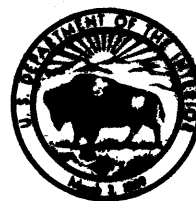


HYDROGEOLOGY OF EASTERN MICHAUD FLATS, FORT HALL INDIAN
RESERVATION, IDAHO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4201

Prepared in cooperation with the
SHOSHONE-BANNOCK TRIBES, FORT HALL INDIAN RESERVATION



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By N. D. Jacobson

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Boise, Idaho

1984



UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below. Constituent concentrations are given in mg/L (milligrams per liter) or $\mu\text{g/L}$ (micrograms per liter), which are equal to parts per million or parts per billion, respectively. Specific conductance is expressed as $\mu\text{mho/cm}$ (micromhos per centimeter at 25 degrees Celsius).

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain SI unit</u>
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon per day per foot [(gal/d)/ft]	0.003785	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.40	millimeter
micromho per centimeter ($\mu\text{mho/cm}$)	1.000	microsiemens per centimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (mi^2)	2.590	square kilometer

Temperature in $^{\circ}\text{C}$ (degrees Celsius) can be converted to $^{\circ}\text{F}$ (degrees Fahrenheit) as follows:

$$^{\circ}\text{F} = 1.8 \text{ }^{\circ}\text{C} + 32$$

Water temperatures are reported to the nearest 0.5°C .

HYDROGEOLOGY OF EASTERN MICHAUD FLATS,
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N. D. Jacobson

ABSTRACT

The Michaud Flats study area occupies about 20 square miles on the Snake River Plain in southeastern Idaho. Tertiary and Quaternary rocks in the area include basalt, pediment gravel, loess, and lacustrine and fluvial deposits. Ground water under artesian and water-table conditions is developed extensively for irrigation and industry.

Electrical resistivity data and geophysical well logs indicate the presence of extensive clay beds overlying the Bighole Basalt and Sunbeam Formation; aquifers in these rock units are artesian with heads below land surface and near those in the shallow water-table aquifer. Transmissivity values in the artesian aquifers range from 19,600 to 444,000 feet squared per day.

Two chemical industries in the area withdraw ground water and use evaporation ponds and sludge storage areas as part of their processing operations. High levels of contamination in ground water, principally from arsenic, were detected on the flats in 1972.

During this study, concentrations of arsenic in ground water ranged from 3 to 54 micrograms per liter. The recommended drinking water limit is 50 micrograms per liter. Concentrations of other principal chemical constituents were generally within public drinking water limits. Analyses of stable isotopes of oxygen and hydrogen suggest more than one source of recharge for ground waters in the study area and indicate the possibility of some mixing between waters from the industrial ponds and local ground water.

Tritium concentrations in sampled wells and springs ranged from less than 6.25 to 100 tritium units; tritium concentrations are highest in the springs and water-table aquifer, which indicates a younger age of the waters relative to the artesian aquifer.

Water-management alternatives being implemented by the industries for control of ground-water contamination include more efficient use of water to reduce amount of effluent, installation of liners and leachate recovery systems in all new and renovated ponds, and removal and reclamation of precipitates in old slurry and evaporation ponds.

Five wells and one spring will be monitored through 1985 to determine any changes in ground-water chemistry and to detect any migration of contaminants.

INTRODUCTION

The Michaud Flats study area occupies about 20 mi² on the eastern Snake River Plain in eastern Power and north-western Bannock Counties, Idaho (fig. 1). The area lies south of American Falls Reservoir and the Snake River, and between the Portneuf River on the east and Bannock Creek on the west.

Ground-water resources on the flats are substantial and are developed extensively for irrigation and industry. Ground-water discharge from irrigation and industrial pumpage and seepage loss to the Portneuf River is about 361,000 acre-ft/yr (Jacobson, 1982, p. 23).

High levels of contamination, principally from arsenic, in water from wells on the flats were first detected in October 1972 (Balmer and Noble, 1979). This prompted the Idaho Department of Health and Welfare to conduct a study of selected chemical constituents in water from various domestic and industrial wells from October 1972 to October 1973. During the study, arsenic concentrations in water from several wells exceeded the U.S. Public Health Service recommended limit of 50 µg/L (Balmer and Noble, 1979).

In the fall of 1980, the U.S. Geological Survey entered into a cooperative agreement with the Shoshone-Bannock Tribes to conduct a two-phase study to: (1) Determine the occurrence and movement of ground water, (2) describe the degree and extent of ground-water contamination, and (3) develop a monitoring program to periodically sample and analyze water from selected wells and springs to help determine the degree and fluctuation of ground-water contamination associated with industrial waste-water disposal practices.

Results of the first phase described geohydrologic and water-quality conditions in the vicinity of a large industrial complex that processes phosphate ores in the eastern Michaud Flats area on and near the Fort Hall Indian Reservation (Jacobson, 1982).

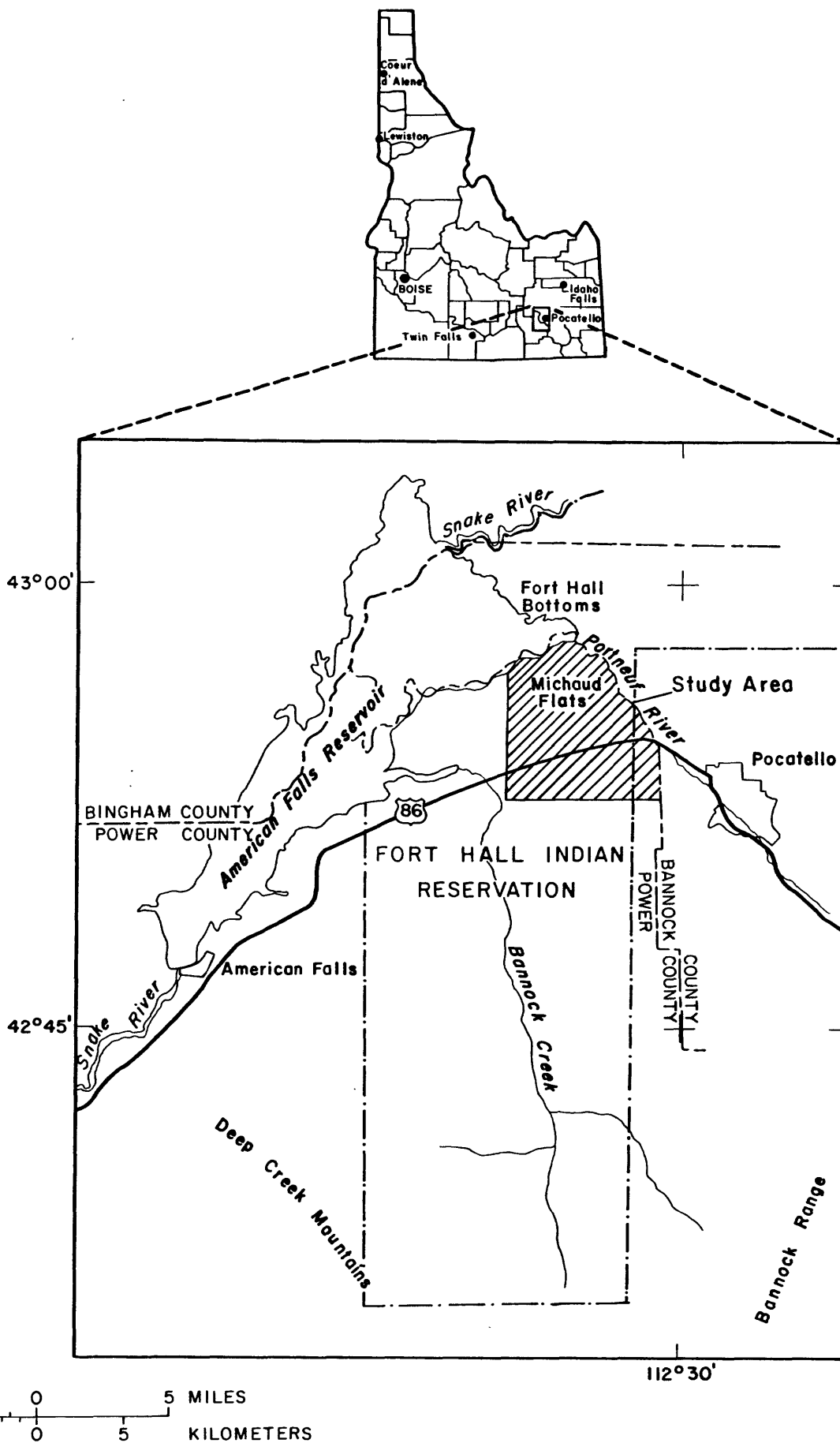


Figure 1.-- Location of study area.

Purpose and Scope

Purposes of this study were to: (1) Describe the hydrology of the study area; (2) identify in-plant processing procedures implemented by the industries to control ground-water contamination; and (3) implement a water-quality monitoring network to detect any changes in ground-water quality and contaminant migration owing to changes in industrial waste disposal procedures.

Scope of the study included: (1) Acquiring lithologic and hydrologic data from well and geophysical logs; (2) estimating specific capacity and transmissivity by using discharge and drawdown measurements in 16 wells; (3) collecting water samples from 6 wells and 2 springs for chemical analyses, which include common ions, the minor elements arsenic and boron, and gross alpha and beta radioactivity; (4) collecting water samples for isotope analyses from 13 wells, 4 ponds, and 5 springs; and (5) selecting 5 wells and 1 spring for inclusion in a monitoring program.

