AVAILABILITY OF WATER FROM THE ALLUVIAL AQUIFER IN PART OF THE GREEN RIVER VALLEY, KING COUNTY, WASHINGTON

By W. E. Lum II, R. C. Alvord, and B. W. Drost

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4178

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MUCKLESHEOOT INDIAN TRIBE

Tacoma, Washington

1984
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WELL-NUMBERING SYSTEM

In this report, wells are designated by symbols that indicate their location according to the official rectangular public-land survey. For example, in the symbol 21/6-28D1, the part preceding the hyphen indicates, successively, the township and range (T. 21 N., R. 6 E.) north and east of the Willamette base line and meridian. The first number following the hyphen indicates the section (sec. 28), and the letter (D) indicates the 40-acre subdivision of the section as shown in the accompanying diagram.

The last number is the number of the well assigned in sequence as the data are gathered in the particular 40-acre tract. Thus, well 21/6-28D1 is in the NW\(^4\)NW\(^4\) sec. 28, T. 21 N., R. 6 E., and is the first well in the tract to be listed. To simplify mention of wells in the text, wells are referred to only by their section, 40-acre subdivision, and serial number. For example, well 21/6-28D1 is referred to in the text as well 28D1. In figures in this report where locations of wells are shown, the section number is dropped and the same well is marked D1. Springs are designated by the letter "s" following the serial number, as in "M1s".
### METRIC CONVERSION FACTORS

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches (in.)</td>
<td>25.4</td>
<td>millimeters (mm)</td>
</tr>
<tr>
<td></td>
<td>2.540</td>
<td>centimeters (cm)</td>
</tr>
<tr>
<td></td>
<td>0.0254</td>
<td>meters (m)</td>
</tr>
<tr>
<td>feet (ft)</td>
<td>0.3048</td>
<td>meters (m)</td>
</tr>
<tr>
<td>miles (mi)</td>
<td>1.609</td>
<td>kilometers (km)</td>
</tr>
<tr>
<td>square miles (mi²)</td>
<td>2.590</td>
<td>square kilometers (km²)</td>
</tr>
<tr>
<td>gallons per minute (gal/min)</td>
<td>0.06309</td>
<td>liters per second (L/s)</td>
</tr>
<tr>
<td>gallons per minute per foot</td>
<td>0.2070</td>
<td>liters per second per meter [L/s]/m</td>
</tr>
<tr>
<td>[(gal/min)/ft)]</td>
<td>0.02832</td>
<td>cubic meters per second (m³/s)</td>
</tr>
<tr>
<td>cubic feet per second (ft³/s)</td>
<td>28.32</td>
<td>liters per second (L/s)</td>
</tr>
<tr>
<td>micromhos per centimeter at 25°C</td>
<td>1</td>
<td>microsiemens per centimeter (uS/cm)</td>
</tr>
<tr>
<td>(umho/cm at 25°C)</td>
<td>0.03048</td>
<td>meters per day (m/d)</td>
</tr>
</tbody>
</table>

To convert degrees Fahrenheit (°F) to degrees Celsius (°C), use the following equation:

\[
°C = \frac{5}{9} (°F - 32)
\]

---

**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. NGVD of 1929 is referred to as sea level in this report.
AVAILABILITY OF WATER FROM THE ALLUVIAL AQUIFER IN PART OF THE GREEN RIVER VALLEY, KING COUNTY, WASHINGTON

By W. E. Lum II, R. C. Alvord, and B. W. Drost

ABSTRACT

The availability of ground water was determined for a 1.56-square-mile area in the Green River valley, Wash., where the Muckleshoot Indian Tribe plans to build a fish hatchery. The tribe intends to use ground water to operate the hatchery.

The maximum long-term rate of pumping from a pair of properly constructed 12-inch-diameter wells will total about 144 gallons per minute near the center of the valley and only about 22 gallons per minute near the northern edge. Wells drilled to supply large quantities of water from the alluvium should be located where data indicate the greatest saturated thickness of aquifer materials to be.

The water table in the alluvial aquifer ranges from 3 to 15 feet below land surface. The saturated thickness of aquifer materials ranges from 0 to 35 feet. The hydraulic conductivity of the aquifer materials is about 130 feet per day, and the leakage coefficient of the riverbed materials under the Green River is about 1.3 feet per day. Recharge to the aquifer from rainfall is about 10 inches per year.

A U.S. Geological Survey two-dimensional ground-water-flow model was calibrated to simulate the ground-water flow system in the study area. Measured water levels in the alluvial aquifer were simulated to within about +1 foot at 7 of 12 observation well locations and to within +2 feet at all 12 locations. When pumping from the aquifer was simulated, it was found that all water pumped from wells was derived from induced leakage from the Green River into the alluvium and (or) from water moving through the alluvium to the Green River. Pumping from the alluvial aquifer will reduce the flow of Crisp Creek, but the amount of reduction could not be determined from the data available.
INTRODUCTION

The Muckleshoot Indian Tribe is constructing (1982) a fish-rearing facility near the Green River about 4 miles northeast of their Reservation near Auburn, King County, Wash. (fig. 1). The fish reared in and released from this facility will provide jobs for Tribal members, benefiting the local economy in general.

Tribal planners determined that using ground water in this facility could be an efficient and cost-effective method of operation. However, little was known of the ground-water resources of the area. For example, it was not known if shallow wells producing from the entire thickness of the alluvial aquifer would be capable of yielding sufficient quantities of water to supply the facility. Additionally, it was not possible, using available data, to determine the effects of pumping on water levels in the alluvial aquifer or on the flow of nearby Crisp Creek.

Purpose and Scope

The purpose of the study was to provide the information on (1) the hydraulic properties of the aquifers in the area of the hatchery; (2) the source of the ground water in the aquifers; and (3) what effect the development of a ground-water supply might have on surface water and ground-water levels in the surrounding area. This information was necessary to the tribe for making management decisions about the ground-water resources of the area near their hatchery.

Lithologic data were collected from 13 test wells drilled for this study. Information on the hydraulic characteristics of aquifers and nonaquifer materials was gathered from the test wells and other wells in the study area. Water levels in wells were measured and altitudes of surface-water features (springs, ponds, streams, and the Green River) were surveyed.

