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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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

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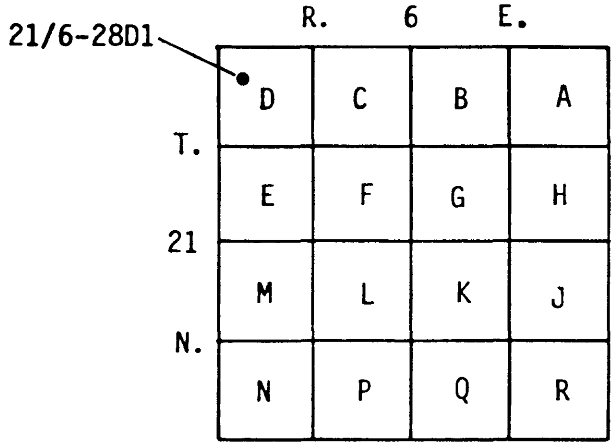
CONTENTS

ILLUSTRATIONS

TABLES

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.



Section 28

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 NW¼NW¼ 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

Multiply	By	To obtain
inches (in.)	25.4	millimeters (mm)
	2.540	centimeters (cm)
	0.0254	meters (m)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
gallons per minute per foot [(gal/min)/ft)]	0.2070	liters per second per meter [(L/s)/m)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
	28.32	liters per second (L/s)
micromhos per centimeter at 25°C (umho/cm at 25°C)	1	microsiemens per centimeter (uS/cm)
feet per day (ft/d)	0.03048	meters per day (m/d)

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

$$°C = 5/9\ (°F-32)$$

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

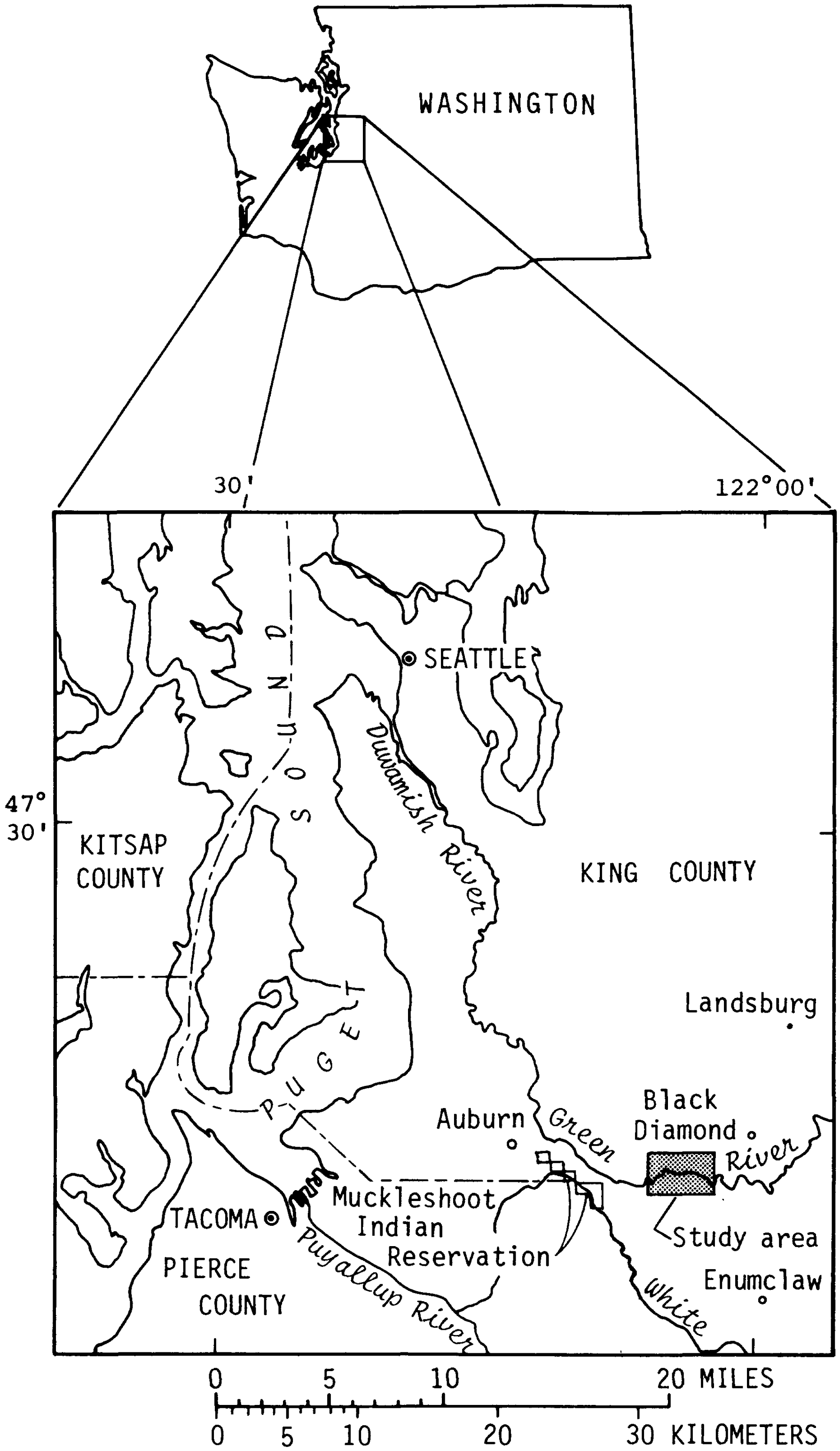


FIGURE 1.--Location of the study area.

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 mi^2) 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.

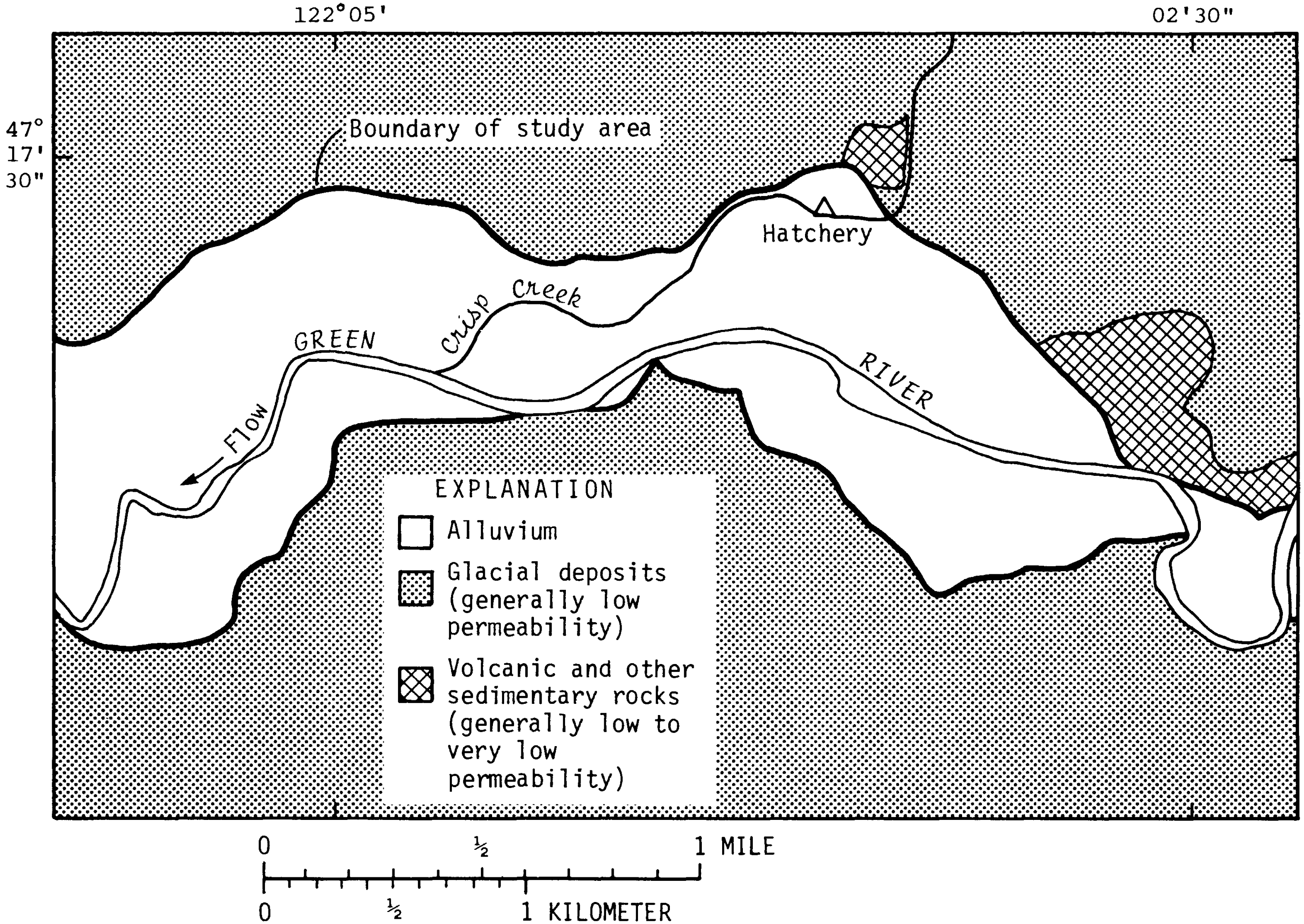


FIGURE 2.--Surficial geology of the study area.

