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CHEMICAL QUALITY OF GROUND WATER IN SALT LAKE VALLEY, UTAH, 1969-85

by

K. M. Waddell, R. L. Seiler, and D. K. Solomon

Prepared by the
United States Geological Survey
in cooperation with the
Utah Department of Natural Resources
Division of Water Rights

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[Plates are in pocket]

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre	4,047	square meter
acre-foot	1,233	cubic meter
cubic foot per second	0.02832	cubic meter per second
cubic foot per second per mile	0.01760	cubic meter per second per kilometer
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
foot per second	0.3048	meter per second
foot per day		meter per day
foot per year		meter per year
gallon per minute	3.785	liter per minute
	0.003785	cubic meter per minute
mile	1.609	kilometer
square mile	2.590	square kilometer
ton (short)	0.9072	ton (metric)

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U.S. Geological Survey

ABSTRACT

During 1979-84, 35 wells completed in the principal aquifer in the Salt Lake Valley, Utah, that had been sampled during 1962-67 were resampled to determine if water-quality changes had occurred. The dissolved-solids concentration of the water from 13 of the wells has increased by more than 10 percent since 1962-67.

Much of the ground water between the mouth of Bingham Canyon and the Jordan River about 10 miles to the east has been contaminated by seepage from reservoirs and evaporation ponds associated with mining activities. Many domestic and irrigation wells yield water with concentrations of dissolved solids that exceed 2,000 milligrams per liter. A reservoir in the mouth of Bingham Canyon contains acidic waters with a pH of 3 to 4 and concentrations of dissolved solids ranging from 43,000 to 68,000 milligrams per liter. Seepage from evaporation ponds, which are about 4.5 miles east of the reservoir, also is acidic and contains similar concentrations of dissolved solids. East of the reservoir, where a steep hydraulic gradient exists along the mountain front, the velocities of contaminant movement were estimated to range from about 680 to 1,000 feet per year.

Ground water underlying a part of the community of South Salt Lake near the Jordan River has been contaminated by leachate from uranium-mill tailings. The major effect of the leachate from the tailings of the Vitro Chemical Co. on the water in the shallow unconfined aquifer downgradient from the tailings was the contribution of measurable quantities of dissolved solids, chloride, sulfate, iron, and uranium. The concentration of dissolved solids in uncontaminated water was 1,650 milligrams per liter, whereas downgradient from the tailings area, the concentrations ranged from 2,320 to 21,000 milligrams per liter. The maximum volume of contaminated water was estimated to be 7,800 acre-feet.

The major effect of the leachate from the Vitro tailings on the confined aquifer was the contribution of measurable quantities of dissolved solids, chloride, sulfate, and iron. The concentration of dissolved solids upgradient from the tailings was 330 milligrams per liter, and beneath and downgradient from the tailings the concentrations were 864 and 1,240 milligrams per liter. The minimum volume of contaminated water in the confined aquifer was estimated to be about 12,000 acre-feet.

A calibrated, 3-dimensional, ground-water flow model was used to simulate potential changes in the potentiometric surface due to hypothetical ground-water withdrawals from a postulated well field in the vicinity of the Salt Lake International Center. Using a pumping rate of 30 cubic feet per second, it would require about 3,900 years for the saline ground water from beneath the lake to travel the 7 miles to the postulated well field.

INTRODUCTION

A detailed study of the hydrologic system in the Salt Lake Valley (fig. 1) was completed in 1970 by Hely and others (1971), who provided a comprehensive description of the ground-water system and predictions of the effects of future development based on an analog model. In 1981, the U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, began a 4-year study to determine changes in ground-water conditions in the Salt Lake Valley since the study of Hely and others (1971) and to predict the effects of possible increased withdrawals on the ground-water system. This report, which is the second report resulting from the later study, emphasizes sources of contamination of the ground water and chemical-quality changes during 1969-85; the report includes predicted effects of increased withdrawals on the chemical quality of the ground water. The first report (Seiler and Waddell, 1984) described the results of an investigation of the shallow unconfined aquifer during 1982-83. The third report (Waddell and others, 1987), emphasizes the ground-water budget for 1969-82 and includes predictions by means of a digital-computer model of increased withdrawals on water levels and ground-water discharge.

This report was prepared by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources. Organizations that contributed to the investigation through the Utah Department of Natural Resources were: Salt Lake County Water Conservancy District, Central Utah Water Conservancy District, Granger-Hunter Improvement District, Magna Water Co. and Improvement District, City of Midvale, City of Murray, Salt Lake City Department of Public Utilities, City of Sandy, City of South Salt Lake, Taylorsville-Bennion Improvement District, City of West Jordan, Holladay Water Company, and White City Water Co.. The period of study on which this report was based is July 1981 to September 1985, but historical data from 1931 until July 1981 were included in the analysis.

WELL- AND SPRING-NUMBERING SYSTEM

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and it is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres[1]. The letters a, b, c, and d indicate, respectively, the northeast, northwest,

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[1] Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

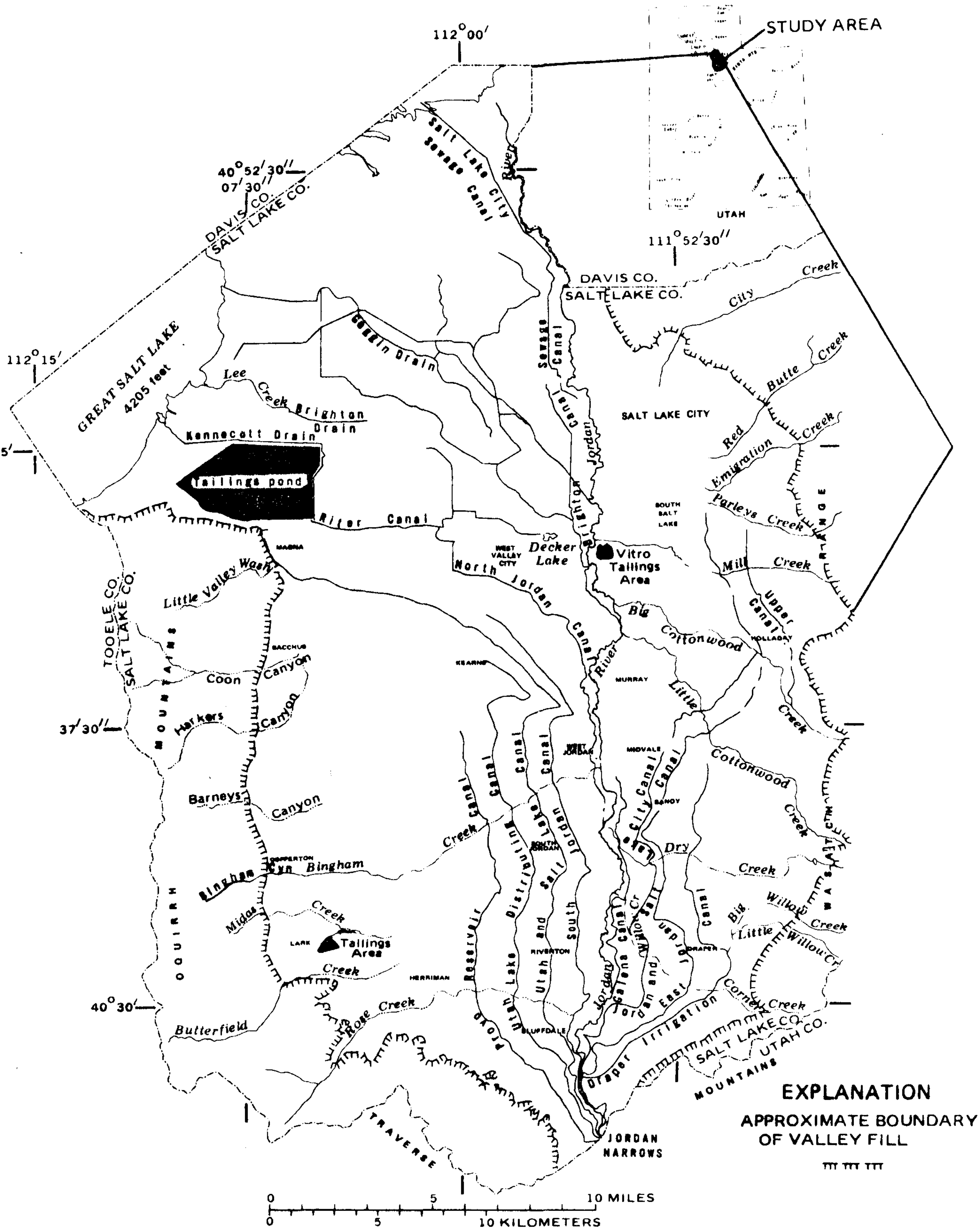


Figure 1.—Location of the study area.

southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract. If the well cannot be located within a 10-acre tract, 1 or 2 location letters are used and the serial number is omitted. Thus, (D-2-1)13acb- 1 designates the first well constructed or visited in the NW$\frac{1}{4}$ SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 13, T.2S., R.1E. The numbering system is illustrated in figure 2.

GROUND-WATER OCCURRENCE

Ground water in the Salt Lake Valley occurs in basin fill in (1) a deep confined (artesian) aquifer, (2) a deep unconfined aquifer between the artesian aquifer and the mountains, (3) a shallow unconfined aquifer overlying the artesian aquifer, and (4) local, unconfined perched aquifers (fig. 3). (See Hely and others, 1971, p. 107-111.) All the unconsolidated water-bearing materials in the valley are connected hydraulically to some degree; thus, together they compose the ground-water reservoir in Salt Lake Valley. The deep confined and unconfined aquifers form the principal aquifer from which most wells obtain water. Most of the water that reaches the deep confined aquifer first passes through the deep unconfined aquifer along the edges of the valley (fig. 3).

Overlying the deep confined aquifer are interfingered deposits of clay, silt, and fine sand, which form a confining layer that ranges from about 40 to 100 feet in thickness. The confining layer is coextensive with the outline of the confined and perched aquifers.

The shallow unconfined aquifer overlies the confining layer, and although the exact thickness of the aquifer is unknown in much of the valley the maximum thickness probably is about 50 feet. The shallow unconfined aquifer is recharged by leakage upward from the deep confined aquifer through the confining layer as well as downward by infiltration from precipitation, canals, irrigated lands, and streams. The shallow unconfined aquifer yields only small quantities of water to wells, and it is contaminated in much of the valley; thus, it is seldom used for domestic or industrial supply (Seiler and Waddell, 1984, p. 1).

The basin fill that contains the ground-water reservoir is of Quaternary age. Underlying the Quaternary deposits are relatively impermeable semiconsolidated deposits of Tertiary age or consolidated rocks of pre-Tertiary age.

VOLUME AND CHEMICAL QUALITY OF RECHARGE WATER AND EFFECT ON WATER IN AQUIFERS

A large part of the recharge to the ground-water reservoir in Salt Lake Valley is from bedrock in the mountains adjacent to the basin fill. Waddell and others (1987, table 1) estimated that the average annual recharge from bedrock to the the ground-water reservoir during 1969-82 was 157,000 acre-feet, which is about 45 percent of the total recharge. Virtually all recharge from the bedrock is believed to enter the deep-unconfined part of the principal aquifer. The quality of that recharge along the eastern edge of the valley probably is similar to the quality of water in streams that enter the

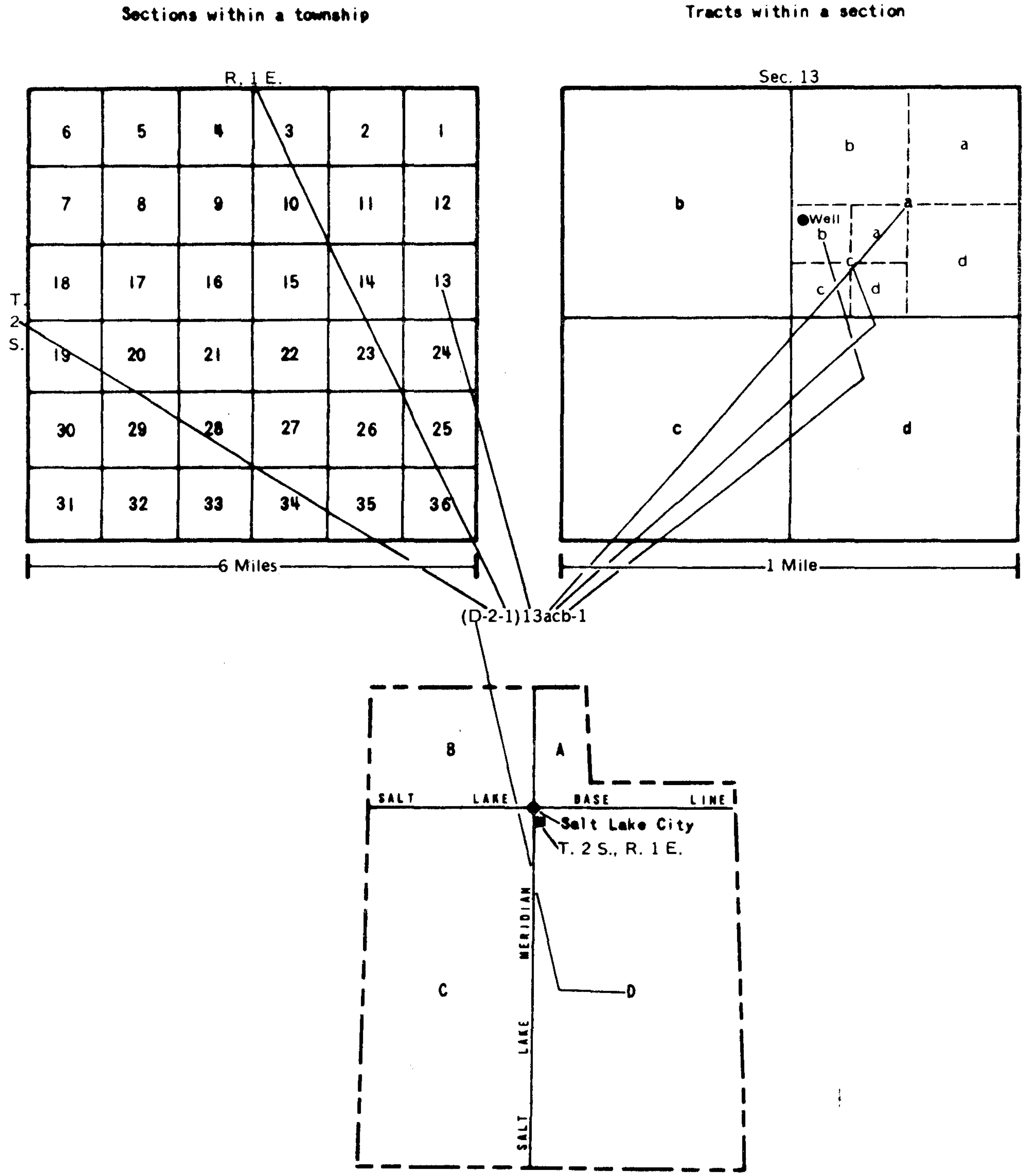


Figure 2.—Well-and spring-numbering system used in Utah.