These data were used to construct a numerical model that was capable of simulating ground-water flow in the alluvial aquifer in the study area. The model was calibrated to simulate closely the observed conditions in the ground-water system, and was then used to predict ground-water availability and the effects on the ground-water system caused by pumping. The results were analyzed to determine the source of the water pumped from the simulated wells.
FIGURE 1.—Location of the study area.
Description of the Study Area

The area described in this report is in the Puget Sound lowland of western Washington, about 7 miles east of the city of Auburn in King County, Wash. (fig. 1) and about 4 miles northeast of the Muckleshoot Indian Reservation. The study area consists of a flat flood plain (1.56 mi²) on both sides of the Green River, bounded on the north and south by steep bluffs (200-300 feet in height) that lead up to a prairielike upland area. On the flood plain are numerous homes, as well as pasture and farm land. The flood plain extends downstream from the study area for several miles to the west. About 1 mile upstream of the study area, the Green River enters a narrow gorge cut in the bedrock. The alluvial deposits are absent in the gorge.

The climate of the study area is typical of the Puget Sound lowland, with wet, mild winters and cool, dry summers. More than 75 percent of the approximately 50 inches of yearly precipitation (mostly rainfall, but some snow) occurs from early October through March.

Previous Investigations

Geology of this area was mapped by Mullineaux (1961), and the ground-water resources of the area were reported by Luzier (1969). Information contained therein provided background geologic and hydrologic information for this study.

GEOLOGY OF THE STUDY AREA

The Green River flood plain in the study area is underlain by up to 50 feet of alluvial deposits, consisting of various mixtures of boulders, cobbles, gravel, sand, and some silt and clay (fig. 2). Some of the flood plain and most of the adjacent upland areas to the north and south of the valley are underlain by glacial deposits of varying thickness that consist of a wide variety of sediments ranging from till to well-sorted outwash sands and gravels. Underlying all of the alluvial and glacial deposits are volcanic rocks and sandstones, siltstones, and occasional coal beds (all geology after Mullineaux, 1961).

The alluvium was probably deposited in a valley cut by the Green River (or equivalent drainage) into the glacial deposits, which in turn had been deposited onto the volcanic and sedimentary rocks. Geologic sections are shown schematically in figure 3.
FIGURE 2.—Surficial geology of the study area.
EXPLANATION

- Alluvium
- Glacial deposits
- Volcanic and other sedimentary rocks

FIGURE 3.--Idealized geologic sections.
GROUND-WATER QUALITY

Analysis of a water sample from well 20Q2 (see fig. 4) which taps the alluvium, showed no unusual or harmful concentrations of common chemical constituents (see table below). The suitability of the water for any proposed use should be confirmed with additional sampling for other critical constituents and (or) properties.

A water sample from well 27R1 which taps the sedimentary rocks underlying the alluvium (not shown in fig. 4) is very different chemically (see table below). Another well (21N1) in the study area appears to have water of similar quality; gas bubbles (methane?) and a small quantity of water (which caused a yellowish-orange staining of the well casing) were observed coming from the well casing during numerous visits to the area in 1980-81. A chemical analysis of the water from 21N1 was not available. A small quantity of natural gas (methane?) has also been observed coming from well 27R1 since it was drilled in 1911 (Luzier, 1969).

<table>
<thead>
<tr>
<th>Constituent and property (mg/L, unless otherwise specified)</th>
<th>21/6-20Q2 (alluvium)</th>
<th>21/6-27R1 (sedimentary rock)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of well (ft)</td>
<td>37.0</td>
<td>1,461.0</td>
</tr>
<tr>
<td>Silica</td>
<td>10</td>
<td>*9,500</td>
</tr>
<tr>
<td>Iron (ug/L)</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Calcium</td>
<td>10</td>
<td>4,300</td>
</tr>
<tr>
<td>Manganese (ug/L)</td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td>Magnesium</td>
<td>10</td>
<td>2,400</td>
</tr>
<tr>
<td>Sodium</td>
<td>10</td>
<td>2,290</td>
</tr>
<tr>
<td>Potassium</td>
<td>10</td>
<td>.7</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>10</td>
<td>5,300</td>
</tr>
<tr>
<td>Sulfate</td>
<td>10</td>
<td>37</td>
</tr>
<tr>
<td>Chloride</td>
<td>10</td>
<td>.05</td>
</tr>
<tr>
<td>Nitrate</td>
<td>10</td>
<td>.01</td>
</tr>
<tr>
<td>Dissolved solids (calculated)</td>
<td>10</td>
<td>10,900</td>
</tr>
<tr>
<td>Hardness (as CaCO3)</td>
<td>10</td>
<td>190</td>
</tr>
<tr>
<td>Specific conductance (umho/cm at 25°C)</td>
<td>171</td>
<td>17,000</td>
</tr>
<tr>
<td>pH (units)</td>
<td>7.0</td>
<td>7.2</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>8.8</td>
<td>13.0</td>
</tr>
<tr>
<td>Oxygen, dissolved</td>
<td>9.1</td>
<td>--</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>9.1</td>
<td>231</td>
</tr>
</tbody>
</table>

*Total iron concentration.
DATA COLLECTION

Well Installation

In addition to gathering data in the study area from two springs and 33 wells drilled by land owners, the GS drilled 13 test wells (fig. 4 and table 1) to determine (1) the lithology of geologic units, (2) water-level fluctuations in the alluvium, and (3) water-yielding capabilities of the alluvium. Test wells were generally drilled where information could not be obtained from existing wells or by other means. A log of materials penetrated was kept for each test well as it was drilled. The test wells range in depth from 7 to 155 feet and were finished with 2-, 6-, or 8-inch casing as noted in table 1 (end of report). Tables 1 and 2 (end of report) list selected information and materials penetrated, respectively, on selected wells in the study area.

Water-Level Measurements

Water levels in 17 wells were measured on an irregular schedule that spanned 1979-81. The water-surface altitude of the Green River was also measured at one location during the same period. Figure 5 shows representative water-level fluctuations in five wells, the altitude of the Green River, and monthly rainfall at Landsburg, Wash. (fig. 1, about 8 miles northeast of the study area). Tables 3 and 4 (end of report) list water-level measurements of wells and the Green River, respectively, for 1979-81.
FIGURE 4.--Well locations in the study area.
FIGURE 5.—Water-level fluctuations in selected wells and the Green River, and monthly rainfall at Landsburg, Washington.
Streamflow Gains and Losses Along Crisp Creek

Streamflow measurements were made on Crisp Creek (fig. 2) on May 7 and 12, 1980, to determine the amount of water leaking between the stream and the alluvium on which the stream flows. The streamflow of Crisp Creek was measured at two sites (sites 1 and 6, fig. 6), and the flow of all streams tributary to Crisp Creek between those two sites was measured at four sites (sites 2–5, fig. 6). If water were leaking from the stream downward into the alluvium, then the sum of flow of Crisp Creek at the upstream end of the reach plus all tributaries would be more than the flow measured at the downstream end. If ground water were leaking upward from the ground-water system into the stream, then the opposite would be true. The data are tabulated below.

