UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

AVAILABILITY OF GROUND WATER FROM THE ALLUVIAL AQUIFER ON THE NISQUALLY INDIAN RESERVATION, WASHINGTON

By W. E. Lum II

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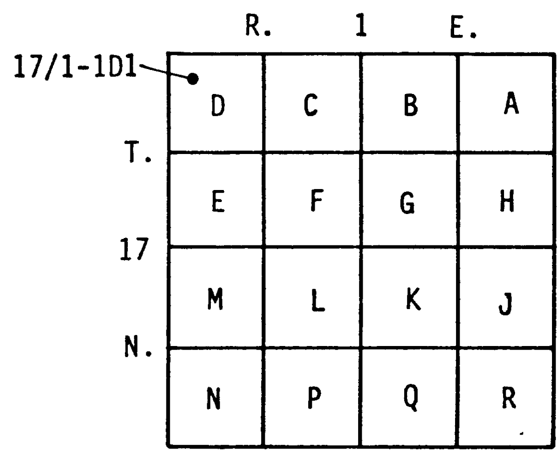
WELL-NUMBERING SYSTEM

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 17/1-1D1, the part preceding the hyphen indicates, successively, the township and range (T.17 N., R.1 E.) north and east of the Willamette base line and meridian. The first number following the hyphen indicates the section (sec. 1), and the letter (D) indicates the 40-acre subdivision of the section as shown in the accompanying diagram.



Section 1

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 17/1-1D1 is in the NW¼NW¼ sec.1, T.17 N., R.1 E., and is the first well in the tract to be listed. For simplification, wells are referred to in the text only by their section, 40-acre subdivision, and serial number. For example, well 17/1-1D1 is referred to in the text as well 1D1. In figures in this report where locations of wells are shown, the section number is dropped and the same well is marked D1.

METRIC CONVERSION TABLE

Multiply	By	To obtain
inches (in.)	25.4	millimeters (mm)
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)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3s)
feet per day (ft/day)	0.03048	meters per day (m/day)
micromho per centimeter at 25° Celsius (umho/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)
degrees Fahrenheit (°F)	0.555, after subtracting 32	degrees Celsius (°C)

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 GROUND WATER FROM THE ALLUVIAL AQUIFER ON THE NISQUALLY INDIAN RESERVATION, WASHINGTON

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ABSTRACT

The hydrology of an alluvial aquifer adjacent to the Nisqually River was studied to determine the feasibility of increasing the quantity of ground water needed to supply an enlarged hatchery facility on the Nisqually Indian Reservation. A model was constructed and calibrated to simulate ground-water flow in the alluvial aquifer. Model results indicate that an additional 4.5 cubic feet per second can be obtained from six wells located along the Nisqually River. Six wells spaced at 250-foot intervals along the Nisqually River could be pumped continuously at 0.75 cubic foot per second (340 gallons per minute). Data were obtained from 22 test holes ranging in depth from 10 to 100 feet drilled for this project. The saturated thickness of the alluvium ranged generally from 10 to 60 feet in the area investigated. The water table is usually less than 10 feet below land surface. Based on available data, the water-bearing deposits underlying the alluvial aquifer have a low hydraulic conductivity and the cost of pumping water from the aquifer is high. These deposits were not investigated further for this study.

A two-dimensional numerical computer model developed by the U.S. Geological Survey simulated measured water levels in the alluvial aquifer (area investigated is 1.1 square miles) to within about ± 1 foot at 13 of 17 test-hole locations throughout the model area and within ± 2 feet at 16 of 17 test-hole locations. In the calibrated model values for the hydraulic conductivity of the aquifer ranged from 8.5 to 170 feet per day. The leakage coefficient of the riverbed material was determined to be 0.06 foot per day. Rate of rainfall recharge to the aquifer is 10 inches per year.

The source of 90 to 100 percent of the water pumped from simulated wells was induced recharge from the Nisqually River into the aquifer and (or) reduced discharge from the aquifer to the Nisqually River. Near steady-state drawdown would be reached within 9 months of continuous pumping. Wells drilled for a large-demand use such as a fish-hatchery supply will achieve the highest yields if they are placed close to the Nisqually River where it was determined that the saturated thickness and hydraulic conductivity of the alluvial aquifer was greatest.

INTRODUCTION

The Nisqually Indian Tribe is currently (1980) operating a fish hatchery near the Nisqually River on the Nisqually Indian Reservation, Washington (fig. 1). The hatchery uses water pumped from a nearby spring-fed stream and a deep well (several open intervals between 162 and 219 feet below land surface). This water-supply system is considered inadequate for use in the hatchery due to problems with increased silt and organic material in the stream during part of the winter and spring. Also, the quantity is inadequate for expanding the present activities, and pumping costs for the deep well are considered excessive due to a large drawdown and the resulting high pumping lift. If a reliable and less costly source of ground water could be found, the hatchery activities could be expanded.

The U.S. Geological Survey entered into a cooperative agreement with the Tribal Council to study the availability of ground water from the alluvial aquifer adjacent to the Nisqually River. The near-surface alluvial materials were considered as a potential source of additional ground water for use in an expanded hatchery for the following reasons:

1. Numerous springs, streams, ponds, and swampy areas near the hatchery indicated the occurrence of ground water in the near-surface materials.

2. Costs of exploration for aquifers deeper than the one tapped by the existing well mentioned above would be excessive.

However, very few data were available on the character of the alluvial materials. In exploring for deeper productive aquifers, existing wells had been drilled and cased through the alluvium.

Purpose and Scope

The purposes of this study are: (1) to determine if additional quantities of ground-water can be obtained from the alluvial aquifer system, (2) to understand or clarify the conceptual operation of the stream-aquifer system, and (3) to postulate the affects of additional ground-water development upon the stream aquifer system.

During the course of this study data were collected and analyzed concerning the hydraulic properties of the alluvium, the source of the observed ground water. Numerous boreholes were drilled in the alluvium and samples of the materials penetrated were examined. Geophysical logs were completed on four of the boreholes. This information was used to determine the permeability of the alluvium and the altitude of the bottom of the alluvial aquifer. Water levels were measured in piezometers over a period of more than 6 months. Staff gages were installed to measure the altitude of the water surface in the river and a pond.

The geohydrologic information gathered was used to calibrate a numerical computer model to simulate the flow of ground water in the alluvial aquifer. When the numerical model was able to duplicate observed conditions in the aquifer, pumping from wells in the aquifer was simulated. The results were then analyzed to determine the availability of water from the alluvial deposits and the source of the water discharged by the simulated pumping wells.

Description of the Study Area

The area decribed in this report is part of the Nisqually Indian Reservation, which is about 10 miles east of Olympia in the Puget Sound lowland area of western Washington (fig. 1). The reservation occupies 2.6 square miles of land south and west of the Nisqually River, including a relatively flat prairielike upland and a flood plain adjacent to the river. The upland area and the flood plain are separated by a steep bluff that ranges from 100 to 200 feet in height. The study area (area covered by model is about 1.1 square miles) includes both uplands and the flood plain.

Residential and commercial development of the reservation is limited primarily to the upland areas. However, a tribally operated fish-rearing facility and several mobile homes are located on the flood plain.

The study area has a climate typical of the Puget Sound lowland, with mild, wet winters and cool, dry summers. More than three-fourths of the nearly 40 inches of yearly precipitation, mostly rainfall but with some snow, occurs from early October through March.

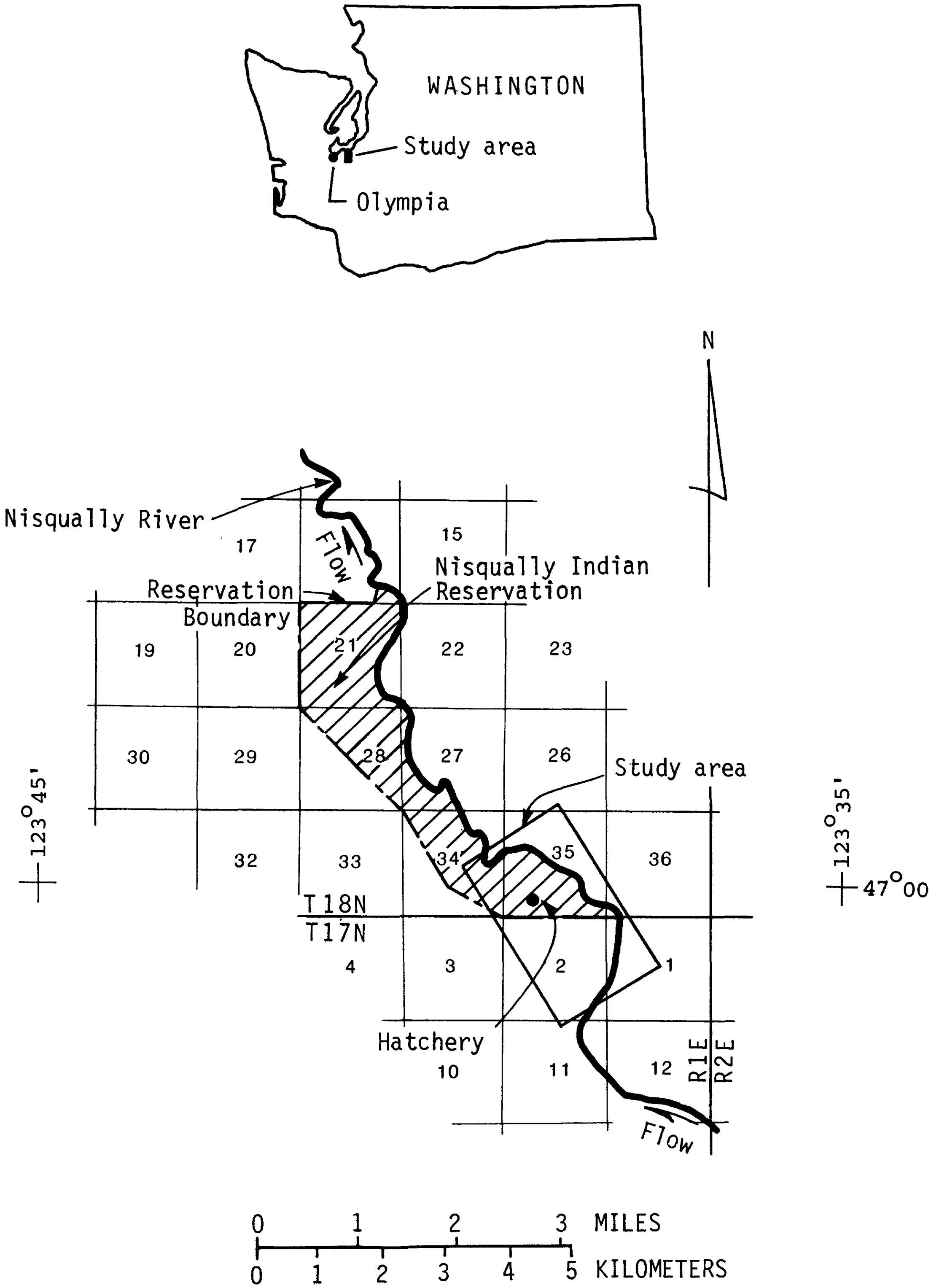


FIGURE 1.--Location of the study area.

Previous Investigations

The Nisqually Indian Reservation was included in the area covered by a general investigation of the geology and ground-water resources of Thurston County by Wallace and Molenaar (1961) and Noble and Wallace (1966). The countywide studies included a canvass of some of the wells on the reservation and a geologic reconnaissance of the area. Ground water in the area of nearby Yelm was studied by Mundorff, Weigle, and Holmberg (1955).

Myers and Cummans (1973) studied the reservation and surrounding area and evaluated the potential for contamination of the ground-water system, water usage, ground- and surface-water quality, and flow characteristics of the Nisqually River.

The soils of the area were examined in a countywide study by Ness and others (1958).

A general evaluation of the hydrologic characteristics of the Nisqually River basin is included in a study by the Puget Sound Task Force, Hydrologic Studies Technical Committee (1970), and the low-flow and temperature characteristics of the Nisqually River were included in studies by Hidaka (1972, 1973). Measurements of water temperature in the Nisqually River were made as part of a statewide study of stream temperatures by Collings (1973) and Collings and Higgins (1973). All these studies were used as background data for this study; however, none dealt specifically with the alluvium or its water-bearing capabilities.

DATA COLLECTION

Exploratory test holes were drilled and cased in the flood-plain area adjacent to the Nisqually River to obtain data on the alluvial aquifer (fig. 2 and table 1). The permanently installed casing (or piezometer) allowed measurements of water levels representative of the aquifer material adjacent to the hole bottom or other openings in the casing.

Project personnel used a truck-mounted hollowstem auger to drill 17 boreholes and install 1-inch wire-wrapped well points attached to 2-inch galvanized pipe, the latter extending above land surface. Five boreholes were drilled using cable-tool percussion-type drilling equipment and were cased with 6-inch-diameter well casing; the wells are finished as shown in table 1.

During all drilling operations, the drilling returns were examined to determine the materials present (see table 2, end of report). Slug tests, bail tests, water-level fluctuations, and other observations were used to estimate the permeability of these materials relative to the materials found in other boreholes in the project area. When drilling was completed, four of the five 6-inch-diameter wells (35K2, 35M2, 35P3, and 35R2) were logged geophysically (figs. 3a-d) to gain more information on the permeability and composition of the materials penetrated.

TABLE 1.--Piezometer data

Piezometer No.	Diameter of casing (inches)	Depth to bottom of well point or openings (feet below land surface)
1D1	2	14.3
1E1	2	11.7
1E2	2	9.6
1M1	2	14.0
2A1	2	17.5
2B1	2	16.7
2R1	2	14.7
2R2	2	13.8
34J1	2	22.2
35F1	2	29.0
35K1	2	13.2
35K2	6	[a]100.0
35L1	2	36.7
35M1	2	29.1
35M2	6	[b]40.0
35N1	2	27.6
35P2	2	14.1
35P3	6	[c]49.4
35R1	2	13.5
35R2	6	[a]18.0
35R3	6	[a]100.2
36N1	2	22.7

[a]Casing open at bottom.
[b]Perforations in casing.
[c]Break at weld in casing, total depth 84 feet.