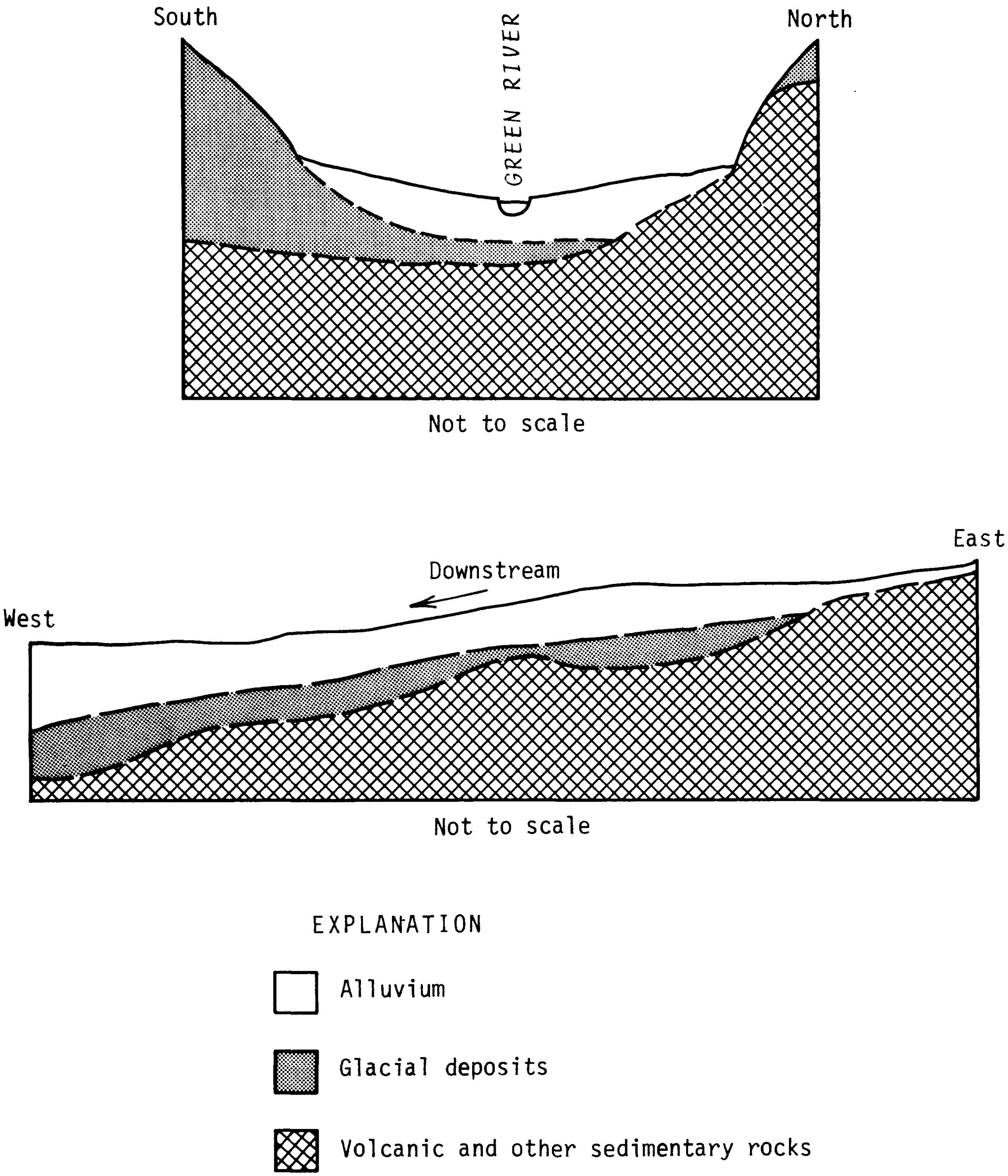


FIGURE 3.--Idealized geologic sections.

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).

Constituent and property (mg/L, unless otherwise specified)	Well number and date of sample		
	21/6-20Q2 (alluvium)	21/6-27R1 (sedimentary rock)	
	3/26/80	1/9/63	10/3/63
Depth of well (ft)	37.0	1,461.0	1,461.0
Silica	--	--	11
Iron (ug/L)	10	--	*9,500
Calcium	--	--	40
Manganese (ug/L)	10	--	--
Magnesium	--	--	20
Sodium	--	--	4,300
Potassium	--	--	34
Bicarbonate	--	2,400	2,290
Sulfate	3.1	--	.7
Chloride	--	--	5,300
Nitrate	1.7	--	37
Phosphate	--	--	.05
Orthophosphorus	--	--	.01
Dissolved solids (calculated)	--	--	10,900
Hardness (as $CaCO_3$)	--	190	180
Specific conductance (umho/cm at 25°C)	171	17,000	17,200
pH (units)	7.0	--	7.2
Temperature (°C)	8.8	--	13.0
Oxygen, dissolved	9.1	--	--
Carbon dioxide	--	--	231

*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.

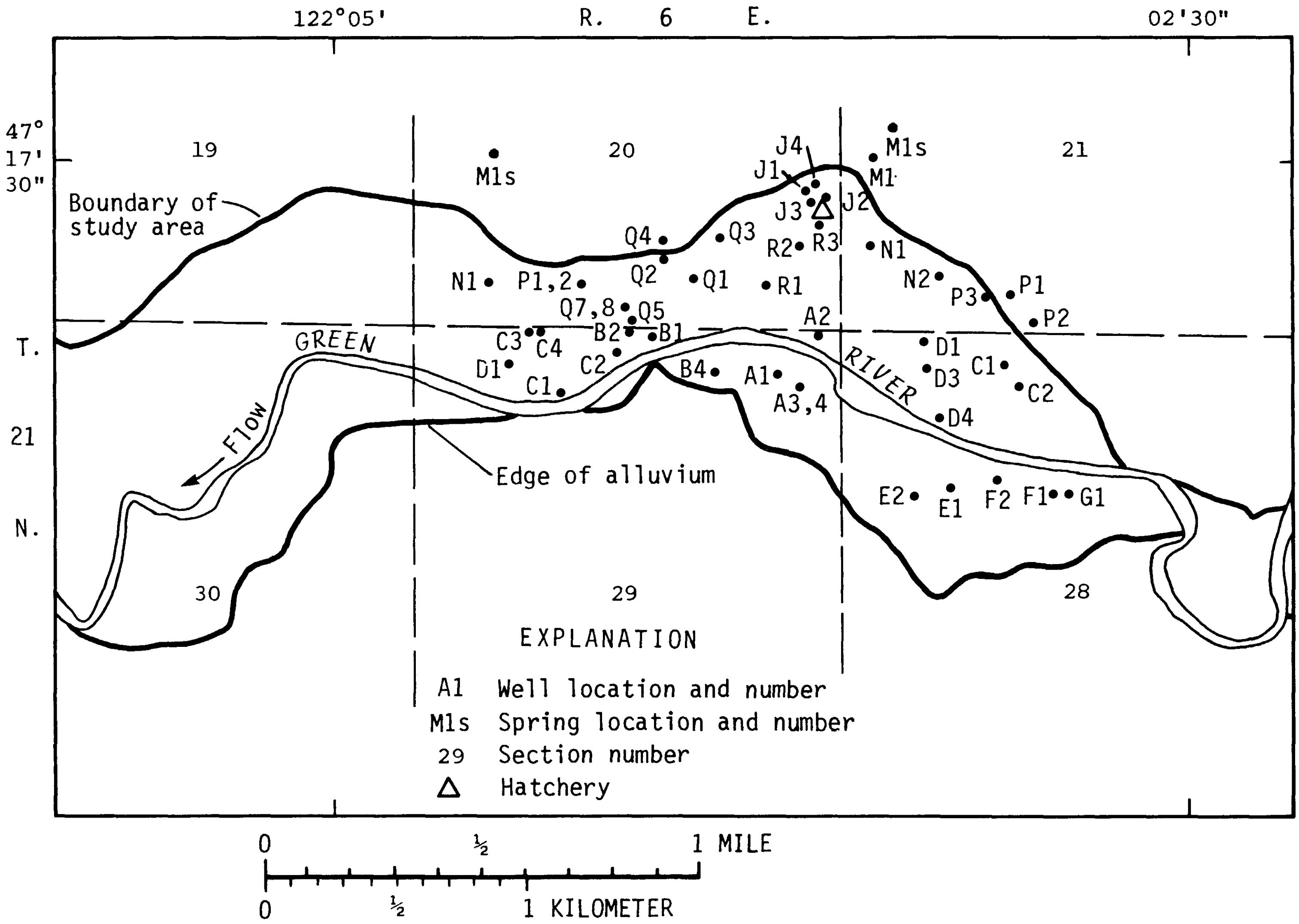


FIGURE 4.--Well locations in the study area.