Acknowledgments

The author expresses gratitude to the Shoshone-Bannock Tribes for their cooperation in conducting this study. Thanks also are due Mr. John Cochran, J. R. Simplot Company; Mr. C. D. Holmes, FMC Corporation; Mr. Clint Buchanan, City of Pocatello; employees of the Fort Hall-Michaud Irrigation Project; and the many residents and farmers of Michaud Flats who allowed access to their property.

Well- and Spring-Numbering System

The numbering system used by the U.S. Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters, which indicate the $\frac{1}{4}$ section (160-acre tract), the $\frac{1}{4}$ - $\frac{1}{4}$ section (40-acre tract), the $\frac{1}{4}$ - $\frac{1}{4}$ - $\frac{1}{4}$ section (10-acre tract); and the serial number of the well within the tract. Quarter sections are lettered A, B, C, and D in counterclockwise order from the northeast quarter of each section (fig. 2). Within quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 6S-33E-12DAD1 is in the SE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$, sec. 12, T. 6 S., R. 33 E., and is the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example, 6S-34E-7ACALS.

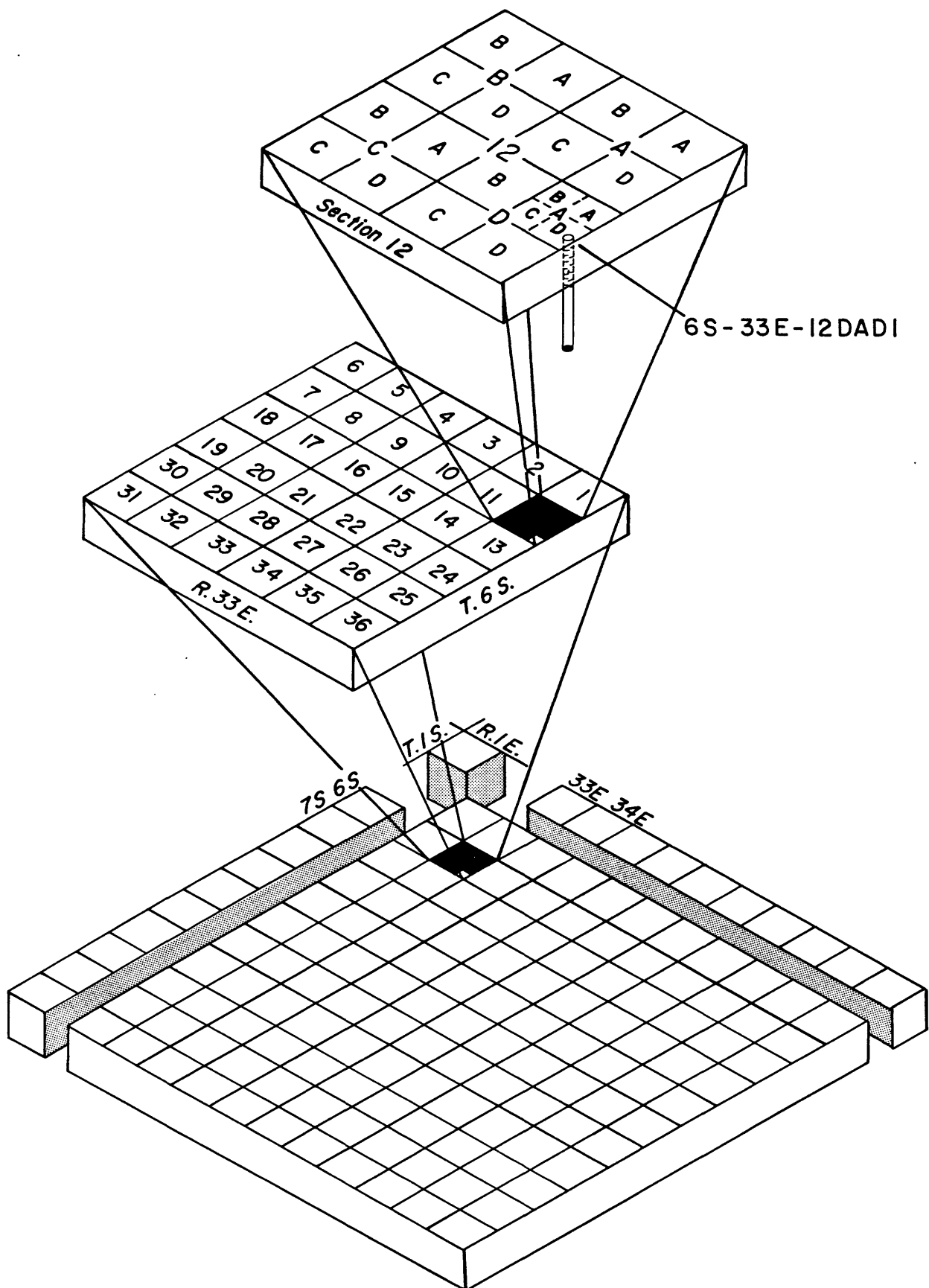


Figure 2.--Well- and spring - numbering system.

HYDROGEOLOGIC FRAMEWORK

Tertiary and Quaternary rocks in the study area include basalt, pediment gravel, loess, and lacustrine and fluvial deposits. The oldest rock unit penetrated by wells is the Starlight Formation, which is composed mainly of massive rhyolitic tuff. Overlying the Starlight Formation is a pediment gravel composed of quartzite, limestone, and dolomite pebbles. Locally, the gravel is as much as 100 ft thick. Ground water in these formations occurs under artesian conditions, but hydraulic heads in wells are below land surface.

The Bighole Basalt and Sunbeam Formations unconformably overlie the pediment gravel. The Bighole Basalt is a dense, blue-black basalt. The Sunbeam Formation is composed chiefly of alluvial and colluvial deposits of sand and gravel. Together, aquifers in these two formations yield most of the irrigation and industrial well water and are referred to locally and in this report as the deep aquifer. Water in wells completed in these formations is under artesian conditions but does not flow at land surface.

The American Falls Lake Beds overlie the Bighole Basalt and Sunbeam Formations and are the confining layer for the deep aquifer. The American Falls Lake Beds average 80 ft in thickness and consist mainly of clay and small amounts of sand and sandy silt. They yield little or no water to wells.

Unconformably overlying the American Falls Lake Beds are gravel and sand deposited by the flood from ancient Lake Bonneville upon its emergence onto the Snake River Plain. These deposits were named the Michaud Gravel by Trimble and Carr (1961, p. 58) and are composed of sand, gravel, and large basalt and quartzite boulders. Water in the Michaud Gravel is generally under water-table conditions.

Alluvial deposits of clay, silt, sand, and gravel overlie the Michaud Gravel. These deposits are thin and are generally above the zone of saturation.

The relation and configuration of these formations were depicted in an earlier report (Jacobson, 1982, p. 8). Subsequent geologic and geophysical work has produced data that further describe geohydrologic conditions in Michaud Flats.

Electrical resistivity methods were employed to obtain a better understanding of the subsurface geology. The ability of rocks to conduct an electrical current is a

function of the mineralogy and porosity of the rock and chemistry of the interstitial fluid. Clays are good conductors of electricity.

Saturated rocks have generally lower resistivities than unsaturated rocks. In general, the higher the porosity of the saturated rocks, the lower the resistivity; the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clay and conductive minerals also reduces the resistivity of the rocks.

Three resistivity surveys were conducted on a north-south line (A-A') along the Taghee Canal (fig. 3). The resulting interpretation (fig. 4) shows an area of low resistivity extending southward over the entire length of the line (R. J. Bisdorf, U.S. Geological Survey, written commun., 1981). The area of low resistivity underlies a band of moderate- to high-resistivity material (fig. 4).

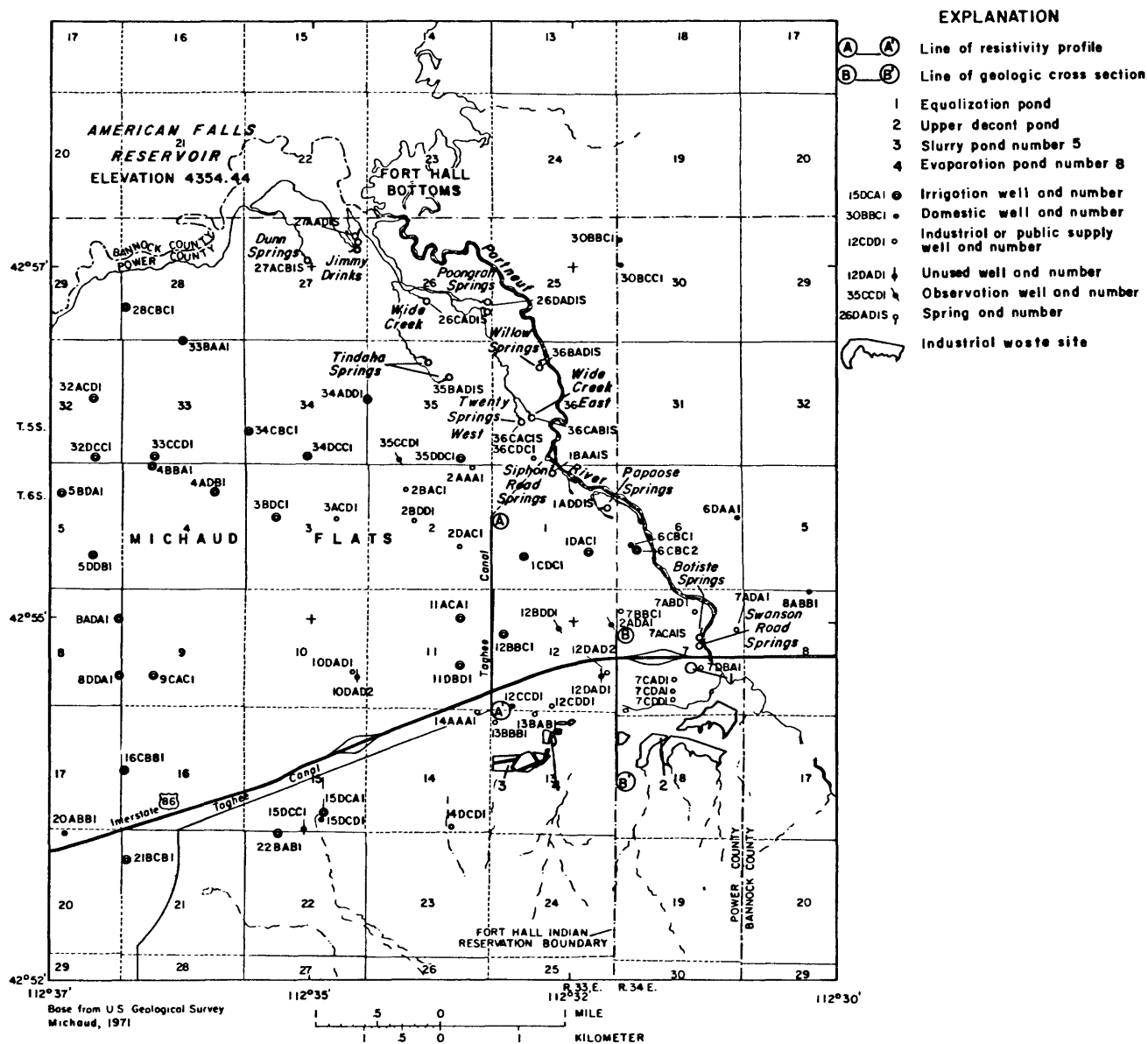
Basalt and dry gravel appear as high-resistivity areas, whereas fine sand, silt, and clay appear as low-resistivity areas. The boundary between the two is probably the contact between the Michaud Gravel and the American Falls Lake Beds.

