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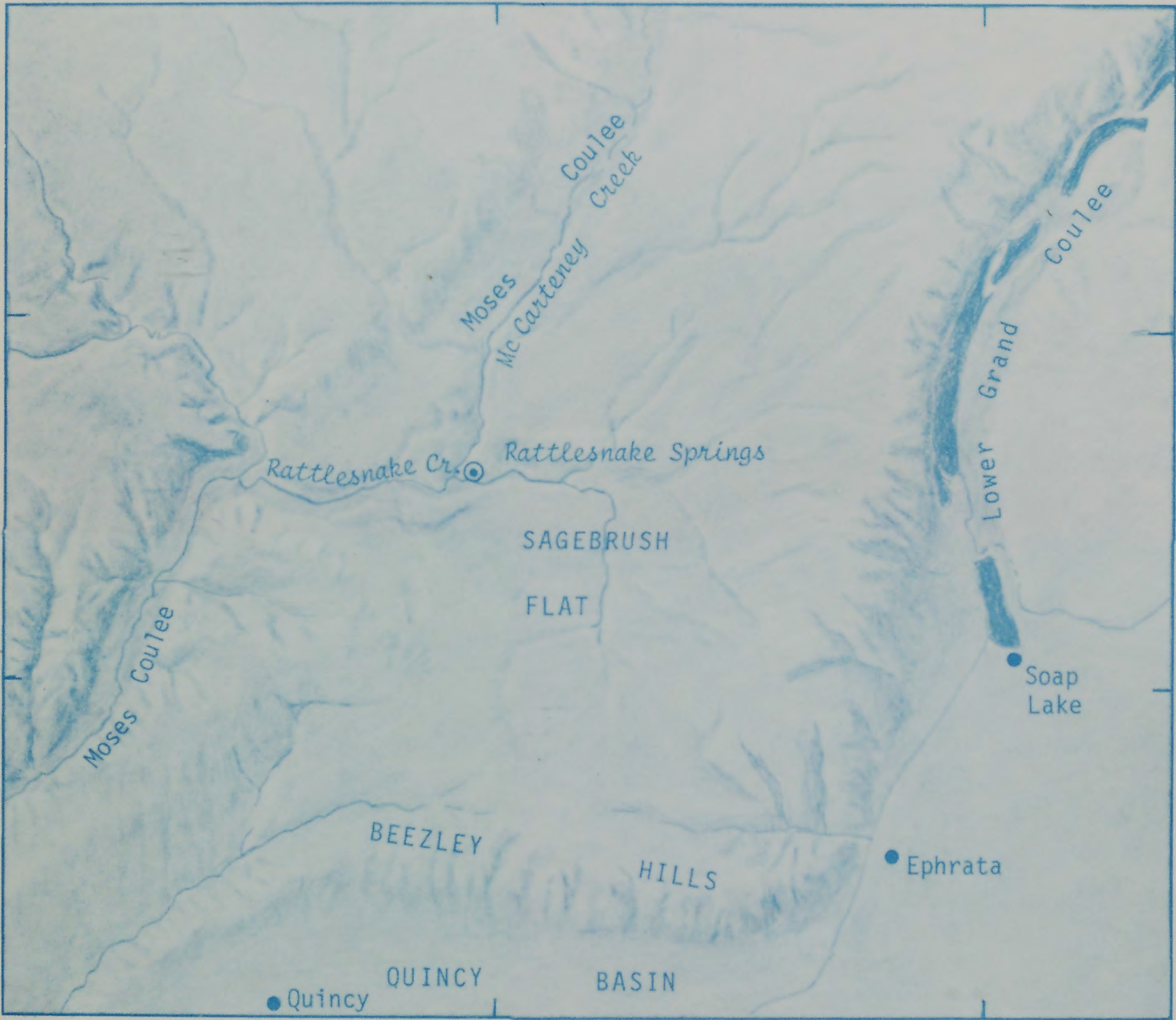
# GROUND-WATER HYDROLOGY OF THE SAGEBRUSH FLAT AREA AND POSSIBLE RELATIONS TO THE DISCHARGE OF RATTLESNAKE SPRINGS, GRANT AND DOUGLAS COUNTIES, WASHINGTON




U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
Open-File Report 79-1530

Prepared in Cooperation With
State of Washington Department of Ecology

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# GROUND-WATER HYDROLOGY OF THE SAGEBRUSH FLAT AREA AND POSSIBLE RELATIONS TO THE DISCHARGE OF RATTLESNAKE SPRINGS, GRANT AND DOUGLAS COUNTIES, WASHINGTON

By K. L. Walters

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1980

UNITED STATES DEPARTMENT OF THE INTERIOR
CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY
H. William Menard, Director



For additional information write to:

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

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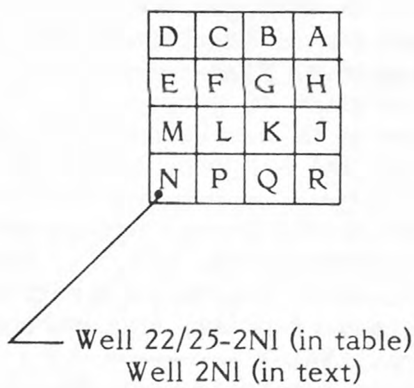
## WELL-NUMBERING SYSTEM

Wells inventoried during this study (table 1) have been assigned numbers identifying them by location, within a section, township, and range, or by latitude and longitude.

For example, in the symbol 22/25-2N1, the part preceding the hyphen indicates successively the township and range (T.22 N., R.25 E.) north and east of the Willamette base line and meridian. Because the study area lies entirely north and east of the base line and meridian, the letters indicating the directions north and east are omitted. The first number following the hyphen indicates the section (sec. 2), and the letter "N" gives the 40-acre subdivision of the section, as shown in the figure below. The numeral "1" indicates that this well is the first one inventoried within the subdivision.

The wells discussed in this report are in two townships and three ranges. However, for simplicity in noting well numbers in the text and because none of the section numbers are repeated in the two townships, in most cases the wells are referred to in the text only by their section and numeral designations.



CONVERSION FACTORS

| Multiply | By | To obtain |
|---|---|---|
| inch (in) | 25.4 | millimeter (mm) |
| | 2.540 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| acre-feet (acre-ft) | 1233. | cubic meter ($m^3$) |
| | 0.001233 | cubic hectometer ($hm^3$) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| | 3.785 | liter per minute (L/m) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| | 28.32 | liter per second (L/s) |

# GROUND-WATER HYDROLOGY OF THE SAGEBRUSH FLAT AREA AND POSSIBLE RELATIONS TO THE DISCHARGE OF RATTLESNAKE SPRINGS, GRANT AND DOUGLAS COUNTIES, WASHINGTON

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## ABSTRACT

In 1978, the U.S. Geological Survey, in cooperation with the State of Washington Department of Ecology, investigated the hydrology of the Sagebrush Flat area as it relates to Rattlesnake Springs.

Rattlesnake Springs and all known wells on Sagebrush Flat obtain water from basalt aquifers. The wells tap aquifers at or below the altitude of the spring discharge.

Water levels in some wells on Sagebrush Flat, and in a well 27 miles to the northeast in an area of no ground-water development, show slight fluctuations that may correspond to annual variations in precipitation. However, hydrographs of most wells on Sagebrush Flat show water-level declines and rises that correspond with the beginning and end of the pumping season. The discharge of Rattlesnake Springs started to decrease at about the beginning of the 1978 pumping season and did not start to increase until after most pumping was stopped.

The water level in deep aquifers beneath Sagebrush Flat is at a lower altitude than in shallow aquifers, and water moves down well boreholes from shallow aquifers to deeper aquifers. This downward movement of water diverts ground water that is moving toward natural discharge points such as Rattlesnake Springs, thereby decreasing the discharge at these points.

## INTRODUCTION

In January 1978 the State of Washington Department of Ecology (DOE) requested the U.S. Geological Survey to investigate the hydrology of the Sagebrush Flat area as it relates to variations in the discharge rate of Rattlesnake Springs. The study mainly involved determinations of pumping periods of irrigation wells through the 1978 irrigation season and contemporaneous determination of the discharge of the springs. Measurements of water levels in wells in the Sagebrush Flat area by DOE personnel since 1975 and precipitation data from nearby Ephrata since 1958 were utilized to help interpret ground-water-level trends in the area. Chemical analyses of water samples also were used in the attempt to evaluate the spring-well-aquifer relationship.

