UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# GEOHYDROLOGIC RECONNAISSANCE OF A GROUND-WATER CONTAMINATION PROBLEM IN THE ARGONNE ROAD AREA NEAR SPOKANE, WASHINGTON

By N. P. Dion

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U.S. GEOLOGICAL SURVEY

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UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

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For additional information write to:

District Chief
U.S. Geological Survey
1201 Pacific Avenue - Suite 600
Tacoma, Washington 98402-4384

Copies of this report
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## CONVERSION FACTORS

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

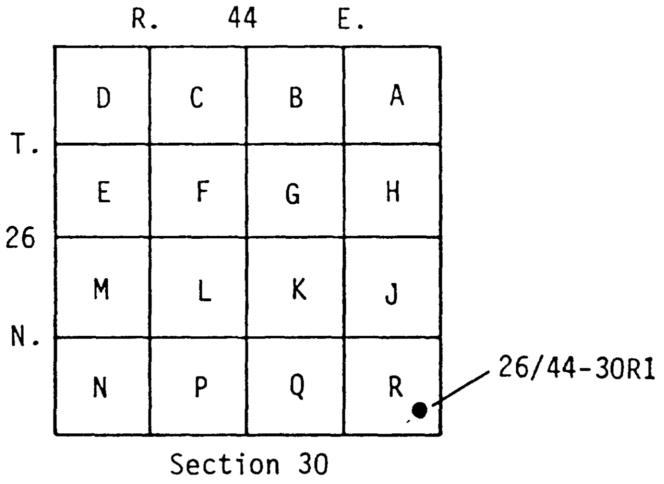
| Multiply inch-pound units | By | To obtain SI units |
|---|---|---|
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile (mi$^2$) | 2.590 | square kilometer (km$^2$) |
| gallon per minute (gal/min) | 0.06308 | liter per second (L/s) |
| gallon per day (gal/day) | 3.785 | liter per day (L/day) |
| micromho per centimeter at 25°Celsius (umhos/cm at 25°C) | 1.000 | microsiemen per centimeter at°Celsius (uS/cm at 25°C) |

degree Fahrenheit (°F) to degree Celsius (°C): °C = 5/9 (°F - 32)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

# WELL-NUMBERING SYSTEM

In this report wells are designated by symbols that indicate their location according to the rectangular-grid system for subdivision of public land. For example, in the symbol 26/44-30R1, the part before the hyphen indicates successively the township and range (T.26 N., R.44 E.) north and east of the baseline and Willamette Meridian. Because all townships mentioned in this report are north of the baseline and east of the Willamette Meridian, the letters "N" and "E" are omitted in the text. The first number after the hyphen indicates the section (30) in which the well is located; the letter denotes the 40-acre subdivision of the section according to the following diagram. The last number is the serial number of the well in the 40-acre subdivision. Thus, well 26/44-30R1 is in the SE¼ SE¼ sec. 30, T.26 N., R.44 E., and is the first well in that tract to be recorded.



In this report, well numbers are commonly abbreviated to the last part of the local well number (for example, 30R1). In illustrations where the section number is plainly shown, well numbers are further abbreviated for the sake of clarity by dropping the section number (for example, R1).

# GEOHYDROLOGIC RECONNAISSANCE OF A GROUND-WATER CONTAMINATION PROBLEM IN THE ARGONNE ROAD AREA NEAR SPOKANE, WASHINGTON

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## ABSTRACT

Three domestic wells that withdraw ground water from an alluvium-filled trough cut into granite were found to be contaminated with the organic solvents tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, and 1,2-trans-dichloroethene. The suspected source of contamination is a nearby septic-tank sludge disposal area. There is concern that the affected aquifer is tributary to the Spokane aquifer, which has been accorded "sole source" status by the U.S. Environmental Protection Agency. Preliminary estimates suggest that ground water in the area is moving toward the Spokane aquifer and that the transit time may range from 2.5 to 25 years. Because of longitudinal dispersion, however, the plume of contaminants may move at a faster rate than the ambient ground water and may arrive at given destinations more quickly than calculated above.

A literature search has indicated that the dissolved solute phase of the contaminants will not be significantly affected by sorption, volatilization, chemical activity, or biodegration.

Because of the preliminary nature of the investigation, many questions relating to the extent of contamination remain unanswered. A list of suggested additional studies to answer those questions and to refine and confirm the findings of this investigation is presented.

# INTRODUCTION

## Background

The State of Washington Department of Ecology (WDOE) has identified more than 400 sites in Washington where the ongoing or previous handling of wastes might cause damage to the environment. One of these sites is northeast of Spokane (fig. 1), where chlorinated hydrocarbons, possibly from a septic-tank sludge disposal area, have seeped into the ground water and contaminated three privately owned domestic water wells.

In the spring of 1981, a complaint from a well owner who resides at the upper end of a narrow, wooded ravine parallel to Argonne Road (fig. 2) led County and State authorities to begin an investigation of possible ground-water contamination. Sampling of the well in question (well 32C1, fig. 2) and subsequent chemical analysis of the water indicated that the well did indeed contain contamination in the form of tetrachloroethene and, to a lesser extent, trichloroethene. These chlorinated hydrocarbons are used extensively as industrial solvents, degreasing agents, dry-cleaning solvents, and septic-tank cleaners. Additional sampling and analysis revealed that two other wells (32C2 and 32D1, fig. 2), downgradient of the first well, were contaminated with the same compounds and that all three wells also contained small amounts of 1,1,1-trichloroethane and 1,2-*trans*-dichloroethene.

The suspected source of contamination was, and continues to be, an unlined 40-acre septic-tank sludge disposal area located uphill and approximately 0.3 mile northwest of the well first found to be contaminated. The site first had been licensed for disposal in the early 1970's by the Spokane County Health District (SCHD). Once contamination of the ground water was confirmed, the county refused to renew the disposal permit and all disposal ceased in April 1984. Disposal activities at the site consisted largely of the uncontrolled discharge of septic-tank sludge directly onto the sloping soil surface. On an average day, several truckloads of waste were dumped at the site.

The concern over the local ground-water contamination problem extends farther than the three wells known to be affected. The geologic materials along the axis of the ravine contain ground water that could be in hydraulic connection with the Spokane aquifer in the Spokane Valley to the south (figs. 1, 2). This aquifer has been accorded "sole source" status in the Spokane Valley under Section 1424(e) of the Safe Drinking Water Act of 1974 (Public Law 93-523). Several high-capacity municipal supply wells are located in the Spokane aquifer near the mouth of the ravine, and the concern is that these wells could eventually become contaminated with the same chlorinated hydrocarbons found in the three affected domestic wells.

Because of the confirmed contamination, WDOE notified the three well owners not to use their well waters for domestic purposes, but encouraged them to continue using the water for stock and irrigation in an effort to accelerate the flushing and natural restoration of the affected aquifer. The well owners of the three affected households were advised to import water for domestic purposes until arrangements could be made by the WDOE and the Pioneer Irrigation Company to extend the Pasadena Park area (fig. 2) municipal water service northward along Argonne Road.

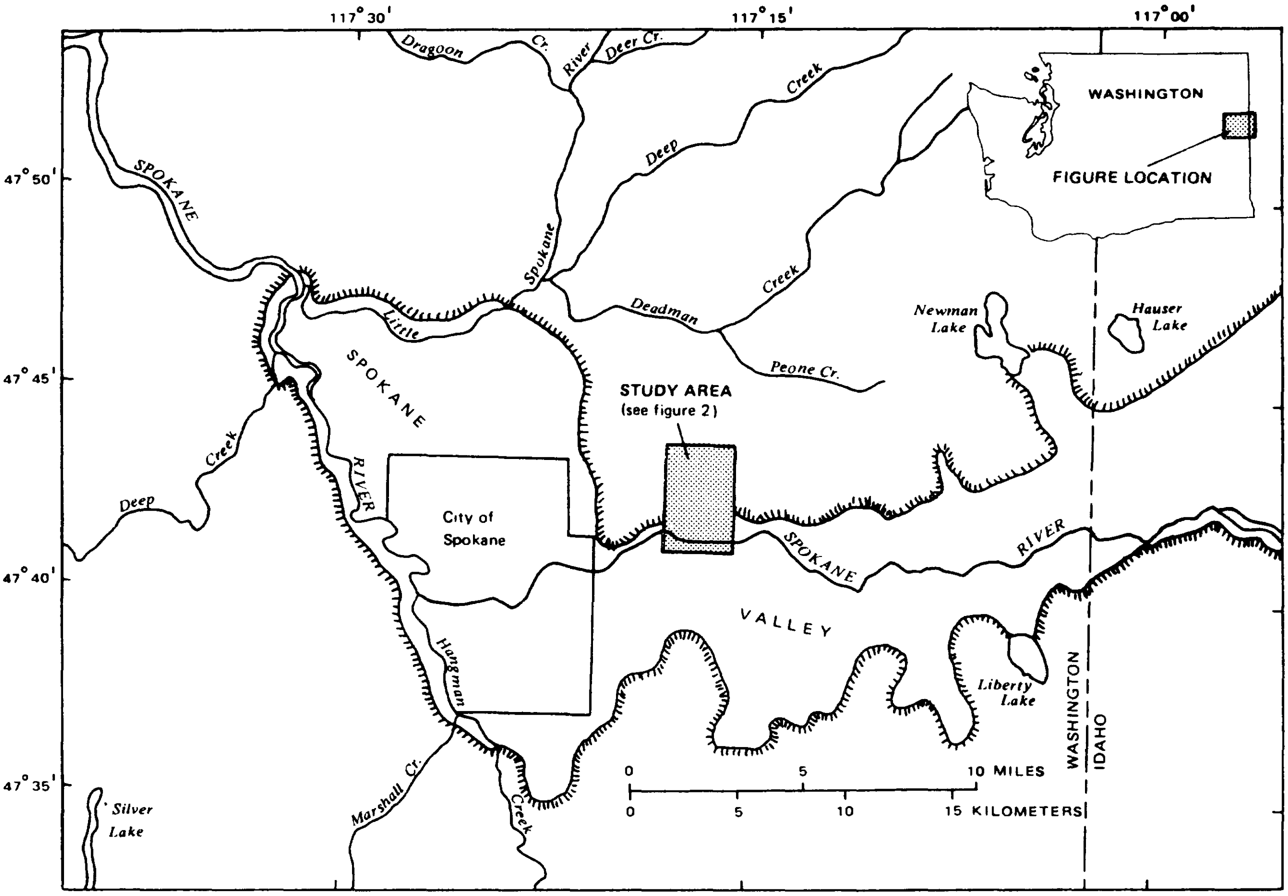


FIGURE 1.--Location of study area.

