for (a) management changes in approximately 10-mile reaches, (b) prediction of quality at diversion points for canals, and (c) delineation of downstream quality now and changes that would likely occur with Malheur Lake water added. Depth and width integrated samples were collected to represent the average concentration in a reach and were used to calibrate equations in tables 10 and 11. For each successive downstream reach, a newly calculated concentration from the upstream reach will be the initial concentration at the upstream site of the next river reach.

The magnitude of flow from the lake (Q_L) routed downstream remains unchanged from the previous reach; the magnitude of the river flow will equal that measured in 1985. The term ΔL in equations 4 and 7 (table 10) will equal zero for all constituents except arsenic and boron.

The chemical change occurring between Hope (site 14) and below Nevada Canal (site 18) is expressed differently because of the large volume of return flows entering the river in this reach. Bully Creek (site 16) and Willow Creek (site 17) represent the largest return flows entering the reach between Hope and the Nevada Canal diversion. Drainage from Bully Creek was considered a new source into Malheur River, since only 10 percent of its flow is estimated to originate from the Vale-Oregon Canal. The Vale-Oregon Canal (diverted from the Malheur River at site 6) is the principal source of water for Willow Creek and is estimated to contribute as much as 90 percent of the total streamflow during the irrigation season (Frank Elferling, Water Master, Malheur County, oral commun., 1985). Water entering Willow Creek includes returned flow from irrigated land and unutilized flow routed through the canal system with minimal change. The remaining 10 percent of the flow in Willow Creek is composed of drainage from the headwaters of Willow Creek and water from North Canal (Owyhee River basin) entering the creek below Jamieson Canal (see fig. 9). Lack of information on the quantity and quality of water entering Willow Creek basin via the Vale-Oregon Canal system and other sources in the basin meant that simulating concentrations of chemical constituents in Willow Creek was not possible. Changes in water chemistry were therefore simulated from a larger perspective; that is, changes in loads were simulated between site 5 above Jonesboro (14 miles upstream from the diversion of Vale-Oregon Canal) and site 18 (below Nevada Canal diversion). The method used in equation 7 of tables 10 and 11 is the same method used for other reaches, except that it is used over a larger reach.

Major Ion Simulation Results

Figures 18, 19, and 20 show the results of simulating the addition of 300 ft^3/s of Malheur Lake water to August flow conditions. In general, the simulated values of sodium, chloride, and specific conductance are all higher than the observed values because of the higher concentrations of constituents in Malheur Lake. The first three sites (3, 5, and 7) show no difference between the two sets of equations because both processes are minimally affecting the water quality. The difference between the "load factor" and the "constant load" simulations for site 9 is due to the form of the equations and the processes they represent. If the increase in the measured load at site 9 is caused by evapotranspiration, the higher simulated values would best predict the concentrations of sodium and chloride and specific conductance values. If the increase in the measured load at site 9 is due to soil dissolution and (or) to a constant-flowing spring of constant quality, the lower simulated values would best predict the concentrations.

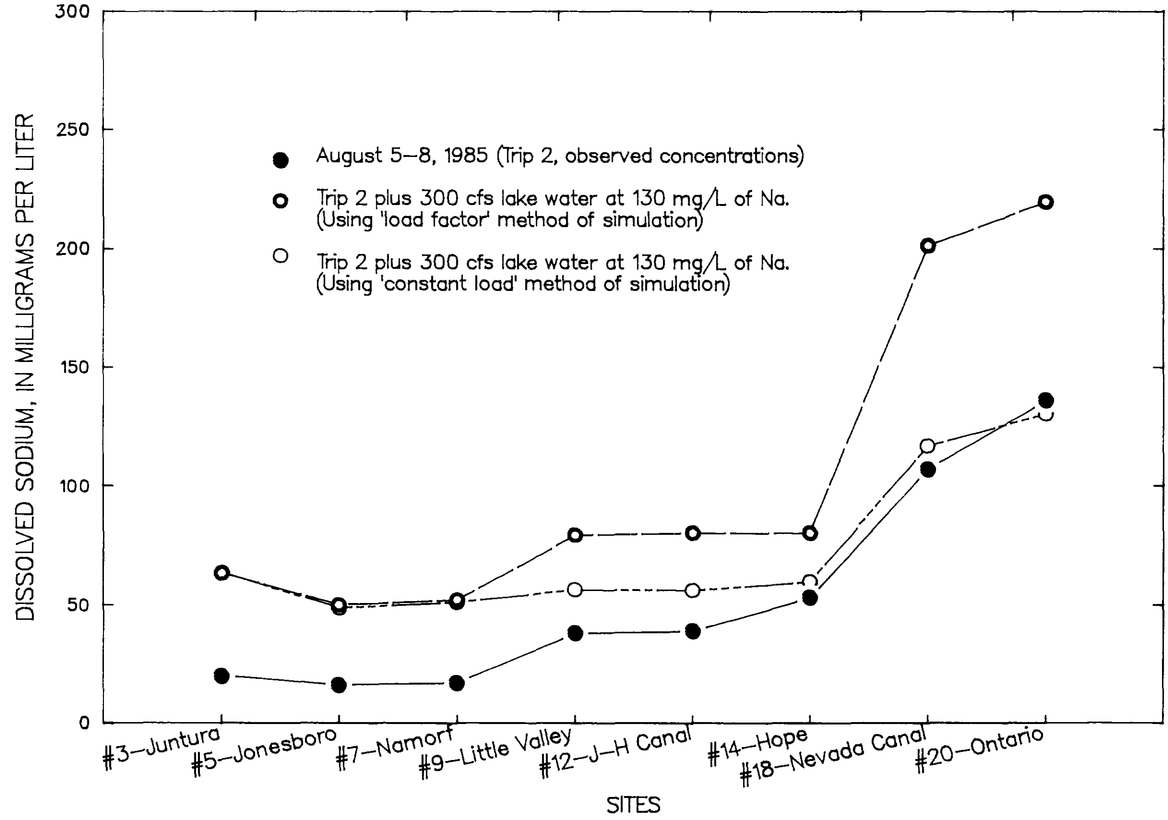


FIGURE 18.--Comparison of measured dissolved sodium concentrations during August with simulated concentrations using 300 cfs of Malheur Lake water mixed with Malheur River water.

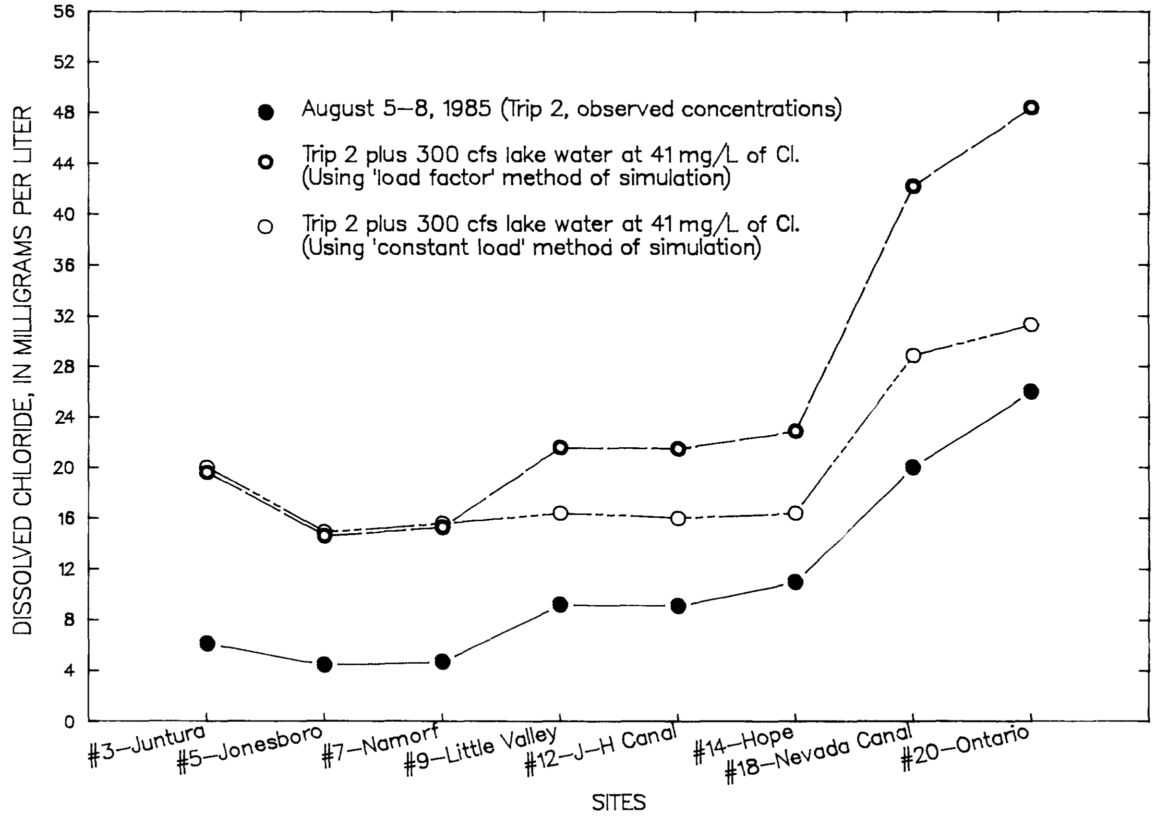


FIGURE 19.--Comparison of measured dissolved chloride concentrations during August with simulated concentrations using 300 cfs of Malheur Lake water mixed with Malheur River water.

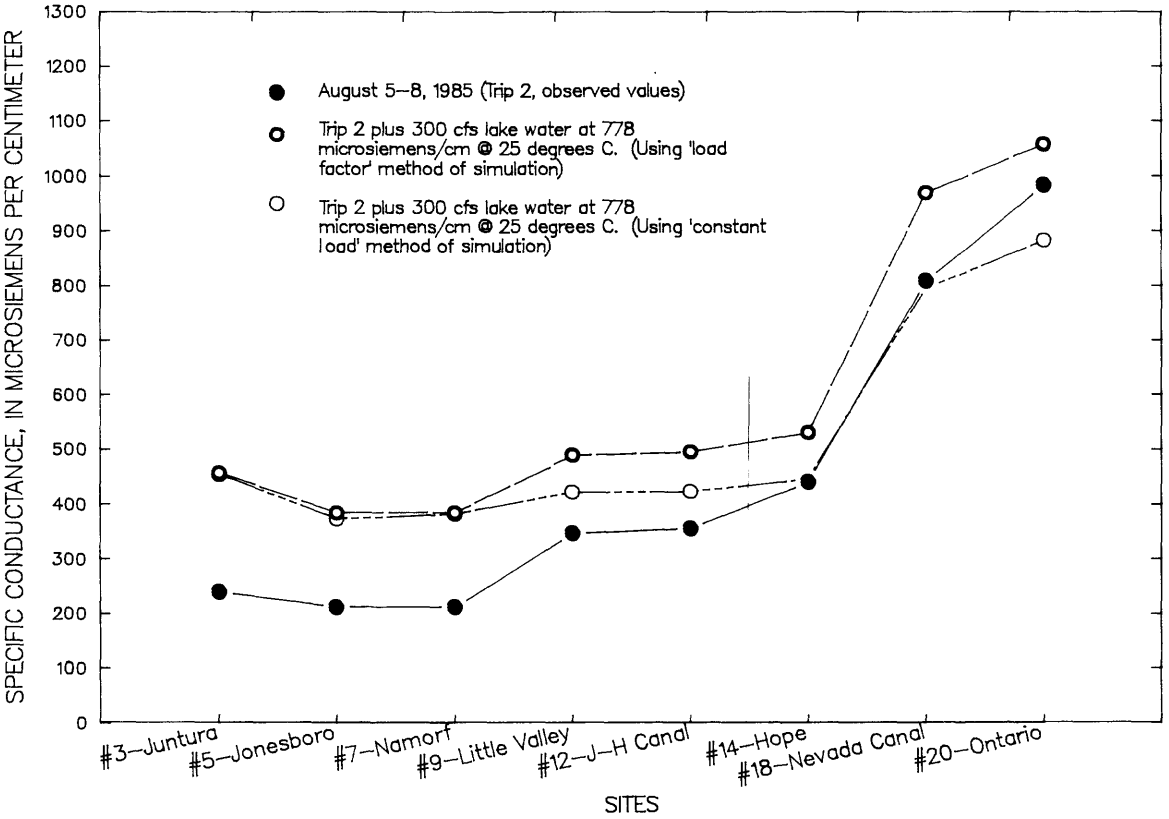


FIGURE 20.--Comparison of measured specific conductance values during August with simulated values using 300 cfs of Malheur Lake water mixed with Malheur River water.