## DESCRIPTION OF THE AREA

Sagebrush Flat covers about 14 $mi^2$ in the bottom of an upland structural and topographic basin between Moses Coulee and Grand Coulee and is about 10 miles northwest of Ephrata, Wash. (fig. 1). The topographic basin comprises approximately 100 $mi^2$ and is drained into Moses Coulee near Rattlesnake Springs, which is at the edge of Sagebrush Flat. The Flat ranges in altitude from about 1,600 to 1,700 feet above mean sea level. It is about 500 feet higher than the adjacent lower part of Moses Coulee on the west and about the same altitude as the upper part of the coulee to the north.

Rattlesnake Springs is the source of Rattlesnake Creek and is situated about 4,800 feet east of the confluence of Rattlesnake Creek and McCarteney Creek. As observed in the field and shown on the 1:24,000 scale U.S. Geological Survey Rattlesnake Springs quadrangle, the springs actually constitute only one principal spring at an altitude of about 1,470 feet. The water flows west into a small pond (less than 1,500 $ft^2$ of surface area), then north to a larger pond, that is the head of Rattlesnake Creek.

Irrigation from wells is practiced not only on Sagebrush Flat (table 1), but also nearby in the upper and lower parts of Moses Coulee. Although about 10 wells on Sagebrush Flat were constructed as irrigation wells, some were never put into service, and only four--31M1, 32M1, 5A1, 5J1--were used in 1978 for that purpose (fig. 2). These wells are 0.8, 1.8, 2.5, and 2.8 miles from the springs, respectively. Irrigation wells in the upper part of Moses Coulee are more than 4 miles from the springs and are not shown in figure 2.

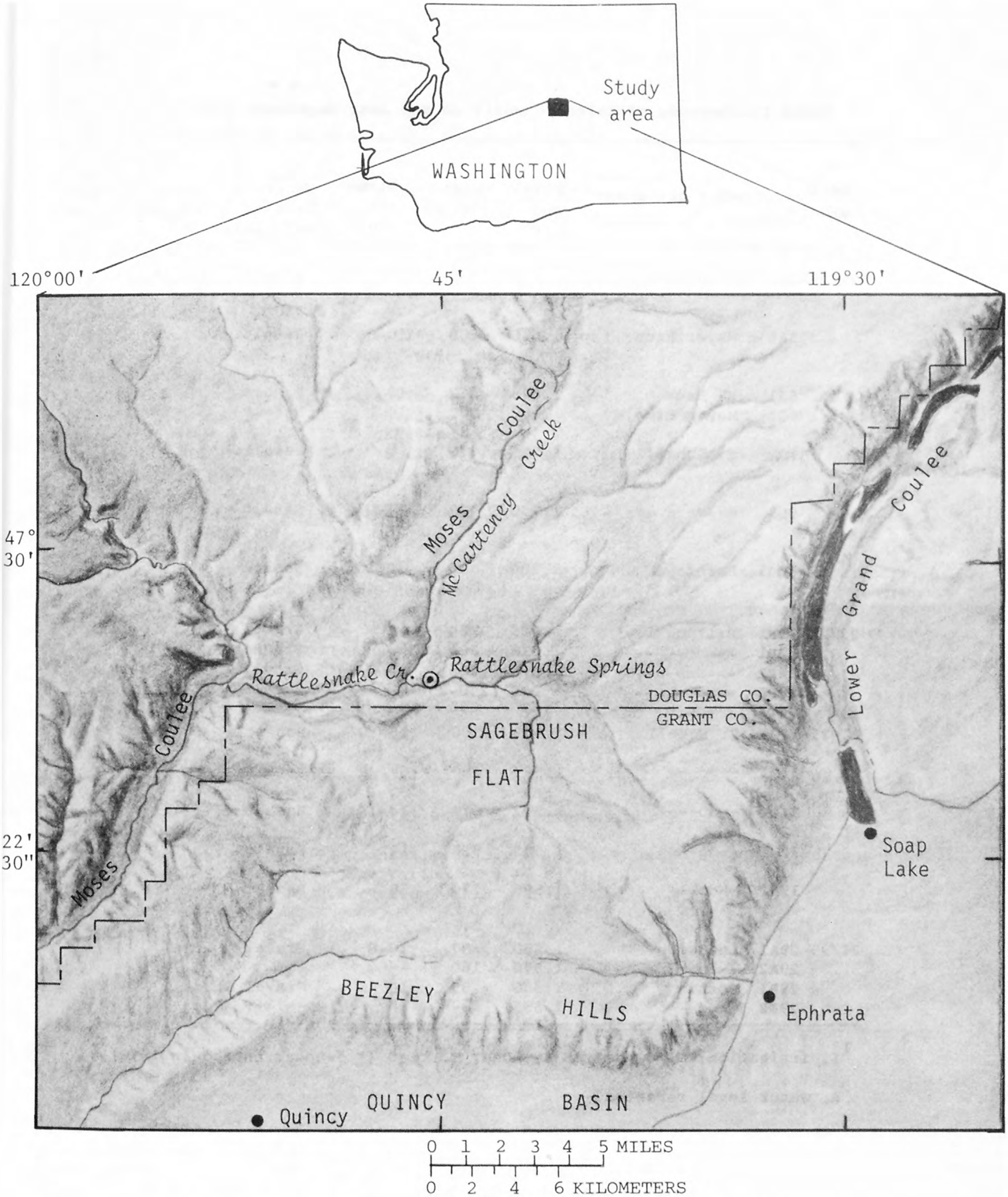


FIGURE 1.--Location of Sagebrush Flat study area.

TABLE 1.--Records of selected wells on and near Sagebrush Flat

| Well number | Owner or tenant | Altitude (ft) | Depth (ft) | Diameter (in.) | Water-bearing material | Intended use[1] |
|---|---|---|---|---|---|---|
| 22/25-2N1 | L. Hansen | 1,770 | 365 | 16-15-8 | Basalt | I* |
| 5A1 | Mayer Bros. | 1,630 | 200 | 10 | Basalt | I |
| 5J1 | H. Heer | 1,645 | 242 | 12 | Basalt | I |
| 6C1 | Mayer Bros | 1,600 | 200 | 10 | Basalt | I* |
| 7D1 | S. Schell | 1,700 | 420 | 6 | Basalt | D* |
| 9L3 | --do--- | 1,750 | 498 | 14-9 | Basalt | I* |
| 10C1 | Barbre | 1,700 | 386 | 12-10 | Basalt | I* |
| 23/24-33K1 | Billingsley | 1,055 | 220 | 12 | Gravel | I |
| 34P1 | ---do------ | 1,070 | 300 | -- | Gravel | I* |
| 34P2 | ---do------ | 1,075 | 285 | -- | Gravel | I* |
| 34P3 | ---do------ | 1,090 | 240-250 | -- | Basalt | D |
| 34Q1 | ---do------ | 1,070 | 235 | 10 | Gravel | I* |
| 23/25-31M1 | S. Schell | 1,605 | 500 | 16-10 | Basalt | I |
| 31Q1 | --do--- | 1,591 | 280 | 6 | Basalt | T* |
| 31R1 | --do--- | 1,592 | 674 | 14-10 | Basalt | I* |
| 32M1 | --do--- | 1,595 | 823 | 14 | Basalt | I |
| 32N1 | --do--- | 1,595 | 130 | 18 | Basalt | I* |
| 24/25-29A1 | Luedeman | 1,580 | 87 | 10-8 | Gravel | I |
| 29A2 | --do--- | 1,575 | 160 | -- | | I* |
| 29B1 | Corning | 1,580 | 85 | 10 | Gravel | I |
| 29B2 | --do--- | 1,585 | -- | 8 | -- | I* |

[1] I, irrigation; D, domestic; N, none; T, test (* denotes unused in 1978).