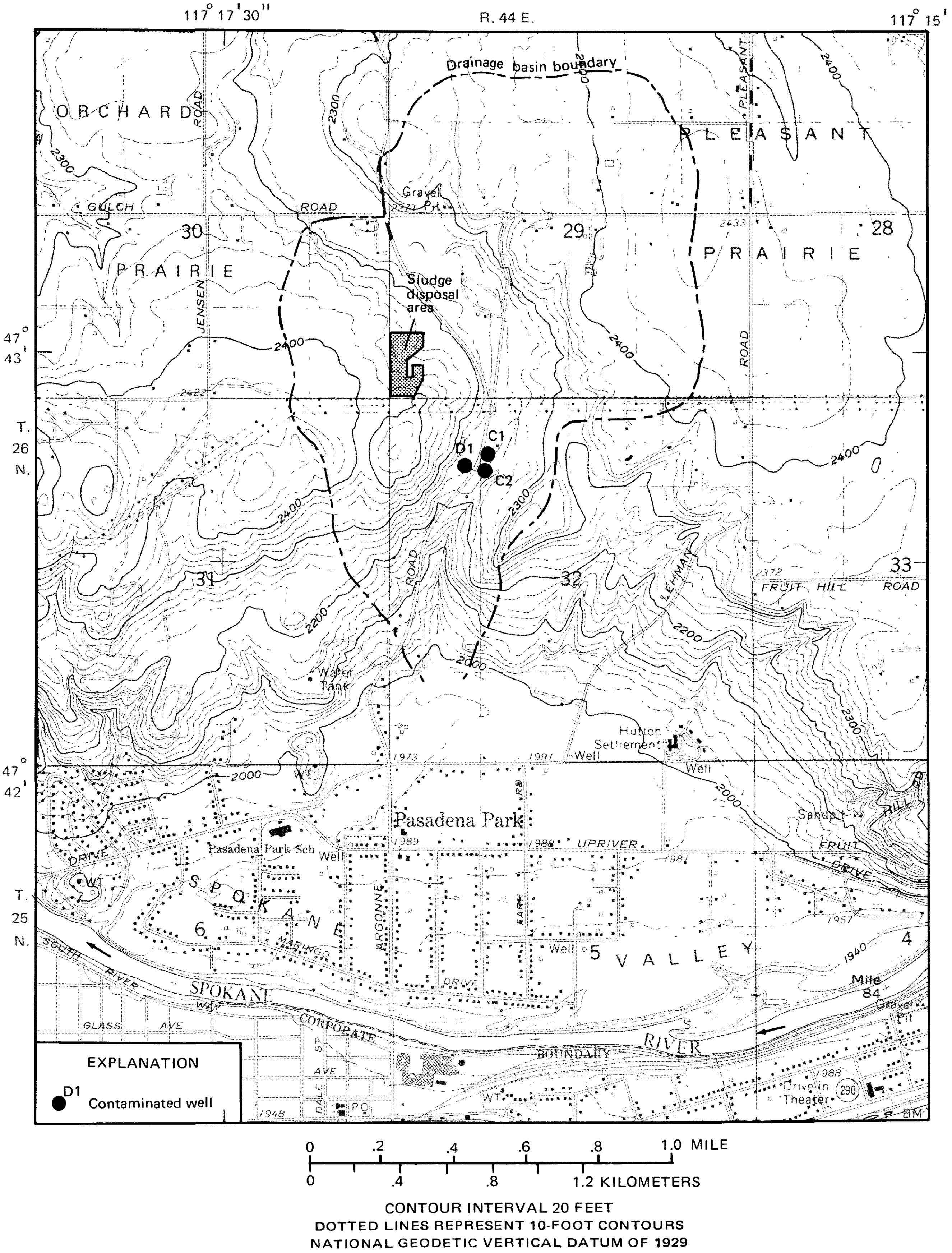


FIGURE 2.--Study area.

Semiannual sampling of the affected wells and analysis of the water for organic and inorganic constituents began in early 1981 and continued through April 1984. Analyses for organic constituents were performed by the U.S. Environmental Protection Agency (EPA); analyses for inorganic constituents were performed by the State of Washington Department of Social and Health Services (DSHS) and WDOE. Although many other wells and a spring in the Argonne Road area were eventually sampled, none was reported to contain the organic contaminants. Traces of the contaminants were found, however, in samples of soil from the disposal site. The results of the sampling effort will be discussed in greater detail in a later section of this report.

## Purpose and Scope

This study is part of a cooperative program between the WDOE and the U.S. Geological Survey to make preliminary assessments of the geohydrologic settings of selected landfill sites and other sites within Washington where contamination has been reported. The report summarizes the results of an investigation that had two principal objectives:

1) Describe, to the extent existing data allow,
    a) the nature and extent of the ground-water contamination that has occurred to date in the vicinity of Argonne Road;
    b) the geohydrologic setting in the immediate vicinity of the contamination problem; and
    c) the projected future flow path of the contaminated water and its possible effects on the local ground-water resource.

2) If existing data are not adequate to meet objective 1 (above) in its entirety, describe what additional data and information are needed in order to do so.

## Data Sources

All pertinent data from various Federal, State, County, and local agencies were assembled to facilitate the completion of this study, and to provide a base of information that can be used as a baseline for future studies. The assembled data were reviewed and those that were applicable to the objectives of this study are included in this report.

Information on geology and hydrology of the area came primarily from published reports of the U.S. Geological Survey, including those by Bolke and Vaccaro (1981), Cline (1969), Drost and Seitz (1978), Griggs (1966), Vaccaro and Bolke (1983), and Weis (1968). The description of the climate was taken in large part from Phillips (1965) and records of the U.S. Weather Bureau. Sources of ground-water-quality data included published and unpublished data of the Geological Survey, and mostly unpublished data from the files of EPA, WDOE, SCHD, and DSHS. All published reports used in completing this study are listed in the Selected References section at the end of this report.

## DESCRIPTION OF STUDY AREA

The Argonne Road study area (figs. 1 and 2) covers about 7 square miles and is located about 6 miles east of Spokane, Wash., and about 12 miles west of the Washington-Idaho State line. It lies partly in foothills and partly in a major river valley.

The northern part of the study area lies in the Northern Rocky Mountain physiographic province described by Fenneman (1931) and consists of rolling hills that reach altitudes of almost 2,500 feet above sea level. For the most part, the southern slopes of the hills are covered with ponderosa pine. Local residents refer to those areas where the trees are absent as "prairies," but the relief there is no less gentle than in other parts of the study area.

The southern part of the study area is in the Columbia Plateau physiographic province described by Fenneman (1931) and consists of part of the relatively flat Spokane Valley, with an altitude of 1,900 to 2,000 feet. For practical purposes, the Spokane River forms the southern boundary of the study area.

Argonne Road is oriented generally north-south and lies along the western slope of a narrow, wooded ravine cut into the hills by an unnamed, intermittent stream. Local residents say that the stream flows only when winter "chinook" winds melt the snow cover that overlies frozen ground, and that the water sinks into the ground shortly after debouching from the ravine and before reaching the Spokane River.

Residential development is sparse in the hills and prairies but more dense in Spokane Valley. Historically, the prairies have been used for the cultivation of grass seed for lawns. In the more recent past, however, much of this agricultural land has been taken out of production to make room for single-family dwellings.

The Spokane area has the characteristics of both marine and continental climates. Summers are typically warm and dry, winters are cold and damp. The mean annual air temperature at the Spokane airport is 47.1°F. As shown in figure 3, July is the warmest month (69.7°F) and January the coldest (25.1°F). Afternoon temperatures in summer generally range from 80° to 90°, but occasionally reach 100°F; however, temperatures drop rapidly after sunset. Afternoon temperatures in winter range from the upper 20's to the upper 30's with nighttime readings of 15° to 25°F.

The mean annual precipitation at Spokane is 16.7 inches. July has the smallest mean monthly precipitation (0.50 inch) and December the largest (2.49 inches). Most of the precipitation between early December and late February falls as snow and remains on the ground. In an average year, 10 to 20 thunderstorms occur between March and October.

Winters are characterized by considerable cloudiness and occasional dense fogs. The percentage of possible sunshine received each month ranges from about 20 percent in December to about 85 percent in July and August. Prevailing winds are from the southwest in summer and northeast in winter. A few warm "chinook" winds are common each winter.

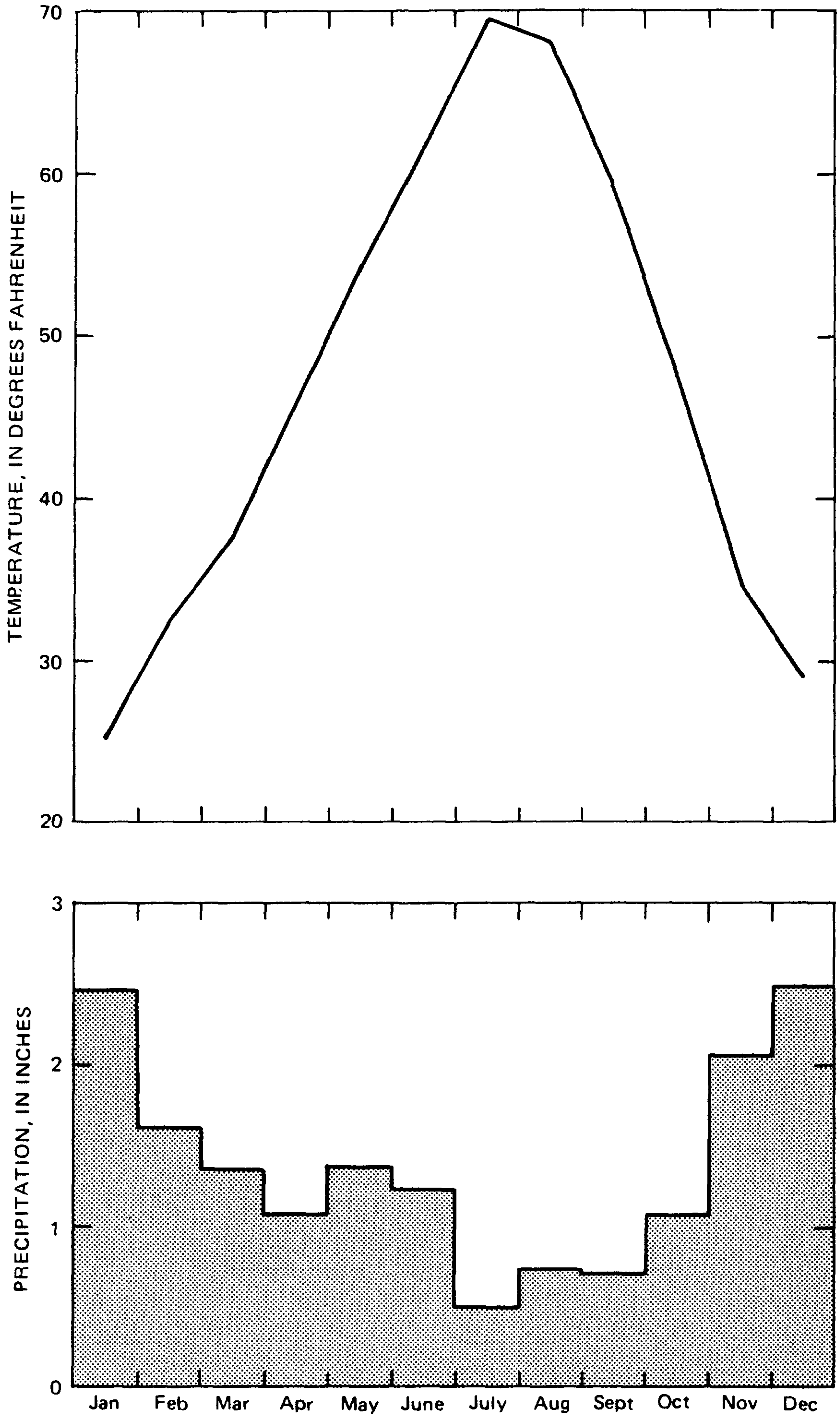


FIGURE 3.--Mean monthly temperature and precipitation at Spokane Airport. Based on National Weather Service records for period 1951-80.