Because both processes are likely occurring and there is no evidence to quantify the separate processes, it would seem most probable that the correct simulation would fall somewhere between these two predicted values.

Sites 12 and 14 predict little change in concentrations from site 9 because of the small volume and loads from inflows relative to the existing loads in the Malheur River. Sites 18 and 20 both show significant increases in concentrations, suggesting that both processes are significant and that the large increases are the result of large flows and loads from surface- and ground-water returns. It also seems most probable that the correct simulation would fall somewhere between these predicted values.

Figures 21, 22, and 23 show the results of simulating the addition of 300 or 500 ft^3/s of Malheur Lake water to October flow conditions. In general, the simulated values show less variability in a downstream direction than measured values because of the small volume of inflows relative to the lake flows.It is interesting to note that there is a greater similarity between methods of calculation than between the two flows from Malheur Lake. Because these simulations are for the post-irrigation season, they should have none to minimal effect on concentration observed during the irrigation season. It should also be noted that these measured and simulated conditions in October would not be representative of the entire non-irrigation period. Because October 1985 had low flows, other parts of the non-irrigation period with higher flows than those measured in October should have lower concentrations.

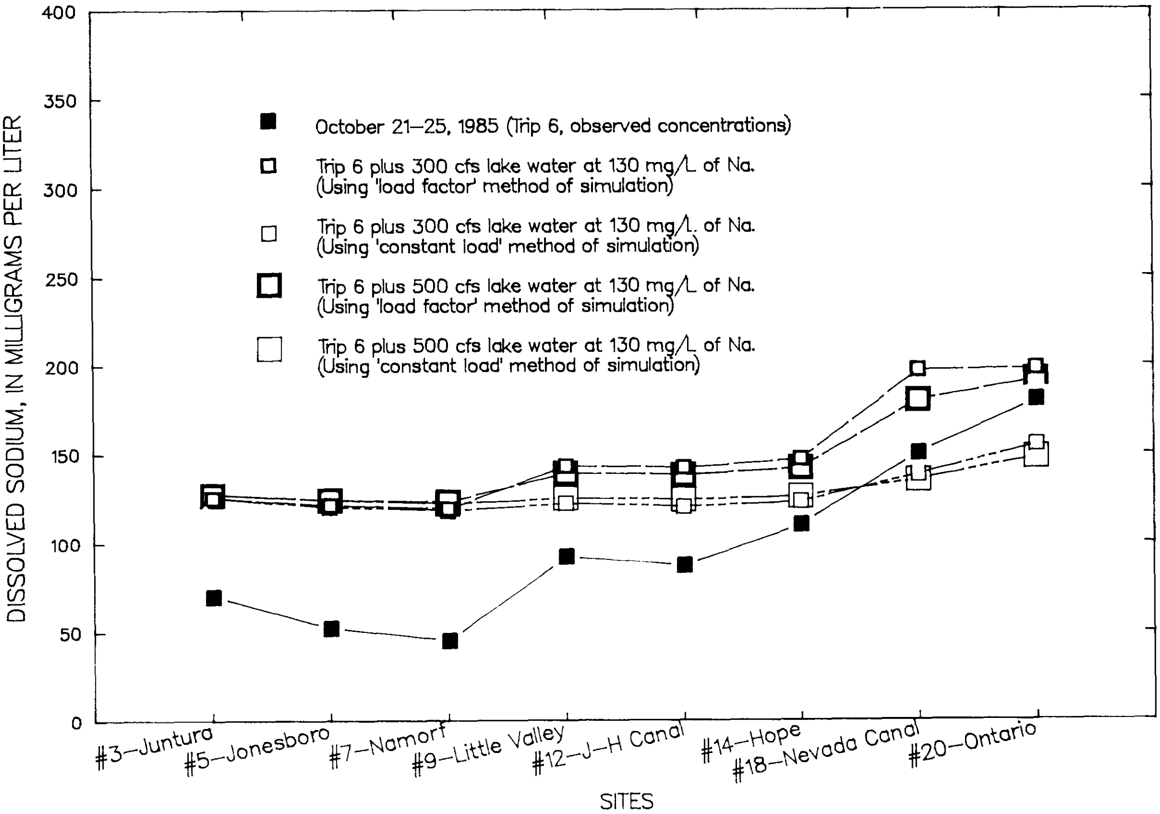


FIGURE 21.--Comparison of measured dissolved sodium concentrations during October with simulated values using 300 and 500 cfs of Malheur Lake water mixed with Malheur River water.

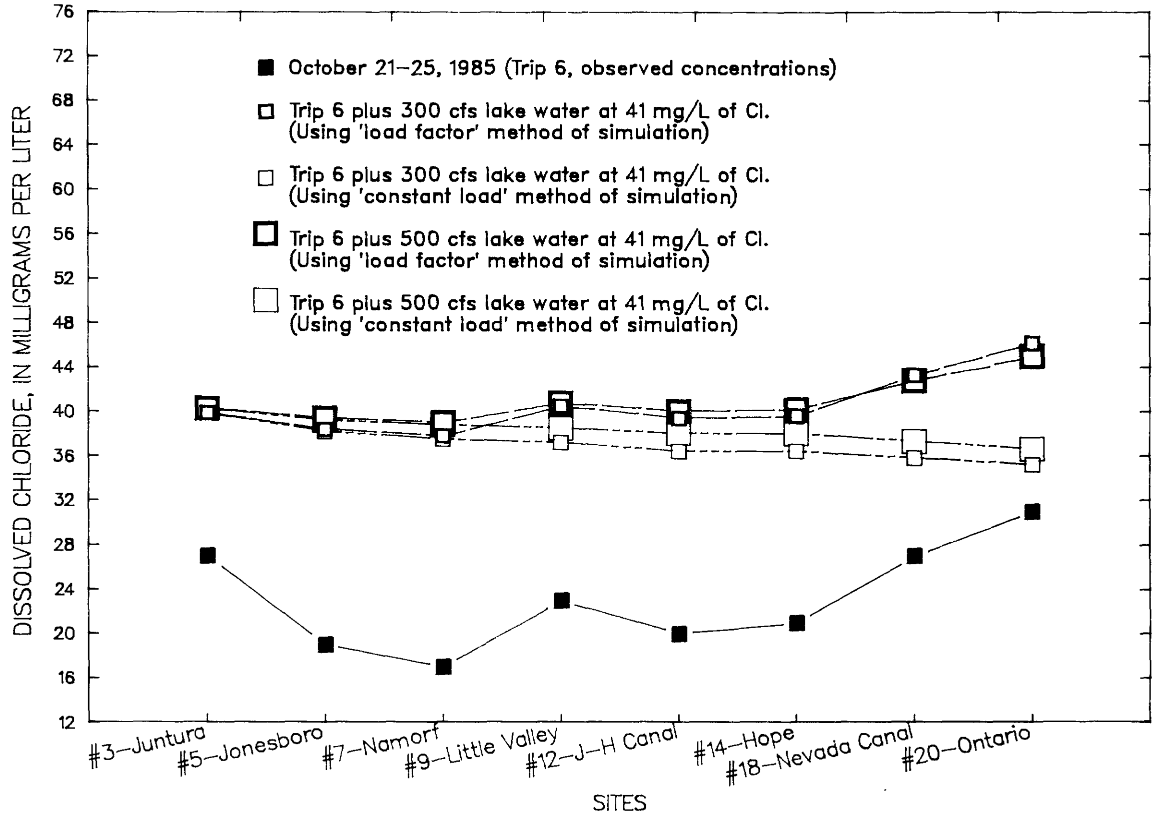


FIGURE 22.--Comparison of measured dissolved chloride concentrations during October with simulated concentrations using 300 and 500 cfs of Malheur Lake water mixed with Malheur River water.

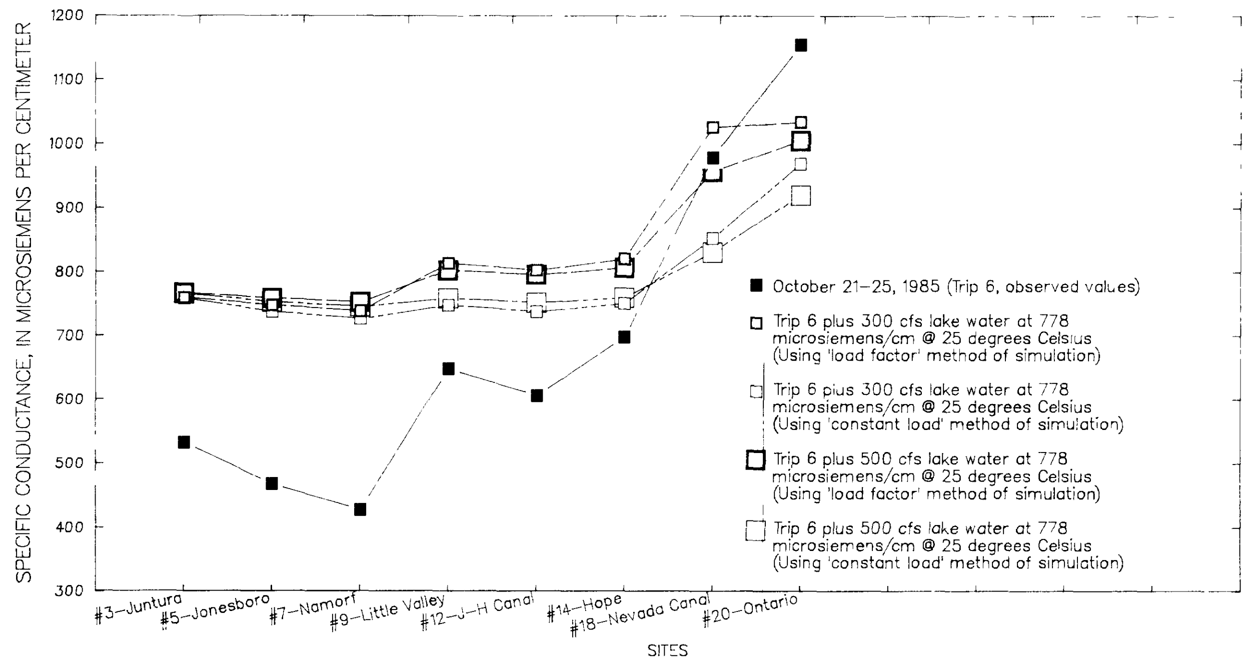


FIGURE 23.--Comparions of measured specific conductance values during October with simulated values using 300 and 500 cfs of Malheur Lake water mixed with Malheur River water.

Predicted SAR (sodium-adsorption ratios) were calculated using simulated concentrations of calcium, magnesium, and sodium with lake flows of 300 ft^3/s (fig. 24). Results show a trend similar to those observed with sodium, chloride, and specific conductance.

