UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GROUND-WATER QUALITY DOWNGRADIENT FROM COPPER-ORE MILLING WASTES AT WEED HEIGHTS, LYON COUNTY, NEVADA

By Harold R. Seitz, A. S. Van Denburgh,
and Richard J. La Camera

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CONVERSION FACTORS AND ABBREVIATIONS

Except for water-quality units of measure, only the "inch-pound" system is used in this report. Abbreviations and conversion factors from inch-pound to International-System (SI) units are listed below.

Multiply	*By*	*To obtain*
Acre-feet (acre-ft)	0.001233	Cubic hectometers (hm^3)
Feet (ft)	0.3048	Meters (m)
Feet squared per day (ft^2/d)	0.09290	Meters squared per day (m^2/d)
Gallons (gal)	3.785	Liters (L)
Gallons per minute (gal/min)	0.06309	Liters per second (L/s)
Gallons per minute per foot [(gal/min)/ft]	0.2070	Liters per second per meter [(L/s)/m]
Inches (in.)	25.40	Millimeters (mm)
Miles (mi)	1.609	Kilometers (km)
Square miles (mi^2)	2.590	Square kilometers (km^2)
Tons (short)	0.9072	Metric tons (t)

Water-quality units used in this report are as follows:

For concentration, milligrams per liter (mg/L) and micrograms per liter (ug/L), which are equivalent to parts per million and parts per billion for dissolved-solids concentrations less than about 7,000 mg/L.

For temperature, degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the formula °F=[(1.8)(°C)]+32.

For specific conductance, micromhos per centimeter at 25°C (micromhos).

ALTITUDE DATUM

The term "National Geodetic Vertical Datum of 1929" (abbreviation, NGVD of 1929) replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The NGVD of 1929 is derived from a general adjustment of the first-order leveling networks of both the United States and Canada. For convenience in this report, the datum also is referred to as "sea level."

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ABSTRACT

To determine the extent of ground-water contamination associated with milling-waste fluids at Weed Heights, 17 shallow test wells were drilled in the valley-floor sedimentary deposits immediately downgradient from ponds used for disposal of an iron- and sulfate-rich acid brine and an alkaline tailings slurry. Chemical analyses indicate that (1) shallow ground water (3-30 feet below land surface) near the ponds has been contaminated to differing degrees, but (2) shallow water more than about 0.2 mile downgradient probably has not. In addition, the analyses suggest that the shallow sedimentary deposits through which the waste fluids percolate can deplete several of the more objectionable contaminants, with an effectiveness ranging from moderate to almost complete.

Chemical analyses of water from six industrial-supply wells in the same area indicate (1) that deeper ground water (50-455 feet below land surface) adjacent to the ponds deteriorated in quality during the period of heavy pumping that began in the mid-1960's, and (2) that the chemical changes might have been due to contamination by percolating acid brine, tailings fluid, or both.

Periodic monitoring of water quality downgradient from the waste-disposal area would provide information useful for management of the area's ground-water resources.

INTRODUCTION

Historical Background

Because of concern regarding possible drinking-water contamination north of Weed Heights, the Nevada Division of Environmental Protection asked the U.S. Geological Survey to determine whether ground water has been affected by waste fluids associated with The Anaconda Company's nearby ore-milling operations. The Company mined and milled copper ore at Weed Heights, near Yerington, Nev. (figure 1), from November 1953 until operations were terminated in June 1978. As of mid-1975, 15 million tons of overburden had been stripped away to permit removal of about 350 million tons of ore and waste from an open pit that was 6,400 feet long, 2,500 feet wide, and 800 feet deep [The Anaconda Company, 1976(?), pages 4, 15]. The ore body contained both copper oxides and copper sulfides. In the on-site milling operations, a copper precipitate was produced from the oxide ore and a copper concentrate was produced from the sulfide ore. Both were shipped elsewhere for smelting. Byproducts of the milling operation were wet gangue from the sulfide ore and wet tailings plus an iron- and sulfate-rich acid brine from the oxide ore. Gangue and tailings were deposited in large dumps and ponds, and the acid brine was disposed of in evaporation ponds (figure 1). Both the brine and tailings fluid are potential ground-water contaminants.

Purpose and Scope

Objectives of the study were to: (1) Appraise the occurrence, movement, and quality of ground water in the area immediately north of the ponds, (2) determine if the ponds have leaked appreciably, and, if so, (3) characterize the the chemical quality of the leakage and its effect on ground-water quality.

This investigation comprised the following activities:

1. Canvassing existing wells near the waste-disposal area to determine the depth to water and the direction of ground-water movement.

2. Drilling shallow test wells downgradient from the tailings and evaporation ponds.

3. Measuring static water levels in the test wells.

4. Pumping the test wells to obtain chemically representative samples of the ground water for laboratory analysis.

5. Sampling and analyzing the acid brine and tailings fluid to determine the quality of possible percolation.

6. Characterizing deeper ground water, both upgradient and downgradient from the waste-disposal areas, using chemical analyses of samples obtained by The Anaconda Company during 1974-79 from their deep production wells.

EXPLANATION

▨	Hilly and mountainous areas
● 41	Anaconda pit-dewatering well, with number

FIGURE 1.--Location and principal features of Weed Heights and vicinity.

(PART A)

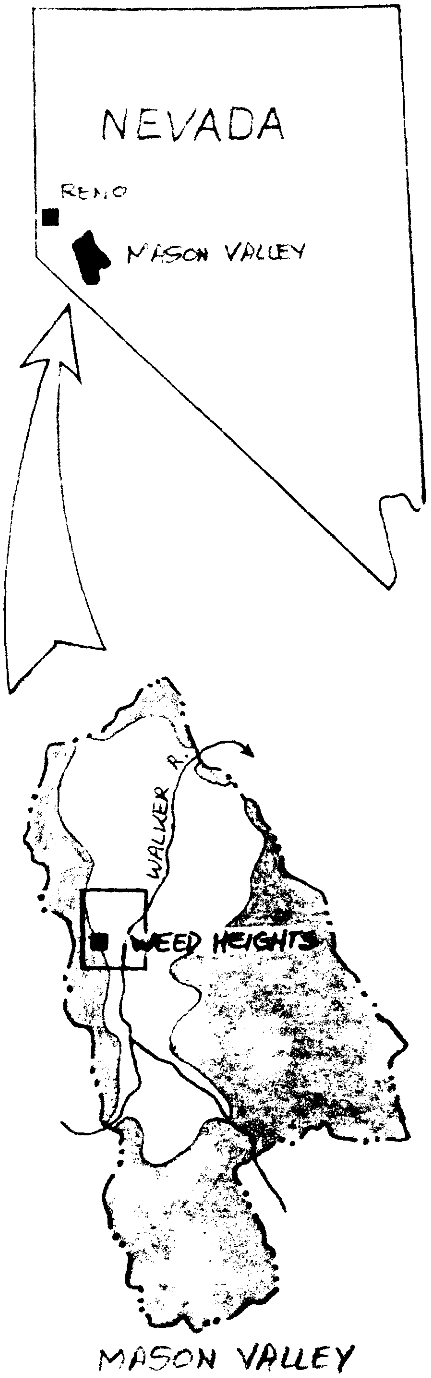


FIGURE 1 (PART B)

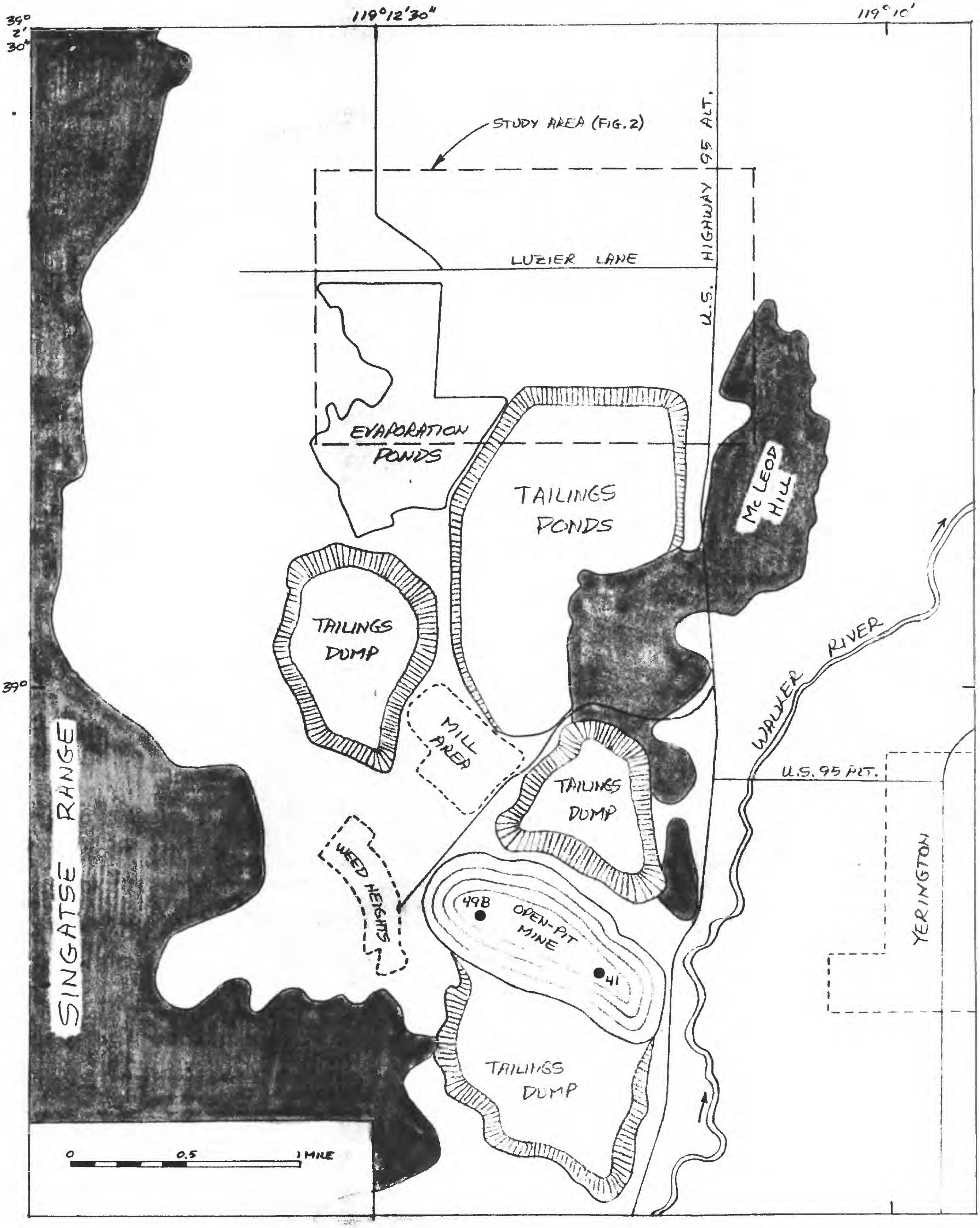


FIGURE 1 (PART C)

This study was begun by A. S. Van Denburgh. Much of the final field work was done by R. J. La Camera, and the report manuscript was prepared largely by H. R. Seitz and Van Denburgh.

Test Wells

Drilling

At 13 sites downgradient from the waste-disposal ponds (figure 2), 17 Geological Survey test wells were augered and cased with 2-inch-diameter polyvinyl chloride ("PVC") pipe. All casings were capped at the bottom. At each site, slots cut by hacksaw were placed within the uppermost 5 feet of saturated sedimentary deposits to ascertain the quality of shallow ground water. At sites 1, 2, 4, and 5 (figure 2), second wells were drilled and cased with perforations at greater depths (27 to 29½ feet below land surface, and about 15 to 28 feet below the water table). At each of these four sites, the shallow well is identified in this report with an "A" and the deeper well with a "B" (table 1).

Preliminary Pumping and Final Sampling

Before final sampling for comprehensive analysis, the wells were pumped to ensure that the final samples were chemically representative of ground water from the aquifer, rather than water influenced by the well drilling or by subsequent storage in the casing. The two rounds of preliminary pumping, in late 1976 and January 1978, were accomplished by using compressed air (in retrospect, an undesirable technique because of the possible chemical influence of oxygen), and the chemical character was monitored by frequent determinations of specific conductance. Total preliminary pumpage ranged from 16 to 86 gallons per well (median, 38 gallons), depending upon the productivity of each well and the time needed for stabilization of specific conductance.

Final pumping and subsequent sampling, which took place in August-September 1978, employed a battery-operated peristaltic device. Continuous measurements of pH, dissolved oxygen, and water temperature were used to monitor the quality of the pumped ground water. The final pumpage prior to sampling ranged from 10 to 29 gallons (median, 17 gallons), again depending on the time required for water-quality stabilization.

