A RECONNAISSANCE OF GROUND-WATER CONTAMINATION AT SELECTED LANDFILLS IN COLORADO

By Paul A. Schneider, Jr., and John T. Turk

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4021

Prepared in cooperation with the

COLORADO DEPARTMENT OF HEALTH

Lakewood, Colorado
1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Colorado District Chief
U.S. Geological Survey, MS 415
Box 25046, Denver Federal Center
Lakewood, CO 80225

For sale by:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey, MS 306
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 234-5888

CONTENTS

ILLUSTRATIONS

TABLES

METRIC CONVERSIONS

The inch-pound units used in this report may be converted to SI (International System of Units) by use of the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain SI unit*
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
foot per mile	0.1894	meter per kilometer
micromho per centimeter at 25° Celsius	1.0	microsiemen per centimeter at 25° Celsius

National Geodetic Vertical Datum of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, and formerly called mean sea level, is referred to as sea level in this report.

A RECONNAISSANCE OF GROUND-WATER CONTAMINATION AT SELECTED LANDFILLS IN COLORADO

By Paul A. Schneider, Jr., and John T. Turk

ABSTRACT

A reconnaissance study of eight landfills in Colorado shows that they have contaminated the shallow ground-water system. Contamination is indicated by values of specific conductance and concentrations of major ions and trace elements. Because only shallow ground water was sampled, it was not possible to determine whether deeper ground-water systems also are contaminated.

The major effects on water quality caused by contaminants in the landfills were increased salinity, nitrogen, iron, manganese, and phenols in the shallow ground-water system.

INTRODUCTION

The location of landfills in the past commonly was based on proximity to population centers and transportation costs rather than on possible effects on the ground water. Disposal of domestic and industrial wastes directly into the ground water by pit excavation or in areas of rapid infiltration has resulted in hazards, including methane-gas generation and ground-water contamination.

The U.S. Geological Survey, in cooperation with the Colorado Department of Health, conducted a reconnaissance of landfills in Colorado, seven of which are within the urbanized Front Range area between Fort Collins and Colorado Springs. The remaining landfill is in Durango (fig. 1). This study, the first such study in Colorado, has documented the presence and the nature of chemical changes in water quality in the vicinity of the landfills. The results are presented both on maps and in tables to facilitate rapid assessment of the relative hazards in various directions from the landfills.

Landfill studies have been conducted in many parts of the country in recent years. In humid climates, contamination by infiltration of rain and snowmelt through the waste is common; typical examples of such contamination are well documented for two Long Island, N.Y., landfills (Kimmel and Braids,

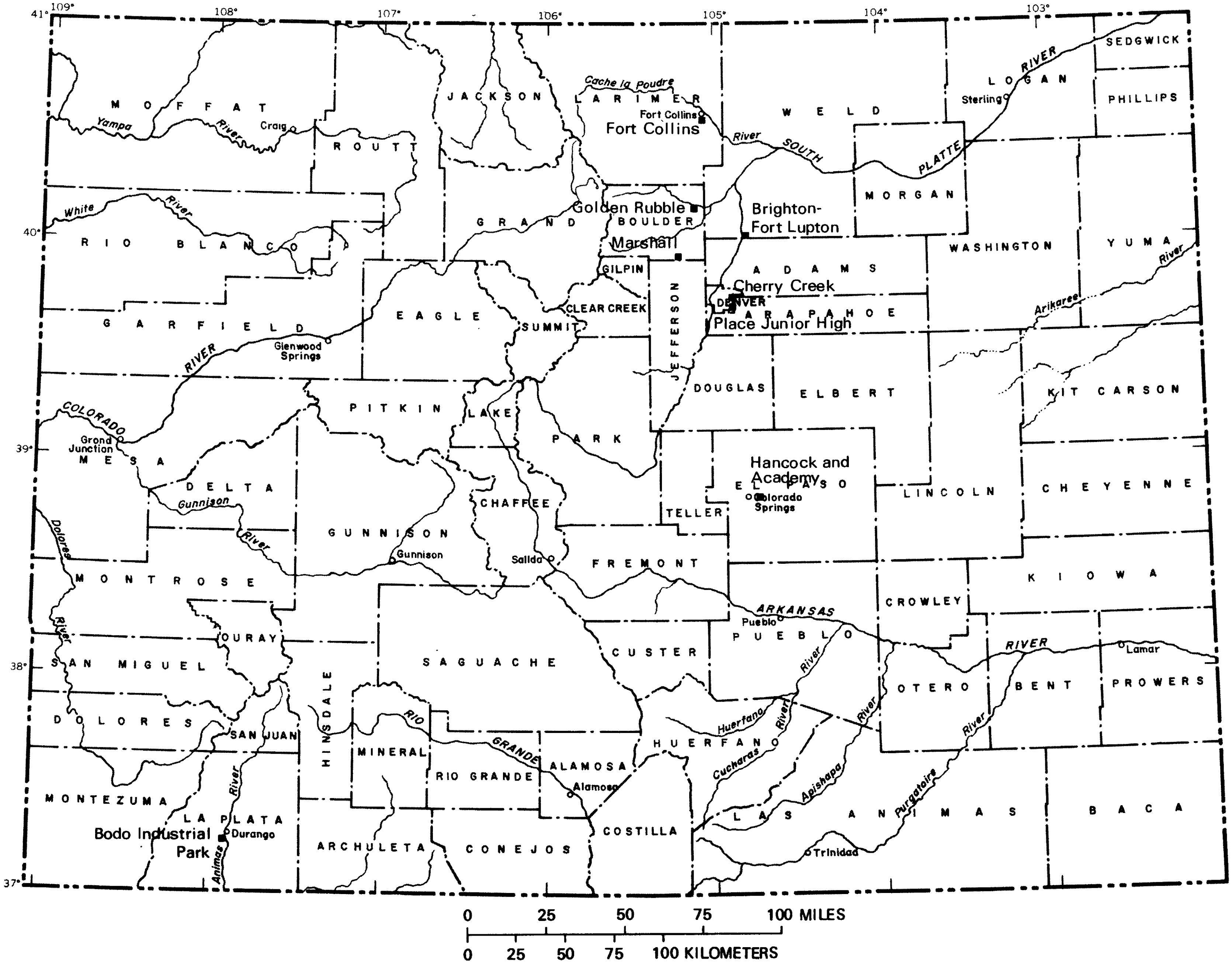

Figure 1.--Location of study sites.

1975; 1977). In these studies the authors found detectable leachate plumes following the general ground-water movement at least 10,600 feet downgradient from the sites studied. The plumes were observed to extend vertically beneath the landfills to the first relatively impermeable layer, mixing and traveling with ground water in the downgradient direction until dilution and interaction with the aquifer matrix made the plume indistinguishable from the ambient ground water.

In arid and semiarid climates, landfills may not contaminate ground water as extensively as in humid climates. The great depth to water in many areas of Colorado can prevent direct contact between waste and the water table, while the small ratio of precipitation to evaporation can limit the effective infiltration of water into the waste. In such cases, landfills in arid or semiarid locales may be effectively isolated from the ground water, and the leachates from these landfills react primarily with the oxygen in the unsaturated soil to release carbon dioxide, methane, and ammonia to the soil atmosphere.

To determine the nature of landfill and ground-water interactions in Colorado requires consideration of the likely geochemical reactions between the waste, the soil atmosphere, the soil itself, and water. Discussion with landfill operators revealed the landfill material to be primarily paper, construction debris, and food waste. Incomplete oxidation of organic matter in such material produces reducing conditions in the immediate vicinity of these wastes. While some major ions can be expected to be leached from construction debris, such as wallboard, and from bleached paper, the principal contributions are likely to be carbon and nitrogen species liberated by the incomplete oxidation of organic material and soil constituents dissolved under the reducing, carbon dioxide-rich conditions resulting from waste decomposition. Thus, iron, manganese, calcium, and magnesium from the soil and bicarbonate, ammonia, organic nitrogen, and organic carbon from the waste might be expected to increase in ground water contaminated by landfills. Such contamination, if it occurs, will be most severe at the waste site, and its transport will be controlled by the ground-water movement near the site.

DATA COLLECTION

Wells were installed in and around the landfill sites by drilling with an auger, installing 3- or 4-inch diameter perforated polyvinyl-chloride casing, and sealing the hole with material from the auger cuttings. Caps were installed immediately, and perforations above ground level were sealed with tape. Full-length perforation was necessary to allow the wells to be used for the sampling of methane, as well as for the collection of water samples. The presence of impermeable surficial materials minimized any possible effect from infiltration around the casing; in addition, samples were not collected during or immediately after periods of rain or snowmelt.

In many cases the wells from which the water samples were drawn had filled with sand and some fine gravel to within the upper foot or so of the zone of saturation, so only the uppermost part could be sampled. Therefore, samples of water exclusively from the upper part may not represent the entire saturated zone. Samples from the upper part might, for example, contain lesser dissolved-solids and transition-metal concentrations than might be found in deeper samples because of changes caused by density stratification and oxidation in the upper samples.

The holes were drilled and cased by contractors under the direction of the individual health departments in whose jurisdiction the particular landfills were situated. The wells were constructed primarily for methane sampling.

Well locations were selected based upon an assumed direction of ground-water flow and the landfill extent, when known. Wells could not be completed successfully in every case, primarily because of slumping of the unconsolidated sand and gravel in the saturated zone. Although all wells yielding sufficient water were sampled for specific conductance, detailed chemical analyses were performed on only three wells at each landfill. These wells were selected, based on specific-conductance data, to represent the most dilute, intermediate, and most concentrated water at each landfill.

After completion, the wells were bailed to remove water; normally, three well volumes were removed before sample collection. Immediately after collection, the unfiltered samples were tested for temperature, specific conductance, and pH by methods described by Skougstad and others (1979). The large concentration of suspended material made it necessary to fill plastic containers with the sample and allow the sealed container to stand for approximately one-half hour prior to filtration to allow sufficient settling of suspended solids. No discoloration was observed. The samples then were analyzed by the methods described by Skougstad and others (1979).

