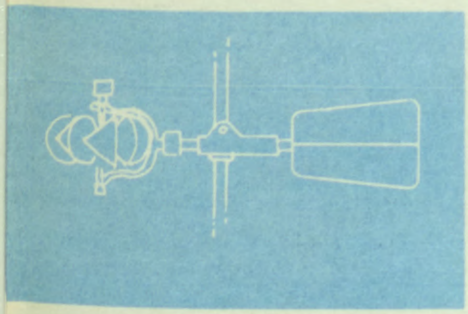
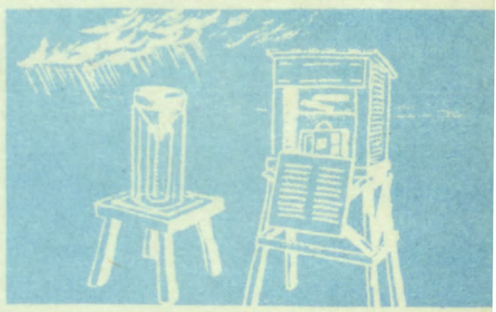
WATER RESOURCES OF THE NISQUALLY LAKE AREA, PIERCE COUNTY, WASHINGTON





U.S. GEOLOGICAL SURVEY

Water-Resources Investigation 78-101

Prepared in Cooperation With
Nisqually Community Council

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Water Resources of the Nisqually Lake Area, Pierce County, Washington			5. Report Date Approved August 1978 6.
7. Author(s) H. E. Pearson and N. P. Dion			8. Performing Organization Rept. No. USGS/WRI-78-101
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division 1201 Pacific Avenue, Suite 600 Tacoma, Washington 98402			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 1201 Pacific Avenue, Suite 600 Tacoma, Washington 98402			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes

Prepared in cooperation with the Nisqually Community Council

16. Abstracts This report presents data on the water resources of an area within, and adjacent to, a part of the Fort Lewis Military Reservation that prior to 1917 was included in the Nisqually Indian Reservation.

The only surface-water bodies of significance in the study area are Muck Creek and Nisqually Lake. A large spring also is in the study area. Development or diversion of Muck Creek near its mouth would provide sufficient water for a small to medium sized fish-rearing facility. The highest water temperature recorded during the 25 months of data collection was 14°C in August 1977, for Muck Creek. Nisqually Lake has a surface area of about 89 acres and is shallow with a flat bottom. Species of warm-water fish are probably best suited for the lake.

Ground water occurs in unconsolidated glacial drift or outwash of gravel, sand, silt, and clay. Drilling of test wells is required to provide more reliable data on yields of ground water.

17. Key Words and Document Analysis. 17a. Descriptors

Water resources; Surface-ground water relationships; Lake basin; Nutrients; Aquatic life; Water temperatures; water year

17b. Identifiers/Open-Ended Terms

Fort Lewis, Pierce County, Washington; Nisqually Indian Reservation, Washington

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 43
No restriction on distribution	20. Security Class (This Page) UNCLASSIFIED	22. Price

WATER RESOURCES OF THE NISQUALLY LAKE AREA,

PIERCE COUNTY, WASHINGTON

By H. E. Pearson and N. P. Dion

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-101

Prepared in cooperation with the
Nisqually Community Council

May 1979

DV
MPV
FO

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

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

CONTENTS

ILLUSTRATIONS

TABLES

GLOSSARY

Acre-foot. Volume of water required to cover 1 acre to a depth of 1 foot, and equal to 43,560 ft^3 or 325,900 U.S. gallons.

Advance outwash. Sand and gravel deposited in front of the advancing ice sheet by melt-water streams. Advance deposits are more compact than recessional deposits that were not overriden by ice.

Algae. Simple plants, many microscopic, that contain chlorophyll and lack roots, stems, and leaves. Most algae are aquatic and may become a nuisance when environmental conditions are suitable for prolific growth.

Aquifer. A rock formation that is capable of yielding water to wells.

Bathymetric. Relating to the measurement of water depths, as for a lake.

Biomass. The weight of all living material present in a unit area or volume at a given time, expressed as weight per unit area or volume.

Cubic foot per second (ft^3/s). The rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and equivalent to 448.8 gallons per minute.

Discharge. The volume of water that passes a given point within a given period of time, usually given in cubic feet per second.

Drainage area. The area drained by, or contributing to, a stream, lake, or other water body.

Dissolved. Refers to the amount of a substance present in true chemical solution. In practice, however, the term includes all forms of the substance that will pass through a 0.45 - micrometer membrane filter, and thus may include some very small (colloidal) suspended particles.

Drawdown. The lowering of the water table caused by pumping.

Fecal-coliform bacteria. Bacteria that are present in the intestine or feces of warmblooded animals. They are often used as indicators of the sanitary quality of the water. Their concentrations are expressed as number of colonies per 100 milliliters of sample water.

Gage height (G.H.). The water-surface elevation, referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term "stage," although gage height is more appropriate when referring to a gage reading.