# GEOHYDROLOGY

Detailed geologic and hydrologic descriptions of the Spokane area were provided by Weis (1968) and Cline (1969), respectively. This section of the report is based largely on those works. A generalized geologic map of the study area is provided in figure 4.

## Geologic Setting

Granitic rocks form the foundation of the study area and are partly covered by lava, loess, glacial deposits, and alluvium. The granitic rocks are of Cretaceous age (table 1) and are referred to in this report as "bedrock"; they have been deeply eroded and therefore have a surface of considerable relief.

In Miocene time, extensive basalt lava flows of the Columbia River Basalt Group were extruded over much of southeastern Washington, including the study area. At the same time, clay, silt, and sand were deposited in drainages ponded by the lava flows. The resulting lake sediments, called the Latah Formation, occur mostly near the flow margins or are intertongued with the basalt flows.

Glaciers moved into Washington from the north and east during Pleistocene time. Erosion by ice and glacial streams left a number of basalt-capped mesas. According to Cline (1969), the glaciers also brought much debris that was deposited in glacial lakes (glaciolacustrine deposits) and by streams of glacial meltwater (glaciofluvial deposits). Fine-grained, wind-transported loess of the Palouse Formation also was deposited in Pleistocene time. During Holocene time, following the retreat of the glaciers, the rivers and streams of the area deposited alluvium along their channels.

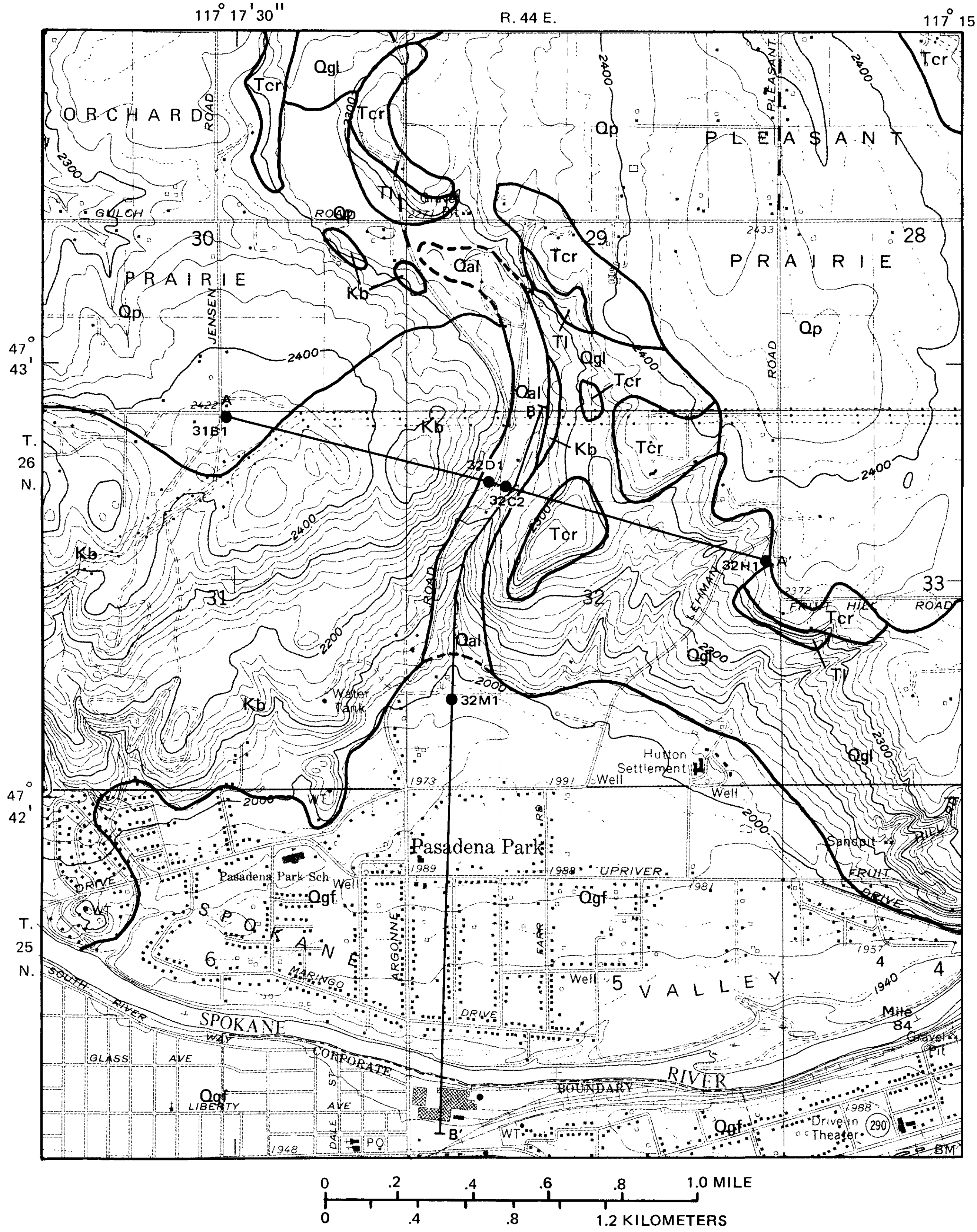
All the geologic units mentioned above are exposed in the study area (fig. 4). The foothills in the west-central part of the area are underlain by bedrock and, although the bedrock is not exposed elsewhere in the area, drillers' logs of wells (appendix A) indicate that the bedrock occurs at depth throughout the study area beneath younger geologic units.

The exposures of the semiconsolidated, fine-grained sediments of the Latah Formation in the study area are few and relatively small. The formation overlies the bedrock below an altitude of about 2,400 feet (Cline, 1969) and is both interbedded with and overlain by basalt of the same age (Miocene).

Basalt is exposed in the northern and eastern parts of the study area, as shown in figure 4. In addition, drillers' reports indicate that the dense, dark-colored rock occurs beneath the younger sediments in the same general area and that the basalt is as much as 77 feet thick. The basalt exposed at land surface commonly forms a hard, resistant cap over the soft, easily eroded sediments of the Latah Formation.

TABLE 1.--Lithologic and hydrologic characteristics of rock units in the study area (modified from Cline, 1969)

| Period | Epoch | Rock unit | Lithologic characteristics | Hydrologic characteristics |
|---|---|---|---|---|
| QUATERNARY | HOLOCENE | Alluvium | Silt, sand, gravel, and lesser amounts of colluvium | Moderately productive aquifer. Well yields range from 5 to 100 gal/min (gallons per minute) |
|  | PLEISTOCENE | Glacio-fluvial deposits | Poorly sorted, coarse-grained sand, gravel, and, in some places, boulders | Highly productive aquifer. Yields from the Spokane aquifer are commonly several thousand gallons per minute |
|  |  | Glacio-lacustrine deposits | Well sorted, fine-grained clay and silt, with lesser amounts of sand and gravel sand or gravel lenses | Yields are highly variable; from 5 to 600 gal/min. Highest yields are from |
|  |  | Palouse Formation | Wind-blown loess, consisting of clay, silt, and fine sand from sand lenses | Yields are small and erratic. Where saturated, yields up to 20 gal/min |
| TERTIARY | MIOCENE | Columbia River Basalt Group | Lava flows of dense, dark basalt | Yields up to 35 gal/min from joints, fractures, and rubbly zones at tops and bottoms of flows |
|  |  | Latah Formation | Generally fine-grained claystone and siltstone, with thin lenses of sand or gravel interbedded with lava flows | Yields up to 35 gal/min from lenses of coarse sand or gravel |
| CRETACEOUS | LATE CRETACEOUS | Bedrock | Granitic rocks, chiefly granodiorite and quartz monzonite. Older metamorphic rocks locally | Mostly impermeable, but yields up to 35 gal/min from fractures and weathered surfaces. |



CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

FIGURE 4.--Generalized geology of the study area.

## DESCRIPTION OF MAP UNITS

| | | | |
|---|---|---|---|
| Quaternary | Holocene | Qal | ALLUVIUM – Silt, sand, and gravel along streams |
| | Pleistocene | Qgf | GLACIOFLUVIAL DEPOSITS – Stream-laid sand and gravel |
| | | Qgl | GLACIOLACUSTRINE DEPOSITS – Lake-laid clay, silt, and sand |
| | | Qp | PALOUSE FORMATION – Wind-deposited loess composed of clay, silt, and fine sand |
| Tertiary | Miocene | Tcr | COLUMBIA RIVER BASALT GROUP – Olivene basalt with sand and gravel interbeds |
| | | Tl | LATAH FORMATION – Lacustrine claystone, siltstone, and sandstone |
| Cretaceous | Late Cretaceous | Kb | BEDROCK – Undifferentiated plutonic and metamorphic rocks, but mostly granite |

- - - ——— Contact – Dashed where approximately located

B ——— B′ Geohydrologic section(see figs 5 and 6)

32D1 ● Well with driller's log used to draw geohydrologic section (see Appendix A)

Much of the northern part of the study area is mantled with the clay, silt, and fine sand of the Palouse Formation. This loess was deposited by the wind during Pleistocene time and may or may not be directly related to glaciation. In most places the loess overlies the basalt and the Latah Formation, but locally it also overlies the bedrock.

The Pleistocene glaciolacustrine deposits of the study area consist of clay, silt, sand, and some interbeds of gravel; they were laid down in a large lake formed by the damming of the Spokane River by a glacier west of the study area. The deposits are exposed in the central and southeastern parts of the study area and probably do not occur elsewhere at depth.

During Pleistocene time, a major channel (the Spokane Valley; fig. 1) was cut into the bedrock at the south end of the study area by the catastrophic outburst of a large glacier-dammed lake to the east (Bretz, 1959). The channel was subsequently filled with coarse glaciofluvial deposits consisting of poorly sorted sand, gravel, and, in places, boulders. Although the sediments are as much as 700 feet thick in the deeper parts of the Spokane Valley, the deposits in the study area occur along the northern margin of the valley and are undoubtedly much thinner.

The narrow ravine in which Argonne Road and the contaminated wells (32C1, 32C2, and 32D1) are located has been cut into bedrock and filled with sand, gravel, and lesser amounts of colluvium; this rock unit is portrayed in figure 4 as alluvium. Although the maximum thickness of the unit is unknown, the alluvium probably becomes thicker in a downstream (southward) direction.