The extent of the American Falls Lake Beds is not well known. Two U.S. Geological Survey observation wells were drilled in 1981 (fig. 3) to better define the areal extent of the lake beds and serve as sites for continued monitoring of the ground-water quality. A geologic cross section was constructed (fig. 5) using drillers' logs from the two Survey observation wells and industrial observation wells (fig. 6) that lie along the north-south section line B-B' (see fig. 3 for location). The cross section indicates that the American Falls Lake Beds probably are continuous throughout the area.

To further identify lithology, three radioactivity logs--natural gamma, gamma-gamma, and neutron--were obtained in the two Survey observation wells. Natural gamma logs show higher natural gamma activity near 59 and 74 ft (fig. 7) and probably indicate the presence of clay. This information correlates well with drillers' logs from the vicinity.

Aquifer Characteristics

Artesian conditions predominate in the study area, and most irrigation and industrial wells are completed in the deep aquifer. Aquifer characteristics discussed in this section pertain to artesian conditions.



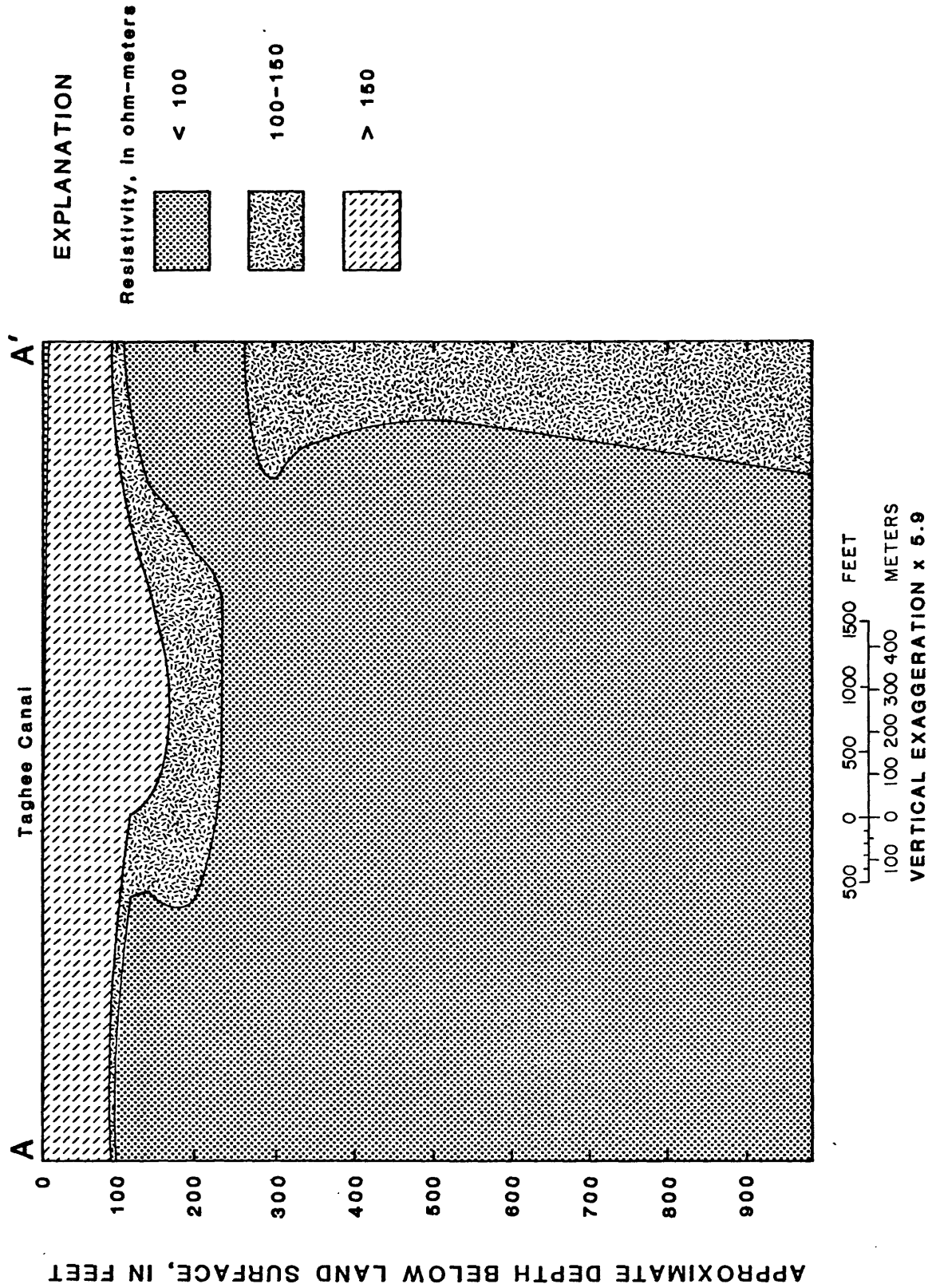


Figure 4.--Resistivity profile along line A - A'.
(Location of resistivity line on fig. 3)

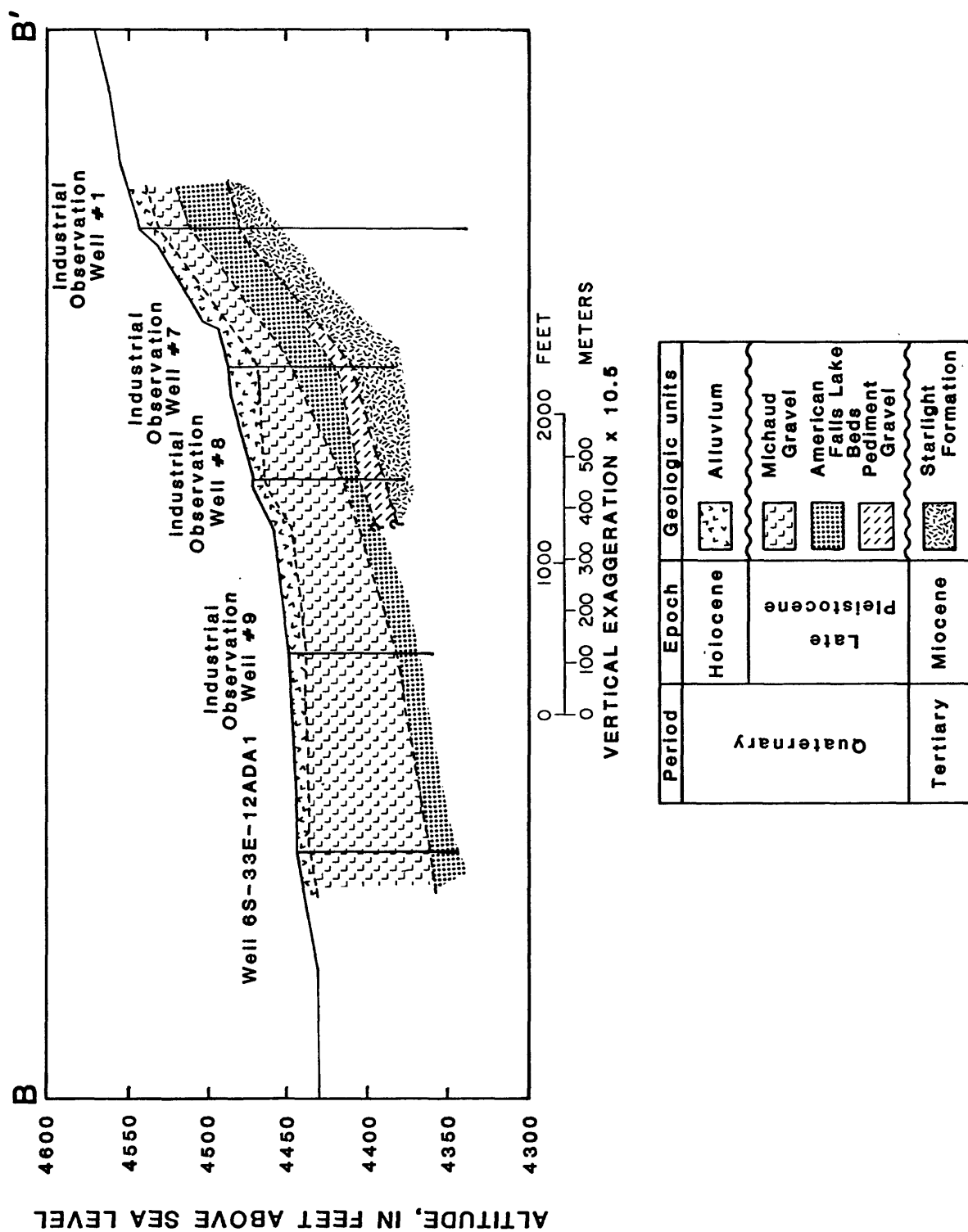


Figure 5.--Generalized geologic cross section along line B - B'.
(Location of cross section on fig. 3)