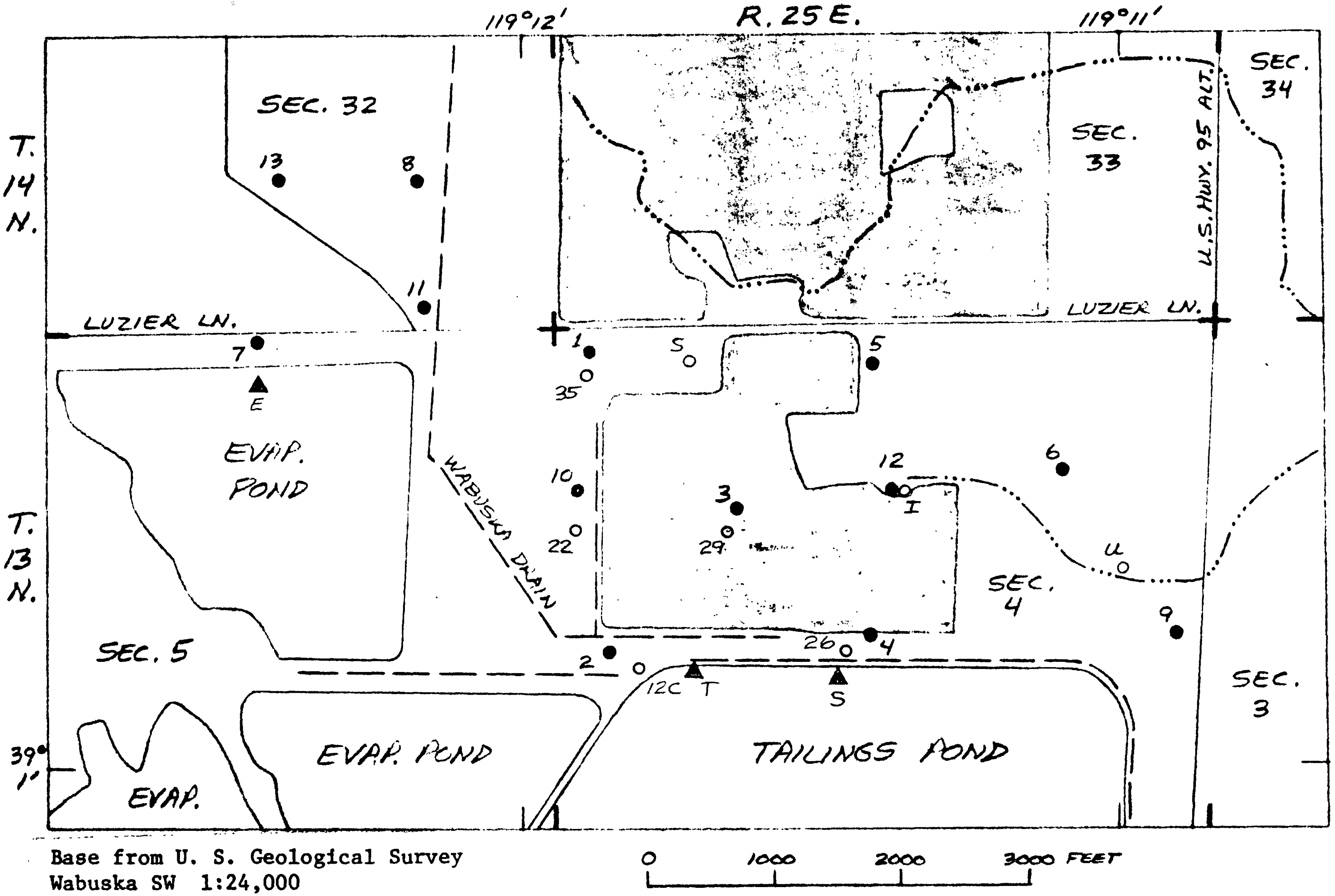
Before final pumping, argon gas was injected into each well. The intent was to replace the oxygen-rich air in the casing with a heavier, inert gas. This would minimize contact between incoming ground water and oxygen, thereby decreasing the opportunity for chemical alterations. The effectiveness of this precautionary procedure is not known.

During the period between drilling and preliminary pumping, test well 8 was damaged by vandals and could not be used for water-quality evaluation.

EXPLANATION

▭	Irrigated area
——•••——	Principal irrigation ditch
— — —	Principal drainage ditch
6 ●	U.S. Geological Survey test-well site, with number
25 ○	Anaconda well, with Company number or designation
▲ E	Waste-fluid sampling site: E, evaporation pond; S, tailings-pond seepage; T, tailings fluid

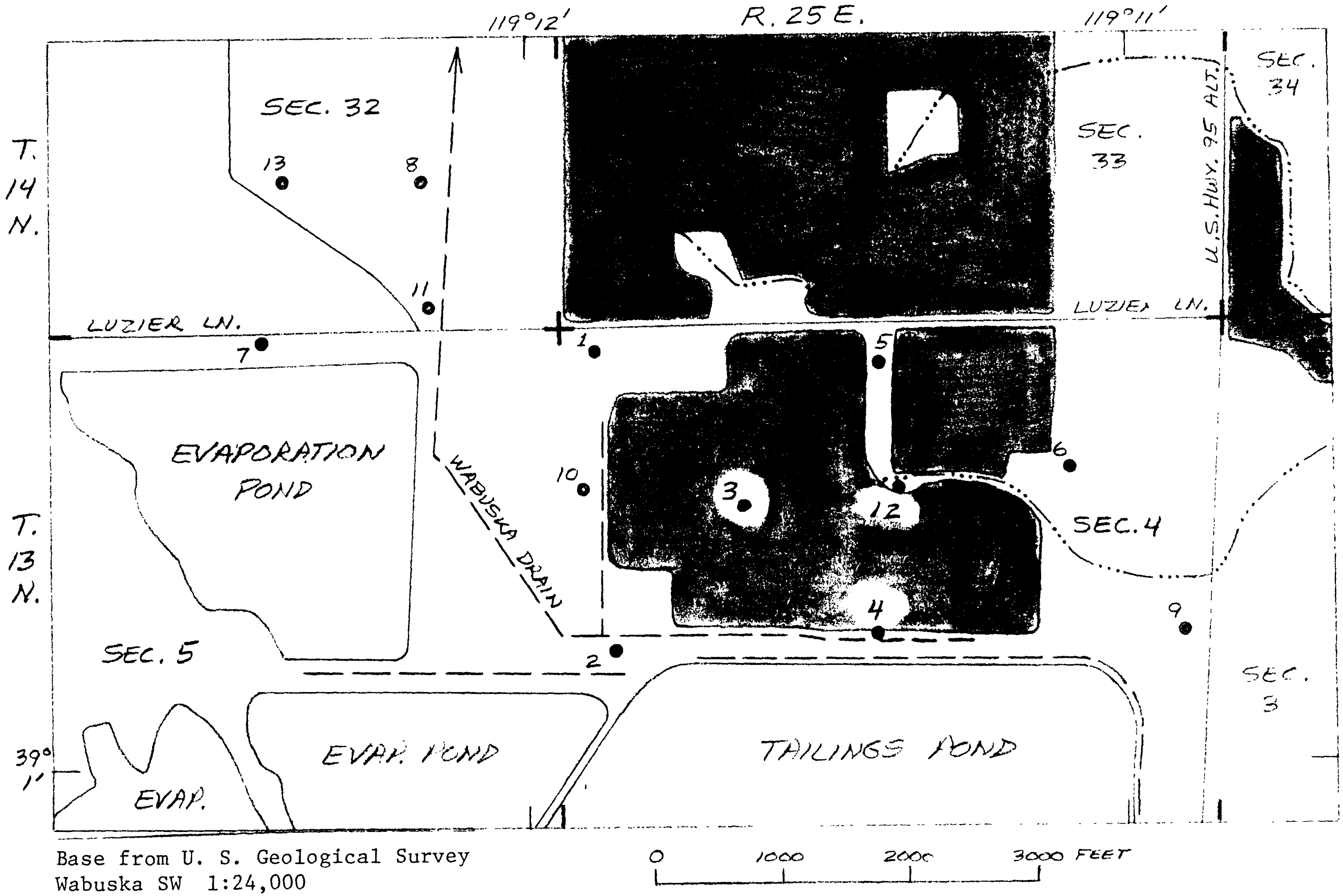
FIGURE 2.--Location of wells, irrigated lands, ditches for irrigation and drainage, and waste-fluid sampling sites.



Base from U. S. Geological Survey
Wabuska SW 1:24,000
orthophotoquad, 1974

FIGURE 2 (CAPTION HERE)

NOTE: FINAL VERSIONS OF FIGURES 2, 4, 7 WILL USE CORRECTED BASE (SEE NEXT PAGE)



Base from U. S. Geological Survey
Wabuska SW 1:24,000
orthophotoquad, 1974

CORRECTED
BASE

FIGURE 2 (CAPTION HERE)

TABLE 1.--*Well records*

Location and site ID: For each well, first line is an abbreviated location designation. Because all wells are in Mason Valley, the hydrographic area number (108) is omitted; for example, complete designation for well 1A would be 108 N13 E25 4BBBB1. Second line is site identification. See text.

Water level: Measurements reported by driller are indicated by an asterisk. All other measurements made by Geological Survey personnel. Wells were not being pumped at time of measurement; however, nearby wells presumably were being pumped except on Sept. 4, 1980, and prior to 1965. "Measuring point" indicates distance above or below (-) land-surface datum, in feet, as of Sept. 4, 1980. All measuring points are top of innermost casing, except that for well I, which is top of diagonal 2-inch access pipe.

Use of well: D, domestic; I, industrial (mining, milling, and other uses); Ir, irrigation; U, unused; X, test well drilled for this study. Former use or intended use in parentheses.

				Casing		Water level			Pumping test			
Well	Location and site ID	Land-surface altitude (feet above sea level)	Well depth (feet below land surface)	Diameter (inches)	Perforated interval (feet below land surface)	Feet below land-surface datum	Date	Measuring point	Reported discharge (gallons per minute)	Specific capacity [(gal/min)/ft of drawdown]	Use of well	Date of well completion
Geological Survey test wells												
1A	N13 E25 4BBBB1	4,350.8	28.6	2	5.0-11.0	9.70	01-09-78	1.3	--	--	X	06-08-76
	390133119115301					4.16	09-04-80					
1B	N13 E25 4BBBB2	4,351.0	29.0	2	27.0-28.9	9.83	01-09-78	1.1	--	--	X	06-08-76
	390133119115302					4.27	09-04-80					
2A	N13 E25 4CBBA1	4,352.4	29.3	2	5.4-11.4	1.00	01-06-78	.7	--	--	X	06-08-76
	390109119115101					1.21	09-04-80					
2B	N13 E25 4CBBA2	4,352.6	29.7	2	27.7-29.6	1.54	01-09-78	.4	--	--	X	06-08-76
	390109119115102					1.94	09-04-80					
3	N13 E25 4BDBB1	4,354.4	29.6	2	4.6-11.1	8.13	01-11-78	.5	--	--	X	06-08-76
	390120119113801					3.68	09-04-80					
4A	N13 E25 4BDDD1	4,356.5	27.0	2	3.5-9.5	5.30	01-10-78	1.1	--	--	X	06-08-76
	390110119112401					4.11	09-04-80					
4B	N13 E25 4BDDD2	4,356.5	29.5	2	27.5-29.4	5.34	01-09-78	.6	--	--	X	06-09-76
	390110119112402					3.96	09-04-80					
5A	N13 E25 4BAAD1	4,354.4	29.1	2	4.1-11.1	4.92	09-04-80	1.0	--	--	X	06-09-76
	390132119112401											
5B	N13 E25 4BAAD2	4,354.3	29.1	2	27.1-29.0	11.88	01-06-78	1.0	--	--	X	06-09-76
	390132119112402					4.83	09-04-80					
6	N13 E25 4AACC1	4,357.7	30.0	2	8.0-14.5	10.78	01-07-78	.6	--	--	X	06-09-76
	390123119110501					5.22	09-04-80					
7	N13 E25 5ABBB1	4,348.7	25.3	2	3.3-9.3	7.20	01-11-78	1.2	--	--	X	06-09-76
	390134119122601					3.07	09-04-80					
8	N14 E25 32DDBB1	4,350.0	29.2	2	6.2-12.2	7.91	01-25-78	.1	--	--	X	06-09-76
	390146119121001					5.02	09-04-80					
9	N13 E25 4ADDD1	4,362.5	40.0	2	15.0-25.0	14.08	01-06-78	.1	--	--	X	06-09-76
	390110119105301					9.01	09-04-80					
10	N13 E25 4BCBB1	4,352.5	28.2	2	3.2-13.2	6.89	01-11-78	1.9	--	--	X	06-10-76
	390122119115401					3.21	09-04-80					
11	N14 E25 32DDCC1	4,349.0	29.6	2	6.6-14.6	7.00	01-05-78	.5	--	--	X	06-10-76
	390136119120901					3.25	09-04-80					
12	N13 E25 4ACBB2	4,357.1	28.0	2	4.5-13.0	11.60	01-09-78	.5	--	--	X	06-10-76
	390122119112201					4.25	09-04-80					
13	N14 E25 32DCBA1	4,348.6	29.2	2	6.2-16.2	8.49	01-05-78	.9	--	--	X	06-10-76
	390146119122401					4.66	09-04-80					

TABLE 1.--*Well records*--Continued

Well	Location and site ID	Land-surface altitude (feet above sea level)	Well depth (feet below land surface)	Casing: Diameter (inches)	Casing: Perforated interval (feet below land surface)	Water level: Feet below land-surface datum	Water level: Date	Water level: Measuring point	Pumping test: Reported discharge (gallons per minute)	Pumping test: Specific capacity [(gal/min)/ft of drawdown]	Use of well	Date of well completion
Anaconda Company wells												
12C	N13 E25 4CBAB1 390108119114801	4,354	465	16	200-455	6* 22.99 3.3	01- -65 03-15-66 09-04-80	0.5	1,490	12	U(I)	01-26-65
22	N13 E25 4BCBC1 390119119115401	4,353	440	18	103-440	20* 3.77	09- -67 09-04-80	4	--	--	U(I)	09-08-67
26	N13 E25 4CAAA1 390109119112701	4,357	322	18	50-322	15* 5.63	07- -68 09-04-80	1.5	--	--	U(I)	07-01-68
29[a]	N13 E25 4BCAD2 390119119113901	4,355	337	16	--	38.52 5.55	05-11-76 09-04-80	1.7	--	--	U(I)	1976?
35[a]	N13 E25 4BBBC2 390131119115301	4,352	420	16	220-420	15* 7.07	11- -72 09-04-80	1.5	--	--	U(I)	11-28-72
41	N13 E25 21BAAD1 385854119112601	4,025	323	--	--	--	--	--	--	--	U(I)	--
49B	N13 E25 17DDAD1 385907119120001	3,912	470	--	--	--	--	--	--	--	U(I)	--
I	N13 E25 4ACBB1 390122119112101	4,357	373	14	100-373	18.84 8.5±	03-15-66 09-04-80	.5	2,800	[b]37	Ir(I)	06-03-61
S	N13 E25 4BBAD1 390132119114301	4,353±	42±	6	--	9.60 9.26 11.96 5.97	03-15-66 05-20-76 12-08-76 09-04-80	-4.9	--	--	U(D)	--
U	N13 E25 4ADCA1 390115119105901	4,360±	151	14	91-151	24* 18.16 16.03 11.40	05- -61 12-08-76 01-26-78 09-04-80	.5	630	6	U(Ir)	05-24-61

[a] Second well at site (original wells 29 and 35 abandoned).