[2] R, water level reported.

| Water level | | |
|---|---|---|
| Depth below land surface[2] (ft) | Date | Remarks |
| R 180 | 8-15-67 | Log. Drilled 1967, tested 1,500 gal/min per with 10 ft drawdown. Observation well. |
| 159.6 | 3- 3-77 | |
| 165.6 | 10- 3-78 | |
| R 25 | 6-20-51 | Drilled 1951, tested 350 gal/min; cased to 62 ft. Observation well. |
| 30.4 | 3- 3-77 | |
| 31.13 | 10- 3-78 | |
| 51.92 | 10- 3-78 | Observation well. |
| 23.68 | 6-12-58 | Log. Drilled 1951, tested 450 gal/min; cased to 62 ft. Observation well. |
| 26.26 | 10- 3-78 | |
| R 62 | 12-10-74 | Log. Drilled 1974; estimated yield 20 gal/min. Observation well. |
| 188 | 10-17-75 | |
| 315 | 10- 3-78 | |
| R 85 | 4- 1-70 | Observation well. |
| 81.7 | 10-17-75 | |
| 82.03 | 10- 3-78 | |
| 98.9 | 10-17-75 | Tested at 325 gal/min, December 1966; pump set at 250 ft; pump now removed. Observation well. |
| 99.75 | 10- 3-78 | |
| R 162 | 5- 4-55 | Log. Drilled 1955, tested at 500 gal/min with 8 ft drawdown. |
| -- | -- | Abandoned, low yield. |
| -- | -- | Abandoned, low yield. |
| R 80 | 10-10-78 | |
| -- | -- | Abandoned, low yield. |
| 83 | 5- 7-76 | Log. |
| 96.3 | 9- 6-78 | |
| 80.6 | 6-18-76 | Log. drilled 1974, tested at 150 gal/min. Observation well. |
| 56.73 | 10- 3-78 | |
| 148.6 | 11-21-75 | Log. Drilled 1975. Observation well. |
| 181 | 10- 3-78 | |
| 243.84 | 9- 6-77 | Pump installed July 1978; backfilled to 600 ft (date unknown). Observation well. |
| 109.23 | 10- 3-78 | |
| 21.95 | 9- 6-77 | Observation well. |
| 18.99 | 10- 3-78 | |
| R 54 | 12- -52 | Log. Drilled 1952. |
| R 61 | -- | Log. |
| 59 | 10-10-78 | |

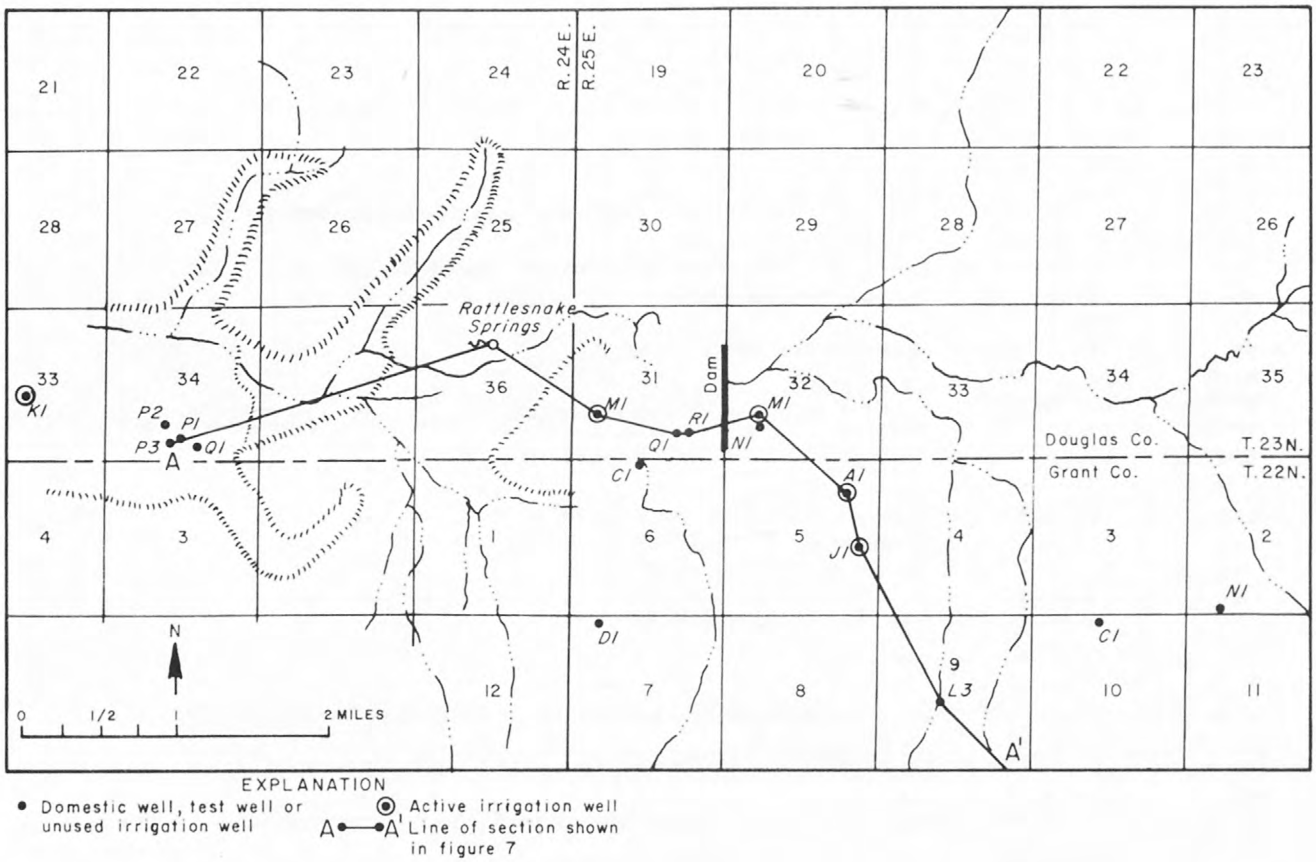


FIGURE 2.--Locations of Rattlesnake Springs and wells on and near Sagebrush Flat.

## GEOHYDROLOGIC SETTING

As determined from well drillers' records (table 2), Sagebrush Flat is underlain by soil, sand, and gravel as much as 44 feet in thickness. These unconsolidated deposits are in turn underlain by basalt whose thickness is in the thousands of feet (Brown, 1978, p. 19). According to Brown, the basalt units beneath Sagebrush Flat are essentially flat lying, with perhaps a slight regional dip to the west. At least five individual basalt flows and one sedimentary interbed are exposed in Moses Coulee near Sagebrush Flat. Brown applied formal geologic names to several exposed basalt units in Moses Coulee immediately west of Sagebrush Flat and, by interpretation of geophysical logs, to similar units penetrated by wells 31M1 and 23/25-32L1 (32M1 in this report).

Rattlesnake Springs issues from the basalt at a point approximately 10 feet below the sand-and-gravel contact. The altitude of the basalt-sand and gravel contact varies locally.

The soil, sand, and gravel that overlie the basalt beneath Sagebrush Flat do not yield appreciable quantities of water to wells. Some water probably percolates downward, during the months of greatest precipitation or snowmelt, through these deposits to the locally permeable upper part of the underlying basalt and then moves laterally to be discharged by Rattlesnake Springs. The total flow of the springs is derived from ground water originating in this manner and from water moving laterally through the basalt. The percentage of the annual discharge of the springs that originates in the sand and gravel is not known. The major recharge area for the basalt is unknown but is probably located in the surrounding uplands.

Basalt is the principal water-bearing material in the Sagebrush Flat area. Water occurs principally in the rubbly tops and bottoms of individual basalt flows and in the sedimentary interbeds that may separate flows. The hard, dense central part of a basalt flow may be as thick as 150 feet, and it usually does not yield water to wells in significant quantities. Except where fractures occur, these dense parts of flows greatly restrict the vertical movement of water between water-bearing zones. Brown (1978) obtained flowmeter logs in wells 31M1 and 32M1 which indicated that the direction of water movement between flows is downward. Field observations confirm that water cascades down the uncased borehole in many wells from flows above the static water level in the wells.