Arsenic and Boron Simulation Results

Even though the increases in both arsenic and boron loads between sites 7 and 9 are relatively constant, with an increasing trend, the magnitude of the increasing concentrations is much larger than expected and the concentrations are larger than one would expect from irrigation return flow. This inflow is most noticeable when river flows are lowest and suggests that sources or processes other than those previously described may predominate in this reach. One potential explanation is the presence of a thermal spring with elevated concentrations of arsenic and boron. Such a spring would have relatively constant flows, concentrations, and loads, and these should not change as the inflowing load at site 7 increases with the simulation of added lake water. The difference in loads, ΔL, between sites 7 and 9 was thus used instead of a loading factor since it best represents the changes in arsenic and boron concentrations occurring in this reach. ΔL has been calculated for arsenic and boron for the six visits made to Malheur River, and values are shown in table 23 (at the back of report).

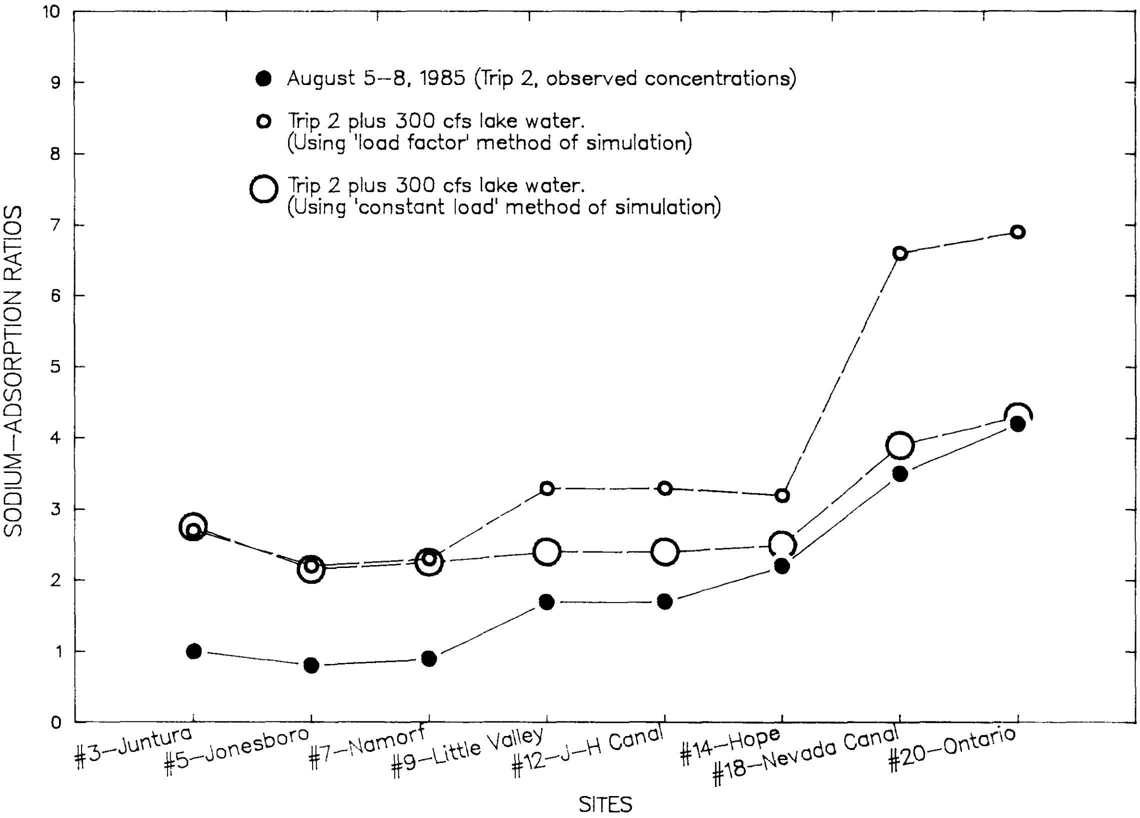


FIGURE 24.--Comparison of measured sodium-adsorption ratios (SAR) during August with simulated SAR values using 300 cfs of Malheur Lake water mixed with Malheur River water.

Simulated arsenic concentrations show a decrease for sites 9, 12, and 14 when 300 ft^3/s of lake water is added to August river flows measured on trip 2 (fig. 25). This decrease results from measurement of low flows and high concentrations of arsenic occurring naturally on this segment of the river (relative to the lake water). The simulation shows that arsenic concentrations increase in the reach where Willow and Bully Creeks enter Malheur River. When lake flows of 300 and 500 ft^3/s are added to post-irrigation flows (trip 6), the result is a noticeable concentration decrease from measured values for sites 9 to 20 (fig. 26).

Simulated concentrations of boron are shown in figures 27 and 28, which use river flows from trips 2 and 6. The difference between simulated and measured concentrations for boron are much greater than the differences in simulated and measured concentrations for arsenic because the difference in boron concentration between Malheur Lake and Malheur River is much greater than the difference in arsenic concentration measured in Malheur Lake and Malheur River.

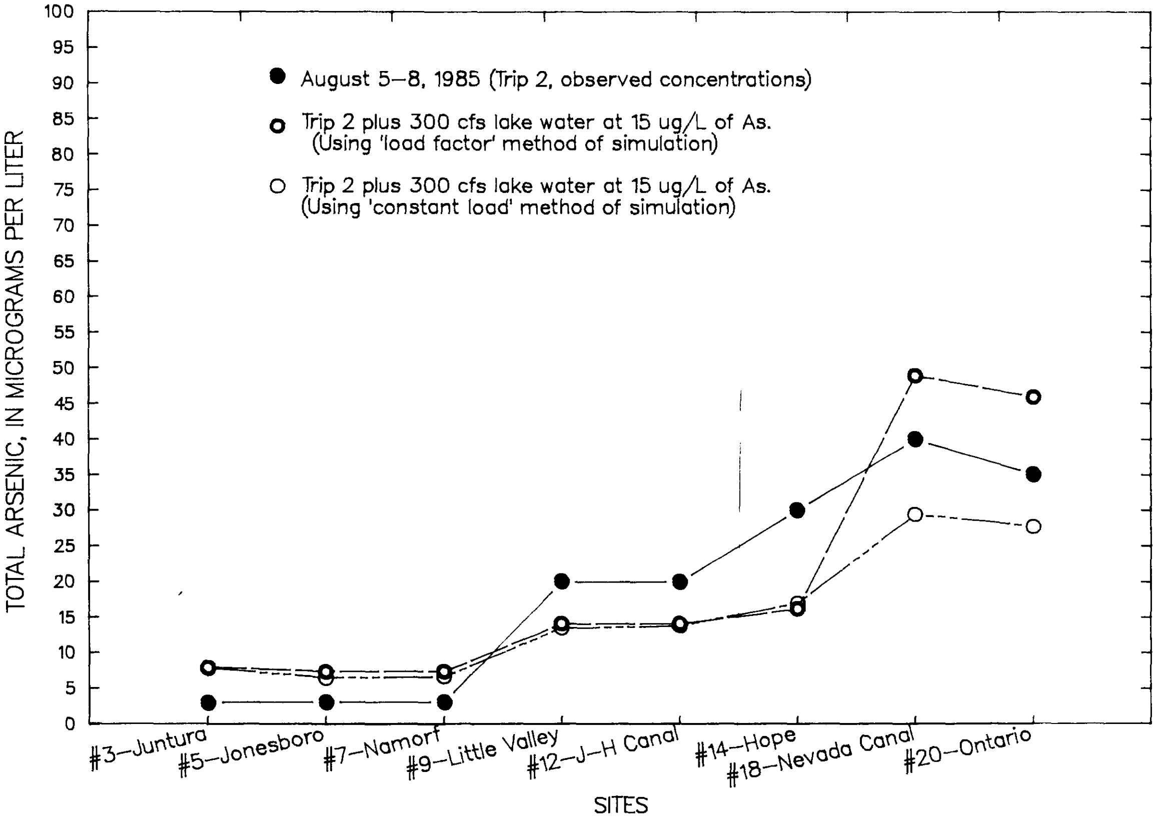


FIGURE 25.--Comparison of measured total arsenic (As) concentrations during August with simulated concentrations using 300 cfs of Malheur Lake water mixed with Malheur River water.

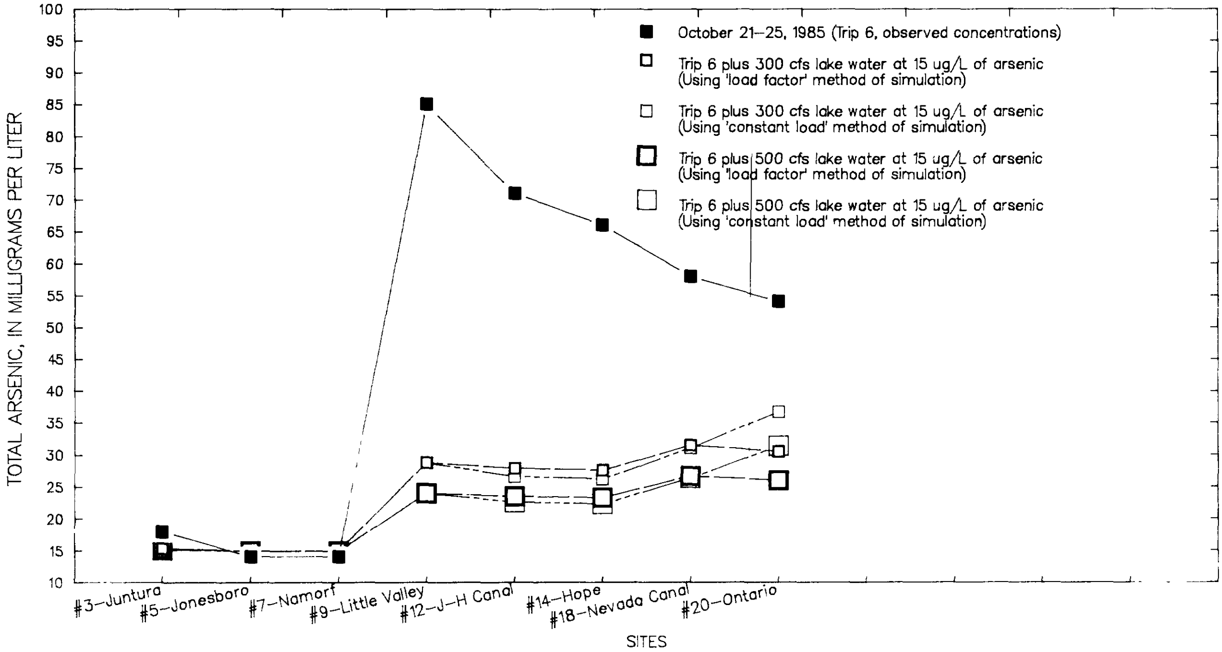


FIGURE 26.--Comparison of measured total arsenic concentrations during October with simulated concentrations using 300 and 500 cfs of Malheur Lake water mixed with Malheur River water.