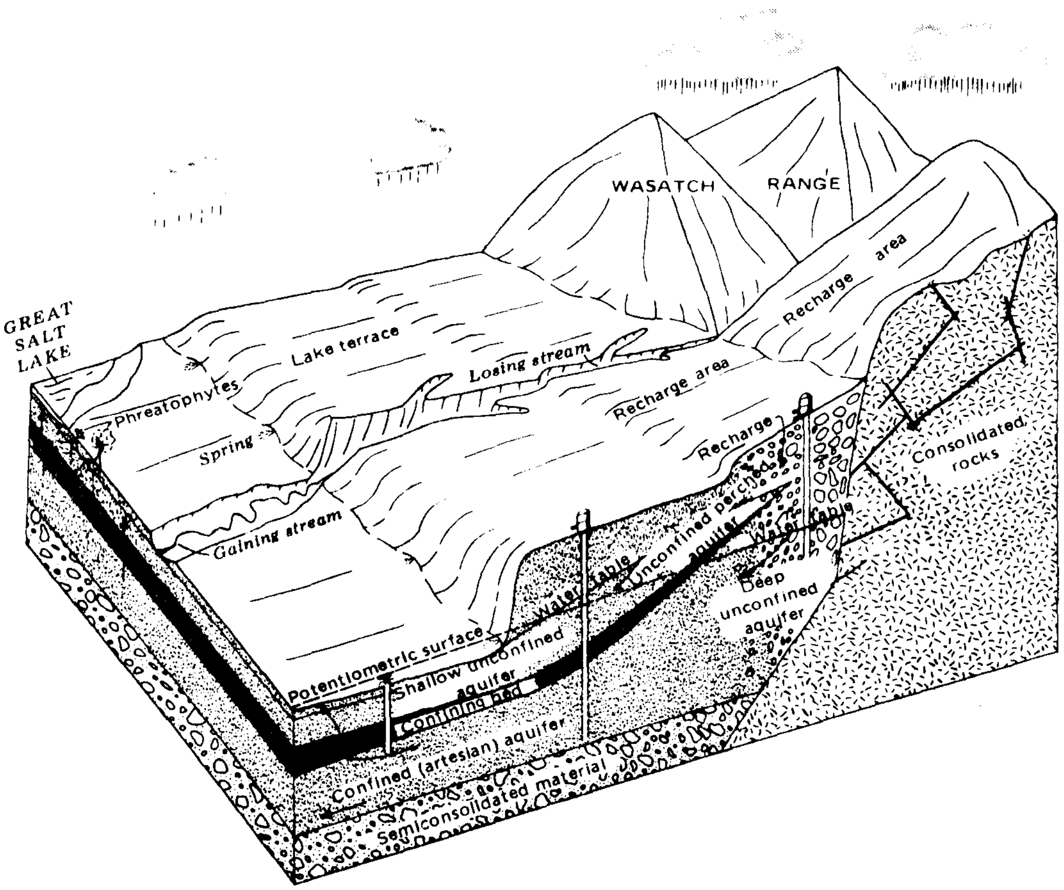


Figure 3.—Generalized block diagram of the ground-water reservoir. (Modified from Hely and others, 1971, fig. 57.)

valley from the Wasatch Range during low flow. Hely and others (1971, p. 162) determined that the dissolved-solids concentration of average low flows ranged from 137 to 227 milligrams per liter from Big and Little Cottonwood Creeks and from 245 to 520 milligrams per liter from City, Red Butte, Emigration, Parleys, and Mill Creeks.

Hely and others (1971, pl. 2) presented the concentration of dissolved solids in the principal aquifer without distinction by depth, and this presentation was updated on plate 1 with data collected during 1979-84. Differences in the concentration of dissolved solids along the eastern boundary of the basin fill reflects the differences in the quality of recharge from bedrock and from streams. North of the Big Cottonwood Creek area as far as City Creek and south of Little Cottonwood Creek to the Jordan Narrows the dissolved-solids concentration ranges from about 250 to 1,000 milligrams per liter, whereas in the vicinity of Big and Little Cottonwood Creeks the concentration ranges from about 100 to 250 milligrams per liter.

The recharge from bedrock in the Oquirrh and Traverse Mountains is considerably less than that from the Wasatch Range (Hely and others, 1971, p. 120-121) and the water contains greater concentrations of dissolved solids. Hely and others (1971, p. 163) determined that the dissolved-solids concentrations in water from eight wells along the Oquirrh Mountains ranged from 408 to 1,460 milligrams per liter. Data collected from five additional wells during 1981-84 indicated that dissolved-solids concentrations ranged from 430 to 910 milligrams per liter in areas not directly downdip from mining activities (pl. 1). Also data collected from four wells during 1981-84 along the north side of the western half of the Traverse Mountains indicated that dissolved-solids concentrations ranged from 550 to 1,140 milligrams per liter. Much of the recharge area between Copperton and Lark has been contaminated by drainage associated with mining activities and dissolved-solids concentrations are considerably greater than 1,500 milligrams per liter in several wells. A detailed discussion of this area is presented in a subsequent section of the report.

About 72,000 acre-feet or 20 percent of the total recharge to the ground-water reservoir comes from seepage from canals and irrigated fields (Waddell and others, 1987, table 1). A large part of this recharge is in the southwestern part of the valley where the dissolved-solids concentration of the water from the Provo Reservoir Canal was reported to be 231 milligrams per liter and that of the Utah Lake Distributing and Utah and Salt Lake Canals to be 1,120 milligrams per liter (Hely and others, 1971, p. 163). A large part of the seepage from the Provo Reservoir Canal enters the principal aquifer, upgradient from the confining layers. The dissolved-solids concentration in water from the Provo Reservoir Canal is considerably smaller than that of the ground water in the area; thus, the quality of the ground water is improved by the seepage from the Provo Reservoir Canal.

Much of the seepage from the Utah Lake Distributing and Utah and Salt Lake Canals enters the shallow unconfined aquifer. Some of the seepage probably reaches the principal aquifer; at least in the area where there is a downward hydraulic gradient from the shallow unconfined aquifer to the principal aquifer. In most of the area receiving seepage from these canals, the concentration of dissolved solids in the principal aquifer ranges from 500 to 2,000 milligrams per liter; thus, the effect of the seepage on the quality of the ground water is locally variable—in some areas it improves the quality and in others it is detrimental.

The concentration of dissolved solids in the shallow unconfined aquifer ranges from less than 1,000 to 29,000 milligrams per liter (pl. 2). The smallest concentrations are on the east side of the valley, and the largest concentrations are in the northwest part of the valley near the Great Salt Lake. The local variability in concentration of dissolved solids as well as of the predominant dissolved constituents is quite large. This variability is attributed to localized differences in evaporation and transpiration, application of fertilizers, road salt, contaminants from landfills and tailings areas, and differences in the source and quantity of recharge.

CHANGES IN CHEMICAL QUALITY OF GROUND WATER SINCE 1968

During 1979-84, 35 wells that had been sampled during 1962-67 were resampled to determine if water-quality changes had occurred in the principal aquifer. The dissolved-solids concentration of the water from 13 of the wells has increased by more than 10 percent since 1962-67 (table 1). The increases apparently have resulted from contamination in recharge areas. Water from mining-related operations, which is stored in ponds and reservoirs in recharge areas in the Oquirrh Mountains, has caused the concentrations of dissolved solids and sulfate to increase in some wells between the mouth of Bingham Canyon and the Jordan River. This is discussed in more detail in a subsequent section of the report.

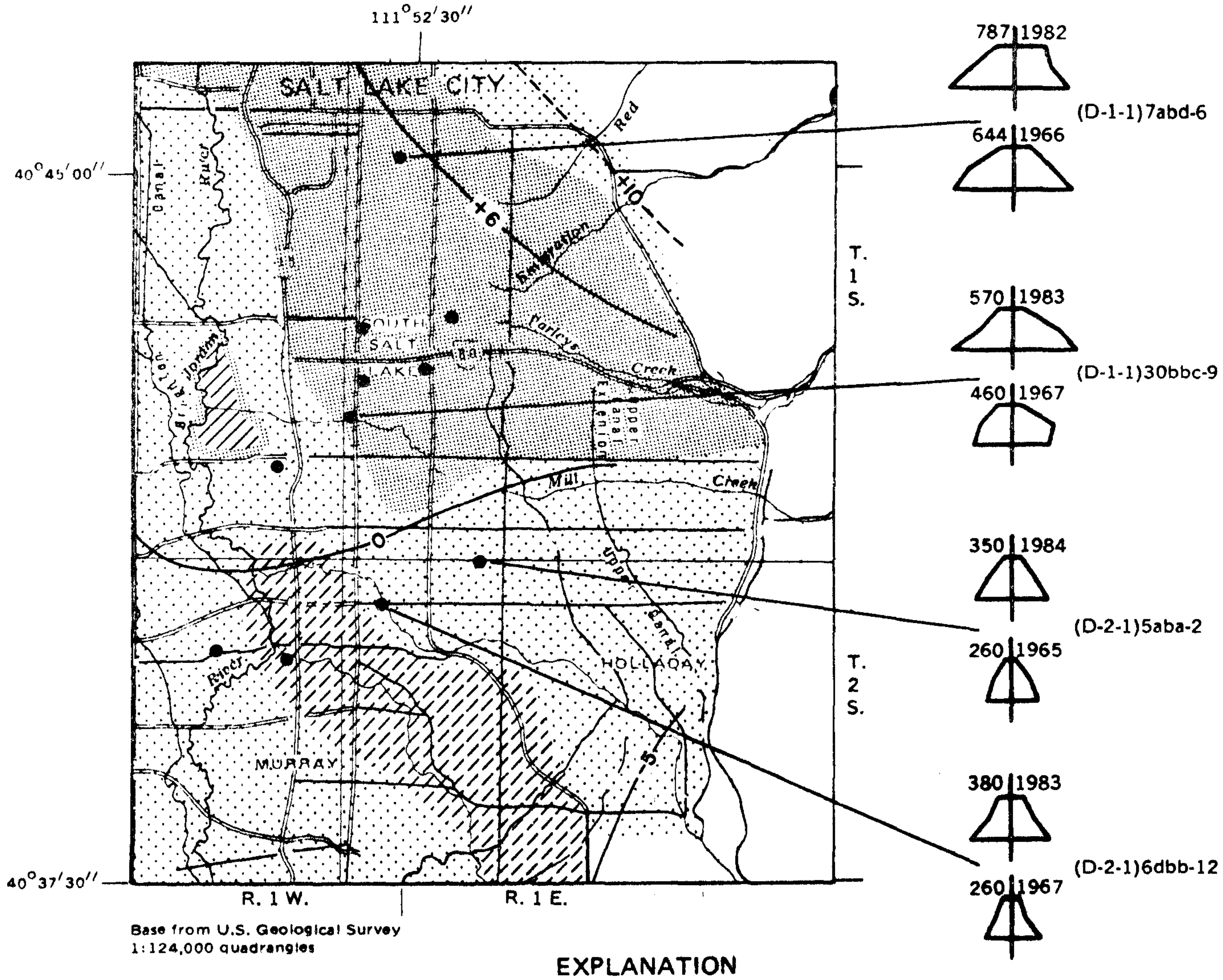
Between 1962-67 and 1979-84 the concentration of dissolved solids in water from wells (D-1-1)30bbc-9, (D-2-1)5aba-2, and (D-2-1)6dbb-12 increased 24, 35, and 46 percent, respectively, with calcium, sulfate, and bicarbonate accounting for most of the increase. The reasons for these increases are not known, but the changes in chemical composition between 1962-67 and 1979-84 were similar and indicate that the causes of the increased concentrations may be due to the same factor(s). The changes in chemical composition of water from wells (D-1-1)30bbc-9, (D-2-1)5aba-2, and (D-2-1)6dbb-12 is illustrated in figure 4. These changes may be related to the same factors that have contributed to the rises of water levels in the east central part of the valley. Between 1969 and 1983, water levels rose as much as 15 feet in the east central part of the study area, whereas declines as great as 5 feet occurred south of South Salt Lake (fig. 4). This relative change of water levels may have resulted in a southwestward movement of some of the water indicated in figure 4 to contain 500-1,000 milligrams per liter dissolved solids.

Considerable urban development has occurred along the bench areas in the eastern part of Salt Lake Valley since 1965, and much of the precipitation that formerly seeped into the recharge areas now runs into storm drains that empty into the Jordan River. The source of much of the water that now percolates to the water table is irrigation water applied to lawns and gardens. Such water contains fertilizers and other added materials which may be causing chemical changes in the ground water downgradient. The extent of these effects cannot be verified with available data.

Table 1.—Summary of water-quality changes in selected wells between 1962-67 and 1979-84

[Dissolved-solids concentration: Sum of constituents except where noted by r, residue on evaporation at 180° Celsius.]

Well	Dissolved-solids concentration (milligrams per liter)		Constituents having the greatest change where the dissolved-solids concentration increased by more than 10 percent	
	1962-67	1979-84	Cation	Anion
(B-1-2) 2dac- 2	485(r)	513(r)		
7caa- 1	3,400	3,100		
7ccc- 1	4,680(r)	4,900		
8abd- 1	880	890		
15bcd- 2	480	450		
16caa- 1	1,300	1,600	Sodium	Chloride
19aca- 1	1,300	1,200		
23bbd- 1	930	930		
36baa- 1	3,930(r)	3,700(r)		
(C-1-1)15bdd-11	500	490		
25cca- 2	260	260		
27dac- 4	340	340		
(C-1-2) 2aba- 2	880	980	Sodium	Chloride
6aaa- 4	1,900	2,200	Sodium	Chloride
22bdd- 4	1,040(r)	1,130(r)		
22cbb- 1	980	1,300	Sodium	Sulfate
(C-2-1)11bad- 1	390	320		
12bac- 1	140(r)	183(r)	Calcium	Sulfate
(C-3-1) 7cbb- 1	530	730	Calcium	Sulfate
12ccb- 1	561(r)	598(r)		
15dda- 1	360	700	Calcium	Chloride
30acd- 1	730	790		
(C-3-2)12dbc- 2	740	1,400	Calcium	Chloride
33cac- 1	785(r)	782(r)		
(C-4-1)23dbb- 1	670	620-730		
(C-4-2) 1bbb- 1	620	750	Calcium	Chloride
(D-1-1) 7abd- 6	644(r)	787(r)	Calcium	Chloride
19bac- 4	590	580		
19cdb-17	620	630		
20bab- 1	650	640		
20cbc- 1	600	630		
30bbc- 9	460	570	Calcium	Sulfate
(D-2-1) 5aba- 2	260	350	Calcium	Sulfate
6dbb-12	260	380	Calcium	Sulfate
(D-3-1)31abb- 1	260	280		



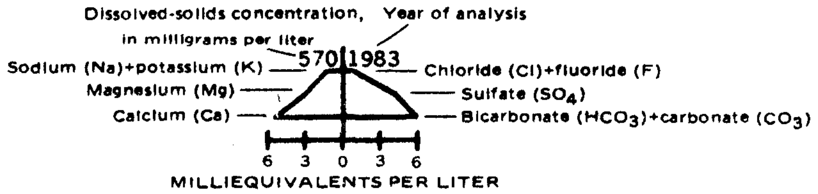
Base from U.S. Geological Survey 1:124,000 quadrangles

EXPLANATION

DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER, 1979-84

▨	100 - 250
░	250 - 500
▒	500 - 1000
▨	1000 - 2000
☐	No data

WATER-QUALITY DIAGRAMS (AFTER STIFF, 1951)



—+6— — LINE OF EQUAL CHANGE OF WATER LEVEL, FEBRUARY-MARCH 1969 TO FEBRUARY-MARCH 1983—Dashed where approximately located. Interval, in feet, is variable. From Waddell and others (1987, fig. 10)

● WELL AT WHICH CHEMICAL-QUALITY DATA WERE OBTAINED DURING 1965-67 AND 1982-84

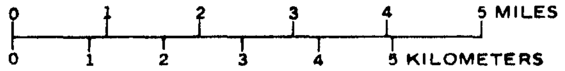


Figure 4.—Chemical composition of water during the 1960's and 1980's and change of water levels between 1969 and 1983 for the principal aquifer in the east-central part of Salt Lake Valley.

The concentrations of dissolved solids and chloride increased considerably in water from well (D-1-1)7abd-6 during 1931-85 (fig. 5). The concentration of dissolved solids in 1931 was about 570 milligrams per liter; but during the late 1950's it began to increase gradually, and by 1985 it was about 710 milligrams per liter. The trend of chloride concentration was similar to that of dissolved-solids concentration, and the chloride concentration almost doubled between 1971 and 1985. Water levels fluctuated about a consistent level during 1931-65, but then a rising trend began that continued through 1983. The rising water levels may be indicative of an increase in recharge or a local decrease in discharge (pumping of wells), which may or may not be related to the larger concentrations of dissolved solids and chloride.

The increased concentrations of chloride were accompanied by increases of sodium and calcium (fig. 4). Some of the increase in sodium and chloride concentration may be due to storage and use of road salt in the recharge areas and in the canyons of the Wasatch Range.

In about 10 percent of the Salt Lake Valley, water produced from the principal aquifer contains more than 1,000 milligrams per liter dissolved solids. This estimate was derived from data on plate 1, which shows the concentration of dissolved solids in water from the principal aquifer. The dissolved-solids concentration in water from 2 wells also increased to more than 1,000 milligrams per liter from 1962-67 to 1979-84 (table 1). This, together with the increases of dissolved solids in 11 other wells (table 1), indicates that the percentage of water in the principal aquifer in the Salt Lake Valley that exceeds 1,000 milligrams per liter dissolved solids may be increasing.