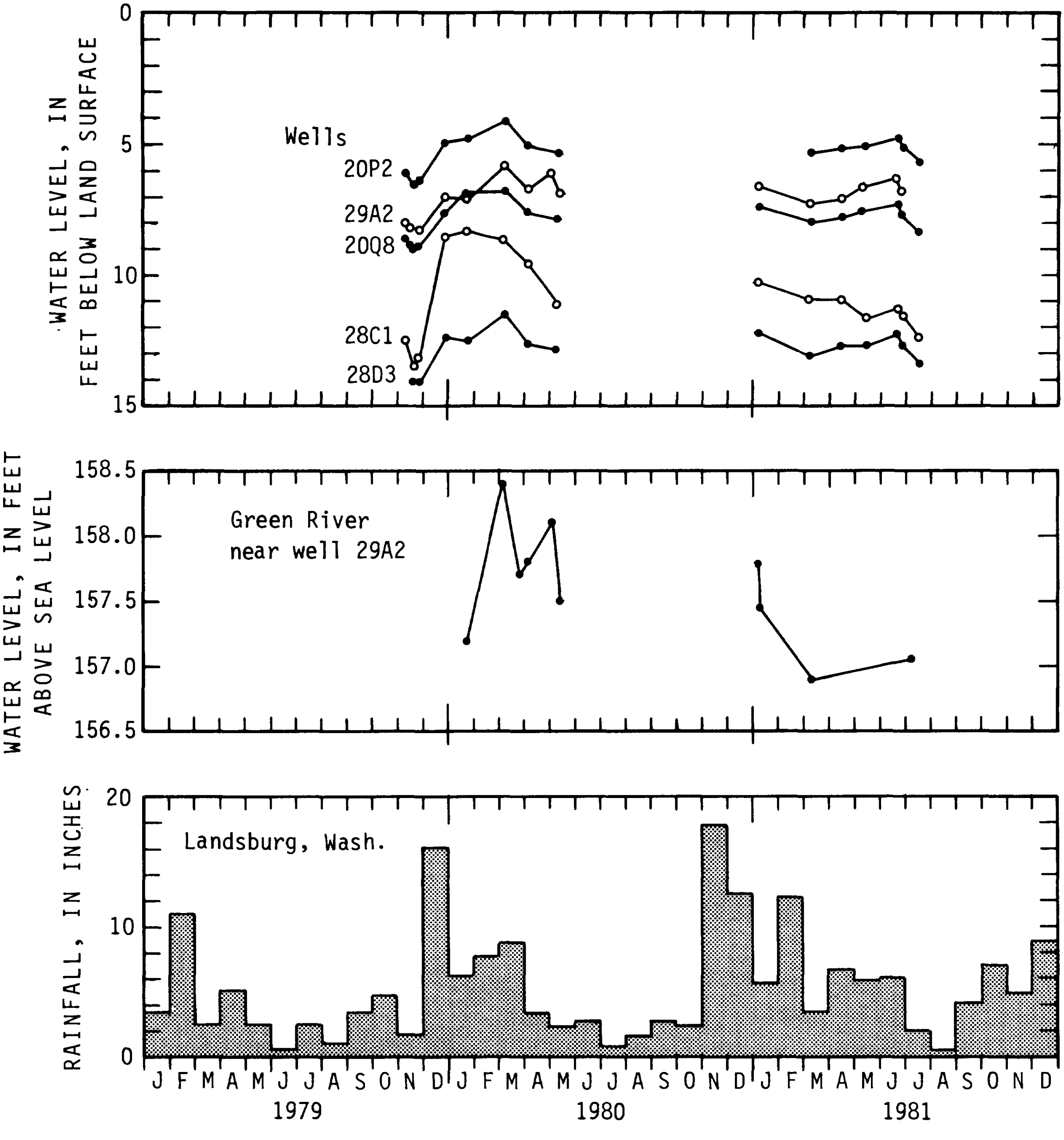


FIGURE 5.--Water-level fluctuations in selected wells and the Green River, and monthly rainfall at Landsburg, Washington.

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.

Site number (see fig. 6)	Name	Tributary inflow (ft^3/s)	Crisp Creek flow (ft^3/s)	Approximate ground-water contribution (ft^3/s)
May 7, 1980				
1	Crisp Creek (upstream station)		7.03	
2	Keta Creek	0.18		
3	Unnamed tributary	.04		
4	Unnamed tributary	.07		
5	Unnamed tributary	.58		
	Total inflow	0.87		
6	Crisp Creek (downstream station)		8.07	+0.17 (downstream gain)
May 12, 1980				
1	Crisp Creek (upstream station)		6.97	
2	Keta Creek	.27		
3	Unnamed tributary	.04		
4	Unnamed tributary	.07		
5	Unnamed tributary	.05		
	Total inflow	0.43		
6	Crisp Creek (downstream station)		7.08	-0.32 (downstream loss)

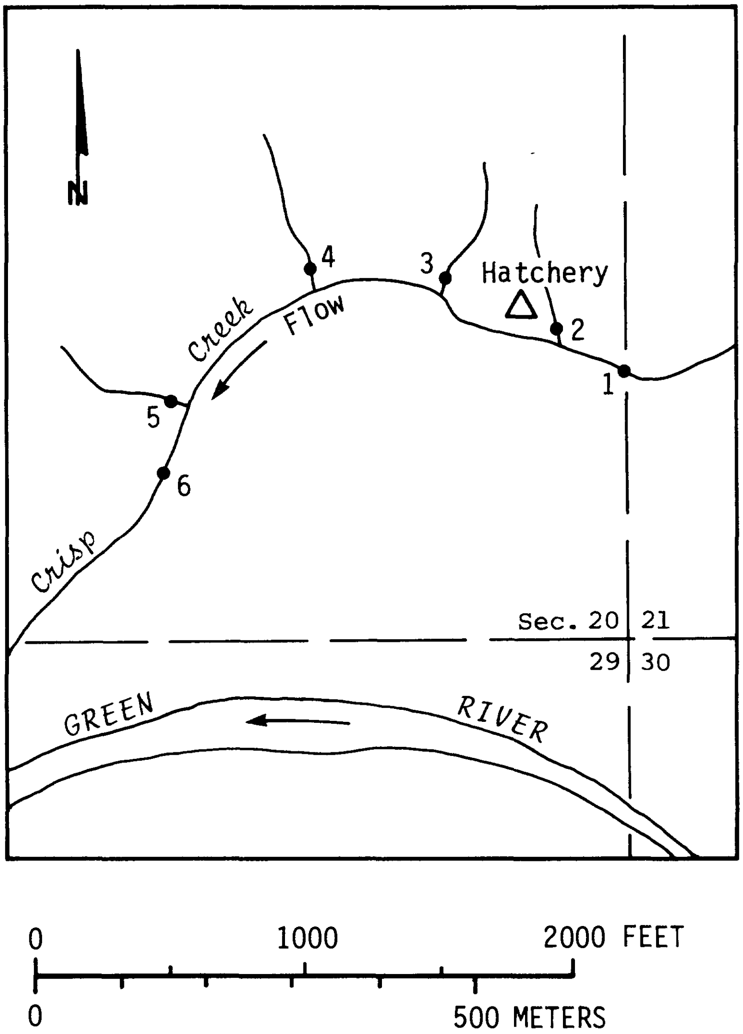


FIGURE 6.--Locations of measurement sites on Crisp Creek, Washington.

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.

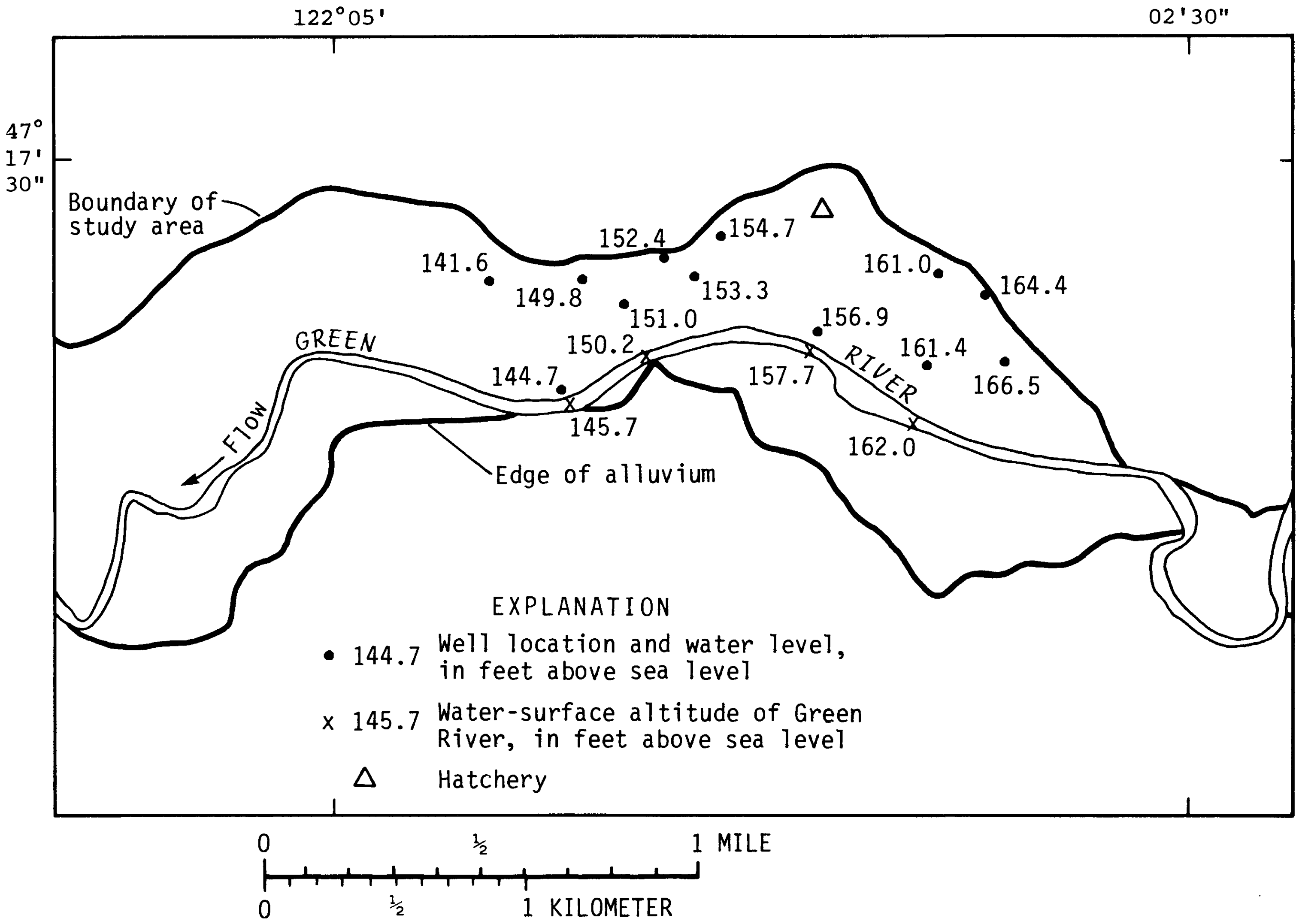


FIGURE 7.--Altitude of the water table at selected sites on May 12, 1980.