RESULTS AND DISCUSSION

Hydrology of the Landfills

Those landfills chosen for the study were constructed on three different types of geologic terrain (fig. 2). Five landfills were constructed on sand and gravel deposits, one was constructed on permeable bedrock, and two were constructed on relatively impermeable bedrock. In all the landfills the water table was either intercepted during the excavation phase, or a perched water table formed during the filling and compaction phase.

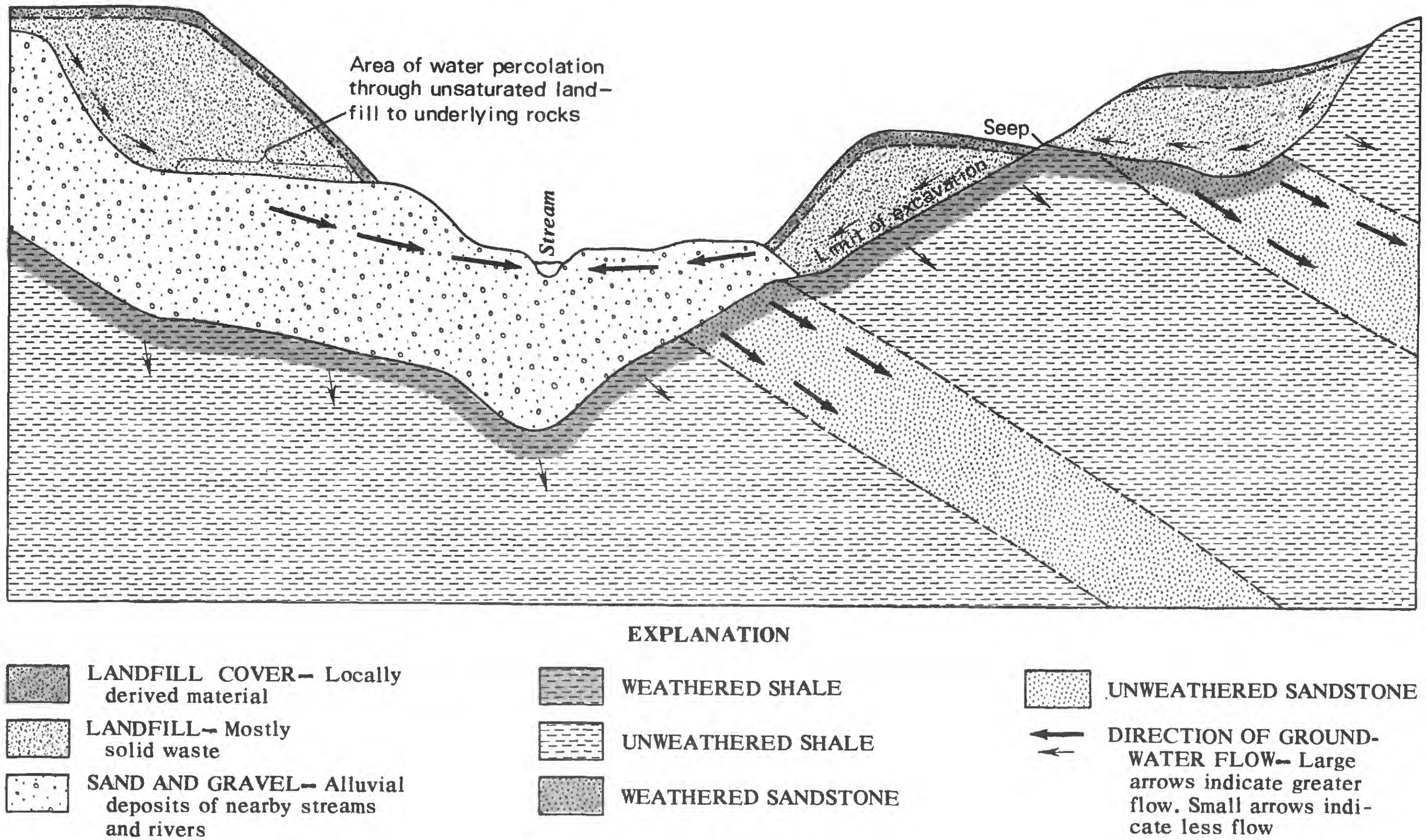

Figure 2.-- Generalized section showing types of landfill and ground-water interaction.

Boulder County

The Golden Rubble and Marshall landfills in Boulder County (figs. 3 and 4 and tables 1 and 2) each had drains constructed to lessen the impact of potential leachate plumes on the shallow ground water. Both drains were constructed on the upgradient side of each landfill to intercept the shallow water table. The drains along the south and west side of the Golden Rubble site made the gradient of the water in that landfill so flat the direction of movement was indeterminate. The water from the Golden Rubble site was pumped from a collection sump into a concrete ditch which conveyed the water from the site to St. Vrain Creek, whereas water intercepted by the drain at the Marshall site flowed into a natural drainage north of the Community Ditch.

Water levels measured in wells constructed for the study showed the activity associated with the landfills has little or no effect on the configuration of the regional water table. The flatness of the shallow water table within the Golden Rubble landfill is due to the presence of the drains. Outside the area of this site the regional water table has a gradient of about 25 feet per mile, mostly to the east (unpublished data on file at the Colorado District Office, U.S. Geological Survey). This site, a gravel pit excavated in the alluvium of St. Vrain Creek, now is covered and inactive. The thickness of the fill was not determined.

The Marshall landfill (fig. 4) is excavated through a veneer of alluvium into the underlying sandstone and shale. The alluvium is about 25 feet thick at the south side of the site and thins toward the Community Ditch on the north. A gravity drain, constructed from near the southwest corner of the landfill at the alluvium-bedrock contact, extends northward along the west side of the fill area. Test holes drilled and cased into the bedrock, where possible, were used to collect water samples and monitor water levels. Water-level measurements indicate there is hydraulic connection between the alluvium and the underlying bedrock. The gradient of the potentiometric surface, therefore, is continuous from near the south boundary of the landfill northward to Cowdrey Reservoir No. 2, and northeast out of the site area. Between Marshall Lake and test wells 2 and 3, the direction of the ground-water movement is inferred from the topographic relief and the eroded bedrock surface. The erosion surface of the bedrock has been mapped from test holes which penetrate it, a prelandfill stream which was incised into it, and several contact springs which seep along the cut of the current manmade drainage course. This gradient indicates some water is leaving the area by flowing across the subcrop and outcrop and entering the surface drainage and some is entering the deeper aquifer. Test drilling at this landfill did not fully penetrate the thickest parts of the fill.

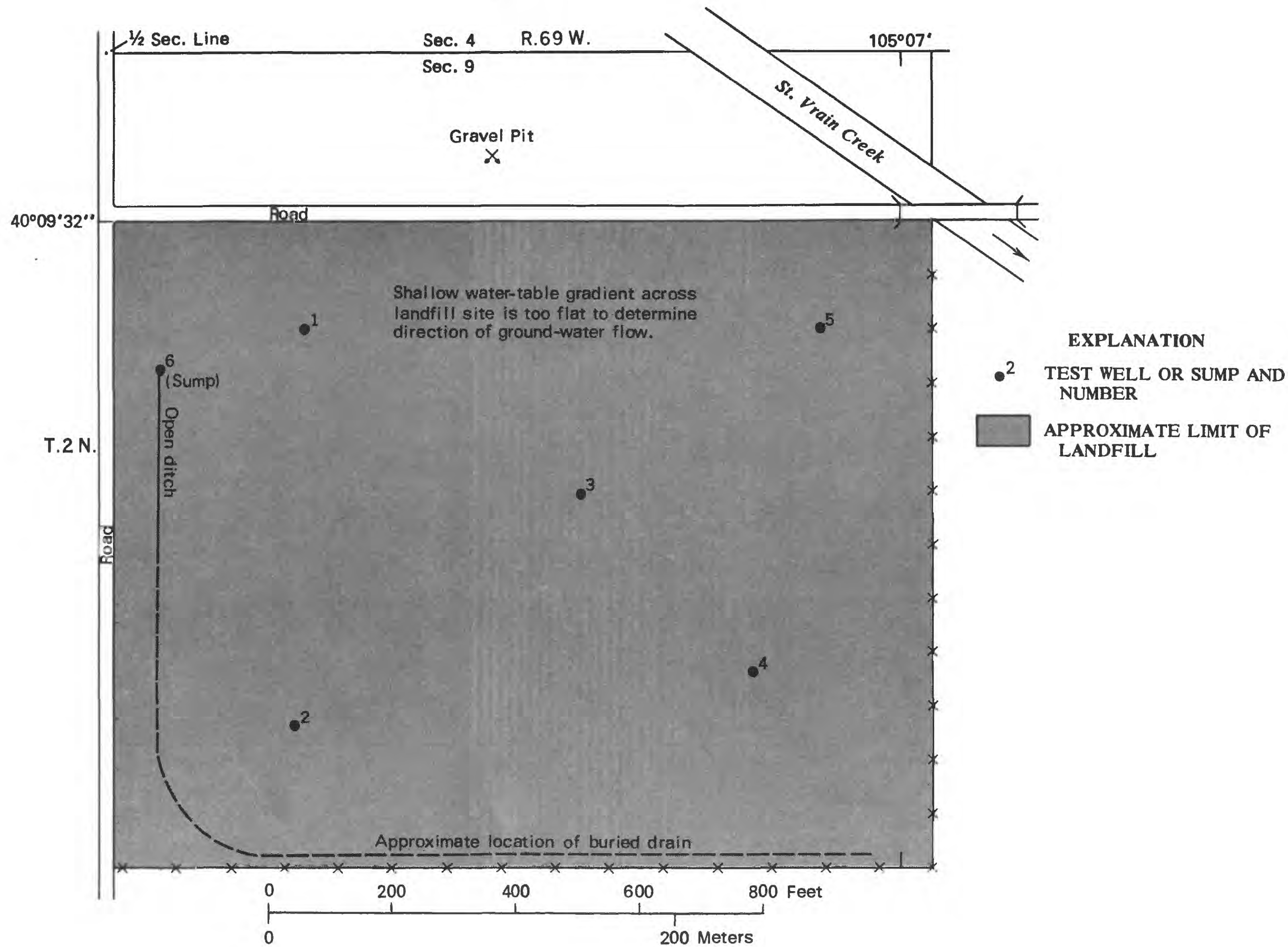

Figure 3.-- Location of test wells and sump at the Golden Rubble site.