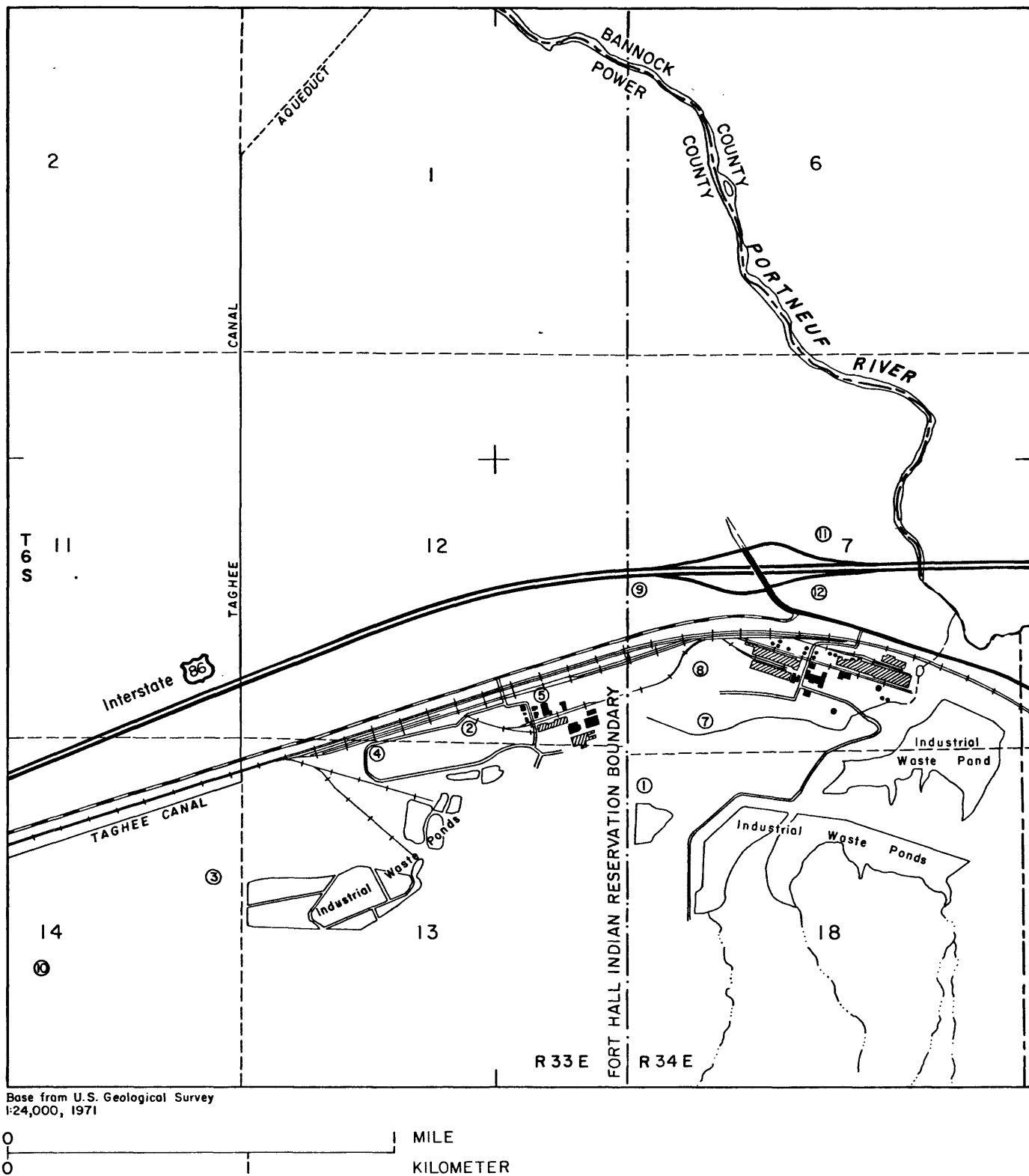


Figure 6.--Locations of industrial observation wells and waste ponds.

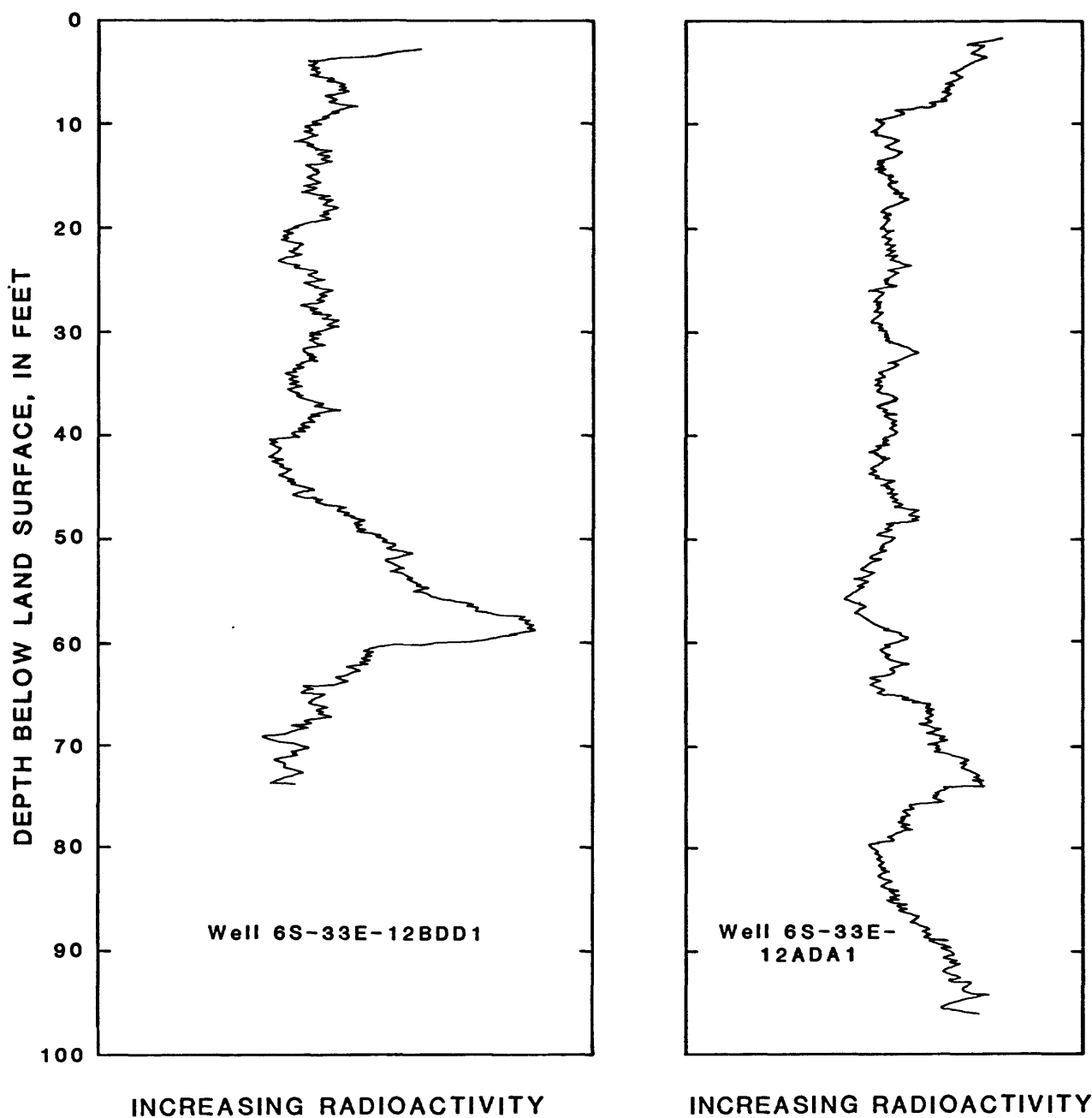


Figure 7.--Gamma logs from U.S. Geological Survey wells.

Hydrologic properties of an aquifer are transmissivity, storage coefficient, and specific capacity. Transmissivity is the rate at which water moves through a unit width of an aquifer under a unit hydraulic gradient. Storage coefficient is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The volume of water thus released or stored, divided by the product of the head change and the area of aquifer surface over which it is effective, determines the storage coefficient of the aquifer. Although rigid limits cannot be established, the storage coefficient of artesian aquifers may range from about 0.001 to 0.0001 (Ferris and others, 1962, p. 76). Specific capacity (C) can be determined by the formula:

$$C = Q/s \quad (1)$$

where Q is the discharge of the pumped well, in gallons per minute, and s is the water-level drawdown during pumping, in feet.