The probable relations of the rock units described above are shown on geohydrologic sections A-A′ and B-B′ in figures 5 and 6, respectively. The sections were drawn using geologic information provided by Cline (1969), well drillers' reports, and hydrologic information provided by records of the U.S. Geological Survey. The configuration and stratigraphic relations of geologic units at depth on the east side of the ravine (fig. 5) and beneath Pasadena Park (fig. 6) are largely unknown and are inferred.

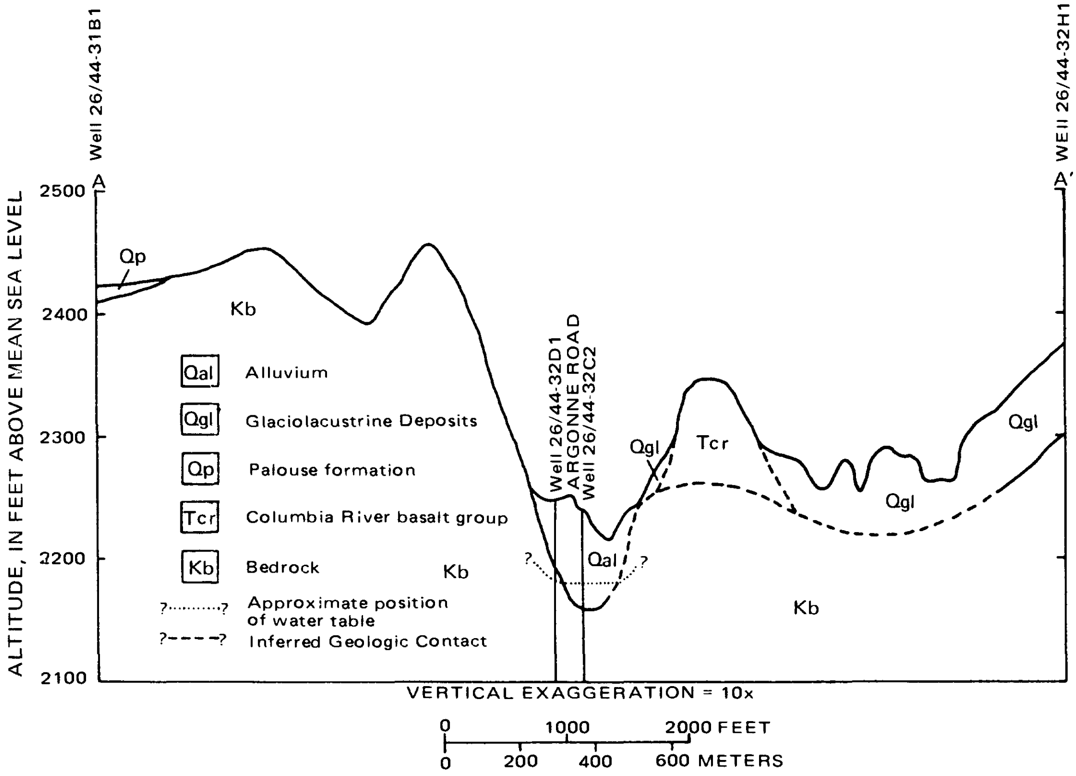


FIGURE 5.--Geohydrologic section A-A'. (See figure 4 for location of section.)

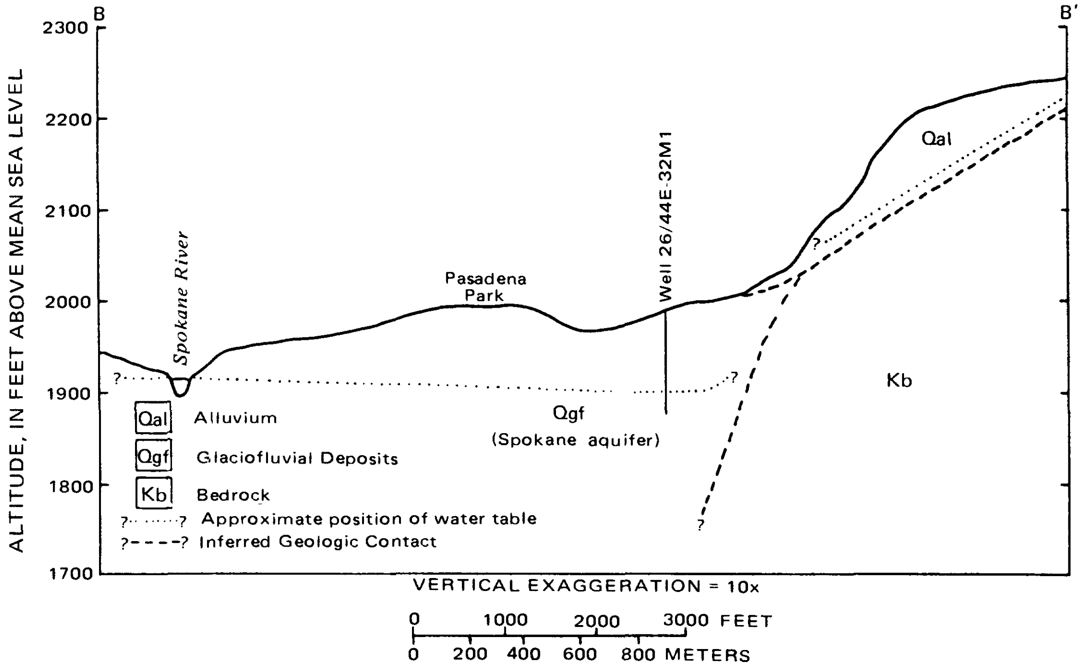


FIGURE 6.--Geohydrologic section B-B'. (See figure 4 for location of section.)

## Occurrence of Ground Water

The geologic units that occur in the study area differ markedly in hydrologic characteristics and water-yielding capabilities (table 1). The following discussion of those characteristics is based in large part on a study of north-central Spokane and southeastern Stevens Counties by Cline (1969). It should be noted that the characteristics of the rocks in the relatively small study area may differ markedly from those described by Cline (1969) for the larger area.

The coarse-grained glaciofluvial sediments are the most permeable and productive rock unit in the study area. Yields of several hundred to several thousand gallons per minute are common in the Spokane aquifer of Spokane Valley. Most of the ground water in the Spokane Valley enters the aquifer from the east, flows quickly along the axis of the valley (fig. 1), and leaves the aquifer many miles to the west, largely as flow into the Spokane and Little Spokane Rivers. The quantity of water flowing through the Spokane aquifer has been estimated by Bolke and Vaccaro (1981) to be in excess of 350 Mgal/d (million gallons per day) or about 243,000 gal/min (gallons per minute).

The granitic bedrock is mostly impermeable. The unit has local secondary permeability, however, and ground water moves through the uppermost part of the bedrock which is fractured and has been decomposed by weathering. Although the bedrock does supply up to 35 gal/min of water to wells locally, the unit as a whole is neither a dependable nor productive source of ground water. Well yields from the sand, gravel, and colluvium of the alluvium unit generally range from 5 to 100 gal/min. Most of the other formations provide water also, but usually at lower yields than the glaciofluvial sediments (see table 1).

Ground-water conditions in the immediate vicinity of Argonne Road are largely unknown and must be inferred from the small amount of data available. The physical characteristics of selected wells in the study area are presented in table 2, and the locations of those wells are shown in figure 7. As indicated in these illustrations, not all well locations have been verified in the field.

Three domestic-supply wells have shown signs of contamination from organic chemicals. All three are drilled wells near the upper end of the ravine, and they draw water from the alluvium and (or) the top of the granitic bedrock. All that is known about one of the wells, 26/44-32C1 (fig. 7), is that it is 72 feet deep and draws water from either the alluvium or the granite. Well 26/44-32D1 is 312 feet deep, has been cased into the granite since first drilled (1947), and taps three fractures within the granite.

Well 26/44-32C2 was originally drilled and cased to 70 feet; the aquifer tapped at that time is unknown. In 1961 the well was deepened to 361 feet and the casing was set in the top of the granite and perforated opposite a water-bearing horizon in the alluvium. Shortly after the discovery of contamination in this well and the two other wells discussed above, well 32C2 was deepened to 400 feet and the openings to the alluvial aquifer were sealed.

The above data suggest that a ground-water body occurs at the base of the alluvium and at the top of the bedrock (see fig. 5). This water body is most likely unconfined. The gradient and direction of ground-water movement are unknown, but based on studies of nearby areas (S.S. Sumioka, U.S. Geological Survey, written commun., December 1985), ground water likely flows to the south with a gradient approximately equal to that of the overlying land surface (see fig. 6). The hydraulic connection between this ground-water body and the Spokane aquifer is unknown, but the former probably is tributary to the latter.

As mentioned previously, the configuration of the bedrock on the east side of the ravine is largely unknown. If the trough in which the alluvium occurs is carved wholly in bedrock, as postulated in figure 5, the flow of ground water would be largely contained within the lowermost part of the alluvium and the topmost part of the bedrock. Under such conditions, the principal direction of flow would be southward, toward the Spokane aquifer, and flow within the top of the granite would be controlled by the type of permeability found there. If this permeability is largely the result of weathering, ground-water flow in the granite would most likely be similar to that in the overlying alluvium. If, however, the permeability is a result of fracturing, ground-water flow in the granite could be oriented in directions parallel to the fractures.

The possibility exists that the alluvium in the Argonne Road ravine abuts rock material other than granite on the east side of the ravine. If so, this material could have a higher permeability than the granite, and ground-water flow might not necessarily be confined to the alluvium-filled ravine. Instead, ground water would be free to flow eastward as well as southward.