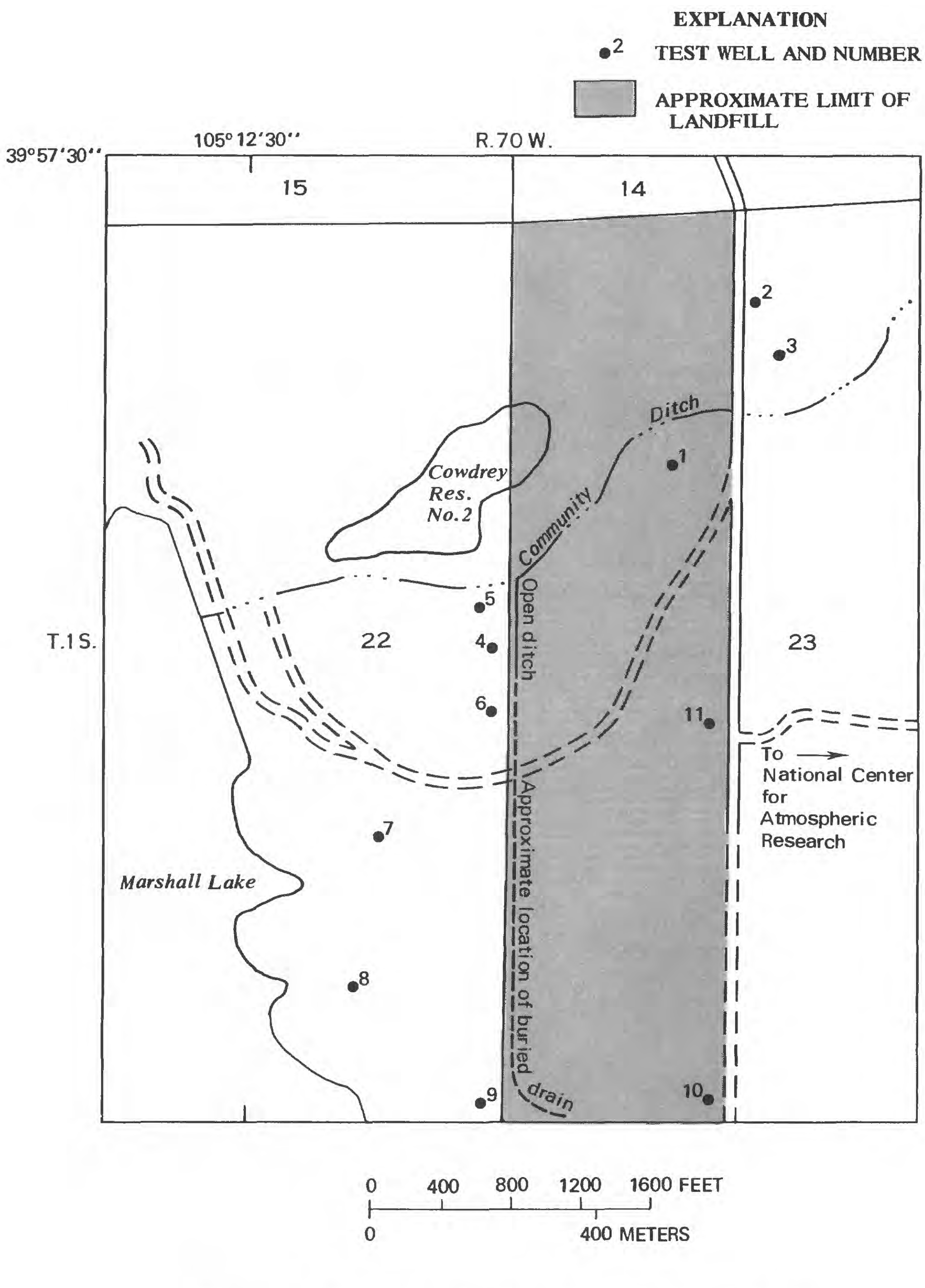

Figure 4.-- Location of test wells at the Marshall site.

Table 1.--*Physical data for wells and sump sampled at the Golden Rubble site*

Well or sump No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	40°09'30"	105°07'11"	4,951.9	4,948.3	4,960.8	13.5	4,500	No.
2--	40°09'23"	105°07'10"	4,951.9	4,950.6	4,959.6	13.0	2,400	No.
3--	40°09'27"	105°07'07"	4,951.8	4,947.6	4,958.8	13.0	4,250	Yes.
4--	40°09'24"	105°07'03"	4,951.6	4,945.9	4,954.9	11.0	2,600	No.
5--	40°09'28"	105°07'01"	4,951.9	4,943.7	4,955.7	12.5	3,100	Yes.
*6--	40°09'32"	105°07'06"	4,950.0	4,943.2	-------	9.0	1,050	Yes.

*Sump for interceptor ditch.

Table 2.--*Physical data for wells sampled at the Marshall site*

Well No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	39°57'12"	105°12'00"	5,648.8	-------	5,670.2	10.5	4,250	Yes.
2--	39°57'22"	105°11'53"	5,607.4	5,604.5	5,612.5	13.0	1,100	No.
3--	39°57'18"	105°11'50"	5,623.1	5,620.3	5,627.3	9.5	850	Yes.
4--	39°57'02"	105°12'12"	5,676.5	5,658.5	5,681.5	9.0	1,250	No.
5--	39°57'04"	105°12'14"	5,657.3	5,657.4	5,660.4	14.0	750	No.
6--	39°56'59"	105°12'12"	5,679.5	-------	5,702.5	12.0	330	No.
7--	39°56'51"	105°12'21"	5,698.4	5,697.2	5,713.2	13.5	450	No.
8--	39°56'43"	105°12'23"	5,695.4	5,692.4	5,715.4	----	-----	No.
9--	39°56'36"	105°12'12"	5,703.1	5,711.5	5,723.5	13.0	200	No.
10--	39°56'36"	105°11'55"	5,718.2	-------	5,732.7	13.5	310	Yes.
11--	39°56'57"	105°11'54"	5,684.8	-------	5,716.5	12.5	380	No.

City and County of Denver

The landfill sites investigated in the city and county of Denver at Cherry Creek and Place Junior High School (figs. 5 and 6 and tables 3 and 4) were formerly sand and gravel pits. After the mining was discontinued, the city and county refilled them with rubbish. The full extent of the areas occupied by the landfills during their active phase is not known. After they were filled, compacted, and covered, the landfills were converted to construction sites by developers. The Cherry Creek site has had differential settling, resulting in damage to some of the structures. Water-level measurements showed that the fill was partly saturated. They also showed that the landfills had little effect on the regional water-table gradient. The thickness of the fill material is as much as 10 feet at the Cherry Creek site and as much as 15.5 feet at the Place Junior High School site.

El Paso County

The landfill site near the intersection of Hancock Road and Academy Boulevard in Colorado Springs (fig. 7 and table 5) was excavated in the alluvium of a tributary to Fountain Creek. The converted gravel pit, used as a landfill for several years, now is inactive. The extent of the area occupied by this landfill during its active phase is not known. Exploratory drill holes were located in and adjacent to the site, and fill penetrated was as much as 20.5 feet thick.

The shallow water table slopes more at this landfill than at others studied which also were located in alluvium. This slope and the beds of well-sorted coarse sand and fine gravel in the saturated zone give the site the most potential for transport of contaminants away from the landfill. Logs of holes 1, 2, 4, and 8 show thicknesses up to 21 feet of coarse sand to fine gravel interbedded below the water table and adjacent to the landfill. These permeable beds are expected here because the site was originally excavated to mine the sand and gravel for construction products.

The eastern part of the landfill between holes 5 and 8 has an elliptically shaped dry area about 100 feet long. Four holes drilled to a maximum of 32 feet within this area encountered no saturated material above the bedrock. This drained area is topographically high, and the shallow ground water on the north and west drain toward the East Fork Sand Creek, which is a losing stream. During the study the creek had water flowing continually in the channel. This created a ground-water mound which expanded from directly beneath the creek out to an indeterminate distance and caused the shallow ground water to flow, in part, downstream parallel to the mound.