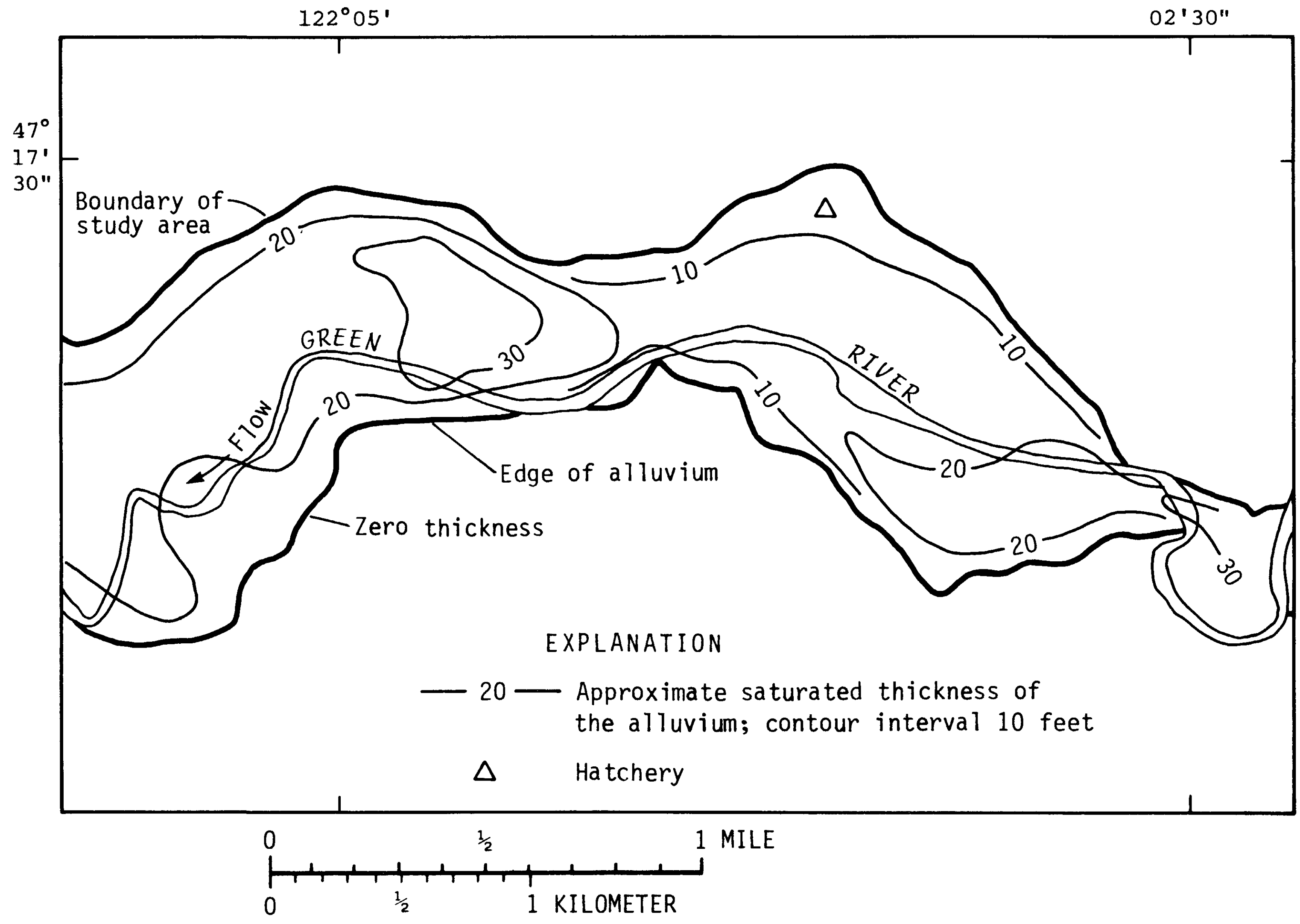


FIGURE 8.--Approximate saturated thickness of the alluvial aquifer.

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.

Well number	Specific capacity [(gal/min)/ft]	Approximate saturated thickness (ft)
20N1	5.3	18
20Q1	1.7	4
20Q2[a]	[a]90	[a]20
20R1	3.3	5
21P3	2.0	7
28D1	3.0	7
28D4	3.4	17
28E2	4.0	3
28F1	.6	11
28F2	4.2	10
28G1	3.0	3
29A3	1.7	3
29A4	3.3	6
29B2	3.0	2
29C1	5.0	3
29C2	5.0	10
29C3	2.5	16
29C4	5.0	4
29D1	4.4	5
Average	3.4	7.4

[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 materals. 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 occuring 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.

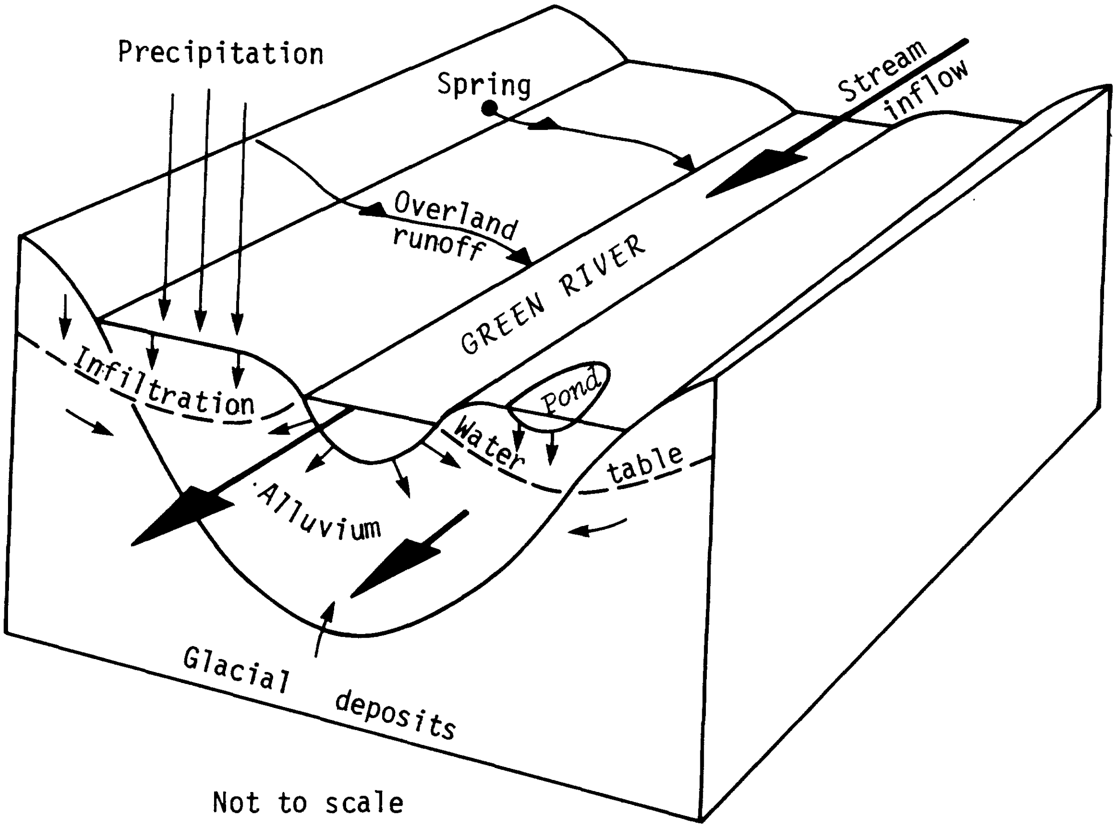


FIGURE 9.--Idealized movement of ground water in the model area.

NUMERICAL MODEL OF THE GROUND-WATER FLOW SYSTEM

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.

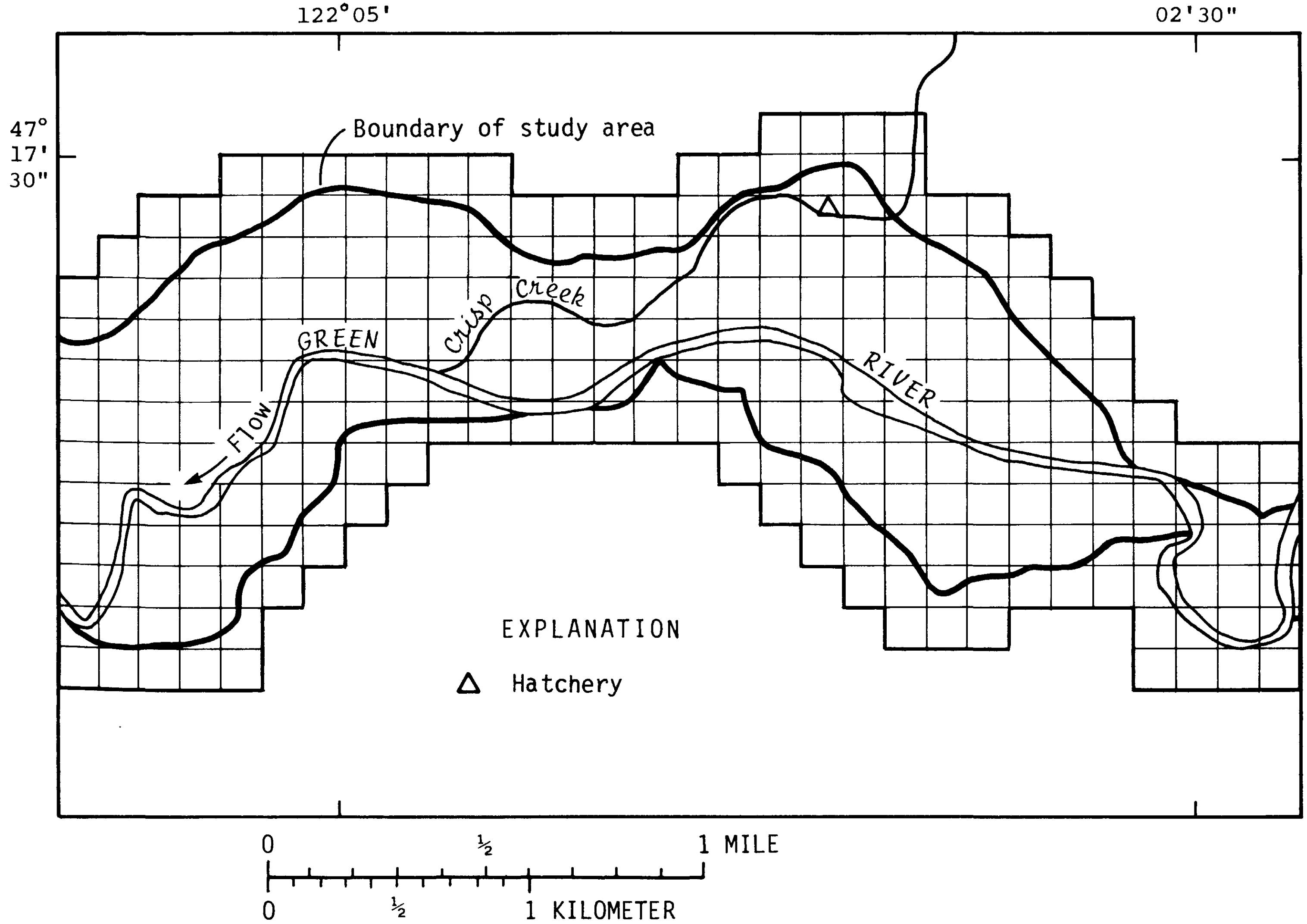


FIGURE 10.--Grid system and selected geologic and hydrologic features in the study area.