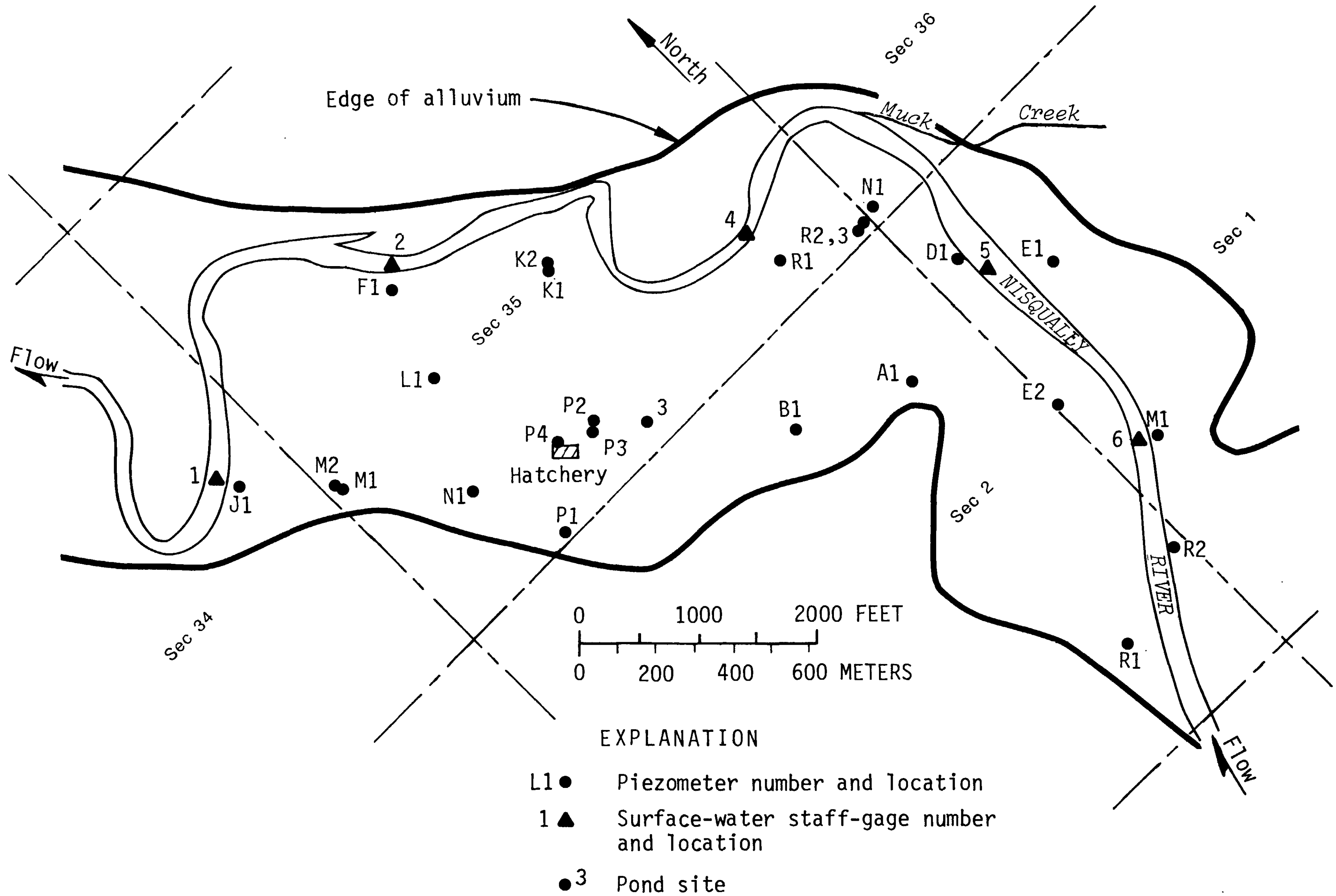


FIGURE 2.--Location of piezometers in the study area.

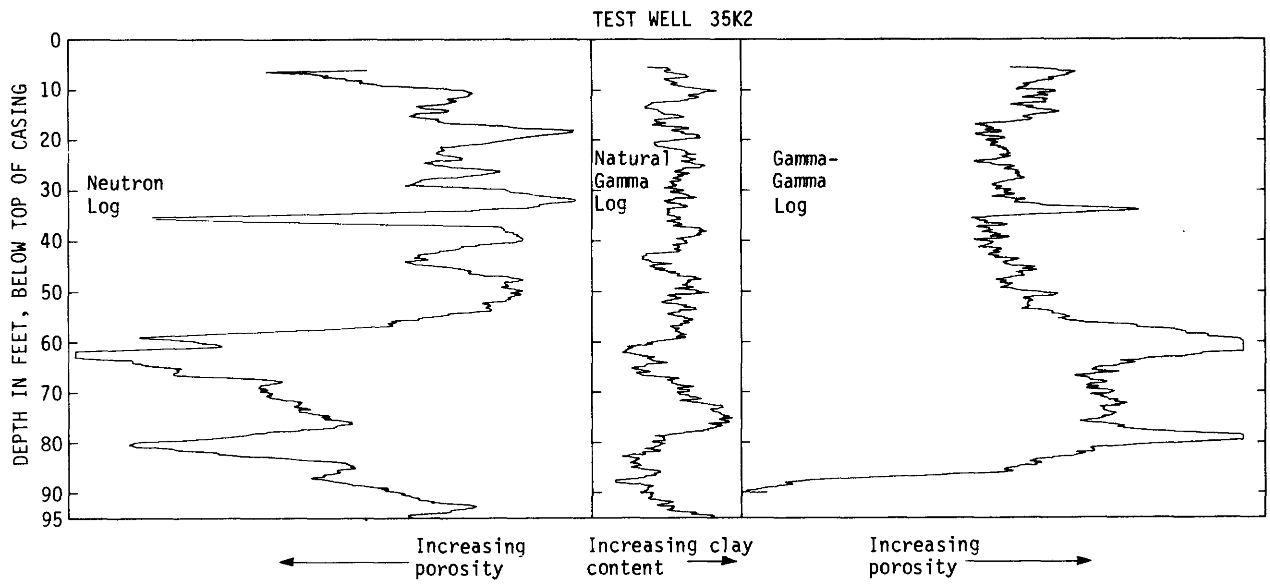


FIGURE 3a.--Geophysical log of test well 35K2.

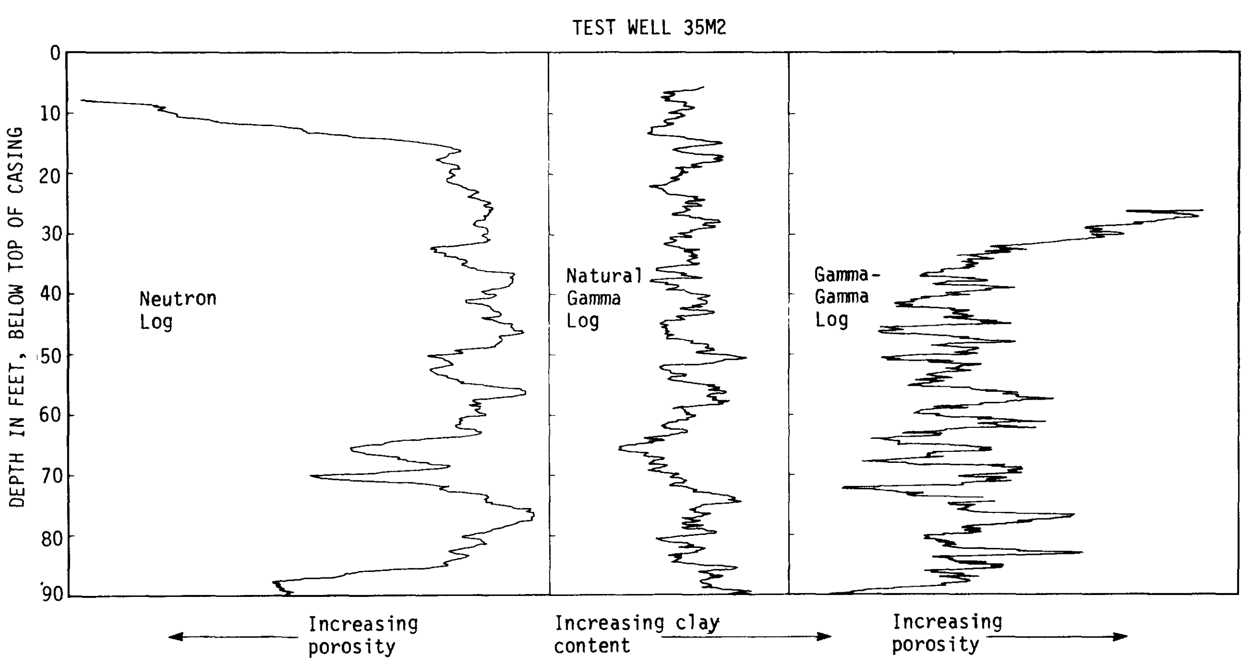


FIGURE 3b.--Geophysical log of test well 35M2.

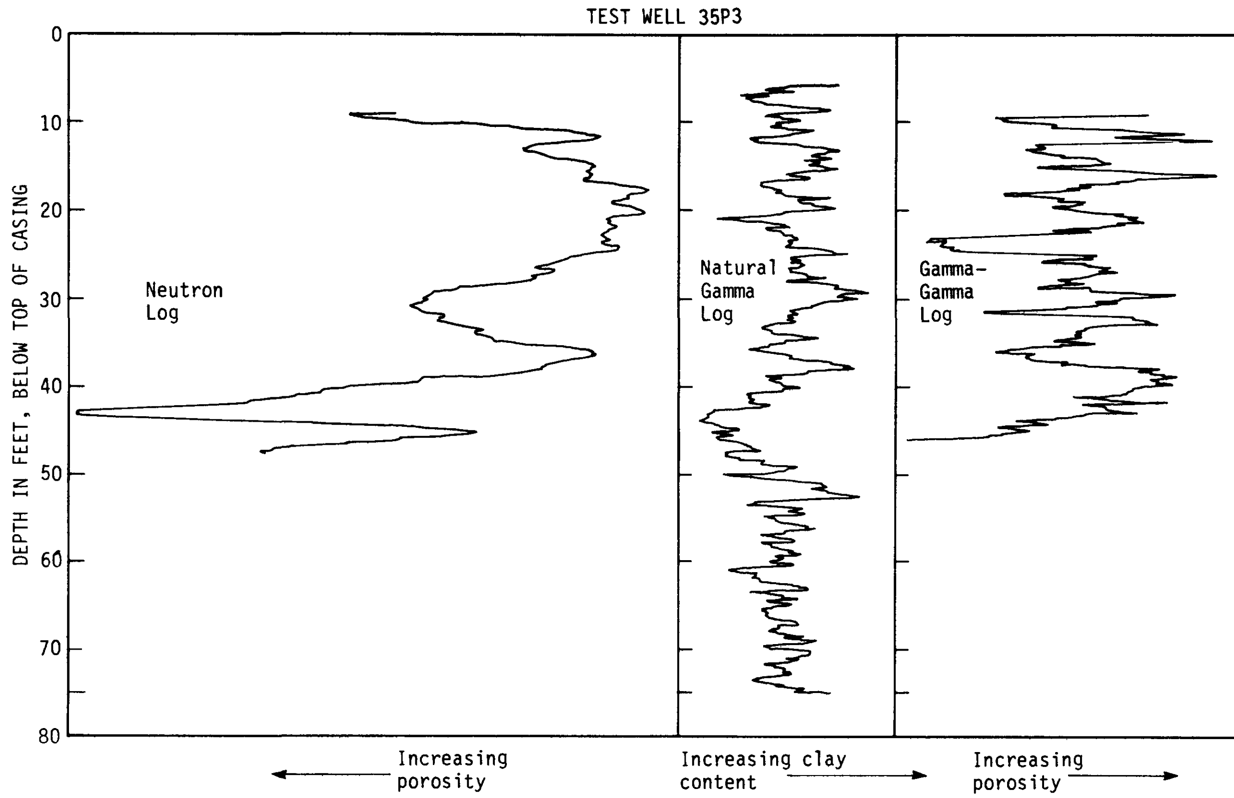


FIGURE 3c.--Geophysical log of test well 35P3.

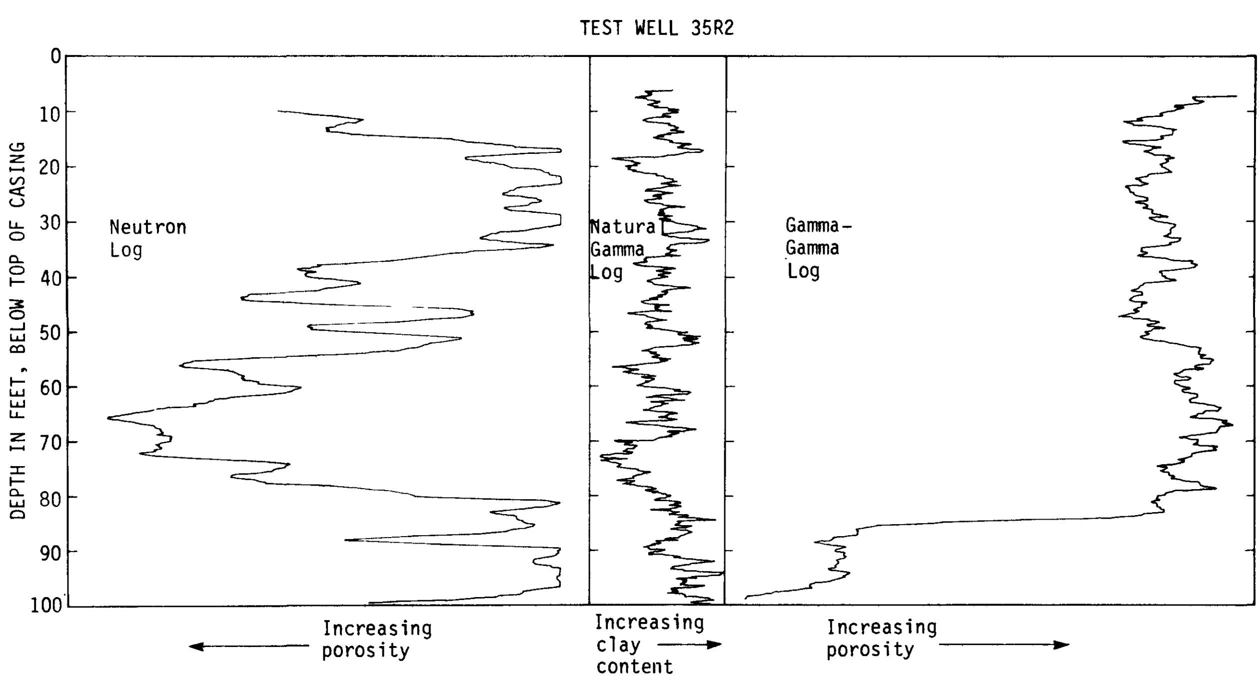


FIGURE 3d.--Geophysical log of test well 35R2.