[b] Estimated on basis of assumed static water level about 10 feet below land surface.

Well-Location Numbers

Two location systems are used in table 1. The first is based on a hydrographic area number and the rectangular subdivision of lands, referenced to the Mount Diablo base line and meridian. A complete designation of location consists of four units: The first is the hydrographic-area number, as defined by Rush (1968); for Mason Valley, the number is 108. The second unit is a township number (with "N" indicating that the township is north of the base line); the third unit is the range number ("E" indicates east relative to the meridian); the fourth unit includes the section number, followed by letters designating the quarter section, quarter-quarter section, and so on (A, B, C, and D indicate northeast, northwest, southwest, and southeast quarters, respectively), followed in turn by a sequence number. For example, well 108 N13 E25 4CBAB1 is in Mason Valley, within a 2½-acre tract identified as NW¼NE¼NW¼SW¼ sec 4, T. 13 N., R. 25 E., and it is the first well recorded in that tract.

Because all wells mentioned in this report are in Mason Valley, the hydrographic area number (108) is omitted throughout.

In table 1, the wells are also identified by the Geological Survey site identification (ID), which is based on the grid system of latitude and longitude. The ID indicates the geographic location of each site, and provides a unique number for each. The ID consists of 15 digits: The first six digits denote the degrees, minutes, and seconds of latitude, the next seven digits denote degrees, minutes, and seconds of longitude, and the last two digits (assigned sequentially) identify the site within a 1-second grid.

Acknowledgments

General Manager Mark B. Nesbitt and other employees of The Anaconda Company cooperated fully in this study by allowing access to the study site, granting permission to install the shallow test wells, and supplying water-quality data from deep production wells owned and operated by the Company. Without the help of Anaconda Company, completion of this study would not have been possible.

Within the Geological Survey, Richard L. Whitehead ably supervised the test-well drilling and David B. Wood did preliminary pumping of the test wells.

DESCRIPTION OF STUDY AREA

Anaconda's open-pit mine and mill are on the west side of Mason Valley, adjacent to the Walker River near Yerington (figure 1). Land-surface altitudes on the periphery of the pit range from 4,600 to 4,400 feet above sea level. The northernmost waste-disposal ponds are on the valley floor at an altitude of about 4,350 feet. The tailings ponds and evaporation ponds cover about 1.8 and 0.4 square miles, respectively.

The study area is arid: precipitation at nearby Yerington averages only about 5 inches per year, whereas water-surface evaporation totals about 48 inches per year (Huxel, 1969, page 9, figure 2).

ORE-PROCESSING OPERATIONS

Milling procedures at Weed Heights depended upon whether the ore was of the oxide or sulfide type. The sulfide ore was finely crushed and the copper sulfide particles were recovered by a flotation process, during which lime (calcium oxide) was added to maintain an alkaline pH (William Norem, The Anaconda Co., oral commun., 1980); the residual gangue was then discarded at the tailings dumps and ponds. Oxide ore was crushed and vat-treated with sulfuric acid. The resulting copper sulfate solution was decanted, and the remaining solids were washed and discarded at the tailings dumps. The copper sulfate solution was chemically altered by exchanging the copper with iron, which produced a solid copper precipitate. Residual acid fluid, dominated by iron (Fe) and sulfate (SO_4), then was disposed of at the evaporation ponds. The copper concentrates from both processes were dried and shipped elsewhere for smelting. [Information on milling procedures is from The Anaconda Company, 1976(?), pages 16-24.]

Fine-grained tailings were transported to the ponds as a slurry, and the liquid portion was then recycled for further use at the mill. The pumping rate for recycling was generally on the order of 6,000 gallons per minute (M. B. Nesbitt, The Anaconda Co., oral commun., 1978). Acid waste fluid was transported to the evaporation ponds at a rate of about 700 gallons per minute (1,100 acre-feet per year), according to Nesbitt (oral commun., 1976).

Seepage from the northernmost tailings pond was collected in a peripheral ditch (figure 2) and recycled along with the tailings fluid. Ditches downgradient from the northeasternmost evaporation ponds captured leakage, which was then pumped back into the ponds.

During the mining operations (1953-78), the dumps and ponds were expanded as needed from the initial area adjacent to the mill, eastward and northward to their current areal extent (figure 1). The tailings ponds dried soon after milling operations ceased in June 1978, whereas the acid brine took appreciably longer to dry.

Wells supplied all water for mining and milling purposes, as well as for domestic use at the company town of Weed Heights. As of 1975, seventeen wells were in operation, and total pumpage was about 10,300 acre-feet that year (The Anaconda Company, written commun., 1976).

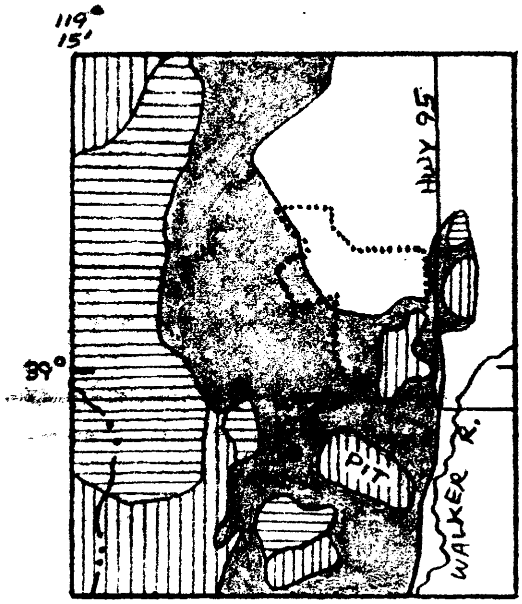
GENERALIZED GEOLOGY

Geologic units in the study area are of two general types: Unconsolidated to semiconsolidated sedimentary deposits of Quaternary age (Huxel, 1969, pages 6-9, plate 1), and consolidated igneous rocks of Tertiary and Cretaceous age (Moore, 1969, plate 1), as shown in figure 3.

The sedimentary units include (1) alluvial-fan deposits along the west margin of the valley and (2) stream- and lake-deposited materials on the valley floor (figure 3). Both units consist of sedimentary materials that range in grain size from clay to boulders, with the valley-floor deposits tending to be the best sorted, least consolidated, and most permeable of the two units. (See Huxel, 1969, table 1.) The Weed Heights tailings dumps and evaporation ponds overlie sedimentary deposits of both units (figure 3). Shallow Geological Survey test wells and deep Anaconda production wells north of the dumps and ponds presumably tap water-bearing zones in the valley-floor sedimentary deposits. The following composite log, from Geological Survey test well 1A and nearby Anaconda original and second well 35 (figure 2), provides an example of deposits underlying the study area:

Material[1]	Thickness (feet)	Depth (feet)
Sand, fine	5	5
Sand, fine, silty	1	6
Sand, silty	13	19
Sand, very fine	7	26
Silt, clayey	3	29
Sand and clay	31	60
Clay, hard	3	63
Sand and clay, interbedded	75	138
Gravel, coarse	14	152
Sand, coarse, with thin layers of clay	224	376
Gravel, coarse, hard	7	383
Sand, coarse, with some thin layers of clay	29	412
Sand and gravel, coarse, firm	8	420
Conglomerate (coarse gravel with matrix of finer-grained sediment; consolidated)	30	450
Consolidated rocks, volcanic	50	500

[1] Sources of data: 0-29 feet, Geological Survey well 1A; 29-420 feet, Anaconda second well 35; 420-500 feet, original well 35.



EXPLANATION

□	Valley-floor sedimentary deposits	QUATERNARY
■	Alluvial-fan sedimentary deposits	
▤	Volcanic rocks	TERTIARY AND CRETACEOUS
▥	Granitic intrusive rocks	
——••——	Basin boundary	
••••••••••••	Areal extent of evaporation and tailings ponds	

Geology from Huxel (1969, pl. 1) and Moore (1969, pl. 1)

FIGURE 3.--Generalized geology of Weed Heights and vicinity.

The igneous units include (1) granitic intrusive rocks and (2) volcanic rocks dominated by pyroclastic-type materials. The ore body at Weed Heights occurs in granitic rocks. (See Moore, 1969, plate 1 and page 26.) Igneous rocks underlie the study area at variable depth, as indicated by the following data for Anaconda wells (figure 2):

Well	Depth to igneous rocks (feet)
12C	> 465 (none encountered)
22	> 440 Do.
26	322 (volcanic)
29[a]	230 Do.
35[a]	450 Do.
I	> 373 (none encountered)
U	146? ("rocks")

[a] From drillers' logs of original wells 29 and 35.

GROUND-WATER HYDROLOGY

The ground-water reservoir in Mason Valley is recharged mostly by percolation from the Walker River and its tributaries and from irrigation ditches and flood-irrigated fields (Huxel, 1969, page 27). In most parts of the valley, ground water moves from south to north, in the same approximate direction as surface drainage (Huxel, 1969, plate 2 and page 15).

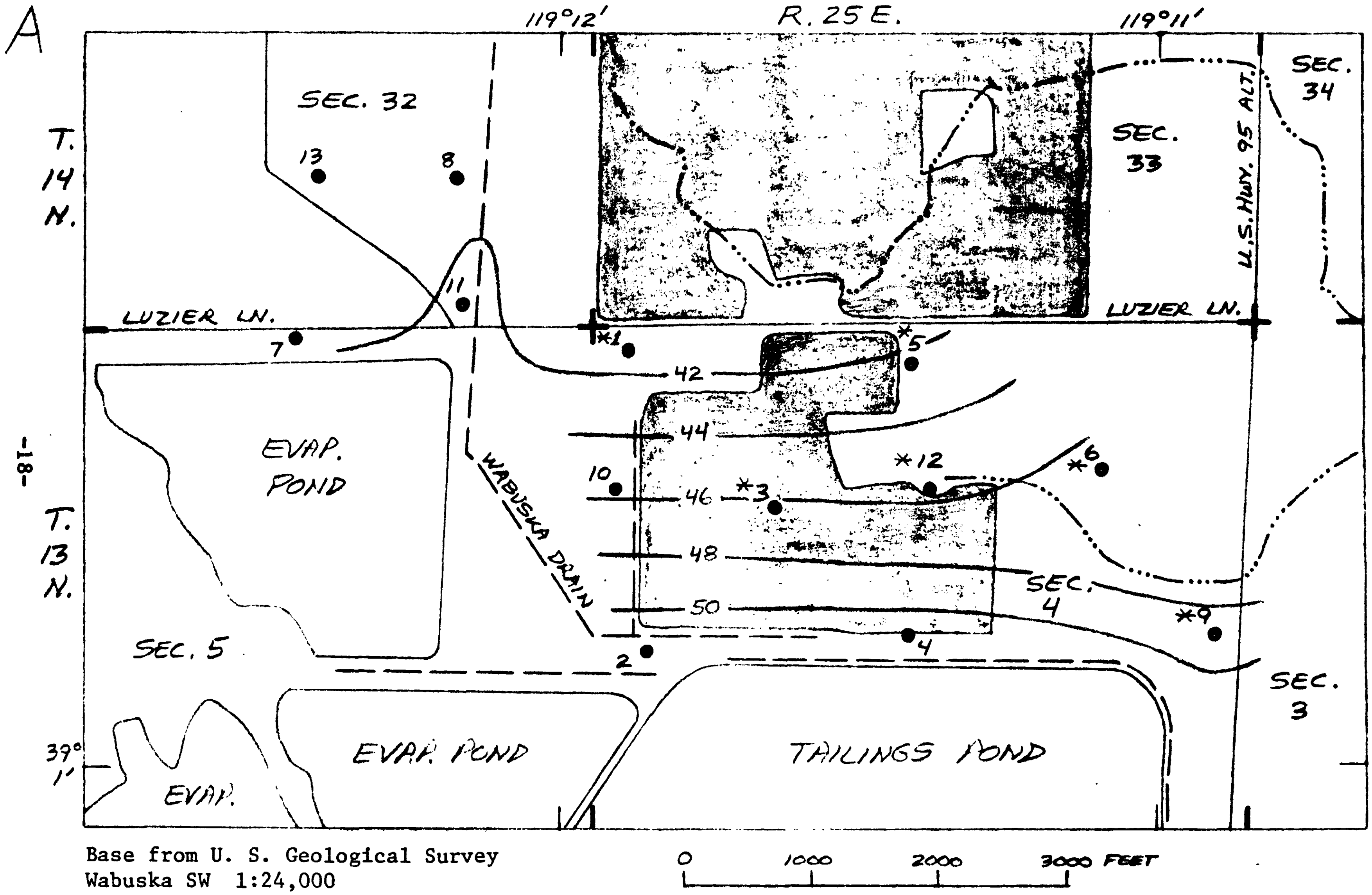
The generalized configuration of the water table north of the Weed Heights waste-disposal ponds is shown in figure 4. As of September 1980, depths to water ranged from 1 to 9 feet below land surface (table 1). Figure 4B indicates that the shallow, unconfined (nonartesian) ground water moves generally northwestward (that is, perpendicular to the water-table contours).