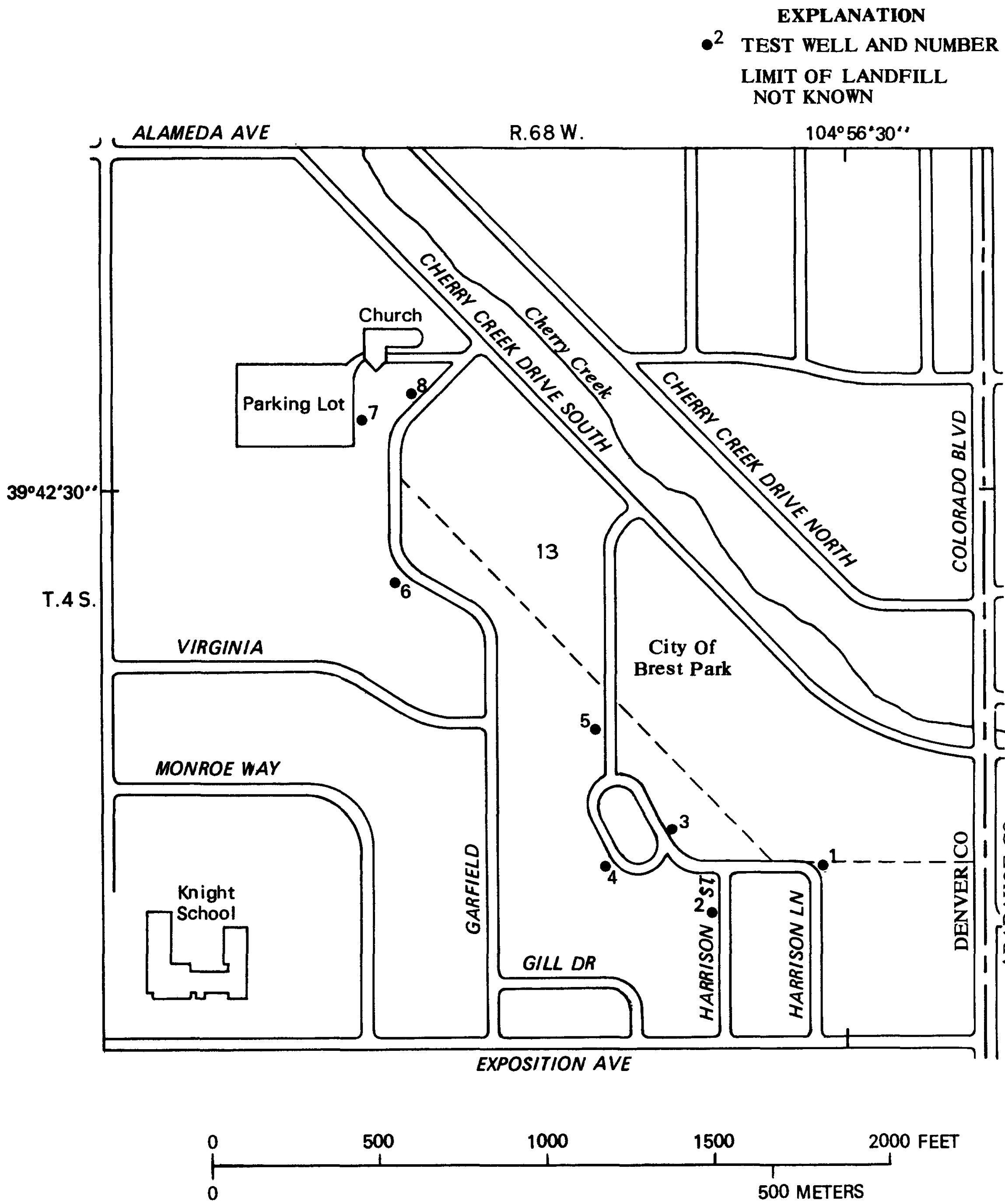

Figure 5.-- Location of test wells at the Cherry Creek site.

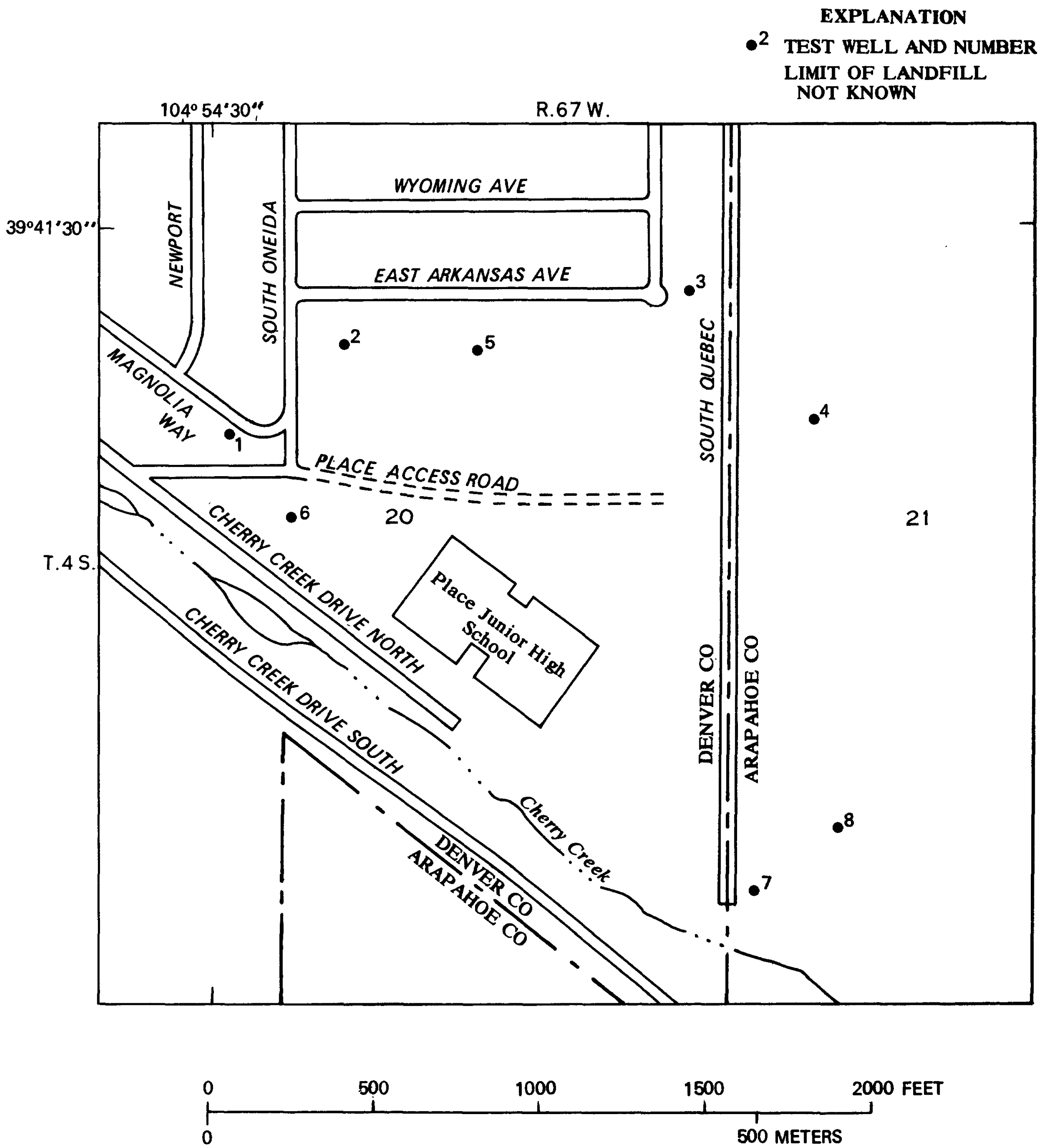

Figure 6.-- Location of test wells at the Place Junior High School site.

Table 3.--*Physical data for wells sampled at the Cherry Creek site*

Well No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	39°42'19"	104°56'30"	5,320.8	5,298.0	5,335.0	15.0	1,150	Yes.
2--	39°42'18"	104°56'34"	5,326.7	5,326.3	5,340.3	10.0	850	No.
3--	39°42'20"	104°56'36"	5,319.6	-------	5,333.6	13.5	750	No.
4--	39°42'19"	104°56'39"	5,322.4	-------	5,331.7	----	-----	No.
5--	39°42'23"	104°56'39"	5,316.6	-------	5,327.6	14.5	1,100	Yes.
6--	39°42'28"	104°56'46"	5,312.4	-------	5,326.9	11.0	900	No.
7--	39°42'32"	104°56'49"	5,308.9	5,288.9	5,323.9	14.0	880	Yes.
8--	39°42'33"	104°56'45"	5,309.9	-------	5,320.8	10.5	1,700	No.

Table 4.--*Physical data for wells sampled at the Place Junior High School site*

Well No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	39°41'24"	104°54'29"	5,377.0	5,367.6	5,387.6	12.0	1,300	No.
2--	39°41'25"	104°54'26"	5,386.1	-------	5,400.9	13.5	1,230	No.
3--	39°41'27"	104°54'11"	5,389.1	-------	5,403.0	12.0	900	No.
4--	39°41'24"	104°54'07"	5,392.9	-------	5,404.2	12.0	900	Yes.
5--	39°41'26"	104°54'20"	5,389.2	-------	5,403.1	13.0	1,900	Yes.
6--	39°41'23"	104°54'28"	5,375.1	5,382.3	5,387.2	14.5	1,500	Yes.
7--	39°41'11"	104°54'10"	5,395.9	5,363.2	5,407.2	10.5	1,250	No.
8--	39°41'12"	104°54'05"	5,398.0	-------	5,407.0	11.0	980	No.