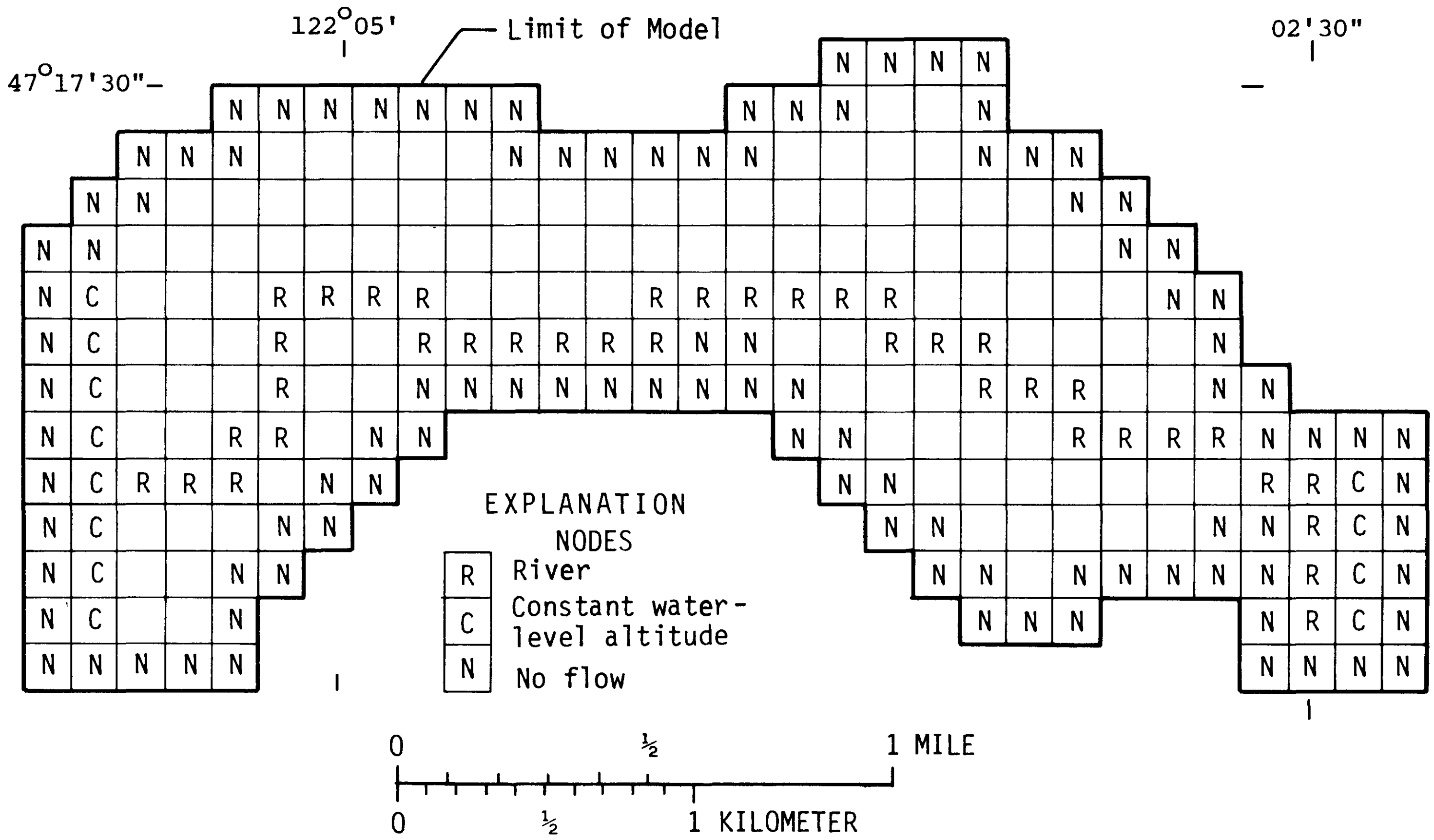


FIGURE 11.--Locations of boundary and river nodes for the model area.

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.

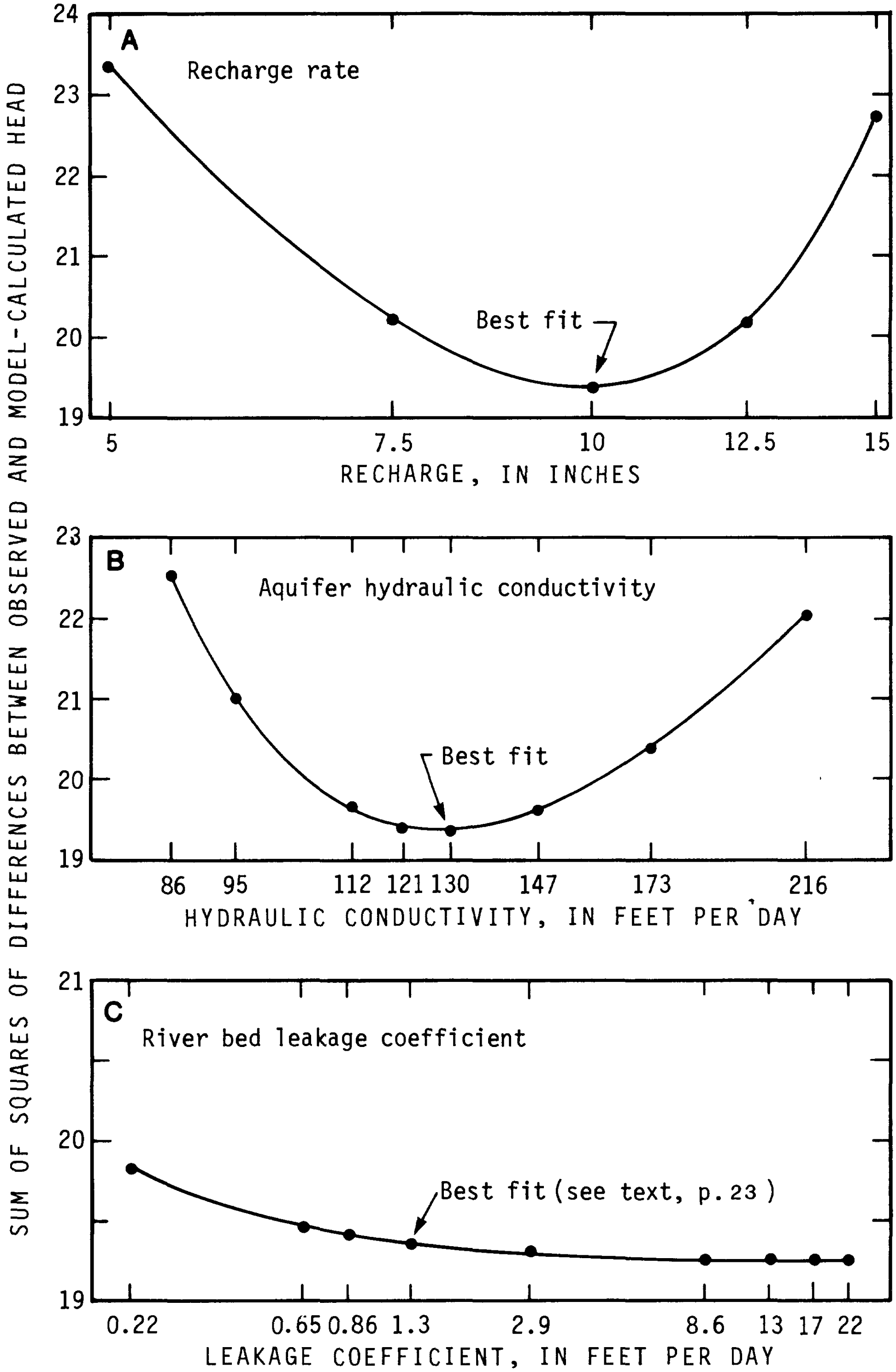


FIGURE 12.--Results of calibration simulations.

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.

Observation well number	Difference between measured water-table altitude and calculated water-table altitude
20N1	-1.9
20P2	1.9
20Q1	.1
20Q2	.1
20Q3	-.9
20Q8	.9
21N2	-1.0
21P3	1.0
28C1	1.9
28D3	-.5
29A2	-1.2
29C1	-1.6

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

Cumulative Mass Balance

Ground water moving into model	(in cubic feet per second)	Ground water moving out of model	(in cubic feet per second)
Constant-head boundary	0.65	Constant-head boundary	0.01
Recharge	.97	Recharge	--
Leakage	.40	Leakage	2.00
Total	2.01	Total	2.01
Percentage of difference	0.09		

(Note: Some inconsistencies in statistical values are due to rounding.)

ESTIMATES OF GROUND-WATER AVAILABILITY FROM THE ALLUVIAL AQUIFER

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.

SOURCE OF WATER TO PUMPING WELLS IN THE ALLUVIAL AQUIFER

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.

	Rate of water moving in and out of the alluvium as calculated by the computer model (in cubic feet per second, unless otherwise noted)			
		Simulated pumping rates		
	Nonpumping	22 gal/min	144 gal/min	108 gal/min
Constant head in	0.65	0.65	0.65	0.65
Constant head out	.01	.01	.01	.01
Upward leakage[1] into river	2.00	1.95	1.83	1.91
Downward leakage into aquifer	.40	.40	.54	.55
Net change in flow of Green River[2]	+1.60	+1.55	+1.29	+1.36
Net change from "nonpumping" simulation in flow of Green River	--	-.05	-.31	-.24
Pumping rate (simulated)	0	.05	.32	.24

[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 were 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

Jenkins, C. T., 1968, Computation of rate and volume of stream depletion by wells: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter D1, 17 p.