The data indicate that ground water may have been flowing into Crisp Creek on May 7 and out of the creek into the alluvium on May 12. However, the method used to make these measurements is only accurate to about plus or minus 5 percent. Since the "gain" on May 7 is only 2.1 percent of the total flow of Crisp Creek and the "loss" on May 12 is only about 4.5 percent of the total flow, the calculated gain or loss may not be accurate since these differences fall within the measurement error. No conclusions concerning gain or loss in this reach of Crisp Creek can be drawn from the data available.

<table>
<thead>
<tr>
<th>Site number</th>
<th>Tributary Name</th>
<th>Crisp Creek Approximate ground-water contribution (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(see fig. 6)</td>
<td>Inflow (ft³/s)</td>
<td>flow (ft³/s)</td>
</tr>
</tbody>
</table>

May 7, 1980

<table>
<thead>
<tr>
<th>Site</th>
<th>Tributary Name</th>
<th>Inflow (ft³/s)</th>
<th>Crisp Creek flow (ft³/s)</th>
<th>Approximate ground-water contribution (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crisp Creek</td>
<td>7.03</td>
<td>7.03</td>
<td>+0.17 (downstream gain)</td>
</tr>
<tr>
<td>2</td>
<td>Keta Creek</td>
<td>0.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Unnamed tributary</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Unnamed tributary</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Unnamed tributary</td>
<td>0.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Crisp Creek</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

May 12, 1980

<table>
<thead>
<tr>
<th>Site</th>
<th>Tributary Name</th>
<th>Inflow (ft³/s)</th>
<th>Crisp Creek flow (ft³/s)</th>
<th>Approximate ground-water contribution (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crisp Creek</td>
<td>6.97</td>
<td>6.97</td>
<td>-0.32 (downstream loss)</td>
</tr>
<tr>
<td>2</td>
<td>Keta Creek</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Unnamed tributary</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Unnamed tributary</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Unnamed tributary</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Crisp Creek</td>
<td>0.43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 6.--Locations of measurement sites on Crisp Creek, Washington.
CHARACTERISTICS OF THE ALLUVIAL AQUIFER

Depth to and Fluctuations of the Water Table

The depth to water in the alluvium ranges from 3 to 15 feet below land surface. The depth to the water commonly changes during the year due to (1) seasonal changes in recharge from rainfall, (2) river-level changes, (3) evaporation of ground water, (4) pumping from the alluvial aquifer, and (5) transpiration of ground water by vegetation. These variations generally recur annually, and range from about 2 to 5 feet. Water levels are generally lower in the late summer–early fall when recharge from rainfall is less, when the river level is at a lower altitude at a particular location (generally a lower flow rate), and when water use by man and vegetation is higher. In winter, a higher river-level altitude (generally a higher flow rate), increased rainfall, and reduced water use cause the water table to rise. These fluctuations are known to occur in this area (Luzier, 1969), but are difficult to detect in figure 5 due to irregular data collection.

Figure 7 shows the altitude of the water table in wells tapping the alluvium and the altitude of the surface of the Green River at selected locations on May 12, 1980.

The Bottom of the Alluvium and Saturated Thickness

The bottom of the alluvium was determined through an analysis of the available well logs describing the materials penetrated (table 2, end of report). This information was supplemented by examining surficial materials and deposits exposed in road cuts and pits. In general, the alluvium is underlain by rocks of low permeability. The bottom of the alluvium ranges from 0 to 40 feet below land surface.

The saturated thickness of the alluvium (fig. 8) was determined by subtracting the depth to the water from the depth to the bottom of the alluvium. It ranges from 0 to about 35 feet in the study area.
FIGURE 7.—Altitude of the water table at selected sites on May 12, 1980.
FIGURE 8.—Approximate saturated thickness of the alluvial aquifer.
Hydraulic Conductivity

The hydraulic conductivity of the alluvium was estimated by using specific-capacity data obtained by bailer testing domestic and test wells. Bail tests consisted of removing water at a specified rate from a well for 1-4 hours and measuring the resulting decline in water level. Using a method described by Theis and others (1963), a mean specific capacity of 3.4 (gal/min)/ft, and an average thickness of water-producing alluvium of 7.4 feet for 18 wells, the calculated average hydraulic conductivity is about 100 feet/day (ft/d), a reasonable value for this type of alluvial material. A tabulation of the data follows.

<table>
<thead>
<tr>
<th>Well number</th>
<th>Specific capacity [gal/min]/ft</th>
<th>Approximate saturated thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20N1</td>
<td>5.3</td>
<td>18</td>
</tr>
<tr>
<td>20Q1</td>
<td>1.7</td>
<td>4</td>
</tr>
<tr>
<td>20Q2\textsuperscript{a}</td>
<td>490\textsuperscript{b}</td>
<td>20</td>
</tr>
<tr>
<td>20R1</td>
<td>3.3</td>
<td>5</td>
</tr>
<tr>
<td>21P3</td>
<td>2.0</td>
<td>7</td>
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<td>28D1</td>
<td>3.0</td>
<td>7</td>
</tr>
<tr>
<td>28D4</td>
<td>3.4</td>
<td>17</td>
</tr>
<tr>
<td>28E2</td>
<td>4.0</td>
<td>3</td>
</tr>
<tr>
<td>28F1</td>
<td>0.6</td>
<td>11</td>
</tr>
<tr>
<td>28F2</td>
<td>4.2</td>
<td>10</td>
</tr>
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<td>28G1</td>
<td>3.0</td>
<td>3</td>
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<td>29A3</td>
<td>1.7</td>
<td>3</td>
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<td>29C4</td>
<td>5.0</td>
<td>4</td>
</tr>
<tr>
<td>29D1</td>
<td>4.4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>3.4</strong></td>
<td><strong>7.4</strong></td>
</tr>
</tbody>
</table>

\textsuperscript{a}Not included in average, see text below for explanation.