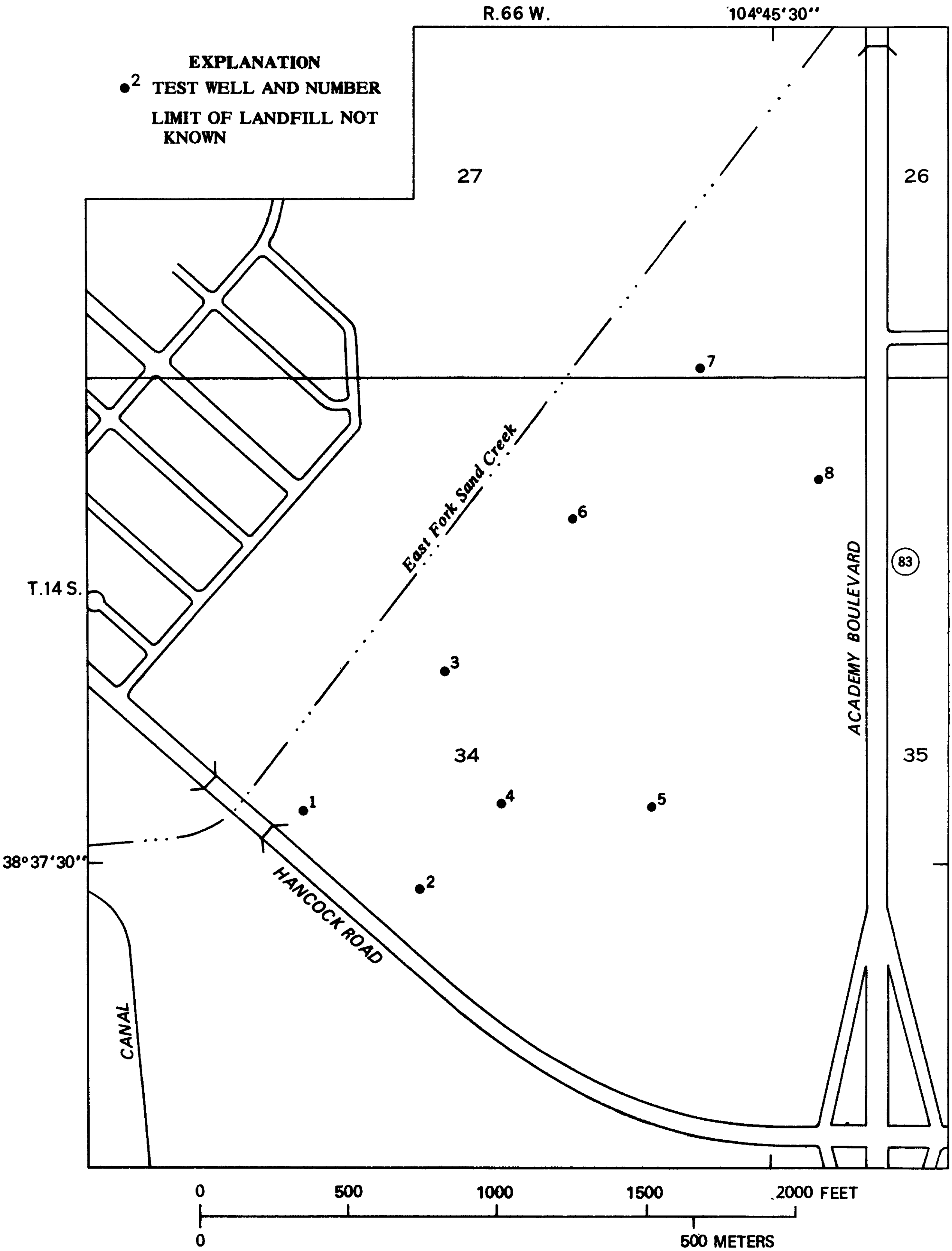

Figure 7.-- Location of test wells at the Hancock Road and Academy Boulevard site.

Table 5.--*Physical data for wells sampled at the Hancock Road and Academy Boulevard site*

Well No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	38°47'32"	104°45'49"	5,865.0	5,833.1	5,879.1	13.0	1,000	No.
2--	38°47'29"	104°45'42"	5,859.2	5,814.1	5,875.6	11.0	700	Yes.
3--	38°47'37"	104°45'43"	5,877.3	5,866.4	5,882.4	12.0	650	No.
4--	38°47'32"	104°45'41"	5,870.4	5,841.7	5,885.7	13.0	1,000	No.
5--	38°47'32"	104°45'34"	5,878.5	5,869.5	5,893.5	12.0	5,500	Yes.
6--	38°47'42"	104°45'39"	5,881.2	5,870.7	5,886.7	11.5	560	No.
7--	38°47'46"	104°45'35"	5,888.4	5,885.1	5,899.1	12.0	800	No.
8--	38°47'46"	104°45'28"	5,887.1	5,881.6	5,922.6	11.5	625	Yes.

La Plata County

The Bodo Industrial Park site (fig. 8 and table 6) is approximately 1 mile south of the city of Durango and about 1 mile west of the Animas River. The site was excavated in colluvium overlying shale. The colluvium was derived from the surrounding steep sandstone cliffs, and the base of the excavation is in the underlying shale. The surface topography slopes steeply towards the Animas River from the cliffs bordering the site. The grade from the middle of the site to the river alluvium is approximately 10 percent.

Several wells not shown in figure 8 completed in the shale bedrock outside of the limits of the landfill were dry--both upgradient and downgradient from the fill. Saturated material was penetrated in wells completed within the landfill limits. The water table is maintained by recharge entering the colluvium and fill material at the site.

Larimer County

The Fort Collins landfill (fig. 9 and table 7) is on relatively impermeable bedrock. The north side is truncated by Fossil Creek, which is an intermittent stream until it receives irrigation-return flow from areas downstream from the landfill. The shallow water table within the site probably has no hydraulic connection with ground water in the surrounding areas. Because most of the landfill is not excavated into the shale but is on the graded surface and is buried by locally derived material, the fill is slowly increasing in height above the original natural land surface. Water levels in test wells 8, 7, 6, and 5 which cross the landfill from west to east showed less than 3 feet of saturated material at the base of the fill when the wells were first measured.

Water levels, measured regularly in the test wells from July through October 1979, showed that during this time the landfill was only intermittently saturated. Water from precipitation and water applied for dust suppression moves down through the fill material and then east along the top of the bedrock. Because of the fill material, shale filler, compaction, and cover, water movement through the fill is very slow. This is also indicated by a relatively steep gradient of approximately 90 feet per mile along the north side near Fossil Creek. The top of the water table here generally is below the bed of Fossil Creek, but during wet seasons water from the landfill may contribute to the flow of the creek.

The gradient across the south part of the site is less steep because the ground-water table is intercepted by a ditch which is normal to the ground-water flow but causes a shift in direction. Most of the water from this part of the landfill leaves the area as a surface stream.

All test holes drilled at the Fort Collins landfill were within the limits of the site, and only test well 2 did not penetrate fill. The 38.5 feet of fill in test well 8 was the thickest penetrated.

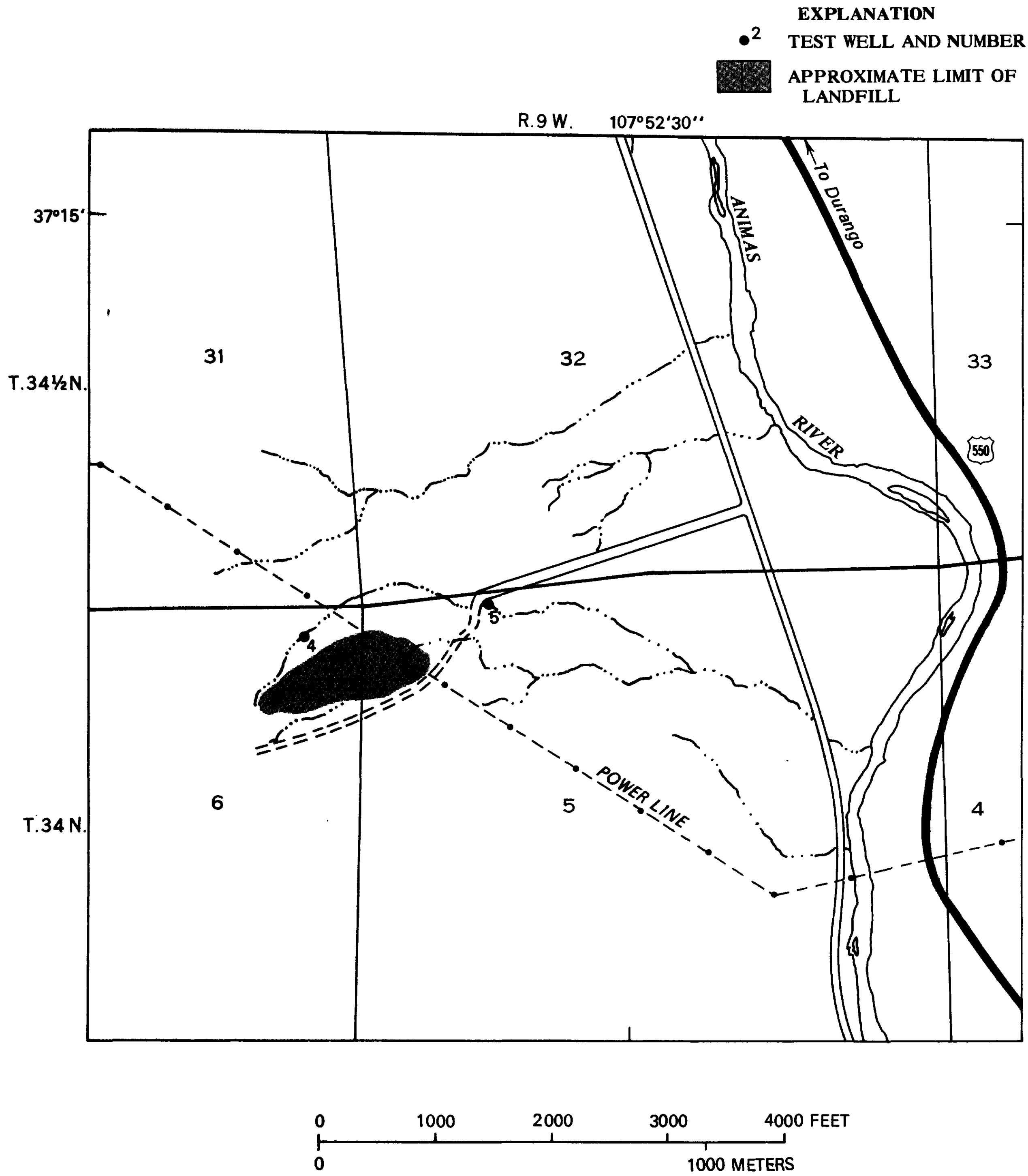

Figure 8.-- Location of test wells at the Bodo Industrial Park site.

Table 6.--*Physical data for wells sampled at the Bodo Industrial Park site*

Well No.	Latitude	Longitude	Water elevation (feet above arbitrary datum)	Bedrock elevation (feet above arbitrary datum)	Land-surface elevation (feet above arbitrary datum)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	37°14'20"	107°53'01"	896.0	-----	963.8	12.0	5,000	No.
2--	37°14'19"	107°52'56"	850.0	-----	937.7	5.0	2,500	Yes.
3--	37°14'18"	107°53'07"	959.2	-----	959.6	12.5	2,100	Yes.
4--	37°14'22"	107°53'04"	914.7	-----	919.9	9.0	1,750	Yes.
5--	37°14'25"	107°52'52"	755.2	-----	766.5	10.5	2,400	No.