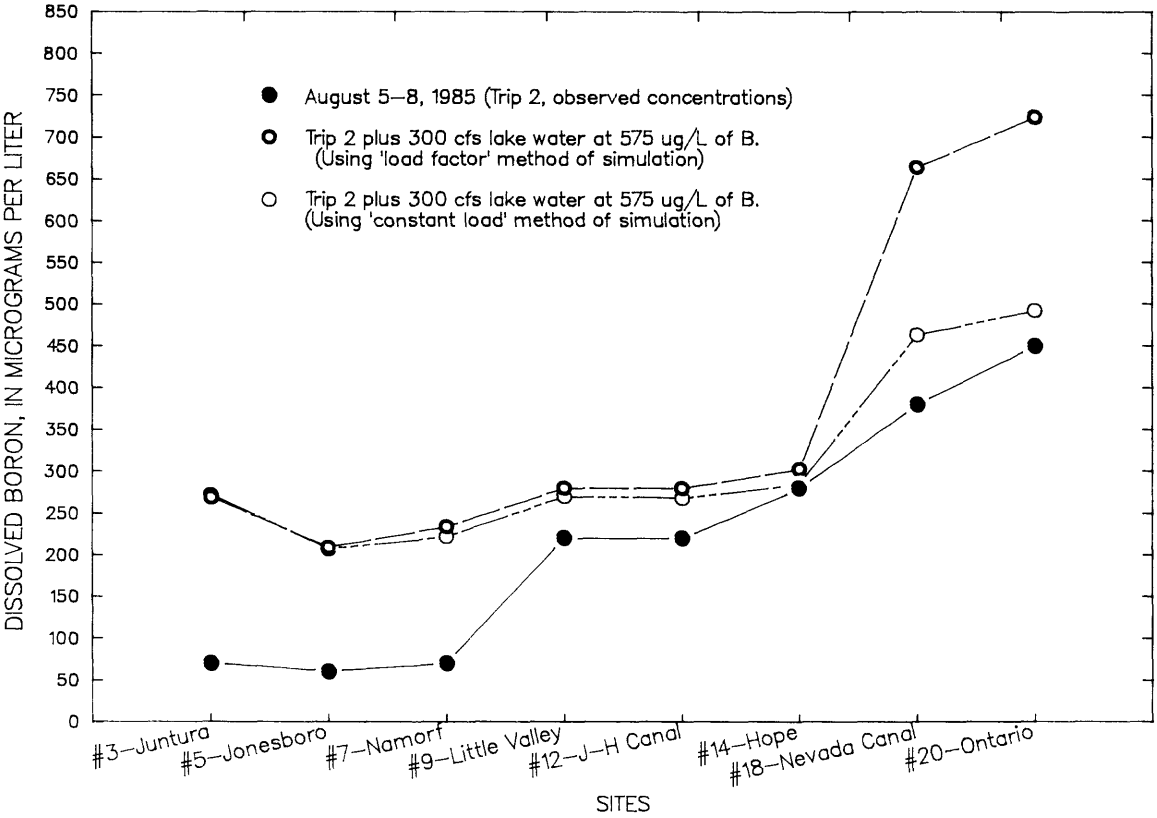


FIGURE 27.--Comparison of measured dissolved boron concentrations during August with simulated concentrations using 300 cfs of Malheur Lake water mixed with Malheur River water.

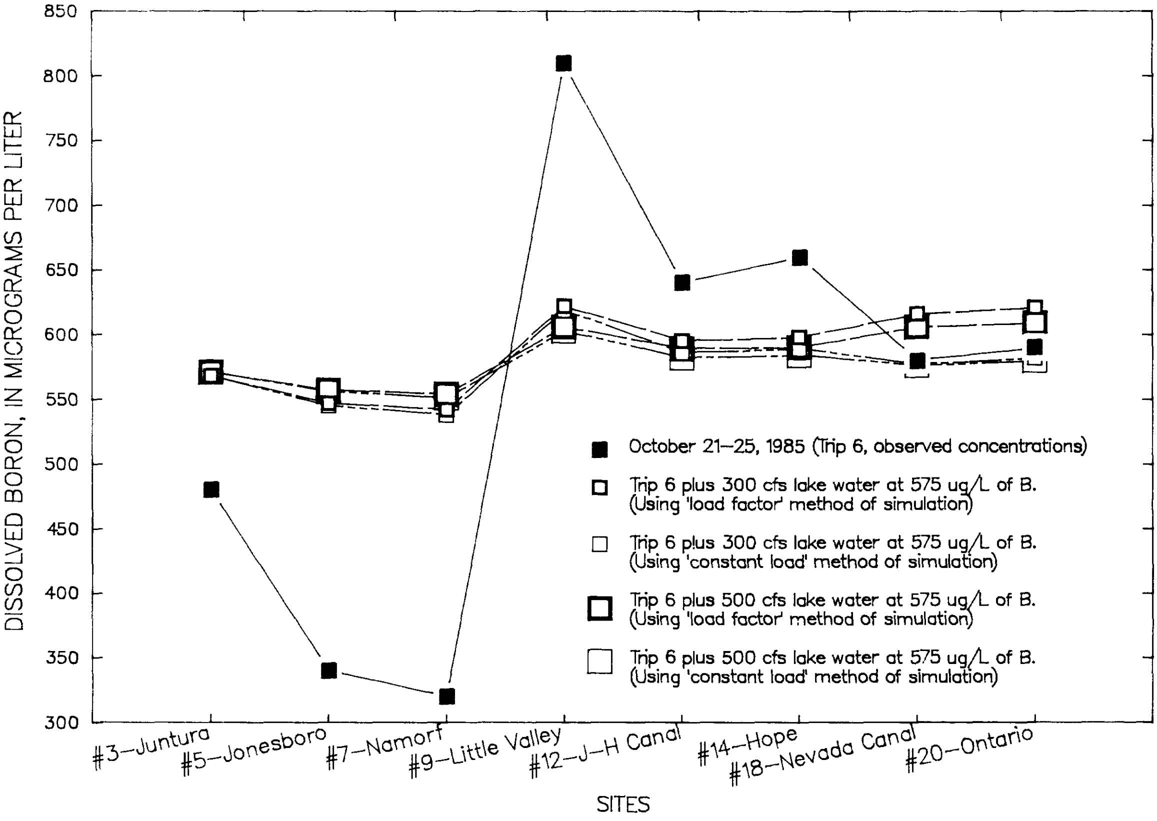


FIGURE 28.--Comparison of measured dissolved boron concentrations during October with simulated concentrations using 300 and 500 cfs of Malheur Lake water mixed with Malheur River water.

Sensitivity of Simulation Method

The sensitivity of the basin to other operational alternatives is tested in two ways: (1) substituting an equivalent amount of water from Malheur Lake for water from Warm Springs Reservoir, and (2) increasing the simulated value of specific conductance in Malheur Lake water by 50 percent (fig. 29). The simulation of substitution of 300 ft^3/s of Malheur Lake water for 300 ft^3/s of water from Warm Springs Reservoir was done to test an alternative water source if Warm Springs Reservoir had insufficient storage. A simulation of 300 ft^3/s of Malheur Lake water with a specific conductance value of 1,170 μS/cm (150 percent of the 1985 median value in Malheur Lake) was used because of the 28 percent increase in specific conductance observed between 1984 and 1985, and the potential for continued increase in chemical concentrations as a result of evaporation of lake water. Both simulations showed higher concentrations in Malheur River than were observed or were simulated by adding 300 ft^3/s of Malheur Lake water at 778 μS/cm. Of the two simulations tested, the worst case (highest values) would be caused by the substitution of reservoir water for an equivalent amount of lake water during the irrigation season.

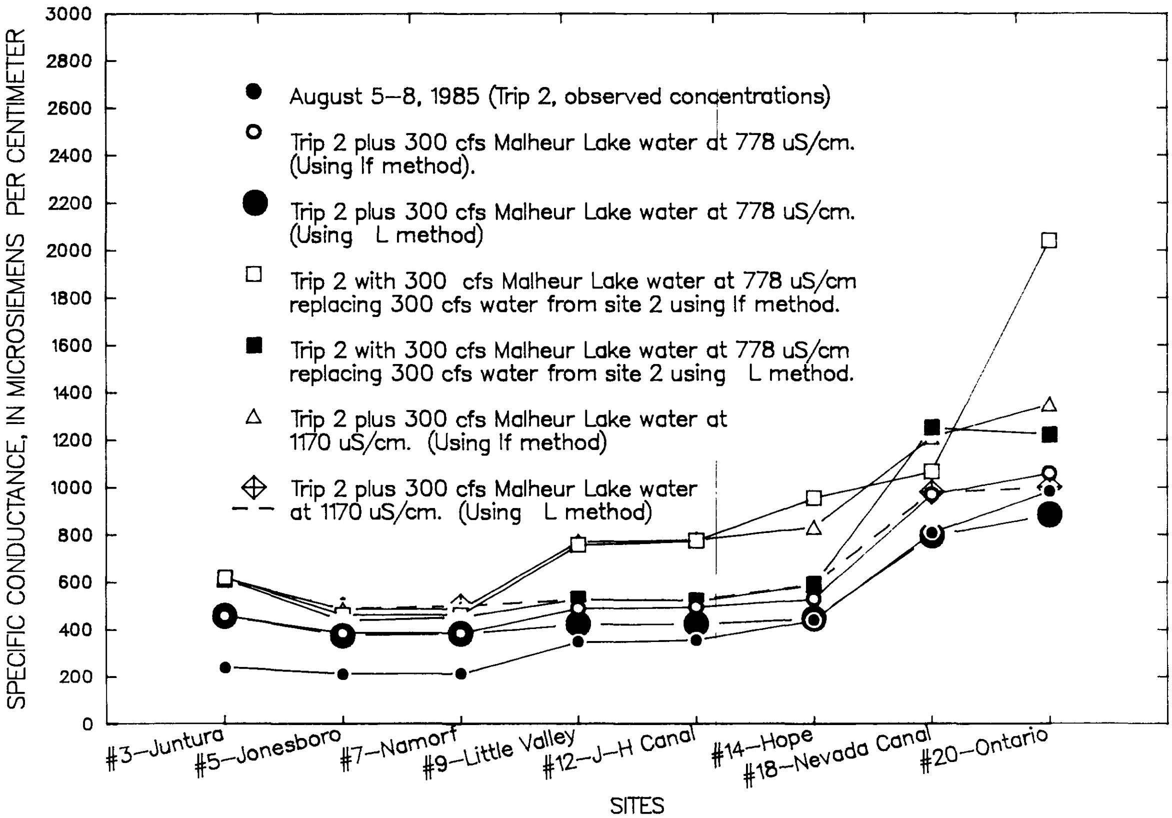


FIGURE 29.--Comparison of measured values of specific conductance during August 1985 with simulated values.

SUMMARY AND CONCLUSIONS

Field visits were made to Harney, Mud, and Malheur Lakes in September 1984 and July 1985 in order to characterize the water quality and to determine the change in water quality in the lakes within a 1-year period. Malheur Lake, east of Cole Island Levee, is characterized by large concentrations of nitrates and low transparency. Productivity is highest towards the center of Malheur Lake, which is periodically freshened by inflows from the Donner und Blitzen River. Nitrate, silica, and bicarbonate concentrations were lowest in this part of the Malheur Lake, whereas chlorophyll a and dissolved oxygen concentrations were highest. Productivity on the eastern part of Malheur Lake is largely controlled by wave action, causing an increase in turbidity.

Concentrations of major cations and anions; silica, arsenic and boron; and values of specific conductance in Malheur Lake increased towards Harney Lake, where concentrations of these constituents and water characteristics were highest.

A 50-percent increase in specific conductance was observed throughout Malheur Lake from 1984 to 1985. This increase was related to an increase in the concentrations of sodium and chloride, which probably was caused by the flow of saline water from Harney Lake into Malheur Lake and dissolution of evaporites in flooded areas around Malheur Lake. Arsenic and boron concentrations in Malheur Lake show a small increase between 1984 and 1985. If flows from Silvies River and from Donner und Blitzen River remain at or below normal, evaporation from Malheur Lake will likely cause an increase in the salinity of the lake, with or without the canal. However, because the canal would remove dissolved solids along with the water from Malheur Lake, the increase in salinity in Malheur Lake would be expected to be less with the operation of the canal than without it. Based on the water-quality data available for the lakes, no prediction can be made on how the water quality will change.

Malheur River was visited six times, from July to October 1985, to assess the quality of water in the river near major diversions to irrigation systems. Streamflows were consistently high above Vale-Oregon Canal; the canal diverted 65 to 79 percent of the total flow from the river. Small increases in flow were observed between Namorf and Hope as a result of irrigation return flows; large increases in flow below Hope included flow from Bully and Willow Creeks. When flows from irrigation reservoirs are curtailed and irrigation ceases, flows in the Malheur River are considerably lower and relatively uniform down to Hope. Return flows below Hope continue to augment the river flows down to its mouth, bringing more mineralized waters into Malheur River.