The specific capacity of a well, if used within certain limits, can be a basis for estimating the transmissivity of the aquifer tapped by the well. The specific capacity of a well cannot be an exact criterion of transmissivity in the vicinity of the well because the yield of the well per foot of drawdown is also a function of other factors such as well diameter, depth to which the well penetrates the aquifer, type and amount of well casing perforations, and the extent to which the well has been developed.

Transmissivity (T) values were calculated for selected wells by use of the equation and the set of constants for artesian conditions described by Theis and others (1963, p. 336):

$$T = \frac{Q}{s} [K - 264 \log_{10} (5S 10^3) + 264 \log_{10} t] \quad (2)$$

where Q is discharge, in gallons per minute; s is water-level drawdown, in feet; S is storage coefficient; and t is time since pumping began, in days. The condition constant, K, was described by Theis and others (1963, p. 333) as:

$$K = -66 - 264 \log_{10} (3.73r^2 10^{-9}) \quad (3)$$

where r is the well radius, in feet.

Values of K computed for selected values of r (expressed as diameter in inches) are as follows:

Casing diameter (inches)	K	Casing diameter (inches)	K
6	2,318	10	2,201
8	2,252	11	2,179
9	2,225	12	2,159

Transmissivity values calculated using equation (2) were obtained using a range for the storage coefficient of 0.001 to 0.0001 (Theis and others, 1963) chosen to bracket calculated transmissivities within reasonable limits.

Transmissivities (table 1) obtained using a storage coefficient of 0.001 ranged from 19,600 to 394,000 ft²/d. Transmissivities obtained using a storage coefficient of 0.0001 ranged from 21,900 to 444,000 ft²/d.

Occurrence and Movement of Ground Water

The more productive aquifers in the study area are the basalt flows of the Bighole Basalt and Starlight Formation and the sand and gravel of the Sunbeam Formation. Aquifers in these formations are confined by the overlying American Falls Lake Beds. The Michaud Gravel contains the shallow water-table aquifer. Water-level measurements of two adjacent wells--12DAD2, completed in the deep artesian aquifer, and 12DAD1, completed in the shallow water-table aquifer--show that the altitude of the water surface is higher in the water-table well. The difference in the water-surface altitudes was 0.59 ft on January 6, 1982, and 0.34 ft on July 20, 1982.

Presently (1982), the number of water-level measurements in wells completed in the water-table aquifer is insufficient to determine hydraulic head differentials for the two aquifers over the entire study area. If hydraulic heads in the shallow aquifer are consistently above those in the deeper confined aquifer, there is potential for some downward movement of water through the confining material. In view of the low head differentials measured (near 0.5 ft) and the likely low hydraulic conductivity of the confining material, the volume of water moving downward is probably small. Additional hydraulic head measurements and subsurface lithologic data are needed to quantify leakage between the two aquifers. Ground-water movement is generally to the north and northwest. Hydraulic gradients range from 1.0 to 5.0 ft/mi.

Table 1.--Discharge, drawdown, specific capacity, and transmissivity of selected wells

Well No.	Casing diameter (inches)	Pumping period (hours)	Discharge (gallons per minute)	Drawdown (feet)	Specific capacity (gallons per minute per foot)	Estimated transmissivity (feet squared per day)	
						0.001	0.0001
5S-33E-32ACD1	10	24	1,430	13.27	108	31,400	35,100
32DDC1	10	24	1,560	3.75	416	121,000	135,700
33BAA1	10	48	867	13.32	65	19,600	21,900
33CCD1	8	24	738	10.96	67	20,000	22,400
34ADD1	10	120	2,330	19.77	118	37,200	41,400
34CBC1	11	168	1,666	14.56	114	36,400	40,400
34DCC1	11	168	1,606	15.51	104	32,900	36,600
35DDC1	11	168	1,894	4.08	464	148,000	164,000
6S-33E-3ACD1	10	168	1,190	10.28	116	37,100	41,200
3BDC1	10	12	2,800	1.99	1,400	394,000	444,000
4BBA1	11	12	1,460	11.84	124	34,200	38,500
5BDA1	10	96	2,750	25.99	106	33,000	36,800
5DDB1	11	72	1,890	11.12	169	51,800	57,800
8ADA1	11	168	1,380	17.87	77	24,500	27,300
9CAC1	11	12	1,520	2.39	636	176,000	199,000
12BBC1	6	96	372	2.47	151	49,400	54,700

During 1981, discharge from all pumping wells was measured with a portable transient-time flowmeter. The flowmeter is noninvasive and uses ultrasonic waves to measure the flow of water in the pipe. Drawdown and discharge from measured pumping wells is shown in table 1.

Ground-water discharge to the Portneuf River from Michaud Flats is about 309,000 acre-ft/yr; an additional 51,900 acre-ft/yr are withdrawn by pumpage (Jacobson, 1982, p. 16, 25). Total ground-water discharge is about 361,000 acre-ft/yr.

GROUND-WATER CHEMISTRY

Water Quality

Ground-water chemistry is affected by geologic environment, geochemical properties of aquifer materials, recharge waters, and man's land- and water-use activities. Effects of man's land- and water-use activities may be indicated by anomalous concentrations of selected dissolved cations, anions, metals, or radioactive elements.

Between December 1981 and January 1982, water samples for chemical analyses were obtained from three wells and two springs previously sampled (Jacobson, 1982) and from two observation wells drilled by the U.S. Geological Survey. Results of the chemical analyses are given in table 2. Well and spring locations are shown in figure 3.

In July 1982, additional water samples were obtained to implement a ground-water quality monitoring network in Michaud Flats. Five wells and one spring were selected as sites where changes in ground-water quality could be observed (table 2). Well 12DAD2, completed in the deep aquifer and adjacent to well 12DAD1, completed in the water-table aquifer, were chosen for comparison of hydraulic heads. Well 14DCD1, completed in the deep aquifer, is the farthest upgradient well and is the only well available for sampling to determine background water quality.

Boron analyses were not obtained during the July 1982 sampling, but because boron is very mobile and previous concentrations were high, it will be included in subsequent analyses.

Table 3 shows concentrations of selected constituents in observation wells and springs since 1980.

Table 2.--Chemical analyses of water from selected wells and springs

[U-nat, uranium (natural); susp., suspended; Cs-137, radioactive isotope cesium-137; Sr/Yt-90, radioactive isotope strontium/yttrium-90; <, less than; --, no data available]

Sample site name or number	Reference No. (see table 4)	Date of sample	Well depth (feet)	Perforated interval (feet)	Specific conductance (microhm-cm)	pH (units)	Temperature (°C)	Hardness (mg/L CaCO ₃)	Calcium, dis- solved (mg/L as Ca)	Magne- sium, dis- solved (mg/L as Mg)	Sodium, dis- solved (mg/L as Na)	Sodium ad- sorption ratio	Percent sodium	Potas- sium, dis- solved (mg/L as K)	Alka- linity, (mg/L as CaCO ₃)	Sulfate, dis- solved (mg/L as SO ₄)
Batiste Springs	18	12/10/81			996	7.0	14.0	370	93	33	62	1.5	26	14	230	160
		7/21/82			1,402	6.8	14.5	510	130	46	87	1.8	26	20	330	260
Twenty Springs West	20	12/ 9/81			995	7.4	11.0	350	85	33	71	1.8	30	5.0	210	170
6S-33E-12ADAL		1/20/82	100		440	9.8	12.0	180	47	16	22	.8	20	4.2	150	46
12B001		1/20/82	80		463	8.0	13.0	190	52	14	35	1.2	28	6.7	160	52
		7/20/82	80		565	7.6	13.5	180	48	14	37	1.3	30	7.2	162	36
12C001	7	12/10/81	196		1,730	7.5	12.5	520	130	48	140	2.9	36	15	240	160
		7/21/82	196		1,564	7.4	14.5	480	120	43	120	2.6	35	13	230	160
12DAD1	8	1/ 6/82	113	81-103	1,720	6.9	17.0	360	74	42	120	3.1	31	170	370	180
		7/20/82	113	81-103	1,638	7.3	20.5	350	73	40	120	3.1	26	150	367	140
12DAD2	9	7/20/82	212	170-200	512	7.8	15.5	180	42	15	31	1.1	26	5.7	157	48
14D001	12	12/10/81	234	95-234	464	8.0	15.0	170	48	15	26	.9	24	8.6	170	19
		7/20/82	234	95-234	475	8.1	17.5	170	43	15	26	.9	24	8.6	169	20