Luzier, J. E., 1969, Geology and ground-water resources of southwestern King County, Washington: Washington Department of Water Resources Water-Supply Bulletin 28, 260p., 3 pl.

Mullineaux, D. R., 1961, Geology of the Renton, Auburn, and Black Diamond quadrangles, Washington: U. S. Geological Survey Open-File Report, 202p.

Theis, C. V., Brown, R. H., and Meyer, R. R., 1963, Estimating the transmissivity of aquifers from the specific capacity of wells, in Bentall, Ray, editor, Methods for determining permeability, transmissivity, and drawdown: U. S. Geological Survey Water-Supply Paper 1536-I, p.331-341.

Trescott, P. C., Pinder, G.F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments: U.S. Geological Survey Techniques of Water Resources Investigations, Book 7, Chapter C1, 116 p.

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

EXPLANATION

Local number: Location as described on page V.

Owner: Owner (or current tenant) at time of visit to well, 1980-81.

Use of water: H, domestic; U, unused; I, irrigation; P, public supply; Q, agriculture; S, stock watering.

Altitude of land surface: The altitude of the land surface adjacent to the well with reference to sea level, surveyed where shown to 0.01 foot, estimated from map if shown in whole numbers.

Depth drilled: Total depth drilled.

Depth of well: Depth of completed well, dashed where unknown or if well is destroyed.

Casing diameter: Diameter of well casing at top of well.

Date completed: Date of completion of drilling of well.

Discharge: The maximum rate reported pumped from well by owner or driller.

WELLS IN THE GREEN RIVER VALLEY

LOCAL NUMBER	OWNER	USE OF WATER	ALTITUDE OF LAND SURFACE (FEET)	DEPTH DRILLED (FEET)	DEPTH OF WELL (FEET)	CASING DIAM-ETER (INCHES)	DATE COMPLETED	DISCHARGE (GALLONS PER MINUTE)
KING COUNTY								
21N/06E-20J01	USGS	U	164.00	52	--	--	10/30/1979	--
21N/06E-20J02	USGS	U	162.30	12	--	--	11/06/1979	--
21N/06E-20J03	USGS	U	162.85	153	146.0	6	05/14/1981	--
21N/06E-20J04	USGS	U	165.62	40	11.5	8	06/29/1981	--
21N/06E-20M01S	MURDOCK, DON	H	430	--	--	--	--	--
21N/06E-20N01	KOCHER, DAVID	H	151.98	40	40.0	6	06/25/1979	85
21N/06E-20P01	USGS	U	155.00	21	--	--	11/01/1979	--
21N/06E-20P02	USGS	U	155.06	7	6.9	2	11/02/1979	--
21N/06E-20Q01	BENZ, GARY	H	159.14	34	34.0	6	01/09/1978	20
21N/06E-20Q02	HIGGINS, DALE	I,Q	159.50	37	37.0	8	--	170
21N/06E-20Q03	HIGGINS, DALE	I	162.40	15	11.2	65	--	20
21N/06E-20Q04	HIGGINS, DALE	U	172.70	348	348.0	8	--	--
21N/06E-20Q05	FURLAN, CARLO	I	155.00	7	7.0	36	1969	--
21N/06E-20Q07	USGS	U	158.80	52	--	--	10/31/1979	--
21N/06E-20Q08	USGS	U	158.80	22	21.0	2	10/31/1979	--
21N/06E-20R01	SEARS, DOUGLAS	H	165.60	23	23.0	8	10/02/1979	20
21N/06E-20R02	USGS	U	164.80	11	--	--	10/30/1979	--
21N/06E-20R03	WADDELL, CAROL	H,I	163	20	20.0	6	05/20/1980	25
21N/06E-21M01	SPAIGHT, TOM	H	250	100	100.0	6	05/20/1980	--
21N/06E-21M01S	DIAMOND SP, WATER ASSN	P	300	--	--	--	--	--
21N/06E-21N01	WA STATE, FISHERIES	U	173	200	200.0	--	--	--
21N/06E-21N02	WA STATE, FISHERIES	U	165.80	18	18.0	--	--	--
21N/06E-21P01	HUOTARI, DUANE	U	219.80	140	62.0	6	01/23/1976	3.0
21N/06E-21P02	STEPHENS, JAMES	H	225	40	40.0	--	1976	--
21N/06E-21P03	HUOTARI, DUANE	H	173.10	38	38.0	6	05/29/1979	12
21N/06E-27R01	LENBER	U	275	--	1461.0	8	1911	--
21N/06E-28C01	USGS	U	177.62	19	19.0	2	11/05/1979	--
21N/06E-28C02	UNKNOWN	U	180	110	93.0	6	01/01/1975	--
21N/06E-28D01	FLETCHER, DOUG	H	170	27	27.0	6	10/23/1978	15
21N/06E-28D03	USGS	U	174.17	23	22.5	2	11/06/1979	--
21N/06E-28D04	USGS	U	173.39	155	25.0	6	06/26/1981	15
21N/06E-28E01	LYTLE, NEALE	H,S	180	39	39.0	--	--	--
21N/06E-28E02	METCALF, JOHN	H	190	21	21.0	6	03/27/1981	12
21N/06E-28F01	NOVAK, ALBERT	H	180	42	42.0	6	01/13/1977	12
21N/06E-28F02	KEMP, DR. AARON	H	190	30	30.0	6	01/27/1982	25
21N/06E-28G01	FERG, DICK	H	180	31	31.0	6	12/01/1976	18
21N/06E-29A01	COHEN, FRED	H	162	20	20.0	6	06/14/1979	30
21N/06E-29A02	USGS	U	163.80	16	16.4	2	10/29/1979	--
21N/06E-29A03	MC CALL, CLETIS	H	162	60	60.0	6	08/11/1978	5.0
21N/06E-29A04	MC CALL, CLETIS	H	162	60	60.0	6	08/11/1978	10
21N/06E-29B01	FURLAN, CARLO	H	150	8	8.0	--	1969	--
21N/06E-29B02	HARTMAN, CHARLES	H	154.50	43	18.0	6	11/11/1978	15
21N/06E-29B04	MATTHAEI, WILLIAM	H	175	30	30.0	6	03/17/1980	35
21N/06E-29C01	CARNEY, ROBERT	H	152.40	50	18.0	6	08/07/1979	20
21N/06E-29C02	ANTONICH, A	H	155	26	26.0	6	01/10/1978	25
21N/06E-29C03	JUERGENS, MRS EMIL	H	155	36	36.0	6	11/29/1979	30
21N/06E-29C04	CANFIELD, WILLIS	H	155	31	31.0	6	09/25/1976	40
21N/06E-29D01	JOHNSON, THOMAS	H	150	32	32.0	6	09/27/1976	35

TABLE 2.--Lithologic logs of selected wells in the study area

	Thickness (ft)	Depth (ft)
21/6-20J1. USGS. Altitude 164 ft. Drilled by USGS, October 1979. Test hole.		
Sand and gravel, many cobbles, brown	14	14[a]
Clay, gray-green (very wet at 25 ft)	38	52
21/6-20J2. USGS. Altitude 163 ft. Drilled by USGS, November 1979. Test hole.		
Sand, gravel, clay, brown	2	2
Clay, sand, silt, brown, gray and black (water-bearing at 3 ft)	6	8
Gravel	2	10[a]
Clay	2	12
21/6-20J4. USGS. Altitude 163 ft. Drilled by Evergreen Drilling, June 1981. Casing: 6-inch to 146 ft.		
Gravel fill	5	5
Silt, gray-brown, sand, fine, wood	3	8[a]
Gravel, small-cobble size, occ. boulder, sand, fine-coarse, much silt and clay, gray, compact	5	13
Sand, fine-coarse, some pebbles, cobbles, occ. boulder, silt, clay, gray	7	20
Clay, sandy to silty, gray-green, dry	5	25
Clay, sandy to silty, gray, fine brown laminations, dry	7	32
Clay, silty, gray and brown, dry	3	35
Clay, silty, gray-green, dry, some sand and wood particles	2	37
Clay, silty, gray-green, dry, hard	13	50
Clay, gray-green	5	55
Clay, gray-green, brown laminations	2	57
Clay, gray, brown laminations	3	60
Clay, gray	2	62
Clay, gray, some brown laminations	10	72
Clay, gray, brown	5	77
Clay, gray, some greenish-brown laminations	45	122
Clay, silty, gray, some greenish-brown coloration, some sand	5	127
Clay, silty, gray	13	140
Clay, silty, bluish-green to gray	2	142
Clay, silty, gray	7	149
Clay, silty, gray, sand, med.	4	153
Clay, silty, gray	-	153+
21/6-20J5. USGS. Altiude 165 ft. Drilled by Evergreen Drilling, July 1981. Casing: 8-in. to 20 ft. Perforated at 11.5 ft.		
Silt, brown	4	4
Silt, gray, sand, gravel, small, occ. boulder	12	16[a]
Clay, gray-green, sand and gravel, small, 1/8 inch	4	20
Clay, gray-green some sand	5	25
Clay, gray-green, brown laminations	15	40
21/6-20N1. David Kocher. Altitude 152 ft. Drilled by Johnson Drilling Co., Inc., June 1979. Casing: 6 in. to 40 ft.		
Sand, brown	8	8
Hardpan, gray	14	22
Gravel, brown, water-bearing	18	40[a]