Limited water-level data for the deeper Anaconda supply wells in the same area (table 1) indicate that heavy pumping beginning in the mid-1960's produced a cone of depression at depth. Thus, during the several-year period of intensive pumping, the natural direction of movement for the deeper, confined ground water was disrupted. Instead of moving generally northward, the deeper water moved radially inward toward the supply wells. Since the termination of mining and milling operations in June 1978, conditions in the deeper water-bearing zones presumably have approached the natural (prepumping) status.

EXPLANATION

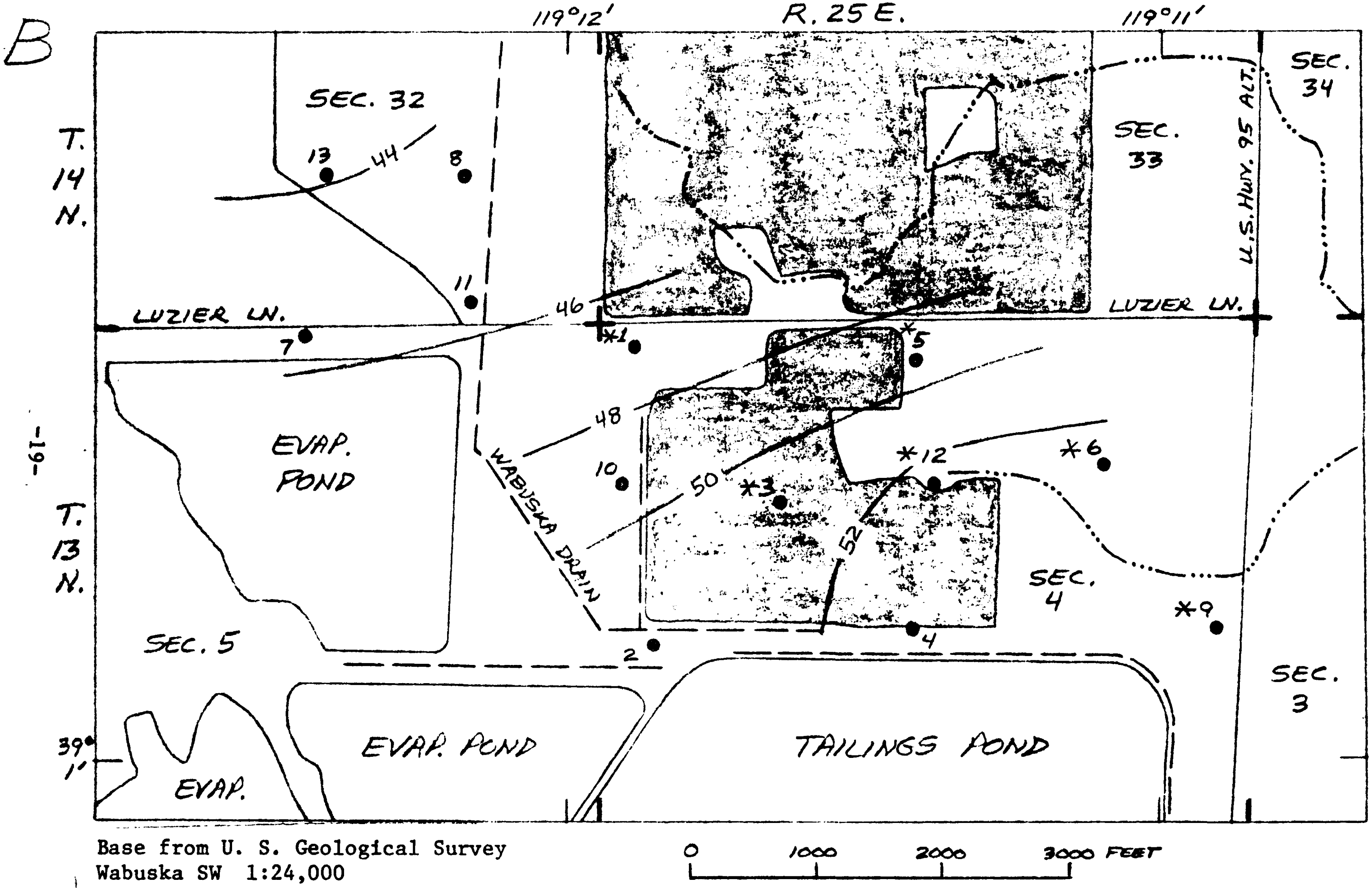
▨	Irrigated area
———•••———	Principal irrigation ditch
— — —	Principal drainage ditch
——42——	Water-table contour. Shows altitude, in feet above 4,300 ft. Approximately located. Contour interval is 2 ft. Datum is sea level. Based on data from Geological Survey test wells (table 2)
6 ●	Geological Survey test well, with number

FIGURE 4.--Altitude of water table, January 1978 (A) and September 1980 (B). Test wells in which water level rose more than 4 ft between January and September 1978 are indicated by asterisks.



Base from U. S. Geological Survey
Wabuska SW 1:24,000
orthophotoquad, 1974

FIGURE 4 (CAPTION HERE)



Base from U. S. Geological Survey
Wabuska SW 1:24,000
orthophotoquad, 1974

FIGURE 4 (CAPTION HERE)

Water levels in shallow wells have fluctuated during the study (table 2, figure 5). During most of the period, the measured magnitude of variation was $1\frac{1}{2}$ feet or less. Between January and mid-September 1978, in contrast, all shallow wells in the north-central and northeastern parts of the study area (figure 4) exhibited water-level rises ranging from 4.3 to 6.1 feet. The general rise could have been associated with either (1) cessation of industrial-well pumping when mining and milling terminated in mid-year, or (2) the irrigation of alfalfa fields in the study area with river water during the spring and summer of 1978. The first alternative is strongly supported by the contrast between water levels in September 1976 and those in September 1978 (at the same time of year before and after the shutdown), and by the shallow levels in April 1979, prior to the start of irrigation that spring (table 2, figure 5). Thus, deeper pumping apparently had a significant effect on shallow ground-water levels in and adjacent to the industrial well field. The pumping also may have induced a downward component of movement for shallow and intermediate-depth ground water near the industrial wells. The magnitude of such a component would be further increased by the concurrent application of imported surface water for irrigation in the same area.

By September 1980, more than 2 years after the termination of industrial ground-water withdrawals, the water table had risen even more, particularly in the northwestern part of the study area (test wells 7 and 13). The net rise since January 1978 (as much as 7.4 feet in the northeast) produced significant changes in water-table configuration and, as a result, in the direction of shallow ground-water movement, as shown by the contrast between figures 4A and 4B. Although some of the change--particularly in the vicinity of test well 12--was due to irrigation at the time of measurements in 1980, most of the contrast apparently results from cessation of industrial pumping.

Land-surface evidence of the rising water table has included inundation of low-lying features such as the barrow pits near test well 9 and the low-gradient drainage ditches--particularly Wabuska Drain--farther to the west.

The downgradient (generally northward) velocity of ground-water flow through the study area can be approximated by using estimates of several hydraulic characteristics of the particular aquifer involved, including its transmissivity, effective porosity, and water-table gradient.

Transmissivity is the rate at which water would be transmitted through a unit width of aquifer under a unit hydraulic gradient (Lohman and others, 1972, page 13). Thomasson and others (1960, page 222) described a rough estimate that, in slightly modified form, relates aquifer transmissivity to the specific capacity of a well (specific capacity is the ratio of pumping yield, in gallons per minute, to water-level drawdown, in feet):

$$T \approx 270(SC),$$

where T is the transmissivity, in feet squared per day, and SC is the specific capacity, in gallons per minute per foot of drawdown. The computation assumes that the well is fully efficient. The degree to which the well is less than fully efficient will have a commensurate effect on the accuracy of the

TABLE 2.--*Ground-water levels and specific conductances for shallow test wells*

Well	Date	Water-surface altitude (feet above sea level)	Specific conductance (micromhos, rounded)[1]
1A	11-18-76	4,341.18	--
	12-09-76	4,341.68	--
	12-27-76	4,342.01	780
	01-09-78	4,341.10	790
	09-06-78	4,345.93	1,400
	09-20-78	4,345.73	--
	04-12-79	4,346.41	--
	09-04-80	4,346.64	--
1B	10-14-76	4,341.72	--
	11-16-76	4,341.17	--
	12-09-76	4,341.73	880
	01-09-78	4,341.17	850
	09-06-78	4,346.01	880
	09-20-78	4,345.79	--
	04-12-79	4,346.50	--
	09-04-80	4,346.73	--
2A	09-07-76	4,349.96	--
	10-14-76	4,350.23	--
	11-18-76	4,350.44	--
	12-09-76	4,350.77	--
	12-27-76	4,350.47	7,200
	01-06-78	4,351.40	--
	01-11-78	--	14,000
	09-05-78	4,351.27	15,000
	09-20-78	4,351.21	--
	04-12-79	4,351.78	--
	09-04-80	4,351.19	--
2B	10-14-76	4,349.68	--
	11-18-76	4,349.90	--
	12-09-76	4,350.22	25,000
	01-09-78	4,351.06	25,000
	09-05-78	4,350.95	--
	09-19-78	--	26,000
	09-20-78	4,350.80	--
	04-12-79	4,351.35	--
	09-04-80	4,350.66	--
3	09-08-76	4,346.62	--
	10-13-76	4,345.35	1,500
	12-09-76	4,345.63	--
	01-11-78	4,346.25	2,300
	09-01-78	4,351.43	520
	09-21-78	4,350.52	--
	04-12-79	4,349.70	--
	09-04-80	4,350.70	--
4A	09-08-76	4,350.86	--
	10-13-76	4,350.07	--
	11-17-76	4,350.77	--
	12-08-76	4,351.06	3,200
	01-10-78	4,351.20	--
	01-11-78	--	1,800
	08-29-78	4,352.26	1,300
	09-21-78	4,352.16	--
	04-12-79	4,351.87	--
	09-04-80	4,352.39	--
4B	10-13-76	4,350.08	--
	12-09-76	4,351.06	--
	12-27-76	4,350.96	2,000
	01-09-78	4,351.19	1,700
	08-29-78	4,352.56	1,600
	09-21-78	4,352.55	--
	04-12-79	4,351.92	--
	09-04-80	4,352.57	--
5A	09-09-76	4,344.16	--
	10-14-76	4,344.18	--
	12-08-76	4,343.97	--
	12-27-76	4,344.40	550
	08-28-78	4,349.13	720
	09-21-78	4,348.41	--
	04-12-79	4,347.66	--
	09-04-80	4,349.43	--
5B	10-14-76	4,344.14	--
	11-17-76	4,343.35	600
	12-10-76	4,344.04	--
	01-06-78	4,342.42	610
	08-21-78	4,349.20	610
	09-21-78	4,348.47	--
	04-12-79	4,347.70	--
	09-04-80	4,349.44	--
6	09-09-76	4,347.17	--
	10-15-76	4,347.17	420
	12-08-76	4,347.30	--
	01-07-78	4,346.89	490
	08-30-78	4,352.12	660
	09-20-78	4,351.89	--
	09-04-80	4,352.48	--
7	09-07-76	4,343.57	--
	10-13-76	4,343.33	--
	11-17-76	4,343.03	7,800
	12-09-76	4,342.90	--
	04-07-77	4,342.96	--
	01-11-78	4,341.51	8,200
	08-31-78	4,343.33	--
	09-19-78	4,343.44	8,600
	04-12-79	4,344.70	--
	09-04-80	4,345.64	--
8	09-08-76	4,342.95	(2)
	10-12-76	4,342.60	(2)
	12-09-76	4,342.91	(2)
	01-25-78	4,342.07	(2)
	09-04-80	4,344.98	(2)
9	09-09-76	4,347.77	--
	10-13-76	4,348.06	--
	11-17-76	4,348.86	3,200
	12-08-76	4,349.15	--
	01-06-78	4,348.40	3,100
	08-30-78	4,353.18	2,900
	09-20-78	4,353.22	--
	09-04-80	4,353.47	--
10	09-07-76	4,346.25	--
	10-14-76	4,345.50	--
	11-18-76	4,344.89	2,000
	12-09-76	4,345.02	--
	01-11-78	4,345.61	2,700
	09-07-78	4,349.66	2,100
	09-20-78	4,349.14	--
	09-04-80	4,349.29	--
11	09-08-76	4,342.51	--
	10-12-76	4,343.17	2,700
	12-09-76	4,342.77	--
	01-05-78	4,341.99	2,600
	08-31-78	4,344.61	2,700
	09-21-78	4,344.85	--
	04-12-79	4,345.56	--
	09-04-80	4,345.74	--
12	09-09-76	4,345.69?	--
	10-14-76	4,345.23?	--
	12-09-76	4,346.33	--
	12-27-76	4,346.60	830
	01-09-78	4,345.30	1,100
	08-28-78	4,352.27	430
	09-21-78	4,350.71	--
	04-12-79	4,349.76	--
	09-04-80	4,352.85	--
13	09-08-76	4,341.61	--
	10-12-76	4,341.47	1,100
	12-09-76	4,341.40	--
	01-05-78	4,340.10	1,100
	08-31-78	4,341.51	1,100
	09-21-78	4,341.79	--
	04-12-79	4,343.37	--
	09-04-80	4,343.93	--

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[1] First value listed for each well indicates conductance at termination of preliminary pumping in 1976 (see text). Cumulative pumpage, 10-51 gallons (median, 26 gallons).