Concentrations of calcium, magnesium, sodium, chloride, and values of specific conductance and sodium adsorption ratios increase downstream; the increase is more noticeable at the end of irrigation season. During the irrigation season, these constituents and water characteristics in the Malheur River increase slightly between Juntura and Namorf, moderately between Namorf and Hope, and rapidly from Hope to the mouth.

Similar trends in concentrations of arsenic and boron between July and September were observed, but with a more rapid increase between Namorf and Little Valley towards the end of irrigation season. Probable sources of arsenic and boron include thermal springs in the area and ground-water seepage that results from current irrigation practices. The seasonal rise of water tables as a result of irrigation may cause the water to come in contact with a soil zone rich in arsenic. This phenomenon may explain the increase of arsenic in the river.

A simulation method was developed to estimate the water quality that results from routing Malheur Lake water into the Malheur River. Two major processes, evapotranspiration and soil and rock dissolution, aided by two methods of transport, surface-water return flows and ground-water seepage, are thought to cause the measured increase in concentrations of major ions in a downstream direction. In the simulations, the Malheur River is divided into eight river reaches. Loading-factor coefficients and constant-load values were calculated for calcium, magnesium, sodium, chloride, arsenic, boron, and specific conductance. Mass-balance equations were then used to predict concentrations for each reach.

The simulations show increased concentrations of calcium, magnesium, sodium, chloride, and values of specific conductance from Juntura to the mouth of Malheur River during the irrigation season. The largest increases occur between Juntura and Namorf, with less increase towards the mouth. When post-irrigation flows are included in the mixture of lake and river water, the more mineralized water from Malheur Lake tends to mask the mineralization naturally occurring in the river and makes the water quality more uniform. This more uniform quality is the result of much smaller natural flows than simulated Malheur Lake flows.

In general, the "loading factor" equations yield higher concentrations than do "constant load" equations. The "loading factor" equations best represent the evapotranspiration process and the "constant load" equations best represent the soil and rock-dissolution process or constant-flowing spring of uniform quality. Because all of these processes are likely to be occurring, it would seem probable that the correct simulation would fall somewhere between the two predicted values.

When 300 ft^3/s of lake water (August) mix with river water, arsenic concentrations tend to decrease below measured instream levels downstream to Hope and to increase downstream from Hope to the mouth. Boron concentrations are greater above Namorf, continue to be slightly higher downstream to Hope, and increase downstream to the mouth. The difference between simulated and measured concentrations of boron in the Malheur River are much greater than the differences in simulated and measured concentrations of arsenic. This results from the difference in boron concentration between Malheur Lake and Malheur River, which is much greater than the difference in arsenic concentration measured in Malheur Lake and Malheur River.

Simulating a curtailed flow from Warm Springs Reservoir and replacing it with an equivalent amount of Malheur Lake water shows river water with larger specific conductance values than would be the case if lake water were actually 50 percent more concentrated and Malheur Lake flows were maintained constant at 300 ft^3/s. Water quality in either condition continues to be most impaired below Hope.

Water quality in Malheur Lake needs to be assessed again prior to routing the lake water into Malheur River basin. The quality of water in Malheur Lake probably will determine the allowable discharge into the Malheur River before irrigation water quality is impaired.

DEFINITION OF TERMS

Acre-foot (acre-ft) - The quantity of water required to cover 1 acre to a depth of 1 foot and equal to 325,900 gallons (1,233.5 cubic meters).

Anions - Ions in solution that are negative in charge, such as chloride, sulfate, bicarbonate, and fluoride.

Cations - Ions in solution that are positive in charge, such as calcium, magnesium, sodium, and potassium.

Dissolved - The term pertains to the amount of a substance that will pass through a 0.45-micrometer membrane filter and thus may include some very small colloidal particles.

Milligrams per liter (mg/L) and micrograms per liter (µg/L) - Units for expressing the concentration of chemical constituents in solution as the the weight of solute per unit volume of water. Concentration of suspended sediment is expressed in milligrams per liter and is based on the weight of sediment per liter of water-sediment mixture.

Nephelometric turbidity unit (NTU) - Refers to the amount of light scattered at 90 degrees when a turbidimeter is calibrated with formazin.

Pounds per day - A unit of measurement for the quantity of a substance, in solution or suspension, that passes a stream section during a 24-hr period.

National geodetic vertical datam of 1929 (NGVD of 1929) - A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

Suspended-sediment concentration - The velocity-weighted concentration of suspended sediment in the sampled zone (from the water surface to a point approximately 0.3 feet above the bed), expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/L).

Sodium adsorption ratio - An expression of the relative activity of sodium ions in exchange reactions with soil and an index of sodium or alkali hazard to the soil. Waters range in sodium hazard from those that can be used for irrigation on almost all soils and crops to those that are generally unsatisfactory for irrigation. The ratio is expressed in units.

Specific conductance - A measure of the ability of water to conduct an electric current, expressed in microsiemens per centimeter at 25 degrees Celsius. Because the specific conductance is related to the number and specific chemical types of ions in solution, it can be used for approximating the dissolved-solids contents of the water.

Total - The total amount of a given constituent (dissolved plus suspended) in a water-suspended sediment sample, regardless of its physical or chemical form.

Total recoverable - The amount of a given constituent that is in solution after a water-suspended sediment sample or bottom-material sample has been digested by a method (usually with an acid or mixture of acids) that results in the dissolution of readily soluble substances.

Water table - That surface in an unconfined ground-water body at which the pressure is atmospheric.

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page 57 follows

SUPPLEMENTAL DATA

Table 12.--Comparison of replicate samples in Harney, Mud, and Malheur Lakes, September 1984 and July 1985

[Boron replicates analyzed in 1985 by U.S. Geological Survey, Central Laboratory, Arvada, Colorado. Field measurements of pH, specific conductance, and total alkalinity done by U.S. Geological Survey personnel. All other samples analyzed by Oregon Department of Environmental Quality. Abbreviations are as follows: HL = Harney Lake, ML = Malheur Lake, S = sample, R = Replicate, #40 = reference distilled-deionized water or analytical blank]

	1984 Harney Lake		1984 Malheur Lake										
	HL6		ML13		ML16		ML17		ML22		ML26		Reference
Constituent/Characteristic	S	R	S	R	S	R	S	R	S	R	S	R	#40
pH (units)	--	--	8.7	8.7	--	--	8.5	8.3	8.5	8.5	8.3	8.3	--
Specific conductance (μS/cm @ 25°C)	--	--	550	550	--	--	510	510	600	600	570	570	--
Suspended solids (mg/L)	--	--	14	12	--	--	13	11	14	14	17	14	--
Dissolved solids (mg/L)	--	--	395	390	--	--	354	352	437	451	473	475	--
Turbidity (NTU)	--	--	23	24	--	--	23	22	44	52	85	85	--
Calcium (dissolved, mg/L)	--	--	31	30	--	--	28	29	31	31	29	28	0.7
Magnesium (dissolved, mg/L)	--	--	15	15	--	--	15	14	16	16	15	15	<0.1
Sodium (dissolved, mg/L)	--	--	82	88	--	--	66	73	91	89	90	91	<0.1
Potassium (dissolved, mg/L)	--	--	14.4	14.4	--	--	12.3	12.6	17.3	17.1	15.9	16.1	<0.1
Chloride (dissolved, mg/L)	--	--	14	14	--	--	12	12	14	14	13	15	0.5
Fluoride (dissolved, mg/L)	--	--	0.4	0.4	--	--	0.4	0.4	0.4	0.4	0.4	0.4	<0.4
Silica (dissolved, mg/L)	--	--	<0.5	0.7	--	--	0.8	0.8	4.9	6.3	10.5	9.7	<0.5
Sulfate (dissolved, mg/L)	--	--	18	18	--	--	17	17	20	20	19	19	0.2
Total alkalinity (mg/L, as $CaCO_3$)	--	--	266	266	--	--	242	239	286	286	278	278	--
Boron (total, mg/L)	--	--	0.6	0.6	--	--	0.5	0.3	0.7	0.7	0.7	0.7	--
Sodium adsorption ratio (units)	--	--	3.0	3.3	--	--	2.5	2.8	3.3	3.2	3.4	3.4	--
Ammonia (dissolved, mg/L)	--	--	0.02	0.03	--	--	0.05	0.04	0.05	<0.02	0.05	0.05	<0.02
Ammonia (total, mg/L)	--	--	<0.02	<0.02	--	--	0.03	0.03	0.04	0.03	0.04	0.09	<0.02
Organic nitrogen plus ammonia as N (total, mg/L)	--	--	1.8	1.7	--	--	1.7	1.6	1.7	2.0	2.0	1.9	<0.02
Phosphate as P (total, mg/L)	--	--	0.146	0.155	--	--	0.146	0.153	0.180	0.186	0.128	0.118	0.016
Orthophosphate as P (mg/L)	--	--	0.009	0.010	--	--	0.009	0.006	0.008	0.012	0.075	0.078	0.002
Chlorophyll a (mg/L)	3.9	3.0	35.4	28.7	68.7	65.9	39.1	54.9	16.2	16.8	12.1	9.0	--
Pheophytin (mg/L)	1.24	1.45	2.50	5.14	<0.01	1.90	0.8	<0.01	3.72	4.72	3.41	3.22	--

	1985 Malheur Lake	
	ML10	
Constituent/Characteristic	S	R
Calcium (dissolved, mg/L)	33	33
Magnesium (dissolved, mg/L)	19	19
Sodium (dissolved, mg/L)	110	130
Chloride (dissolved, mg/L)	31	31
Specific conductance (μs/cm @ 25°C)	750	760
Arsenic (total recoverable, μg/L)	12	12
Boron (dissolved, mg/L)	510	520

Table 13.--Quality-assurance results for samples collected in Harney, Mud, and Malheur Lakes: comparison of blind standards and measured values, September 1984

[Concentrations in micrograms per liter (µg/L) or milligrams per liter (mg/L) as indicated]

Constituent (mg/L)	Major ions and nutrients DEQ Laboratory		Constituent (µg/L)	Total-recoverable trace elements USGS Central Laboratory	
	Standard	Lab value		Standard	Lab value
Potassium (dissolved)	4.62	4.6	Aluminum	9.0	<10
Sodium (dissolved)	77.2	85	Arsenic	2.4	1
Calcium (dissolved)	71.5	67	Barium	62	<100
Magnesium (dissolved)	28.3	25	Cadmium	0.7	<1
Chloride (dissolved)	44.4	47	Cobalt	3.8	<1
Fluoride (dissolved)	1.99	1.9	Copper	8.4	6
Silica (dissolved)	13.3	13.4	Iron	4.5	<7
Sulfate (dissolved)	219.7	230	Mercury	0.3	0.8
Ammonia as N (dissolved)	1.52	1.5	Mercury	1.99	0.8
Orthophosphate (dissolved)	0.27	0.49	Molybdenum	7.0	5
Organic nitrogen plus ammonia as N (total)	4.88	4.8	Nickle	4.3	4
Phosphate as P (dissolved)	1.06	1.02	Lead	4.3	<1
			Selenium	2.0	2
			Zinc	10	10

Table 14.--Field measurements of total alkalinity, carbonate and bicarbonate; fecal coliform and fecal streptococcal bacteria concentrations; and Secchi disk readings in Harney, Mud, and Malheur Lakes, and major inflows, September 1984

[Abbreviations are as follows: HL = Harney Lake, MD = Mud Lake, ML = Malheur Lake, DUBR = Donner und Blitzen River, WFSR = West Fork Silvies River, EFSR = East Fork Silvies River, SHSP = Sodhouse Spring, B = postcript indicates that count is based on non-ideal colony count]