Sample site name or number	Date of sample	Chlo- ride, dis- solved (mg/L as Cl)	Fluo- ride, dis- solved (mg/L as F)	Silica, dis- solved (mg/L as SiO ₂)	Solids, sum of consti- tuents, dis- solved (mg/L)	Solids, residue at 180°C, dis- solved (mg/L)	Nitro- gen, dis- solved (mg/L as N)	Nitro- gen, ammonia dissolved (mg/L as N)	Nitro- gen, dis- solved (mg/L as N)	Nitro- gen, organic dissolved (mg/L as N)	Nitro- gen, dis- solved (mg/L as N)	Nitro- gen, ammonia dissolved (mg/L as NH ₄)	Phos- phate, ortho, dis- solved (mg/L as PO ₄)	Phos- phorus, ortho, dis- solved (mg/L as P)	Phos- phorus, ortho, dis- solved (mg/L as P)	Phos- phorus, ortho, dis- solved (mg/L as P)
Batiste Springs	12/10/81	74	0.4	38	640	652	6.2	5.40	6.4	1.0	13	7.0	4.6	7.4	1.50	1.50
	7/21/82	83	.3	44	913	—	9.9	<.070	.52	—	—	.09	.06	—	.030	.020
Twenty Springs West	12/ 9/81	97	.8	29	623	627	1.2	.110	.68	.57	1.5	.14	.12	—	.030	.040
6S-33E-12ADAL	1/20/82	32	.8	28	290	270	.79	.090	.47	.38	1.0	.12	.15	—	.030	.050
12B001	1/20/82	37	1.2	36	333	320	.57	—	—	—	—	—	—	—	—	—
	7/20/82	31	1.2	36	318	—	.67	—	—	—	—	—	—	.21	.070	—
12C001	12/10/81	38	.5	46	1,020	1,090	6.2	.080	1.1	1.0	7.3	.10	.09	—	.040	.030
	7/21/82	240	.6	46	893	—	4.9	—	—	.00	7.9	2.2	27	.12	.040	8.80
12DAD1	1/ 6/82	210	<.1	69	1,120	1,110	6.4	1.70	1.5	—	—	—	—	.55	.180	—
	7/20/82	190	<.1	69	1,030	—	6.2	—	—	—	—	—	—	.40	.130	—
12DAD2	7/20/82	30	.9	33	309	—	.71	—	—	—	—	—	—	—	—	—
14D001	12/10/81	38	.4	60	316	302	.94	<.070	.41	—	1.4	.09	.12	—	.040	.040
	7/20/82	36	.4	61	316	—	.93	—	—	—	—	—	—	.61	.200	—

Sample site name or number	Date of sample	Arsenic, dis- solved (µg/L as As)	Boron, dis- solved (µg/L as B)	Cadmium, dis- solved (µg/L as Cd)	Chro- mium, dis- solved (µg/L as Cr)	Iron, dis- solved (µg/L as Fe)	Lead, dis- solved (µg/L as Pb)	Mercury, dis- solved (µg/L as Hg)	Molyb- denum, dis- solved (µg/L as Mo)	Selen- ium, dis- solved (µg/L as Se)	Zinc, dis- solved (µg/L as Zn)	Gross alpha, dis- solved (µg/L as U-nat)	Gross beta, dis- solved (pci/L as Cs-137)	Gross beta, dis- solved (pci/L as Sr-90)	Gross beta, dis- solved (pci/L as Cs-137)	Gross beta, dis- solved (pci/L as Sr-90)	Gross beta, dis- solved (pci/L as Sr-90)
Batiste Springs	12/10/81	16	180	< 1	< 10	< 10	< 10	0.3	< 10	2	< 3	< 18	< 0.4	16	15	< 0.4	< 0.4
	7/21/82	23	—	—	—	—	—	—	—	—	—	< 18	< 0.4	< 12	< 12	< 0.4	< 0.4
Twenty Springs West	12/ 9/81	6	120	< 1	< 10	< 10	< 10	.1	< 10	1	< 3	< 21	< 0.8	8.3	8.0	< 0.4	< 0.4
6S-33E-12ADAL	1/20/82	3	70	< 1	< 10	67	< 10	< 1	< 10	< 1	3	< 7.0	9.5	3.5	3.4	1.5	1.4
12B001	1/20/82	9	80	< 1	< 10	< 10	< 10	< 1	< 10	< 1	45	< 7.6	4.7	4.5	5.9	5.6	5.6
	7/20/82	6	—	—	—	—	—	—	< 10	—	—	< 8.0	.4	9.3	4.5	< 0.4	< 0.4
12C001	12/10/81	11	190	< 1	< 10	< 10	< 10	.1	< 10	1	420	< 38	.4	16	16	< 0.4	< 0.4
	7/21/82	7	—	—	—	—	—	—	—	—	—	< 25	< 1	15	14	< 0.4	< 0.4
12DAD1	1/ 6/82	54	810	< 1	< 10	36	< 10	.3	50	1	< 3	< 32	< 4	160	150	< 0.4	< 0.4
	7/20/82	51	—	—	—	—	—	—	—	—	—	< 23	< 5	150	140	< 0.4	< 0.4
12DAD2	7/20/82	5	—	—	—	—	—	—	—	—	—	7.6	< 4	7.3	7.0	< 0.4	< 0.4
14D001	12/10/81	21	60	< 1	< 10	< 10	< 10	.2	< 10	< 1	100	< 9.2	< 4	8.1	8.1	< 0.4	< 0.4
	7/20/82	16	—	—	—	—	—	—	< 10	—	—	< 5.2	< 4	9.4	9.4	< 0.4	< 0.4

Table 3.—Concentrations of selected constituents in observation wells and springs since 1980
[U-nat, uranium (natural); Cs-137, radioactive isotope cesium-137; Sr/Yt-90,
radioactive isotope strontium/yttrium-90; <, less than; —, no data available]

Sample site name or number	Date	Arsenic (µg/L)	Boron (µg/L)	Fluoride (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Phosphorus (mg/L)	Specific conductance (µmhos)	Sulfate (mg/L)	Total dissolved solids (mg/L)	Gross alpha dissolved as U-nat (µg/L)	Gross beta dissolved as Cs-137 (pci/L)	Gross beta dissolved as Sr/Yt-90 (pci/L)
6S-33E-12BDD1	1/20/82	9	80	1.2	6.7	35	0.05	463	52	333	< 7.6	4.7	4.5
	7/20/82	6	—	1.2	7.2	37	.07	565	36	318	< 8.0	9.8	9.3
12CCD1	12/10/80	7	160	.8	1.4	140	23	1,764	150	1,020	—	—	—
	6/10/81	5	90	.5	8.6	64	.05	910	85	581	<14	8.4	8.1
	12/10/81	11	190	.5	15	140	.03	1,730	160	1,020	<38	17	16
	7/21/82	7	—	.6	13	120	.04	1,564	150	893	<25	15	14
12DAD1	12/ 9/80	40	960	—	140	130	.16	1,608	150	1,010	—	—	—
	6/11/81	40	740	.0	190	130	9.7	1,590	210	1,150	<26	150	150
	1/ 6/82	54	810	.1	170	120	8.8	1,720	180	1,120	<32	160	150
	7/20/82	51	—	<.1	150	120	.18	1,638	140	1,030	<23	150	140
12DAD2	12/ 9/80	3	40	1.1	5.4	29	.06	464	48	306	—	—	—
	6/11/81	—	—	—	—	—	—	—	—	—	—	—	—
	1/ 6/82	—	—	—	—	—	—	—	—	—	—	—	—
14DCD1	7/20/82	5	—	.9	5.7	31	.13	512	48	309	7.6	7.3	7.0
	12/11/80	17	40	.4	8.6	25	.06	455	20	315	—	—	—
	6/10/81	19	60	.4	8.1	26	.06	417	20	304	<6.5	9.9	9.5
	12/10/81	21	60	.4	8.6	26	.04	464	19	316	<9.2	8.3	8.1
	7/20/82	16	—	.4	8.6	26	.20	475	20	316	<5.2	9.9	9.4
Batiste Springs	¹ 12/11/80	3	90	.3	5.7	50	.03	657	42	443	—	—	—
	² 6/10/81	21	220	.3	21	89	4.5	1,453	290	960	<22	15	15
	² 12/10/81	16	180	.4	14	62	1.5	996	160	640	<18	16	15
	² 7/21/82	23	—	.3	20	87	2.4	1,402	260	913	<18	<12	<12

¹Sample taken from Rowlands Dairy headbox; not indicative of complete springs.

²Sample taken from near spring orifice.

Specific electrical conductance of the sampled ground waters ranged from 417 μ mhos in background well 14DCD1 to 1,764 μ mhos in well 12CCD1. Specific conductance in ground water from the Michaud Flats area generally ranges between 400 and 600 μ mhos (Jacobson, 1982). Water that contains low concentrations of dissolved constituents has a proportionally low electrical conductance.

Dissolved-solids concentrations frequently are used to evaluate the general water quality and are a convenient means of comparing waters. Dissolved-solids concentrations are calculated as the sum of cations (positively charged ions of calcium, magnesium, sodium, and potassium) and anions (negatively charged ions of sulfate and chloride), plus silica and alkalinity. Dissolved-solids concentrations in ground water may be increased by infiltration of irrigation-return flow, organic and chemical waste-water effluent and solid waste-disposal leachates, or by dissolution of aquifer materials. In Michaud Flats, concentrations of dissolved solids in ground water ranged from 290 to 1,150 mg/L; in wells 12CCD1 and 12DAD1 and in Batiste Springs, concentrations exceeded the maximum EPA (U.S. Environmental Protection Agency, 1976) recommended public drinking water limit of 500 mg/L (table 3).

Arsenic concentrations in water from all wells ranged from 3 to 54 μ g/L and exceeded the recommended limit (EPA, 1977a) of 50 μ g/L in two samples from a single well. Both arsenic concentrations in excess of the recommended limit were observed in analyses collected from well 12DAD1 on January 6, 1982, and July 20, 1982. In general, arsenic concentrations in most waters sampled did not fluctuate during the irrigation season as readily as did other constituents.

Boron is a light element and its ionic and solute species tend to be somewhat volatile and quite mobile (Hem, 1978, p. 187). Sodium tetraborate, a compound containing boron, is used widely as a cleaning aid and detergent and often is present in sewage and industrial wastes. Concentrations of boron from selected wells ranged from 40 to 960 μ g/L (table 3). Concentrations of boron decreased northward away from the industrial areas.