TABLE 2.--Drillers' logs of wells

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| 22/25-2N1. Lars Hansen. Irrigation well drilled by Frank Zimmerman, August 1969. 16-inch casing to 25 ft, 15-inch open hole to 200 ft, 8-inch open hole to 365 ft. | | |
| Topsoil | 3 | 3 |
| Hardpan | 4 | 7 |
| Rock, broken | 14 | 21 |
| Basalt, hard, gray | 76 | 97 |
| Basalt, coarse | 35 | 132 |
| Basalt, hard, gray | 35 | 167 |
| Basalt, broken, water-bearing | 13 | 180 |
| Basalt, coarse, hard, gray | 130 | 310 |
| Basalt, broken | 30 | 340 |
| Interflow, water-bearing | 25 | 365 |
| 22/25-6C1. Mayer Bros. Irrigation well drilled by Edwin Robinson, May 1951. 10-inch casing to 60 ft; perforated 25-35 ft and 50-60 ft. | | |
| Soil and clay | 17 | 17 |
| Basalt, broken | 7 | 24 |
| Basalt, broken, water-bearing | 11 | 35 |
| Basalt, hard | 15 | 50 |
| Basalt, broken | 12 | 62 |
| Basalt, some trace of water | 88 | 150 |
| Basalt, hard | 50 | 200 |

TABLE 2.--Drillers' logs of wells--Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| 22/25-7D1. S. Schell. Domestic well drilled by Coeur d'Alene Drilling Co., December 1974. 6-inch casing to 26 ft, open hole to 420 ft. | | |
| Clay and boulders | 20 | 20 |
| Basalt, broken | 8 | 28 |
| Basalt, decomposed | 34 | 62 |
| Basalt, broken, water-bearing | 2 | 67 |
| Basalt, firm, blue | 143 | 210 |
| Basalt, broken | 10 | 220 |
| Basalt, firm | 135 | 355 |
| Basalt, broken, water-bearing | 5 | 360 |
| "Hardpan" interbed | 18 | 378 |
| Basalt, firm | 42 | 420 |
| 23/24-33K1. Billingsley, Irrigation well drilled by Victor Dilley, May 1955. 12-inch casing. | | |
| Soil | 39 | 39 |
| Gravel, sand and boulders | 123 | 162 |
| Basalt, porous, black (boulder?), water-bearing | 10 | 172 |
| Gravel | 6 | 178 |
| Gravel and clay | 42 | 220 |

TABLE 2.--Drillers' logs of wells--Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| 23/25-31M1. S. Schell. Irrigation well drilled by A and W Deep-Well Drilling, Inc., 1975. 16-inch casing to 48 ft; open hole to 500 ft. | | |
| Soil | 3 | 3 |
| Sand and boulders | 31 | 34 |
| Sand and gravel | 10 | 44 |
| Basalt, soft, brown | 3 | 47 |
| Basalt, hard, gray | 54 | 101 |
| Basalt, soft, brown | 8 | 109 |
| Basalt, hard, gray | 54 | 163 |
| Basalt, soft, brown | 30 | 193 |
| Clay, brown | 3 | 196 |
| Basalt, soft, brown | 19 | 215 |
| Basalt, hard, gray | 61 | 276 |
| Basalt, medium, black | 29 | 305 |
| Basalt, gray | 20 | 325 |
| Basalt, soft, brown | 29 | 354 |
| Basalt, gray | 7 | 361 |
| Basalt, soft and porous, brown; with green clay | 7 | 368 |
| Basalt, soft, gray | 102 | 470 |
| Basalt, soft, weathered | 15 | 485 |
| Basalt, hard, gray | 15 | 500 |
| 23/25-31Q1. S. Schell. Test well drilled by Coeur d'Alene Drilling Co., November 1974. 6-inch casing to 21 ft; open hole to 280 ft. | | |
| Overburden, clay-loam | 16 | 16 |
| Basalt, broken, gray | 2 | 18 |
| Basalt, firm, coarse, gray | 56 | 74 |
| Basalt, broken, water-bearing, gray | 11 | 85 |
| Cinders, gray, yellow, and red | 15 | 100 |
| Basalt, broken, water-bearing, brown and gray | 30 | 130 |
| Cinders, water-bearing, red and gray | 105 | 235 |
| Basalt, fine, gray | 8 | 243 |
| Basalt, broken, water-bearing | 2 | 245 |
| Basalt, fine-grained | 3 | 248 |
| Basalt, porous | 4 | 252 |
| Basalt, fine-grained | 28 | 280 |

TABLE 2.--Drillers' logs of wells--Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| 23/25-31R1. S. Schell. Irrigation well drilled by A and W Deep-Well Drilling Inc., September 1975. 14-inch casing to 27 ft; open hole to 674 ft. | | |
| Soil | 18 | 18 |
| Basalt, medium-hard, brown | 9 | 27 |
| Basalt, hard, black | 50 | 77 |
| Basalt, hard, fractured, black | 5 | 82 |
| Basalt, hard, fractured, gray | 10 | 92 |
| Basalt, vesicular, water-bearing, brown | 10 | 102 |
| Basalt, vesicular, brown | 5 | 107 |
| Basalt, gray | 55 | 162 |
| Clay, red, brown, and gray; mixed with basalt | 25 | 187 |
| Basalt, hard, oxidized, gray and black | 130 | 317 |
| Basalt, soft, vesicular, black and brown | 10 | 327 |
| Clay, red, gray, and brown; mixed with basalt | 55 | 382 |
| Basalt, hard, gray | 75 | 457 |
| Basalt, hard, fractured, gray | 73 | 530 |
| Basalt, hard, gray | 77 | 607 |
| Basalt, medium hard, fractured, brown | 15 | 622 |
| Basalt, hard, gray | 52 | 674 |
| 24/25-29A1. Luedeman. Irrigation well drilled in December 1952. 10-inch casing to 66 ft, 8-inch casing from 57 to 83 ft. | | |
| Soil | 10 | 10 |
| Gravel and small rocks | 17 | 27 |
| Boulders, large, and mud with gravel | 15 | 42 |
| Gravel, mud, boulders | 18 | 60 |
| Boulders, mud, and gravel, water-bearing | 27 | 87 |

TABLE 2.--Drillers' logs of wells--Continued

| Material | Thickness (feet) | Depth (feet) |
|---|---|---|
| 24/25-29B1. M. Corning. Irrigation well drilled in January 1953. 10-inch casing to 85 ft; perforated 57 to 80 ft. | | |
| Soil and coarse gravel | 10 | 10 |
| Gravel, coarse, and boulders | 15 | 25 |
| Gravel, coarse; sand and boulders | 36 | 61 |
| Gravel, water-bearing | 9 | 70 |
| Gravel, water-bearing, some mud and small boulders | 10 | 80 |
| Boulders, large; some gravel, sand, and mud | 5 | 85 |

## SPRING DISCHARGE

On April 17, 1978—before the beginning of the irrigation season--a continuous water-level recorder was installed in the small pond fed by Rattlesnake Springs. A total of five spring discharge measurements were made during the following six months and a rating curve was derived between pond stage and spring discharge. Figure 3 shows the daily discharge of the springs as determined from this curve. The daily value shown in figure 3 represents the mean discharge of the springs on that day. Spring discharge was essentially constant at 0.33 $ft^3/s$ until May 12, at which time a general decline started that lasted to July 31. During June and July several apparent short-term increases in spring discharge are indicated, while the long-term effect was reduced discharge. These increases in discharge were calculated from a rise in water level at the gage and could have been caused by runoff of localized precipitation or by an accumulation of aquatic vegetation obstructing the outlet of the pond surrounding the gage. From July 31 to September 10, spring discharge varied only from 0.04 to 0.06 $ft^3/s$. A gradual increase in discharge to 0.11 $ft^3/s$ began on September 10.

Variations in spring discharge are caused by changes in water levels in the basalt unit from which the springs issue. Water levels in basalt units fluctuate because of changes in recharge to or discharge from the unit. As stated on page 7 , recharge to the basalt unit occurs from local precipitation percolating through the overlying sand and gravel and probably from the infiltration of precipitation to the basalt unit in the upland areas. Discharge from the basalt unit occurs from springs along the walls of Moses Coulee, from pumping of wells, and from the vertical movement of water downward to underlying basalt flows. Movement of water downward can occur naturally in fractures in the hard dense central part of basalt flows or through well bores.