Gaging station. A site on a stream, canal, lake or reservoir where systematic observations of gage height or water discharge are obtained. When used in connection with a discharge record, the term is applied only to those gaging stations where a continuous record of discharge is collected.

Genus. The taxonomic category below family, consisting of one or more species.

Hardness. A physical-chemical characteristic of water that is commonly recognized by the increased quantity of soap required to produce lather. It is attributable mostly to the presence of alkaline earths (principally calcium and magnesium) and is expressed as an equivalent concentration of calcium carbonate ($CaCO_3$).

Hydrology. The science of the behavior of water in the atmosphere, on surface of the earth, and underground.

Impermeable. Having a texture that does not permit water to move through it perceptibly under the head difference ordinarily found in subsurface water.

Infiltration. The flow of a fluid into a substance through pores or small openings. The common use of the word is to denote the flow of water into, rather than through, soil material.

Littoral. The shoreward region of a body of water.

Loam. Soil material composed of a mixture of clay, silt, sand, and organic matter.

Micrograms per liter (µg/L). A unit expressing the concentration of chemical constituents in solution as weight (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

Milligrams per liter (mg/L). A unit expressing the concentration of chemical constituents in solution. Milligrams per liter represents the weight of solute per unit volume of water.

Morphometric. Relating to the definition of physical shape and size, as of a water body.

Muck. A mixture containing highly decomposed organic material in which the original plant parts are not recognizable. Muck contains more mineral matter and is usually darker than peat.

Percolation. Movement, under hydrostatic pressure, of water through the interstices of rock or soil; does not include movement through large openings such as caves.

Permeability. The capacity of rock or soil for transmitting a fluid. Degree of permeability depends not only on the volume of the openings and pores, but also on how the openings are interconnected.

pH. The negative logarithm of the hydrogen-ion activity, expressed as a number from 0 to 14. A pH of 7 is neutral,a pH of less than 7 is acidic, and a pH of greater than 7 is basic.

Photosynthesis. The process by which chlorophyll-containing plants convert carbon dioxide and water into sugar and oxygen.

Plankton. Suspended or floating organisms that drift passively with water currents.

Quaternary. The younger of the two geologic periods or systems in the Cenozoic Era (Erathem). It comprises all geologic time and deposits from the end of the Tertiary (about two million years ago) to the present.

Recurrence interval. The average number of years between hydrologic events for a calculated value.

Runoff. The quantity of water discharged through surface streams, expressed usually in units of volume such as gallons, cubic feet, or acre-feet.

Sodium-adsorption-ratio (SAR). An expression of the relative activity of sodium ions in exchange reactions with soil, and an index of sodium or alkali hazard to the soil.

Solute. Any substance that is dissolved, usually in water.

Specific capacity. The rate of discharge of water from a well divided by the drawdown of water level within the well.

Specific conductance. A measure of the ability of a water to conduct an electrical current, expressed in micromhos per centimeter at 25°C.

Stage. The height of a water surface above any chosen reference plane.

Stage-discharge relation. The relation between gage height and the amount of water flowing in a channel.

Stream, gaining. A stream or reach of stream whose flow is being increased by the inflow of ground water.

Stream, losing. A stream or reach of stream that is losing water to the ground.

Streamflow. The discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a natural stream course.

Thermal stratification. A temperature distribution characteristic of many deeper lakes in which the water is separated into three horizontal layers: a warm layer at the top, an intermediate layer in which temperature changes rapidly with depth, and a cold layer at the bottom.

Till. Unstratified glacial material deposited directly by the ice and consisting of clay, sand, gravel, and boulders intermixed in any proportion.

Total coliform bacteria. A measurement that may be used as an alternative to a fecal-coliform measurement. The major limitation to this index is the uncertain correlation to the occurrence of pathogenic micro-organisms. Their concentrations are expressed as number of colonies per 100 milliliters of sample water.

Turbidity. The presence of particulate materials suspended in water that reduce the penetration of light.

Water table. The upper surface of a zone of saturation except where that surface is formed by an impermeable body.

Water year. The 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months.

METRIC CONVERSION TABLE

Multiply	By	To obtain
Inches (in)	2.540	centimeters (cm)
	25.40	millimeters (mm)
Feet (ft)	0.3048	meters (m)
Miles (mi)	1.609	kilometers (km)
Acres	0.004047	square kilometers (km^2)
	0.4047	hectares (ha)
Gallons (gal)	3.785	liters (L)
Acre-feet (acre-ft)	1233.	cubic meters (m^3)
Cubic feet per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Gallons per minute (gal/min)	0.06308	liters per minute (L/min)
Degrees Fahrenheit (°F)	Subtract 32, multiply remainder by 0.5556	degrees Celsius (°C)

WATER RESOURCES OF THE NISQUALLY LAKE AREA, PIERCE COUNTY, WASHINGTON

By H. E. Pearson and N. P. Dion

ABSTRACT

This report presents data assembled during a July 1975 to August 1977 study of the water resources of an area within, and adjacent to, a part of the Fort Lewis Military Reservation that prior to 1917 was included in the Nisqually Indian Reservation. Because the area is within or near the artillery ranges of the U.S. Army, the existing water resources of the study area are almost undeveloped.