		Concentration in mg/L			Number colonies per 100 mL		
Station number	Time day/hour	Total alkalinity as $CaCO_3$	Total carbonate as CO_3	Total bicarbonate as HCO_3	Fecal coli-form	Fecal strep-tococci	Secchi disk (meters)
HARNEY LAKE							
HL5	15/1025	--	--	--	--	--	0.25
HL6	15/1100	720	81	710	--	60 B	.28
HL7	15/1115	--	--	--	--	--	.25
HL8	15/1130	--	--	--	--	--	.25
HL9	15/1150	--	--	--	--	--	.25
HL10	15/1220	--	--	--	--	--	.25
HL11	15/1240	--	--	--	--	--	.28
HL12	15/1335	--	--	--	--	--	.33
HL13	15/1410	710	65	730	--	<1 B	.33
HL14	15/1430	--	--	--	--	--	.30
HL15	15/1500	--	--	--	--	--	.27
HL16	15/1515	720	85	700	--	<1 B	.30
MUD LAKE							
MD1	14/1045	640	24	710	--	--	.20
MD2	14/1445	--	--	--	--	--	.25
MD3	14/1510	--	--	--	--	--	.25
MALHEUR LAKE							
ML5	16/0945	360	18	410	450 B	69 B	.43
ML6	16/1100	330	12	370	--	--	.43
ML7	16/1145	360	18	400	--	--	.24
ML8	16/1300	350	26	370	--	--	.24
ML9	16/1235	300	12	340	--	--	.37
ML10	16/1210	300	10	350	--	--	.49
ML11	17/1100	--	--	--	--	--	.34
ML12	17/1115	310	16	350	--	--	.21
ML13	17/1145	280	14	320	550	31 B	.34
ML14	17/1200	280	10	320	--	--	.37
ML15	17/0945	270	10	310	--	--	.34

Table 14.--Field measurements of total alkalinity, carbonate and bicarbonate; fecal coliform and fecal streptococcal bacteria concentrations; and Secchi disk readings in Harney, Mud, and Malheur Lakes, and major inflows, September 1984--Continued

		Concentration in mg/L			Number colonies per 100 mL		
Station number	Time day/hour	Total alkalinity as $CaCO_3$	Total carbonate as CO_3	Total bicarbonate as HCO_3	Fecal coliform	Fecal streptococci	Secchi disk (meters)
				MALHEUR LAKE			
ML16	17/1515	270	12	300	--	--	0.34
ML17	17/1500	260	10	300	23 B	110 B	.30
ML18	17/1430	280	12	330	--	--	.24
ML19	17/1410	300	14	340	--	--	.40
ML20	17/1345	--	--	--	--	--	.37
ML21	18/1250	--	--	--	--	--	.52
ML22	18/1230	330	6	370	43 B	100	.34
ML23	18/1100	300	--	370	--	--	.12
ML24	18/1030	260	--	320	--	--	.25
ML25	18/1000	260	14	310	--	--	.15
ML26	18/1400	310	--	370	9 B	17 B	.15
ML26A	18/1430	--	--	--	--	--	.18
ML27	18/1340	330	--	400	37 B	13 B	.15
ML28	18/1315	320	6	380	--	--	.24
ML29	19/1210	330	6	390	--	--	.12
ML30	19/1240	330	--	400	<1 B	180	.12
ML31	19/1255	310	--	380	--	--	.12
ML32	19/1115	320	--	390	--	--	.09
ML33	19/1145	330	--	400	--	--	.09
				MAJOR INFLOWS			
DUBR	15/1054	68	--	83	450	420	--
WFSR	14/1045	110	--	130	370	1100	--
EFSR	14/0800	139	--	170	800	1300	--
SHSP	17/0945	182	--	220	--	--	--

Table 15.--Concentrations of nutrients, chlorophyll a, and pheophytin in Harney, Mud, and Malheur Lakes, and major inflows, September 1984

[Abbreviations are as follows: HL = Harney Lake, MD = Mud Lake, ML = Malheur Lake, DUBR = Donner und Blitzen River, EFSR = East Fork Silvies River, WFSR = West Fork Silvies River, SHSP = Sodhouse Spring. Samples collected by U.S. Geological Survey and analyses performed by Oregon Department of Environmental Quality. Concentrations in milligrams per liter]

Station number	Time day/hour	Dissolved ammonia as N	Total ammonia as N	Total nitrate plus nitrite (as N)	Total organic nitrogen plus ammonia (as N)	Total phosphorus (as P)	Dissolved orthophosphate (as P)	Chlorophyll a	Pheophytin
					HARNEY LAKE				
HL6	15/1100	0.05	0.04	0.11	1.5	0.75	0.66	3.9	1.2
HL13	15/1410	.04	.02	.11	1.5	.80	.68	4.7	1.4
HL16	15/1515	.04	.03	.14	1.6	.78	.70	2.6	1.2
					MUD LAKE				
MD1	14/1045	.15	.20	.05	2.1	.31	.073	5.8	1.9
					MALHEUR LAKE				
ML5	16/0945	.03	<.02	<.02	2.2	.19	.03	23	13
ML6	16/1100	.03	<.02	<.02	1.8	.15	.01	31	5.1
ML7	16/1145	.02	<.02	<.02	2.3	.26	.01	29	4.2
ML8	16/1300	.02	<.02	<.02	2.2	.25	.02	35	5.1
ML9	16/1235	.02	<.02	<.02	2.0	.18	.01	33	3.4
ML10	16/1210	<.02	<.02	<.02	1.9	.15	.01	31	3.0
ML12	17/1115	.03	<.02	<.02	2.0	.20	.01	34	6.0
ML13	17/1145	.02	<.02	.02	1.8	.15	.01	35	2.5
ML14	17/1200	<.02	.03	.02	1.7	.13	.01	27	8.6
ML15	17/0945	<.02	<.02	<.02	1.8	.16	.01	69	<.01
ML16	17/1515	.02	<.02	.02	2.0	.18	.01	69	<.01
ML17	17/1500	.05	.03	.11	1.7	.15	.01	39	.80
ML18	17/1430	.04	.02	.09	1.6	.18	.01	32	<.01
ML19	17/1410	.03	.03	.05	1.6	.16	.01	25	6.3
ML22	18/1230	0.05	0.04	0.16	1.7	0.18	0.01	16	3.7
ML23	18/1100	.04	.04	.43	1.9	.22	.03	18	2.1
ML24	18/1030	.13	.08	.21	1.9	.20	.01	33	12
ML25	18/1000	.09	.06	.07	2.6	.26	.01	82	25
ML26	18/1400	.05	.04	.61	2.0	.13	.08	12	3.4
ML27	18/1340	.06	.05	.50	2.1	.14	.07	10	4
ML28	18/1315	.03	.04	.10	1.9	.23	.12	19	6.5
ML29	19/1210	.06	.03	.13	2.0	.14	.03	32	7.4
ML30	19/1240	.09	.03	.80	2.4	.19	.11	6.0	3.0
ML31	19/1255	.05	.03	.76	2.1	.11	.08	5.6	5.6
ML32	19/1115	.07	.04	.90	2.5	.16	.03	8.2	4.1
ML33	19/1145	.04	.04	.46	2.4	.33	.04	9.0	2.2
					MAJOR INFLOWS				
DUBR	15/1054	<.02	<.02	.08	.4	.10	.03	---	---
WFSR	14/1045	<.02	.09	<.02	.5	.18	.04	---	---
EFSR	14/0800	<.02	.27	<.02	.8	.20	.03	---	---
SHSP	17/0945	<.04	<.02	1.5	.2	.17	.17	---	---

Table 16.--Concentrations of major cations and anions, turbidity, suspended and dissolved solids, hardness and sodium adsorption ratios in Harney, Mud, and Malheur Lakes, and major inflows, September 1984

[Abbreviations are as follows: HL = Harney Lake, MD = Mud Lake, ML = Malheur Lake, DUBR = Donner und Blitzen River, EFSR = East Fork Silvies River, WFSR = West Fork Silvies River, SHSP = Sodhouse Spring. Concentration in milligrams per liter. Nephelometric turbidity units abbreviated as NTU. Samples collected by U.S. Geological Survey personnel and analyses performed by Oregon State Department of Environmental Quality]

Station number	Time day/hour	Dissolved				Total	Hardness (as $CaCO_3$)	Sodium adsorption ratio (units)	Dissolved				Dissolved solids	Turbidity (NTU)	Suspended solids
		Ca	Mg	Na	K	B			SO_4	Cl	F	SiO_2			
							HARNEY LAKE								
HL6	15/1100	16	11	640	40	3.6	85	30	150	470	1.1	36	1951	33	9
HL13	15/1410	15	9.1	640	43	6.7	75	32	130	560	1.1	38	1965	29	4
HL16	15/1515	15	9.6	660	41	4.6	77	33	140	530	1.1	37	1980	31	27
							MUD LAKE								
MD1	14/1045	29	17	230	26	1.1	140	8.4	46	130	.6	6.3	841	41	21
							MALHEUR LAKE								
ML5	16/0945	31	18	120	22	.9	150	4.2	19	39	.4	12	520	17	16
ML6	16/1100	32	17	93	17	.7	150	3.3	19	17	.4	2.2	446	16	19
ML7	16/1145	30	19	110	20	.8	150	3.9	17	17	.4	11	484	32	46
ML8	16/1300	29	17	95	20	.8	140	2.9	19	16	.4	12	466	32	29
ML9	16/1235	31	12	83	16	1.2	130	3.2	18	10	.4	1.8	409	23	19
ML10	16/1210	32	16	81	15	.6	150	2.8	18	13	.4	1.2	404	13	15
ML12	17/1115	31	16	89	17	.7	140	3.2	20	14	.4	1.5	436	28	22
ML13	17/1145	31	15	82	14	.6	140	3.0	18	14	.4	<.5	395	23	14
ML14	17/1200	30	15	83	14	.6	140	3.1	17	16	.4	.5	373	13	63
ML15	17/0945	30	14	86	13	.6	130	3.2	18	17	.4	.6	365	18	27
ML16	17/1515	29	14	75	13	.5	130	2.9	17	10	.4	1.1	366	20	21
ML17	17/1500	28	15	66	12	.5	130	2.5	17	12	.4	.8	354	23	13
ML18	17/1430	30	15	80	15	.6	140	3.0	19	8.9	.4	1.1	413	35	11
ML19	17/1410	31	9.5	81	16	.6	120	3.3	19	11	.4	1.3	435	29	13
ML22	18/1230	31	16	91	17	0.7	140	3.3	20	14	0.4	4.9	437	44	14
ML23	18/1100	29	15	83	16	.7	130	3.1	20	14	.4	7.8	462	64	10
ML24	18/1030	28	14	79	13	.6	130	3.0	17	10	.4	1.4	382	41	15
ML25	18/1000	27	14	81	13	.6	130	3.2	17	15	.4	.6	356	33	25
ML26	18/1400	29	15	90	16	.7	130	3.4	19	13	.4	10	473	85	17
ML27	18/1340	29	16	97	18	.7	140	3.6	21	15	.4	.9	512	84	13
ML28	18/1315	36	20	94	17	.7	170	3.1	25	13	.4	7.8	449	47	21
ML29	19/1210	33	16	92	19	.7	150	3.3	18	15	.3	6.4	458	65	32
ML30	19/1240	27	16	97	19	.7	130	3.7	21	13	.4	15	530	105	12
ML31	19/1255	27	15	93	18	.8	130	3.6	21	15	.4	13	513	92	10
ML32	19/1115	25	14	100	18	.8	120	4.0	22	17	.4	14	533	110	13
ML33	19/1145	29	16	98	20	.8	140	3.6	21	16	.4	14	497	78	14
							MAJOR INFLOWS								
DUBR	15/1054	12	4.6	7.3	1.6	.3	49	.45	2.8	1.7	.1	28	102	9	20
WFSR	14/1045	24	5.9	12	3.3	.3	84	.59	9.3	3.3	.2	39	182	23	50
EFSR	14/0800	33	8.6	20	3.5	.2	120	.81	34	4.7	.1	34	249	32	39
SHSP	17/0945	27	15	40	6.5	.6	130	1.8	24	15	.4	40	274	<1	1