	Thickness (ft)	Depth (ft)
21/6-20P1. USGS. Altitude 155 ft. Drilled by USGS, November 1979. Test hole.		
Soil, sandy, brown	4	4
Sand and clay, brown	2	6
Sand and gravel (cobbles) with clay matrix, brown, water-bearing at 12 ft or less	8	14[a]
Clay, gray-green	5	19
Clay and gravel, gray	2	21
21/6-20P2. USGS. Altitude 155 ft Drilled by USGS, November 1979. Casing: 2 in to 5 ft. Screen: 5-7 ft.		
Soil, sandy, brown	3	3
Sand and clay, gray and brown	2	5
Gravel (cobbles)	2	7
21/6-20Q1. Gary and Rose Benz. Altitude 159 ft. Drilled by Johnson Drlling Co., Inc., January 1978. Casing: 6 in to 34 ft.		
Sand, brown	9	9
Gravel, hardpan, brown	8	17
Gravel, brown, water-bearing	5	22[a]
Clay, gray	7	29
Sand, water-bearing, brown	5	34
Clay, gray	-	34+
21/6-20Q2. Dale Higgins. Altitude 160 ft. Drilled by Johnson Drilling Co., Inc.		
Clay, sandy, brown	7	7
Hardpan, brown	10	17
Gravel, brown, water-bearing	20	37[a]
21/6-20Q3. Dale Higgins. Altitude 162 ft. Dug by owner, October 1979. Casing: 6.5 ft to 11 ft.		
Sand and gravel	15	15
Clay	-	15+
21/6-20Q4. Dale Higgins. Altitude 173 ft. Drilled by Johnson Drilling Co., Inc. Casing: 8 in to 100 ft. Open hole 100-348 ft		
No log available	310	310
Silt, sand, blue, water-bearing (?)	28	338
No log available	10	348
21/6-20Q7. USGS. Altitude 159 ft. Drilled by USGS, October 1979. Test hole.		
Soil, sandy, brown	3	3
Sand and gravel (cobbles), brown, water-bearing at 12 ft or less	23	26[a]
Clay, gray-blue	26	52
21/6-20Q8. USGS. Altitude 159 ft. Drilled by USGS, October 1979. Casing: 2 in. to 18.5 ft. Screen: 18.5-21 ft.		
Soil, sandy, brown	3	3
Sand and gravel (some cobbles), brown, water-bearing at 12 ft or less	19	22

	Thickness (ft)	Depth (ft)
21/6-20R1. Douglas Sears. Altitude 166 ft. Drilled by Johnson Drilling Co., Inc., October 1979. Casing: 8 in. to 23 ft.		
Soil	3	3
Sand and gravel, brown	10	13
Hardpan, brown	5	18
Sand and gravel, brown, water-bearing	5	23a
Clay, gray	-	23+
21/6-20R2. USGS. Altitude 165 ft. Drilled by USGS, October 1979. Test hole.		
Soil, sandy, brown	2	2
Sand and gravel, fine, brown	2	4
Gravel, coarse	7	11
21/6-20R3. Carol Waddell. Altitude 163 ft. Drilled by Northwest Pump and Drilling Co., May 1980. Casing: 6 in. to 20 ft.		
Topsoil, brown	2	2
Sand and gravel, cemented, brown	14	16
Sand and gravel, brown, water-bearing	4	20
21/6-21M1. Tom Spaight. Altitude 250 ft. Drilled by Northwest Pump and Drilling Co., May 1980. Casing: 6 in. to 80 ft.		
Sand, brown, dry	15	15
Sand, silty, brown	1	16
Sand and gravel, brown, damp	1	17
Sand. occ. gravel, brown, dry	1	18
Sand, silty, brown, dry	5	23
Sand and gravel, silty, blue, damp	19	42
Clay, blue, yellow, gray	58	100
21/6-21P1. Duane Huotari. Altitude 220 ft. Drilled by Johnson Drilling Co. Inc., January 1976. Casing: 6 in. to 62 ft. Perforated 39-42 ft.		
Soil	2	2
Gravel hardpan, brown	17	19
Clay, brown	20	39
Gravel, brown (water seepage)	3	42
Clay, blue	73	115
Silt, brown	25	140
21/6-21P3. Duane Huotari. Altitude 173 ft. Drilled by Northwest Pump and Drilling Co., May 1979. Casing: 6 in. to 38 ft. Perforated 20-23 ft.		
Top soil	5	5
Sand and gravel, silty	11	16
Sand and gravel, water-bearing	7	23a
Silt, blue	13	36
Sand	2	38
21/6-28C1. USGS. Altitude 178 ft. Drilled by USGS, November 1979. Casing: 2 in. to 16.5 ft. Screen: 16.5-19 ft.		
Soil, sandy, brown	2.5	2.5
Sand, brown, dry	.5	3
Sand and clay, gray, brown, red-orange	11	14
Gravel	5	19

	Thickness (ft)	Depth (ft)
21/6-28C2. Owner unknown. Altitude 180 ft. Drilled by Evergreen Drilling, 1975. Casing to 93 ft. Abandoned.		
Boulders (?)	18	18[a]
Hardpan, brown	7	25
Clay, sand, gray	15	40
Clay, gray	10	50
Clay, light brown, bits of wood	5	55
Clay, dark brown, bits of wood	10	65
Sandstone, decomposed, light beige, wood pieces	27	92
Sandstone, very coarse grit, white (open hole)	18	110
21/6-28D1. Doug Fletcher. Altitude 170 ft. Drilled by Northwest Pump and Drilling Co., October 1978. Casing: 6 in. to 27 ft.		
Topsoil	1	1
Sand and gravel, brown	14	15
Till, brown	5	20
Sand and gravel, water-bearing	7	27
21/6-28D3. USGS. Altitude 174 ft. Drilled by USGS, November 1979. Casing: 2 in. to 20.5 ft. Screen: 20.5-22.5 ft.		
Soil, sandy, brown	3	3
Gravel, coarse	6	9
Gravel, fine, water-bearing at 12 ft or less	14	23
21/6-28D4. USGS. Altitude 173 ft. Drilled by Evergreen Drilling, June 1981. Casing: 6 in. to 133 ft. Screen: 15-25 ft.		
Topsoil, brown, sand, fine	5	5
Silt, brown, gravel, small cobble size, occ. boulder sand, fine-coarse, water-bearing 18-20 ft.	17	22[a]
Silt, gray, light	6	28
Gravel, small cobble size, sand, fine-coarse, silt, gray	2	30
Silt, gray, gravel, small cobble size, occ. boulder, sand, fine-coarse	12	42
Gravel, up to cobble size, silt, brownish-gray, sand, medium	1	43
Clay, silty, gray	4	47
Clay, silty, gray, some sand, coarse, occ. gravel, small	5	52
Clay, gray, some sand, coarse	3	55
Clay, greenish-gray, some sand, coarse	7	62
Clay, greenish-graay	8	70
Clay, greenish-gray, some brown laminations	12	82
Clay, gray and greenish-gray, brown laminations	3	85
Clay, gray, brown laminations	15	100
Clay, gray, bluish-gray, brown	5	105
Clay, gray, brown laminations	35	140
Clay, gray, brown laminations, some dark gray silty clay	2	142
Clay, gray, brown laminations	5	147
Clay, silty, dark greenish-gray	3	150
Clay, silty, dark gray, sand, fine	2	152
Clay, silty, gray, sand, fine	-	155+
21/6-28E2. John Metcalf. Altitude 190 ft. Drilled by Northwest Pump and Drilling Co. March 1981. Casing: 6 in. to 21 ft.		
Topsoil, brown, dry	2	2
Sand and gravel, brown, dry	12	14
Sand and gravel, water-bearing	3	17[a]
Clay, brown	4	21

	Thickness (ft)	Depth (ft)
21/6-28F1. Albert Novak. Altitude 180 ft. Drilled by Northwest Pump and Drilling Co., January 1977. Casing: 6 in. to 42 ft. Perforated 28-38 ft.		
Topsoil	3	3
Sand, gravel and boulders	10	13
Silt, sand, gravel, boulders	15	28
Sand and gravel, water-bearing	11	39a
Clay, brown	1	40
Clay, blue	1	42
21/6-28F2. Dr. Aaron Kemp. Altitude 200 ft. Drilled by Northwest Pump and Drilling Co., January 1982. Casing: 6 in. to 30 ft.		
Topsoil, brown, dry	4	4
Sand and gravel, brown, dry	11	15
Sand and gravel, brown, damp	5	20
Sand and gravel, water-bearing	10	30
21/6-28G1. Dick Ferg. Altitude 180 ft. Drilled by Northwest Pump and Drilling Co., December 1976. Casing: 6 in. to 31 ft.		
Topsoil	4	4
Till and cobbles, brown	24	28
Sand and gravel, water-bearing	3	31
21/6-29A1. Fred Cohen. Altitude 162 ft. Drilled by Northwest Pump and Drilling Co., June 1979. Casing: 6 in. to 20 ft.		
Topsoil	2	2
Till, brown	14	16
Sand and gravel, water-bearing	4	20
21/6-29A2. USGS Altitude 164 ft. Drilled by USGS, October 1979. Casing: 2 in. to 13 ft. Screen: 13-15 ft.		
Sand and gravel (cobbles)	-	15+
21/6-29A3. Cletis McCall. Altitude 162 ft. Drilled by Northwest Pump and Drilling Co., August 1978. Casing: 6 in. to 60 ft. Perforated 20-25 ft.		
Topsoil	2	2
Sand and gravel, brown	17	19
Sand and gravel, water-bearing	3	22a
Silt, blue	38	60
21/6-29A4. Cletis McCall. Altitude 162 ft. Drilled by Northwest Pump and Drilling Co., August 1978. Casing: 6 in. to 60 ft. Perforated 20-25 ft.		
Topsoil	1	1
Sand and gravel, brown	18	19
Sand and gravel, water-bearing	6	25a
Till, blue	24	49
Silt, blue	11	60
21/6-29B1. Carlo Furlan. Altitude 150 ft. Drilled by Johnson Drilling Co., Inc., 1970. Casing: 6 in. to 8 ft.		
Sand and gravel	-	8+