Well 20Q2, located near the northern edge of the alluvium, is used primarily for irrigation, and has been pumped at a rate of 175 gal/min for long periods during the summer. The specific capacity for this well was calculated to be about 90 (gal/min)/ft (drawdown 2 feet). The hydraulic conductivity calculated from this specific capacity value is about 800 ft/d. This value, much higher than the average hydraulic conductivity for the study area (100 ft/d), is probably the result of locally coarser alluvial materials. The extent of the coarser materials appears to be limited, because alluvial materials penetrated by wells adjacent to 20Q2 have specific-capacity values within the range of those of all other wells in the study area.
Movement of Ground Water

The vertical and lateral movement of ground water in the alluvium and the interaction between the surface- and ground-water systems of the study area are illustrated in figure 9. Sources of water moving into the alluvial ground-water system include infiltration of precipitation, downward leakage from the Green River and nearby streams and ponds, and upward leakage from underlying water-bearing deposits. Ground-water movement out of the alluvium includes seepage to stream channels or ponds and possibly upward leakage into the Green River. Ground water also moves laterally through the alluvium into and out of the study area at its upstream and downstream ends. The upward leakage of water from the alluvium into the Green River cannot be documented with available data; however, it is probably occurring in the downstream third of the study area.

Collecting the data to determine the quantities of water involved in this continuous interaction was beyond the scope of this investigation; however, the quantities of water moving into and out of the aquifer are governed by the hydraulic conductivity and saturated thickness of the aquifer and by the hydraulic gradient. If these hydraulic properties are accurately represented in a computer simulation of the ground-water-flow system and some simplifying assumptions are made (discussed in the following section), it is possible to simulate the system numerically and to estimate these quantities without having measured them.
FIGURE 9.—Idealized movement of ground water in the model area.
The computer program used to simulate the ground-water-flow system of the Green River alluvial aquifer in two dimensions was written by Trescott, Pinder, and Larson (1976). No modifications to the program were necessary. The program uses standard mathematical techniques involving finite-difference approximations to nonlinear, partial differential equations to solve the appropriate ground-water-flow equations. The theory and mechanics of this program were described by Trescott, Pinder, and Larson (1976), and will not be discussed further in this report.

The numerical flow model requires estimates of the hydraulic characteristics of the aquifer and its boundaries, and the rate of recharge to and pumpage from the aquifer. On the basis of these estimates, water-table altitude and flow quantities are calculated by the computer. If the calculated water-table altitudes compare favorably with those measured in the field, then it is assumed that the calculated flow quantities will closely approximate actual values.

**Grid Spacing and Assumptions Made for the Model**

The use of finite-difference approximations to solve the flow equations for ground water requires that several simplifying assumptions be made about the hydraulic characteristics of the aquifer and surrounding materials. The assumptions and simplifications made during the simulation of the Green River alluvial aquifer are as follows:

1. The aquifer is divided by a rectangular grid into many small blocks that are assumed to have uniform hydraulic characteristics.

2. All water flowing into or out of the blocks of aquifer material is assumed to do so only at right angles to the block sides.

3. Recharge from rainfall is assumed to be at an equal rate throughout the model area and not to vary with time.

4. The material that lines the channel of the Green River has uniform leakage characteristics and a hydraulic conductivity lower than that of the aquifer material.

5. Blocks located at the upstream and downstream ends of the model area (see section on "Boundaries of the Model," p. 20) are assumed to have a water-table altitude and saturated thickness that does not vary with time. The amount of simulated water flow through the blocks is also constant with time.
6. The only ground-water movement is that due to recharge from rainfall, leakage out of and into the Green River (from or to the alluvial aquifer), and ground water flowing into and out of the modeled area at the upstream and downstream ends.

7. Ground-water interaction between the alluvial aquifer and underlying units, spring discharge onto the surface of the alluvium or from the alluvium, and any flow to or from small streams (including Crisp Creek) and (or) ponds were assumed to be negligible and were not considered during the simulation.

The grid spacing and orientation (fig. 10) were chosen to minimize the possible effect of assumptions 1 and 2. Assumptions 3 through 5 are commonly used in modeling of ground-water flow and are assumed to have little effect on the results of this model. Ignoring possible ground-water or surface-water inflow (assumption 6 and 7) may make the results of the simulations somewhat conservative in estimating the impact of pumping.

**Boundaries of the Model**

The numerical model uses different methods to deal with the ends and sides of the modeled area. At the upstream and downstream ends, the model blocks are treated as having a constant water-level altitude (fig. 11) and allow any amount of ground water to enter the model through the upstream end or leave it through the downstream end. The simulated amount of water that enters and leaves through these blocks is controlled by using reasonable hydraulic characteristics for adjacent blocks within the model. It should be noted that these boundary blocks do not materially affect model results when pumping is simulated, because they are located a considerable distance from the area where the simulated pumping stress was applied.

The two sides of the modeled area where the alluvium terminates against glacial deposits or volcanic and sedimentary rocks, are treated as no-flow boundaries. No water is allowed to enter or leave through these boundaries, as stated in the previous section (assumption 6 and 7). By ignoring any possible inflow of ground water from the sides, the drawdown in the model area in response to simulated pumping may be greater than would be seen under real conditions. Thus, model results are conservative estimates of the impact of pumping.
FIGURE 10.—Grid system and selected geologic and hydrologic features in the study area.
FIGURE 11.--Locations of boundary and river nodes for the model area.
Model Calibration

After initial estimates of aquifer characteristics were made and boundary conditions were defined, the process of model calibration was begun. This trial-and-error process involved making a series of simulations, changing the value of one input data set at a time (for example: hydraulic conductivity, streambed leakage, recharge, constant water-level boundaries, etc.), and then evaluating how closely the model reproduced observed water levels in wells in the model area. The goal was to make the simulation produce calculated water levels that fit as closely as possible to the observed water levels that were measured in the aquifer on May 12, 1980, a time of relative equilibrium between the surface- and ground-water systems.

The quality of fit of the simulation to observed conditions in the aquifer was evaluated by using the sum of squares and a cumulative mass balance calculated by the model for each simulation. The sum of squares was calculated by taking the difference between the model-calculated water level and the measured water level at each observation well, squaring the difference, and totaling the values for 12 observation wells open to the water table. The resulting number is a measure of the quality of fit of the simulation—the smaller the number, the closer the simulation is to observed conditions in the aquifer. The cumulative mass balance is the algebraic sum of the quantities of all water moving into and out of the model. The closer the number is to zero the closer the simulation balances inflow and outflow of water in the model.

Some of the data—altitude of the bottom of the aquifer and altitude of the water surface of the river—were known to be accurate and representative of the true aquifer properties, and were not changed during the calibration process. The data that were not well defined, such as rate of recharge to the aquifer from rainfall, hydraulic conductivity of the aquifer, and leakage coefficient of the streambed, were put into the model and then varied within limits established by the field data. Estimates were made from information available for areas of similar hydrology and from the estimate of aquifer hydraulic conductivity.