Table 17.--Concentrations of trace elements at selected sites in Harney and Malheur Lakes and Sodhouse Spring, September 1984

[All analyses are total recoverable with the exception of bromide, iodide, and vanadium, which are dissolved. Analyses from U.S. Geological Survey, Central Laboratory, Arvada, Colorado. Concentrations in micrograms per liter]

Station number	Time day/hour	Al	As	B	Ba	Be	Br	Cd	Co	Cr	Cu	Fe	Hg	I	Mo	Ni	Pb	Sb	Se	V	Zn
HARNEY LAKE																					
HL6	15/1100	60	120	6200	<100	10	<10	1	<1	<1	3	140	<0.01	240	24	<1	<5	2	<1	24	<10
HL13	15/1410	30	120	6200	<100	10	180	<1	<1	<1	5	140	<0.01	72	26	2	<5	2	<1	27	<10
HL16	15/1515	50	120	6300	<100	20	150	<1	<1	<1	9	100	<0.01	97	28	2	<5	2	<1	27	<10
MALHEUR LAKE																					
ML5	16/0945	140	9	810	35	<1	41	<1	1	<1	21	140	<0.01	21	<1	6	9	<1	<1	5.4	10
ML17	17/1500	210	4	470	25	1	29	<1	<1	<1	2	270	<0.01	11	1	2	<5	<1	<1	7.9	10
ML25	18/1000	150	4	500	16	<1	29	<1	1	<1	3	97	<0.01	13	<1	4	<5	<1	<1	7.5	10
ML30	19/1240	100	9	730	23	<1	17	<1	<1	<1	5	110	<0.01	17	2	6	<5	<1	<1	8.0	9
ML31	19/1255	410	9	680	27	<1	29	<1	2	<1	4	230	<0.01	16	<1	4	<5	<1	<1	8.8	15
SODHOUSE SPRING																					
SHSP	17/0945	<10	5	210	7	1	49	<1	<1	<1	2	<3	<0.01	7	1	1	<5	<1	<1	19	7

Table 18.--Concentrations of dissolved calcium, magnesium, sodium, and chloride; total arsenic and boron; and sodium adsorption ratios, in Harney, Mud, and Malheur Lakes, July 1985

[Samples collected by U.S. Geological Survey personnel and analyses performed by Oregon State Department of Environmental Quality except arsenic and boron which were analyzed by USGS Central Laboratory, Arvada, Colorado. Abbreviations are as follows: HL = Harney Lake, MD = Mud Lake, ML = Malheur Lake]

Station number	Time day/hour	Dissolved (milligrams per liter) Ca	Mg	Na	Cl	Total arsenic (µg/L)	Total boron (µg/L)	Sodium adsorption ratio (units)
HARNEY LAKE								
HL13	19/1555	16	9.8	680	510	140	4,000	33.0
MUD LAKE								
MD1	20/1000	29	17	300	220	63	1,800	10.9
MD2	20/1115	26	16	290	230	81	2,100	11.0
MD3	20/1135	28	17	320	230	70	1,800	11.8
MALHEUR LAKE								
ML5B	18/1345	30	19	160	52	22	800	5.6
ML6	18/1245	31	20	130	50	18	610	4.5
ML7A	18/1320	29	19	140	58	17	700	5.0
ML8	18/1140	29	20	120	31	11	540	4.2
ML10	18/1216	33	19	110	31	12	510	3.8
ML27	18/1532	32	19	110	29	12	510	3.8

Table 19.--Comparison of replicate samples for dissolved calcium, magnesium, sodium, and chloride; total arsenic and boron; and specific conductance in the Malheur River basin, July-October, 1985

[Ratio represents sample:replicate]

	Trip					
	1	2	3	4	5	6
Constituent/Characteristic	Jul 22-25	Aug 5-9	Aug 19-23	Sept 9-13	Sept 23-26	Oct 21-25
Calcium (mg/L)	50:50	18:17	19:18	18:19	12:13	28:28
Magnesium (mg/L)	18:16	6.7:6.2	7.5:7.0	6.9:7.0	4.4:4.6	11:12
Sodium (mg/L)	130:120	20:19	19:19	21:23	8.4:11	52:55
Chloride (mg/L)	24:20	6.1:6.2	4.9:5.1	5.3:5.8	2.2:1.6	19:19
Specific conductance (μS/cm at 25°C)	960:920	230:230	230:230	240:240	140:142	470:470
Arsenic (μg/L)	35:35	3:3	4:3	3:3	2:2	14:11
Boron (μg/L)	210:210	70:70	70:70	60:60	50:50	340:340

Table 20.--Quality-assurance results for samples collected in Malheur River basin: comparison of blind standards and measured values, August-October, 1985

[Error = ((standard - measured)/standard) x 100, in percent]

	Trip 2 Aug 5-9			Trip 3 Aug 19-23			Trip 4 Sept 9-13			Trip 5 Sept 23-26			Trip 6 Oct 21-25		
Constituent	Blind standard (mg/L)	Measured value (mg/L)	Error (pct)	Blind standard (mg/L)	Measured value (mg/L)	Error (pct)	Blind standard (mg/L)	Measured value (mg/L)	Error (pct)	Blind standard (mg/L)	Measured value (mg/L)	Error (pct)	Blind standard (mg/L)	Measured value (mg/L)	Error (pct)
Calcium	70.6	72	2	143.5	130	9	25.3	23	9	70.6	65	8	25.3	23	9
Magnesium	28	25	11	53.6	48	10	10.4	8.9	14	28	25	11	10.4	10	4
Sodium	77	71	8	118.5	112	5	5.9	5.3	10	77	75	3	5.9	5.5	7
Chloride	44.8	47	5	37.5	41	9	4.2	4.2	0	44.8	47	5	4.2	5.3	26
Specific conductance1/	859	880	2	1,399	1,410	1	293	290	1	859	860	0	293	290	1
Boron	---	---	--	184	180	2	133	120	10	184	180	2	240	210	12

1/ Specific conductance is measured in microsiemens per centimeter at 25°C.

Table 21.--Quality-assurance results: comparison of blind standards and measured values of total-recoverable trace element August and October, 1985

[Concentration in micrograms per liter; error is calculated as [(standard - measured)/standard] x 100, in percent]

	Trip 3 August 23			Trip 6 October 25		
Element	Standard	Measured	Error	Standard	Measured	Error
Alumimum	79	100	+27	496	500	+1
Arsenic	26	26	0	109	110	+1
Manganese	26	30	+15	45	50	+11
Cadmium	5.2	6	+15	23	21	-9
Chromium	16	26	+63	154	150	-3
Copper	16	17	+6	72	75	+4
Nickel	26	29	+12	45	44	-2
Selenium	5.2	7	+35	26	31	+19
Zinc	11	30	+173	30	60	+100

Table 22.--Instantaneous discharge measurements in Malheur River basin, July-October 1985

[Discharge is in units of ft3/s]

	Trip						
	1	2	3	4	5	6	
Site	Jul 22-25	Aug 5-8	Aug 19-23	Sept 9-13	Sept 23-26	Oct 21-25	Remarks
1	5.3	11	4.4	14	13	22	Inflow
2	576	443	511	344	193	0.18	Main stem
3	561	451	471	341	190	25	Main stem
4	252	291	252	85	25	0.30	Inflow
5	801	750	805	421	222	44	Main stem
6	585	490	549	292	175	0.00	Outflow
7	223	206	167	154	76	51	Main stem
8	38	38	36	31	12	4.8	Outflow
9	246	224	186	163	96	74	Main stem
10	18	13	13	9.3	2.8	2.0	Outflow
11	32	22	28	2.4	0.47	0.28	Outflow
12	134	118	45	128	61	48	Main stem
13	99	88	101	51	43	28	Outflow
13A	11	6.2	11	6.1	0.50	0.50	Outflow
14	142	130	60	136	71	50	Main stem
15	105	81	61	50	38	34	Outflow
15A	---	---	---	145	74	62	Main stem
16	57	43	48	70	59	26	Inflow
17	100	116	78	170	129	75	Inflow
18	140	251	112	305	180	102	Main stem
19	192	155	145	108	104	78	Outflow
20	285	292	242	613	397	254	Main stem

Table 23.--Concentrations of dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; field measurements of specific conductance; and calculated sodium adsorption ratios (SAR) in the Malheur River basin, July-October 1985

[Analyses were done by Oregon Department of Environmental Quality, except for analyses for arsenic and boron, which were done by the USGS Central Laboratory, Arvada, Colorado]

	Trip					
	1	2	3	4	5	6
Site	Jul 22-25	Aug 5-8	Aug 19-23	Sept 9-13	Sept 23-26	Oct 21-25
Calcium, dissolved, in mg/L						
1	33	35	26	36	31	27
2	17	17	19	18	20	22
3	17	18	19	19	21	29
4	12	12	13	12	12	20
5	16	17	19	19	21	28
7	16	17	19	19	23	27
9	21	24	25	24	27	31
12	21	24	27	25	30	32
14	26	29	35	28	34	36
15A	--	--	--	--	39	47
16	46	53	51	48	51	59
17	51	53	57	49	50	67
18	48	46	52	48	47	58
20	50	52	55	52	53	63
Magnesium, dissolved, in mg/L						
1	14	14	13	13	12	12
2	6.2	6.5	6.9	6.9	7.7	9.1
3	6.3	6.7	6.8	7.0	7.5	11
4	3.9	3.8	4.2	4.3	4.4	9.2
5	5.9	6.5	6.6	7.5	6.2	11
7	5.9	6.7	7.5	7.4	8.0	11
9	7.2	8.4	9.0	8.8	10	12
12	7.6	8.3	9.5	9.1	11	13
14	9.0	9.5	11	10	12	14
15A	--	--	--	--	13	14
16	13	16	15	14	12	18
17	16	18	19	17	18	23
18	15	15	16	15	16	20
20	18	17	20	17	18	23

Table 23.--Concentrations of dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; field measurements of specific conductance, and calculated sodium adsorption ratios (SAR) in the Malheur River basin, July-October 1985--Continued

	Trip					
Site	1 Jul 22-25	2 Aug 5-8	3 Aug 19-23	4 Sept 9-13	5 Sept 23-26	6 Oct 21-25
			Sodium, dissolved, in mg/L			
1	160	114	125	120	110	83
2	17	18	18	21	24	21
3	19	20	20	27	31	70
4	7.3	6.9	7.7	8.2	8.4	11
5	17	16	18	24	30	52
7	18	17	19	25	28	45
9	34	38	44	55	72	92
12	35	39	44	57	76	87
14	51	53	72	68	93	110
15A	--	--	--	--	100	120
16	83	88	91	92	120	130
17	130	133	148	120	140	170
18	110	107	126	110	130	150
20	130	136	162	130	140	180
			Chloride, dissolved, in mg/L			
1	60	55	50	48	39	31
2	4.7	5.2	5.7	5.3	7.4	9.5
3	5.1	6.1	5.7	7.1	8.5	27
4	1.3	1.7	1.6	1.5	2.2	1.1
5	4.6	4.4	4.9	6.2	9.6	19
7	4.0	4.7	4.9	6.4	9.6	17
9	7.2	9.2	9.8	12	17	23
12	6.9	9.1	9.8	12	17	20
14	10	11	14	14	18	21
15A	--	--	--	--	23	26
16	15	16	18	17	19	22
17	20	21	25	19	22	26
18	19	20	23	19	21	27
20	24	26	30	22	30	31

Table 23.--Concentrations of dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; field measurements of specific conductance; and calculated sodium adsorption ratios (SAR) in the Malheur River basin, July-October 1985--Continued