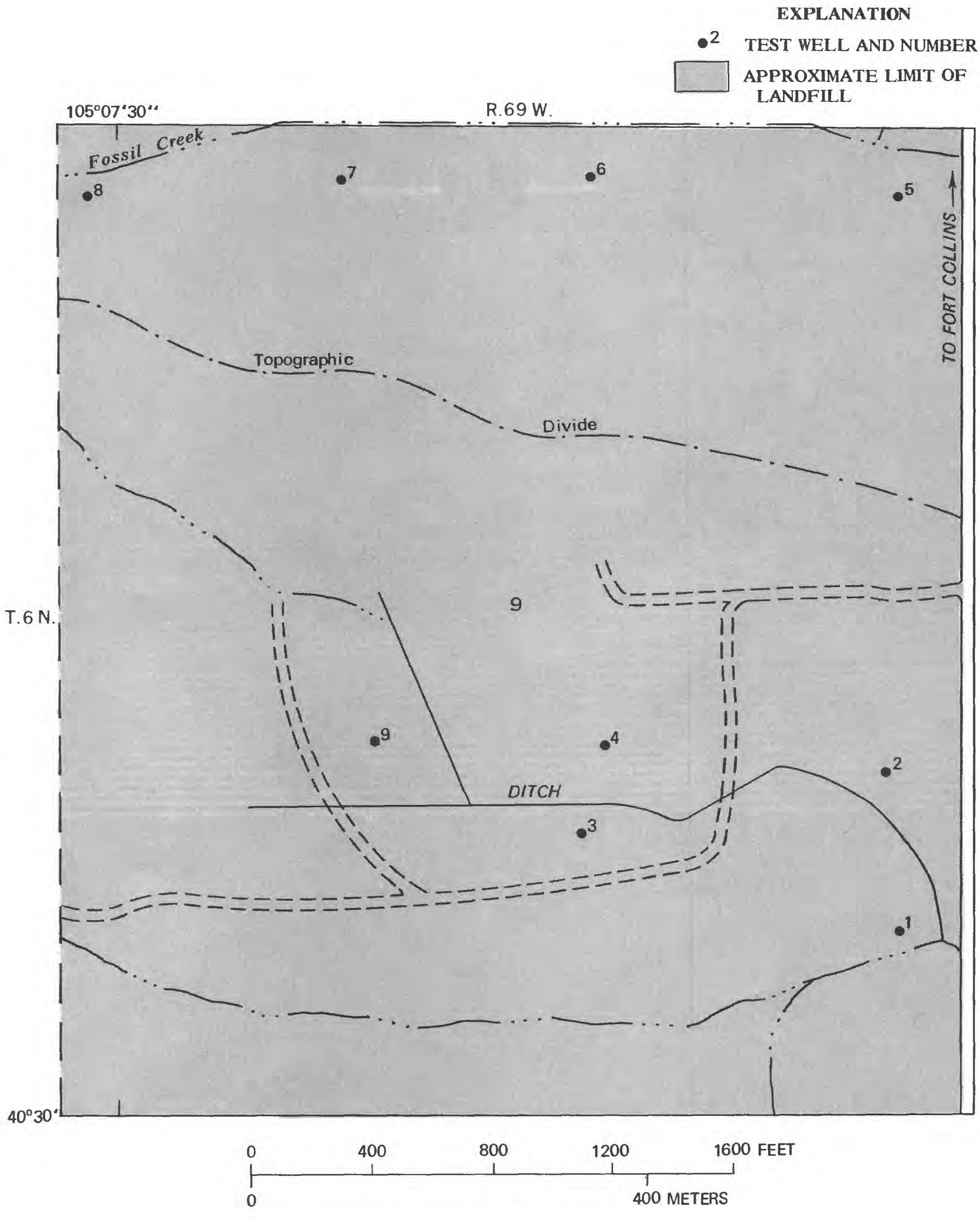

Figure 9.-- Location of test wells at the Fort Collins site.

Table 7.--*Physical data for wells sampled at the Fort Collins site*

Well No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	40°30'06"	105°06'57"	5,072.4	5,058.1	5,080.1	22.0	8,000	No.
2--	40°30'12"	105°06'57"	5,074.2	5,062.1	5,082.1	22.0	11,100	Yes.
3--	40°30'09"	105°07'10"	5,080.1	5,076.1	5,089.1	20.0	8,000	No.
4--	40°30'12"	105°07'08"	5,082.8	5,072.2	5,086.2	16.0	4,250	Yes.
5--	40°30'30"	105°06'56"	5,087.7	5,084.0	5,120.0	17.5	9,900	Yes.
6--	40°30'31"	105°07'09"	5,096.8	5,073.1	5,120.6	17.0	3,000	No.
7--	40°30'31"	105°07'21"	5,117.9	5,104.2	5,144.2	23.0	3,100	No.
8--	40°30'28"	105°07'30"	5,152.5	5,145.1	5,185.1	18.5	7,000	No.
9--	40°30'12"	105°07'18"	5,120.6	5,111.4	5,126.4	25.5	6,000	No.

Weld County

The towns of Brighton and Fort Lupton converted a gravel pit into a landfill (fig. 10 and table 8). The excavation was completed below the top of the water table in the alluvium of the South Platte River.

The regional water table slopes north-northwest at 10 feet per mile (unpublished data, on file at the Colorado District Office, U.S. Geological Survey) and is affected by both surface-water application and ground-water pumpage for large-scale irrigation. The presence of large-capacity irrigation wells and the proximity of the South Platte River also preclude any effects of the landfill site on the major ground-water features. None of the test holes fully penetrated the fill material.

Water Quality of the Landfills

The results of the analyses of all water samples collected during this study are tabulated in the "Water-Quality Data" section of this report. The data are useful not only in determining whether the water quality is suitable for specific uses but also for indicating the extent and nature of interaction between the wastes and the ground-water system.

To facilitate the investigation of waste and ground-water interactions, selected data have been ranked in table 9. Three wells at each landfill were selected for water-quality analysis. One sample was collected from each well. Six indicators (specific conductance, iron, manganese, nitrogen, chemical-oxygen demand, and phenols) of chemical interaction between the waste and ground water in the landfills were selected to compare the relative well-water quality.

A ranking of the wells by each indicator is shown in table 9. For a given landfill site in table 9, the top row lists the well number having the smallest value for an indicator. The middle or second row lists the well number having the intermediate value. The third or bottom row lists the well number having the largest value for an indicator.

To rank the wells for a combined score, count the number of occurrences of the well number in row 1. Each occurrence is given the value of 1. Next, count the number of occurrences of the well number in row 2 and then in row 3. Each occurrence in row 3 is given the value of 3.

For example: Well No. 10 at the Marshall landfill occurs

3 times	in row 1	3x1=(3)
2 times	in row 2	2x2=(4)
1 time	in row 3	1x3=(3)

For a combined score of (10).

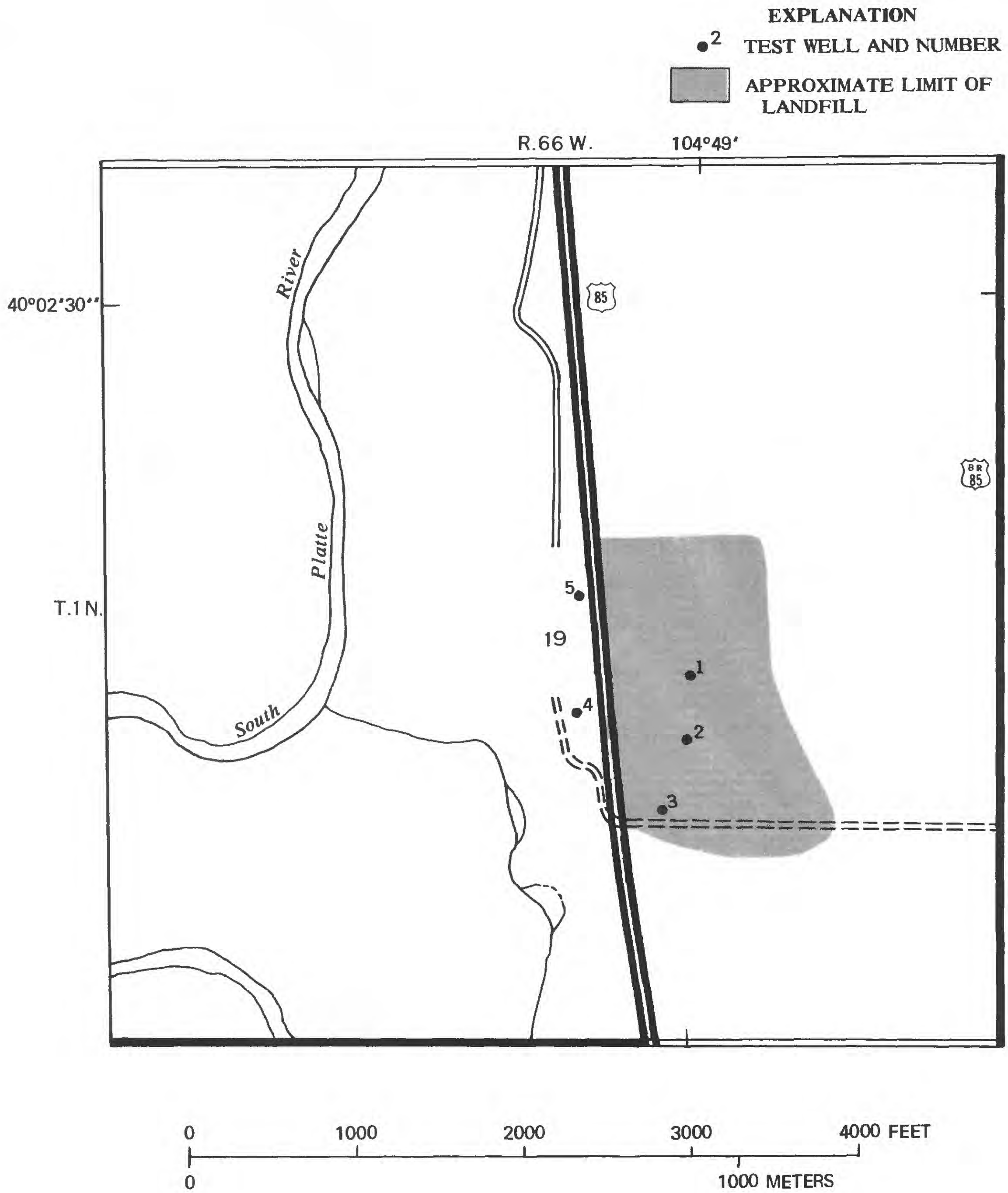

Figure 10.-- Location of test wells at the Brighton-Fort Lupton site.