First, the rate of recharge to the alluvium from precipitation was evaluated with the model. Rates of 5, 7.5, 10, 12.5, and 15 inches per year were simulated; the results are shown in graph A of figure 12. On the basis of the quality-of-fit criteria, a recharge rate of 10 inches per year was chosen for the best-fit value. Subsequently, the same technique was used to obtain best-fit value for hydraulic conductivity of the aquifer (graph B, fig 12). The hydraulic conductivity of the alluvium was determined to be about 130 ft/d on the basis of the best fit of observed water levels. This value is slightly higher than the estimated value of 100 ft/d. The discrepancy may be due to the inaccuracies in the model or in the method used to estimate the hydraulic conductivity method, such as short bailing time for bailer tests and inaccurate measurements of water volume removed from the well during testing and inaccurate measurement of drawdown. The value for the leakage coefficient of the streambed material that gave the best fit of observed water levels was 1.3 ft/d. This is based on a cumulative mass balance of −0.1 percent and a low value for sum of squares. The ratio of the riverbed leakage coefficient to the aquifer hydraulic conductivity is 1:100, a reasonable value.
FIGURE 12.—Results of calibration simulations.
Results of the calibration process showed that (1) the model was able to estimate hydraulic-characteristic values that match well the values derived by other means; and (2) using these derived values plus known geometry, the model was able to simulate water levels closely, and probably ground-water-flow quantities in the aquifer as well. Below is a tabulation of the difference between the measured water-table altitude on May 12, 1980, and the computer-calculated water-level altitude at that same location for 12 observation wells. The table is based on the simulation that was determined to have the best fit to the observed data. A cumulative mass balance table for the best-fit simulation shows the quantities of water moving into and out of the model area.

<table>
<thead>
<tr>
<th>Observation well number</th>
<th>Difference between measured water-table altitude and calculated water-table altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>20N1</td>
<td>-1.9</td>
</tr>
<tr>
<td>20P2</td>
<td>1.9</td>
</tr>
<tr>
<td>2001</td>
<td>.1</td>
</tr>
<tr>
<td>20Q2</td>
<td>.1</td>
</tr>
<tr>
<td>20Q3</td>
<td>-.9</td>
</tr>
<tr>
<td>20Q8</td>
<td>.9</td>
</tr>
<tr>
<td>21N2</td>
<td>-.1</td>
</tr>
<tr>
<td>21P3</td>
<td>1.0</td>
</tr>
<tr>
<td>28C1</td>
<td>1.9</td>
</tr>
<tr>
<td>28D3</td>
<td>-.5</td>
</tr>
<tr>
<td>29A2</td>
<td>-1.2</td>
</tr>
<tr>
<td>29C1</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

Mean value of differences -0.1
Standard deviation 1.3
Sum of squares 19.3

Cumulative Mass Balance

<table>
<thead>
<tr>
<th>Ground water moving into model (in cubic feet per second)</th>
<th>Ground water moving out of model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant-head boundary</td>
<td>0.65</td>
</tr>
<tr>
<td>Recharge</td>
<td>0.97</td>
</tr>
<tr>
<td>Leakage</td>
<td>0.40</td>
</tr>
<tr>
<td>Total</td>
<td>2.07</td>
</tr>
<tr>
<td>Constant-head boundary</td>
<td>0.01</td>
</tr>
<tr>
<td>Recharge</td>
<td>--</td>
</tr>
<tr>
<td>Leakage</td>
<td>2.00</td>
</tr>
<tr>
<td>Total</td>
<td>2.01</td>
</tr>
</tbody>
</table>

Percentage of difference 0.09

(Note: Some inconsistencies in statistical values are due to rounding.)
The calibrated model was used to estimate ground-water availability by simulating pumping at varying rates from wells located in several areas of the alluvial aquifer. Two wells were simulated as pumping a total of 22 gal/min in the vicinity of the hatchery site (fig. 4). Drawdown in each well was about 4 feet, the original saturated thickness was about 8 feet. The area where water-level drawdown in the aquifer exceeded 0.5 foot was about 0.1 square mile. Two wells were simulated as pumping a total of 144 gal/min in the vicinity of 20Q1 and 20Q2 (fig. 4). Drawdown in each well was about 13 feet, the original saturated thickness was about 23 feet. The area where drawdown exceeded 0.5 foot was about 0.2 square mile, measuring about 1,500 feet east-west and 500 feet north-south. Finally, two wells were simulated as pumping a total of 108 gal/min in the vicinity of wells 28D3 and 28D4 (fig. 4). Drawdown in each well was about 7 feet, the original saturated thickness was about 13 feet. The area where drawdown exceeded 0.5 foot was about 0.1 square mile.

For each simulation it was assumed that properly constructed, fully penetrating 12-inch-diameter wells 500 feet apart were pumped simultaneously. Drawdown in each well was limited to about half the original saturated thickness of the aquifer (at the well) to account for probable well and pump inefficiencies. (The quantity of water that could be pumped from actual wells would probably be somewhat greater, by an unknown amount, than the simulated rate, due to conservative manner in which the model was constructed and drawdown limited.)

Pumping was simulated to be continuous at the specified rate, and the resulting drawdowns represented steady-state conditions. Under steady-state conditions the ground-water-flow system was assumed to have reached a new equilibrium, drawdowns remained constant with time and all water being pumped was derived from sources other than storage within the aquifer. Using a method described by Jenkins (1968), it is estimated that steady-state conditions would be reached within approximately 30 to 70 days after pumping commences. The sources of the pumped water are discussed in the next section of the report.

The amount of water that can be pumped from any well in this area is most strongly influenced by the saturated thickness of aquifer materials from which the well pumps. Drilling of additional wells in the area for uses that require continuous yields of more than a few gallons per minute should be planned only where data indicate the greatest thickness of saturated aquifer materials to be (fig. 8).

Areas of locally coarser alluvium may be found in the study area (as penetrated by well 20Q2). Yields from wells tapping this material may be considerably larger and drawdown of water levels less than those calculated by the model. The location and extent of other areas where similar coarse materials occur is not known.
Water pumped from wells in the alluvial aquifer is initially removed from storage in the pore space between grains of aquifer material, resulting in lowered water levels around the well. Water in adjacent areas flows toward the pumping well to replace that which has been removed, causing the area of lowered water level to expand. This occurs in a generally circular pattern surrounding the pumping well. In each case of simulated pumping from the Green River alluvial aquifer, the area within which water levels have been lowered expands, and drawdown occurs in the alluvial material adjacent to and under the river in a short, but undetermined, time.