Water from wells (C-2-1)12bac-1, (D-1-1)7adb-6, (D-1-1)30bbc-9, (D-2-1)5aba-2, and (D-2-1)6dbb-12 on the eastern side of the valley had an increase in dissolved-solids concentration of greater than 10 percent between 1962-67 and 1979-84. The average concentration for these five wells, which was 450 milligrams per liter in 1979-84, increased by an average of 6 milligrams per liter per year since 1962-67. West of the Jordan River, in about 40 percent of the area, or 10 percent of the Salt Lake Valley, the principal aquifer produces water that contains more than 1,000 milligrams per liter dissolved solids. Twenty-three wells west of the Jordan River were resampled during 1979-84, and many of the wells were in areas where the concentrations exceeded 1,000 milligrams per liter. Also, three wells were sampled in an area of suspected contamination. Eliminating those wells that were resampled that exceeded 1,000 milligrams per liter and the three wells that were in areas of suspected contamination, the rate of increase was estimated to be 6 milligrams per liter per year and the average concentration in water from the remaining area was about 700 milligrams per liter. Because this increase in dissolved-solids concentration will affect the quality of water that is used for public consumption, the reasons for the increase in dissolved solids need to be determined.

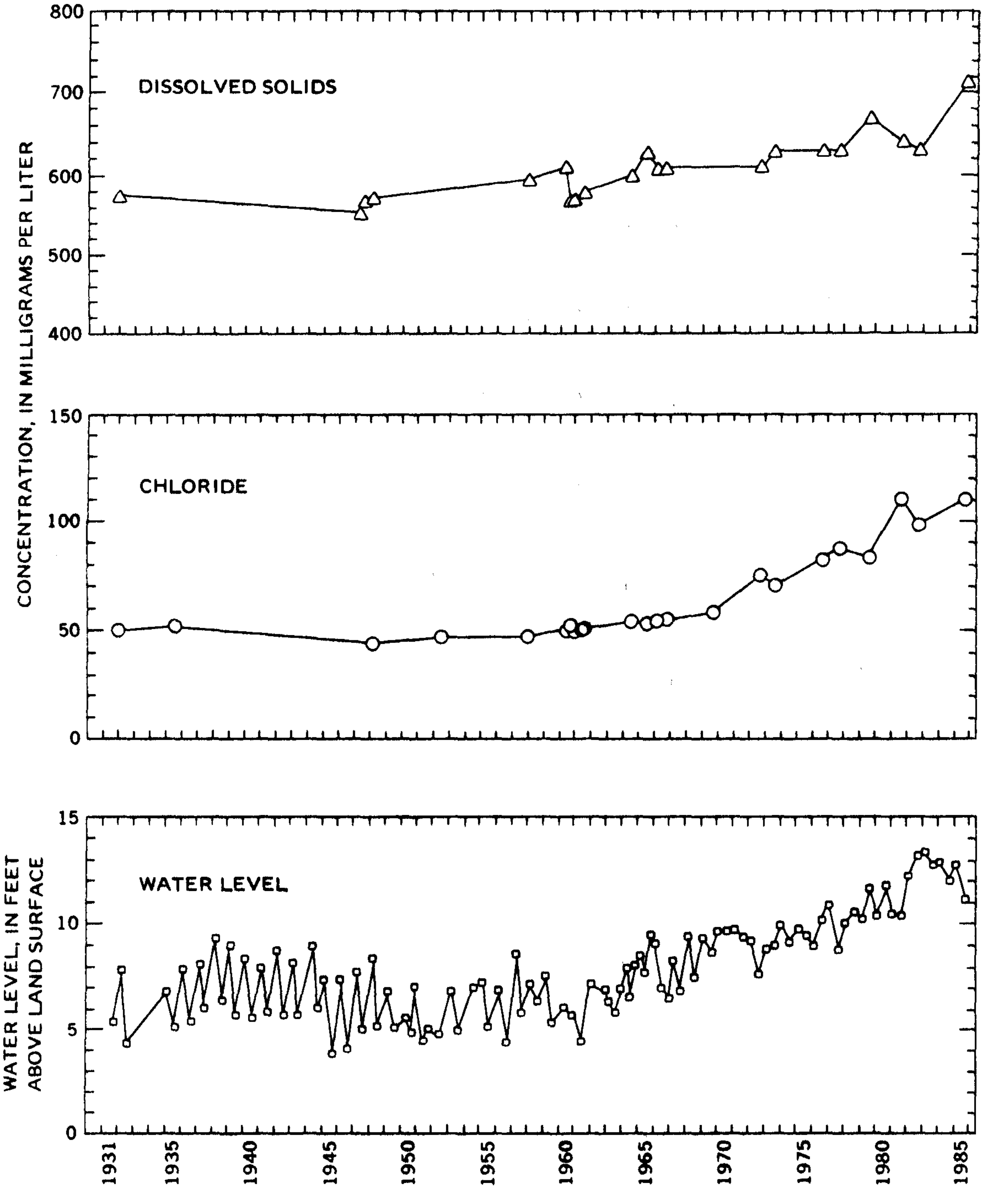


Figure 5.—Concentrations of dissolved solids and chloride, and water levels for well (D-1-1)7abd-6, 1931-85.

SUSCEPTIBILITY OF GROUND WATER TO CONTAMINATION BY AREA

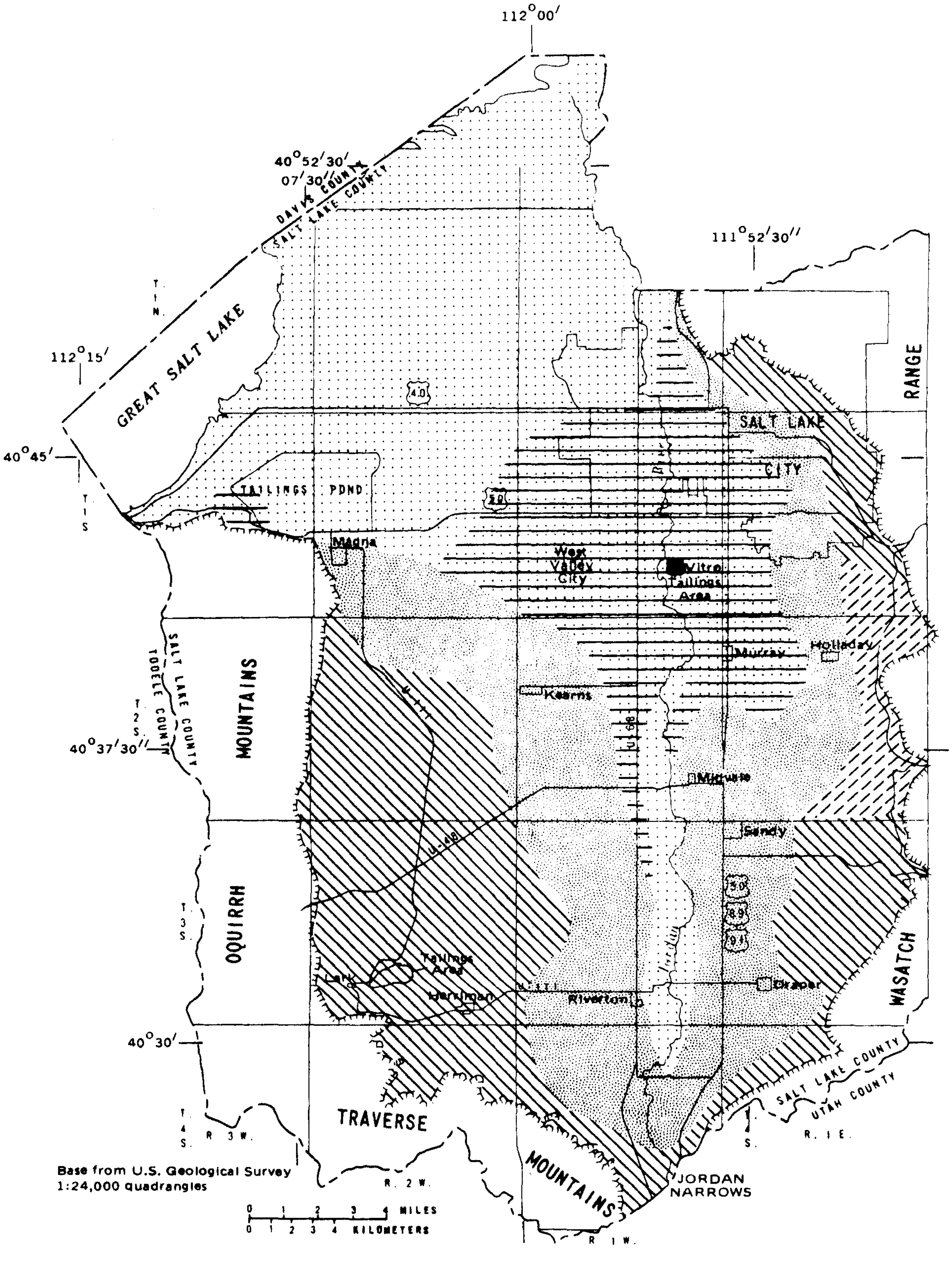
The Salt Lake Valley was divided into areas where the susceptibility of ground water to contamination is similar based on differences in geology, the rate of ground-water movement, and direction of vertical hydraulic gradients. The rate of travel of contaminants is dependent on the rate of ground-water movement and other factors including dispersion and advection and sorptive characteristics of the soil and aquifer through which the contaminants move. The rate of ground-water movement is directly proportional to the product of the hydraulic conductivity and the hydraulic gradient, therefore, these factors are important in determining how fast contaminants will spread through an aquifer. Vertical gradients, which are downward in recharge areas can cause contaminants to move deep into an aquifer. Then, if these contaminants move into the confined part of the aquifer, where the downward gradient eventually is reversed and movement is upward toward discharge points such as wells and rivers or areas of phreatophytes, the contaminants become further dispersed through the aquifer.

The Salt Lake Valley was divided into four general areas where the susceptibility of ground water to contamination is similar as shown in figure 6. Areas 1 and 2, which have the greatest susceptibility, are areas where contaminants can infiltrate directly to the principal aquifer without appreciable impediment by fine-grained deposits. For the saturated parts of the principal aquifer, area 1 was separated from area 2 on the basis of rates of ground-water movement. For the saturated parts of the principal aquifer in both areas, assuming equal porosity, the relative rates of movement, V_1 and V_2, were computed from the ratio of the product of the permeability, K, and the hydraulic gradient, I, of each area. Area 1 was defined as having 10 times the rate of area 2, or

$$V_1 = 10 \times V_2 = \frac{10 \text{x} K_2 I_2}{K_1 I_1}$$

Thus, contaminants (after they have reached the water table) in area 1 will move about 10 times faster than those in area 2.

Areas 3 and 4 are areas of intermediate to least susceptibility to contamination where the shallow unconfined and principal aquifers are separated by a confining layer, and the downward migration of contaminants is impeded by the fine-grained materials in the confining layer. Also, in area 3, the vertical hydraulic gradient is either downward into the principal aquifer or is zero. In area 4, the vertical hydraulic gradient is upward; therefore, this area has less susceptibility for infiltration of contaminants through the confining layer to the principal aquifer. The direction of the vertical hydraulic gradients for areas 3 and 4 were determined by computing the differences between the water levels in the shallow unconfined and principal aquifers during 1983. A decline of water levels in the principal aquifer in area 4 could decrease the upward gradient or reverse it, in which case the area would have the same susceptibility as area 3. Locally within each of the four areas, the presence or absence of confining layers may cause the classification shown in figure 6 to be in error; therefore, it is appropriate for use only as a general guideline.



Base from U.S. Geological Survey
1:24,000 quadrangles

Figure 6.—Areas of differing susceptibility for contamination of water in the principal aquifer.

EXPLANATION

☐ OUTSIDE BOUNDARY OF PRINCIPAL AQUIFER

Boundaries between areas 1 and 3 and between areas 2 and 3 modified from Hely and others (1971, fig. 58)

Boundary between areas 3 and 4 modified from Hely and others (1971, pl. 1)

AREA	SUSCEPTIBILITY TO CONTAMINATION	CRITERIA
1	Greatest	Unconfined recharge area, rapid ground-water velocity
2	Great	Unconfined recharge area, ground-water velocity 1/10 that in area 1
3	Intermediate	Clay layer overlies principal aquifer, downward hydraulic gradient
4	Least	Clay layer overlies principal aquifer, upward hydraulic gradient
▤	Area in which susceptibility increases from least (area 4) to intermediate (area 3) during a hypothetical increase in well discharge	
╥╥╥	APPROXIMATE BOUNDARY OF VALLEY FILL	

Waddell and others (1987, p. 31) evaluated the effects of doubling the pumpage of all wells existing in 1982 that discharged more than 0.3 cubic foot per second (an increase from 115,000 to 180,000 acre-feet). After about 38 years of pumping, the upward hydraulic gradient that existed in 1982 was reversed in part of the confined aquifer. The part of area 4 that was transformed to the same susceptibility as area 3 by the increased pumping is indicated in figure 6.

In areas 1 or 2, leakage or spills of contaminants into or onto the ground could result in long-term contamination of the principal aquifer. For example, an unknown spill of contaminant in area 1 (fig. 6) might percolate to the water table at considerable depth below the land surface and spread throughout a large area within the principal aquifer before being detected. The principal aquifer in areas 3 and 4 is less susceptible to contamination. Water-level declines in the principal aquifer that caused a reversal of the upward hydraulic gradient in area 4, however, could result in the movement of water from the shallow unconfined aquifer or from the Jordan River into the principal aquifer.

AREAS OF GROUND-WATER CONTAMINATION

The extent of contaminated ground water in the Salt Lake Valley ranges from areas of less than 0.1 square mile to areas greater than 5 square miles. The contaminants include both organic and inorganic constituents, and some have infiltrated only to the shallow unconfined aquifer, whereas others have caused deterioration of the water quality in the principal aquifer.

Seiler and Waddell (1984, p. 1) reported that organic chemicals were detected in water from several wells completed in the shallow unconfined aquifer, with the greatest concentrations in water from wells near landfills or tailings areas (pl. 2). The greatest measured concentrations were: benzene, 400 micrograms per liter; phenol, 660 micrograms per liter; 1,1 dichloroethane, 20 micrograms per liter; trichloroethylene, 8 micrograms per liter; and chloroethylene, 11 micrograms per liter. All these concentrations exceed the recommended limits by the U.S. Environmental Protection Agency (1980) of zero for carcinogens.

Additional unpublished data obtained by the Utah Division of Environmental Health after completion of the study by Seiler and Waddell (1984) indicate that at several sites in the valley the shallow unconfined aquifer contains exceedingly large concentrations of organic chemicals. Concentrations of napthalene in three samples of water from a shallow excavation in T.1S., R.1W., sec. 2, 2 miles west of Salt Lake City, ranged from 400 to 5,000 micrograms per liter; concentrations of trichloroethylene in water from two wells in T.1S., R.1W., sec. 16, in West Valley City, ranged from 2,100 to 910,000 micrograms per liter; and the cumulative concentration of several toxic organic chemicals in water from wells in T.1S., R.1W., sec. 14, in South Salt Lake, totaled 1,180 micrograms per liter. All these concentrations exceed the recommended limit by the U.S. Environmental Protection Agency (1980) of zero for carcinogens.

The greatest concentrations of trace elements in water in the shallow unconfined aquifer were from wells near landfills or tailings areas. The greatest measured concentrations were: arsenic, 360 micrograms per liter; cadmium, 200 micrograms per liter; iron, 37,000 micrograms per liter; and mercury, 0.1 microgram per liter. All these concentrations, except for mercury, exceed the quality criteria of the U.S. Environmental Protection Agency (1977 and 1980) for domestic water supply (Seiler and Waddell, 1984, p. 1).

Contamination of the principal aquifer by organic chemicals has not been documented, but contamination by inorganic chemicals has caused deterioration of the quality of the ground water in two known areas in the Salt Lake Valley. These areas are discussed below.

Area East of Copperton

Copper, molybdenum, gold, silver, lead, and zinc have been mined in the Bingham Mining District in the Oquirrh Mountains near Copperton in the southwest part of the Salt Lake Valley since 1863, shortly after the settlement of the valley. Two reservoirs in the mouth of Bingham Canyon (pl. 3) were constructed by Kennecott Minerals Co. in the early- to mid-1960's to contain mine drainage and waste waters from ore-leaching facilities. Evaporation ponds about 4.5 miles east of the reservoirs also have received mine-waste waters, and aerial photographs taken by the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, show that these ponds have been in existence since at least 1946. Much of the water in the principal aquifer between the mouth of Bingham Canyon and the Jordan River about 10 miles to the east has been contaminated by seepage from the reservoir and evaporation ponds (pl. 3). Many domestic and irrigation wells in the area yield water with concentrations of dissolved solids that exceed 2,000 milligrams per liter (pl. 3).