Table 8.--*Physical data for wells sampled at the Brighton-Fort Lupton site*

Well No.	Latitude	Longitude	Water elevation (feet above sea level)	Bedrock elevation (feet above sea level)	Land-surface elevation (feet above sea level)	Water temperature (degrees Celsius)	Specific conductance (micromhos per centimeter at 25°C)	Water-quality data
1--	40°02'08"	104°49'00"	4,921.7	-------	4,940.9	13.0	2,025	Yes.
2--	40°02'04"	104°49'00"	4,921.8	-------	4,942.8	15.0	1,275	Yes.
3--	40°01'59"	104°49'02"	4,923.5	-------	4,941.8	----	-----	No.
4--	40°02'06"	104°49'08"	4,921.1	-------	4,933.9	13.0	1,300	No.
5--	40°02'14"	104°49'09"	4,919.6	-------	4,925.1	10.0	1,250	Yes.

Table 9.--*Water-quality rank of samples from sump or wells at each landfill site*

[For each landfill site, the sump or the number of the well with the smallest value for each listed water-quality characteristic is listed in row 1, the number of the well with the intermediate value is listed in row 2, and the number of the well with the largest value is listed in row 3. Giving a value of 1 for each occurrence in row 1, a value of 2 for each occurrence in row 2, and a value of 3 for each occurrence in row 3, the values are summed and recorded in parentheses beside the well number in the last column]

Row	Specific conductance	Iron	Manganese	Nitrogen	Chemical oxygen demand	Phenols	Combined score
			Golden Rubble site				
1--	Sump	Sump	Sump	Sump	Sump	Sump	Sump(6)
2--	5	3	3	5	5	5	5(14)
3--	3	5	5	3	3	3	3(16)
			Marshall site				
1--	10	3	10	3	10	3	3(9)
2--	3	10	3	1	3	10	10(10)
3--	1	1	1	10	1	1	1(17)
			Cherry Creek site				
1--	7	7	1	1	1	1	1(9)
2--	5	1	7	7	7	7	7(13)
3--	1	5	5	5	5	7	5(14)
			Place Junior High School site				
1--	4	6	4	6	6	4	4,6(9)
2--	6	4	6	4	4	6	4,6(9)
3--	5	5	5	5	5	5	5(18)
			Hancock Road and Academy Boulevard site				
1--	8	([1])	8	5	([1])	8	8(6)
2--	2	([1])	2	2	([1])	2	2(8)
3--	5	5	5	8	([1])	5	5(13)
			Bodo Industrial Park site				
1--	4	4	3	4	4	4	4(7)
2--	3	3	4	3	3	3	3(11)
3--	2	2	2	2	2	2	2(18)
			Fort Collins site				
1--	4	2	2	5	5	2	2(11)
2--	5	4	4	4	2	4	4(12)
3--	2	5	5	2	4	5	5(13)
			Brighton-Fort Lupton site				
1--	5	([1])	2	5	1	([1])	2(7)
2--	2	([1])	1	2	2	([1])	5(11)
3--	1	1	5	1	5	5	1(18)

[1]Analysis was performed, but constituent was not present at concentrations above the detection limit.

The sum of all scores for a sample is in parentheses next to the sample number. It should be emphasized that these scores have only relative values in determining which samples are most likely to represent the degradation of water quality caused by the interaction with wastes. A score of 10, for example, does not necessarily imply a water quality twice as degraded as a score of 5. Neither are the scores transferable from site to site; they are valid only within a given site. Also, the arbitrary choice of the indicators of chemical interaction can affect the score for a given sample and perhaps its rank relative to the other samples.

In selecting wells for sampling, an attempt was made to obtain wells suspected of intercepting water representing no interaction with wastes, the most interaction, and an intermediate level of interaction or mixing between leachate and unaffected water typical of the aquifer. Thus, if it is desired to estimate the worst-case water quality which is likely to move downgradient from a given site, the analysis of the sample with the largest combined score shown in table 9 can be used as a guide. In some instances, such as the samples from the Marshall or Hancock Road and Academy Boulevard sites, this water quality may be unsuitable for many uses. Recommended and mandatory standards (U.S. Environmental Protection Agency, 1977) are available to judge the suitability of water for various uses. On the basis of these standards for the more restrictive uses, such as for drinking supplies or as a source of water to stream or lake systems containing aquatic life, concentrations commonly exceeded standards with respect to iron (300 micrograms per liter, recommended), manganese (50 micrograms per liter, recommended), phenols (1 microgram per liter), nitrate as nitrogen (10 milligrams per liter, mandatory), and salinity (250 milligrams per liter, recommended, of chloride or sulfate). Constituents in some water samples representing the least contaminated--perhaps uncontaminated--water at a site may exceed these standards because of the quality of water in the surrounding deposits or bedrock or the use of land for purposes other than landfill. The presence of reducing conditions within or beneath a landfill may even cause a decrease in sulfate concentrations by the reduction of sulfate to sulfide followed by precipitation of the sulfide. Similarly, the nitrogen standard is 10 milligrams per liter of nitrate plus nitrite expressed as nitrogen, whereas reducing conditions favorable to nitrogen generation in landfills typically produce ammonia or organic nitrogen. Oxidation of these reduced nitrogen species to nitrate may occur if contaminated ground water moves away from the landfill and mixes with oxygenated ground water or interacts with oxygen in the soil atmosphere.

The data collected in this study are useful in estimating the direction from the landfill that ground-water deterioration may occur, the probable chemical nature, and the magnitude of the degradation. For sites with many wells intercepting the water table, variations in the specific-conductance values (tables 1-8) may be used as a guide in delineating the areal extent of present degradation.

SUMMARY

The eight landfills sampled in this study all have interacted with the shallow ground water to some extent, as exemplified by the variation in specific conductance and the analytical data for major and trace chemical species. This study of the contamination of the ground water generally was restricted to the geographical limits of the original landfills, although a few nearby wells have been sampled; however, data are not sufficient to rule out the contamination of nearby surface-water systems at some sites. Similarly, data are not sufficient to rule out the contamination of deeper ground-water systems at some sites.

Water-quality degradation at the sites was similar in nature to the degradation at other sites in other studies. Decomposition products of organic matter (ammonia, organic nitrogen, and phenols), increased salinity caused by leaching debris or increased weathering of soil materials, and dissolution of metals from the soil materials caused by reducing conditions (iron and manganese) occur to some extent at all of the sites. Some samples thought to represent water uncontaminated by the landfills exceeded standards for drinking-water supplies or water used by aquatic life, as did all samples thought to represent contaminated well water.

Data from this study are useful in predicting the direction of possible ground-water degradation now or in the future. The data also are useful in estimating the chemical nature and possibly the worst-case magnitude of ground-water degradation shown at each site.

REFERENCES CITED

Kimmel, G. E., and Braids, O. C., 1975, Preliminary findings of leachate study on two landfills in Suffolk County, New York: U.S. Geological Survey Journal of Research, v. 3, no. 3, p. 273-280.

_____1977, Leachate plumes in ground water from Babylon and Islip landfills, Long Island, New York: U.S. Geological Survey Open-File Report 77-583, 72 p.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., 1979, Methods of analysis of water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigation, Book 5, Chapter A-1, 626 p.

U.S. Environmental Protection Agency, 1977, Quality criteria for water: Washington, D.C., U.S. Government Printing Office, 256 p.

WATER-QUALITY DATA

MULTIPLE STATION LISTING

Explanation of Abbreviations

FT, foot
DEG C, degree Celcius
MG/L, milligram per liter
UG/L, microgram per liter
AC-FT, acre foot
PH, pH

SITE	DATE OF SAMPLE	TIME	SAMPLING DEPTH (FT)	TEMPERATURE (DEG C)	AGENCY ANALYZING SAMPLE (CODE NUMBER)	SPECIFIC CONDUCTANCE (MICROMHOS)	OXYGEN DEMAND, CHEMICAL (HIGH LEVEL) (MG/L)	PH	ALKALINITY (MG/L AS CACO3)	NITROGEN, DISSOLVED (MG/L AS N)	NITROGEN, ORGANIC DISSOLVED (MG/L AS N)
37°14'22" 107°53'04"	03-20-80	0900	---	9.0	80020	1750	49	7.1	530	1.9	.30
37°14'18" 107°53'07"	03-20-80	1000	---	12.5	80020	2100	99	7.0	980	25	11
37°14'19" 107°52'56"	03-20-80	1100	---	5.0	80020	2500	240	7.0	1130	46	32
38°47'29" 104°45'42"	11-28-79	0900	---	10.5	80020	700	33	7.4	160	3.0	.56
38°47'32" 104°45'34"	11-28-79	1000	---	---	80020	5500	---	6.7	710	1.0	.77
38°47'46" 104°45'28"	11-28-79	1100	---	10.5	80020	630	22	7.5	290	3.1	.68
39°41'24" 104°54'07"	11-09-79	1100	11	12.0	80020	900	33	7.0	280	5.2	.91
39°41'23" 104°54'28"	11-09-79	1000	12	15.0	80020	1500	30	6.3	260	3.0	.76
39°41'26" 104°54'20"	11-09-79	0900	15	13.0	80020	1900	210	---	590	39	36
39°42'19" 104°56'30"	12-03-79	0900	---	15.0	80020	1150	19	7.3	340	11	.63
39°42'23" 104°56'39"	12-03-79	1000	---	14.5	80020	1100	170	7.2	510	14	1.0
39°42'32" 104°56'49"	12-03-79	1100	---	14.0	80020	880	26	7.1	320	6.9	1.7
39°56'36" 105°11'55"	11-29-79	1100	---	9.0	80020	240	11	8.3	47	10	.40
39°57'12" 105°12'00"	11-29-79	0900	---	10.5	80020	4250	4400	6.2	2480	3.6	3.3
39°57'18" 105°11'50"	11-29-79	1000	---	9.5	80020	850	24	7.4	320	.70	.39
40°02'04" 104°49'00"	12-17-79	0900	---	15.0	80020	1275	24	6.6	200	31	1.2
40°02'08" 104°49'00"	12-17-79	1100	---	13.0	80020	2025	21	6.7	300	67	2.3
40°02'14" 104°49'09"	12-17-79	1000	---	10.0	80020	1250	41	7.2	440	14	4.3
40°09'27" 105°07'07"	12-04-79	1000	---	13.0	80020	4250	390	6.7	740	28	4.0
40°09'28" 105°07'01"	12-04-79	1100	---	12.5	80020	3100	210	6.7	740	19	2.0
40°09'32" 105°07'06"	12-04-79	0900	---	9.0	80020	1050	0	7.9	210	3.8	.45
40°30'12" 105°06'57"	11-27-79	0900	---	---	80020	11100	67	---	400	63	2.6
40°30'12" 105°07'08"	11-27-79	1000	---	---	80020	4575	190	---	1440	57	.00
40°30'30" 105°06'56"	11-27-79	1100	---	---	80020	9940	60	---	610	4.4	2.3
Recommended maximum (U.S. Environmental Protection Agency, 1977)				---	-----	-----	---	[1]9.0	----	-----	----