CHARACTERISTICS OF THE AQUIFER

Geology

The Nisqually Indian Reservation is underlain to a depth of at least several hundred feet by unconsolidated to poorly consolidated glacial and nonglacial deposits consisting mainly of till and (or) various mixtures of sand, gravel, silt, and clay. Underlying these deposits to an unknown depth are older volcanic and consolidated sedimentary rocks (Noble and Wallace, 1966).

Younger alluvial deposits which consist of more permeable mixtures of sand, gravel, silt, and some clay were deposited in a valley previously cut into the surrounding till-covered uplands by the Nisqually River (shown in figs. 4 and 5). These deposits form the flood plain adjacent to the Nisqually River, in the area where the computer model was applied.

Altitude of the Bottom of the Alluvium

The altitude of the bottom of the alluvium (fig. 6a) was determined from geophysical logs of four wells (figs. 3a-d) and geologic logs of all wells (table 2). This information was supplemented by examination of the surficial materials and the deposits exposed in road cuts and pits in the area. In general, materials below the alluvium were observed to have a lower permeability. A review of the work done earlier in this area by Noble and Wallace (1966) and Myers and Cummans (1973) provided additional information on the thickness of the alluvium in nearby areas.

Saturated Thickness of the Alluvium

The saturated thickness of the alluvium (fig. 6b) was determined by subtracting the altitude of the bottom of the alluvium (fig. 6a) from the water-level altitude as measured in piezometers on November 15, 1979 (fig. 9). Saturated thickness of the alluvium ranged from 10 to 60 feet in the area investigated.

Hydraulic Conductivity

Extensive testing of the alluvium would be required to determine accurately the aquifer hydraulic conductivity in the model area. This was beyond the scope of this project. It was possible, however, to make estimates of the areal variations in hydraulic conductivity of the alluvium (fig. 7). The following estimated values of relative hydraulic conductivity were assigned to the alluvium: 1, fine-grained materials; 10, coarse-grained materials; and 20, very coarse-grained materials. These values were based on information such as water-level fluctuations, slug and bail tests of the piezometers, examination of drill cuttings, geophysical logs, and other field observations gathered during this and numerous studies. The value of the hydraulic conductivity was refined on the basis of the results of the computer flow model (discussed later in the report).

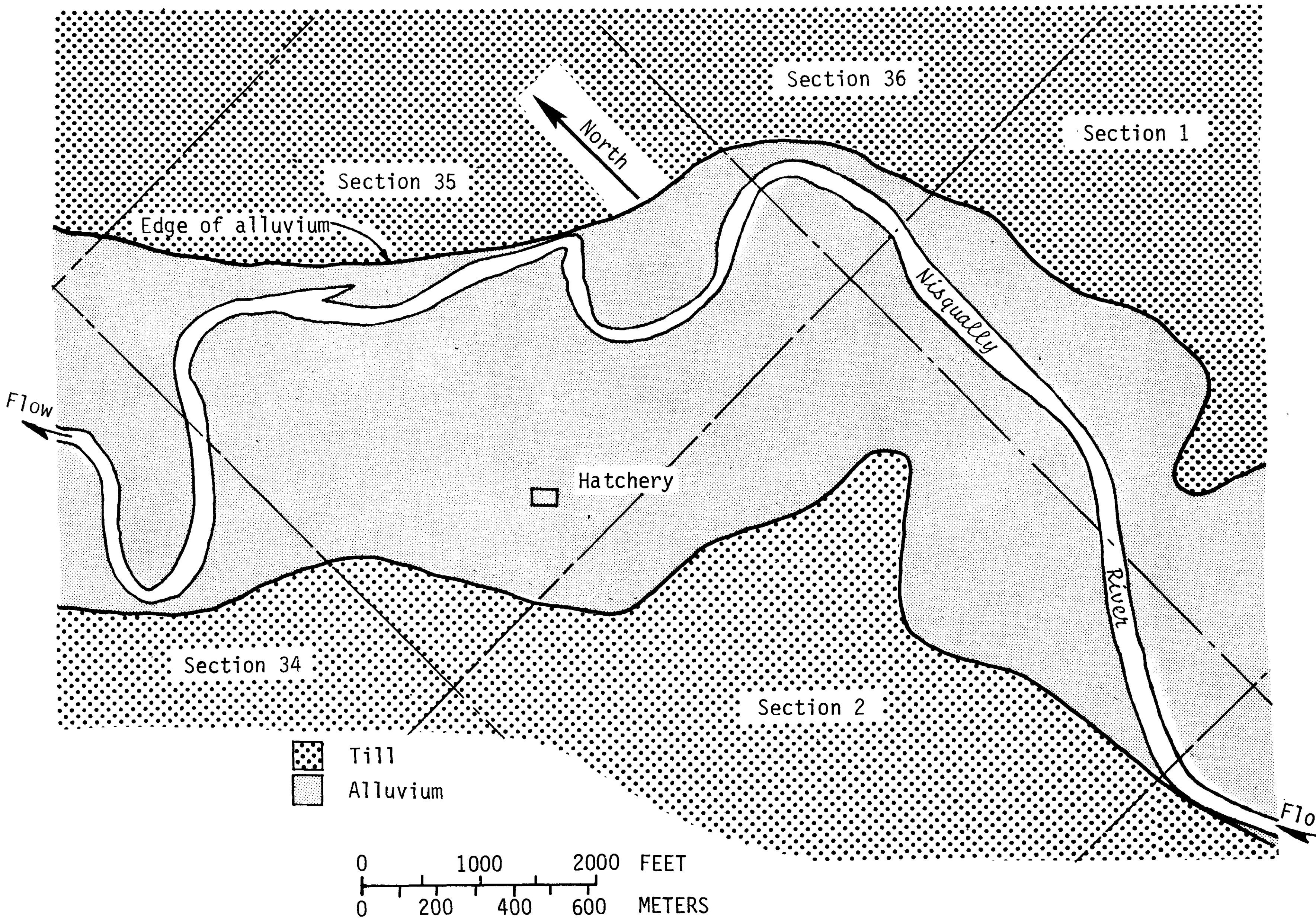


FIGURE 4.--Surficial geology of the study area.

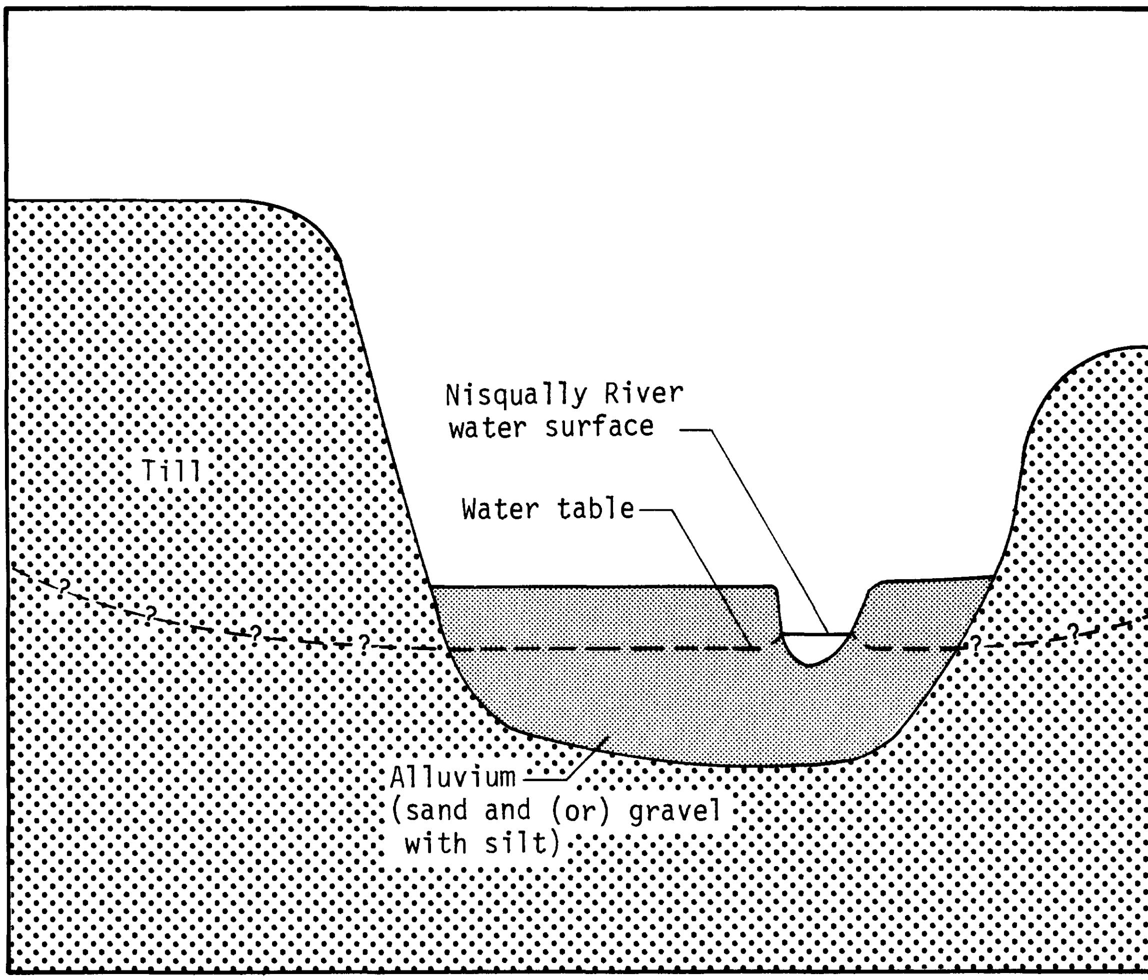


FIGURE 5.--Idealized hydrogeologic section through the study area.

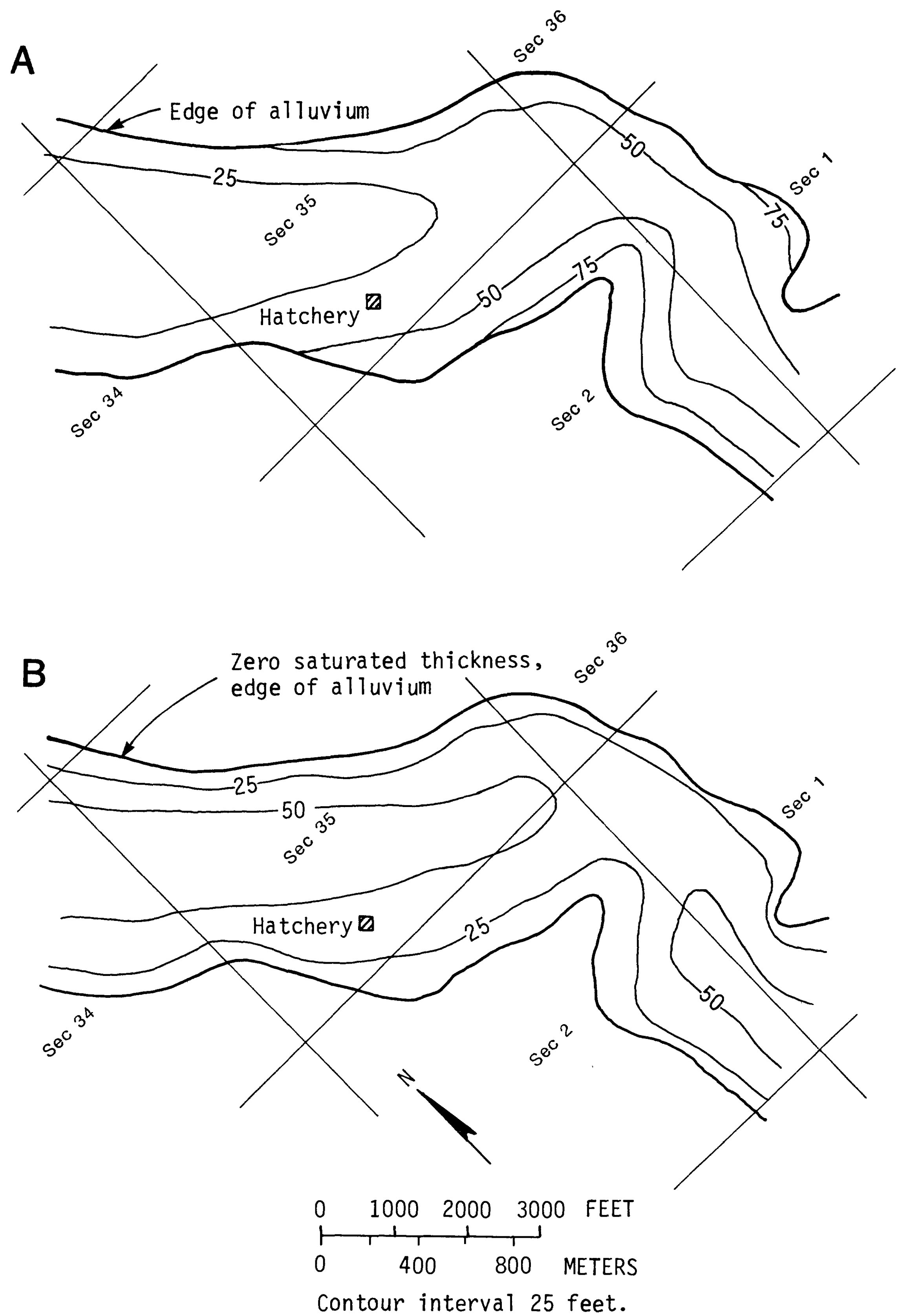
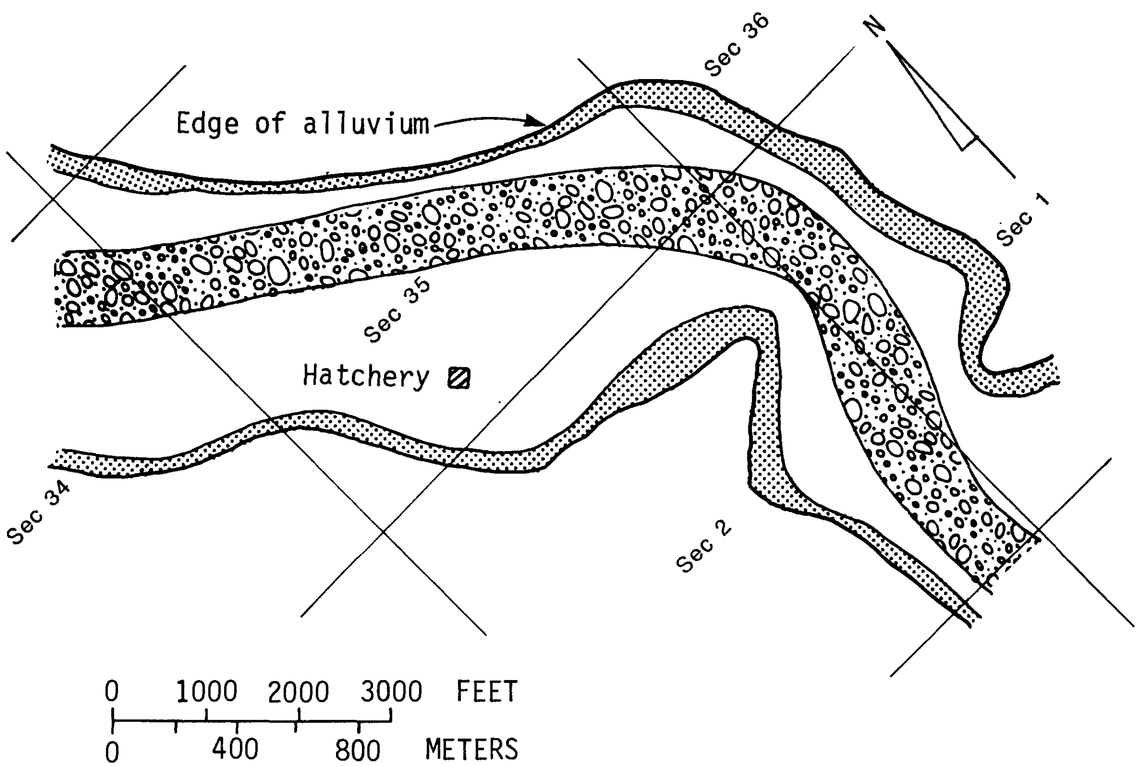


FIGURE 6.--(a) Approximate altitude of the bottom of the alluvium, and (b) approximate saturated thickness of the alluvium.