As the water level in the alluvium under the river is lowered, the amount of ground-water flow to or from the river will change. In areas where the water levels in the aquifer are higher than the surface altitude of the river, pumping may cause a reduction in flow from the aquifer into the river (data indicate that this may occur in less than a third of the study area). It is also possible that the direction of flow between aquifer and river may reverse if pumping causes the aquifer water level to change from above to below the surface altitude of the river. If, during nonpumping conditions, there was downward movement of water from the river into the aquifer because the surface altitude of the river was higher than the water level in the aquifer (as occurs in about two-thirds of the study area), a lowering of the aquifer water level by pumping could increase the amount of this downward flow.

Under nonpumping equilibrium conditions in the model area, the computer simulation indicated that river water flows downward into the alluvial aquifer in some places, and in other places ground water moves upward into the river. When pumping was simulated, the results showed that these places of upward and downward movement of water persisted, but the quantity of water involved in the interchange changed somewhat. Pumpage from the aquifer is directly correlated to an increase in quantities of water moving into the aquifer from the river.
The quantities of water calculated to be moving between the aquifer and the river are shown below, for different rates of simulated pumping.

<table>
<thead>
<tr>
<th>Simulated pumping rates</th>
<th>Nonpumping</th>
<th>22 gal/min</th>
<th>144 gal/min</th>
<th>108 gal/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant head in</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Constant head out</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Upward leakage(^1) into river</td>
<td>2.00</td>
<td>1.95</td>
<td>1.83</td>
<td>1.91</td>
</tr>
<tr>
<td>Downward leakage into aquifer</td>
<td>0.40</td>
<td>0.40</td>
<td>0.54</td>
<td>0.55</td>
</tr>
<tr>
<td>Net change in flow of Green River(^2)</td>
<td>+1.60</td>
<td>+1.55</td>
<td>+1.29</td>
<td>+1.36</td>
</tr>
<tr>
<td>Net change from &quot;nonpumping&quot; simulation in flow of Green River</td>
<td>--</td>
<td>-0.05</td>
<td>-0.31</td>
<td>-0.24</td>
</tr>
<tr>
<td>Pumping rate (simulated)</td>
<td>0</td>
<td>0.05</td>
<td>0.32</td>
<td>0.24</td>
</tr>
</tbody>
</table>

\(^1\)Rate of flow of water moving from the alluvial aquifer to the Green River, as indicated by the difference in water levels in the aquifer and the river-surface altitude. "Downward leakage" water levels indicate the flow of water to be from the river into the aquifer.

\(^2\)Net difference in Green River flow, between the point where it enters the model area and the point where it leaves the area, due to leakage to or from the alluvium.

On this basis, all of the water pumped from the aquifer will be derived from reduced flow of the Green River (or possibly Crisp Creek) as it flows out of the immediate area. Actual pumping and simulations of other combinations of wells, locations, and pumping rates (including water pumped from the locally coarser alluvium) would probably have similar results.
REFERENCES