MULTIPLE STATION LISTING

DATE OF SAMPLE	NITROGEN, AMMONIA DISSOLVED (MG/L AS N)	NITROGEN, AMMONIA + ORGANIC DIS. (MG/L AS N)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N)	PHOSPHORUS, DISSOLVED (MG/L AS P)	CARBON, ORGANIC TOTAL (MG/L AS C)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)	CALCIUM, DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)	SODIUM ADSORPTION RATIO	SODIUM PERCENT
03-20-80	1.1	1.4	.51	.010	15	1100	580	230	130	110	1.4	18
03-20-80	14	25	.02	.010	32	1300	300	280	140	110	1.3	15
03-20-80	14	46	.07	.010	---	1400	220	310	140	160	1.9	20
11-28-79	.10	.66	2.3	.000	9.0	270	110	78	18	46	1.2	33
11-28-79	.20	.97	.03	.010	92	3100	2400	790	280	38	.3	4
11-28-79	.05	.73	2.4	.020	23	310	16	91	19	19	.5	15
11-09-79	.03	.94	4.3	.000	37	370	90	120	17	64	1.4	27
11-09-79	.13	.89	2.1	.040	28	360	100	120	15	220	5.0	56
11-09-79	3.5	39	.10	.000	160	590	0	170	39	110	2.0	27
12-03-79	.14	.77	10*	.080	19	310	0	100	14	180	4.5	56
12-03-79	13	14	.10	.010	52	370	0	110	23	110	2.5	36
12-03-79	.40	2.1	4.8	.120	22	310	0	100	14	99	2.5	40
11-29-79	.04	.44	9.6	.180	4.6	110	59	35	4.5	5.1	.2	9
11-29-79	.34	3.6	.03	.020	.0	3900	1400	1200	220	130	.9	7
11-29-79	.10	.49	.21	.010	5.1	430	110	91	50	90	1.9	31
12-17-79	.09	1.3	30*	.050	7.6	460	260	130	33	120	2.4	44
12-17-79	.12	2.4	65*	.020	9.3	810	510	230	58	230	3.5	46
12-17-79	4.4	8.7	4.9	.060	24	440	0	120	34	110	2.3	42
12-04-79	24	28	.04	.380	130	2300	1500	450	280	390	3.6	26
12-04-79	17	19	.08	.030	110	2500	1700	500	300	160	1.4	12
12-04-79	.04	.49	3.3	.020	26	570	360	140	54	55	1.0	17
11-27-79	.09	2.7	60*	.000	31	3700	3300	1200	160	1300	9.4	43
11-27-79												
11-27-79	1.9	4.2	.15	.000	28	3300	2700	110	730	1700	13	93
	-----	-----	[1]10	-----	---	-----	-----	-----	-----	-----	-----	-----

MULTIPLE STATION LISTING

DATE OF SAMPLE	SODIUM+ POTASSIUM, DISSOLVED (MG/L AS NA)	POTASSIUM, DISSOLVED (MG/L AS K)	CHLORIDE, DISSOLVED (MG/L AS CL)	SULFATE, DISSOLVED (MG/L AS SO4)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO2)	ARSENIC, DISSOLVED (UG/L AS AS)	BORON, DISSOLVED (UG/L AS B)	CADMIUM, DISSOLVED (UG/L AS CD)	CHROMIUM, DISSOLVED (UG/L AS CR)	COPPER, DISSOLVED (UG/L AS CU)	IRON, DISSOLVED (UG/L AS FE)
03-20-80	120	6.2	15	740*	.3	14	1	260	0	0	2	40
03-20-80	140	29	36	430*	.2	19	3	500	0	0	2	9800*
03-20-80	190	28	220	190	.4	22	3	800	0	0	2	23000*
11-28-79	51	5.0	25	170	.3	17	1	80	<1	0	0	20
11-28-79	43	5.1	1800*	15	.1	26	9	200	0	10	0	65000*
11-28-79	21	1.9	14	31	.1	35	1	40	<1	0	0	20
11-09-79	71	7.1	39	140	.5	30	2	80	0	0	2	20
11-09-79	230	7.1	250*	190	.6	34	2	110	0	0	0	10
11-09-79	170	59	190	80	.6	39	--	---	--	--	--	17000*
12-03-79	180	4.3	73	220	1.3	26	1	250	3	0	0	20
12-03-79	150	42	48	110	1.2	29	6	550	2	0	0	80
12-03-79	110	9.8	47	140	1.2	24	5	230	2	0	1	<10
11-29-79	5.9	.8	4.9	34	.9	17	1	20	3	0	0	570*
11-29-79	130	1.2	470*	15	.5	18	8	210	0	0	2	50000*
11-29-79	90	.4	32	260*	3.5	17	2	50	2	0	0	<10
12-17-79	130	10	140	210	.6	26	1	380	<1	0	0	<10
12-17-79	240	12	220	410*	.6	27	1	500	1	10	0	40
12-17-79	130	20	160	54	.8	21	2	310	<1	0	0	<10
12-04-79	510	120	350*	80	.9	23	8	1800*	10*	10	0	5900*
12-04-79	280	120	64	17	.4	33	3	1300*	10*	0	0	8000*
12-04-79	58	3.1	9.7	450*	1.4	8.3	1	140	2	0	0	20
11-27-79	1300	32	130	6200*	.1	11	1	490	1	10	0	80
11-27-79	480	79	310*	1100*	.3	17	6	1200*	0	0	0	5200*
11-27-79	1700	19	150	6100*	.2	15	3	780*	0	10	0	9800*
	-----	---	[1]250	[1]250	----	----	[1]50	[2]750	[2]10	[1]50	[1]1000	[1]300

MULTIPLE STATION LISTING

DATE OF SAMPLE	LEAD, DIS-SOLVED (UG/L AS PB)	MANGA-NESE, DIS-SOLVED (UG/L AS MN)	ZINC, DIS-SOLVED (UG/L AS ZN)	LITHIUM, DIS-SOLVED (UG/L AS LI)	SELE-NIUM, DIS-SOLVED (UG/L AS SE)	PHENOLS (UG/L)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, DIS-SOLVED (TONS PER AC-FT)	NITRO-GEN, AMMONIA, DIS-SOLVED (MG/L AS NH4)	MERCURY, DIS-SOLVED (UG/L AS HG)
03-20-80	1	1200*	10	180	0	2*	1570	2.14	1.4	.0
03-20-80	1	1100*	10	70	0	8*	1650	2.24	18	.0
03-20-80	0	1600*	10	40	1	20*	1780	2.42	18	.0
11-28-79	0	1200*	<3	20	3	1*	467	.64	.13	.0
11-28-79	0	7000*	20	70	0	35*	3450	4.69	.26	.0
11-28-79	0	110	<3	40	0	0	396	.54	.06	.0
11-09-79	0	10*	0	20	4	1*	605	.82	.04	.0
11-09-79	0	1300*	0	30	6	8*	1000	1.36	.17	.0
11-09-79	--	2900*	--	--	--	19*	1060	1.44	4.5	--
12-03-79	1	230	<3	40	18*	2*	866	1.18	.18	.0
12-03-79	0	1400*	8	30	0	3*	782	1.06	17	.0
12-03-79	1	550*	<3	40	3	5*	649	.88	.52	.0
11-29-79	1	20*	<3	10	0	6*	174	.24	.05	.0
11-29-79	4	22000*	30	40	0	1000*	3620	4.92	.44	.0
11-29-79	1	360*	<3	40	0	5*	738	1.00	.13	.0
12-17-79	1	100*	8	40	2	0	923	1.26	.12	.0
12-17-79	0	310*	40	30	3	0*	1660	2.26	.15	.0
12-17-79	0	3700*	6	30	1	3*	810	1.10	5.7	.0
12-04-79	1	990*	80	60	0	20*	2050	2.79	31	.0
12-04-79	1	1300*	20	40	0	13*	1650	2.24	22	.0
12-04-79	0	2*	<3	40	3*	3*	863	1.17	.05	.0
11-27-79	0	510*	200	2500	180	0*	9540	13.0	.12	.0
11-27-79	0	580*	0	230	1	7*	3340	4.54	73	.0
11-27-79	0	3100*	0	1300	1	11*	9210	12.5	2.4	.0
	[1]50	[1]50	[1]5000	-----	[1]10	[1]1	-----	-----	-----	[1]2

1 U.S. Environmental Protection Agency, 1976, Drinking-water criterion.

2 U.S. Environmental Protection Agency, 1976, Irrigation-water criterion.

* Equals or exceeds U.S. Environmental Protection Agency, 1976, Water-quality criterion.

☆ U.S. Government Printing Office 1984 - 680-386/395 Reg. 8