TABLE 2.--Selected wells in the study area

| Local well number | Altitude (ft) | Depth (ft) | Casing diameter (in.) | Water use[1] | Water-yielding aquifer[2] | Remarks[3] |
|---|---|---|---|---|---|---|
| A) Well locations verified in field | | | | | | |
| 25/44-4E1 | 1,975 | 177 | 6 | S | Qgf | L |
| -5D1 | 1,996 | 202 | 16 | P | Qgf | L,M,O |
| -5K1 | 1,958 | 234 | 16 | P | Qgf | L,M |
| -6A1 | 1,982 | 104 | 84 | P | Qgf | L,M,O |
| -6E1 | 1,900 | 18 | 4 | H | Qgf | L |
| 26/44-28D1 | 2,405 | 320 | 6 | H | Tl | L |
| -28D2 | 2,400 | 37 | 30 | I | -- | |
| -28M1 | 2,415 | 47 | 48 | H | -- | |
| -28M2 | 2,415 | 166 | 6 | H | Kb | L |
| -29A1 | 2,385 | 22 | 36 | H | Qp | L |
| -29G2 | 2,410 | 387 | 8 | U | -- | L |
| -29L1 | 2,370 | 68 | 8 | H | Tcr | L |
| -30D1 | 2,330 | 96 | 6 | H | -- | |
| -30D2 | 2,340 | 113 | 42 | I | Tcr | L |
| -30E1 | 2,285 | 495 | 8 | H | -- | |
| -30G1 | 2,310 | 230 | 6 | U | Kb | L |
| -32D1 | 2,245 | 312 | 6 | H | Kb | L,O,C |
| -32H1 | 2,365 | 140 | 6 | U | -- | L. Destroyed |
| -32J2 | 2,225 | 455 | 8 | H | Kb | L |
| -32L1 | 2,070 | 17 | 72 | H | Tl | L |
| -32N2 | 1,970 | 170 | 6 | H | Qgf | L |
| -32P1 | 1,990 | 141 | 12 | H | -- | |
| -32Q1 | 1,988 | 148 | 8 | P | Qgf | L,M,O |
| -32R1 | 2,003 | 113 | 72 | P | Qgf | M,O |
| -33E1 | 2,395 | 508 | 6 | U | Tl | L |
| -33E2 | 2,390 | 510 | 6 | H | Tl | L |
| -33L1 | 2,390 | 128 | 6 | H | -- | |
| -33M1 | 2,370 | 338 | 6 | H | Tl | L |
| B) Well locations not verified in field | | | | | | |
| 25/44-6A2 | 1,990 | 155 | 16 | P | Qgf | L,M |
| 26/44-28F1 | 2,410 | 200 | 6 | H | Tl | L |
| -29A3 | ,2395 | 162 | 6 | H | Tcr | L |
| -29C1 | 2,380 | 60 | 6 | H | Tcr | L |
| -29D1 | 2,320 | 52 | 6 | H | Tcr | L |
| -29F1 | 2,360 | 60 | 6 | H | -- | M,O |
| -29L2 | 2,300 | 10 | 48 | H | -- | M,O |
| -29L3 | 2,260 | 60 | 6 | H | -- | O |
| -29L4 | 2,260 | 55 | 8 | H | -- | O |

(continued)

TABLE 2.--Selected wells in the study area--Continued

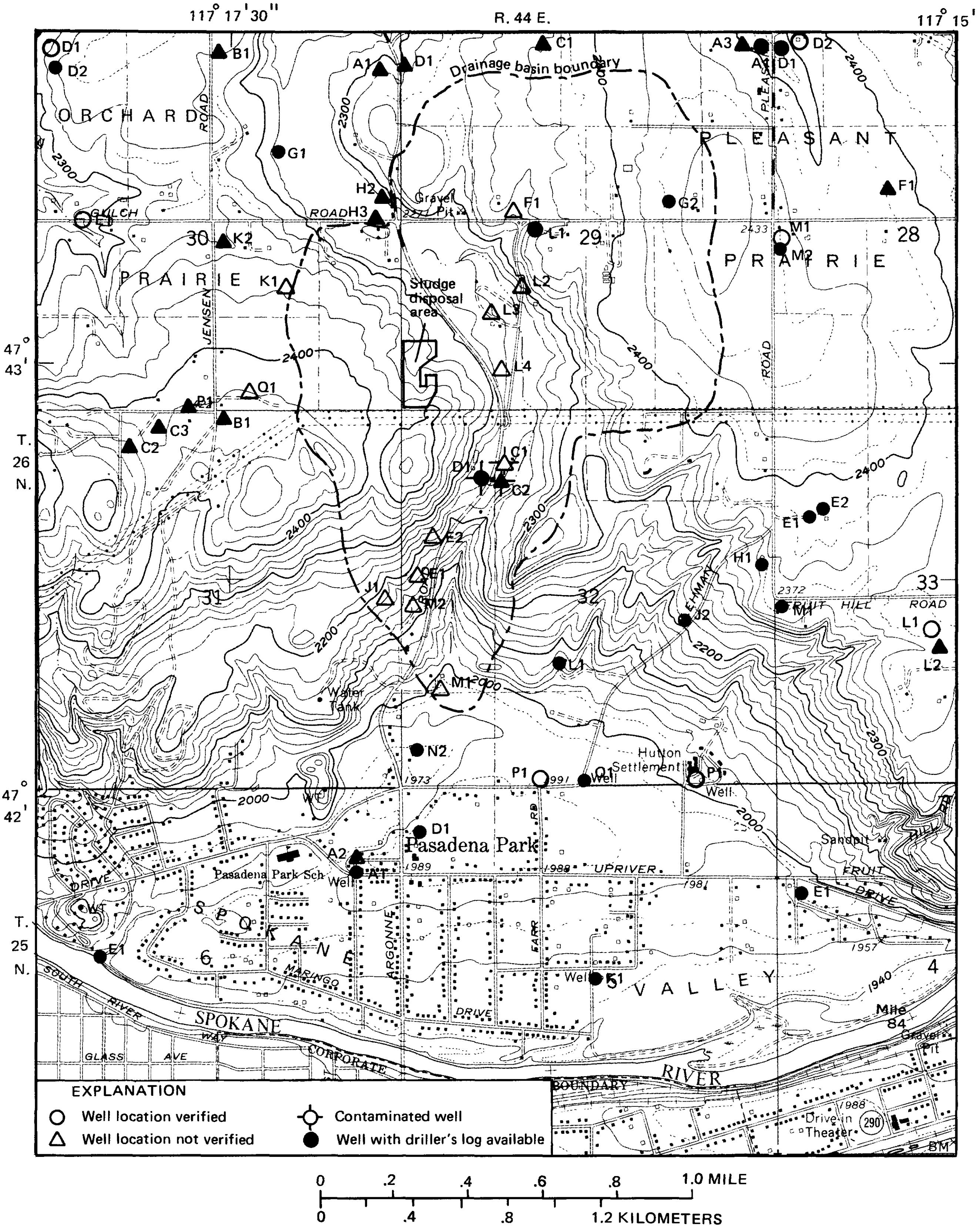
| Local well number | Altitude (ft) | Depth (ft) | Casing diameter (in.) | Water use[1] | Water-yielding aquifer[2] | Remarks[3] |
|---|---|---|---|---|---|---|
| 26-44-30A1 | 2,320 | 337 | 6 | H | Tl | L |
| -30B1 | 2,340 | 543 | 6 | U | -- | L. Dry |
| -30H2 | 2,270 | 340 | 6 | H | Kb | L |
| -30H3 | 2,280 | 361 | 6 | H | Kb | L |
| -30K1 | 2,375 | 150 | 8 | H | -- | |
| -30K2 | 2,360 | 198 | 6 | H | Kb | L |
| -30P1 | 2,420 | 222 | 6 | H | Kb | L |
| -30Q1 | 2,410 | 145 | 6 | H | -- | M,O |
| -31B1 | 2,425 | 505 | 6 | H | Kb | L |
| -31C2 | 2,435 | 505 | 6 | H | Kb | L |
| -31C3 | 2,415 | 242 | 6 | H | Kb | L |
| -31J1 | 2,140 | 160 | 6 | -- | -- | M,O |
| -32C1 | 2,245 | 72 | 6 | H | -- | O,C |
| -32C2 | 2,240 | 400 | 6 | H | Kb | L,O,C |
| -32E1 | 2,160 | 168 | 6 | H | -- | M,O |
| -32E2 | 2,240 | 372 | 6 | I | -- | M,O |
| -32M1 | 1,988 | 92 | 6 | U | -- | |
| -32M2 | 2,100 | 435 | 6 | H | -- | M,O |
| -33L2 | 2,385 | 225 | 6 | H | Tl | L |

---

[1] H, domestic; I, irrigation; P, public supply; S, stock; U, unused.

[2] See figure 4 for aquifer codes.

[3] C, contaminated with halogenated aliphatic hydrocarbons (see table 4).
L, driller's log available (see appendix A).
M, water-quality data available for major dissolved constituents (see table 3).
O, sampled and analyzed for presence of organic contaminants.



CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

FIGURE 7.--Locations of selected wells in the study area. (See table 2 for physical characteristics.)

## Ground-Water Flow in Argonne Road Area

Because of uncertainties in the geologic framework of the ground-water system near Argonne Road and of water levels in the alluvium, it does not appear practical to attempt a calculation of the amount of water flowing through the alluvium. By making certain assumptions, however, it is possible to calculate the range of linear velocities over which the water is moving. In order to do so, it is assumed that ground-water flow is restricted to the alluvium and the direction of flow is southward, parallel to the axis of the ravine.

The linear velocity at which ground-water flows through a granular medium can be expressed as follows:

$$v = \frac{KI}{n} \tag{1}$$

where

v = the average linear velocity of water through the pore openings of the alluvium, in feet per day (ft/d);
K = the hydraulic conductivity (permeability) of the alluvium, in feet per day (cubic feet per square foot per day);
I = the hydraulic gradient, in feet per foot; and
n = the porosity of the alluvium, dimensionless.

The hydraulic conductivity of the alluvium is estimated to range from 1.5 to 15 ft/d (Todd, 1959, p. 53); the porosity is estimated to be 0.35, based on values given by Todd (1959, p. 24) and Freeze and Cherry (1979, p. 37) for earth materials commonly found in alluvium. The gradient of the water table is assumed to equal the gradient of the land surface along the axis of the ravine, and was measured on a topographic map at 0.093 foot per foot.

The likely minimum ground-water velocity would result from inserting the lowest value of hydraulic conductivity into equation 1, namely:

$$v = \frac{1.5 \text{ ft/d } (0.093 \text{ ft/ft})}{0.35} = 0.40 \text{ ft/d} \tag{2}$$

Increasing the hydraulic conductivity to the highest likely value (15 ft/d) increases the velocity tenfold, to 4.0 ft/d. Using the minimum and maximum values of hydraulic conductivity, it is reasonable to state that ground water moves southward through the alluvium at a rate of from 0.40 to 4.0 ft/d. In order to apply these flow rates to the situation under discussion, the following table of distances traveled per unit time, and of times required per unit distance, is provided:

| | Ground-water velocity (ft/d) | |
|---|---|---|
| | 0.40 | 4.0 |
| Distance traveled in 1 year | | |
| - feet | 146 | 1,460 |
| - miles | 0.028 | 0.28 |
| Time required to travel 1 mile | | |
| - days | 13,200 | 1,320 |
| - years | 36 | 3.6 |

For comparison purposes, Vaccaro and Bolke (1983) have indicated that ground-water velocities in the Spokane aquifer in the vicinity of Pasadena Park range from 10 to 50 ft/d.

## General Ground-Water Quality

Background chemical conditions in the ground water of the general study area for major dissolved constituents are shown in table 3. It should be emphasized that the data are limited in several respects. Data are not available for all wells, and there are no pre-contamination water-quality data available for the three wells known to be contaminated. In addition, chemical analyses were performed by many agencies and at widely differing times. For reasons of simplicity and clarity, data known to have been collected on multiple dates were included in table 3 under a single, specific date.

Specific-conductance values ranged from 135 to 406 umhos/cm (micromhos per centimeter) and are typical of ground water in the Spokane area. The few available data for pH indicate that the water is slightly alkaline. Hardness values ranged from 96 to 220 mg/L (milligrams per liter), indicating that the water is moderately hard to very hard.