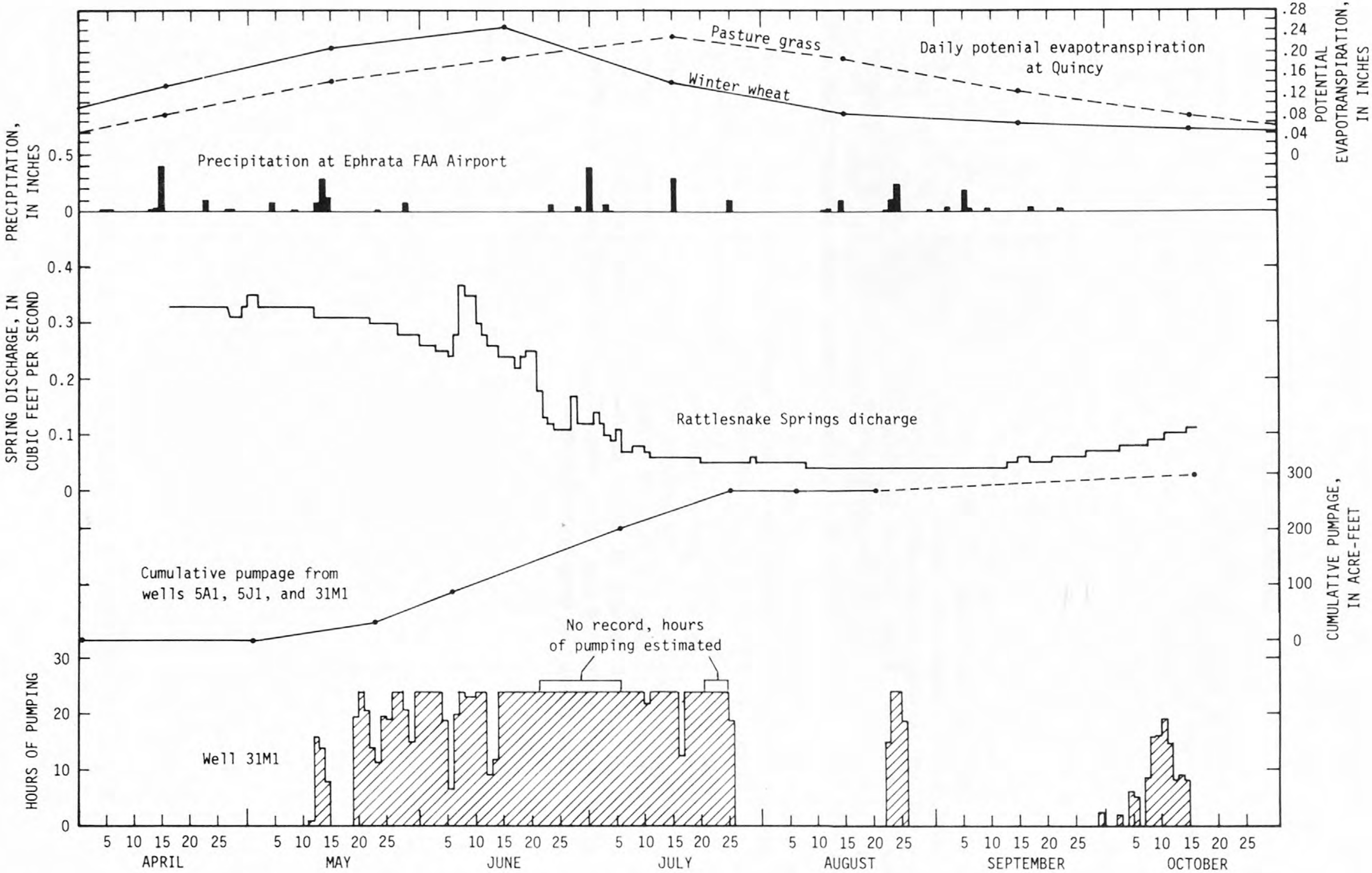


FIGURE 3.--Data relating to the pumping of well 31M1, the discharge of Rattlesnake Springs, and precipitation at Ephrata FAA Airport, 1978.

## PRECIPITATION

Precipitation is the major source of recharge to practically all ground-water bodies. Water levels normally do not respond immediately to variations in precipitation, however. Factors which affect the magnitude and time of water-level changes due to precipitation include (1) intensity and duration of rainfall or rate of snowmelt; (2) condition of the land surface when precipitation occurs--precipitation on frozen or already saturated ground results in a high rate of runoff; (3) depth below land surface of the ground-water body that is being recharged; and (4) the vertical hydraulic conductivity of the material above the water table.

Climatological data are not available for the Sagebrush Flat area or the surrounding uplands, but long-term data are available from the weather station at Ephrata, approximately 12 miles southeast of Rattlesnake Springs (fig. 4). Rainfall at Ephrata may differ somewhat from that at Sagebrush Flat, but long-term trends should be similar. According to annual summaries of the U.S. Department of Commerce (1958-73) and U.S. National Oceanic and Atmospheric Administration (1974-77), the average annual precipitation at Ephrata during the 20-year period ending in 1977 was 7.11 inches. The wettest year during that period was 1958 (9.41 inches), and the driest was 1976 (3.00 inches).

Annual precipitation and a 3-year moving average of precipitation at Ephrata since 1958 are shown in figure 4. Since 1974, annual precipitation was below average (1958-77). This suggests that annual ground-water recharge was probably below average also.

## EVAPOTRANSPIRATION

Evapotranspiration is the return of water to the atmosphere through the combined processes of transpiration from the leaves of plants and evaporation from soil and water surfaces. Potential evapotranspiration is the amount that would be returned by these processes if no water deficiency occurred throughout the period of time under consideration. Insufficient climatological data were available for computing potential evapotranspiration at Ephrata. However, the values shown in figure 5 were computed by the Blaney-Criddle method (U.S. Department of Agriculture, 1967) for the potential evapotranspiration at Quincy (fig. 1) by winter wheat and pasture grass, the two principal types of vegetation on Sagebrush Flat. These values for the growing season are also shown in figure 3. There, the monthly rates were converted to daily rates for ease of comparison with other data. During an average year, ground-water recharge from precipitation occurs only in the months of November, December, January, and February, when precipitation may exceed evapotranspiration.

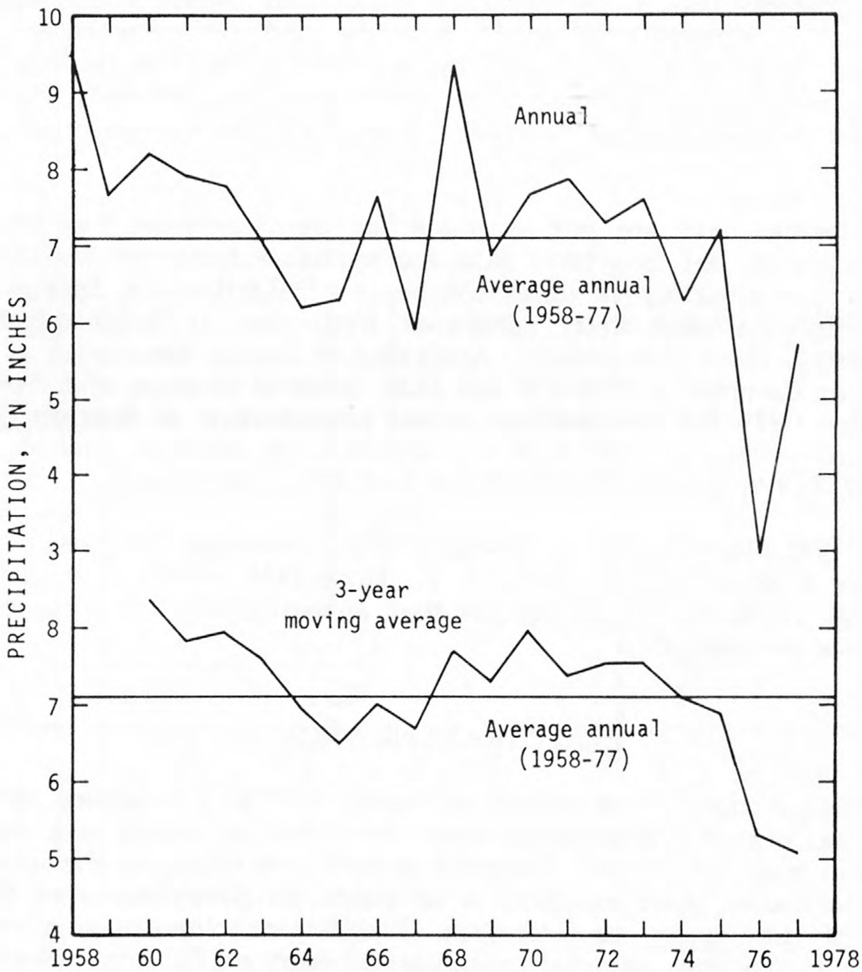


FIGURE 4.--Annual and 3-year moving-average annual precipitation at Ephrata FAA Airport, 1958-77.