EXPLANATION

Areal variations in hydraulic conductivity of the alluvium :

Very coarse materials, boulders, cobbles, sand, and gravel

Coarse materials, cobbles, sand, gravel, and some silt

Fine-grained materials, sand, gravel, silt, and clay with some very fine grained landslide materials

FIGURE 7.--Estimated relative hydraulic conductivity and lithology of the alluvium in the study area.

Fluctuations and Altitude of the Water Table

The water table—the top of the zone of water-saturated materials—in the alluvial aquifer ranges from 3 to 12 feet below land surface in the study area. Annual variations in the water-table altitude due to seasonal changes in rainfall, river altitude (or stage), evaporation, pumpage, and transpiration of ground water by vegetation range from 1 to 3 feet (Mundorff and others, 1955). Water levels are generally lower in the late summer-early fall, when rainfall is less, the river is at a lower stage (generally, a lower flow rate), and water use by man and vegetation is higher. In winter, a higher river stage (and an increase in flow rate), increased rainfall, and reduced water use by man and vegetation cause the water table to rise. A tabulation of water levels measured in all piezometers appears in table 3 (end of report), and a tabulation of water-level altitudes at selected surface-water sites appears in table 4 (end of report).

The limited period of data collection for this study does not show seasonal variations very clearly. However, figure 8 shows the response of the water table to rainfall and river-stage variations. Small amounts of rainfall from October 27 to November 29 had little measureable effect on the river stage or the water table. The large amount of rain occurring December 1-4 caused an increase in the altitude of the water table in the alluvium, the river stage, and the altitude of the water surface in a pond near the hatchery. The highest water levels were not measured however, and by the time measurements were made on December 6, water levels were declining. Figure 9 shows the altitude of the water table in the alluvium on November 15, 1979.

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 10. Sources of water moving into the alluvial ground-water system include infiltration of precipitation, downward leakage from the Nisqually River and nearby springs, 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 upward leakage into the Nisqually River. This is in addition to ground water that is moving laterally through the alluvium into or out of the model area at its upstream and downstream ends. Field data indicate that all these interactions (as shown in fig. 10 and described above) between the surface- and ground-water systems occur in the modeled area.

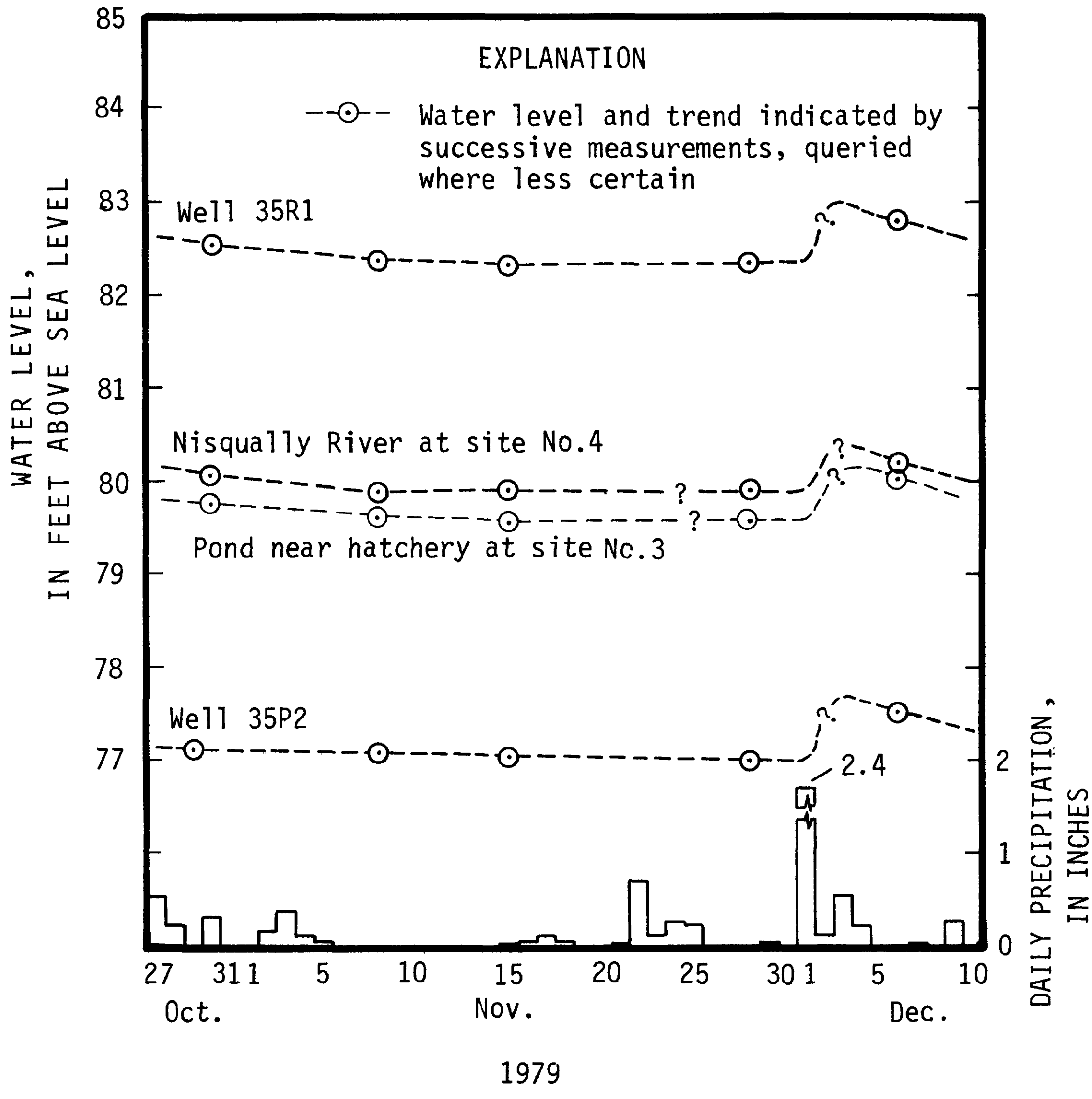


FIGURE 8.--Water-level fluctuations in the study area, and rainfall at Olympia, Washington.

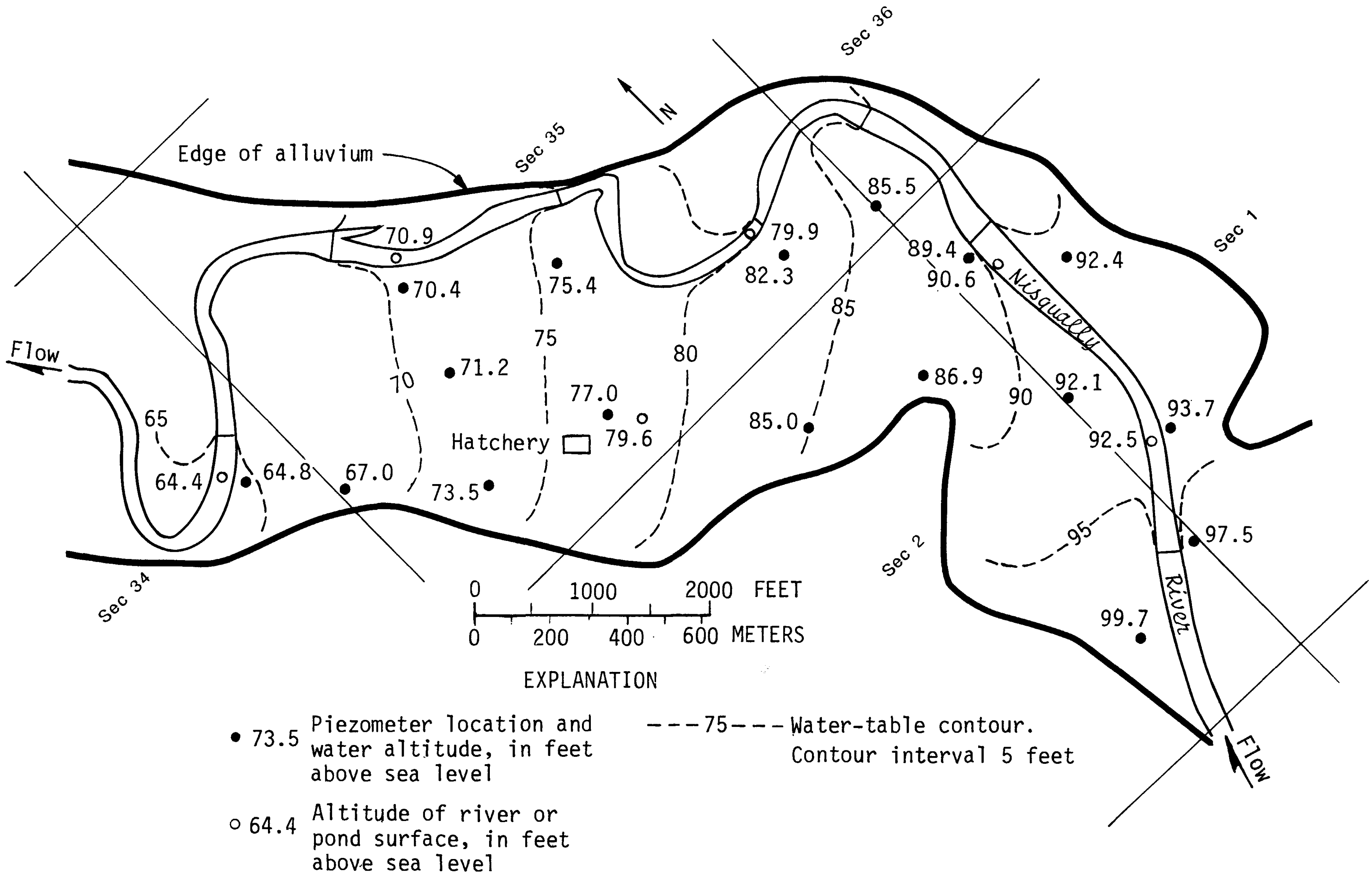


FIGURE 9.--Altitude of the water table and river surface on November 15, 1979.

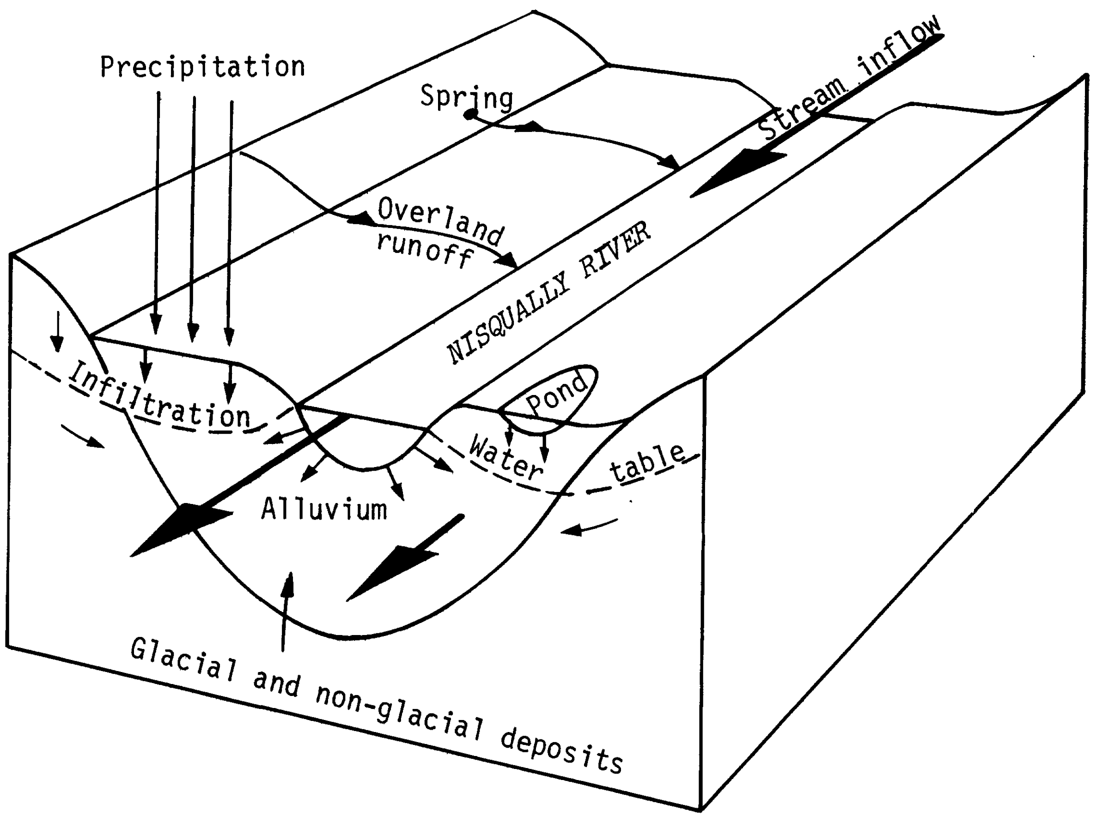


FIGURE 10.--Diagrammatic sketch of the movement and interaction of ground and surface water in the study area.