Calcium is the predominant cation and, although data are not shown, bicarbonate is the predominant anion (Vaccaro and Bolke, 1983). Nitrate concentrations were less than 2.3 mg/L except in wells 26/44-32Q1 and 32R1, where they were 15 and 17 mg/L, respectively. These concentrations are above the federally recommended limit of 10 mg/L (U.S. Environmental Protection Agency, 1976). The cause of these relatively high nitrate concentrations is not known, but may be related to the use of septic tanks or the application of agricultural fertilizers. The high-nitrate wells are not in the same drainage basin as the organically contaminated wells; consequently, the high nitrates most likely are not related to the organic contamination problem.

In aggregate, the limited data listed in table 3 suggest that ground-water quality in the study area is typical of the region as described by Van Denburg and Santos (1965), Vaccaro and Bolke (1983), and Ebbert (1984) for the major dissolved constituents.

TABLE 3.--Ground-water quality at selected sites--major dissolved constituents

[Results in milligrams per liter except as indicated]

| | Well 25/44- | | | | Well 26/44- | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5D1 | 5K1 | 6A1 | 6A2 | 29F1 | 29L2 | 30Q1 | 31J1 | 32E1 | 32E2 | 32M2 | 32Q1 | 32R1 |
| Date | 7/27/82 | 6/11/80 | 7/27/82 | 7/26/83 | 11/9/81 | 11/9/81 | 11/9/81 | 11/9/81 | 11/9/81 | 11/9/81 | 11/9/81 | 7/27/82 | 7/27/82 |
| Specific conductance (umhos/cm) | 205 | 200 | 155 | 135 | 387 | 367 | 189 | 296 | 287 | 235 | 406 | 375 | 345 |
| pH (units) | 8.2 | -- | 8.1 | 7.7 | -- | -- | -- | -- | -- | -- | -- | 8.0 | 8.1 |
| Temperature (°C) | 12.0 | -- | 11.5 | 11.0 | -- | -- | -- | -- | -- | -- | -- | 15.0 | 17.0 |
| Hardness (as $CaCO_3$) | -- | -- | -- | -- | 170 | 160 | 96 | 150 | 150 | 100 | 220 | -- | -- |
| Calcium (Ca) | 30.4 | -- | [a]24 | [a]22 | -- | -- | -- | -- | -- | -- | -- | [a]40 | [a]42 |
| Magnesium (Mg) | 12.7 | -- | [a]7.6 | [a]7.4 | -- | -- | -- | -- | -- | -- | -- | [a]27 | [a]17 |
| Sodium (Na) | 4.0 | [a]10 | [a]3.7 | [a]3.6 | -- | -- | -- | -- | -- | -- | -- | [a]8.7 | [a]6.7 |
| Potassium (K) | 2.0 | -- | [a]1.5 | [a]1.7 | -- | -- | -- | -- | -- | -- | -- | [a]4.3 | [a]3.2 |
| Sulfate ($SO_4$) | 10 | 10 | 14 | 9 | [b]39 | [b]34 | [b]37 | [b]51 | [b]30 | [b]28 | [b]34 | 22 | 14 |
| Chloride (Cl) | 2 | 10 | 3 | 2 | 12 | 12 | 1.5 | 4.6 | 3.1 | 3.8 | 14 | 20 | 2 |
| Nitrate (N) | [a]2.3 | [a]1.5 | [a]1.7 | [a]1.7 | -- | -- | -- | -- | -- | -- | -- | [a]15 | [a]17 |
| Fluoride (F) | .13 | .40 | .11 | .09 | -- | -- | -- | -- | -- | -- | -- | .21 | .26 |
| Dissolved solids | -- | -- | -- | -- | 360 | 330 | 180 | 240 | 230 | 220 | 300 | -- | -- |

[a] Represents a total concentration rather than a dissolved concentration.
[b] Sample collected 11/16/81.

## OCCURRENCE OF KNOWN ORGANIC CONTAMINATION

As mentioned in the "Background" section of this report, sampling of numerous wells and a spring from early 1981 through April 1984 showed that only three (domestic) wells were contaminated with organic compounds. The locations of the three wells (26/44-32C1, 32C2, and 32D1) are shown in figure 7. All three contaminated wells are located at the upper end of the ravine.

The types and concentrations of the organic compounds present in the wells as of October 1, 1981, are presented in table 4. As shown, the principal contaminants, in order of decreasing concentration, were tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, and 1,2-*trans*-dichloroethene. For reasons of simplicity, these compounds will be abbreviated as follows throughout the remainder of this report:

| Scientific name[1] | Common name | Abbreviation |
|---|---|---|
| tetrachloroethene | Perchloroethylene | PCE |
| trichloroethene | Trichloroethylene | TCE |
| 1,1,1-trichloroethane | Methyl chloroform | TCA |
| 1,2-*trans*-dichloroethene | Acetylene dichloride | EDC |

[1] As given in Weast, 1975.

TABLE 4.--Ground-water quality at selected sites--organic compounds

[All concentrations are total, in micrograms per liter]

| | | Local well number 26/44- | | |
|---|---|---|---|---|
| | | 32C1 | 32C2 | 32D1 |
| Compound | Abbreviation | --- October 1, 1981 ---- | | |
| 1,1-dichloroethane | | <1 | <1 | <1 |
| 1,2-dichloroethane | | <1 | 1.4 | <1 |
| 1,1,1-trichloroethane | (TCA) | 5.4 | <1 | <1 |
| 1,1-2,2-tetrachloroethane | | <1 | <1 | <1 |
| 1,2-*trans*-dichloroethene | (EDC) | 2.9 | 4.1 | <1 |
| tetrachloroethene | (PCE) | 880 | 116 | 1.7 |
| trichloroethene | (TCE) | 67 | 8.6 | <1 |
| dichloromethane | | <1 | <1 | <1 |
| tetrachloromethane | | <1 | <1 | <1 |
| trichloromethane | | <1 | <1 | <1 |
| 1,2-dichloropropane | | <1 | <1 | <1 |

The organic concentrations in table 4 are generally highest in well 32C1, lowest in well 32D1, and intermediate in well 32C2. Much of this variation can be explained by an examination of the locations and construction details of the wells in question. Well 32C1 is closest to the suspected source of contamination (fig. 7), is relatively shallow (72 feet), and is finished in either the alluvium or the topmost part of the granite. Well 32C2 is topographically and hydraulically downgradient of well 32C1 and, although 400 feet deep, at the onset of contamination was open to the alluvial aquifer. Both wells 32C1 and 32C2 are situated near the axis of the trough where the alluvium is probably thickest. Well 32D1, 312 feet deep, is situated on the west side of the ravine (see fig. 5), away from the axis of the trough, and is finished only in the granite.

The relative concentrations of PCE and TCE remained highest in well 32C1 throughout the sampling period (see figs. 8 and 9) and no definite trends in concentration were observed. Because sampling was suspended in April 1984, it is presently (June 1985) unknown if concentrations in the affected wells, and the geographic extent of contamination, have changed since that time.

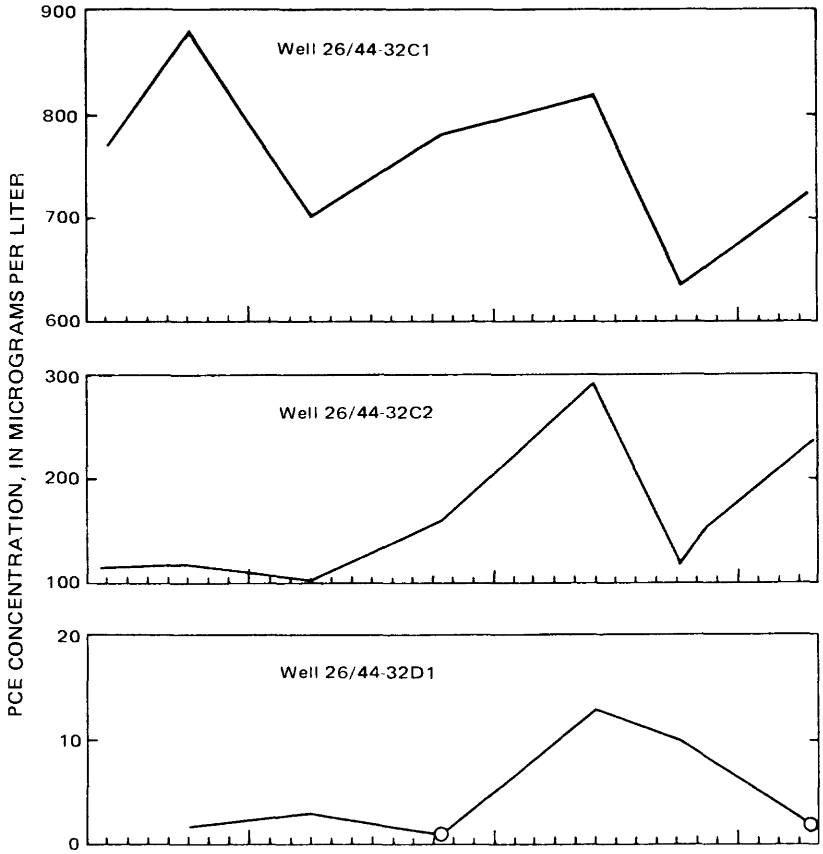


FIGURE 8.--PCE concentrations in contaminated wells.

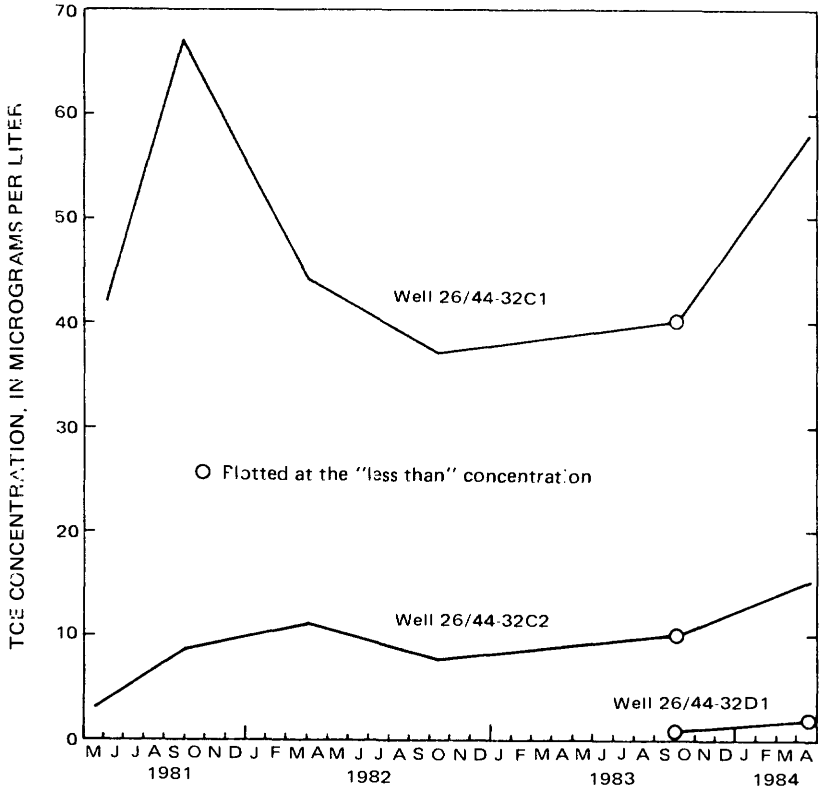


FIGURE 9.--TCE concentrations in contaminated wells.