### TABLE 1.--Records of selected wells and springs in the study area

<table>
<thead>
<tr>
<th>LOCAL NUMBER</th>
<th>USE OF WATER</th>
<th>ALTITUDE OF LAND SURFACE (FEET)</th>
<th>DEPTH OF WELL DRILLED (FEET)</th>
<th>CASING DIAMETER (INCHES)</th>
<th>DATE COMPLETED</th>
<th>DISCHARGE (GALLONS PER MINUTE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21N/06E-20J01</td>
<td>U</td>
<td>164.00</td>
<td>52</td>
<td>--</td>
<td>--</td>
<td>10/30/1979</td>
</tr>
<tr>
<td>21N/06E-20J02</td>
<td>U</td>
<td>162.30</td>
<td>12</td>
<td>164.0</td>
<td>8</td>
<td>11/06/1979</td>
</tr>
<tr>
<td>21N/06E-20J03</td>
<td>USGS</td>
<td>162.05</td>
<td>153</td>
<td>146.0</td>
<td>6</td>
<td>05/14/1981</td>
</tr>
<tr>
<td>21N/06E-20J04</td>
<td>USGS</td>
<td>165.62</td>
<td>40</td>
<td>11.5</td>
<td>8</td>
<td>06/29/1981</td>
</tr>
<tr>
<td>21N/06E-20M01</td>
<td>MUNDOCK DON</td>
<td>430</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>21N/06E-20N01</td>
<td>KOCHER DAVID</td>
<td>151.98</td>
<td>40</td>
<td>40.0</td>
<td>6</td>
<td>06/25/1979</td>
</tr>
<tr>
<td>21N/06E-20Q02</td>
<td>USGS</td>
<td>155.00</td>
<td>21</td>
<td>--</td>
<td>--</td>
<td>11/01/1979</td>
</tr>
<tr>
<td>21N/06E-20Q03</td>
<td>REYNOLDS GARY</td>
<td>155.06</td>
<td>6</td>
<td>6.9</td>
<td>2</td>
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<tr>
<td>21N/06E-20Q04</td>
<td>USGS</td>
<td>159.14</td>
<td>34</td>
<td>34.0</td>
<td>6</td>
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<td>21N/06E-20Q05</td>
<td>BEARDSLEY DALE</td>
<td>159.50</td>
<td>37</td>
<td>37.0</td>
<td>8</td>
<td>01/09/1978</td>
</tr>
<tr>
<td>21N/06E-20Q06</td>
<td>MCGAYN MEL</td>
<td>182.40</td>
<td>50</td>
<td>--</td>
<td>--</td>
<td>10/31/1979</td>
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<tr>
<td>21N/06E-20Q07</td>
<td>USGS</td>
<td>158.80</td>
<td>22</td>
<td>21.0</td>
<td>2</td>
<td>10/31/1979</td>
</tr>
<tr>
<td>21N/06E-20Q08</td>
<td>USGS</td>
<td>158.80</td>
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<td>21.0</td>
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</tr>
<tr>
<td>21N/06E-20Q09</td>
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<tr>
<td>21N/06E-20Q10</td>
<td>SEAHY DOUGLAS</td>
<td>165.60</td>
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<td>23.0</td>
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<td>10/02/1979</td>
</tr>
<tr>
<td>21N/06E-20Q11</td>
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<td>164.80</td>
<td>11</td>
<td>--</td>
<td>--</td>
<td>10/30/1979</td>
</tr>
<tr>
<td>21N/06E-20Q12</td>
<td>WADDELL CAROL</td>
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<td>6</td>
<td>05/29/1980</td>
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<td>21N/06E-21M01</td>
<td>SPAIGHT TOM</td>
<td>250</td>
<td>100</td>
<td>100.0</td>
<td>6</td>
<td>05/20/1980</td>
</tr>
<tr>
<td>21N/06E-21M01</td>
<td>DIAMOND SPR WATER ASSN</td>
<td>300</td>
<td>--</td>
<td>--</td>
<td>--</td>
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</tr>
<tr>
<td>21N/06E-21M02</td>
<td>WA STATE FISHERIES</td>
<td>173</td>
<td>200</td>
<td>200.0</td>
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</tr>
<tr>
<td>21N/06E-21M03</td>
<td>WA STATE FISHERIES</td>
<td>169.80</td>
<td>18</td>
<td>18.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>21N/06E-21P01</td>
<td>NUTARIAI OUANE</td>
<td>219.00</td>
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<td>6</td>
<td>01/23/1976</td>
</tr>
<tr>
<td>21N/06E-21P02</td>
<td>PHILIP JAMES</td>
<td>225</td>
<td>40</td>
<td>40.0</td>
<td>--</td>
<td>01/09/1976</td>
</tr>
<tr>
<td>21N/06E-21P03</td>
<td>NUTARIAI OUANE</td>
<td>173.10</td>
<td>30</td>
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<td>6</td>
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</tr>
<tr>
<td>21N/06E-22P01</td>
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<td>--</td>
<td>146.0</td>
<td>8</td>
<td>01/09/1979</td>
</tr>
<tr>
<td>21N/06E-22P02</td>
<td>RAF DICK</td>
<td>177.62</td>
<td>10</td>
<td>15.0</td>
<td>2</td>
<td>11/05/1979</td>
</tr>
<tr>
<td>21N/06E-22P03</td>
<td>UNKNOWN</td>
<td>180</td>
<td>110</td>
<td>93.0</td>
<td>6</td>
<td>01/01/1975</td>
</tr>
<tr>
<td>21N/06E-22P04</td>
<td>FLETCHER DOUG</td>
<td>170.00</td>
<td>27</td>
<td>27.0</td>
<td>6</td>
<td>10/23/1978</td>
</tr>
<tr>
<td>21N/06E-22P05</td>
<td>KEMP D&amp;H</td>
<td>174.17</td>
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<td>22.5</td>
<td>2</td>
<td>11/09/1979</td>
</tr>
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<td>25.0</td>
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<td>06/26/1981</td>
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<td>LYTLE NEALE</td>
<td>180</td>
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<td>39.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>21N/06E-22P08</td>
<td>TATELLA JOHN</td>
<td>190</td>
<td>21</td>
<td>21.0</td>
<td>6</td>
<td>03/27/1981</td>
</tr>
<tr>
<td>21N/06E-22P09</td>
<td>NOVAK ALBERT</td>
<td>180</td>
<td>42</td>
<td>42.0</td>
<td>6</td>
<td>03/13/1977</td>
</tr>
<tr>
<td>21N/06E-22P10</td>
<td>KEMP D&amp;H</td>
<td>190</td>
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<tr>
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<td>FELTON DICK</td>
<td>180</td>
<td>31</td>
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<td>6</td>
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</tr>
<tr>
<td>21N/06E-22P12</td>
<td>COHEN FRED</td>
<td>162</td>
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<td>21N/06E-22P13</td>
<td>USGS</td>
<td>163.80</td>
<td>16</td>
<td>16.4</td>
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<td>10/29/1979</td>
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<tr>
<td>21N/06E-22P14</td>
<td>MC CALL CLETIS</td>
<td>162</td>
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<td>60.0</td>
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</tr>
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<td>21N/06E-22P15</td>
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<td>FURSAN CARLO</td>
<td>150</td>
<td>8</td>
<td>8.0</td>
<td>--</td>
<td>1969</td>
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<td>21N/06E-22P17</td>
<td>HARTMAN CHARLES</td>
<td>154.50</td>
<td>43</td>
<td>43.0</td>
<td>6</td>
<td>11/11/1978</td>
</tr>
<tr>
<td>21N/06E-22P18</td>
<td>MATTHEIS WILLIAM</td>
<td>175</td>
<td>30</td>
<td>30.0</td>
<td>6</td>
<td>03/17/1979</td>
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<td>21N/06E-22P19</td>
<td>CARNEY ROBERT</td>
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<td>21N/06E-22P20</td>
<td>ANTONICO A</td>
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<td>21N/06E-22P21</td>
<td>JUERGENS MRS EMIL</td>
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<td>36</td>
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<td>21N/06E-22P22</td>
<td>CAMPFIELD WILLIS</td>
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<td>31.0</td>
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<td>21N/06E-22P23</td>
<td>JOHNSON THOMAS</td>
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<td>32</td>
<td>32.0</td>
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### TABLE 2.--Lithologic logs of selected wells in the study area

<table>
<thead>
<tr>
<th>Well</th>
<th>Altitude (ft)</th>
<th>Driller</th>
<th>Date</th>
<th>Casing</th>
<th>Material Details</th>
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<tbody>
<tr>
<td>21/6-20J1</td>
<td>164</td>
<td>USGS</td>
<td>October 1979</td>
<td>Test hole</td>
<td>Sand and gravel, many cobbles, brown; Clay, gray-green (very wet at 25 ft)</td>
</tr>
<tr>
<td>21/6-20J2</td>
<td>163</td>
<td>USGS</td>
<td>November 1979</td>
<td>Test hole</td>
<td>Sand, gravel, clay, brown; Clay, sand, silt, brown, gray and black (water-bearing at 3 ft)</td>
</tr>
<tr>
<td>21/6-20J4</td>
<td>163</td>
<td>USGS</td>
<td>June 1981</td>
<td>6-inch to 146 ft</td>
<td>Gravel fill; Silt, gray-brown, sand, fine, wood; Clay, gray-green, sand, fine-coarse, much silt and clay, gray, compact</td>
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<tr>
<td>21/6-20J5</td>
<td>165</td>
<td>Evergreen Drilling</td>
<td>July 1981</td>
<td>8-in. to 20 ft</td>
<td>Silt, brown; Silt, gray, sand, gravel, small, occ. boulder; Clay, gray-green, sand and gravel, small, 1/8 inch</td>
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<tr>
<td>21/6-20N1</td>
<td>152</td>
<td>David Kocher</td>
<td>June 1979</td>
<td>6 in. to 40 ft</td>
<td>Sand, brown; Hardpan, gray; Gravel, brown, water-bearing</td>
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<table>
<thead>
<tr>
<th>Thickness (ft)</th>
<th>Depth (ft)</th>
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<td>14</td>
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<tr>
<td>38</td>
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<td>153</td>
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<td>153*</td>
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<td>Well</td>
<td>Altitude (ft)</td>
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<td>21/6-20P1</td>
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<td>21/6-20P2</td>
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<td>21/6-20Q1</td>
<td>159</td>
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<td>21/6-20Q3</td>
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<td>21/6-20Q4</td>
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<td>21/6-20Q7</td>
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<td>21/6-20Q8</td>
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TABLE 2.—Lithologic logs of selected wells in the study area—Continued
TABLE 2.--Lithologic logs of selected wells in the study area--Continued