COMPUTER MODEL

Computer Program

The computer program used to simulate ground-water flow for this project 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 are described by Trescott, Pinder, and Larson (1976) and will not be discussed further in this report.

The numerical computer model requires data on the hydraulic characteristics of the aquifer, its physical boundaries, and the rate of recharge to the aquifer. Distribution and rates of water withdrawn from the aquifer must also be identified. On the basis of these data, water levels are calculated by the model. Information concerning the edges of the model, subdivision of the model area, assumptions made when using the particular mathematical scheme of the model, and adjustments to the model are discussed below.

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 for the simulation of the Nisqually 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 bottom of the Nisqually River in the model area has uniform leakage characteristics and hydraulic conductivity lower than that of the aquifer material.

5. Blocks located at the upstream and downstream ends of the model area (see "Boundaries of the Model," page 20) are assumed to have a water-table altitude (and saturated thickness) that does not vary with time or with the amount of water flowing through them.

6. The only ground water flowing in the model area is that due to recharge from rainfall in the model area, leakage out of and into the Nisqually River (from or to the alluvial aquifer), and ground water flowing downvalley at the model's upstream and downstream ends.

7. Ground-water interaction between the alluvium and the underlying deposits, spring discharge from the alluvium, and any ground-water flow to or from small streams and (or) ponds were not considered during simulation of the alluvial aquifer.

The grid spacing and orientation (fig. 11) were chosen to come as close as possible to fulfilling assumptions 1 and 2. Assumptions 3 through 5 are commonly used in modeling of ground-water flow and have little effect on the results of this model. Assumptions 3, 6, and 7, by ignoring possible ground-water inflow into the model area, may make the results of simulated water-level drawdown more than that which would occur in nature.

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 (fig. 12). Theoretically, this could allow large amounts of ground water to enter the model through the upstream end or leave it through the downstream end. This assumption probably has little effect on the results because (1) the quantity of water that actually enters or leaves the area through each block depends on the hydraulic characteristics of adjacent blocks in the modeled area; (2) the hydraulic characteristics assigned to the blocks adjacent to the boundary blocks are based on observed conditions and the assumptions stated earlier; and (3) the boundary blocks are located a considerable distance from the present fish hatchery where the additional pumping stress was applied in this study.

The two sides of the modeled area where the alluvium terminates against the till deposits are treated as no-flow boundaries. No water is allowed to enter or leave through these boundaries, as stated in the previous section covering assumptions. By ignoring any possible inflow of ground water from the sides, the drawdown in the model area in response to simulated pumping would be greater than would occur under real conditions.

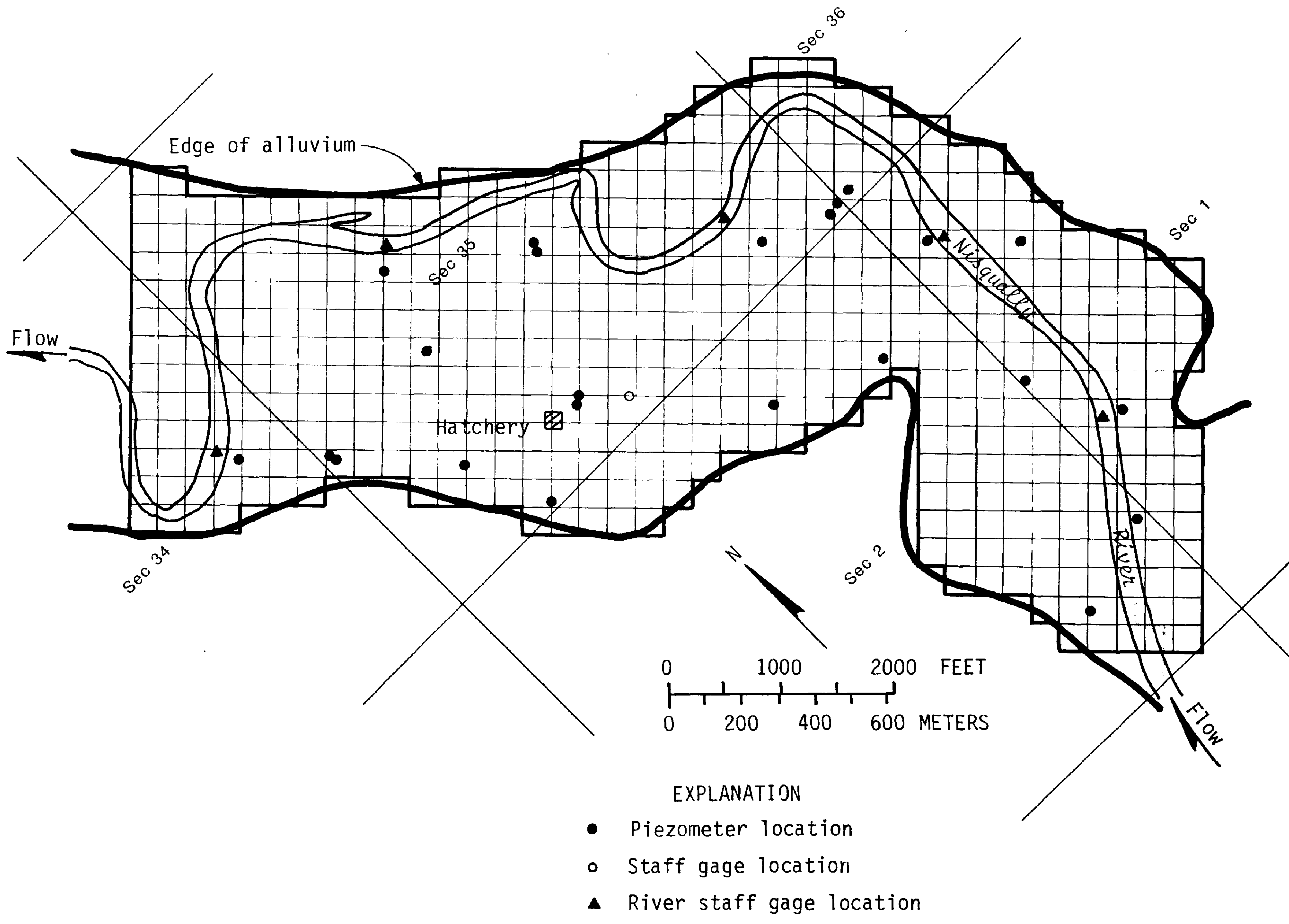


FIGURE 11.--Grid system of the model and its relationship to selected hydrologic features.

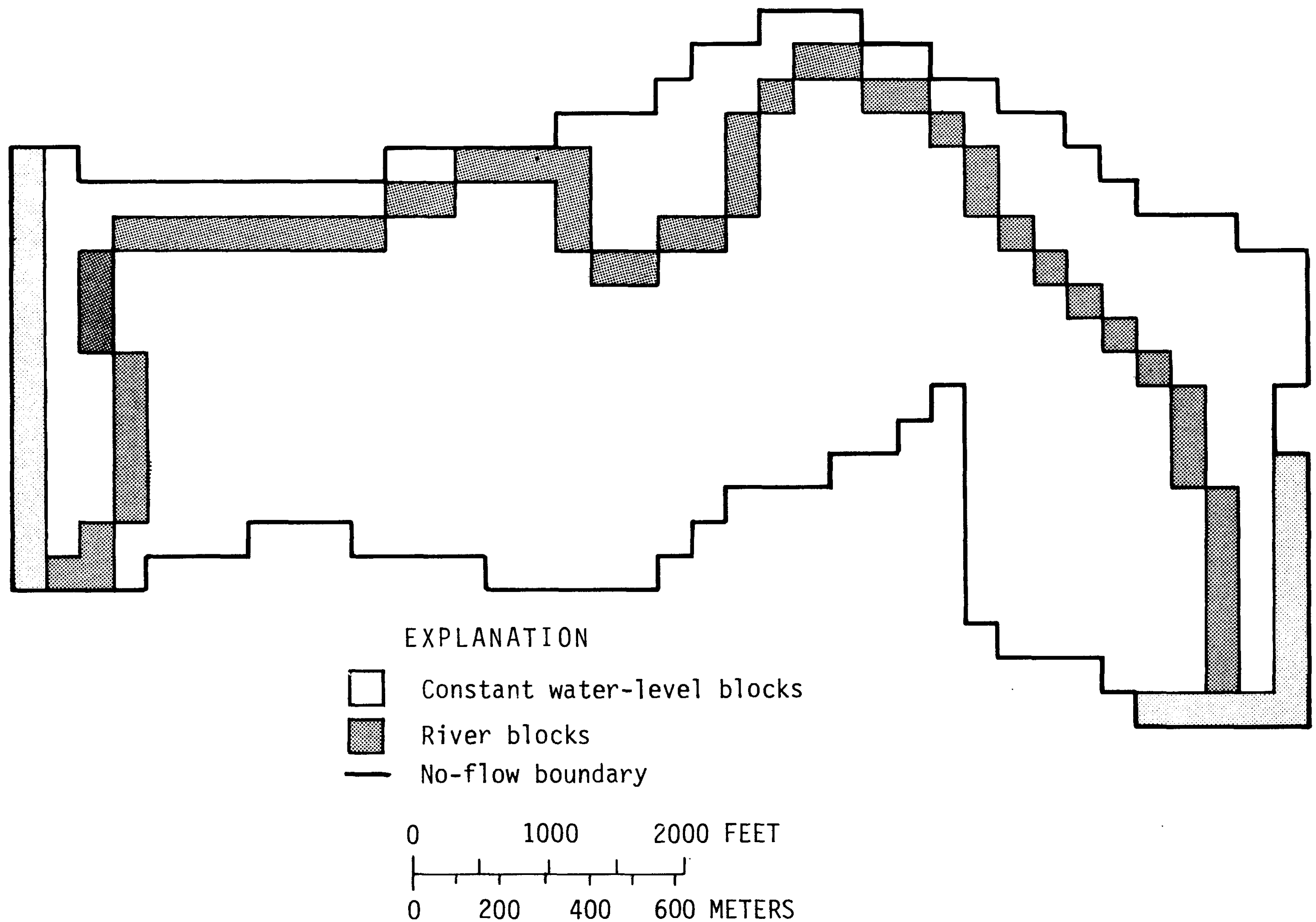


FIGURE 12.--Modeled area with locations of constant head boundaries, no-flow boundaries, and the river blocks.

Model Calibration

After initial estimates of aquifer characteristics were made and boundary conditions were defined, the process of calibration of the model was begun. This trial-and-error process involved making a series of simulations, changing the value of one set of input data (hydraulic conductivity, streambed leakage, recharge, constant water-level boundaries, and so forth) at a time, and then evaluating how closely the model reproduced observed water levels in wells in the model area. The goal was to make the simulations fit as closely as possible to the observed water levels in the aquifer.

Evaluating the quality of fit of the simulation to observed conditions in the aquifer was done with standard statistical techniques using the sum of squares, standard deviation, and mean values. The sum of squares was calculated by taking the difference between the model-simulated water level in the aquifer and the measured water level at each piezometer, squaring the difference, and totaling the values for 17 piezometers 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 mean and standard deviation of the differences were also used to evaluate the quality of fit for each simulation.

The altitude of the bottom of the aquifer and the altitude of the surface of the river were known to be fairly accurate and representative of the true aquifer properties, and were not changed during the calibration process. They were determined (as described earlier in this report) by geophysical logging, from geologic information gathered during drilling, and by a survey of altitudes in the model area. Data that were not well known and could not be accurately determined in the field--hydraulic conductivity of the aquifer, leakage coefficient of the streambed, and rate of recharge to the aquifer from rainfall--were estimated from information available for areas of similar hydrology.

The rate of recharge to the alluvium from precipitation was evaluated first. Rates of 5, 7.5, 10, 12.5, and 15 inches per year were simulated; the results are shown in figure 13a. On the basis of the minimum value for the sum of squares, a recharge rate of 10 inches per year was chosen for the best-fit value. The same technique was used to obtain best-fit values for hydraulic conductivity of the aquifer, and for the streambed leakage coefficient (figs. 13b and c). The hydraulic conductivity of the alluvium was determined to range from 8.5 to 170 ft/day, on the basis of the best fit of observed water levels. This range of values (see fig. 9) means that the very coarse material near the center of the alluvium has a hydraulic conductivity of about 170 ft/day; the coarse materials away from the center, about 85 ft/day; and the fine-grained materials near the edge of the alluvium, about 8.5 ft/day. The value for the leakage coefficient of the streambed material that gave the best fit of observed water levels was 0.06 ft/day.

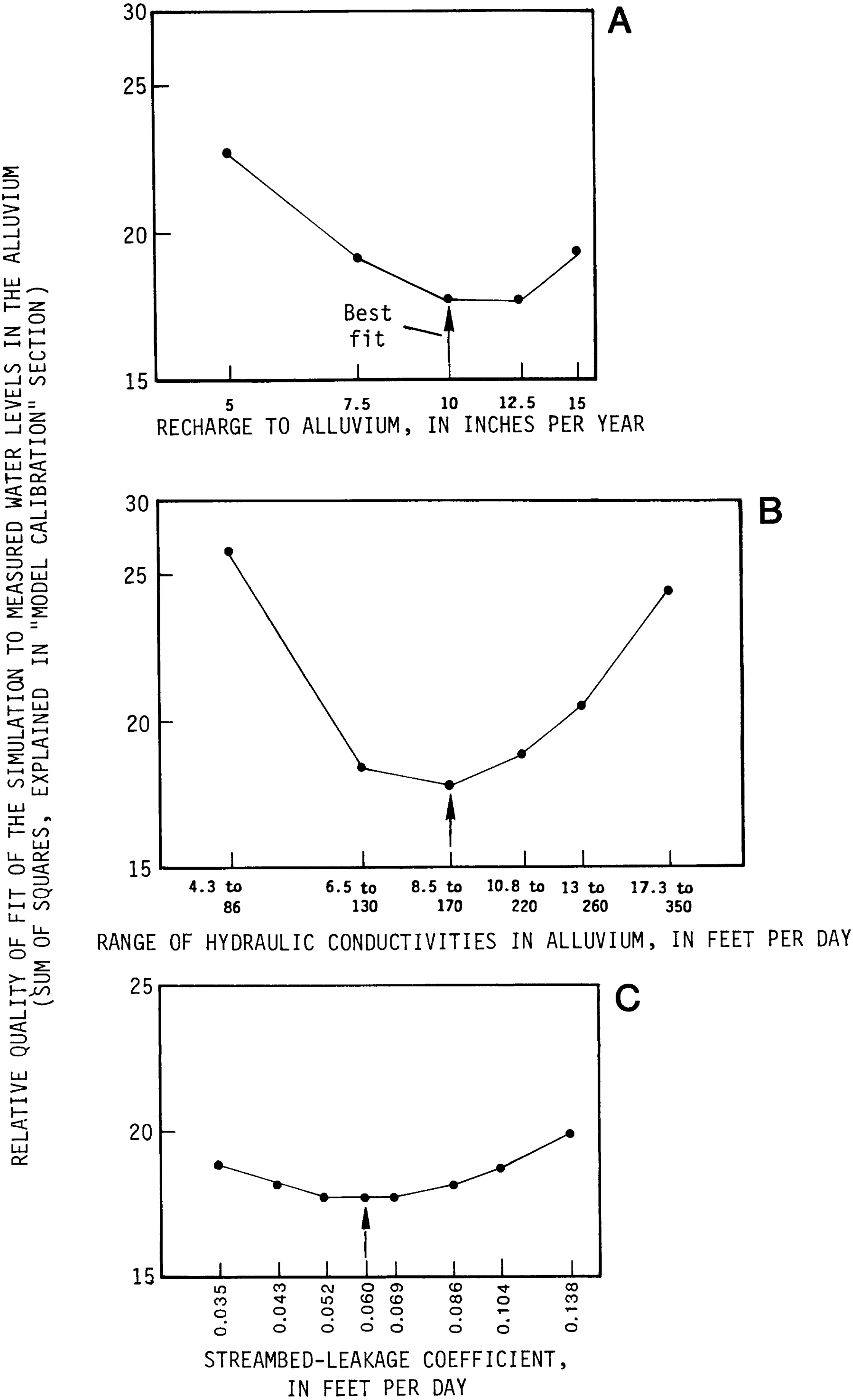


FIGURE 13a-c.--Results of calibration simulations.