[2] Well damaged by vandals; could not be sampled.

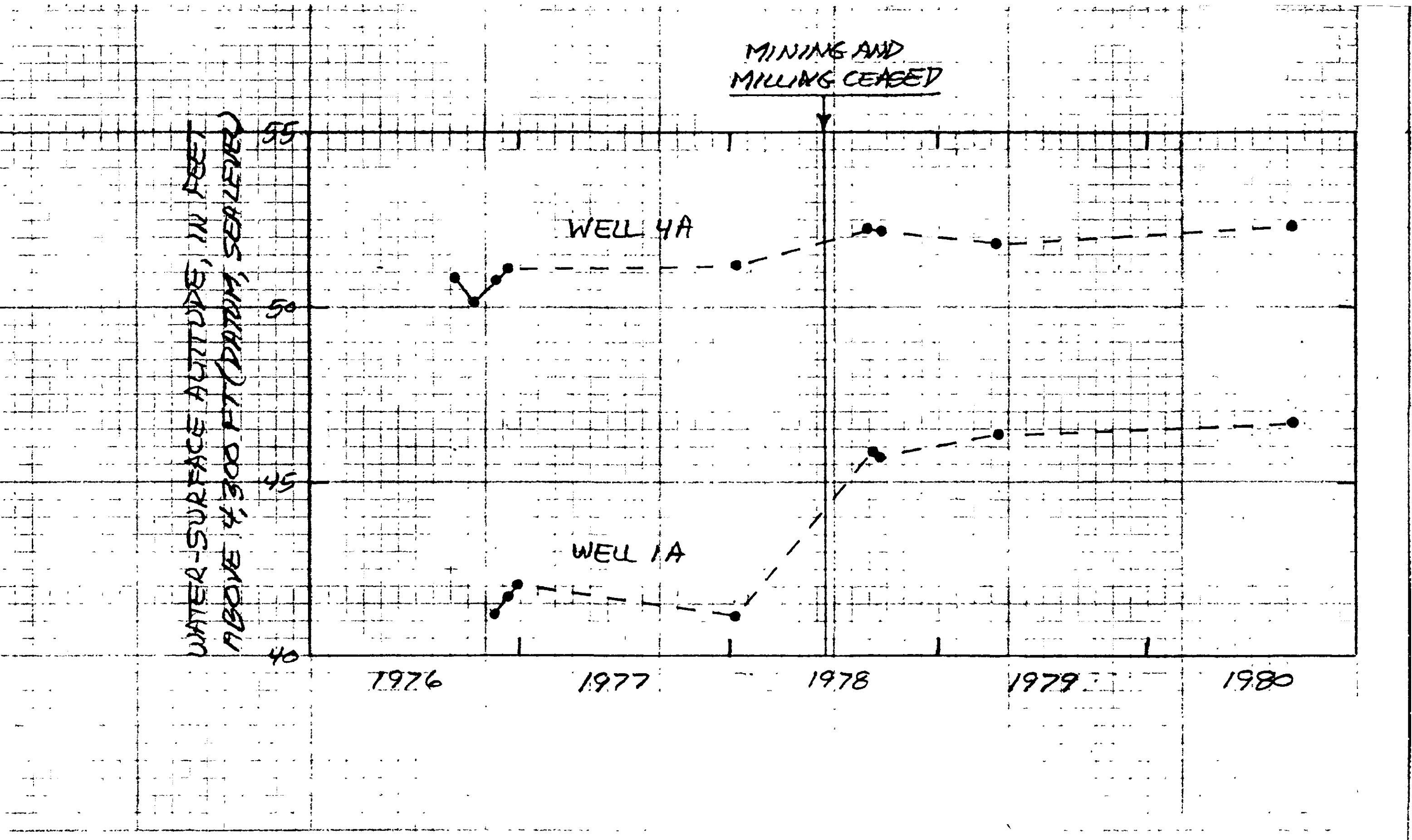

FIGURE 5.--Water-level fluctuations in representative shallow test wells 1A and 4A, 1976-80.

estimated transmissivity. Drillers' records for Anaconda deep wells 12C and I (table 1) indicate specific capacities of 12 and about 37 gallons per minute per foot, respectively, which suggest an average transmissivity on the order of 7,000 feet squared per day for water-bearing materials 100-455 feet below land surface. If the lower of the two specific capacities is a reflection of low well efficiency, a higher transmissivity, based only on the larger specific capacity, would be more reflective of true conditions.

The average velocity of ground-water movement through an aquifer can be estimated by using the following equation:

$$\overline{v} = \frac{T\ (dh/dl)}{b\theta},$$

where $\overline{v}$ is the average velocity, in feet per day; T is the transmissivity; dh/dl is the water-table gradient (negative for a falling gradient), in feet per foot; b is the aquifer thickness, in feet; and θ is the effective porosity, expressed as a decimal fraction. Effective porosity refers to the amount of interconnected pore space that is available for fluid transmission (Lohman and others, 1972, page 10). Johnson (1967) presents data on effective porosity for various earth materials. Applying his data to drillers' logs from the Weed Heights study area, values of 0.1 to 0.2 seem reasonable.

Assuming an average transmissivity of 7,000 feet squared per day and an average effective porosity of 0.15 for the uppermost 500 feet of saturated sedimentary deposits, along with an average water-table gradient of -0.002 foot per foot, the average ground-water velocity would be about 0.2 foot per day (or 50-100 feet per year). This estimate of velocity is, at best, only an order-of-magnitude value, because it is based on extremely meager aquifer-hydraulics data.

WATER QUALITY

Waste Fluids

Chemical analyses of tailings water from the recyling ditch, seepage from the tailings pond, and residual brine from one of the evaporation ponds are listed in table 3 (sampling sites are shown in figure 2). The alkaline tailings fluid contains about 1,100 mg/L of dissolved solids dominated by calcium and sulfate, with only small concentrations of elements such as copper that normally are minor constituents of natural water.

Seepage from the tailings pond is likewise dominated by calcium and sulfate, but it has a much lower pH, a somewhat greater dissolved-solids concentration (about 1,500 mg/L), and much greater concentrations of copper and zinc. The seepage presumably represents tailings water that has changed chemically during percolation through the tailings pile.

TABLE 3.-- Chemical analyses of waste fluids and water from shallow test wells and deeper supply wells

SITE	DATE OF SAMPLE	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	OXYGEN, DISSOLVED (MG/L)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	BICARBONATE (MG/L AS HCO3)	CARBONATE (MG/L AS CO3)	SULFATE DISSOLVED (MG/L AS SO4)
		WASTE FLUIDS[1]									
T	76-12-14	1540	11.4	--	210	2.2	110	27	0	21	580
S	76-12-08	1800	4.2	--	240	13	110	24	0	0	860
E	76-12-08	32500	1.75	--	700	4700	2700	1.6	0	0	47000
		GEOLOGICAL SURVEY TEST WELLS									
1A	78-09-06	1430	7.5	1.6	20	4.6	340	2.3	820	0	81
1B	78-09-06	880	7.6	.9	68	14	110	5.4	410	0	81
2A	78-09-05	14600	4.1	4.3	68	930	860	7.2	0	0	15000
2B	78-09-19	25800	3.8	1.2	53	2000	2900	64	0	0	26000
3	78-09-01	520	7.2	3.3	43	5.6	70	3.2	280	0	28
4A	78-08-29	1320	7.1	1.9	110	16	110	3.6	170	0	400
4B	78-08-29	1600	7.3	.8	180	39	130	7.9	39	0	690
5A	78-08-28	720	7.0	1.3	37	7.7	110	2.3	280	0	97
5B	78-08-21	610	7.1	6.0	53	13	64	4.1	240	0	84
6	78-08-30	660	6.8	1.3	64	14	60	3.3	230	0	110
7	78-09-19	8600	6.4	2.0	320	10	1800	1.6	1390	0	2200
9	78-08-30	2870	7.6	1.1	270	46	360	2.4	150	0	1300
10	78-09-07	2080	7.4	1.2	150	30	320	1.9	500	0	670
11	78-08-31	2740	7.5	.9	400	62	190	2.9	270	0	1200
12	78-08-28	430	7.3	5.0	40	6.9	42	11	230	0	27
13	78-08-31	1100	7.8	3.1	63	15	140	2.4	160	0	210
		ANACONDA WELLS[2]									
12C	79-04-00	2180	--	--	340	72	140	7.0	510	0	880
22	77-08-00	1020	--	--	96	22	95	5.5	290	0	240
26	79-01-00	1760	--	--	260	68	93	10	150	0	800
29	79-04-00	1880	--	--	300	72	110	9.0	290	0	910
35	79-04-00	440	--	--	36	11	49	4.0	150	0	87
I	79-04-00	1140	--	--	120	46	100	8.0	190	0	460

Footnotes at end of Table

TABLE 3--continued

SITE	DATE OF SAMPLE	CHLORIDE, DIS-SOLVED (MG/L AS CL)	FLUORIDE, DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	PHOSPHORUS, DIS-SOLVED (MG/L AS P)	ARSENIC DIS-SOLVED (UG/L AS AS)	BORON, DIS-SOLVED (UG/L AS B)	CADMIUM DIS-SOLVED (UG/L AS CD)	CHROMIUM, DIS-SOLVED (UG/L AS CR)	COBALT, DIS-SOLVED (UG/L AS CO)	COPPER, DIS-SOLVED (UG/L AS CU)	IRON, DIS-SOLVED (UG/L AS FE)	LEAD, DIS-SOLVED (UG/L AS PB)
WASTE FLUIDS[1]													
T	76-12-14	86	1.8	32	.020	1	330	0	0	0	6	50	0
S	76-12-08	78	2.5	83	.070	2	280	0	0	11	70000	100	0
E	76-12-08	1000	470	9.3	990	42000	11000	600	9000	28000	330000	30000000	3000
GEOLOGICAL SURVEY TEST WELLS													
1A	78-09-06	24	2.4	95	.140	200	970	1	0	0	1	30	0
1B	78-09-06	24	.4	48	.050	24	760	0	0	0	1	50	0
2A	78-09-05	210	.8	95	2.30	23	4700	6	40	4400	24000	3400000	8
2B	78-09-19	340	.6	270	.340	3	6500	10	50	6800	21000	6300000	560
3	78-09-01	7.2	.7	57	.240	100	520	0	0	0	8	20	1
4A	78-08-29	39	1.2	51	.117	27	750	1	0	--	50	20	9
4B	78-08-29	86	1.5	56	.020	6	410	3	10	--	0	30	10
5A	78-08-28	26	1.4	59	.087	40	460	0	10	--	1	190	0
5B	78-08-21	21	.8	43	.121	7	310	0	0	--	0	30	2
6	78-08-30	23	.5	47	.048	7	370	0	0	--	1	40	3
7	78-09-19	1100	.6	79	.080	73	6400	0	0	2	6	20	0
9	78-08-30	91	1.1	51	.021	18	940	0	10	--	0	20	2
10	78-09-07	110	.8	75	.050	340	1600	0	10	0	3	20	3
11	78-08-31	110	.3	54	.020	25	1000	0	10	0	0	20	0
12	78-08-28	7.9	.6	41	.232	30	280	0	0	--	3	20	2
13	78-08-31	120	.7	51	.060	60	480	0	10	0	0	20	3
ANACONDA WELLS[2]													
12C	79-04-00	84	.3	--	--	--	--	--	--	--	--	--	--
Z2	77-08-00	31	1.1	--	--	--	--	--	--	--	--	--	--
Z6	79-01-00	140	.3	--	--	--	--	--	--	--	--	--	--
Z9	79-04-00	81	.3	--	--	--	--	--	--	--	--	--	--
35	79-04-00	19	.6	--	--	--	--	--	--	--	--	--	--
I	79-04-00	48	<.1	--	--	--	--	--	--	--	--	--	--

Footnotes at end of Table.

TABLE 3 -- continued

SITE	DATE OF SAMPLE	MANGANESE, DISSOLVED (UG/L AS MN)	MERCURY DISSOLVED (UG/L AS HG)	MOLYBDENUM, DISSOLVED (UG/L AS MO)	NICKEL, DISSOLVED (UG/L AS NI)	SELENIUM, DISSOLVED (UG/L AS SE)	ZINC, DISSOLVED (UG/L AS ZN)	SOLIDS, SUM OF CONSTITUENTS, DISSOLVED (MG/L)
			WASTE FLUIDS[1]					
T	76-12-14	10	3.7	36	2	30	10	1090
S	76-12-08	180	5.2	1	0	26	460	1490
E	76-12-08	420000	1.2	500	21000	0	56000	97100
			GEOLOGICAL SURVEY WELLS					
1A	78-09-06	20	.1	61	0	2	10	973
1B	78-09-06	40	.2	40	0	2	10	556
2A	78-09-05	88000	.1	2	2	6	6800	20700
2B	78-09-19	45000	.3	40	6200	12	13000	38000
3	78-09-01	0	.1	30	0	1	10	354
4A	78-08-29	220	.0	32	--	3	10	816
4B	78-08-29	880	.1	45	--	0	20	1210
5A	78-08-28	700	.1	27	--	0	10	480
5B	78-08-21	10	.1	11	--	1	10	404
6	78-08-30	220	.1	7	--	1	10	437
7	78-09-19	3400	.0	27	3	0	30	6210
9	78-08-30	30	.2	32	--	1	10	2190
10	78-09-07	10	.1	23	0	1	10	1610
11	78-08-31	20	.1	23	2	2	10	2150
12	78-08-28	0	.1	9	--	1	10	291
13	78-08-31	70	.1	33	0	2	10	682
			ANACONDA WELLS[2]					
12C	79-04-00	--	--	--	--	--	--	[a]1980
22	77-08-00	--	--	--	--	--	--	[a]726
26	79-01-00	--	--	--	--	--	--	[a]1620
29	79-04-00	--	--	--	--	--	--	[a]1780
35	79-04-00	--	--	--	--	--	--	[a]350
I	79-04-00	--	--	--	--	--	--	[a]960

---

[1] T, tailings fluid; S, tailings-pond seepage; E, evaporation pond. Additional determinations, in micrograms per liter, for sites T, S, and E, respectively: Aluminum (Al), 300, 2,800, 6,400,000; antimony (Sb), 2, 0, --; beryllium (Be), 0, 0, 700; silver (Ag), 0, 0, 20; uranium (U), <0.4, 1.8, 6,200; vanadium (V), 5.8, 5.4, --. Water temperatures: 4.0°C (1600 hr); 10.5°C (1030 hr); 5.5°C (1245 hr).