TABLE 2.--Lithologic logs of selected wells in the study area--Continued

	Thickness (ft)	Depth (ft)
21/6-29B2. Charles Hartman. Altitude 155 ft. Drilled by Johnson Drilling Co., Inc., November 1978. Casing: 6 in. to 18 ft.		
Sand, brown	7	7
Hardpan, brown	9	16
Sand and gravel, gray, water-bearing	2	18[a]
Clay, blue-gray	25	43
21/6-29B4. William Malthaei. Altitude 175 ft. Drilled by Northwest Pump and Drilling Co., March 1980. Casing: 6 in. to 30 ft.		
Topsoil	2	2
Sand and gravel, brown	22	24
Sand and gravel, water-bearing	6	30
21/6-29C1. Robert Carney. Altitude 152 ft. Drilled by Johnson Drilling Co., Inc., August 1979. Casing: 6 in to 18 ft.		
Soil	3	3
Sand, brown	4	7
Hardpan, brown	8	15
Sand and gravel, brown, water-bearing	3	18[a]
Clay, gray	12	30
Gravel, hardpacked, gray	20	50
Clay, gray	-	50[+]
21/6-29C2. A. G. Antonich. Altitude 155 ft. Drilled by Johnson Drilling Co., Inc., January 1978. Casing: 6 in. to 26 ft.		
Sand, brown	7	7
Gravel hardpan, brown	9	16
Gravel, brown, water-bearing	10	26[a]
Clay, blue	-	26[+]
21/6-29C3. Emil Juergens. Altitude 155 ft. Drilled by Johnson Drilling Co., Inc., November 1979. Casing: 6 in. to 36 ft.		
Soil	3	3
Sand and gravel, brown	5	8
Hardpan, brown	12	20
Sand and gravel, brown, water-bearing	16	36[a]
Hardpan, gray	-	36[+]
21/6-29C4. Willis Canfield. Altitude 150 ft. Drilled by Johnson Drilling Co., Inc., September 1976. Casing: 6 in. to 31 ft. Perforated 21-31 ft.		
Soil	2	2
Loam, sandy, brown	4	6
Gravel hardpan, boulders, brown	21	27
Gravel, water-bearing	4	31
21/6-29D1. Thomas Johnson. Altitude 150 ft. Drilled by Johnson Drilling Co., Inc., September 1971. Casing: 6 in. to 32 ft. Perforated 22-30 ft.		
Soil	2	2
Sand and gravel	6	8
Gravel hardpan, brown	18	26
Gravel, water-bearing	5	31[a]
Hardpan, brown	1	32

[a]Bottom of the alluvial aquifer.
[+]Material not fully penetrated, may extend below this depth.

TABLE 3.--Water-level measurements in selected wells in the study area

21N/06E-20J04
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 165.62

DATE MEASURED	WATER LEVEL
JUL 07,1981	4.40

21N/06E-20N01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 151.98

DATE MEASURED	WATER LEVEL
JUN 25,1979	11.50
MAR 05,1980	8.60
APR 02,1980	9.70
MAY 12,1980	10.37

21N/06E-20P02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 155.06

DATE MEASURED	WATER LEVEL
NOV 08,1979	6.10
NOV 20,1979	6.50
NOV 26,1979	6.40
DEC 31,1979	4.90
JAN 25,1980	4.80
MAR 05,1980	4.17
APR 02,1980	5.01
MAY 12,1980	5.30
MAR 12,1981	5.30
APR 16,1981	5.17
MAY 12,1981	5.04
JUN 24,1981	4.76
JUN 29,1981	5.09
JUL 14,1981	5.62

21N/06E-20Q01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 159.14

DATE MEASURED	WATER LEVEL
JAN 09,1978	3.50
MAR 05,1980	4.72
APR 02,1980	5.61
MAY 12,1980	5.80
MAR 12,1981	5.95
APR 16,1981	5.80
MAY 12,1981	5.58
JUN 24,1981	5.26
JUN 29,1981	5.66
JUL 14,1981	6.39

21N/06E-20Q02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 159.50

DATE MEASURED	WATER LEVEL
DEC 31,1979	7.00
MAY 01,1980	9.00
MAY 07,1980	9.10
MAY 12,1980	7.13
MAR 12,1981	7.37
APR 16,1981	7.09
MAY 12,1981	6.95

21N/06E-20Q03
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 162.40

DATE MEASURED	WATER LEVEL
DEC 31,1979	7.20
MAR 05,1980	6.55
APR 02,1980	7.61
MAY 12,1980	7.71
MAR 12,1981	7.93
APR 16,1981	7.72
MAY 12,1981	7.57
JUN 24,1981	7.14
JUN 29,1981	7.51
JUL 14,1981	8.37

21N/06E-20Q04
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 172.70

DATE MEASURED	WATER LEVEL
MAR 05,1980	5.42
APR 02,1980	5.91
MAY 12,1980	5.86

21N/06E-20Q08
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 158.80

DATE MEASURED	WATER LEVEL
NOV 08,1979	8.60
NOV 13,1979	8.80
NOV 20,1979	9.00
NOV 26,1979	8.90
DEC 31,1979	7.60
JAN 25,1980	6.80
MAR 05,1980	6.74
APR 02,1980	7.55
MAY 12,1980	7.81
JAN 09,1981	7.38
MAR 12,1981	7.94
APR 16,1981	7.79
MAY 12,1981	7.55
JUN 24,1981	7.26
JUN 29,1981	7.65
JUL 14,1981	8.33

21N/06E-20R01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 165.60

DATE MEASURED	WATER LEVEL
OCT 02,1979	11.00

21N/06E-20R03
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 163.00

DATE MEASURED	WATER LEVEL
MAY 21,1980	8.00

21N/06E-21N02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 165.80

DATE MEASURED	WATER LEVEL
MAR 05,1980	3.14
APR 02,1980	4.23
MAY 12,1980	4.61
MAR 12,1981	4.63
APR 16,1981	4.56
MAY 12,1981	4.79
JUN 24,1981	4.54
JUN 29,1981	4.64
JUL 14,1981	5.39

21N/06E-21P01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 219.80

DATE MEASURED	WATER LEVEL
JAN 23,1976	29.00
MAR 05,1980	25.36
APR 02,1980	25.62
MAY 12,1980	25.87

TABLE 3.--Continued

21N/06E-21P03
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 173.10

DATE MEASURED	WATER LEVEL
MAY 29,1979	6.90
DEC 31,1979	4.20
MAR 05,1980	3.40
APR 02,1980	6.36
MAY 12,1980	8.71

21N/06E-28C01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 177.62

DATE MEASURED	WATER LEVEL
NOV 08,1979	12.50
NOV 21,1979	13.50
NOV 26,1979	13.20
DEC 31,1979	8.50
JAN 25,1980	8.40
MAR 05,1980	8.66
APR 02,1980	9.55
MAY 12,1980	11.09
JAN 09,1981	10.27
MAR 12,1981	10.88
APR 16,1981	10.94
MAY 12,1981	11.63
JUN 24,1981	11.25
JUN 29,1981	11.52
JUL 14,1981	12.42

21N/06E-28D01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 170.00

DATE MEASURED	WATER LEVEL
OCT 24,1978	14.00

21N/06E-28D03
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 174.17

DATE MEASURED	WATER LEVEL
NOV 20,1979	14.10
NOV 26,1979	14.10
DEC 31,1979	12.40
JAN 25,1980	12.50
MAR 05,1980	11.46
APR 02,1980	12.57
MAY 12,1980	12.79
JAN 09,1981	12.21
MAR 12,1981	13.05
APR 16,1981	12.74
MAY 12,1981	12.72
JUN 24,1981	12.26
JUN 29,1981	12.63
JUL 14,1981	13.37

21N/06E-28D04
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 173.39

DATE MEASURED	WATER LEVEL
JUN 26,1981	9.50

21N/06E-28E01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 180.00

DATE MEASURED	WATER LEVEL
AUG 09,1962	17.54

21N/06E-28F01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 180.00

DATE MEASURED	WATER LEVEL
JAN 13,1977	17.00

21N/06E-28F02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 190.00

DATE MEASURED	WATER LEVEL
JAN 27,1982	11.00

21N/06E-28G01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 180.00

DATE MEASURED	WATER LEVEL
DEC 01,1976	16.00

21N/06E-29A01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 162.00

DATE MEASURED	WATER LEVEL
JUN 14,1979	9.00

TABLE 3.--Continued

21N/06E-29A02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 163.80

DATE MEASURED	WATER LEVEL
NOV 08,1979	8.00
NOV 13,1979	8.20
NOV 26,1979	8.30
DEC 31,1979	7.00
JAN 25,1980	7.00
MAR 05,1980	5.78
APR 02,1980	6.66
MAY 01,1980	6.10
MAY 12,1980	6.91
JAN 09,1981	6.64
MAR 12,1981	7.30
APR 16,1981	7.03
MAY 12,1981	6.66
JUN 24,1981	6.25
JUN 29,1981	6.77

21N/06E-29A03
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 162.00

DATE MEASURED	WATER LEVEL
AUG 11,1978	11.00

21N/06E-29A04
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 162.00

DATE MEASURED	WATER LEVEL
AUG 11,1978	11.00

21N/06E-29B02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 154.50

DATE MEASURED	WATER LEVEL
JAN 11,1978	5.00
MAY 12,1980	4.07

21N/06E-29B04
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 175.00

DATE MEASURED	WATER LEVEL
MAR 17,1980	18.00

21N/06E-29C01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 152.40

DATE MEASURED	WATER LEVEL
AUG 07,1979	5.98
MAR 05,1980	6.71
APR 02,1980	7.47
MAY 12,1980	7.70

21N/06E-29C02
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 155.00

DATE MEASURED	WATER LEVEL
JAN 10,1978	8.00

21N/06E-29C03
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 155.00

DATE MEASURED	WATER LEVEL
NOV 29,1979	9.00

21N/06E-29C04
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 155.00

DATE MEASURED	WATER LEVEL
SEP 25,1976	10.00

21N/06E-29D01
WATER LEVELS IN FEET BELOW LAND SURFACE
LAND SURFACE ALTITUDE 150.00

DATE MEASURED	WATER LEVEL
SEP 27,1976	8.00

TABLE 4.--Water-level observations of the Green River, near well 29A2

Date of observation	Water level in feet above mean sea level
1/25/80	157.20
3/5/80	158.40
3/25/80	157.70
4/2/80	157.80
5/1/80	158.10
5/12/80	157.50
1/7/81	157.80
1/9/81	157.50
3/12/81	156.90
7/2/81	157.05