<table>
<thead>
<tr>
<th>Well Number</th>
<th>Well Name</th>
<th>Altitude (ft)</th>
<th>Drilled by</th>
<th>Date</th>
<th>Casing:</th>
<th>Soil Description</th>
<th>Thickness (ft)</th>
<th>Depth (ft)</th>
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<tbody>
<tr>
<td>21/6-20R1</td>
<td>Douglas Sears</td>
<td>166</td>
<td>Johnson Drilling Co., Inc.</td>
<td>October 1979</td>
<td>8 in. to 23 ft.</td>
<td>Soil: 3 Sand and gravel, brown: 10 Hardpan, brown: 5 Sand and gravel, brown, water-bearing: 5 Clay, gray: 0</td>
<td>3</td>
<td>3</td>
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<tr>
<td>21/6-20R2</td>
<td>USGS</td>
<td>165</td>
<td>USGS</td>
<td>October 1979</td>
<td>Test hole</td>
<td>Soil: 2 Sand and gravel, fine, brown: 2 Gravel, coarse: 7</td>
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<tr>
<td>21/6-20R3</td>
<td>Carol Waddell</td>
<td>163</td>
<td>Northwest Pump and Drilling Co.</td>
<td>May 1980</td>
<td>6 in. to 20 ft.</td>
<td>Topsoil: 2 Sand and gravel, cemented, brown: 14 Sand and gravel, brown, water-bearing: 4</td>
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<td>16</td>
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<tr>
<td>21/6-28C1</td>
<td>USGS</td>
<td>178</td>
<td>USGS</td>
<td>November 1979</td>
<td>2 in. to 16.5 ft. Screen: 16.5-19 ft.</td>
<td>Soil: 2 Sand, brown, dry: .5 Sand and clay, gray, brown, red-orange: 11 Gravel: 5</td>
<td>2.5</td>
<td>2.5</td>
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</table>
TABLE 2.--Lithologic logs of selected wells in the study area--Continued

<table>
<thead>
<tr>
<th>Well</th>
<th>Owner</th>
<th>Altitude (ft)</th>
<th>Drilled by</th>
<th>Casing to (ft)</th>
<th>Abandoned</th>
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<tbody>
<tr>
<td>21/6-28C2</td>
<td>Owner unknown</td>
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<td>Evergreen Drilling, 1975.</td>
<td>93</td>
<td>Abandoned</td>
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<td>Boulders (?) 18</td>
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<td>Hardpan, brown 7</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Clay, sand, gray 15</td>
<td>40</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Clay, gray 10</td>
<td>50</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay, light brown, bits of wood</td>
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<td>55</td>
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<tr>
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<td></td>
<td></td>
<td>Clay, dark brown, bits of wood</td>
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<td>65</td>
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<tr>
<td></td>
<td></td>
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<td>Sandstone, decomposed, light beige, wood pieces</td>
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<td>Sandstone, very coarse grit, white (open hole)</td>
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<tr>
<td>21/6-28D1</td>
<td>Doug Fletcher</td>
<td>170</td>
<td>Northwest Pump and Drilling Co., October 1978.</td>
<td>6 in. to 27 ft.</td>
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<td>Topsoil 1</td>
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<td>Sand and gravel, brown 14</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>Till, brown 5</td>
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<td>Sand and gravel, water-bearing</td>
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<td>21/6-28D3</td>
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<td>174</td>
<td>USGS, November 1979.</td>
<td>2 in. to 20.5 ft. Screen: 20.5-22.5 ft.</td>
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<td>Soil, sandy, brown 3</td>
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<td>Gravel, coarse 6</td>
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<td>Gravel, fine, water-bearing at 12 ft or less 14</td>
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<td>21/6-28D4</td>
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<td>173</td>
<td>Evergreen Drilling, June 1981.</td>
<td>6 in. to 133 ft. Screen: 15-25 ft.</td>
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<td>Topsoil, brown, sand, fine 5</td>
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<td>Silt, brown, gravel, small cobble size, occ. boulder sand, fine-coarse, water-bearing 18-20 ft. 17</td>
<td>22a</td>
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<td>Silt, gray, light 6</td>
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<td>Gravel, small cobble size, sand, fine-coarse, silt, gray 2</td>
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<td>Silt, gray, gravel, small cobble size, occ. boulder, sand, fine-coarse 12</td>
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<td>Gravel, up to cobble size, silt, brownish-gray, sand, medium 1</td>
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<td>Clay, silty, gray 4</td>
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<td>Clay, silty, gray, some sand, coarse, occ. gravel, small 5</td>
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<td>Clay, gray, some sand, coarse 3</td>
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<td>Clay, greenish-gray, some sand, coarse 7</td>
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<td>Clay, greenish-gray 8</td>
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<td>Clay, greenish-gray, some brown laminations 12</td>
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<td>Clay, silty, dark gray, sand, fine 2</td>
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<td>21/6-28E2</td>
<td>John Metcalf</td>
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<td>Northwest Pump and Drilling Co., March 1981.</td>
<td>6 in. to 21 ft.</td>
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<td>Sand and gravel, brown, dry 12</td>
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<td>Sand and gravel, water-bearing 3</td>
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<td>Clay, brown 4</td>
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<td>Altitude (ft)</td>
<td>Drilled by</td>
<td>Casing:</td>
<td>Perforated to (ft)</td>
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<td>6 in. to 42 ft.</td>
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TABLE 2.--Lithologic logs of selected wells in the study area--Continued

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<td>25 43</td>
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*aBottom of the alluvial aquifer.

*Material not fully penetrated, may extend below this depth.
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**TABLE 3.--Water-level measurements in selected wells in the study area**

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**21N/06E-20R01**

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