[2] Analyses by The Anaconda Company.

[a] Residue on evaporation at 105°C.

The residual brine (almost 100,000 mg/L of dissolved solids) could be termed an impure sulfuric-acid solution, with large concentrations of iron, magnesium, and sodium, plus far-greater-than-normal amounts of many other constituents (particularly aluminum, copper, fluoride, and phosphorus).

The general chemical character of each waste fluid is depicted diagramatically in figure 6. The two triangles in that figure show the proportions of cations and anions, and the diamond shows the overall chemical character of each water. The type of diagram represented by figure 6 can be used as an aid in determining whether a particular water (1) is chemically similar to some other water, (2) is a simple mixture of two chemically different water types, or (3) has been affected by cation exchange or by the dissolution or precipitation of a particular mineral (Hem, 1970, page 268).

Each of the three waste fluids must be considered a potential source of ground-water contamination in the areas beneath and north of (hydraulically downgradient from) the tailings dump or evaporation ponds. However, the fluids differ greatly in undesirability, as indicated by their chemical status relative to the Federal standards for drinking water (table 4): the tailings fluid, tailings seepage, and acid brine are unacceptable in 5, 8, and 13 of the 16 listed categories, respectively.

Shallow Ground Water

Chemical analyses of water samples collected from the Geological Survey test wells in August and September 1978 are listed in table 3 and the waters are characterized in figure 6. The diagram indicates that most of the water is dominated by sodium and (or) calcium among the cations and by sulfate or bicarbonate among the anions.

Several chemical types of shallow ground water are evident in figure 6. The most dilute and least sulfate-rich is water from wells 1B, 3, 5A, 5B, 6, and 12, all of which are at least 0.2 mile downgradient from the tailings pond and in areas likely to have been influenced by percolating irrigation water (figure 2). In contrast, the most concentrated shallow ground water is from wells 2A and 2B. This acidic water closely resembles the nearby sulfuric brines, with large concentrations of copper, iron, and other normally minor constituents (table 3).

The water of well 4B is chemically similar to the nearby tailings fluid in several respects, whereas that of shallower well 4A may represent a mixture of tailings fluid and more dilute water perhaps related to nearby stream-water irrigation.

Water from wells 9 and 11 resembles the tailings fluid in several respects, but contains significantly greater concentrations of dissolved solids and boron, and appreciably less potassium and (at well 11) fluoride.

(page 29 follows)

TABLE 4.--*Evaluation of waste fluids with regard to Federal drinking-water standards*

Constituent or property	Upper limit or acceptable range	Unacceptable values (X)		
		Tailings fluids	Tailings seepage	Acid brine
Primary standards[1]				
Arsenic (As)	50 ug/L			X
Cadmium (Cd)	10 ug/L			X
Chromium (Cr)	50 ug/L			X
Fluoride (F)[2]	1.8 mg/L		X	X
Lead (Pb)	50 ug/L			X
Mercury (Hg)	2 ug/L	X	X	
Selenium (Se)	10 ug/L	X	X	
Silver (Ag)	50 ug/L			
Secondary standards[3]				
Chloride (Cl)	250 mg/L			X
Copper (Cu)	1,000 ug/L		X	X
Dissolved solids	500 mg/L	X	X	X
Iron (Fe)	300 ug/L			X
Manganese (Mn)	50 ug/L		X	X
pH	6.5-8.5 units	X	X	X
Sulfate (SO_4)	250 mg/L	X	X	X
Zinc (Zn)	5,000 ug/L			X

[1] Mandatory for public water supplies; U.S. Environmental Protection Agency, 1975, page 59570.

[2] Fluoride limit is based on an average maximum daily air temperature of 20.5°C for the Yerington weather station (Huxel, 1969, page 10).

[3] Recommended for public water supplies; U.S. Environmental Protection Agency, 1977, page 17146.

EXPLANATION

⑦ [illegible] Data for water from Geological Survey well 7. Number outside circle is dissolved-solids concentration, in milligrams per liter, rounded

△T [illegible] Data for waste fluids: E, evaporation pond; S, tailings-pond seepage; T, tailings fluid. Number outside triangle is dissolved-solids concentration, in milligrams per liter, rounded

FIGURE 6.--Proportions of major dissolved constituents in water from shallow U.S Geological Survey test wells, tailings pond, and evaporation pond. Cation and anion percentages are based on milliquivalents per liter. Chemical symbols are given in table 3. By convention, potassium (K), normally a minor constituent, is combined with sodium (Na) in calculating cation percentages. Similarly, carbonate (CO_3), when present, is combined with bicarbonate (HCO_3). See text for discussion of this type of diagram.

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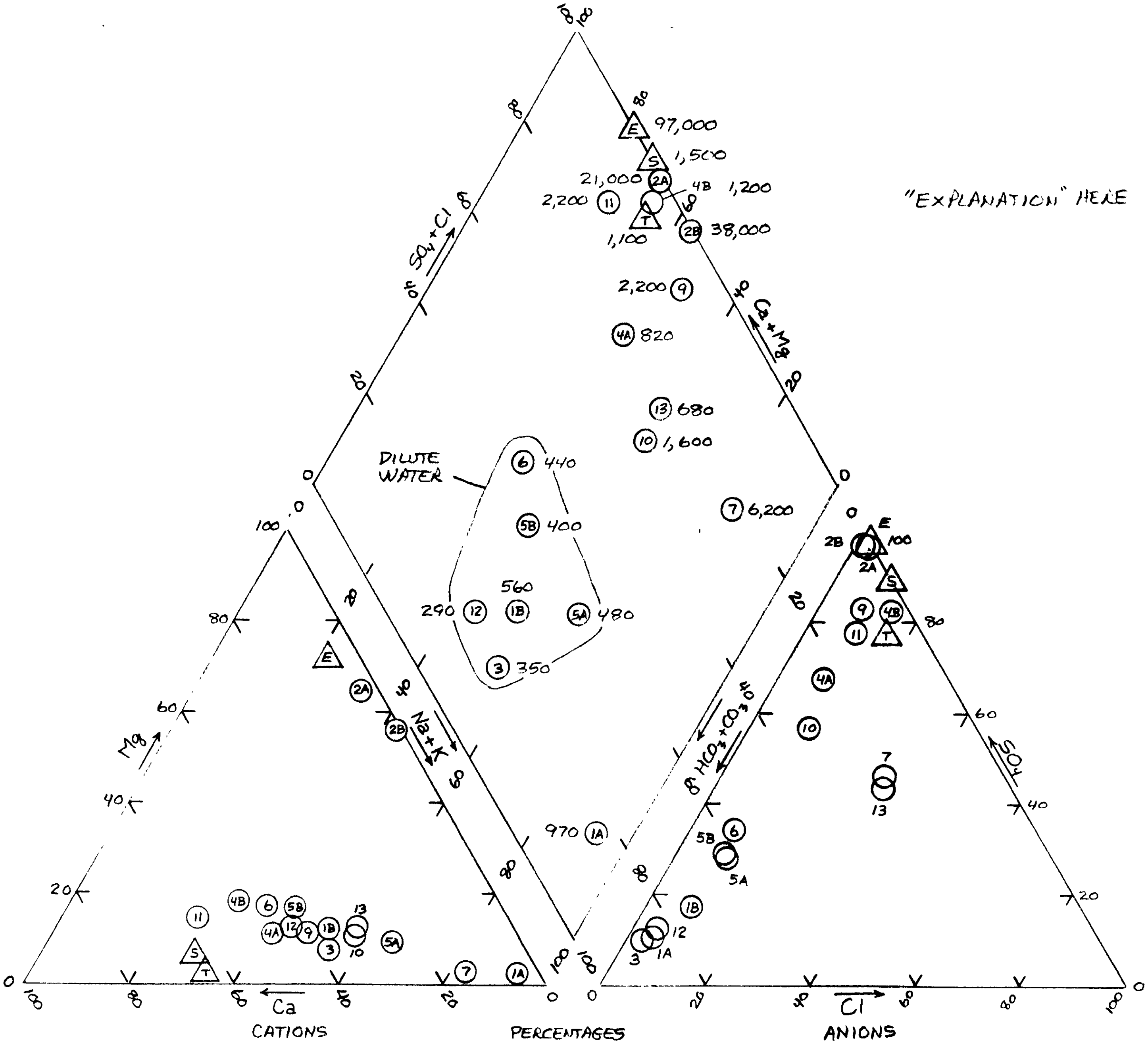

FIGURE 6 (TITLE HERE)

Ground water at well 9 may be directly influenced chemically by percolation from the tailings pond. At well 11 the influence may be by way of Wabuska Drain (figure 2), as indicated by comparable specific conductances.[1]

The chemical history of the remaining shallow ground water sampled (from wells 1A, 7, 10, and 13) is not readily explained by the relationships in figure 6. Water from one or more of these wells may reflect chemically the influence of ground-water evapotranspiration.

Except at wells 2A and 2B, the concentrations of normally minor constituents such as copper and other metals are characteristically small in the sampled shallow ground water (table 3).

Water from several of the shallow wells has exhibited seasonal and perhaps long-term changes in dissolved-solids concentration, as indicated by specific-conductance data in table 2 and figure 7. During the 12½-15 months between late 1976 and January 1978, pronounced net increases occurred at wells 2A, 3, 10, and 12, whereas a pronounced decrease occurred at well 4A; changes were negligible or modest at the other 10 monitored wells. During the subsequent 7½-8 months, significant net changes included increases at wells 1A and 6 and decreases at wells 3, 4A, 10, and 12. For the overall period of almost 2 years, gradual changes in specific conductance included an increase at well 7 and decreases at wells 4B and 9. Negligible changes during the overall period characterized the water of deeper wells 1B, 2B, and 5B, and shallow wells 11 and 13.

At shallow wells 3, 10, and 12, which are within or adjacent to irrigated areas, the fluctuating dissolved-solids concentrations indicated by specific-conductance data in figure 7 may be seasonal and related to the irrigation. In contrast, the pronounced increase at well 2A may reflect the influence of contamination from the nearby evaporation pond.

Trends at well 7 are of particular interest because of the well's closeness to the northernmost evaporation pond. The pond is asphalt lined, but the lining is cracked in places, presumably permitting some leakage. Although the final sample from well 7, collected on Sept. 19, 1978, did not chemically resemble the adjacent brine (figure 6), data for specific conductance and pH during the period November 1976-September 1978 show significant trends not exhibited by other well water for which similar