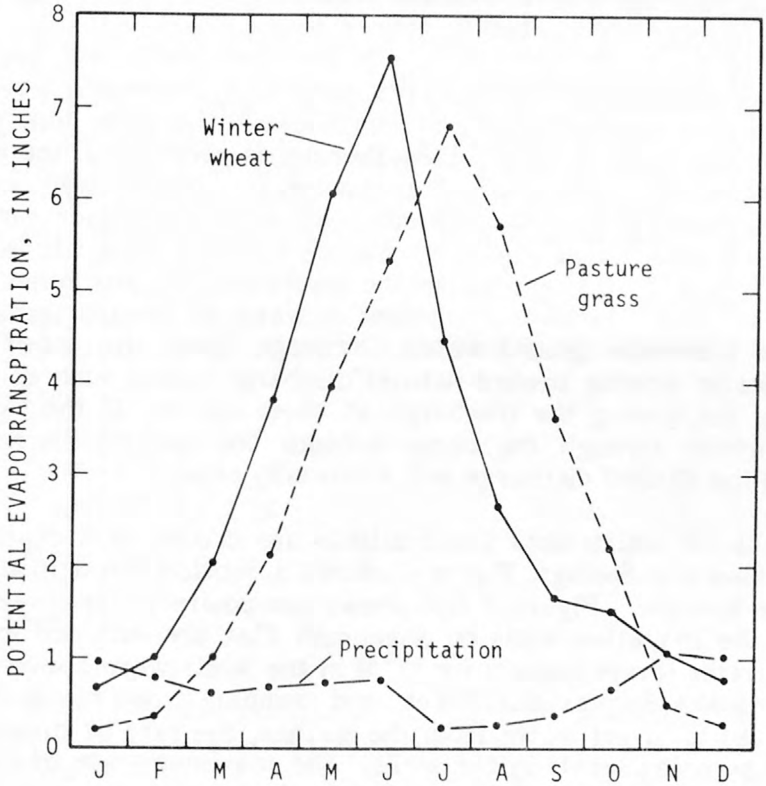


FIGURE 5.--Potential evapotranspiration from winter wheat and from pasture grass, and average monthly precipitation at Quincy, 1941-70.

## GROUND-WATER DISCHARGE

The construction technique used in all the wells in Sagebrush Flat for which drillers' logs are available (including the irrigation wells) consists of casing the well through the unconsolidated overburden down to the first unweathered, unbroken basalt. If the first basalt penetrated is weathered and broken and water-bearing, the casing is extended through it, but perforated to permit the entry of this water. The remainder of the well is uncased. Because of this construction technique the well will obtain water from all water-bearing zones in the basalt flow sequence penetrated.

As mentioned previously, the direction of water movement between basalt flows is downward, and this movement continues in the well bore even during nonpumping periods, unless a state of equilibrium is reached or the upper basalt flows are dewatered. The latter phenomenon presumably explains the water-level decline of 175 feet that has occurred in well 7D1 since early 1976 (fig. 6). In this unused well, the water level has declined to an altitude lower than Rattlesnake Springs and also lower than the water level in any other known well on Sagebrush Flat. This continual movement of water downward through the well bore represents manmade ground-water discharge from the upper zones that diverts ground water moving toward natural discharge points such as Rattlesnake Springs, thereby decreasing the discharge at these points. If the rate of water movement downward through the bores exceeds the natural discharge of the upper unit, then the natural discharge will eventually cease.

All the wells for which data are available are drilled to a depth below the altitude of Rattlesnake Springs. Figure 7 shows a section through selected wells and Rattlesnake Springs. Figure 7 also shows composite water levels in each of the wells. All the irrigation wells on Sagebrush Flat are included in the figure. The composite water levels (mostly for 1975) in the wells were above the altitude at which Rattlesnake Springs discharges, and pumping from the irrigation wells might be expected to divert water from the springs, the rate of diversion being a function of the pumping levels in the wells. The maximum rate of diversion will occur when the pumping levels are at or below the base of the unit in which the springs are located, assuming the basalt flows are not hydraulically connected other than through the well bores. The degree to which downward flow through the well bores in Sagebrush Flat has decreased the flow of Rattlesnake Springs is unknown.

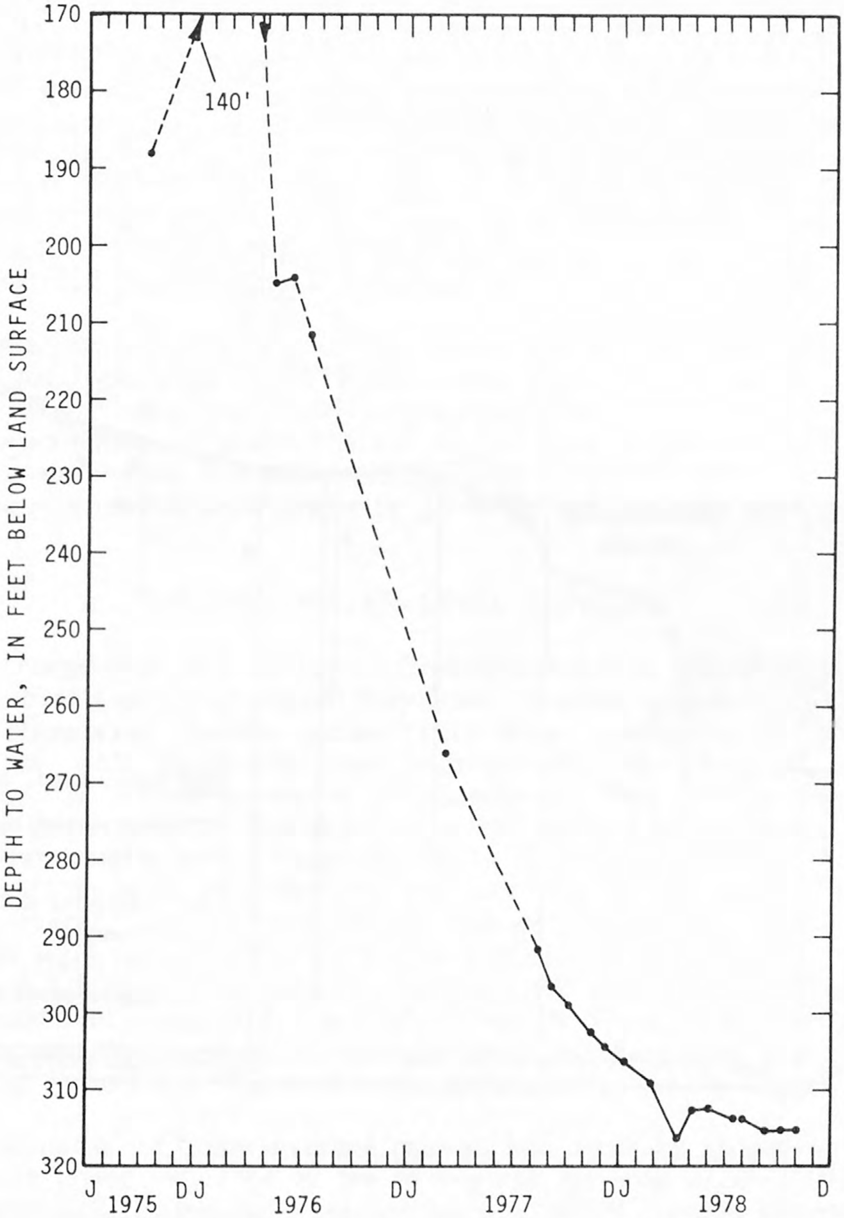


FIGURE 6.--Hydrograph of water levels in well 7D1.