Hely and others (1971) sampled several wells in the area during 1964-68, and as many of those wells as possible were resampled during 1979-84. Kennecott Minerals Co., Utah Copper Division, presently (1985) is midway through a study to assess environmental problems associated with past mining activities. The numbering system for Kennecott's observation wells and much of the chemical and water-level data used herein were obtained from the Kennecott Minerals Co. (1984a, b).

Hydrology

The deep unconfined part of the principal aquifer near the Oquirrh Mountains receives ground-water recharge from bedrock, precipitation on the land surface, and seepage from ephemeral streams, reservoirs, and evaporation ponds. About 5 miles downgradient from the mountain block, the principal aquifer becomes confined by fine-grained deposits that extend under the Jordan River to the east side of the valley (pl. 3). The shallow unconfined aquifer above the confining layer is recharged by upward leakage from the deep confined aquifer and from seepage from canals, irrigation, and seasonal inflow from the ephemeral streams.

Hely and others (1971, fig. 58) indicate that the western boundary of the shallow unconfined aquifer and confining layer is slightly west of the evaporation ponds. Data collected during 1983-84, however, indicate that the confining layer does not extend west of the easternmost evaporation pond (pl. 3). A test hole drilled to 95 feet below land surface at the east edge of the evaporation ponds encountered water at 89.5 feet below land surface (about 4,627 feet above sea level) and "...did not encounter any clayey confining beds..." (Christenson, 1985, p. 13). Logs for well P199, which is about 0.25 mile east of the easternmost evaporation pond (pl. 3), do not indicate clay layers shallower than 110 feet below land surface. The water level in well P199 was about 105 feet below land surface, and there was no evidence of a shallow unconfined or perched zone at shallower depths.

About 0.5 mile east of the easternmost evaporation pond, the logs of wells (C-3-1)8cdd-2, and -3, indicate thin clay, sand, and gravel layers at about 70 and 110 feet but no clay below 110 feet. The principal aquifer is not under artesian pressure, and the water surface is about 200 feet below the land surface. About 0.5 mile east of wells (C-3-1)8cdd-2, and -3, and 1 mile east of the easternmost evaporation pond, the logs of wells (C-3-1)8dda-1, 9ccc-1, and 16bcb-1 indicate the presence of thick clay layers, and water levels show that the aquifer is under artesian pressure. The western boundary of the confining beds along section A-A' (pl. 3) is estimated to be about 0.25 mile east of wells (C-3-1)8cdd-2, and -3, or 0.7 mile east of the easternmost evaporation pond.

Seepage from the Provo Reservoir Canal is believed to recharge the principal aquifer and seepage from the Utah Lake Distributing Canal and the Utah and Salt Lake Canal is believed to recharge the shallow unconfined aquifer in this area. Herbert and others (1984, p. 39, fig. 15) reported that the Provo Reservoir Canal loses about 2 cubic feet per second per mile in the reach just east of the evaporation ponds. The Utah and Salt Lake Canal loses about 1 cubic foot per second per mile through the area.

The potentiometric surface of the principal aquifer from Bingham Canyon to the Jordan River is shown on plate 3. The average gradient of the potentiometric surface from the reservoirs in the mouth of Bingham Canyon to the Jordan River is about 100 feet per mile. The gradient directly east of the reservoirs is much steeper (about 330 feet per mile), but just east of this area and west of the westernmost evaporation pond the gradient ranges from less than 1 foot to about 100 feet per mile. A recharge mound under the westernmost evaporation pond distorts the regional pattern by forming an area where recharge water from the ponds moves not only east but also west against the regional pattern. The eastward gradient for about 0.9 mile directly east of the westernmost evaporation pond is about 260 feet per mile, whereas farther towards the river the gradient is about 20 feet per mile.

Near the mountain front, directly east of and downgradient from the reservoirs, the hydraulic head probably decreases with depth, as would be expected in a recharge area where water is moving down into the aquifer. There is little change in hydraulic head with depth in the area west of the upper evaporation ponds, as is illustrated by the almost vertical equipotential lines and horizontal flow lines on plate 3. Directly beneath the evaporation ponds, the hydraulic head probably decreases with depth, especially near the upper part of the saturated zone. This is illustrated on plate 3 by the convex downward shape of the equipotential lines and the almost vertical flow lines, which apparently result from recharge to the aquifer by seepage from the evaporation ponds.

East of the evaporation ponds, there is little vertical hydraulic gradient. Near the Jordan River, however, an upward gradient undoubtedly exists because, according to Hely and others (1971, p. 83), the river is gaining in the area intersected by section A-A' (pl. 3). The water moving up from the deep confined aquifer enters the shallow unconfined aquifer from which it discharges into the Jordan River and also into the atmosphere by evapotranspiration. Hely and others (1971, p. 186) estimate ground-water discharge by evapotranspiration at about 1,000 acre-feet per year in T.3S., R.1W., which includes the area from the evaporation ponds to the Jordan River (pl. 3). The Jordan River between the Jordan Narrows and 9400 South Street is estimated to gain about 4 cubic feet per second per mile from ground water (Hely and others, 1971, p. 83). Most of the water gained by the river, however, is from recharge from the Wasatch Range to the east.

Effects of Ore-Leaching Operations on Ground-Water Quality

The major sources of contamination to the ground water east of Bingham Canyon are the two reservoirs in the mouth of Bingham Canyon and the evaporation ponds about 4.5 miles to the east (pl. 3). Kennecott's mine waste has been artificially leached since the early 1930's. The waste is dumped along the east side of the Oquirrh Mountains and covers a 4.5-square-mile area that extends south from the town of Copperton (Kennecott Minerals Co., 1984b, p. 9). Aerial photographs taken by the U.S. Department of Agriculture show the existence of the evaporation ponds (pl. 3) and a feeder canal in 1946. A reservoir with a storage capacity of 60-acre-feet was constructed during 1962, and a 1,500-acre-foot reservoir was constructed during 1965. Prior to construction of the reservoirs, untreated mine drainage and waste water from the leaching process were discharged into Bingham Creek or diverted to the evaporation ponds. Thus, direct seepage from Bingham Creek could have contributed significant contamination to the ground-water system prior to construction of the reservoirs. Since construction of the reservoirs, the waste water has been treated with lime and is diverted to the evaporation ponds. Infiltration through the unlined bottoms of the reservoirs and evaporation ponds is a source of recharge of contaminated water to the principal aquifer.

Many of the metals that were mined in the Bingham Mining District are sulfide ores in fractured limestone (Kennecott Minerals Co., 1984a, p. 6). Metal sulfides can be oxidized on exposure to oxygen and water, and this results in (1) putting the metal ion into solution or into the form of an insoluble compound that is stable under surface conditions, (2) conversion of the sulfide ion to the sulfate ion, and (3) production of relatively acid solutions (Krauskoph, 1967, p. 514).

Nothing is known about the chemical quality of the ground water downgradient from Bingham Canyon prior to the beginning of leaching operations. However, along the Oquirrh Mountain front, wells (C-1-2)31aaa-1, (C-2-2)11adc-1, (C-2-2)16aab-1, and (C-3-2)33cac-1 (pl. 1) north and south of the leaching operations in Bingham Canyon, have water with dissolved-solids concentrations ranging from 390 to 910 milligrams per liter. The chemical composition of water from most of these wells is dominated by calcium, magnesium, bicarbonate, and chloride, as indicated by the water-quality diagrams on plate 1.

Before mining operations began in 1863, the recharge to the ground-water reservoir from the Oquirrh Mountains near Bingham Canyon may have had large sulfate and heavy-metal concentrations because of the natural oxidation of ores. Such waters also may have been acidic, but acidification probably was tempered by the presence of carbonate rocks that neutralized the acidity. Mining operations that increased the surface area of the metal sulfides exposed to the atmosphere would have increased the natural rate of acid production. In addition, leaching processes, wherein acidic water was passed through mine wastes in order to dissolve and recover minerals, would have resulted in acidic waters with large concentrations of dissolved solids and sulfate. Any increase of the concentration of dissolved solids or of any individual dissolved ion due to mining or leaching operations could result in eventual contamination of the ground-water reservoir.

Dissolved-solids concentrations exceeding 1,000 milligrams per liter downgradient from the mouth of Bingham Canyon usually are associated with large concentrations of dissolved sulfate and are considered to be indicative of contamination from leaching operations. Large concentrations of heavy metals such as copper, iron, lead, and zinc also are indicative of contamination from the leaching operations. The absence of these metals, however, does not indicate a lack of contamination because the metals can be adsorbed or precipitated from solution as the pH increases.

Water in the 1,500-acre-foot reservoir in the mouth of Bingham Canyon is acidic, with a pH ranging from 3 to 4. During 1978-83, concentrations of dissolved solids ranged from 43,000 to 68,000 milligrams per liter, and the concentrations of sulfate ranged from 34,000 to 41,000 milligrams per liter. The predominant ions in the water were magnesium, hydrogen, and sulfate (Kennecott Minerals Co., 1984b, p. A-69). The concentration of hydrogen ions contributed by the acidity were not included in the Stiff diagrams which depict chemical composition on plate 3. This accounts for the apparent imbalance of cations and anions represented by Stiff diagrams for the water with pH values less than about 4.5. The only available chemical analysis for the smaller, 60-acre-foot reservoir, made in December 1983, had a pH of 3.9; concentrations of dissolved solids are not given (Kennecott Minerals Co., 1984b, p. A-71). During March 1984, the pH ranged from 4.1 to 7.4 and the dissolved-solids concentrations from different parts of the evaporation ponds ranged from 5,000 to 8,700 milligrams per liter (Kennecott Minerals Co., 1984b, p. A-71). The evaporation ponds presumably have received more acidic and more mineralized water in the past. This is indicated by analyses of water made during 1975-78 from well K99, which was drilled in the evaporation ponds (pl. 3). The values of pH ranged from 3.6 to 4.7, concentrations of dissolved solids ranged from 35,900 to 55,400 milligrams per liter, and the chemical composition was dominated by magnesium, hydrogen, and sulfate (Kennecott Minerals Co., 1984b, p. A-27).

The horizontal movement and the change in chemical quality of water in the principal aquifer between the recharge areas near the mouth of Bingham Canyon and the discharge area near the Jordan River are illustrated on plate 3. The change in concentration of dissolved solids along section A-A' indicates that the reservoirs and evaporation ponds are sources of contaminants which are diluted downgradient. The plume of water from the reservoirs with concentrations of dissolved solids exceeding 2,000 milligrams per liter has not extended downgradient to the evaporation ponds during the more than 20 years during which the reservoirs have been in operation. A similar plume of contaminated water extends from the evaporation ponds, which have been in existence for at least 40 years, to within 1 mile of the Jordan River. There is little or no evidence of contamination in the deeper parts of the principal aquifer. Much of the deeper water contains less than 1,000 milligrams per liter dissolved solids, and the chemical composition generally is dominated by calcium, bicarbonate, and chloride.

A major transition in concentration and chemical composition takes place within about 1.5 miles downgradient from the reservoirs and the westernmost evaporation pond. For example, downgradient from the reservoirs the concentration of dissolved solids at wells K120, K88, and P213b ranged from about 48,000 to 74,000 milligrams per liter. The dominant dissolved ions were magnesium and sulfate, and the pH ranged from 3.1 to 3.4, indicating considerable acidity. At well P209b, which is about 0.55 mile downgradient from well P213b, the concentration of dissolved solids ranged from 2,550 to 3,380 milligrams per liter, the dominant dissolved ions were calcium and sulfate, the pH ranged from 6.9 to 7.4, indicating that most of the acidity had been neutralized. Also, the concentrations of bicarbonate were considerably greater at well 209b than at upgradient well P213b. The transition of chemical composition is due primarily to dissolution of carbonate minerals from the aquifer.

A similar transition in concentration and chemical composition takes place below the evaporation ponds (pl. 3). About 0.5 mile east of the evaporation ponds, however, a deep body of contaminated water was detected at well P199. The source of that water is unclear. Water sampled at nearby well P198, which is completed at a shallower depth than is well P199, contained a smaller dissolved-solids concentration than did the water at well P199. This indicates that deep percolation of contaminated water from the evaporation ponds through the aquifer is not the source of contamination in well P199. It may be that contaminated water is flowing down through the borehole or through a rupture in the casing of well P199. It is possible, however, that the source is contaminated water that seeps from the reservoirs in the mouth of Bingham Canyon and then moves downgradient at depth.

Changes in Ground-Water Quality

Changes in ground-water quality, which are believed to have resulted from migration of contaminants, have been detected in wells along section A-A' (pl. 3). The concentration of dissolved solids for eight wells during 1957-84 are summarized in figure 7. The graphs for the seven wells that are west of the Jordan River, which is the approximate ground-water divide, show short-term variations, and a few show long-term increases in the concentration of dissolved solids. Some of the short-term variations may be due to sampling and analytical error; but some peaks, such as were noted for wells K87, P196b, and P197a, may be due to variations in recharge, and they are discussed in detail in the following section on "Time of Travel of Ground Water".

Most of the changes in chemical composition are increases in the concentrations of calcium, magnesium, sulfate, and chloride. The changes are shown in figure 8 for four wells that were sampled in the 1960's and again in the 1980's. Increases in all constituents except chloride are consistent with the effects expected from passage of acidic waters containing large concentrations of magnesium and sulfate through an aquifer containing carbonate minerals. The reason for the increase of chloride is not known.

West of the evaporation ponds, an increase in concentration of dissolved solids from 1969-84 in well (C-3-2)14baa-1 (K109) was accompanied by an increase of sulfate (fig. 7). The concentration of dissolved solids was 410 milligrams per liter in 1969 and 1,070 milligrams per liter in 1984. The chemical composition of the water in 1969 was dominated by calcium, chloride, and bicarbonate; but in 1984 the composition was dominated by calcium, chloride, and sulfate, and it resembled the composition of contaminated water in nearby well P197b. (Compare water-quality diagrams on plate 3.)

The chemical quality of water from wells (C-3-1)7cbb-1 and (C-3-2)12dbc-2 also has deteriorated since the late 1960's. The concentration of dissolved solids in water from well (C-3-1)7cbb-1 increased from 530 milligrams per liter in 1967 to 730 milligrams per liter in 1984 (table 1). The chemical composition of the water in 1967 (fig. 8) was dominated by calcium, chloride, and bicarbonate, whereas in 1984, calcium, chloride, and sulfate were the dominant ions. The concentration of dissolved solids in water from well (C-3-2)12dbc-2 increased from 740 milligrams per liter in 1966 to 1,400 milligrams per liter in 1984 (table 1), and notable increases in the concentration of all major constituents were observed in 1984 (fig. 8).