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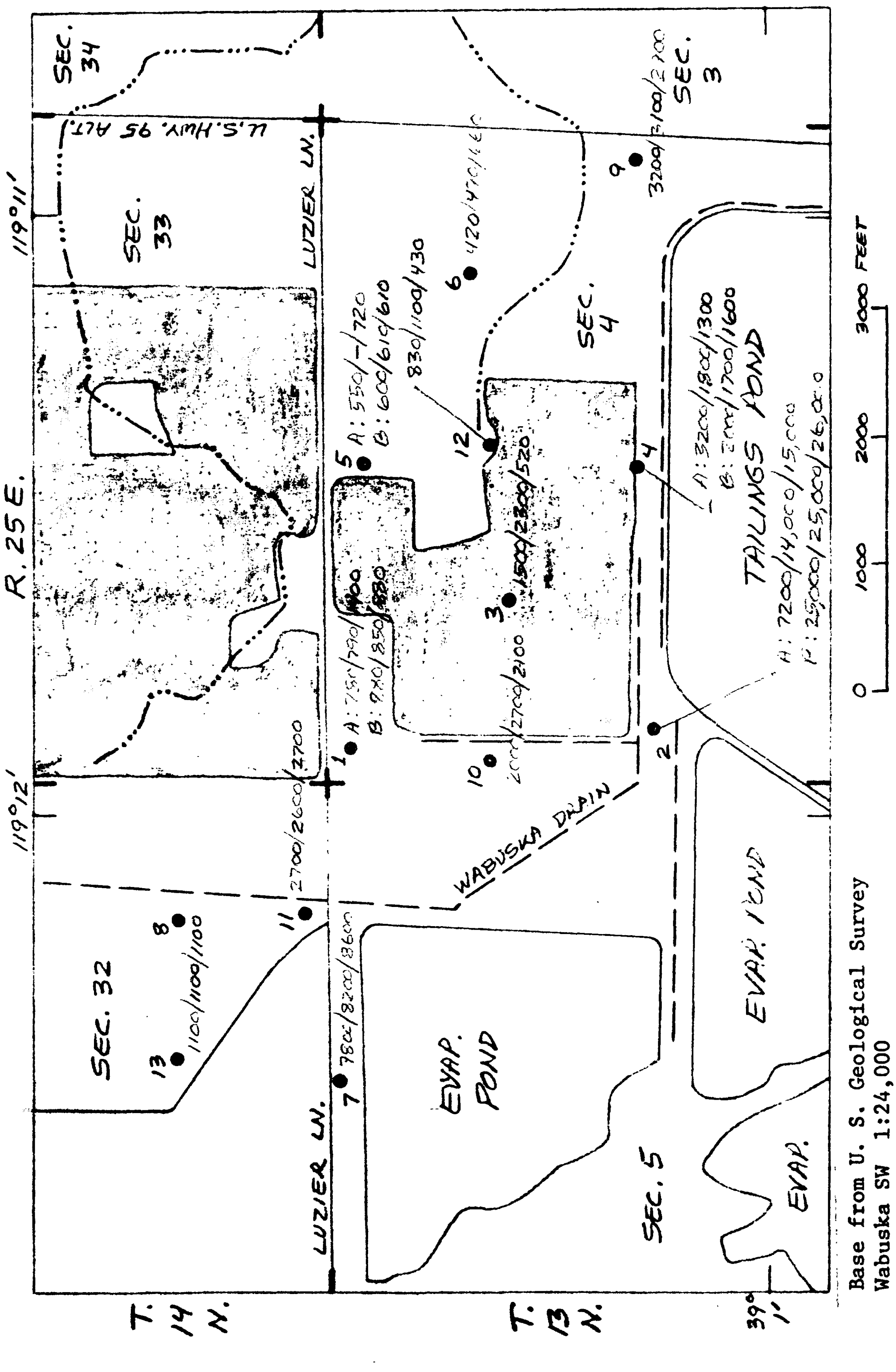
[1] The conductance of drainage at Luzier Lane, adjacent to well 11, was 2,500-2,700 micromhos in mid-1976 (page 45)--similar to that of water from well 11 (table 2). Specific conductance, which is the measure of water's ability to conduct electric current, is rather closely related to dissolved-solids concentration. The concentration, in milligrams per liter, is characteristically 65 to 75 percent of the specific-conductance value, in micromhos.

EXPLANATION

▨	Irrigated area
——•••——	Principal irrigation ditch
— — —	Principal drainage ditch
7 ● 7800/8200/8600	Well (and number), with specific-conductance data for late 1976, January 1978, and August-September 1978 (from left to right). At sites 1, 2, 4, and 5, data are shown for shallow wells (A) and deeper wells (B)

FIGURE 7.--Changes in specific conductance of water from Geological Survey test wells during 1976-78.



Base from U. S. Geological Survey
Wabuska SW 1:24,000
orthophotoquad, 1974

FIGURE 7 (CAPTION HERE)

information is available (sites 2B, 5B, and 11). The data for well 7 are as follows:

Date	Cumulative gallons produced	Specific conductance (micromhos)	pH (units)
11-11-76	24	7,830	--
1-26-78	40	8,050	7.6
8-31-78	57	8,460	7.0
9-19-78	74	8,600	6.4

The increasing dissolved-solids concentration and decreasing pH suggest that shallow ground water at site 7 may have been beginning to show the influence of leaking acid brine from the nearby evaporation pond.

Deeper Ground Water

Anaconda water-supply wells 12C, 22, 26, 29, 35, and "I" (the latter originally drilled as an irrigation well) are located north of, and hydraulically downgradient from, the tailings pond and easternmost evaporation pond (figure 2). The wells produce water from depths that range from 50 to 455 feet below land surface (table 1). Representative chemical analyses for the six wells are listed in table 3, and the general chemical character is shown in figure 8. The dissolved solids, which ranged from 350 to about 2,000 mg/L, were dominated by calcium or calcium and sodium among the cations and by sulfate or sulfate and bicarbonate among the anions; the proportions of calcium and sulfate tended to increase with increasing dissolved-solids concentration.

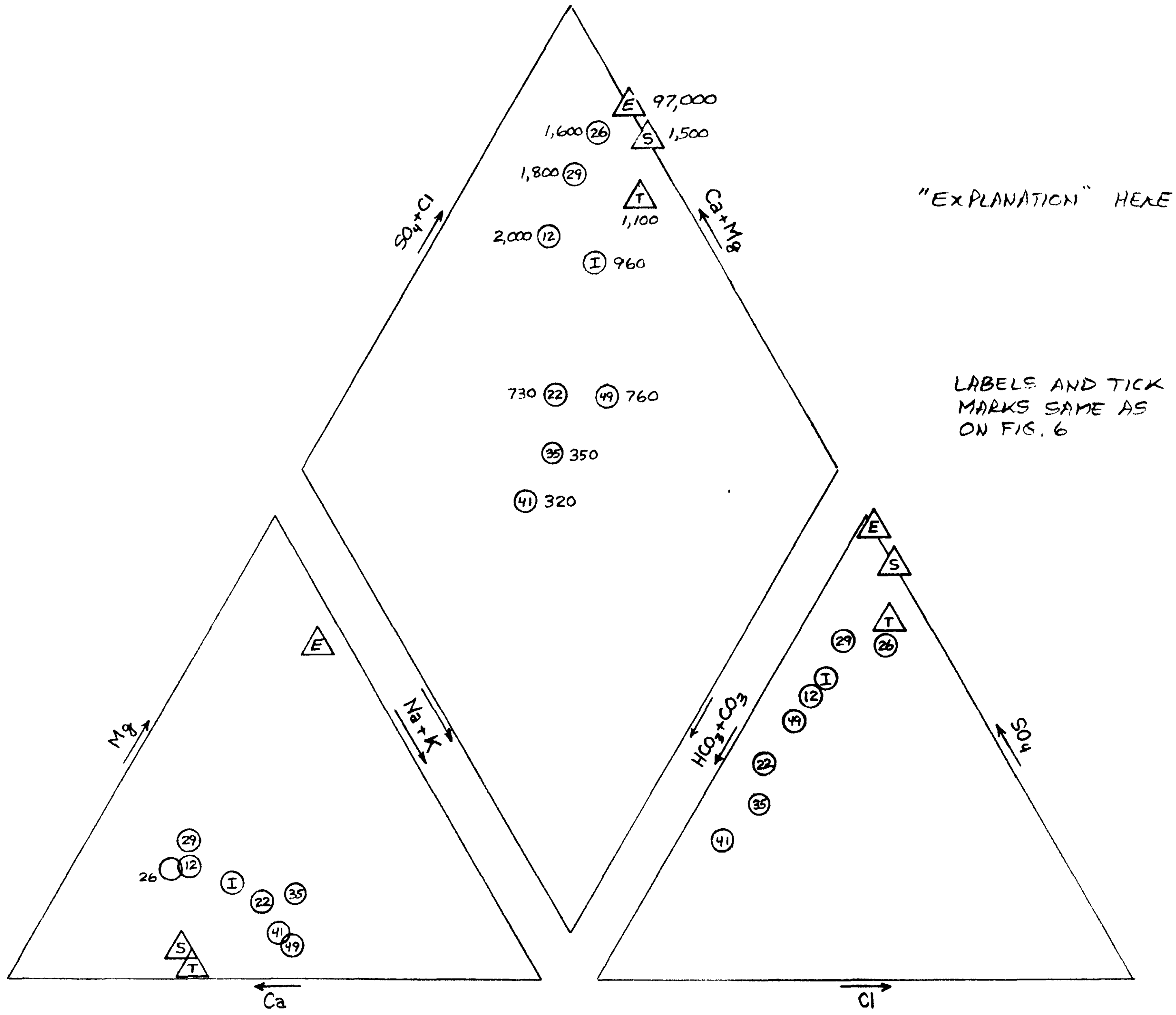
Also shown in figure 8, for comparison, is the chemical character of (1) the waste fluids and (2) water from Anaconda pit-dewatering wells 41 and 49B, which are south of, and presumably uninfluenced by, the fluid-waste disposal (figure 1).

Among the deeper well water north of the fluid-disposal area, two groups are evident in figure 8: Water from wells 35 and 22 (dissolved solids, 350 and 730 mg/L, respectively) and water from the other four wells (960 to 2,000 mg/L). The first group chemically resembles water of upgradient wells 41 and 49B. In contrast, water from the other four wells more nearly resembles the tailings fluid, which is not surprising because the water used to transport the fine-grained tailings to the pond was supplied largely by the six wells north of the disposal area.

EXPLANATION

㉟	350	Data for water from Anaconda well 35. Number outside circle is dissolved-solids concentration, in milligrams per liter, rounded
△T	1,100	Data for waste fluids: E, evaporation pond; S, tailings-pond seepage; T, tailings fluid. Number outside triangle is dissolved-solids concentration, in milligrams per liter, rounded

FIGURE 8.--Proportions of major dissolved constituents in water from deeper Anaconda supply wells, tailings pond, and evaporation pond. Dissolved-solids data: Anaconda wells, residues on evaporation at 105°C (data from The Anaconda Company); waste fluids, calculated values. Chemical symbols are given in table 3. See text and caption of figure 6 for discussion of this type of diagram.



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LABELS AND TICK
MARKS SAME AS
ON FIG. 6

FIGURE 8 (TITLE HERE)

The Anaconda Company monitored the chemical character of water from wells 12C, 22, 26, and 35 during 1974-79. Figure 9 shows that the dissolved-solids concentration of each well water increased during that period. The greatest recorded change was at well 26--from 700 mg/L in June 1974 to 1,600 mg/L in January 1979, an increase of 130 percent.

The proportions of major constituents in the deeper ground water also changed in varying degrees during the period, as shown in figure 10. The characteristic change was an increase in the abundance of calcium, magnesium, and sulfate relative to sodium and bicarbonate. Water from well 26 (which has the shallowest perforations among the industrial wells) exhibited the most pronounced overall change in chemical character.

If deeply percolating waste fluids, unaltered chemically during their migration, were responsible for the change in ground-water character shown in figure 10, the direction of chemical change would have been toward the symbols representing the waste fluids. For the most saline and sulfate-rich water, which also is nearest the disposal ponds (wells 12C and 26), the direction of change was not toward the waste fluids but, instead, toward water significantly richer in calcium plus magnesium relative to sodium (and significantly more saline than the tailings fluid). This indicates either (1) that the waste fluids were not responsible for the chemical change, or (2) that the fluids were responsible but had first undergone a significant chemical modification themselves during percolation. If waste fluids were not responsible, the changing chemical character of the well water could have resulted from the pumping-induced northward migration of more saline ground water originally associated with the ore body. The likelihood of this alternative is diminished, however, by the low dissolved-solids concentration and only moderate proportions of calcium and sulfate in water from Anaconda wells 41 and 49B, which are closely associated with the ore body (figures 1 and 8). Therefore, the other alternative--contamination by water originating in the waste ponds--seems the most probable explanation.

Among the three types of sampled waste fluids, the specific source of the deeper contamination is uncertain. On the basis of dissolved-solids concentrations, the acid brine and fluids similar to the acid tailings seepage are the most likely candidates. Chemical reactions with aquifer materials that could cause the increased proportion of calcium, implied by figure 10, as the acid waste fluids percolate downward include dissolution of carbonate minerals and ion exchange with clay minerals.

As with the shallow ground water, the areal extent of deeper contamination is as yet limited. This may be due, at least in part, to the directions of ground-water movement that were imposed by the industrial pumping north of the ponds (page 16).