Concentrations of potassium ranged from 1.4 to 190 mg/L and sodium from 25 to 140 mg/L (table 3). Sodium usually remains in solution once it has been dissolved from silicate minerals (Hem, 1978, p. 150). Potassium dissolves with greater difficulty from silicate minerals and exhibits a

strong tendency to be reincorporated, especially in certain clay minerals (Hem, 1978, p. 150). In most natural water, the concentration of potassium is much lower than the concentration of sodium. Potassium concentrations commonly may be half or one-tenth those of sodium. Such is the case with the wells and spring listed in table 3, with the exception of well 12DAD1, where the potassium concentration in every sample was greater than that of sodium.

Sulfate concentrations ranged from 19 to 290 mg/L in the observation wells and spring (table 3). High concentrations of sulfate in local ground waters may be caused by precipitation, flooding of gypsum storage areas, and percolation of sulfate-enriched water to local aquifers.

Alpha-emitting substances in ground water are mainly isotopes of radium and radon, which are products of uranium and thorium. Beta activity is characteristic of potassium-40 and of the fission products strontium-90, phosphorus-32, and cesium-137 (Hem, 1978, p. 210). Radioactivity levels are expressed in pci/L (picocuries per liter, or curies $\times 10^{-12}$). One curie is 3.7×10^{10} disintegrations per second (Hem, 1978, p. 211). Two types of radioactivity commonly measured in ground water are gross alpha and gross beta. Dissolved gross alpha particle concentrations in sampled waters ranged from 5.2 to 38 $\mu\text{g/L}$. Alpha and beta activity is greater in water from wells near the industrial areas relative to wells over the entire area.

Water from wells 12CCD1 (103 ft deep) and 12DAD1 (113 ft deep) probably is representative of that in the water-table aquifer in the vicinity of the heavy industrial-use area. About 0.5 mi downgradient, wells 12BDD1 and 12ADAL were drilled to 80 and 100 ft, respectively, to define the extent of pollutant migration. Analytical samples indicate that the contamination has not yet traveled that distance.

Deuterium and Oxygen-18

Concentrations of the stable isotopes, D (deuterium) and ^{18}O (oxygen-18), characterize and indicate the origins and mixing patterns of individual waters. Atmospheric water derived from the ocean is depleted in ^{18}O and D. Isotopic composition of precipitation depends on the fraction of water remaining in and temperature of the air mass from which the rain or snow is derived (Ellis and Mahon, 1977, p. 75).

Results of stable-isotope analyses of water from selected wells and springs are included in table 4 and figure 8. Data are expressed in the δ notation:

Table 4.—Isotope analyses of water from selected sites

[<, less than; —, no data available; TU, tritium units]

Sample site name or number ¹	Temperature (°C)	D SMOW	SMOW	Depth (feet)	Tritium (TU)	Reference No. (see fig. 8)
Equalization pond	10.5	-117	-16.4		< 6.25	1
Gypsum decant pond	5.0	-127	-16.0		< 6.25	2
Slurry pond #5	1.0	-102	-12.8		11.6	3
Evaporation pond #8	12.5	-125	-15.9		< 6.25	4
6S-33E-10DAD2	11.0	-139	-18.2	214	< 6.25	5
12CCD1	8.5	-132	-17.4	103	10.6	6
12CDD1	14.5	-134	-17.6	196	7.81	7
12DAD1	18.0	-134	-17.6	113	11.6	8
12DAD2	12.5	-137	-18.3	212	< 6.25	9
13BBB1	14.0	-138	-18.2	210	< 6.25	10
14AAA1	12.5	-138	-18.1	120	< 6.25	11
14DCD1	15.5	-103	-18.0	234	< 6.25	12
15DCD1	6.5	-130	-17.1	—	34.4	13
6S-34E- 7ADA1	13.0	-125	-17.4	146	100	14
7BBC1	10.5	-131	-17.5	151	23.8	15
7CAD1	13.5	-138	-18.2	300	< 6.25	16
7CDA1	12.0	-137	-18.0	229	< 6.25	17
Batiste Springs	13.5	-127	-16.4		84.4	18
Jimmy Drinks	11.0	-136	-17.9		14.4	19
Siphon Road Springs	11.0	-131	-17.2		40.6	20
Tindaha Springs	11.0	-135	-17.6		27.0	21
Twenty Springs West	11.0	-131	-17.1		34.4	22

¹See figure 3 for locations of ponds.

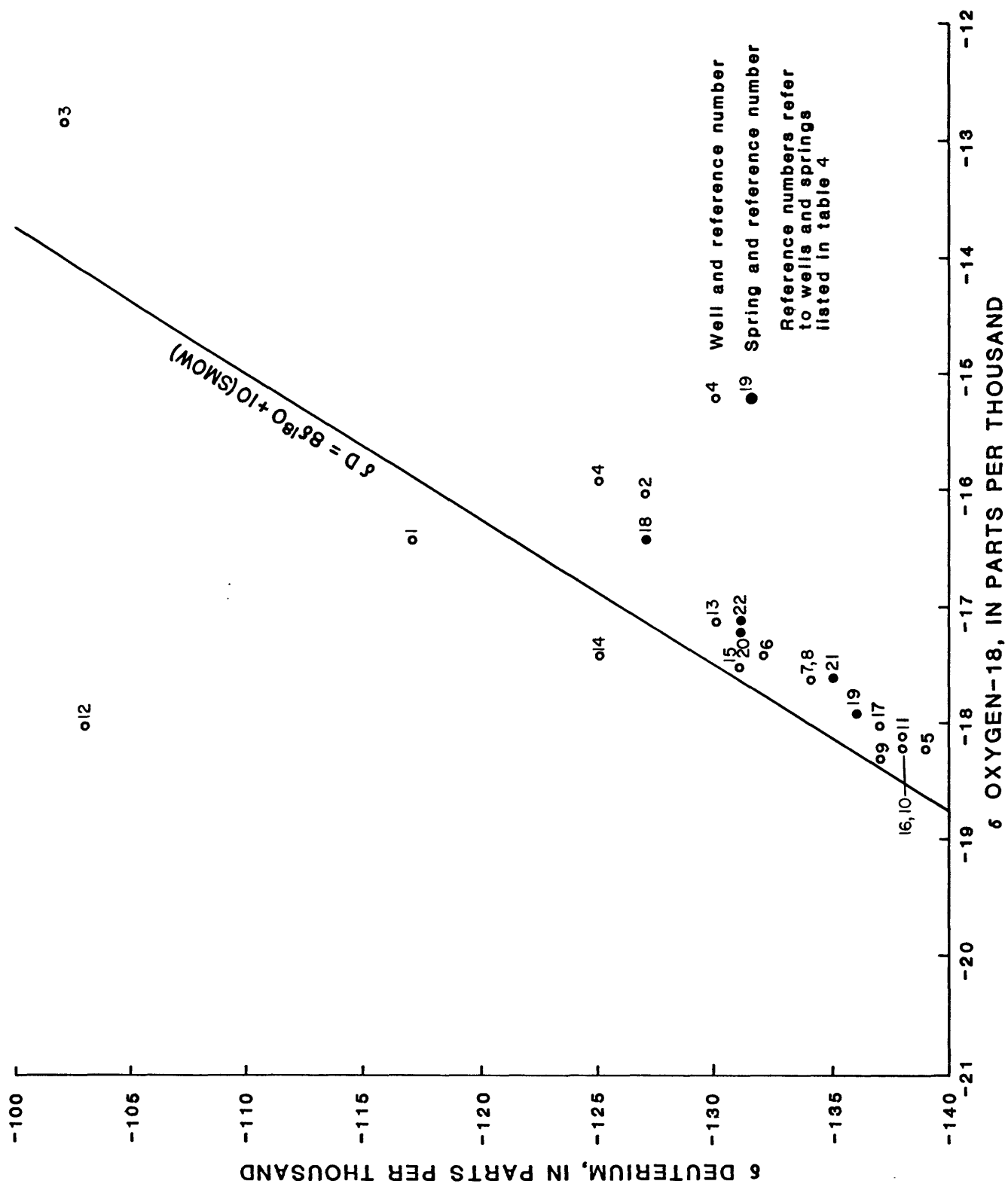


Figure 8.--Relation between concentrations of deuterium and oxygen-18.

$$\delta = \frac{R - R_{\text{std}}}{R_{\text{std}}} 10^3 \quad (4)$$

where $R = (D/H)$ or $(^{18}O/^{16}O)$ of the sample, and R_{std} is the corresponding ratio for SMOW (standard mean ocean water).

Figure 8 shows stable-isotope data relative to SMOW. No high-altitude cold-water springs were available for sampling to indicate the stable-isotope composition of potential recharge waters. A complete discussion of stable-isotope relations of waters from so small an area and without data from adjacent areas is not possible; however, several observations can be made.

Some evaporation prior to recharge is indicated by an enrichment shifting from the SMOW line (fig. 8). The wide range of D and ^{18}O indicates that there is no single source of recharge for all wells and springs. If only one source of recharge were involved, deuterium values for all the waters would be more nearly identical because there is no mechanism to explain deuterium exchange during movement of ground water through the system. Water represented by points 5, 9, 10, 11, 16, and 17 in figure 8 may be more representative of typical ground water having its recharge area to the south with some influence by recharge from the southwest. A similar pattern of ground-water movement could explain variation of stable isotopes in the spring waters. Springs 19 and 21 are isotopically more similar to the ground waters described above and may be influenced by some component of recharge originating to the west. Springs 20, 22, and even more so, 18, are isotopically more enriched and may be influenced to a greater extent by recharge originating in the Portneuf River drainage to the southeast.