The result of the calibration process was that the model was able to simulate water levels, and probably the flow of ground water in the aquifer, with a good degree of accuracy. Below is a tabulation for 17 piezometers of the difference between the measured water-table altitude on November 15, 1979, and the computer-calculated water-level altitude. The table is based on the simulation that was determined to have the best fit to the observed data.

Piezometer No.	Difference (feet)
1D1	0.6
1E1	1.4
1E2	-1.3
1M1	.7
2A1	1.0
2B1	2.7
2R1	.3
2R2	.1
34J1	-.2
35F1	-.7
35K1	.1
35L1	-1.1
35M1	-1.9
35N1	-.2
35P2	.4
35R1	-.1
36N1	-.1

A water-level-contour map (fig. 14) was drawn using altitudes calculated by the model.

The real values of recharge, aquifer hydraulic conductivity, and streambed leakage coefficient could not be determined during the calibration process. Changing the best-fit values for these three variables (all at the same time by the same multiple; for example, multiplying all by 10) produced an exact match on quality-of-fit criteria mentioned above. This emphasizes that there is not a unique set of input data for the model. This does not imply, however, that the model has no correlation with the real conditions in the aquifer and cannot be used to predict the amount of water that can be withdrawn from the aquifer. By determining the absolute value for one of these variables, the other two will be determined approximately.

The actual value for the unit rate of recharge to the aquifer from precipitation, although not accurately known, is between 10 and 20 inches per year (Mundorff and others, 1955). Therefore, by using 10 inches, maximum simulated drawdowns should be obtained when simulating a given pumpage from the aquifer. As determined above, the best-fit solution, using 10 inches per year recharge from precipitation, has a streambed leakage coefficient of 0.06 ft/day and a range of aquifer hydraulic conductivity from 8.5 to 170 ft/day. The riverbed, on the average, covers about half a model block in the model area. Therefore, the ratio of streambed leakage coefficient to aquifer hydraulic conductivity under the steambed is about 1:1400. These values are probably as close to actual values as can be determined without extensive testing of the alluvial aquifer.

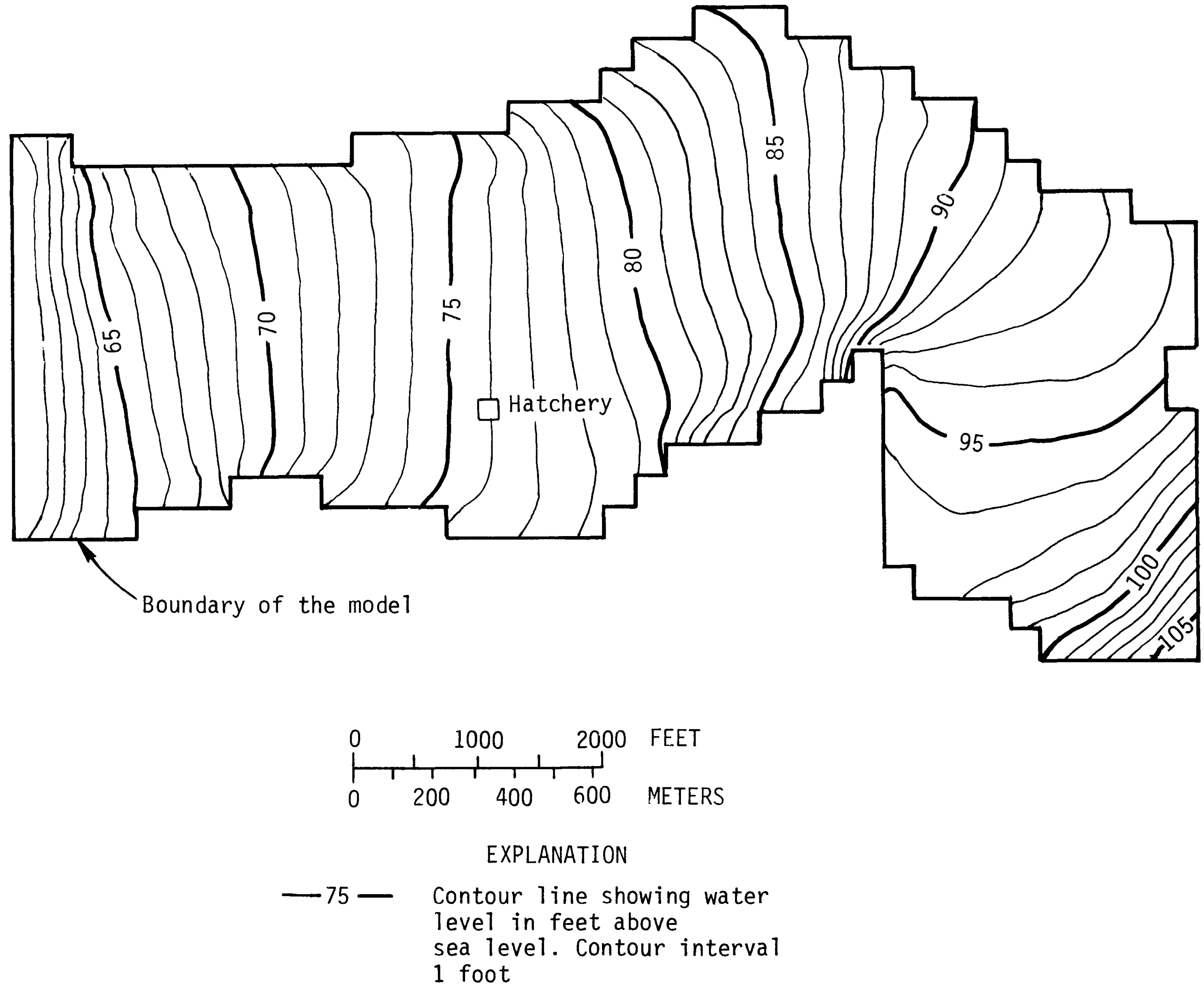


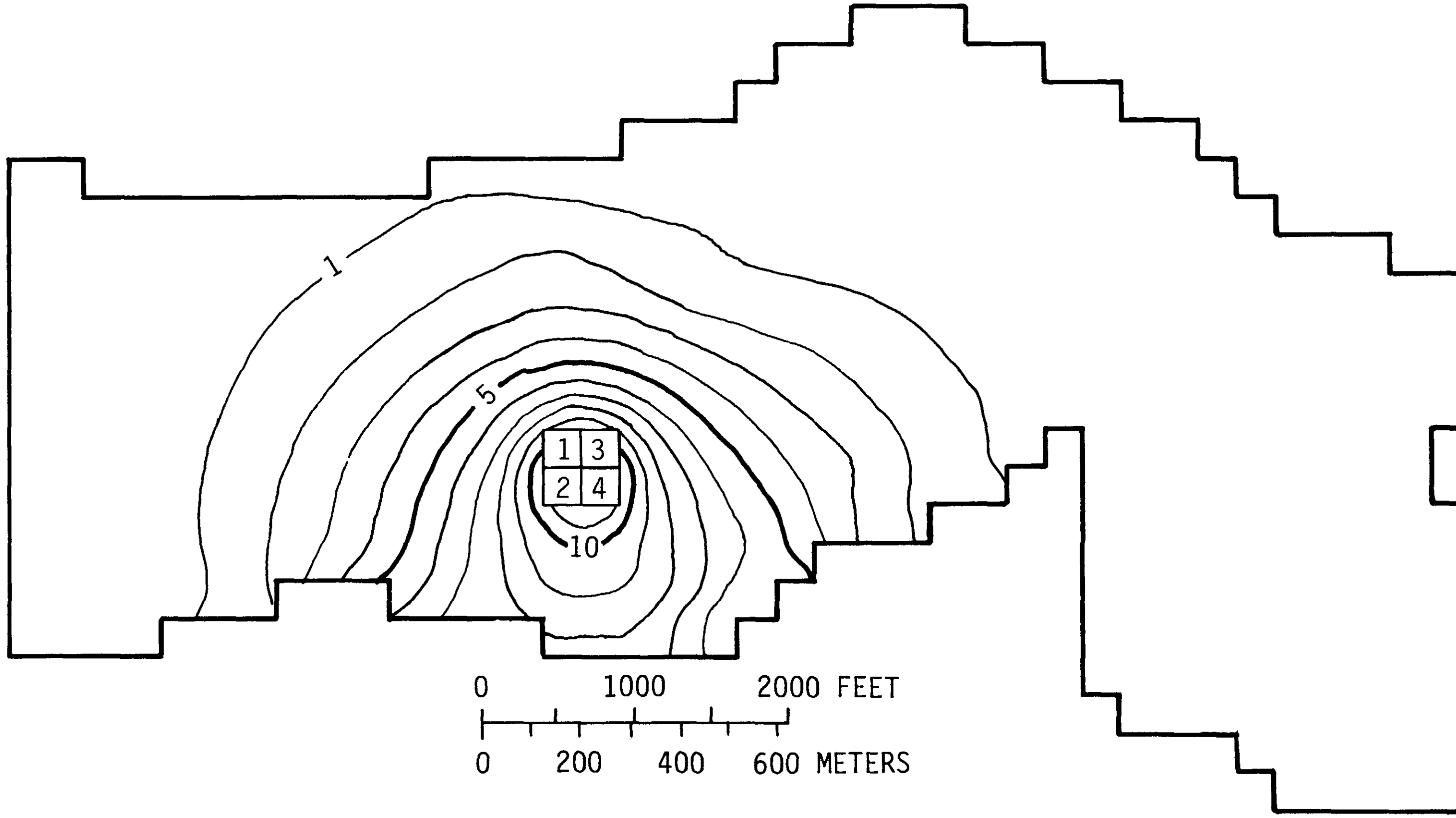
FIGURE 14.--Water-level contour map based on model-calculated water levels.

RESULTS OF AQUIFER SIMULATIONS

Estimates of Ground-Water Availability from the Alluvium

The calibrated model was used to estimate the maximum rate of withdrawal of ground water from the alluvium and the resulting drawdown of the water level for a variety of pumping scenarios. Model results indicate that the maximum pumping rate for four wells at 250-foot spacing near the existing hatchery is 110 gal/min each. Near the Nisqually River, four wells could be pumped at 400 gal/min each and six wells at 340 gal/min each (well spacing 250 feet in each case). The results of these three scenarios are shown in figures 15, 16, and 17. The drawdown in each pumping well (in tabular form on each figure) was calculated on the basis of a properly constructed, 12-inch-diameter well that fully penetrates the aquifer material. The maps represent the drawdown in the aquifer material away from the wells. The rate of pumping for each figure was chosen by assuming that the maximum drawdown in any of the pumping wells must be less than about one-half of the original saturated thickness (altitude of the aquifer bottom subtracted from the altitude of the water table) at that location. The amount of drawdown is for steady-state conditions; that is, the ground-water-flow system has reached a new equilibrium and the drawdown is no longer changing with time. Water is not being removed from storage within the alluvium but is constantly replenished by ground water flowing toward the pumped wells. The source of the water is discussed in the next section of this report. Using a method described by Jenkins (1968), near steady-state conditions of drawdown would be reached within 9 months of continuous pumping at specified rates.

The actual drawdown in the aquifer materials and wells will probably be less than that shown in figures 15-17 because of the assumptions used to calibrate the model. This means that the quantity of water that could be pumped from wells in the alluvium may be larger, by an unknown amount, than the quantities used to obtain the results for the simulations shown.