## NATURE AND MOBILITY OF ORGANIC CONTAMINANTS

The organic compounds found in wells 26/44-32C1, 32C2, and 32D1 (table 4) are technically considered halogenated aliphatic hydrocarbons. Aliphatic hydrocarbons are compounds in which the carbon atoms are joined in such a way as to form open chains, as opposed to closed chains or rings. The halogenated aliphatic hydrocarbons contain atoms of the halogen group, usually chlorine (Cl), in their molecular structure. A concise and basic discussion of organic compounds and how they relate to ground-water pollution is presented by Pettyjohn and Hounslow (1983).

The four contaminating compounds of interest, abbreviated earlier as PCE, TCE, TCA, and EDC, are commonly considered industrial solvents and are used extensively to clean grease and oil from industrial machines, to remove stains from clothes in dry cleaning, to clean pipes and drains connected to septic tanks, in household cleaning products, and as refrigerants, fumigants, and anesthetics. Because all four solvents are similar in chemical composition and behavior, they will be discussed as a group.

The contaminants of concern are only slightly soluble in water (table 5) and are considerably more dense than water (specific gravity 1.26 to 1.62). Organic liquids more dense than water are commonly referred to as "sinkers." When present in concentrations in excess of aqueous solubilities, sinkers commonly migrate to the bottom of an aquifer or to a layer of lower permeability (Pettyjohn and Hounslow, 1983) as an immiscible organic liquid phase. In general, the fate and movement of organic liquid phases are poorly understood.

Whether an organic liquid phase of industrial solvents occurs in the Argonne Road area is unknown. It is known, however, that a dissolved solute phase exists, as evidenced by the contaminant concentrations observed in three affected wells. Consequently, the discussion in this report is confined to the processes that influence the fate of dissolved organic solutes in ground water. These processes include advection, dispersion, sorption, volatilization, and chemical and biological transformation.

Advection is the process by which solutes are transported by the motion of flowing ground water. In the absence of other influences, ground-water contaminants would be expected to travel at the same rate (velocity) as the ground water in which they are dissolved. The ground-water velocity range determined previously for the Argonne Road area is 0.4 to 4.0 ft/d.

Field and laboratory evidence indicate that dissolved contaminants spread both longitudinally and transversely as they move with the ground water. This process, called dispersion, results in the formation of a contaminant plume, the dilution of solute concentrations, and the attenuation of concentration peaks. As pointed out by Mackay and others (1985), dispersion may result in the arrival of detectable contaminant concentrations at a given location significantly before the arrival time that is expected solely on the basis of the average ground-water flow rate. Existing data are insufficient to quantify the effects of dispersion in the study area. As in most field situations, however, dispersion in the direction of flow is likely to be greater than dispersion transverse to the flow (Mackay and others, 1985).

Because the solvents are hydrophobic, their sorption to aquifer materials would generally be expected; this sorption would tend to retard their movement through the aquifer. Pettyjohn and Hounslow (1983), however, state that low molecular weight hydrocarbons, such as TCE, are sorbed only by soils that contain appreciable amounts of organic matter. It is unlikely that the alluvium or bedrock in the Argonne Road area contain appreciable amounts of organic matter.

The distribution, or partitioning, of a hydrophobic compound between solid organic matter and water in an aquifer can be approximated by the partition coefficient of that compound (Newsom, 1985). The partition coefficient is defined as the ratio of the solubility of the compound in octanol, an alcohol, to its solubility in water. The partition coefficients shown in table 5 for the contaminants of concern are considered low, suggesting that movement of the solvents through an aquifer would not be slowed substantially even if organic matter was present in the aquifer. Wilson and others (1981) found that halogenated aliphatic hydrocarbons moved readily through fine sand. The same investigators postulated that this may account for the frequent occurrence of these compounds in ground water.

Volatilization is a major transport process for industrial solvents at land surface. The solvents have relatively low molecular weight, high vapor pressure, and low boiling point (table 5), and evaporation to the atmosphere can be rapid. Even when dissolved in water, the solvents evaporate appreciably more rapidly than the water. This may explain the almost ubiquitous presence of these solvents in the atmosphere in minute quantities (McConnell and others, 1975). Callahan and others (1979) report that, once transported to the troposphere, the solvents are rapidly photooxidized in the presence of sunlight.

Volatilization, however, proceeds at a much slower rate in the subsurface. According to Pettyjohn and Hounslow (1983), the rate of transport (volatilization) is greatly reduced when the compounds lie deeper than a foot below land surface. Indeed, Wilson and others (1981) found that, compared to volatilization from water, soil inhibited the process by an order of magnitude. It is interesting to note that the observed concentrations of the four solvents in the contaminated wells (table 4) were inversely proportional to vapor pressure and boiling point, suggesting that proportionately greater volumes of the more volatile compounds may have been lost at some time to the atmosphere. This is especially likely if, as suspected, the contamination originated from the dumping of septic-tank sludge onto the land surface. The possibility also exists that the concentrations observed in the contaminated wells are a reflection of the relative concentrations of the compounds at the source of contamination.

Organic contaminants can be transformed or degraded into other compounds by numerous chemical and biological mechanisms. Mackay and others (1985) point out chemical reactions that generally affect organic contaminants in water, such as hydrolosis and oxidation, may not be significant in a ground-water environment, and that most chemical reactions occurring in the ground-water zone are likely to be slow compared with transformation mediated by microorganisms. Much uncertainty exists as to whether halogenated aliphatic hydrocarbons in particular are transformed or degraded biologically. The consensus of opinion seems to be that microbial degradation does not occur aerobically, and that if it occurs anaerobically it does so at a very slow rate (Bouwer and others, 1981; Newsom, 1985). Although a few laboratory studies have demonstrated the occurrence of anaerobic microbial degradation, Wilson and others (1981) suggest that such laboratory studies only indicate a potential for degradation that may or may not be realized in the field.

Taken in aggregate, the information presented above suggests that the dissolved solute phase of the contaminating organic solvents found in ground water near Argonne Road will not be significantly affected by sorption, volatilization, chemical activity, or biodegradation. The process of dispersion, however, could affect the fate of the contamination plume in at least three ways: (1) regardless of the source and history of contamination, concentrations in ground water will be diluted with distance traveled (with time); (2) the plume of contamination probably will move at a faster rate (higher velocity) than was estimated previously in this report for the ambient ground water; and (3) although no long-term trends are evident in the data of figures 8 and 9, the peak concentrations of the contamination plume may not have reached the affected wells by April 1984, when sampling ended.

TABLE 5.--Physical and chemical characteristics of organic contaminants and water

| | | Halogenated aliphatic hydrocarbon[1] | | | |
|---|---|---|---|---|---|
| | Water | Tetrachloroethene | Trichloroethene | 1,1,1-trichloroethane | 1,2-*trans*-dichloroethene |
| Abbreviated name[2] | -- | PCE | TCE | TCA | EDC |
| Chemical formula | $H_2O$ | $Cl_2C:CCl_2$ | $CHCl:CCl_2$ | $CH_3CCl_3$ | $ClHC:CHCl$ |
| Molecular weight | 18 | 166 | 131 | 133 | 97 |
| Specific gravity | 1.00 | 1.62 | 1.46 | 1.32 | 1.26 |
| Melting point (°C) | 0 | -23 | -73 | -30 | -50 |
| Boiling point (°C) | 100 | 121 | 87 | 74 | 48 |
| Vapor pressure at 20°C (torr) | 18 | 14 | 58 | 96 | 200 |
| Solubility in water at 20°C (mg/L) | -- | 150-200 | 1100 | 480-4400 | 600 |
| Log octanol/water partition coefficient | -- | 2.88 | 2.29 | 2.17 | 1.48 |

[1] From Callahan and others, 1979.

[2] As used in this report only.

## PROJECTED FLOW PATH

Utilizing the geologic, hydrologic, and chemical information presented thus far, an idea of the potential flow path of the contaminants can be formulated. This formulation is based on the assumption that the contaminants are in the dissolved solute phase and that the plume of contaminants will move in the same direction as the ambient ground water. As pointed out previously, ground water in the Argonne Road area likely flows southward toward Spokane Valley and the Spokane aquifer.

Assuming that the plume of organics travels at the same rate as the ambient ground water, the time needed for the plume to reach the Spokane aquifer can be estimated. If the plume first arrived at the contaminated wells in spring 1981 and is traveling at the slowest likely velocity (0.40 ft/d), it would take about 25 years for the plume to reach the northern edge of the Spokane aquifer, about 3,600 feet away. If, however, the velocity of the plume is 4.0 ft/d, the plume could have reached the Spokane aquifer in only 2.5 years (by fall 1983). These calculations do not take into account the effects of dispersion. Because of longitudinal dispersion in the direction of ground-water flow, the contamination plume could arrive at selected destinations more quickly than was calculated above. Existing data are insufficient to quantify the differential in velocities and (or) traveltimes.

## ADDITIONAL DATA AND STUDY NEEDS

The Spokane aquifer is one of the most productive and heavily used aquifers in Washington; contamination of such a resource would have severe consequences. Of immediate concern is the possible contamination of domestic and public-supply wells in the Pasadena Park area. Now that an aquifer tributary to the Spokane aquifer has been found to be contaminated, County, State, and Federal regulatory agencies have an interest in determining the extent of the contamination problem, safeguarding the health of potential users of the ground water, and restoring the affected aquifer(s) or restricting their use. Implicit in these objectives are the additional objectives of finding the original source of the contamination and preventing further contamination.

The data presented in this report are not sufficient to meet the objectives stated above. As a consequence, additional data would have to be collected and additional interpretations of those data made. This report, which is preliminary in nature and based only on readily available information, serves only to describe in a very general manner the hydrogeologic conditions in the area of interest and the type of ground-water contamination problem that has occurred. Many questions remain unanswered, and most of the preliminary conclusions reached in this report need to be confirmed and (or) refined.

A suggested, generalized approach to meeting the non-regulatory objectives mentioned above is as follows:

A) Refine the existing hydrologic knowledge of the contaminated alluvial aquifer along Argonne Road.
    1) Refine the geologic and hydrologic boundaries of the alluvium. Determine if the alluvium is bounded on the east by bedrock or by some more permeable sedimentary rock unit. This could best be accomplished using surface geophysical techniques, such as seismic refraction or resistivity, in conjunction with confirmatory drilling or augering.
    2) Determine the hydraulic characteristics of the affected aquifer, to include permeability and porosity, using field and (or) laboratory testing procedures.
    3) Using water levels measured in observation wells, determine ground-water gradients, flow directions, and flow velocities.