The positions of point 12, and to some degree, point 14, in figure 8 probably are caused by sample contamination or by analytical error, most likely in the determination of deuterium. Stable-isotope analyses of water from the industrial ponds are represented by points 1, 2, 3, and 4 in figure 8. Evaporation and the introduction of various chemical compounds to the water in the ponds may result in anomalous isotopic analyses. The purpose of obtaining samples from the ponds was to identify their isotopic composition so that mixing with local ground water could be qualitatively determined. Water from one or more of the ponds could be mixing with more isotopically depleted waters (represented by points 5, 9, 10, 11, 16, or 17) to yield waters that plot between the two end members in figure 8. The water from Batiste Springs (point 18, fig. 8) may originate from outside the area or could be influenced by mixing

with water from one of the ponds represented by points 2 and 4. To some lesser degree, springs 20 and 22 and wells 6, 13, and 15 could be similarly influenced by waters from the ponds. Hydraulic gradients presented by Jacobson (1982, p. 17), however, seem to indicate ground-water movement that would preclude any such mixing pattern. Additional work may be needed to accurately define the mixing patterns apparent in the local ground waters.

Tritium

Tritium (^3H) is produced naturally in small quantities in the upper atmosphere during bombardment of subatomic particles. The tritium, incorporated in water molecules, enters the water cycle in rain and snow. Having a half-life of about 12.3 years, tritium can be used to determine how long a particular water may have been stored out of contact with the atmosphere. The transit or residence time can be determined from the concentration of tritium in the discharge water if the amount of tritium in the recharge water and the nature of the subsurface flow regime are known.

Before extensive thermonuclear testing began in 1954, tritium in the atmosphere ranged from 10 to 20 TU (tritium unit). One TU equals a $^3\text{H}/\text{H}$ ratio of about 10^{-18} , or 3.2 pci/L. During the mid-1960's when atmospheric testing was at its greatest frequency, tritium levels in some parts of the country were as high as 7,000 TU (Pearson and Truesdell, 1978). Tritium levels in precipitation in southwestern Idaho in 1979 averaged about 50 TU (Young and Lewis, 1982, p. 59).

Tritium content in a ground-water system is a function of tritium content in recharge water, residence time, and nature of flow in the system. Water samples were obtained from 4 ponds, 5 springs, and 13 wells and analyzed for tritium. Results of the analyses are shown in table 4.

Concentrations of tritium in the ponds ranged from less than 6.25 to 11.6 TU. Except for well 7ADA1, concentrations of tritium in wells completed in the deep aquifer system ranged from less than 6.25 to 34.4, values which are similar to concentrations in water from the ponds. Well 7ADA1 contained a concentration of 100 TU. This well is less than 150 ft deep, and tritium concentrations may be influenced by mixing with water similar to that in the nearby springs. Concentrations of tritium in the springs ranged from 14.4 to 84.4 TU. Concentrations of tritium in water from the springs decreased northwest toward American Falls Reservoir and probably indicate normal radioactive decay with increasing age of the water as it moves along a flow path.

INDUSTRIAL PONDS AND STORAGE AREAS

Two chemical industries are located in the study area: a plant that since 1945 has produced dry and liquid fertilizers from phosphate ore and also manufactures gypsum and phosphoric acid as byproducts, and a plant that has produced elemental phosphorus since 1949.

In the 1950's, the fertilizer plant dispersed gypsum waste into nearby gravel pits. Currently, about 1 Mgal/d are pumped to a gypsum stack (storage area) as a slurry which is spread to allow the water to evaporate and infiltrate. An infiltration rate of about 0.25 in./d is used as a standard for the ponds. Water that infiltrates is collected by slotted pipes buried beneath the ponds and carried to a decant pond where it is eventually recirculated. About 1 Mgal/d of ground water are pumped daily to the phosphoric acid-reclaim water circuit as makeup water.

Surface area of retention and sludge ponds totals about 213 acres. Three ponds, totaling 2.75 acres, are lined with plastic. Two ponds, totaling 11.25 acres, are clay lined. An impound pond, totaling 38 acres, is lined with a bentonite-polymer mixture and receives about 1 Mgal/d of treated waste water, which is distributed as irrigation water to local farmers. Two remaining areas, a reclaim-water overflow pond and the gypsum storage areas, were originally constructed as unlined ponds. As the liquids accumulated, an aggregate compound of calcium phosphate, sulfate, and/or fluoride with iron or magnesium formed. Laboratory studies show the formation of this compound involved a change from a calcareous to a noncalcareous state and resulted in a natural pond lining of low hydraulic conductivity material (Chojnacki and Olsen, 1975).

The elemental phosphorus plant pumps about 3.6 Mgal/d of ground water to supplement recycled water in the manufacturing process. About 2.8 Mgal/d of applied water are reclaimed and recirculated, and about 1.7 Mgal/d of ground water are returned to the Portneuf River under permit from the Idaho Department of Water Resources. About 1.6 Mgal/d of water are consumed by evaporation and cooling processes.

The plant currently (1984) maintains 22 acres of holding and evaporation ponds. Several ponds were dried up after 1975. In 1972, a secondary condenser was installed; in 1974, a slurry dryer was installed and the surge pond was lined. Four existing ponds are lined with a 40-mil PVC

(polyvinyl chloride) liner. Two other ponds remain unlined and total about 10 acres. New ponds are lined with an initial plastic liner leading to manholes where leachates can be recovered. A second layer of plastic covers the soil and sediment on the initial liner to provide a double-lined system.

In recent years, measures have been implemented by both industries to eliminate or reduce the potential for migration of contaminants into local ground-water systems. These include: (1) More efficient use of water in processing the ore to reduce the amount of effluent produced, (2) installation of PVC or bentonite-polymer liners and leachate-recovery systems in all new and renovated ponds and holding areas to reduce infiltration, and (3) removal and reclamation of concentrated precipitates in older slurry ponds and evaporation areas to reduce further leaching of contaminants.

PLANS FOR CONTINUED WATER-QUALITY MONITORING

Monitoring of ground-water quality on Michaud Flats will continue through July 1985. Five wells and one spring in strategic locations were selected to provide necessary data to determine any changes in concentrations of constituents and to detect any migration of contaminants.

The sites to be sampled semiannually in December and July are: 6S-33E-12BDD1, 12CCD1, 12DAD1, 12DAD2, 14DCD1, and Batiste Springs. Water samples will be analyzed for arsenic, boron, calcium, magnesium, potassium, silica, sodium, nitrate, chloride, fluoride, sulfate, gross alpha, and gross beta. Determinations of specific conductance, pH, and air and water temperatures will be made onsite.

This monitoring program will be subject to annual evaluations by a technical advisory committee, which will review the analyses and determine the upcoming year's activities. In September 1985, the data will be examined and a report of the findings will be published.

SUMMARY

The Michaud Flats study area occupies about 20 mi² on the eastern Snake River Plain in southeastern Idaho. Tertiary and Quaternary rocks in the area include basalt, pediment gravel, loess, and lacustrine and fluvial deposits. Aquifers in the Bighole Basalt and Sunbeam Formation provide most of the water for irrigation and industry.

An electrical resistivity survey conducted on a north-south line along the Taghee Canal shows a low-resistivity unit, probably representing the clay layer overlying the Bighole Basalt and Sunbeam Formation, extending over the entire length of the line. Geophysical logs obtained from two U.S. Geological Survey observation wells indicate the presence of significant clay layers. Geophysical data, along with lithologic data from drillers' logs, support the assumption that confining layers are continuous over much of Michaud Flats.

Hydraulic heads are slightly lower in the artesian aquifer than in the water-table aquifer; however, leakage between the two aquifers is probably low. Hydraulic gradients in the confined aquifer are 1-5 ft/mi; ground-water movement is generally north and northwest.

Transmissivity values in the artesian aquifer, estimated using specific-capacity data from wells and a storage coefficient of 0.001, ranged from 19,600 to 394,000 ft²/d; values estimated using a storage coefficient of 0.0001 ranged from 21,900 to 444,000 ft²/d.

Specific electrical conductance ranged from 417 to 1,764 μ mhos. Concentrations of dissolved solids ranged from 290 to 1,150 mg/L and exceeded the recommended limits in several wells and springs. Concentrations of arsenic ranged from 3 to 54 mg/L and exceeded the EPA-recommended limit on two sampling dates at one well. Concentrations of boron ranged from 40 to 960 μ g/L and decreased northward away from the industrial areas. Concentrations of potassium and sodium ranged from 1.4 to 190 and 25 to 140 mg/L. Concentrations of sulfate in 5 wells and 1 spring, all sampled semiannually, ranged from 19 to 290 mg/L. Relative to other wells in the area, radioactivity was highest in water from wells near the industrial areas. Dissolved gross alpha particle concentrations ranged from 5.2 to 38 μ g/L.

Stable isotope analyses suggested more than one source of recharge for ground waters in the study area and indicated the possibility of some mixing between waters from the industrial ponds and local ground water.

Concentrations of tritium in all waters ranged from less than 6.25 to 100 TU. Concentrations of tritium were highest in the springs and water-table aquifer, which indicates a younger age of the waters relative to the artesian aquifer.

In-plant processing procedures being implemented by the industries for control of ground-water contamination include more efficient use of water to reduce amount of effluent, installation of liners and leachate recovery systems in all new and renovated ponds, and removal and reclamation of precipitates in old slurry and evaporation ponds.

Ground-water quality monitoring in Michaud Flats will continue through July 1985. Water samples will be obtained semiannually from five wells and one spring to monitor changes in ground-water quality and to detect any migration of contaminants.

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