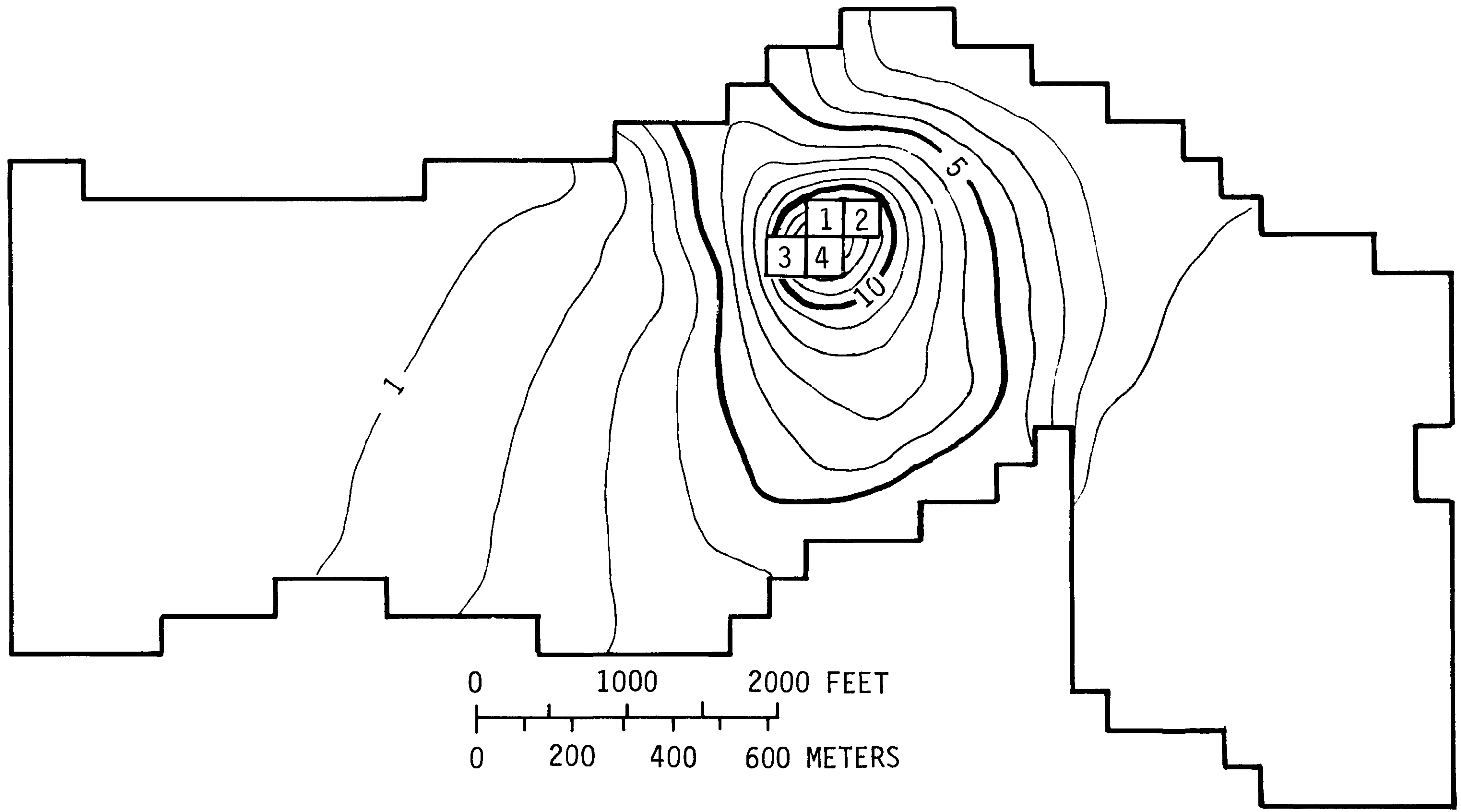
EXPLANATION

[1] Simulated pumping from this node and number of simulated well

— 5 — Contour line indicating water level drawdown due to pumping from alluvium.
Contour interval 1 foot

Well Number	Drawdown (in feet)	Drawdown (in percentage of saturated thickness of aquifer)
1	17	35
2	17	36
3	20	43
4	20	46

FIGURE 15.--Drawdown of water levels in the alluvium due to simulated pumping of four wells near the hatchery at a rate of 110 gallons per minute each.



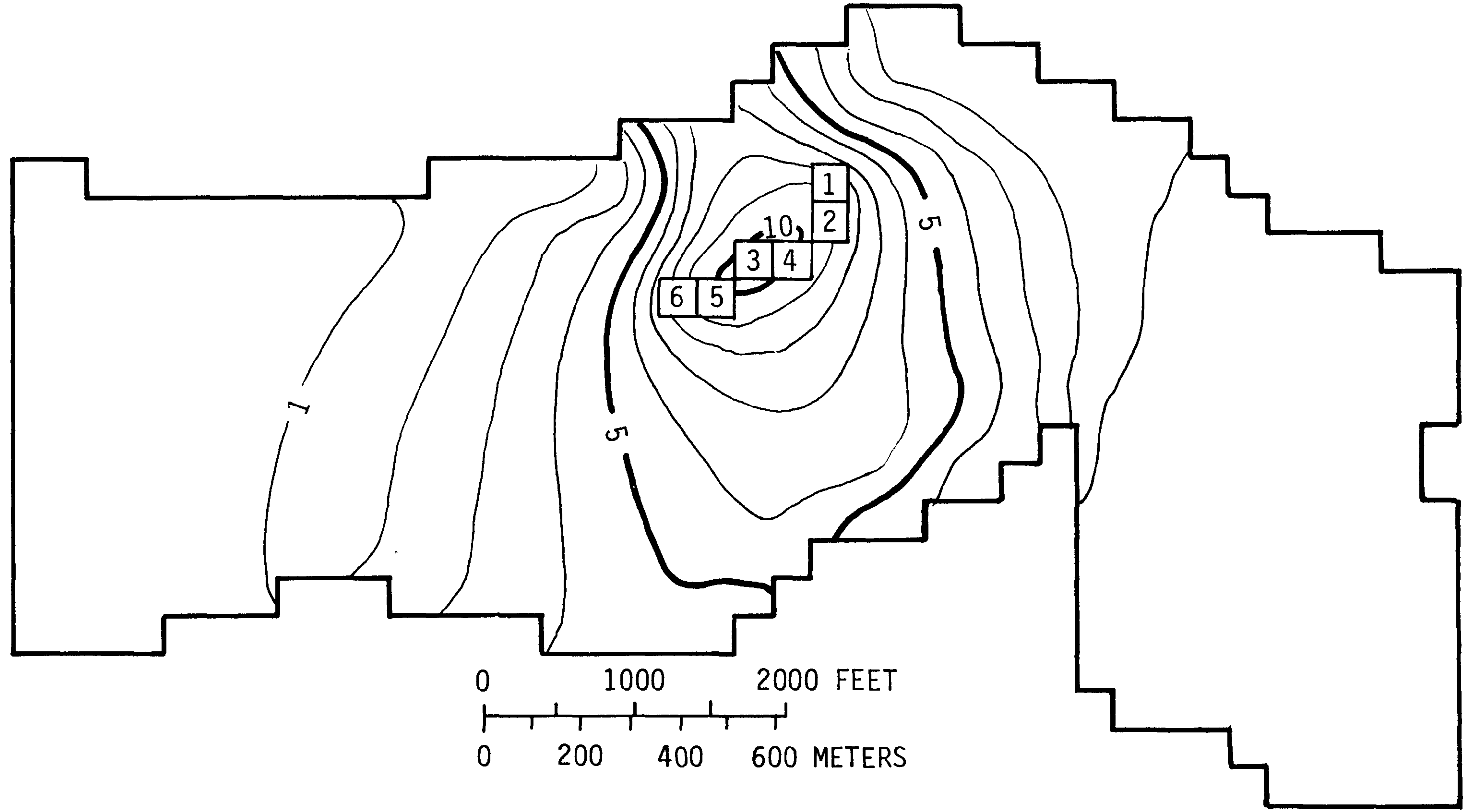
EXPLANATION

[1] Simulated pumping from this node and number of simulated well

— 5 — Contour line indicating water level drawdown due to pumping from alluvium. Contour interval 1 foot

Well Number	Drawdown (in feet)	Drawdown (in percentage of saturated thickness of aquifer)
1	24	49
2	24	45
3	22	42
4	26	49

FIGURE 16.--Drawdown of water levels in the alluvium due to simulated pumping of four wells near the Nisqually River at a rate of 400 gallons per minute each.



EXPLANATION

[1] Simulated pumping from this node and number of simulated well

—5— Contour line indicating water level drawdown due to pumping from alluvium. Contour interval 1 foot

Well Number	Drawdown (in feet)	Drawdown (in percentage of saturated thickness of aquifer)
1	18	40
2	18	37
3	19	36
4	18	36
5	28	54
6	25	48

FIGURE 17.--Drawdown of water levels in the alluvium due to simulated pumping of six wells near the Nisqually River at a rate of 340 gallons per minute each.

Source of Water to Pumping Wells in the Alluvium

The water pumped from wells in the alluvial aquifer is initially removed from storage in the pore space between grains of aquifer material, resulting in lowering of the water level 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 simulated pumping from the Nisqually River alluvial aquifer, the area in which the water level has been lowered expands, reaching the alluvial material underneath the riverbed in a relatively short but undetermined time.

As the water level in the alluvium under the river is lowered, the direction and amount of ground-water flow to or from the river will change. In areas where the water level in the aquifer is normally higher than the surface altitude of the river, there would be a reduction in flow from the aquifer into the river. It is also possible that the direction of flow would reverse if the aquifer water level is changed from above to below the surface altitude of the river. If, during normal, nonpumping conditions, there were 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, a lowering of the water level in the aquifer would increase the amount of flow into the aquifer as long as hydraulic continuity between the river and ground-water system is maintained.

Within the model area, the computer simulation indicates that under nonpumping conditions through about half (48 percent) the area of the riverbed, river water is flowing downward into the alluvial aquifer. Through the other part (52 percent), ground water is moving upward into the river (water levels in the aquifer are higher than the surface altitude of the river). When steady-state pumpage was simulated, the model results indicated that there were still areas of upward (into the river) and downward (into the aquifer) movement of water. However, the percentage of area of the riverbed with upward and downward movement changed significantly.

Simulated pumping shown in figure 15, resulted in an increase, to about 71 percent, in the area of the riverbed where water levels in the aquifer were lower than the river surface, indicating downward movement of water from the river to the aquifer. When the rate of pumping was increased and the locations of the simulated wells were moved closer to the river, shown in figures 16 and 17, the area having downward movement of river water into the aquifer increased to 80 percent.

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 numerical model, in cubic feet per second; numbers in parentheses are percent			
	Nonpumping condition	Simulated pumping condition (fig. 15)	(fig. 16)	(fig. 17)
Upward leakage[1] into river-----	1.4	1.2	1.0	1.1
Percentage of area-------------	(52)	(29)	(20)	(20)
Downward leakage into aquifer--	1.0	1.7	4.2	5.1
Percentage of area-------------	(48)	(71)	(80)	(80)
Net change in flow of Nisqually River[2]-------------	+.4	-.5	-3.2	-4.0
Net change from "nonpumping" simulation in flow of Nisqually River---------------	--	-.9	-3.6	-4.4
Pumping rate (simulated)	0	1.0	3.6	4.5

[1]Rate of flow of water moving from the alluvial aquifer to the Nisqually River, as indicated by the difference in water levels in the aquifer and the river-surface altitude. "Percentage of area" is the part of the total area covered by the riverbed that has water levels indicating upward flow or "leakage" from the aquifer into the river and increasing its rate of flow. "Downward leakage" and "Percentage of area" are for areas in which water levels indicate the flow of water to be from the river into the aquifer.

[2]Net difference in Nisqually 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 the basis of the values in the table above and calculations made by the numerical model, it appears that if the alluvial aquifer is pumped and steady-state conditions are reached (as was simulated, or in most other combinations of well locations and rate of pumpage), almost all (90 to 100 percent) of the water removed from the aquifer will be derived from reduced flow of the Nisqually River as it flows out of the immediate area. Any additional water (0 to 10 percent) will probably be derived from a reduction in the amount of ground water that flows in a downstream direction out of the immediate area.

CONCLUSIONS

Model results indicate that an additional 4.5 ft^3/s of water can be obtained from the alluvial deposits from six wells located near the Nisqually River. Each well simulated pumpage equal to 0.75 ft^3/s. Pumpage rates were determined by limiting model-predicted drawdown in the well to 50 percent of the original saturated thickness. This constraint should result in estimates of the minimum yield from each well. Wells were spaced 250 feet apart and were located in the area of maximum thickness and hydraulic conductivity of the aquifer. The latter two conditions, coupled with the closeness of the wells to the river should result in maximum well yields from a hydrologic viewpoint. The source of the ground water pumped from wells in the alluvium would probably be as follows: (1) more than 90 percent is leakage from the Nisqually River to the alluvium; and (2) less than 10 percent is reduced ground-water outflow from the immediate area in the downstream direction.

The numerical model designed to simulate ground-water flow in the alluvial aquifer adjacent to the Nisqually River was able to calculate water levels that closely matched measured water levels in most areas of the aquifer. The saturated thickness of the alluvial aquifer was found to range from about 10 to 60 feet in the area investigated. On the basis of numerical model results, the hydraulic conductivity of the aquifer ranges from 8.5 to 170 ft/day, the leakage coefficient of the streambed material under the Nisqually River is about 0.06 ft/day, and the rainfall recharge rate to the aquifer is about 10 inches per year.

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APPENDIX. Quality of the Ground Water

The quality of the ground water in the alluvial aquifer, on the basis of one sample from piezometer 1D1, appears satisfactory for most uses (see table below). No unusual or harmful physical characteristics or chemical constituents were found in the water. The second analysis shown below is for a sample collected from well number 35P1 (fig. 2). This well has openings between 118 and 123 ft below land surface, and the sample is representative of water in an aquifer that is below the bottom of the alluvial aquifer. The analysis is shown to provide a comparison with water from the alluvial aquifer.

Ground-water quality in two wells on the Nisqually Indian Reservation, Wash.

[°C, degrees Celsius; Pt-Co, platinum-cobalt units; umho/cm, micromhos per centimeter at 25°C; mg/L, milligrams per liter; ug/L, micrograms per liter; <, less than]

Constituent or property	Local well number of well sampled and date of sample	
	17/1-1D1 Feb. 2, 1980	18/1-35P1 Jan. 10, 1972
Temperature (°C)	5.0	9.8
Color (Pt-Co units)	100	20
Specific conductance (umho/cm at 25°C)	51	163
pH	7.4	7.2
Alkalinity (mg/L as calcium carbonate)	22	84
Nitrite plus nitrate (mg/L as nitrogen)	.28	.01
Hardness (mg/L as calcium carbonate)	20	56
Hardness, noncarbonate	0	0
Calcium (mg/L)	5.1	10
Magnesium (mg/L)	1.7	7.5
Sodium (mg/L)	3.4	12
Potassium (mg/L)	.8	1.1
Chloride (mg/L)	2.9	3.0
Sulfate (mg/L)	3.7	2.5
Fluoride (mg/L)	.0	.3
Silica (mg/L)	15	58
Chromium (mg/L)	--	<30
Copper (mg/L)	--	<50
Iron (ug/L)	160	--
Lead (ug/L)	--	<100
Manganese (mg/L)	80	--
Strontium (ug/L)	--	<50
Zinc (ug/L)	--	<10
Aluminum (ug/L)	--	<10
Lithium (ug/L)	--	<20
Coliform, fecal (colonies per 0.1 L)	<5	--
Dissolved solids, residue at 180°C	44	108

TABLE 2.--Lithologic logs of exploratory holes in the modeled area

[Installed by U.S. Geological Survey unless noted otherwise.]