Table 5 evaluates the suitability of the deeper well water for drinking purposes, on the basis of data in table 3. The table indicates that, at the time of sampling, dissolved solids and sulfate were the only determined items for which concentrations exceeded the drinking-water limits. Suitability of

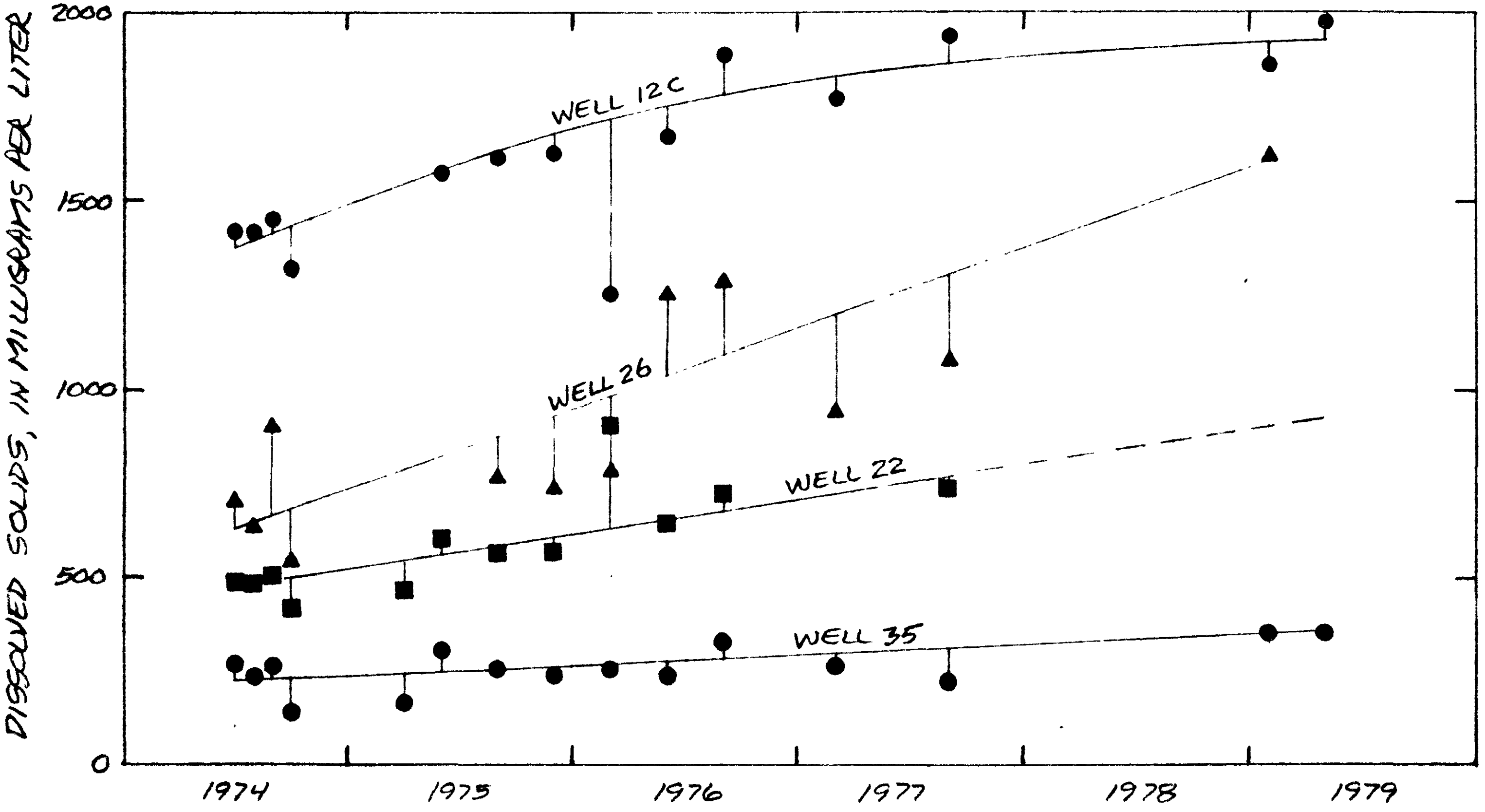
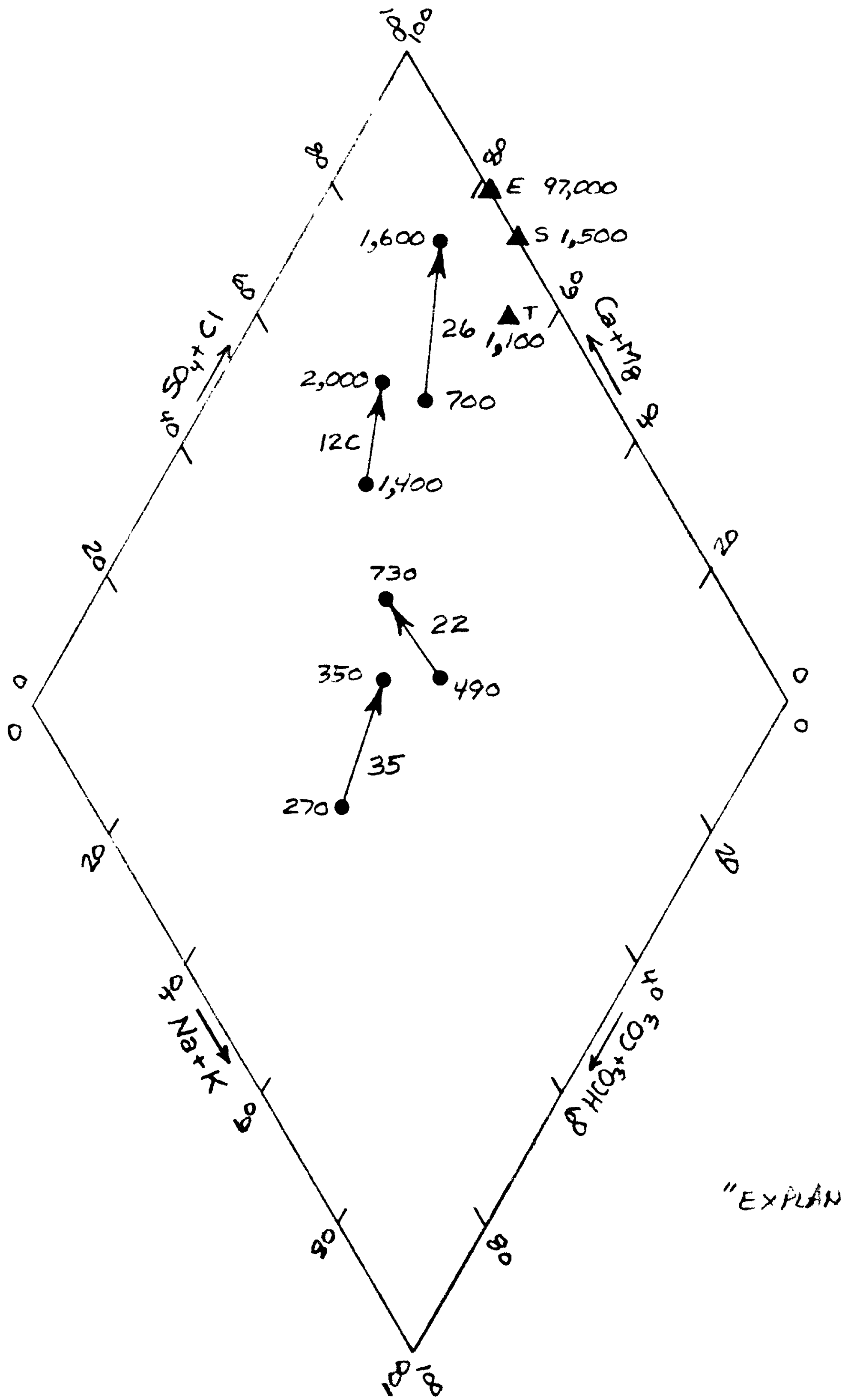


FIGURE 9.--Increasing dissolved-solids concentration in water from Anaconda supply wells 12C, 22, 26, and 35 during 1974-79. Dissolved-solids data: residues on evaporation at 105°C (data from The Anaconda Company).

EXPLANATION

270 ●——35——>● 350	Data for water from Anaconda wells in June 1974 and in August 1977 (well 22) or early 1979 (wells 12C, 26, and 35). Number adjacent to symbol is dissolved-solids concentration, in milligrams per liter, rounded. Arrow indicates direction of change in chemical character during 1974-79
1,100 ▲ T	Data for waste fluids: E, evaporation ponds; S, tailings-pond seepage; T, tailings fluid. Number adjacent to symbol is dissolved-solids concentration, in milligrams per liter, rounded

FIGURE 10.--Changes in chemical character of water from Anaconda supply wells 12C, 22, 26, and 35 during 1974-79. Dissolved-solids data: residues on evaporation at 105°C (data from The Anaconda Company). Chemical symbols are given in table 3. See text and caption of figure 6 for disccusion of this type of diagram.



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PERCENTAGES

FIGURE 10 (TITLE HERE)

the well water for irrigation depends on several factors in addition to water chemistry (for example, crop type and soil characteristics) and is beyond the scope of this report.

TABLE 5.--*Suitability of deeper well water for drinking*

Constituent or property	Upper limit[1] (milligrams per liter)	Well water exceeding upper limit[2]
Chloride (Cl)	250 (S)	None
Dissolved solids	500 (S)	12C, 22, 26, 29, I
Fluoride (F)	1.8 (P)	None
Sulfate (SO_4)	250 (S)	12C, 26, 29, I

[1] P, primary standard; S, secondary standard (see footnotes, table 4).

[2] Evaluation includes Anaconda supply wells 12C, 22, 26, 29, 35, and I (table 3).

CONCLUSIONS REGARDING GROUND-WATER CONTAMINATION

Contaminated shallow ground water has been identified with certainty only at test wells 2A and 2B, which are near the easternmost evaporation ponds (figure 2). At site 4, which is near the tailings-water recycling ditch, ground water 27.5-29.4 feet below land surface (well 4B) chemically resembles the tailings fluid in several respects. Shallow ground water at wells 4A, 9, and 11 also resembles the tailings fluid, but to a much lesser degree. Ground water at site 7, adjacent to the northernmost evaporation pond, showed evidence of slight but increasing contamination by the acid brine. Water from the remaining nine shallow wells--all of which are more than 0.2 mile downgradient from the ponds--showed little if any resemblance to the waste fluids.

This evidence suggests that, as of 1978, contaminated shallow ground water was localized in occurrence. The continued use of dilute stream water for irrigation would help to minimize the severity of shallow contamination in much of the study area.

Much of the shallow contamination ultimately might leave the study area as surface flow rather than ground water. The rising water table has filled low-gradient Wabuska Drain (page 20). Specific conductances indicate that the dissolved-solids concentration of the very slow-moving northward drainage at Luzier Lane (figure 2) was somewhat greater in September 1980 than when first determined in mid-1976, prior to the water-table rise:

Date	Specific conductance (micromhos)
05-20-76	2,670
06-08-76	2,510
09-04-80	3,570

Deeper ground water nearest the waste-disposal ponds has deteriorated appreciably in quality during the period of heavy pumping, and geochemical evidence implicates the acid brine or acidic percolation from the tailings ponds, or both. The areal extent and severity of deeper contamination apparently are as yet limited. However, changes in the directions of ground-water movement that have followed the termination of industrial pumping may cause a further spread of slightly to moderately contaminated deeper ground water in a downgradient (presumably northward) direction.

The quality of intermediate-depth ground water in the study area has not been evaluated. (The deepest perforations in Geological Survey test wells--Nos. 1B, 2B, 4B, and 5B--are about 30 feet below land surface, whereas the shallowest perforations in Anaconda supply wells range from 50 feet below land surface for well 26 to 220 feet for well 35.) This could be an important consideration because of the contamination potential implied by the probable downward movement of shallow ground water as a result of (1) pumping at the six deeper industrial-supply wells and (2) concurrent irrigation (page 20).

Among the three waste fluids, the acid brine has the greatest chemical potential for ground-water contamination (table 4). Chemical similarities and differences between the brine and the water of well 2B, which is about 400 feet north of the easternmost evaporation pond (figure 2), suggest that contaminants in the brine have been depleted with differing efficiency during percolation and northward migration to the well. Assuming that the brine adjacent to well 2B chemically resembles sampled fluid in the northernmost evaporation pond (table 3; figure 2), the data imply the following degrees of depletion.

Moderate: Cobalt, iron, lead, mercury, nickel, and zinc.
Considerable: Copper and manganese.
Almost complete: Arsenic, cadmium, chromium, fluoride, and phosphorus.

The ability of sedimentary materials to assimilate or impede the migration of a particular dissolved constituent depends on a complex of factors. Therefore, the specific grouping of elements listed above presumably applies only to the localized situation discussed. Nonetheless, the data provide a tentative, qualitative indication of depletion potentials for sedimentary materials elsewhere in the study area where geochemical conditions are similar.

FUTURE MONITORING

Although the areal extent of positively identified ground-water contamination was limited as of 1978, the potential nonetheless exists for further deterioration of ground-water quality. For example, the average velocity of generally northward ground-water movement may be on the order of 500-1,000 feet per decade in the upper 500 feet of saturated sedimentary deposits (page 23). Several monitoring activities probably would be useful in the future management of ground-water resources downgradient from the Weed Heights waste-disposal area:

1. Water-level measurements in selected wells adjacent to and downgradient from the waste-disposal area would monitor hydraulic relationships between the shallow and deeper aquifers.

2. Chemical analysis of water from selected shallow test wells and deep industrial-supply wells would monitor the possible migration of waste fluids from the disposal area. Analysis of water from Wabuska Drain, in conjunction with the flow-rate measurements, would provide similarly useful information.

3. The determination of tritium in water from deep wells 12C and 26 might prove useful as an indicator of ground-water contamination by waste fluids.[2]

4. Chemical analysis of all domestic well-water supplies less than about a mile downgradient from the waste-disposal area would determine whether those supplies meet and continue to meet drinking-water standards.

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[2] Hem (1970, page 214) gives the following discussion of tritium in the environment:

> "Tritium is produced naturally in small quantities in the upper atmosphere. Tritium so produced is incorporated into water molecules and is, therefore, present in rainwater. * * * The half life of tritium is 12.3 years, and it can, therefore, be used as a means of determining how long a particular water may have been stored out of contact with fresh supplies of tritium. The amount of tritium in the atmosphere was greatly increased by the testing of nuclear weapons, and this caused all the precipitation in the Northern Hemisphere for a long period, beginning in 1954, to be "tagged" with excess tritium. Various studies of the tritium contents of water have been made and used for such purposes as tracing and dating of ground water * * * and calculating rates of water circulation in the hydrologic cycle * * *."

Regarding the frequency of monitoring, water levels (item 1) could be measured once per year, whereas the routine sampling of well water (items 2 and 4) would seem advisable about once every 2 years, unless analytical results suggest a greater or lesser frequency. Because of seasonal changes in ground-water levels and quality, measurement and sampling at about the same time each year would permit detection of longer term net changes. The sampling of shallow ground water probably would be best done in March or April, well after the termination of irrigation.

Quarterly determinations of quality and flow quantity in Wabuska Drain (item 2) would seem worthwhile during at least the first year, at Luzier Lane and perhaps at a second site farther downstream.

Except for the one-time tritium sampling (item 3) and the first-time sampling for item 4, analyses can be limited to determinations of specific conductance unless the conductance data indicate more than about a 20-percent increase in dissolved-solids concentration relative to previous values.

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