East of the evaporation ponds, changes in concentration of dissolved solids in water from some wells indicate the continued downgradient movement of contaminants. The concentration of dissolved solids in water from well

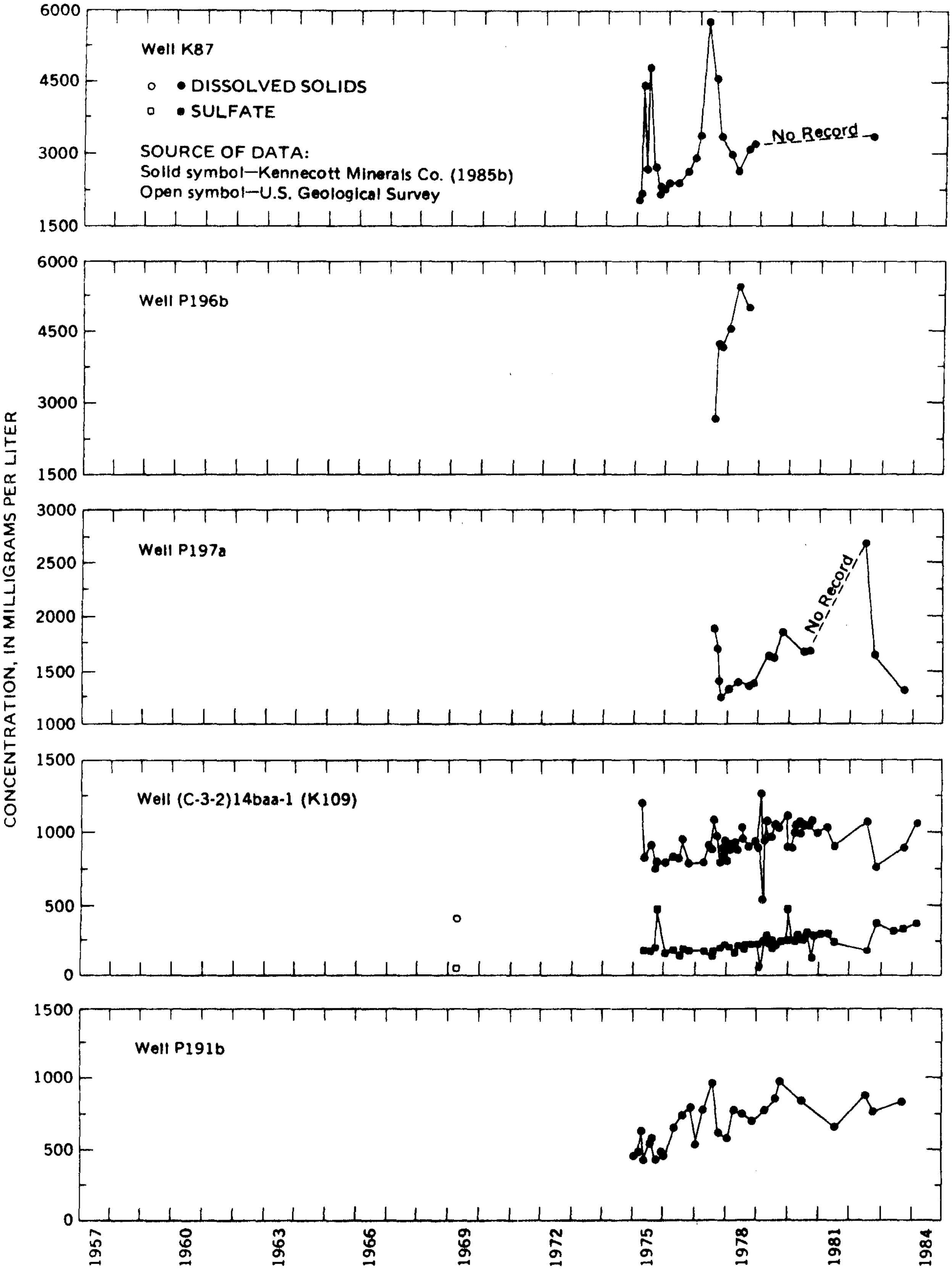


Figure 7.—Concentration of dissolved solids and sulfate in water from selected wells along flow line from Oquirrh Mountains to the Jordan River (section A–A′, plate 3).

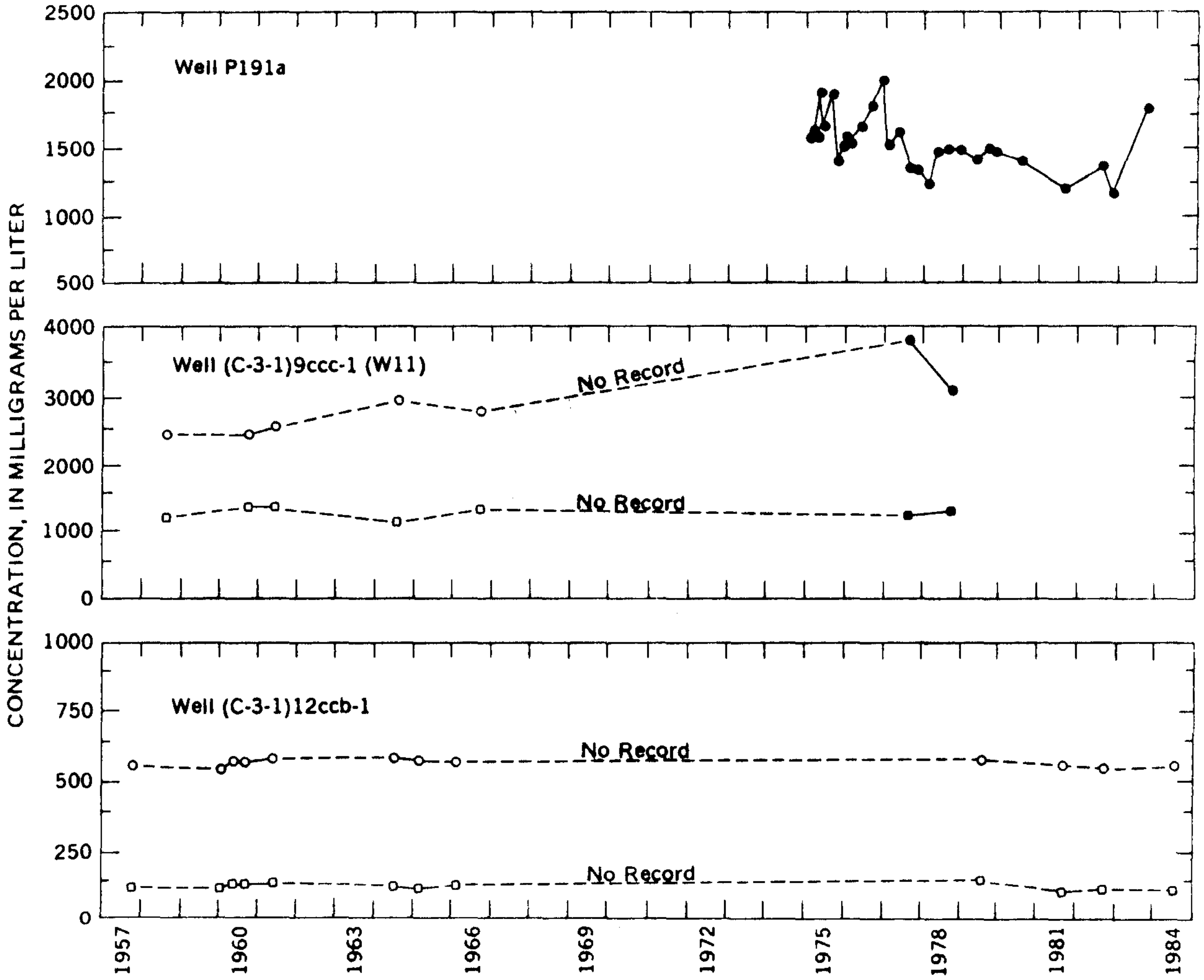


Figure 7.—Concentration of dissolved solids and sulfate in water from selected wells along flow line from Oquirrh Mountains to the Jordan River (section A—A′, plate 3)—Continued.

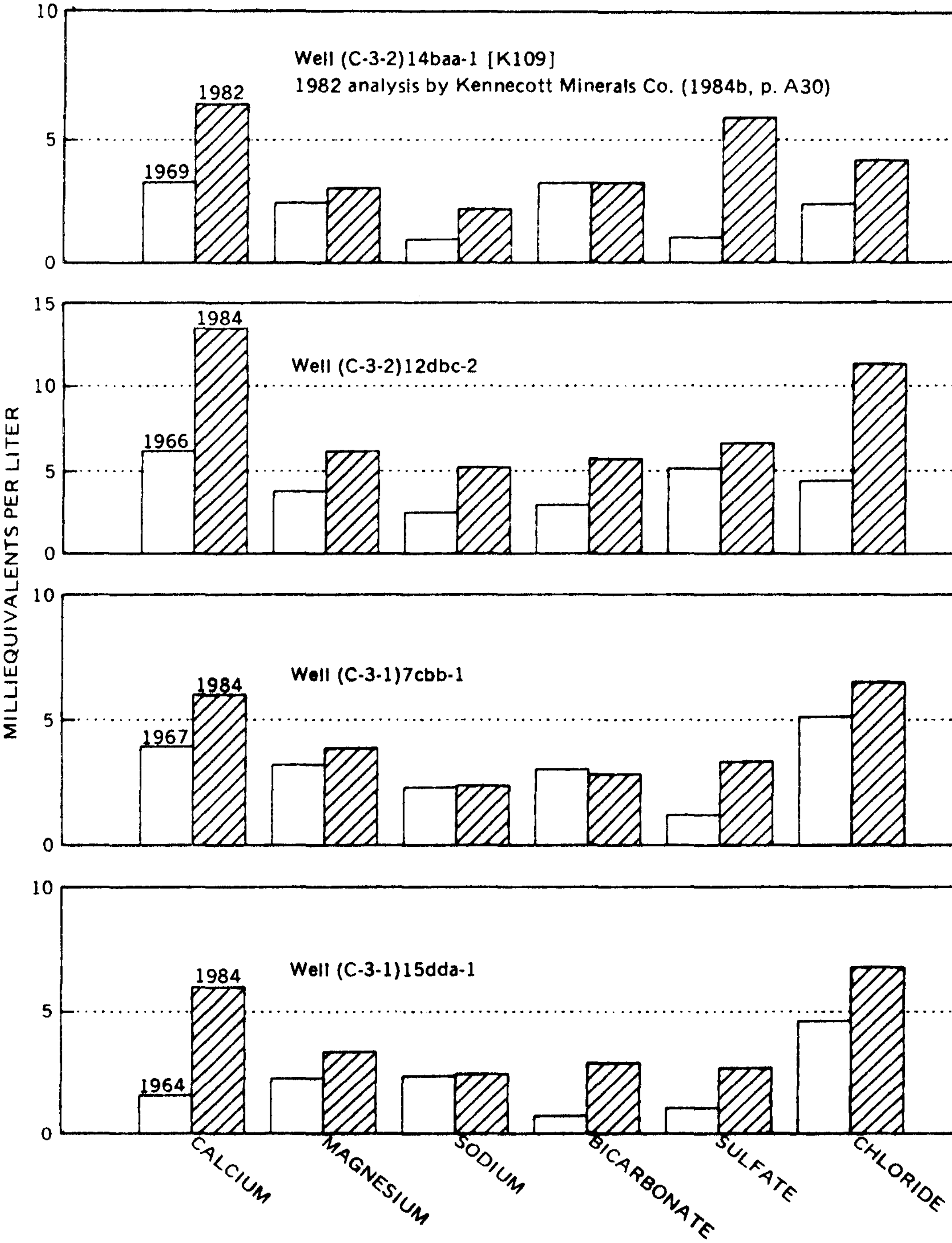


Figure 8.—Comparison of concentration of selected constituents in water collected during the 1960's and 1980's from wells between Bingham Canyon and the Jordan River.

(C-3-1)9ccc-1 increased from about 2,400 milligrams per liter in 1958 to 3,070 milligrams per liter in 1978 (fig. 7). The concentration of dissolved solids in well (C-3-1)15dda-1 increased from 360 milligrams per liter in 1964 to 700 milligrams per liter in 1984 (table 1). The chemical composition in both 1964 and 1984 was dominated by calcium and chloride, but notable increases in calcium, bicarbonate, sulfate, and chloride were noted by 1984 (fig. 8).

East of the Jordan River, no significant change in concentration of dissolved solids occurred during 1957-84 in water from well (C-3-1)12ccb-1 (fig. 7). This well is east of the ground-water divide; thus, contaminants moving from the west would not be expected to affect it.

Time of Travel of Ground Water

The rate at which water moves through an aquifer affects the time in which an aquifer can cleanse itself and the time necessary for a contaminant to move from the source area to downgradient wells. Travel time may be determined by injecting a tracer into the aquifer and then measuring the time required for the tracer to appear at a downgradient point. Travel time also may be determined by measuring the rate of movement of peak concentrations of dissolved ions or constituents in contaminated water.

If the quantity of contaminated water that infiltrates an aquifer remains constant but the quantity of dilutant downgradient is decreased because of decreased recharge, a flux of water containing relatively greater concentrations of contaminant will result. A similar flux of water also can occur because of a change in the infiltration rate or concentration of contaminants seeping into the aquifer.

During 1977-82, peaks in the concentration of dissolved solids were detected in several wells downgradient from the reservoirs in Bingham Canyon (fig. 7). These peaks are believed to have resulted from a flux of water containing relatively large concentrations of dissolved solids that resulted from less dilution of contaminants due to decreased recharge from bedrock. Data from Waddell and others (1987, fig. 6) indicate that during 1976 recharge from bedrock was only 55 percent of the average for 1969-82. Regardless of the cause of the peak concentration, if it is assumed that the peaks occurring in the wells resulted from the same flux of contaminated water, and that the hydraulic gradient between wells was constant, then the rate of contaminant movement can be determined from the times at which the peak concentrations occurred in different wells. The peak concentrations in wells K87 and P197a are defined quite distinctly (fig. 7). It does not appear that the contaminant slug has reached wells K109 and P191b. Wells K109 and P191b show a steady increase in concentration with time but no peak is obvious (fig. 7). The last analysis for well P191a shows a marked increase in 1983 (fig. 7) and may have occurred because of the contaminant slug.

The most upgradient well, K87, shows a distinct peak in the concentration of dissolved solids in April 1977 (fig. 7). At well P197a, a peak occurred in July 1982 (fig. 7), but since there were no measurements during the prior 1.8 years, it is possible that a greater concentration occurred earlier and was not measured. Thus, the time between the peaks in wells K87 and P197a could range from 3.4 to 5.2 years.

By using the historical peaks as indicators of the time (t) for a contaminant to move between two wells and the corresponding distance (d) between the wells, the average velocity (v) of movement of contaminant between the wells can be determined from the relation v=d/t. The calculations indicate that the average velocity of contaminant movement between wells K87 and P197a ranges from 680 to 1,000 feet per year.

Using Darcy's law, the computation of average velocity can be roughly checked by assuming that the rate of contaminant movement is the same as the rate of ground-water movement between the wells. The average ground-water velocity (v) is related to hydraulic conductivity (K), hydraulic gradient (dH/dL), and porosity (P) by Darcy's law as

$$v = (K \times dH/dL)/P \qquad (1)$$

The hydraulic conductivity (K), which was calculated from a map showing the distribution of transmissivities (Waddell and others, 1987, fig. 18) and from a map showing the thickness of saturated deposits of Quaternary age by Hely and others (1971, p. 132), was estimated to range from about 1.0×10^{-4} to 3.5×10^{-4} foot per second. The gradient (dH/dL) between the two wells is about 0.025. The porosity (P) for the type of material between wells K87 and P197a is estimated to be about 30 percent (Hely and others, 1971, p. 116). The velocity computed with equation 1 is between 260 and 920 feet per year, and the travel time is between 3.9 and 13.5 years. Thus, the range of 3.4 to 5.2 years, which was computed using peak concentrations, probably is reasonable.

The gradient of the potentiometric surface is small between wells P197a and K109, and accurate travel times could not be calculated. The travel time for contaminant movement from the reservoirs to well K109 may be less than 20 years (700 feet per year), however, as the dissolved-solids concentration in well K109 has more than doubled since completion of the 1,500-acre-foot reservoir during 1965. If seepage of contaminated water from Bingham Creek or small ponds in Bingham Canyon prior to completion of the reservoirs caused increased concentrations at well K109, then the travel time could be greater than 20 years (less than 700 feet per year).

The historical data base that is being developed by Kennecott Minerals Co. to describe chemical-quality trends for wells downgradient from Bingham Canyon provides valuable data for calibrating a solute-transport model. Such a model could be used to predict the movement of the contaminated water under various development alternatives.