Material	Thickness (ft)	Depth (ft)
17/1-1D1. Altitude LSD[a] = 96.8 ft.		
Silt and sand--------------------------------------	10	10
Silty sand with cobbles----------------------------	5	15
17/1-1E1. Altitude LSD = 96.8 ft.		
Silt, sand, cobbles, unsorted---------------------	1	1
Silt and fine sand--------------------------------	6	7
Silt, sand, and cobbles---------------------------	5	12
17/1-1E2. Altitude LSD = 96.6 ft.		
Silt, sand, and gravel to cobbles-----------------	10	10
17/1-1M1. Altitude LSD - 103.5 ft.		
Silt, sand, and gravel to cobbles-----------------	7	7
Silt, sand, and pebbles---------------------------	3	10
Silt, sand, and gravel----------------------------	2	12
Silt, sand, and pebbles---------------------------	2	14
17/1-2A1. Altitude LSD = 96.3 ft.		
Silt and sand-------------------------------------	7	7
Silt, sand, and cobbles---------------------------	5	12
Silt, sand, and gravel----------------------------	5	17
Silt, sand, and cobbles to gravel-----------------	2	19
17/1-2B1. Altitude LSD = 91.4 ft.		
Silt and sand-------------------------------------	7	7
Silt and cobbles----------------------------------	10	17

TABLE 2.--Lithologic logs of exploratory holes in the modeled area--Con.

Material	Thickness (ft)	Depth (ft)
17/1-2R1. Altitude LSD = 110.1 ft.		
Silt and sand	7	7
Silt, sand, and gravel	8	15
17/1-2R2. Altitude LSD = 109.3 ft.		
Silt and sand	6	6
Silt, sand, and gravel	6	12
Silt, sand, and gravel to cobbles	2	14
18/1-34J1. Altitude LSD = 70.2 ft.		
Silt and sand	8	8
Sand, very fine, with silt and pebbles	3	11
Gravel with silt and sand	3	14
Silt, sand, and gravel to cobbles	9	23
18/1-35F1. Altitude LSD = 77.6 ft.		
Silt with sand	17	17
Silt, sand, and gravel to cobbles	12	29
18/1-35K1. Altitude LSD = 80.8 ft.		
Silt and sand	5	5
Silt, sand, and gravel to cobbles	2	7
Silt, sand, and small gravel	2	9
Silt, sand, and gravel to cobbles	5	14
18/1-35K2. Altitude LSD = 81.1 ft. Drilled 9/10/79 to 9/14/79 by Clearwater Drilling Co. of Olympia, Wash.		
Silt and sand	5	5
Sand, gravel to cobbles, and silt	29	34
Sand, gravel, silt, and some clay	4	38
Sand and silt	4	42
Sand, silt, and gravel	4	46

(continued)

TABLE 2.--Lithologic logs of exploratory holes in the modeled area--Con.

Material	Thickness (ft)	Depth (ft)
18/1-35K2--Continued		
Sand, gravel, and silt----------------------------	6	b52
Sand, silt, and clay------------------------------	4	56
Sand and silt-------------------------------------	6	62
Sand, silt, and clay (ash?), whitish-gray color---	1	63
Silt, gravel, sand, and clay----------------------	3	66
Sand, silt, and gravel----------------------------	5	71
Silt, clay, sand, and gravel----------------------	6	77
Sand, silt, and clay------------------------------	3	80
Sand and silt with some gravel--------------------	5	85
Sand, fine, with silt-----------------------------	10	95
Silt, sand, gravel, and clay----------------------	5	100
18/1-35L1. Altitude LSD = 77.8 ft.		
Sand and silt with some pebbles-------------------	12.5	12.5
Sand and silt with some gravel--------------------	24.5	37
18/1-35M1. Altitude LSD = 71.8 ft.		
Silt and sand-------------------------------------	4.5	4.5
Gravel with silt----------------------------------	24.5	29
18/1-35M2. Altitude LSD = 72.5 ft. Drilled 8/22/79 to 8/26/79 by Clearwater Drilling Co. of Olympia, Wash.		
Silt with clay------------------------------------	4	4
Silt with clay, sand, and gravel------------------	2	6
Cobbles---	1	7
Silt, sand, and gravel to cobbles-----------------	20	27
Sand, gravel, silt, and clay----------------------	5	32
Sand, gravel to cobbles, and silt-----------------	5	37
Silt, sand, gravel, and clay----------------------	2	39
Sand, gravel to cobbles, and silt-----------------	6	b45
Sand, gravel, and cobbles, with silt--------------	2	47
Sand, gravel, silt and clay-----------------------	23	70
Sand, fine, with clay-----------------------------	16	86
Sand, coarse, with some gravel--------------------	2	88
Sand, coarse--------------------------------------	3	91
Sand with silt------------------------------------	9	100

TABLE 2.--Lithologic logs of exploratory holes in the modeled area--Con.

Material	Thickness (ft)	Depth (ft)
18/1-35N1. Altitude LSD = 79.5 ft.		
Silt with some sand------------------------------	12	12
Silt, sand, and gravel--------------------------	2	14
Silt with clay----------------------------------	2	16
Silt with sand----------------------------------	12	28
18/1-35P2. Altitude LSD = 85.0 ft.		
Soil zone (silt and sand)-----------------------	2	2
Silt with some gravel---------------------------	7	9
Sand, very fine---------------------------------	1	10
Sand, gravel, and silt--------------------------	5	15
18/1-35P3. Altitude LSD = 84.7 ft. Drilled 8/14/79 to 8/17/79 by Clearwater Drilling Co. of Olympia, Wash.		
Sand, silt, and some gravel---------------------	14	14
Sand, fine, with gravel to cobbles--------------	5	19
Sand, silt, and gravel--------------------------	2	21
Sand and gravel---------------------------------	14	35
Sand, gravel, and silt (clay?)------------------	3	38
Sand, gravel, and silt--------------------------	3	41
Sand, gravel to cobbles, and silt---------------	2	43
Sand, coarse, and gravel to cobbles-------------	8	51
Sand, fine, and silt----------------------------	3	b54
Sand and clay-----------------------------------	3	57
Sand, silt, gravel, and clay (ash?)-------------	5	62
Sand, fine, with some silt and gravel-----------	3	65
Sand, gravel, and silt--------------------------	4	69
Sand with silt and (or) clay--------------------	6	75
Sand, clay, and gravel--------------------------	6	81
18/1-35R1. Altitude LSD = 87.2 ft.		
Gravel to cobbles with silt and sand------------	14	14

TABLE 2.--Lithologic logs of exploratory holes in the modeled area--Con.

Material	Thickness (ft)	Depth (ft)
18/1-35R2 and 35R3[c]. Altitude LSD = 93.1 ft. Drilled 8/27/79 to 9/7/79 by Clearwater Drilling Co. of Olympia, Wash.		
Silt and sand	2	2
Silt, sand, and gravel to cobbles	15	17
Gravel, coarse	2	19
Cobbles with silt	1	20
Sand, coarse, with silt	3	23
Sand, gravel, and silt	10	33
Sand and silt	2	35
Sand, gravel, silt, and some clay	9	44
Gravel, sand, and silt	2	46
Sand, gravel, silt and some clay	5	[b]51
Sand, coarse, and some silt and clay	14	65
Sand and silt	6	71
Sand, fine, and silt	2	73
Sand, fine, with layers of clay (ash?), green, gray, and white	5	78
Silt, clay, sand, and gravel	1	79
Sand and gravel	6	85
Sand, fine, and silt	7	92
Sand, gravel, and silt	8	100
18/1-36N1. Altitude LSD = 94.8 ft.		
Gravel, poorly sorted, with some silt	7	7
Sand and gravel	16	23

[a]Land surface datum.

[b]Considered to be the bottom of the alluvial aquifer.

[c]Wells 35R2 and 35R3 are 10 ft apart, their respective depths are 18.0 and 100.2 ft.

TABLE 3.--Observed altitude of water levels in piezometers and wells in the modeled area. Altitudes are in feet above see level

DATE	1D1	1E1	1E2	1M1	2A1	2B1	2R1	2R2	34J1	35F1	35K1
8/14/79	[a]--	--	--	--	--	--	--	--	--	--	--
8/15	--	--	--	--	--	--	--	--	--	--	--
8/16	90.37	--	--	93.49	--	--	99.37	--	--	--	--
8/22	89.98	--	--	--	--	--	99.52	--	64.85	--	--
8/24	--	--	--	--	--	--	--	--	--	--	--
8/28	--	--	--	--	--	--	--	--	64.82	--	--
8/29	89.78	92.42	91.88	93.54	--	--	99.46	97.16	--	--	--
8/30	--	--	--	--	86.80	--	--	--	64.71	--	--
9/6	89.89	92.64	92.01	93.72	86.77	84.96	99.56	97.27	64.87	70.36	--
9/12	--	--	--	--	--	--	--	--	--	--	75.12
9/13	--	--	--	--	--	--	--	--	64.71	70.19	75.04
9/14	89.64	92.36	91.84	93.55	86.73	84.95	99.45	97.15	--	--	75.04
9/19	89.57	92.29	91.78	93.48	86.63	84.85	99.39	97.13	64.67	70.11	74.95
9/21	89.57	92.29	91.76	93.45	86.63	84.86	99.39	97.13	64.69	70.13	74.97
9/25	89.58	--	--	--	86.63	--	99.50	--	--	--	75.10
10/1	89.45	92.38	91.88	93.53	86.62	84.81	99.50	97.22	64.76	70.09	75.08
10/9	89.39	92.35	91.87	93.70	86.61	84.83	99.50	97.27	64.73	70.18	75.11
10/15	89.35	92.37	91.90	93.52	86.61	84.74	99.50	97.31	64.74	70.19	75.13
10/17	89.34	--	--	--	--	--	--	--	--	--	--
10/19	89.45	92.49	--	93.66	--	--	99.58	97.38	64.81	70.27	--
10/23	89.39	92.45	92.01	93.57	86.73	84.84	99.60	97.35	64.80	70.26	75.25
10/29	89.85	92.78	92.38	94.07	86.97	85.04	99.91	97.65	65.20	70.63	75.66
10/30	--	--	--	--	--	--	--	--	65.08	70.58	--
11/8	89.49	92.36	92.11	93.73	86.92	85.15	99.64	97.49	64.92	70.43	75.48
11/15	89.41	92.43	92.05	93.66	86.86	84.98	99.69	97.47	64.83	70.37	75.40
11/28	89.39	--	92.05	--	86.84	84.97	99.69	--	64.83	70.33	75.37
12/6	89.99	--	92.65	--	87.44	85.40	100.34	--	65.31	71.03	76.23
1/15/80	91.71	94.18	94.26	96.61	88.12	85.893	102.04	99.92	66.90	73.05	77.56
1/22	91.19	--	93.68	--	88.18	85.70	101.58	--	66.24	72.50	77.01
2/13	90.97	93.58	83.38	95.95	87.73	85.40	101.12	99.16	65.91	72.07	76.45

DATE	35K2	35L1	35M1	35M2	35N1	35P2	35P3	35R1	35R2	35R3	36N1
8/14/79	--	70.95	67.10	--	73.05	76.33	--	82.13	--	--	--
8/15	--	70.73	66.94	--	73.07	76.39	--	--	--	--	--
8/16	--	--	--	--	--	76.49	--	82.16	--	--	--
8/22	--	70.72	66.78	--	73.12	--	--	82.31	--	--	--
8/24	--	--	--	--	--	--	75.71	--	--	--	--
8/28	--	70.79	66.85	66.87	73.29	--	--	--	--	--	85.56
8/29	--	--	--	--	--	76.53	75.79	82.17	--	--	--
8/30	--	70.77	66.92	66.85	73.32	--	--	--	--	--	85.48
9/6	--	70.87	67.00	66.98	73.35	76.61	75.82	82.32	--	--	85.62
9/12	--	--	--	--	--	--	--	--	--	--	--
9/13	--	70.87	66.95	66.93	73.38	76.57	75.80	82.15	85.29	(b)	85.46
9/14	--	--	--	--	--	--	--	--	--	--	--
9/19	75.00	70.81	66.91	66.90	73.37	76.49	75.72	82.12	85.23	(b)	85.43
9/21	75.31	70.80	67.04	66.91	73.37	76.55	75.70	82.11	85.22	(b)	85.42
9/25	75.68	--	67.04	66.94	73.36	76.51	75.70	82.23	85.30	(b)	85.49
10/1	76.02	70.91	67.05	66.96	73.39	76.53	75.74	82.22	85.26	(b)	85.52
10/9	76.27	70.92	67.00	66.91	73.44	76.76	76.05	82.02	85.27	(b)	85.44
10/15	76.39	70.97	67.00	66.90	73.46	76.80	76.12	82.24	85.26	(b)	85.47
10/17	--	--	--	--	--	--	--	--	--	--	--
10/19	--	71.01	67.03	66.96	73.51	76.88	--	--	--	(b)	--
10/23	76.82	71.05	67.04	66.97	73.51	76.91	76.20	82.30	85.31	(b)	85.52
10/29	76.65	71.30	67.29	67.21	73.69	77.12	76.40	82.64	85.64	(b)	85.84
10/30	--	--	--	--	--	--	--	82.54	--	--	--
11/8	76.76	71.25	67.19	67.03	73.55	77.10	76.35	82.39	85.39	(b)	85.99
11/15	76.80	71.16	66.98	66.97	73.52	77.03	76.26	82.33	85.31	(b)	85.51
11/28	76.51	71.18	66.98	66.98	73.54	77.00	76.26	82.35	85.31	(b)	85.50
12/6	76.73	71.84	67.35	67.34	73.73	77.52	76.71	82.81	85.86	(b)	85.97
1/15/80	77.36	72.92	68.34	66.33	73.96	77.83	76.93	83.41	86.72	(b)	86.89
1/22	77.33	72.71	67.85	67.84	73.73	77.73	76.76	82.81	86.29	(b)	86.47
2/13	77.04	72.23	67.68	67.62	73.65	77.33	76.44	82.46	86.00	(b)	86.22

[a]No water-level measurement available for this date.

[b]Well observed flowing over top of casing, which is 95.62 ft above sea level.

TABLE 4.--Observed altitude of water levels at selected surface-water sites in the modeled area. Altitudes are in feet above sea level

	1	2	3	4	5	6
10/17/79	--	--	--	--	90.47	--
10/19	64.42	70.93	79.49	--	90.55	92.58
10/30	64.53	71.08	79.79	80.08	--	--
11/1	--	--	--	--	90.61	92.64
11/8	64.39	70.94	79.65	79.90	90.57	92.57
11/15	64.35	70.89	79.58	79.91	90.57	92.54
11/28	64.35	70.92	79.59	79.91	90.56	92.55
12/6	64.60	71.20	80.05	80.20	90.74	92.82
1/15/80	(a)	(a)	80.35	80.97	(a)	(a)
1/22	(a)	(a)	[b]80.31	79.95	(a)	(a)
2/13	(a)	(a)	79.86	(a)	(a)	(a)

[a]Gage destroyed by flood, no measurement available this date.
[b]Ice on water.