B) Delineate the lateral and vertical extent of the contamination plume both upgradient and downgradient of the contaminated wells using an organic vapor analyzer in conjunction with drilling, augering, and surface geophysical techniques.
    1) Sample existing wells frequently and regularly for the presence of organic substances.
    2) Where needed, install additional monitoring wells or piezometers.
    3) Determine the vertical profile of contaminant concentration at selected sites, including concentrations in the unsaturated (vadose) zone.
    4) Continue monitoring observation wells for changes in plume configuration and concentration with time.

C) Determine the degree of hydraulic interconnection between the alluvial aquifer near Argonne Road and the Spokane aquifer, using surface geophysical techniques and water-level measurements.

D) Determine the fate of the contamination plume should it reach the Spokane aquifer, using the knowledge gained in the plume-delineation phase (B, above). Describe the number, depths, and locations of wells likely to be affected, and the number of people who depend on those wells for domestic or public supply.

# SUMMARY

In the spring of 1981, three domestic wells near the head of a wooded ravine along Argonne Road near Spokane were found to be contaminated with organic solvents. The suspected source of contamination was an unlined 40-acre septic-tank sludge disposal area located uphill and approximately 0.3 mile northwest of the wells. Under orders of the Spokane County Health District, all dumping ceased at the disposal area in April 1984. A major concern now is that the contaminated aquifer could be in hydraulic connection with the Spokane aquifer to the south, which supplies numerous domestic and public-supply wells and which has been accorded "sole source" status.

The primary objective of this study was to describe the nature and extent of ground-water contamination, the geohydrologic setting, and the projected flow path of the water. In the event existing data were not adequate to meet the primary objective, a secondary objective was to describe what additional data and information would be needed in order to do so.

The geologic units in the study area include, from oldest to youngest, granitic bedrock, the Columbia River Basalt Group, claystone and siltstone of the Latah Formation, loess of the Palouse Formation, fluvial and lacustrine glacial deposits, and alluvium. The ravine along Argonne Road consists of an alluvium-filled trough cut into granitic bedrock.

An unconfined ground-water body exists at the base of the alluvium and at the fractured and weathered top of the granite. Although confirming data are generally lacking, the ground water is probably moving southward, toward the Spokane aquifer at an estimated velocity range of 0.40 to 4.0 ft/d. It is this ground-water body that has been found to be contaminated.

Ground-water samples collected in autumn 1981 indicate that three wells were contaminated with tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, and 1,2-*trans*-dichloroethene. Periodic sampling from 1981 to 1984 showed that concentrations in the affected wells did not change appreciably and that no trends were detectable.

The contaminating chemicals are halogenated aliphatic hydrocarbons and all four are similar in chemical composition and behavior. They are used extensively to clean grease and oils from machinery, to remove stains from clothes in dry cleaning, in household cleaning products, and to clean pipes and drains connected to septic tanks. The four hydrocarbons are relatively insoluble in water. In addition, they are more dense than water and would probably tend to sink to the bottom of an aquifer or to a layer of lower permeability if present in concentrations in excess of aqueous solubilities. This study dealt only with the dissolved solute phase of the contaminants, and the processes that are likely to affect that phase.

The solvents in question have relatively low molecular weight, high vapor pressure, and low boiling point, and evaporation to the atmosphere at land surface can be rapid. Solvent concentrations in the affected wells were inversely proportional to vapor pressure and boiling point, suggesting that proportionately greater volumes of the more volatile compounds may have been lost, at some time, to the atmosphere. This may have occurred if, as

suspected, the contamination originated from the dumping of septic-tank sludge onto the land surface. The possibility exists, however, that the concentrations observed in the contaminated wells are a reflection of the relative concentrations of the compounds at the source of contamination.

A literature search has indicated that the dissolved solute phase of the contaminants in the ground water will not be significantly affected by sorption, volatilization, chemical activity, or biodegradation. The fate of the contaminants could be significantly affected, however, by the process of dispersion.

Based on the limited data available, it seems likely that the contaminated ground water in the alluvial aquifer of the Argonne Road ravine is moving southward toward the Spokane aquifer. Assuming that the plume of contamination is traveling at the slowest likely velocity (0.40 ft/d), it would take about 25 years for the plume to reach the Spokane aquifer. If, however, the velocity of the plume is 4.0 ft/d, the plume could have reached the Spokane aquifer in only 2.5 years (by fall 1983). These time estimates should be considered maximum values because of the longitudinal dispersion of the plume that is likely to occur, resulting in the arrival of detectable contaminant concentrations at a given location significantly before the arrival time that would be expected solely on the basis of the average ground-water flow rate.

Because of the very preliminary nature of this investigation, numerous questions remain to be answered and many preliminary conclusions need to be confirmed and refined. Consequently, the following additional studies are suggested.

A) Refine the existing knowledge of the contaminated alluvial aquifer along Argonne Road.
B) Delineate the lateral and vertical extent of the contamination plume.
C) Determine the degree of hydraulic interconnection between the alluvial (Argonne Road) aquifer and the Spokane aquifer.
D) Determine the fate of the contamination plume should it reach the Spokane aquifer.

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## APPENDIX A. Drillers' logs of representative wells

| Local well number | Altitude (feet) | Materials | Thick-ness (feet) | Depth (feet) |
|---|---|---|---|---|
| | | A) Well locations verified in field | | |
| 25/44-4E1 | 1975 | Clay | 100 | 100 |
| | | Sand | 75 | 175 |
| | | Gravel | 2 | 177 |
| 25/44-5D1 | 1996 | Gravel | 43 | 43 |
| | | Sand | 159 | 202 |
| 25/44-5K1 | 1958 | Gravel | 79 | 79 |
| | | Clay | 6 | 85 |
| | | Sand | 149 | 234 |
| 25/44-6A1 | 1982 | Gravel | 104 | 104 |
| 25/44-6E1 | 1900 | Gravel | 18 | 18 |
| 26/44-28D1 | 2405 | Clay and sand | 45 | 45 |
| | | Basalt | 62 | 107 |
| | | Clay | 67 | 174 |
| | | Basalt | 10 | 184 |
| | | Clay | 136 | 320 |
| 26/44-28M2 | 2415 | Clay and broken basalt | 42 | 42 |
| | | Hard basalt | 58 | 100 |
| | | Clay | 63 | 163 |
| | | Gneiss (granite?) | 3 | 166 |
| 26/44-29A1 | 2385 | Sand and clay | 22 | 22 |
| 26/44-29G2 | 2410 | Topsoil | 1 | 1 |
| | | Clay | 2 | 3 |
| | | Sand | 7 | 10 |
| | | Clay | 47 | 57 |
| | | Basalt | 59 | 116 |
| | | Clay | 271 | 387 |
| 26/44-29L1 | 2370 | Basalt | 65 | 65 |
| | | Clay | 3 | 68 |
| 26/44-30D2 | 2340 | No record | 57 | 57 |
| | | Basalt | 56 | 113 |
| 26/44-30G1 | 2310 | Clay, sand, boulders | 188 | 188 |
| | | Granite | 42 | 230 |

APPENDIX A. Drillers' logs of representative wells--Continued

| Local well number | Altitude (feet) | Materials | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|
| 26/44-32D1 | 2245 | Granitic sand; some granite blocks | 50 | 50 |
| | | Granite | 262 | 312 |
| 26/44-32H1 | 2365 | Sand | 65 | 65 |
| | | Decomposed granite | 75 | 140 |
| 26/44-32J2 | 2225 | Sand and clay | 320 | 320 |
| | | Granite | 71 | 391 |
| 26/44-32L1 | 2070 | Clay | 17 | 17 |
| 26/44-32N2 | 1970 | Sand and gravel | 170 | 170 |
| 26/44-32Q1 | 1988 | Sand, gravel, boulders | 52 | 52 |
| | | Sand | 96 | 148 |
| 26/44-33E1 | 2395 | Till | 20 | 20 |
| | | Basalt | 20 | 40 |
| | | Sand, hardpan, etc. | 360 | 400 |
| | | Hardpan | 60 | 460 |
| | | Quicksand | 48 | 508 |
| 26/44-33E2 | 2390 | Sand and clay | 18 | 18 |
| | | Basalt | 32 | 50 |
| | | Sand and clay | 460 | 510 |
| 26/44-33M1 | 2370 | Sand and clay | 19 | 19 |
| | | Basalt | 37 | 56 |
| | | Sand, silt, clay | 296 | 352 |

B) Well locations not verified in field

| Local well number | Altitude (feet) | Materials | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|
| 25/44-6A2 | 1990 | Sand and gravel | 155 | 155 |
| 26/44-28F1 | 2410 | Overburden | 9 | 9 |
| | | Basalt | 77 | 86 |
| | | Sand | 90 | 176 |
| | | Sand and gravel | 24 | 200 |
| 26/44-29A3 | 2395 | Clay | 73 | 73 |
| | | Basalt | 39 | 112 |
| | | Clay | 50 | 162 |
| 26/44-29C1 | 2380 | Soil and clay | 18 | 18 |
| | | Basalt | 40 | 58 |
| | | Clay | 2 | 60 |

APPENDIX A. Drillers' logs of representative wells--Continued

| Local well number | Altitude (feet) | Materials | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|
| 26/44-29D1 | 2320 | Basalt | 49 | 49 |
| | | Clay | 3 | 52 |
| 26/44-30A1 | 2320 | Basalt | 34 | 34 |
| | | Clay | 204 | 238 |
| | | Sand | 33 | 271 |
| | | Clay | 66 | 337 |
| 26/44-30B1 | 2340 | Soil and clay | 24 | 24 |
| | | Basalt | 35 | 59 |
| | | Clay and sand | 484 | 543 |
| 26/44-30H2 | 2270 | Soil and clay | 21 | 21 |
| | | Granite | 319 | 340 |
| 26/44-30H3 | 2280 | Clay | 14 | 14 |
| | | Basalt | 33 | 47 |
| | | Clay | 239 | 286 |
| | | Granite | 75 | 361 |
| 26/44-30K2 | 2360 | Soil and clay | 3 | 3 |
| | | Clay and granite blocks | 195 | 198 |
| 26/44-30P1 | 2420 | Clay | 100 | 100 |
| | | Granite | 122 | 222 |
| 26/44-31B1 | 2425 | Sand and boulders | 48 | 48 |
| | | Granite | 457 | 505 |
| 26/44-31C2 | 2435 | Soil and clay | 30 | 30 |
| | | Granite | 475 | 505 |
| 26/44-31C3 | 2415 | Soil and clay | 10 | 10 |
| | | Granite | 232 | 242 |
| 26/44-32C2 | 2240 | No record | 85 | 85 |
| | | Granite | 276 | 361 |
| 26/44-33L2 | 2385 | Sand | 72 | 72 |
| | | Clay | 19 | 91 |
| | | Basalt | 90 | 181 |
| | | Clay | 44 | 225 |

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