Area in South Salt Lake

During 1951-64, the Vitro Chemical Co. of America processed uranium ore for sale to the U.S. Atomic Energy Commission at a mill in South Salt Lake (U.S. Department of Energy, 1984). When the plant was dismantled during 1970, the radioactively contaminated materials from the processing operations (approximately 1.9 million dry tons of uranium-mill tailings and more than 1 million dry tons of other contaminated material) remained on the mill site (fig. 9), piled as high as 16 feet in some areas (U.S. Department of Energy, 1984). (See table 2 for cross reference between identification numbers of U.S. Geological Survey and U.S. Department of Energy.) Some of the tailings

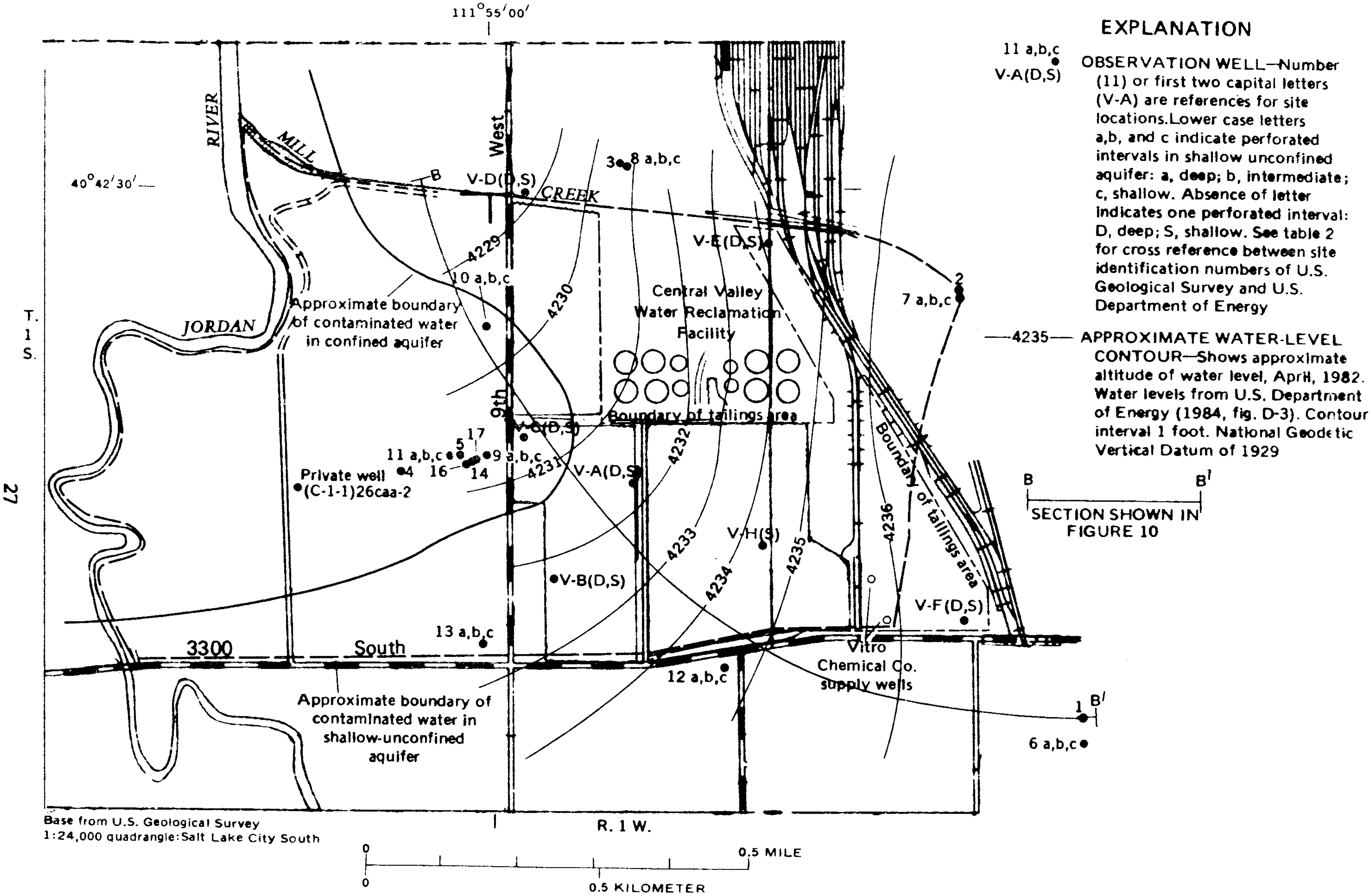


Figure 9.—Potentiometric surface for the shallow unconfined aquifer, approximate boundaries of contaminated ground water, and location of wells and test holes at which data were collected on and near the Vitro Chemical Co. tailings area.

Table 2.—Cross reference between site-identification numbers used by the U.S. Geological Survey and the U.S. Department of Energy (1984, Vol. II, app. D, p. D-2)

U.S. Geological Survey	U.S. Department of Energy
(C-1-1)25bdc-1	2
-2	7c
-3	7b
-4	7a
25cdd-1	6c
-2	6b
-3	6a
-4	1
26aac-1	3
-2	8a
-3	8b
-4	8c
26aca-1	10c
-2	10b
-3	10a
26caa-1	4
-2	"Private Well"
26dba-1	9c
-2	9b
-3	9a
-4	14
-5	15
-6	17
-7	16
26dbb-1	5
-2	11c
-3	11b
-4	11a
26dca-2	13c
-3	13b
-4	13a

removed from the site for off-site construction materials, but in 1984 the bulk of the tailings remained at the Vitro site.

Leaching of the tailings has resulted in increases of concentrations of dissolved solids and heavy metals in the ground water beneath and downgradient from the tailings. The U.S. Department of Energy (1984) prepared an environmental-impact statement that includes a description of the problem and remedial action to alleviate the problem. Information used for this section of the report comes from the U.S. Department of Energy (1984) and from additional water-quality, water-level, and aquifer-test data collected by the U.S. Geological Survey during 1982-84.

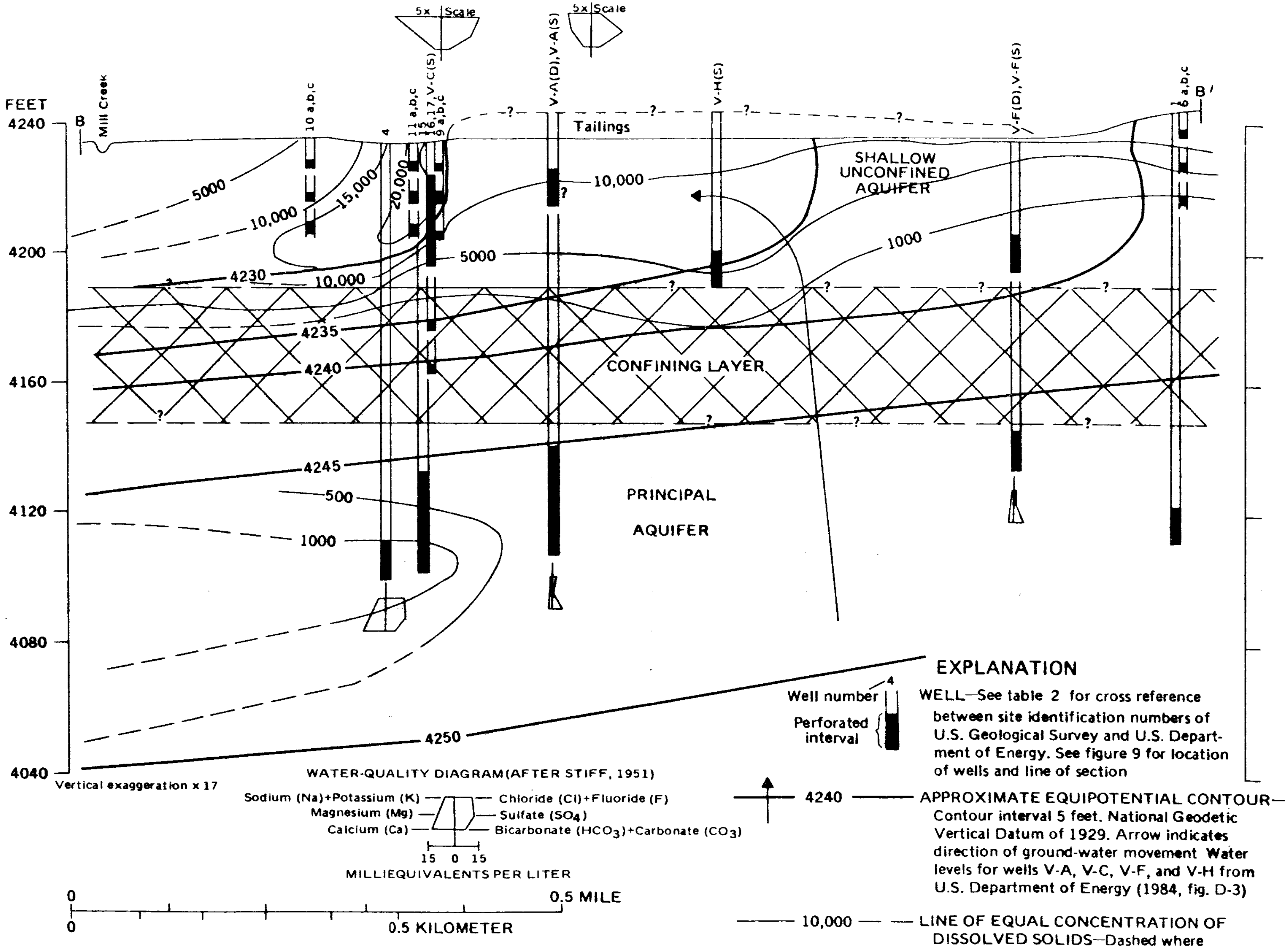
Hydrology

In the general area of the Vitro tailings, ground water occurs in both the shallow unconfined and principal aquifers. The principal aquifer is confined in this area; and most of the recharge to the aquifer originates from the Wasatch Range to the east. Recharge to the shallow unconfined aquifer comes primarily from upward leakage from the confined aquifer and from precipitation directly on the land surface at the tailings site. Horizontal ground-water movement generally is northwest in both the shallow unconfined and deep confined aquifers. The shallow unconfined aquifer discharges to the Jordan River, to the downstream reach of Mill Creek, and to ditches tributary to the Jordan River.

A generalized section of the two aquifers along an approximate flow line through the tailings area shows the equipotential and flow lines and concentrations of dissolved solids upgradient, beneath, and downgradient of the tailings (fig. 10). Many of the wells used for preparing the section are not directly on the flow line, and the section only is an approximation of conditions existing during 1982. For example, during 1984, an excavation immediately north of the tailings area by the Central Valley Water Reclamation Facility induced inflow from the shallow unconfined aquifer, resulting in considerable changes to the flow lines shown in figure 9 and represented in figure 10.

Effects of Mill-Tailings Leaching and Volume of Contaminated Ground Water

In order to assess the effects of the leachate from the uranium-mill tailings on the chemical quality of water, it was proposed to compare the concentrations of dissolved solids and selected major constituents (chloride and sulfate), selected minor constituents (arsenic, cadmium, iron, molybdenum, selenium, and vanadium) and selected radionuclides (uranium, radium-226, thorium-230, lead-210, and gross alpha) in ground water upgradient from the tailings area with concentrations beneath and downgradient from the tailings area. Wells 6a, b, and c were chosen as the upgradient sites (fig. 9) until it was determined that the concentration of dissolved solids at a depth of 7 to 9 feet in well 6c was 16,000 milligrams per liter and other dissolved chemical constituents were similar to those in water from wells within the tailings area. Apparently some tailings were deposited near wells 6a, b, and c or contamination from the tailings has migrated upgradient. For this reason, wells 6a, b, and c were not used to represent uncontaminated upgradient conditions. Instead, well 12c, which is crossgradient from the



WELL—See table 2 for cross reference between site identification numbers of U.S. Geological Survey and U.S. Department of Energy. See figure 9 for location of wells and line of section

APPROXIMATE EQUIPOTENTIAL CONTOUR—Contour interval 5 feet. National Geodetic Vertical Datum of 1929. Arrow indicates direction of ground-water movement Water levels for wells V-A, V-C, V-F, and V-H from U.S. Department of Energy (1984, fig. D-3)

LINE OF EQUAL CONCENTRATION OF DISSOLVED SOLIDS—Dashed where approximately located. Interval, in milligrams per liter, is variable

Figure 10.—Approximate equipotential contours, direction of ground-water movement, and concentration of dissolved solids along a flow line through the Vitro Chemical Co. tailings area, 1982-84.

tailings area, was used as representative of uncontaminated conditions in the shallow unconfined aquife..

Shallow Unconfined Aquifer.--The major effect of the leachate from the uranium-mill tailings on water in the shallow unconfined aquifer downgradient from the tailings area was the contribution of measurable quantities of dissolved solids, chloride, sulfate, iron, and uranium. For example, the concentration of dissolved solids in well 12c was 1,650 milligrams per liter, whereas downgradient from the tailings area the concentrations ranged from 2,320 to 21,000 milligrams per liter (table 3).

The maximum areal and vertical extent of contamination of the shallow unconfined aquifer was documented by data from wells 6a,b,c; 7a,b,c; 8a,b,c; 9a,b,c; 10a,b,c; 11a,b,c; 12a,b,c; 13c, V-A(S), V-B(S), V-D(S), V-E(S), V-F(S), and V-H(S) and by assuming that the contaminant plume does not move past the natural discharge boundaries—Mill Creek and the Jordan River (fig. 9) and that withdrawals from the Vitro Chemical Co. supply wells during the 1960's created a horizontal gradient that caused the contaminated water in the shallow unconfined aquifer to move east from the tailings area to the vicinity of the supply wells. The plume was determined to be about 3,100 to 3,700 feet wide, 5,000 to 6,000 feet long, and about 50 feet thick (fig. 9). Assuming a porosity of 0.3 (or 30 percent), the maximum total volume of the contaminant plume is estimated to be 7,800 acre-feet.

Deep Confined Aquifer.—The major effect of the tailings on water in the deep confined aquifer was the contribution of measurable quantities of dissolved solids, chloride, sulfate, and iron. This is shown in table 4 by comparison of chemical analyses of water from wells 1, V-C(D), and 15, which were considered to represent conditions upgradient from the tailings area, beneath the tailings area, and downgradient from the tailings area. Well V-C(D), which is near the western boundary of the tailings area (fig. 9), is the only well completed in the deep confined aquifer within the tailings area that yields water that may be contaminated. The concentration of dissolved solids in water from well V-C(D) was 864 milligrams per liter, whereas in water from 4 other wells completed in the deep confined aquifer within the tailings area, the dissolved-solids concentration ranged from 316 to 510 milligrams per liter. Downgradient from well V-C(D), across the western boundary of the tailings area, several wells completed in the deep confined aquifer yield water that may be contaminated. The concentration of dissolved solids in water from wells 4, 5, and 15 ranged from 580 to 1,800 milligrams per liter, and at a "private well" [(C-1-1)26caa-2] about 0.4 mile west of the boundary of the tailings area the concentration was 2,040 milligrams per liter. At well (C-1-1)23caa-1, which is about 0.7 mile northwest of the northwest corner of the boundary and just west of the Jordan River, the concentration of dissolved solids was 1,000 milligrams per liter and the chemical composition was indicative of contamination.

If the eastern edge of the contaminated zone in the deep confined aquifer was assumed to be midway between well V-C(D) and wells V-A(D), V-B(D), and V-D(D), (the nearest wells at which uncontaminated water was found), the boundary of contamination within the site would be delineated as shown in figure 9. Outside the site, the western and northwestern boundaries of contamination could not be well defined because of lack of control. The

Table 3.—Comparison of water quality of the shallow unconfined aquifer in wells crossgradient from, beneath, and downgradient from the Vitro tailings area

[Concentrations are in milligrams per liter, except for radium-226, thorium-230, lead-210, and gross alpha, which are in picocuries per liter. Adapted from U.S. Department of Energy, 1984, tables D-4, D-5, and D-6 and Seiler, 1987, table 4]

Constituent	Crossgradient from tailings area (Well 12c)	Beneath tailings area [Wells V-A(S), V-B(S), V-C(S), V-E(S), V-F(S), and V-H(S)]	Downgradient from tailings area (Wells 9a,b, and c; 10a,b, and c; 11a,b, and c; 13c; and 14)
Dissolved solids	1,650	310-10,600	2,320-21,000
Chloride (Cl), dissolved	320	11-2,690	520-5,400
Sulfate (SO_4), dissolved	410	<5-6,010	250-7,900
Arsenic (As), dissolved	0.02	<0.01-0.09	[1]0.001-0.525
Cadmium (Cd), dissolved	<0.01	<0.01-0.04	<0.001-0.004
Iron (Fe), dissolved	0.02	<0.05-54	<0.01-33
Molybdenum (Mo), dissolved	0.02	<0.1 -0.2	<0.01-0.045
Selenium (Se), dissolved	<0.01	<0.01	<0.0005-0.01
Vanadium (V), dissolved	0.01	<0.5	0.01-0.04
Uranium (U), dissolved	0.017	0.004-0.61	0.01-2.12
Radium-226 (Ra-226), total	<1.0	1.0-114	<1.0-13
Thorium-230 (Th-230), total	<1.0	<1.1-29	<1.0-1.0
Lead-210 (Pb-210), total	<1.5	<2.2-161	<1.5-3.0
Gross alpha, total	<45	<40-1,180	0.42-819

[1] Anomalously large concentration from well 13c.