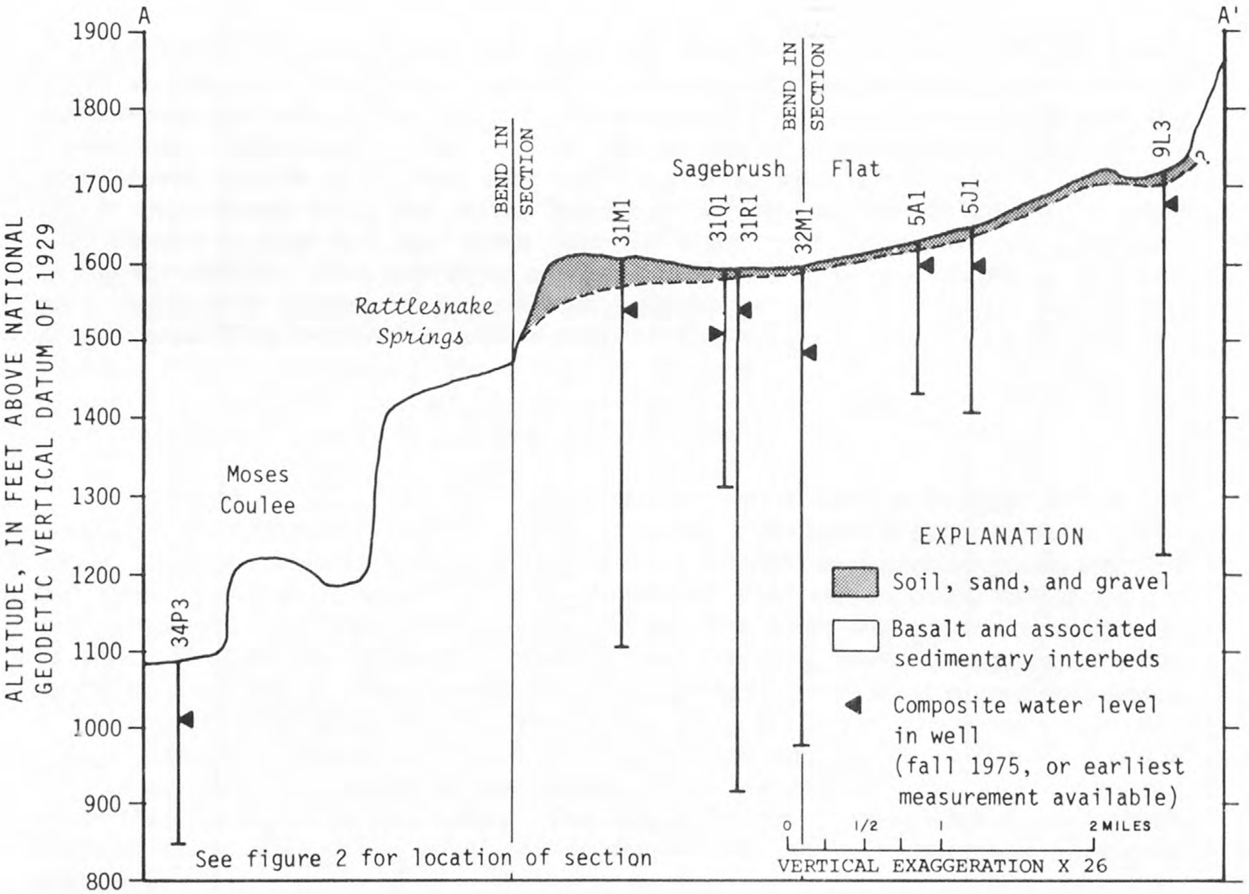


FIGURE 7.--Section through selected wells and Rattlesnake Springs.

No data are available for reconstructing historical pumpage in the area. Well 31M1 was drilled in 1975, and well 5A1 was drilled in 1951, but the dates for construction of the other two irrigation wells are unknown. During this study an instrument to record hours of pump operation was installed on well 31M1 on March 31, 1978. Collection of these data continued through the 1978 irrigation season. The well is equipped with a totalizing flowmeter, and the volume of water pumped from the well was recorded periodically during the irrigation season. Total pumpage from well 31M1 during the 1978 irrigation season was about 260 acre-ft. Total pumpage from wells 5A1 and 5J1 during the 1978 irrigation season was estimated at 7 and 36 acre-ft, respectively, from the owners' records and observations by field personnel. Pumpage from 32M1 could not be estimated, but was probably insignificant.

A comparison of the calculated values of spring discharge with the cumulative total pumpage from three wells shown in figure 3 indicates a decreasing spring discharge with increasing cumulative pumpage. Spring discharge remainded virtually constant during August and the first half of September, a time when the wells were pumped very little. These data indicate a direct time relationship between spring discharge and pumpage from wells.

## GROUND-WATER-LEVEL CHANGES

The discharge from the springs is directly related to the altitude of water levels in the basalt unit from which they issue. In order to obtain information on water-level trends in shallow basalt, that were unaffected by pumping, a hydrograph of well 27/26-25D1 was plotted (fig. 8). Well 27/26-25D1 is approximately 27 miles northeast of Sagebrush Flat in an area of no ground-water development. The well is 60 feet deep and is open to basalt that is overlain by sand and gravel. Assuming the hydrograph to be representative of the Sagebrush Flat area, two features are pertinent to this study. First, there has been an overall water-level decline in the well since 1974. The net decline between May 1974 and October 1978 was 5 feet. A greater, but temporary, decline (about 8 ft) occurred between mid-May 1975 and October 1977. Second, since the middle of April 1978, the water level in the well has changed little. This suggests that the declines in water levels in the Sagebrush Flat area since April 1978 (fig. 9) were due to ground-water pumpage, not natural causes.

The combination of below-average rainfall and declining ground-water levels since 1974, the latter indicated by the hydrograph for well 27/26-25D1, suggests that the discharge of Rattlesnake Springs has probably decreased somewhat since 1974 due to a decrease in ground-water recharge from precipitation. However, if the hydrograph of this well represents natural conditions, the discharge of Rattlesnake Springs should have been about constant during the 1978 irrigation season. This was not the case.

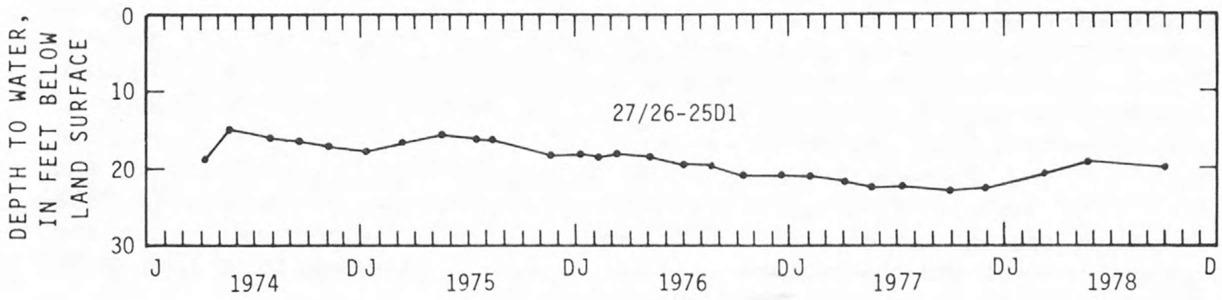


FIGURE 8.--Hydrograph of water levels in well 27/26-25D1.