	Trip					
	1	2	3	4	5	6
Site	Jul 22-25	Aug 5-8	Aug 19-23	Sept 9-13	Sept 23-26	Oct 21-25
			Boron, dissolved, in µg/L			
1	780	930	1100	930	820	610
2	40	50	60	60	70	70
3	50	70	70	100	120	480
4	40	40	40	50	50	50
5	50	60	70	90	110	340
7	50	70	70	100	130	320
9	110	220	290	350	500	810
12	110	220	270	340	480	640
14	150	280	380	380	510	660
16	160	350	360	360	410	540
17	210	350	400	310	340	480
18	230	380	460	360	420	580
20	270	450	520	400	450	590
			Arsenic, total, in µg/L			
1	40	39	38	38	33	23
2	2	2	3	3	3	3
3	3	3	3	5	6	18
4	1	1	3	2	2	3
5	3	3	4	5	6	14
7	3	3	4	5	7	14
9	17	20	29	34	53	85
12	18	20	25	32	53	71
14	20	30	21	32	50	66
16	17	21	24	25	33	44
17	35	45	35	33	35	52
18	32	40	42	34	41	58
20	35	35	35	36	43	54

Table 23.--Concentrations of dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; field measurements of specific conductance; and calculated sodium adsorption ratios (SAR) in the Malheur River basin, July-October 1985--Continued

	Trip					
	1	2	3	4	5	6
Site	Jul 22-25	Aug 5-8	Aug 19-23	Sept 9-13	Sept 23-26	Oct 21-25
Specific conductance, in microsiemens/cm @ 25 degrees C						
1	958	799	840	778	694	560
2	216	218	245	251	266	314
3	229	239	243	276	298	532
4	135	129	142	145	146	228
5	216	211	235	264	293	468
6	---	---	238	---	---	---
7	216	211	239	266	294	428
9	318	347	389	445	515	648
10	---	---	391	---	---	---
11	---	---	400	---	---	---
12	334	356	400	448	529	606
13	---	---	395	---	---	---
14	435	440	600	523	628	698
15	---	---	660	---	---	---
15A	---	---	---	---	674	799
16	696	762	790	724	799	901
17	950	958	1075	854	892	1150
18	808	808	930	766	847	979
19	---	---	930	---	---	---
20	988	983	1110	872	937	1155
Sodium-adsorption ratios, in units						
1	5.9	4.1	5.0	4.4	4.3	3.3
2	0.9	0.9	0.9	1.1	1.2	1.0
3	1.0	1.0	1.0	1.3	1.5	2.8
4	0.5	0.4	0.5	0.5	0.5	0.5
5	0.9	0.8	0.9	1.2	1.5	2.1
7	1.0	0.9	0.9	1.2	1.5	1.8
9	1.6	1.7	1.9	2.4	3.0	3.6
12	1.9	1.7	1.9	2.5	3.0	3.3
14	2.3	2.2	2.7	2.8	3.5	3.9
16	2.8	2.7	2.9	3.0	3.5	3.8
17	4.1	4.0	4.3	3.8	3.9	4.6
18	3.6	3.5	3.9	3.6	4.3	4.3
20	4.0	4.2	4.8	4.2	4.2	4.9

Table 24.--Loading-factor coefficients for dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; and specific conductance in Malheur River for trips 1 to 6, July-October 1985

[Values for boron and arsenic in reach 7 to 9 represent actual load units in (µg*ft3)/(liter*seconds) entering Malheur River between Namorf (site 7) and Little Valley (site 9)]

	Trip					
River reach	1	2	3	4	5	6
			Calcium			
1 to 3	0.96	1.03	0.91	0.97	0.94	1.21
3 to 5	1.02	1.10	1.25	1.07	1.09	1.69
5 to 7	1.01	.93	.89	1.06	1.24	1.12
7 to 9	1.75	1.88	1.87	1.67	1.76	1.84
9 to 12	1.20	1.10	1.15	1.26	1.25	1.10
12 to 14	1.31	1.33	1.73	1.19	1.32	1.17
5 to 18	1.04	1.29	.71	2.06	2.22	7.23
18 to 20	2.12	1.32	2.29	2.18	2.49	2.71
			Magnesium			
1 to 3	.97	1.00	.89	.93	.87	1.04
3 to 5	1.05	1.18	1.25	1.15	.90	1.74
5 to 7	1.01	.96	1.01	1.05	1.46	1.16
7 to 9	1.62	1.67	1.70	1.58	1.88	1.75
9 to 12	1.26	1.09	1.12	1.25	1.23	1.16
12 to 14	1.25	1.26	1.54	1.17	1.27	1.12
5 to 18	.90	1.11	.64	1.65	2.79	6.47
18 to 20	2.44	1.32	2.70	2.28	2.48	2.86
			Sodium			
1 to 3	1.00	.98	.97	1.03	.97	.96
3 to 5	1.09	1.09	1.28	1.02	1.09	1.31
5 to 7	1.07	.99	.94	1.10	1.06	1.00
7 to 9	2.51	2.98	3.29	2.92	3.86	3.28
9 to 12	1.23	1.13	1.06	1.25	1.19	1.01
12 to 14	1.54	1.50	2.18	1.27	1.42	1.32
5 to 18	2.33	3.30	1.93	3.86	4.48	10.32
18 to 20	2.41	1.48	2.78	2.38	2.38	2.99

Table 24.--Loading-factor coefficients for dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; and specific conductance in Malheur River for trips 1 to 6, July-October 1985--Continued

River reach	Trip					
	1	2	3	4	5	6
			Chloride			
1 to 3	0.95	0.95	0.86	0.97	0.83	0.99
3 to 5	1.16	1.02	1.28	1.02	1.28	1.24
5 to 7	.88	.99	.89	1.09	1.13	1.04
7 to 9	2.39	2.61	2.84	2.48	2.66	2.17
9 to 12	1.15	1.09	1.06	1.21	1.12	.93
12 to 14	1.54	1.33	1.90	1.24	1.23	1.09
5 to 18	1.48	2.25	1.28	2.55	2.27	5.13
18 to 20	2.57	1.51	2.82	2.33	3.15	2.86
			Boron			
1 to 3	1.03	.97	.93	1.01	.94	.89
3 to 5	1.05	1.04	1.31	.99	1.02	1.25
5 to 7	1.01	1.08	.89	1.18	1.34	1.09
7 to 9	17,800	37,500	44,800	44,800	39,700	45,200
9 to 12	1.20	1.10	.99	1.17	1.08	.84
12 to 14	1.45	1.40	1.88	1.19	1.24	1.07
5 to 18	1.23	2.22	1.00	2.08	2.27	3.02
18 to 20	2.39	1.38	2.98	2.23	2.36	2.53
			Arsenic			
1 to 3	1.23	1.03	0.83	1.09	1.13	0.89
3 to 5	1.24	1.37	1.48	1.12	1.12	1.37
5 to 7	1.01	.93	.89	1.06	1.32	1.16
7 to 9	3,630	3,980	4,870	4,930	4,640	5,640
9 to 12	1.27	1.10	.92	1.14	1.12	.89
12 to 14	1.18	1.65	1.12	1.06	1.10	.97
5 to 18	2.51	5.05	1.48	3.50	3.80	5.93
18 to 20	2.23	1.02	1.80	2.13	2.31	2.32
			Specific conductance			
1 to 3	.99	1.02	0.89	0.97	0.94	1.08
3 to 5	1.06	1.09	1.26	1.04	1.08	1.54
5 to 7	1.01	.93	.90	1.07	1.13	1.06
7 to 9	1.96	2.19	2.31	2.22	2.63	2.43
9 to 12	1.26	1.13	1.09	1.22	1.15	1.00
12 to 14	1.38	1.36	2.00	1.24	1.38	1.20
5 to 18	1.32	1.87	1.06	2.39	2.97	7.42
18 to 20	2.49	1.42	2.58	2.29	2.44	2.94

Table 25.--Constant-load values for dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; and specific conductance in Malheur River for trips 1 to 6, July-October 1985

[Constant loads are in units of (ft3 x mg)/(l x s)]

River reach	Trip					
	1	2	3	4	5	6
			Calcium			
1 to 3	-430	202	-874	-217	-273	127
3 to 5	255	1,140	3,070	500	372	501
5 to 7	112	-918	-1,690	475	1,110	145
7 to 9	2,210	2,520	2,160	1,580	1,120	1,050
9 to 12	1,010	557	696	1,010	641	227
12 to 14	878	938	885	608	584	264
5 to 18	498	3,650	-4,380	8,460	5,680	7,670
18 to 20	7,530	3,640	7,490	17,200	12,600	10,100
			Magnesium			
1 to 3	-111	12	-380	-169	-217	9
3 to 5	209	748	1,050	405	-159	206
5 to 7	41	-212	57	143	632	77
7 to 9	680	756	692	524	448	380
9 to 12	463	170	207	356	225	136
12 to 14	260	256	233	195	181	76
5 to 18	-487	527	-1,920	2,060	2,460	2,650
18 to 20	3,030	1,200	3,050	5,850	4,270	3,800
			Sodium			
1 to 3	19	-208	-328	303	-172	-80
3 to 5	1,120	972	3,130	200	560	535
5 to 7	927	-168	-886	1,050	368	7
7 to 9	5,030	5,660	5,700	5,890	5,120	4,730
9 to 12	1,930	1,130	528	2,250	1,280	46
12 to 14	2,550	2,290	2,340	1,950	1,970	1,320
5 to 18	18,200	27,700	13,500	28,900	23,200	21,300
18 to 20	21,600	12,900	25,100	46,100	32,200	30,400

Table 25.--Constant-load values for dissolved calcium, magnesium, sodium, chloride, and boron; total arsenic; and specific conductance in Malheur River for trips 1 to 6, July-October 1985--Continued

River reach	Trip 1	2	3	4	5	6
			Chloride			
1 to 3	-164	-158	-448	-74	-320	-9
3 to 5	496	54	857	62	461	161
5 to 7	-453	-29	-436	244	278	31
7 to 9	1,030	1,270	1,180	1,170	1,020	917
9 to 12	257	189	118	406	200	-126
12 to 14	495	356	399	368	241	90
5 to 18	1,770	4,130	1,100	4,050	2,710	3,450
18 to 20	4,180	2,570	4,680	7,690	8,130	5,120
			Boron			
1 to 3	876	-810	-2,530	440	-1,370	-1,430
3 to 5	1,920	1,790	13,300	-460	370	2,940
5 to 7	350	3,720	-6,230	6,710	8,210	1,360
7 to 9	17,800	37,500	44,800	44,800	39,700	45,200
9 to 12	5,280	5,100	-480	9,860	3,730	-9,520
12 to 14	6,560	10,400	10,600	8,160	6,930	-2,280
5 to 18	27,200	94,200	44,600	85,600	70,700	75,400
18 to 20	44,800	36,000	74,300	135,000	103,000	90,700
			Arsenic			
1 to 3	319	38	-287	141	132	-56
3 to 5	468	606	1,050	230	142	165
5 to 7	21	-162	-356	125	425	98
7 to 9	3,630	3,980	4,870	4,930	4,640	5,640
9 to 12	1,110	464	-444	756	624	-697
12 to 14	428	1,540	135	256	317	-108
5 to 18	7,250	-3,150	6,420	10,200	8,360	8,680
18 to 20	5,500	10,200	3,770	11,700	9,690	7,800
			Specific conductance			
1 to 3	-1,020	2,430	-14,400	-3,120	-3,740	924
3 to 5	10,500	12,900	38,900	4,700	4,780	7,220
5 to 7	1,510	-11,400	-18,100	7,490	8,750	1,240
7 to 9	38,300	42,300	41,000	39,800	30,600	28,200
9 to 12	20,000	10,300	6,850	15,600	7,570	-211
12 to 14	17,000	15,200	18,000	13,800	12,300	5,810
5 to 18	55,600	150,000	11,900	155,000	128,000	132,000
18 to 20	168,000	84,200	164,000	301,000	220,000	194,000

GPO 592-289/66506