Table 4.—Comparison of water quality of the confined aquifer in wells upgradient from, beneath, and downgradient from the Vitro tailings area

[Concentrations are in milligrams per liter, except for radium-226, thorium-230, lead-210, and gross alpha, which are in picocuries per liter. Adapted from U.S. Department of Energy, 1984, table D-11.]

Constituent	Upgradient from tailings area (Well 1)	Beneath tailings area [Well V-C(D)]	Downgradient from tailings area (Well 15)
Dissolved solids	330	864	1,240
Chloride (Cl), dissolved	10	220	310
Sulfate (SO_4), dissolved	10	230	340
Arsenic (As), dissolved	0.03	<0.01	0.01
Cadmium (Cd), dissolved	0.01	<0.01	0.01
Iron (Fe), dissolved	0.21	0.22	1.3
Molybdenum (Mo), dissolved	0.01	<0.01	0.01
Selenium (Se), dissolved	0.01	<0.01	0.01
Vanadium (V), dissolved	0.06	0.01	0.01
Uranium (U), dissolved	0.01	<0.003	0.003
Radium-226 (Ra-226), total	1.0	<1.0	1.0
Thorium-230 (Th-230), total	1.0	<1.0	1.0
Lead-210 (Pb-210), total	1.5	1.5	1.5
Gross alpha, total	30	20	100

contamination, however, is believed to extend west at least to well (C-1-1)26caa-2 and northwest to well (C-1-1)23caa-1 (pl. 1). The minimum east-west extent of the plume is about 2,600 feet, the minimum north-south extent is about 6,900 feet, and the thickness of the plume is estimated to be about 100 feet. Thus, assuming a porosity of 0.3, the minimum volume of contaminated water in the confined aquifer would be about 12,000 acre-feet.

Effect of Withdrawals on Ground-Water Movement

An aquifer test conducted in May 1983 demonstrated that pumping near the Vitro tailings area could locally cause a reversal of the horizontal and vertical gradients in the deep confined aquifer. During a 91-hour test, a drawdown of 59 feet was measured in well 15 (fig. 9), which is completed in the deep confined aquifer, while it was being pumped at 300 gallons per minute. Prior to pumping, the hydraulic head in the deep confined aquifer was 15 feet above that of the water level in the shallow unconfined aquifer, but during pumping the hydraulic head was about 40 feet below the water level in the shallow unconfined aquifer. Based on drawdowns measured in nearby observation wells, it is estimated that the hydraulic head in the deep confined aquifer was less than that of the shallow unconfined aquifer in an area of about 1.2 to 1.6 acres.

Specific-conductance data collected before, during, and after the aquifer test indicated an increase of about 100 milligrams per liter dissolved solids in water from well 15. Water from well 4, which is 950 feet west of well 15, contained 1,400 milligrams per liter dissolved solids. Apparently, during the aquifer test, the horizontal gradient in the deep confined aquifer was reversed locally, allowing for lateral movement of more mineralized water to the pumping well from the west. The 91-hour test probably was too short to induce water from the shallow unconfined aquifer through the confining layer into the deep confined aquifer.

Movement of water from the shallow unconfined aquifer through the confining layer into the deep confined aquifer probably did occur during the 1960's. At that time, pumping of supply wells completed in the deep confined aquifer by the Vitro Chemical Co. in the southeast part of the site (fig. 9) may have lowered water levels locally and reversed the hydraulic gradient allowing the contaminated water in the shallow unconfined aquifer to migrate downward into the deep confined aquifer. The Vitro Chemical Co. wells have not been pumped since 1969. Thus, any movement of contaminated water into the deep confined aquifer probably ceased soon after 1969.

Assuming that the lateral downgradient movement of contaminants began when the withdrawal from the supply wells ceased in 1969, the extent of the downgradient movement can be estimated from ground-water velocity and time of travel. Based on the results of an aquifer test using well 15 (Waddell and others, 1987, p. 30) and an estimated aquifer thickness of 100 feet, the hydraulic conductivity was estimated to be about 40 feet per day. Using the hydraulic conductivity of 40 feet per day, an average gradient of the potentiometric surface of 0.009 in the deep confined aquifer (Waddell and others, 1987, fig. 8), and an assumed porosity of 0.3, the velocity of ground-water movement was estimated to be 440 feet per year. Assuming that the rate of lateral contaminant movement would be the same as the rate of ground-water movement from 1969-84, the distance of travel would be 6,600 feet. Well (C-1-1)23caa-1, which yields water that may be contaminated, is about 7,400 feet downgradient from the area of the supply wells, or 800 feet farther than was estimated from consideration of ground-water velocity and time of travel. Considering the approximations of hydraulic properties and assumptions used for the computations, it is reasonable to believe that contaminants could have moved downgradient from the supply-well area to the vicinity of well (C-1-1)23caa-1.

Susceptibility of Ground Water to Contamination

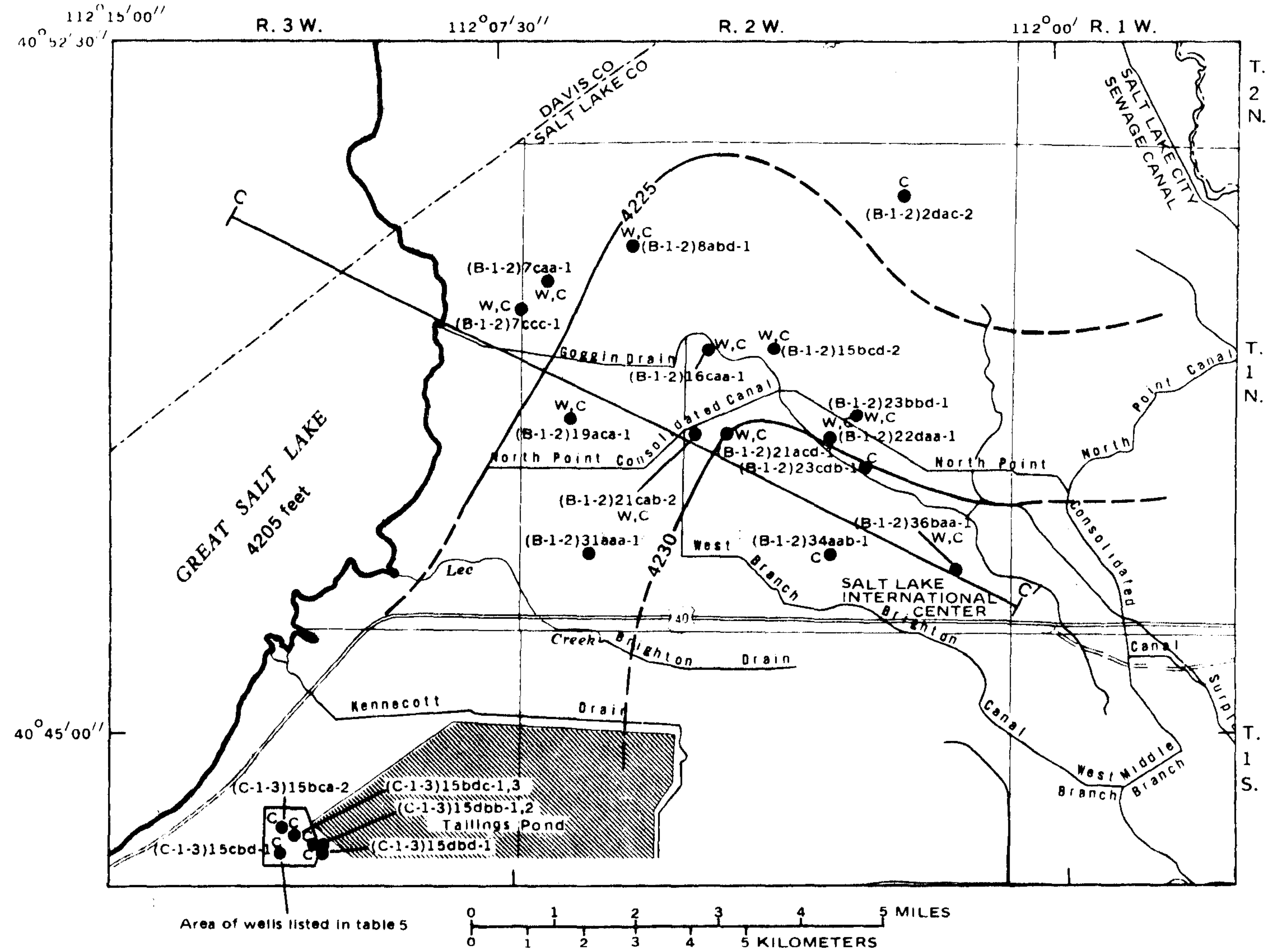
The Vitro tailings area is in area 4, least susceptibility of ground water to contamination, as shown in figure 6. If on-site pumping during the 1960's caused the hydraulic gradient to be reversed, however, the classification could have been changed to that of area 3, intermediate susceptibility of ground water to contamination.

POTENTIAL FOR MIGRATION OF SALINE GROUND WATER FROM NEAR GREAT SALT LAKE

The rise of the level of Great Salt Lake from 1963-84 and the possibility of increased pumping of ground water associated with future commercial development provides potential for migration of saline ground water from near Great Salt Lake towards pumping centers in the northwestern part of the Salt Lake Valley. Saline ground water has been observed in wells near Garfield (fig. 11), and in other wells within a few miles of the lake shore. During 1963-84, the level of the lake rose almost 18 feet, and the shore of the lake moved from 1 to 4 miles southeast into the valley. The Salt Lake International Center has been developed in the northwestern part of the valley; if ground-water pumping were to increase as a result of that or associated developments, a decline of water levels could induce saline ground water to spread farther into the valley.

Both the deep confined aquifer and the shallow unconfined aquifer occur in the northwestern part of Salt Lake Valley. Water movement in the deep confined aquifer generally is toward the northwest and upward, and it discharges into the shallow unconfined aquifer or into the Great Salt Lake (fig. 11). Hely and others (1971, p. 137) estimated the subsurface flow to the lake to be 4,000 acre-feet per year during 1964-68, and Waddell and others (1987, p. 29) estimated the subsurface flow to be 3,100 acre-feet during 1982.

The Kennecott Minerals Co. has 8 wells near Garfield, within about 1 to 2 miles of the shore of Great Salt Lake, the distance depending on the level of the lake. The concentration of dissolved solids in water from 7 of the wells that were sampled by the Kennecott Minerals Co. during 1982-83 ranged from about 5,000 to 10,000 milligrams per liter. The concentration varied considerably at each well (table 5), increasing at some wells and decreasing at others. This variation could be a result of changes in pumping, rise of the Great Salt Lake, or a combination of both. Prior to 1984, the wells were pumped for water supply at industrial plants owned by the Kennecott Minerals Co.. Drawdown of ground-water levels due to pumping and the rising lake levels could have induced movement of brine into the aquifer, however, definite conclusions regarding such movement can not be made due to a lack of long-term water-level records.



EXPLANATION

——4225— — APPROXIMATE WATER-LEVEL CONTOUR—Shows approximate altitude of the potentiometric surface. Dashed where inferred. Potentiometric surface has been adjusted to pressures at a depth of 400 feet below land surface. Contour interval 5 feet. National Geodetic Vertical Datum of 1929

(B-1-2)2dac-2 ● W,C OBSERVATION WELL AND NUMBER—W indicates water-level measurement; C indicates chemical-quality data

C ├──┤ C′ SECTION SHOWN IN FIGURE 13

Figure 11.—Potentiometric surface during 1984, and data-collection sites in the northwestern part of the Salt Lake Valley near Great Salt Lake.

Table 5.—Concentration of dissolved solids in water from wells near Garfield, 1982-83

[Data from Kennecott Minerals Co., September 1984.
Well no.: See figure 11 for approximate location of wells]

Well no.	Date	Dissolved-solids concentration (milligrams per liter)	
		Minimum	Maximum
1	August 8, 1983	--	5,700
	October 26, 1983	5,130	--
2	July 28, 1982	--	6,030
	October 20, 1983	5,360	--
3	July 28, 1982	--	6,800
	October 26, 1983	5,630	--
4	August 8, 1983	--	7,880
	September 26, 1983	7,440	--
5	August 8, 1983	5,660	--
	October 26, 1983	--	5,940
6	July 7, 1983	7,230	--
	October 26, 1983	--	10,400
6A	October 28, 1982	--	8,210
	July 7, 1983	7,160	--

Water-quality data obtained during 1937-67 for seven wells near Garfield with known depths at which the casing was perforated show a significant relationship between dissolved solids and depth (fig. 12). The concentration of dissolved solids ranged from 2,500 milligrams per liter at a depth of 200 feet to about 14,000 milligrams per liter at a depth of 900 feet. It was not possible to determine if the concentration-depth relationship had changed by 1982 because accurate information about depths at which the casing was perforated could not be obtained from the Kennecott Minerals Co. for the wells sampled during 1982-83.

Between the Salt Lake International Center and the shoreline of the Great Salt Lake (at the altitude of 4,205 feet) nine wells that were sampled during 1964-68 were resampled during the summer of 1984. The only significant change was measured at well (B-1-2)7ccc-1, where the concentration of dissolved solids was 4,930 milligrams per liter in 1984 compared to 4,680 milligrams per liter in 1965. This is about a 5-percent increase, and it may only reflect different analytical accuracy. Well (B-1-2)7ccc-1 is the nearest well to the lake shore, however, and the water has the largest concentration of dissolved solids of all wells that were sampled in the area. The chemical composition of water from the well is comprised principally of sodium and chloride, which is also characteristic of brine from Great Salt Lake.

Considering the possibility of contamination of the principal aquifer by water from or near Great Salt Lake, additional water-level and water-quality data were collected inland and upgradient along a flow line (section C-C') extending approximately northwest from the Salt Lake International Center toward well (B-1-2)7ccc-1. During the summer of 1984, 12 flowing wells were selected in close proximity to section C-C' in figure 11 to provide a good representation of depths for measurement of water levels and collection of water-quality data. The water-quality data were collected first, then the wells were capped and allowed to equilibrate for 24 hours before pressure measurements were made. The hydraulic head for each well was determined after establishing land-surface altitudes by instrument level.

The equipotential lines (lines of equal hydraulic head) are almost horizontal through section C-C' (fig. 13). Ground-water movement is perpendicular to the equipotential lines in the direction of decreasing heads, which is indicated by the almost vertical arrow in figure 13.

The concentration of dissolved solids in the principal aquifer along section C-C' varies with depth and proximity to the Great Salt Lake. For example, the concentration of dissolved solids in water from well (B-1-2)8abd-1 was 893 milligrams per liter at a depth of 300 feet, whereas at well (B-1-2)7ccc-1, which is about 0.8 mile closer to the lake, the concentration was 4,930 milligrams per liter at a depth of 379 feet.