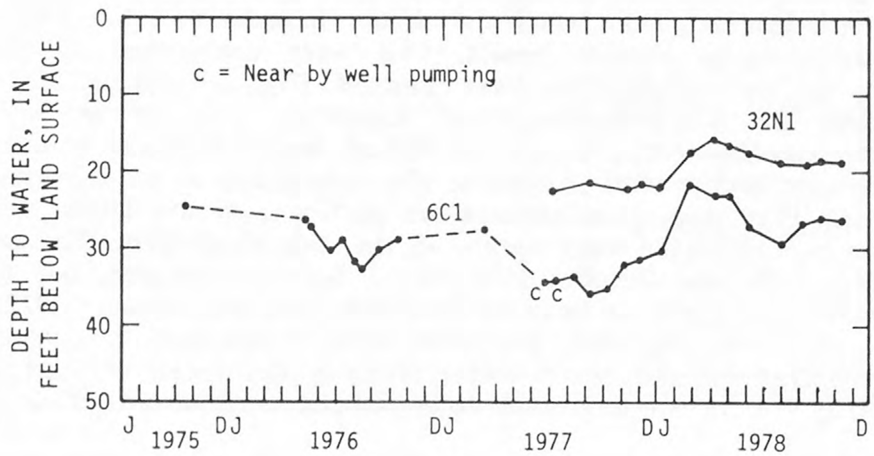


FIGURE 9.--Hydrographs of water levels in wells 32N1 and 6C1.

In order to obtain information on ground-water-level changes in the basalt at the approximate altitude of the springs, hydrographs of wells 6C1 and 32N1 were made (fig. 9). These wells are 1.2 and 1.8 miles from Rattlesnake Springs, respectively. Their bottom-hole altitudes are 1,400 feet and 1,465 feet compared to the springs altitude of 1,470 feet. Because of their proximity to the springs, and their bottom-hole altitude, the two wells should accurately portray these changes. Well 6C1 is the closest well to irrigation well 31M1, at a distance of approximately 2,100 feet, and well 32N1 is the closest well to irrigation well 32M1, at a distance of about 500 feet.

In 1978, water-level declines began in 32N1 during April and in 6C1 sometime between late February and early April. These declines continued until September in 32N1, when the water level began to rise slightly. The decline continued in 6C1 until August, when the water level began to rise. The total decline was 3.05 feet and 7.88 feet in wells 32N1 and 6C1, respectively. Assuming these trends to be representative of the ground-water level at Rattlesnake Springs, the discharge of the springs would be expected to decrease from approximately April to or through August and then begin to increase. As indicated by figure 3, this is the actual pattern followed by the discharge of the springs.

## CHEMICAL QUALITY OF GROUND WATER

Water samples from irrigation wells 5A1 and 31M1 and from Rattlesnake Springs were analyzed to determine if there was a significant difference in water quality, which would have suggested that the wells and the springs do not obtain water from the same aquifer. The three samples of water were similar in chemical quality (table 3), and no conclusions relating to this study can be drawn from examination of the analyses.

TABLE 3.--Chemical analyses of water from Rattlesnake Springs and two irrigation wells on Sagebrush Flat

[All values are in milligrams per liter except as noted]

| Constituent | 22/25-5A1 (5-24-78) | 23/25-31M1 (7-6-78) | Rattlesnake Springs (5-23-78) |
|---|---|---|---|
| Total alkalinity (as $CaCO_3$) | 160 | 160 | 110 |
| Bicarbonate | 190 | 200 | 140 |
| Dissolved calcium | 54 | 43 | 29 |
| Dissolved chloride | 30 | 20 | 11 |
| Dissolved fluoride | .5 | .5 | .4 |
| Noncarbonate hardness | 57 | 17 | 7 |
| Total hardness | 223 | 180 | 120 |
| Total iron (µg/L) | 30 | 180 | 0 |
| Dissolved magnesium | 22 | 18 | 12 |
| Total manganese | 0 | 0 | 0 |
| Dissolved potassium | 5.0 | 4.5 | 4.0 |
| Dissolved solids (residue at 180 °C) | 347 | 301 | 222 |
| Dissolved silica | 45 | 46 | 39 |
| Dissolved sodium | 22 | 25 | 20 |
| Dissolved sulfate | 42 | 37 | 31 |
| Color | 1 | 1 | 1 |
| pH (units) | 7.8 | 7.8 | 7.8 |
| Sodium adsorption ratio | .7 | .8 | .8 |
| Specific conductance (micromhos) | 507 | 456 | 326 |
| Temperature (°C) | 11.5 | -- | 9.1 |

## SUMMARY

Sagebrush Flat is underlain by unconsolidated deposits consisting of soil, sand, and gravel. Basalt which underlies these deposits at depths as great as 44 feet (according to drillers' logs) is the principal water-bearing material in the area. Water occurs principally in the rubbly tops and bottoms of individual basalt flows and in sedimentary interbeds that separate flows. Recharge to the basalt unit occurs from local precipitation infiltrating through the overlying sand and gravel and probably from precipitation directly on the basalt-unit outcrops in the upland areas. Discharge from the basalt unit occurs from springs along the walls of Moses Coulee, from the pumping of wells, and from the downward movement of water to underlying basalt flows. Movement of water downward between flows occurs naturally in fractures in the hard, dense central part of the flow or through well bores.

Rattlesnake Springs, located at the edge of Sagebrush Flat, issues from the basalt at a point approximately 10 feet below the sand and gravel contact. Daily discharge values for Rattlesnake Springs during the 1978 irrigation season were calculated on the basis of the water level in the small pond into which they drain. Spring discharge was about constant at 0.33 $ft^3/s$ until May 12, at which time a general decline began that lasted to July 31. A gradual rise in discharge to 0.11 $ft^3/s$ by October 15 began about September 10.

Data on precipitation at Ephrata indicate that annual precipitation in the Sagebrush Flat area has been below normal since 1974. This would suggest that annual ground-water recharge has been below average. The hydrograph of a well located approximately 27 miles from Sagebrush Flat and situated in shallow basalt in an area unaffected by pumping indicates a net water-level decline in the well of 4.5 feet since 1975. The below-average rainfall since 1974, accompanied by generally declining ground-water levels, as indicated by the well hydrographs, suggests that some decrease in the discharge of Rattlesnake Springs since 1974 has resulted from a decrease in ground-water recharge.

Available information on wells in Sagebrush Flat indicates that all the wells have been drilled deeper than the altitude of Rattlesnake Springs and obtain water from all the water-bearing basalt flows they penetrate. Because water levels in the flows are different, a continuous movement of ground water between flows exists in well bores. Work by Brown (1978) and information from drillers' logs indicate that the direction of movement is downward from flow to flow.

The continual movement of water downward through well bores represents manmade ground-water relocation that diverts ground water moving toward natural discharge points in the upper flows such as Rattlesnake Springs, thereby decreasing the flow at these discharge points. The rate of this downward movement and the magnitude of its effect on Rattlesnake Springs is unknown.

Four irrigation wells on Sagebrush Flat were pumped during the 1978 irrigation season. Total pumpage for irrigation during the 1978 season was estimated to be about 300 acre-ft. About 86 percent of the water pumped for irrigation on Sagebrush Flat in 1978 was from well 31M1. This well is 0.8 mile from Rattlesnake Springs and is the closest irrigation well to the springs.

A comparison of the calculated values of spring discharge to the cumulative total pumpage from irrigation wells indicated a decreasing spring discharge with increasing cumulative pumpage. Spring discharge remained about constant during August and the first half of September, however, when well 31M1 was pumped only briefly.

## REFERENCES


Brown, J. C., 1978, Discussion of geology and ground-water hydrology of the Columbia Plateau, with special analysis of the Horse Heaven, Sagebrush Flat, and Odessa-Lind areas, Washington: Washington State University, College of Engineering Research Division Research Report 78/15-23, 56 p., 4 plates.

U.S. Department of Agriculture, 1967 (revised 1970), Irrigation water requirements: U.S. Soil Conservation Service Technical Release 21, 88 p.

U.S. Department of Commerce, 1958-73, Climatological data, Washington: (annual summaries), v. 62 no. 13 through v. 77 no. 13.

U.S. National Oceanic and Atmospheric Administration, 1974-78, Climatological data, Washington: (annual summaries), v. 78 no. 13 through v. 82 no. 8.