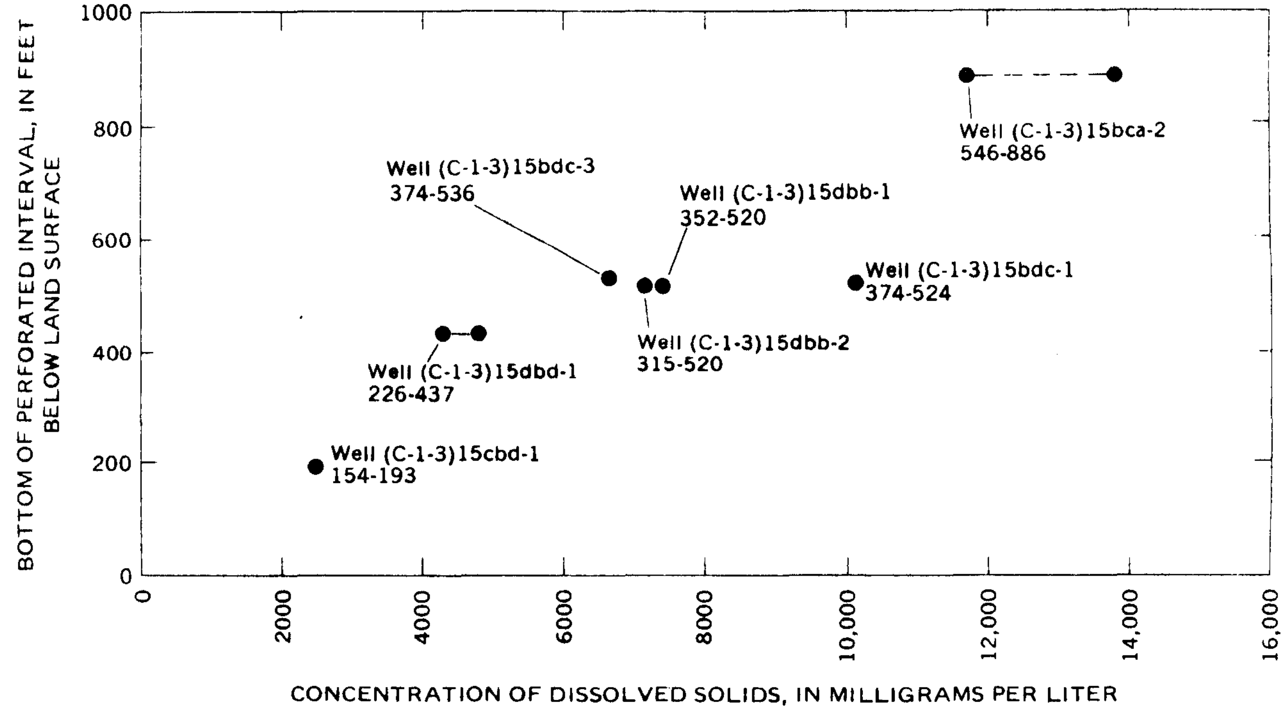


Figure 12.—Relation of concentration of dissolved solids to depth of bottom of perforated interval in selected wells near Garfield, 1937-67. Location of wells are shown in figure 11; figures beneath well numbers are depth of perforated interval, in feet.

The concentration of dissolved solids in the shallow unconfined aquifer also is variable. It ranges from 4,000 to 9,000 milligrams per liter near the southeast end of section C-C' and from 9,000 to 29,000 milligrams per liter near well (B-1-2)31aaa-1 (fig. 13), which is about 2.5 miles east of the shore of Great Salt Lake.

A decline of water levels caused by increased withdrawals of ground water from wells in the northwestern part of the Salt Lake Valley could induce movement of saline water farther into the valley from near Great Salt Lake. In order to evaluate this possibility, lateral travel times for inland movement of water were estimated for section C-C' in figure 11.

A calibrated, 3-dimensional ground-water flow model (Waddell and others, 1987, p. 35) was used to simulate changes in the potentiometric surface due to ground-water withdrawals from a postulated well field in the vicinity of the Salt Lake International Center. To determine the effect of pumping, average hydraulic gradients were computed for the principal aquifer along section C-C' for simulated pumping rates ranging from 5 to 30 cubic feet per second, for 1982-2020. Water levels began to stabilize for the various pumping rates after 2-3 years, but hydraulic gradients were computed for 2020. The hydraulic gradient from near the shore of Great Salt Lake to the Salt Lake International Center is not reversed until pumpage exceeds about 5 cubic feet per second (fig. 14). The greater the gradient from the lake toward the pumping center, the greater is the potential for increasing the velocity of flow toward the pumping center. The hypothetical cone of depression created by pumping 30 cubic feet per second from 1982-2020 in the vicinity of the International Center is presented in figure 15. The discharge from the only well at the Salt Lake International Center was estimated to be 0.1 cubic foot per second during 1985 (Corbin Bennion, Bingham Engineering, oral commun., 1985).

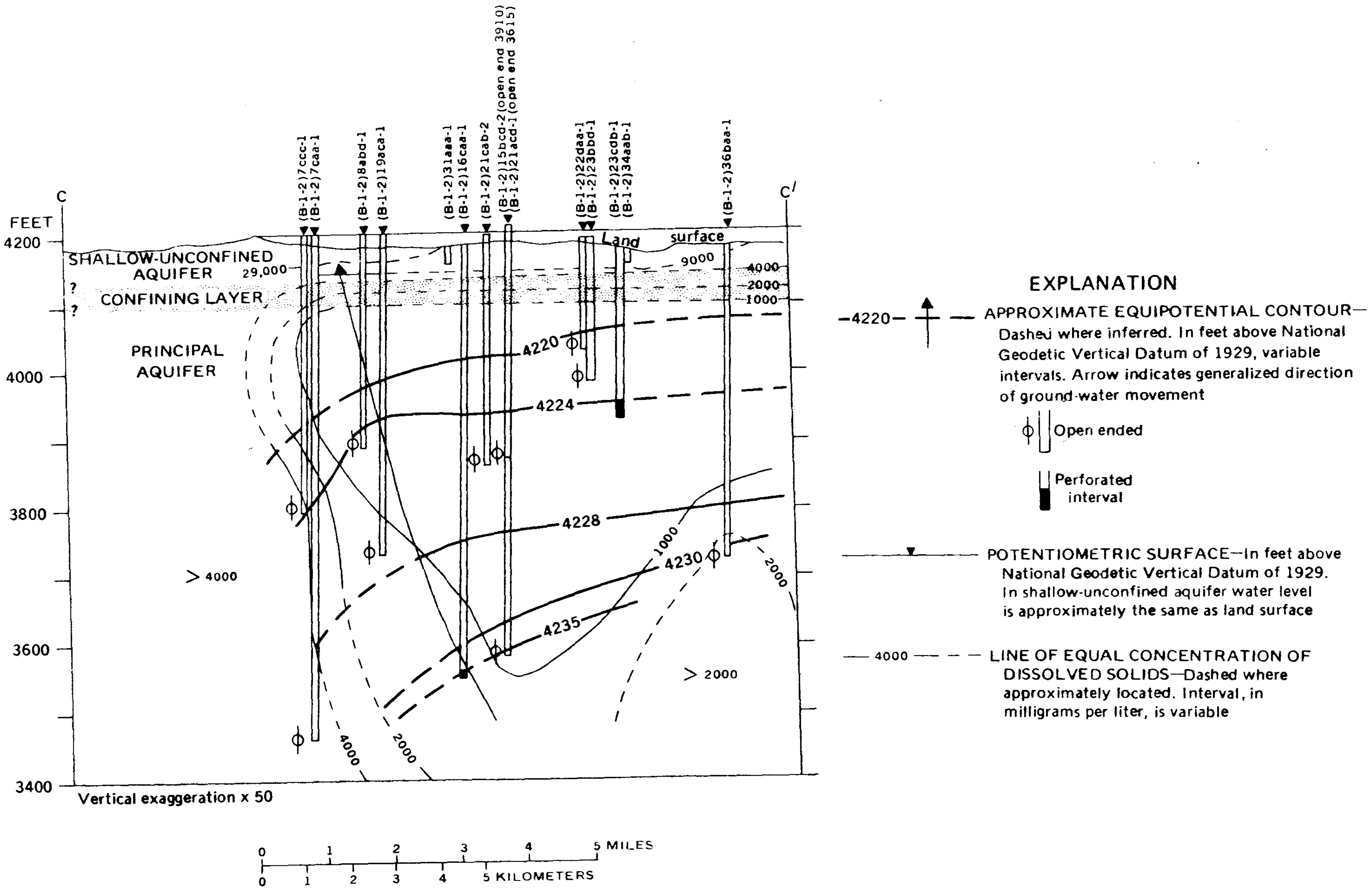


Figure 13.—Ground-water movement and concentration of dissolved solids along a cross section of the Salt Lake Valley near the Great Salt Lake, 1984.

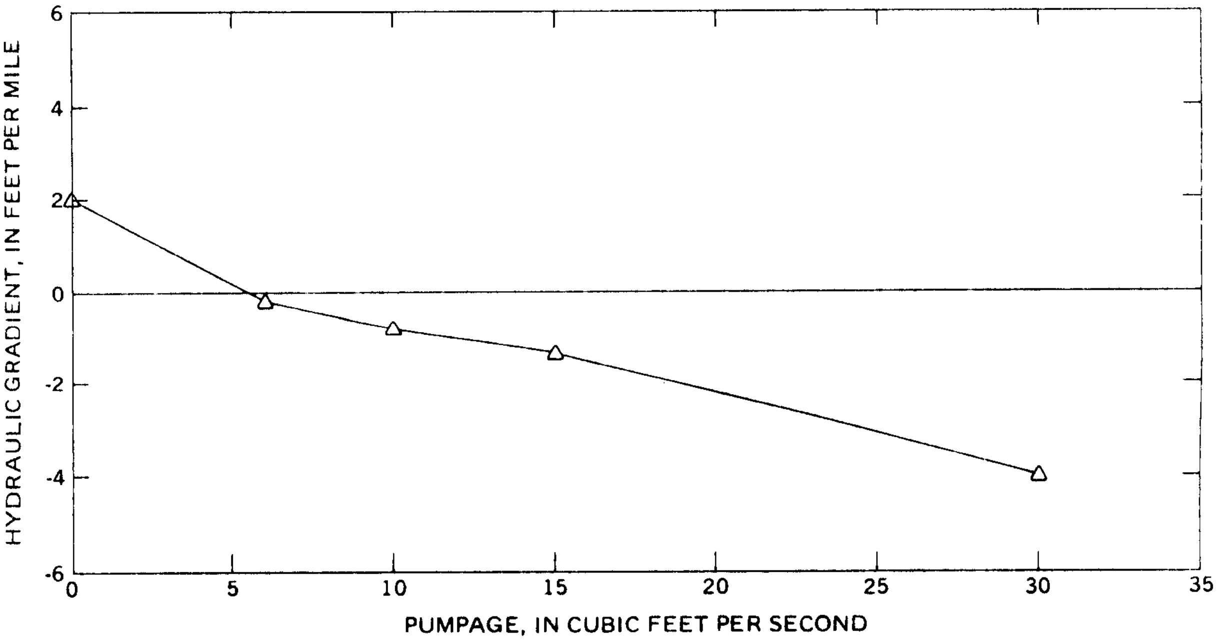
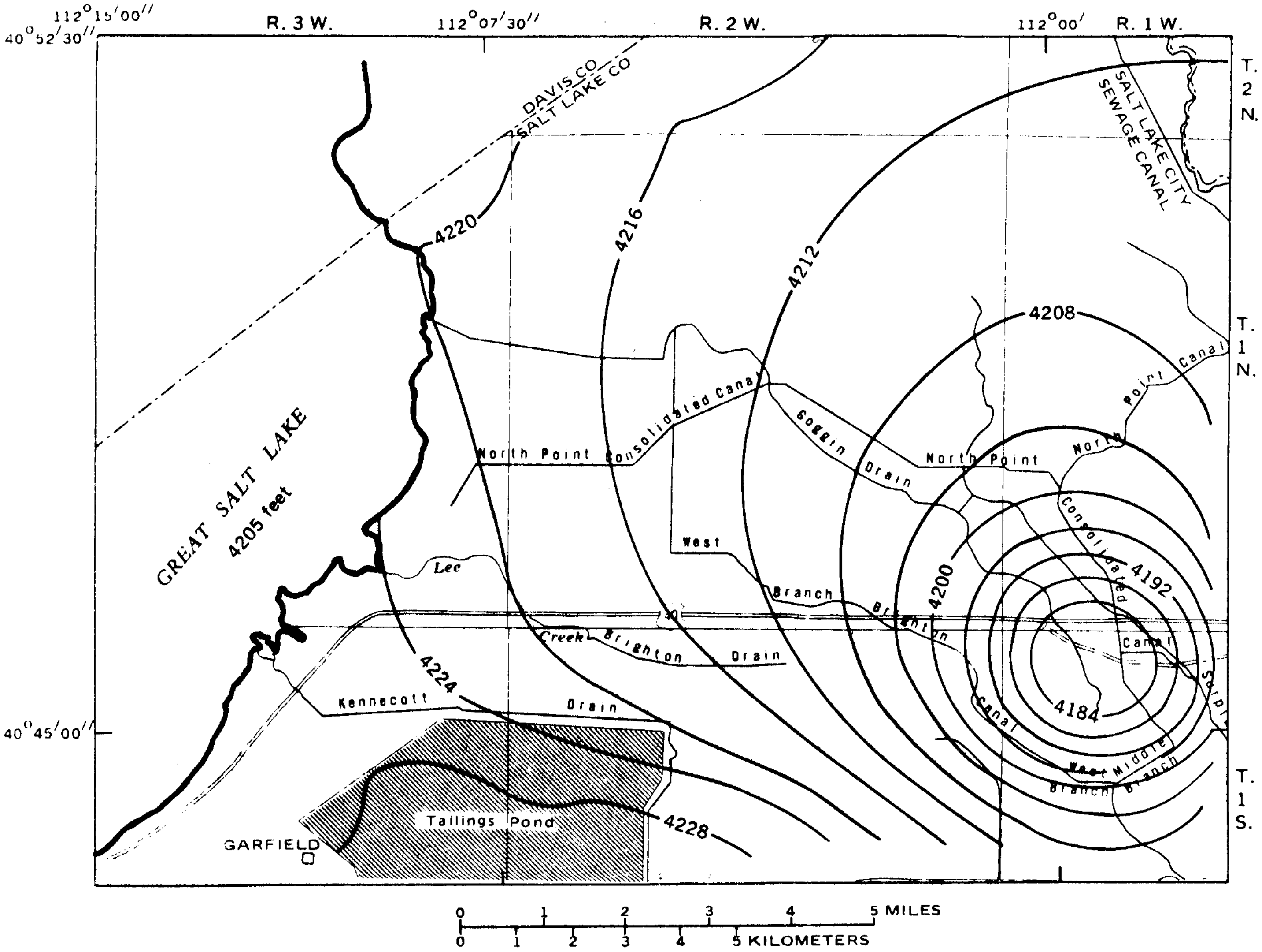


Figure 14.—Relation of hydraulic gradient along section C-C' (fig. 13) to postulated pumpage rates after 38 years of simulation.

Using a pumpage rate of 30 cubic feet per second for 38 years and assuming the initial position of the saline water to be near well (B-1-2)7ccc-1 (fig. 13), calculations of lateral travel time for the 7 miles from the well to the pumping center were made using Darcy's equation. It was assumed that dispersion was negligible and that movement of the saline water primarily was by advection or directly proportional to the velocity of groundwater flow. The estimated time for the saline water to reach the pumping center was 3,900 years.

Water containing 3,600 milligrams per liter dissolved solids was collected from a depth of 464 feet at well (B-1-2)36baa-1. This well is about 2 miles from the postulated pumping center, and such mineralized water could be induced upward into the pumping center within a relatively short time. The areal and vertical extent of this mineralized water have not been well defined.



EXPLANATION

—4208— WATER-LEVEL CONTOUR—Shows altitude of the potentiometric surface in the confined aquifer which was calculated from the digital-computer model. Contour interval 4 feet. National Geodetic Vertical Datum of 1929

Figure 15.—Potentiometric surface resulting from postulated pumpage of 30 cubic feet per second from 1982-2020, near Great Salt Lake.

For a more complete understanding of the relation between the Great Salt Lake and the principal aquifer in the northwest part of the Salt Lake Valley, the following information would be desirable: (1) Hydraulic, water-level, and water-quality data at test wells of different depths extending from the shoreline northwest into the lake; and (2) annual water-level and water-quality data at the Kennecott Minerals Co. wells near Garfield. The effects of possible increased pumping of ground-water in conjunction with variable levels of Great Salt Lake could be understood best with the assistance of a digital-computer model with the capability of incorporating variable density for solute transport.

CONCLUSIONS

The historical data that is being developed by Kennecott Minerals Co. to describe chemical-quality trends for wells downgradient from Bingham Canyon provides valuable data for calibrating a solute-transport model. Such a model could be used to predict the movement of the contaminated water under various development alternatives.

The Vitro tailings area provides an example of how contamination of a part of the principal aquifer has been limited by the upward gradient in area 4 (fig. 6). Prior to 1969 on-site pumping may have reversed the gradient, thereby increasing the susceptibility of ground water to contamination; whereas since 1969, after the on-site pumping ceased, the susceptibility has been small.

It was estimated that about 3,900 years would be required to induce saline water from beneath the Great Salt Lake into the confined aquifer at a hypothetical pumping center near the Salt Lake International Center for a simulated pumpage of 30 cubic feet per second. The effects of possible increased pumping of ground water in conjunction with variable levels of Great Salt Lake could be understood best with the assistance of a digital-computer model with the capability of incorporating variable density for solute transport.

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