The only surface-water bodies of significance in the study area are Muck Creek, Nisqually Lake, and springs. The flow of Muck Creek as measured at a gaging station at Roy, east of the study area, ranged from no flow to a maximum discharge of 692 cubic feet per second during the period 1956-77. No flow occurred there about 9 percent of the time during the period 1956-71. A large spring discharged from 0.12 to 4.56 cubic feet per second during the study period.

Development or diversion of Muck Creek near its mouth would provide sufficient water for a small- to medium-sized fish-rearing facility. The highest water temperature recorded at this site during the study was 14.0°C, in August 1977, with a stream discharge of 7.12 cubic feet per second.

Nisqually Lake, with a surface area of about 89 acres, is shallow with a flat bottom. The existing lake water is relatively high with dissolved solids, organic nitrogen and phosphorus, and biologically productive. Species of warm-water fish are probably best suited for the lake.

Ground water beneath the study area occurs in unconsolidated glacial drift or outwash of gravel, sand, silt, and clay. One of the permeable rock units is the Steilacoom Gravel of Pleistocene age. Yields to wells from this material in a nearby area are from 100 to 250 gallons per minute. Drilling of test wells in the study area would provide more reliable data on ground water.

INTRODUCTION

Purpose and Scope of the Study

A 2-year reconnaissance study of the water resources of the Nisqually Lake area for the period July 1975-August 1977, was made by the U.S. Geological Survey. The study was made in cooperation with the Nisqually Community Council (the tribal government for the Nisqually Indian Reservation) to determine the quantity, quality, availability, and use of ground and surface water in the area, which is part of the Fort Lewis Military Reservation. The Nisqually Lake area is of particular interest to the council because it was formerly part of the original Nisqually Indian Reservation; this area of approximately 3,300 acres--in Pierce County and east of the Nisqually River--was ceded to Camp Lewis (now Fort Lewis) in 1917.

The main interest of the Nisqually Community Council regarding the water resources of the area is the availability of water for the enhancement and development of the fisheries resources of Muck Creek and Nisqually Lake. In the lower reaches of the Muck Creek basin, proper fisheries management would depend primarily on sufficient streamflow and water of good quality.

Data collection during the study consisted of measuring the discharge of Muck Creek and one large spring, and sampling and analyzing the chemical and sanitary quality of the spring, the creek, and Nisqually Lake. In addition, a bathymetric (water-depth) map of the lake was prepared and the lake water was analyzed for the presence of nutrients, chlorophyll a, fecal-coliform bacteria, and aquatic plants. Because there are no wells in the study area only rough estimates of ground-water availability could be made. These estimates would be based on existing knowledge of generalized geologic conditions in the surrounding Pierce County area.

Description of the Study Area

The old Indian treaty area covers approximately 3,300 acres and is east of, and across the Nisqually River from the existing Nisqually Indian Reservation (fig. 1). The area is uninhabited because it is in, or adjacent to, the impact area of the Fort Lewis (U.S. Army) artillery firing ranges. Consequently, the water resources of the area have been undeveloped except for some diversion from adjacent Muck Creek to replenish Nisqually Lake.

The old treaty and adjacent area includes parts of the Muck Creek drainage basin and the Nisqually Lake drainage basin. The Muck Creek drainage basin extends from the town of Roy to the creek's mouth at the Nisqually River, and has an area of 5.2 mi^2. Nisqually Lake usually receives diversion water from Muck Creek during December to March, but is outside the natural drainage basin of Muck Creek. Small springs also occur in densely vegetated areas along the bluff above the Nisqually River flood plain.

Land-surface altitudes in the old treaty area range from about 15 feet above sea level at the Nisqually River to about 260 feet above sea level at the eastern edge near the old treaty boundary. The town of Roy, about 4 miles east of the old treaty area, is about 315 feet above sea level.

The western edge of the old treaty area--along the Nisqually River--consists of steep bluffs heavily covered by vegetation which descend to the alluvial flood plain of the river.

Climate

The old treaty and adjacent areas are characterized by a maritime climate, with cool, dry summers and mild, wet winters. Precipitation data are published for Yelm, about 4 miles south, and temperature data are published for the Olympia airport, about 12 miles west (U.S. Department of Commerce, 1956-71, and 1976).

The average annual precipitation at Yelm for the period 1957-71 (water years) was about 34 inches (fig. 2); nearly 75 percent of the precipitation occurs during the months October to March (fig. 3). At Olympia, the average annual temperature is 50.1°F, and monthly average temperatures ranged from 37.2°F in January to 63.6°F in July (U.S. Department of Commerce, 1976).

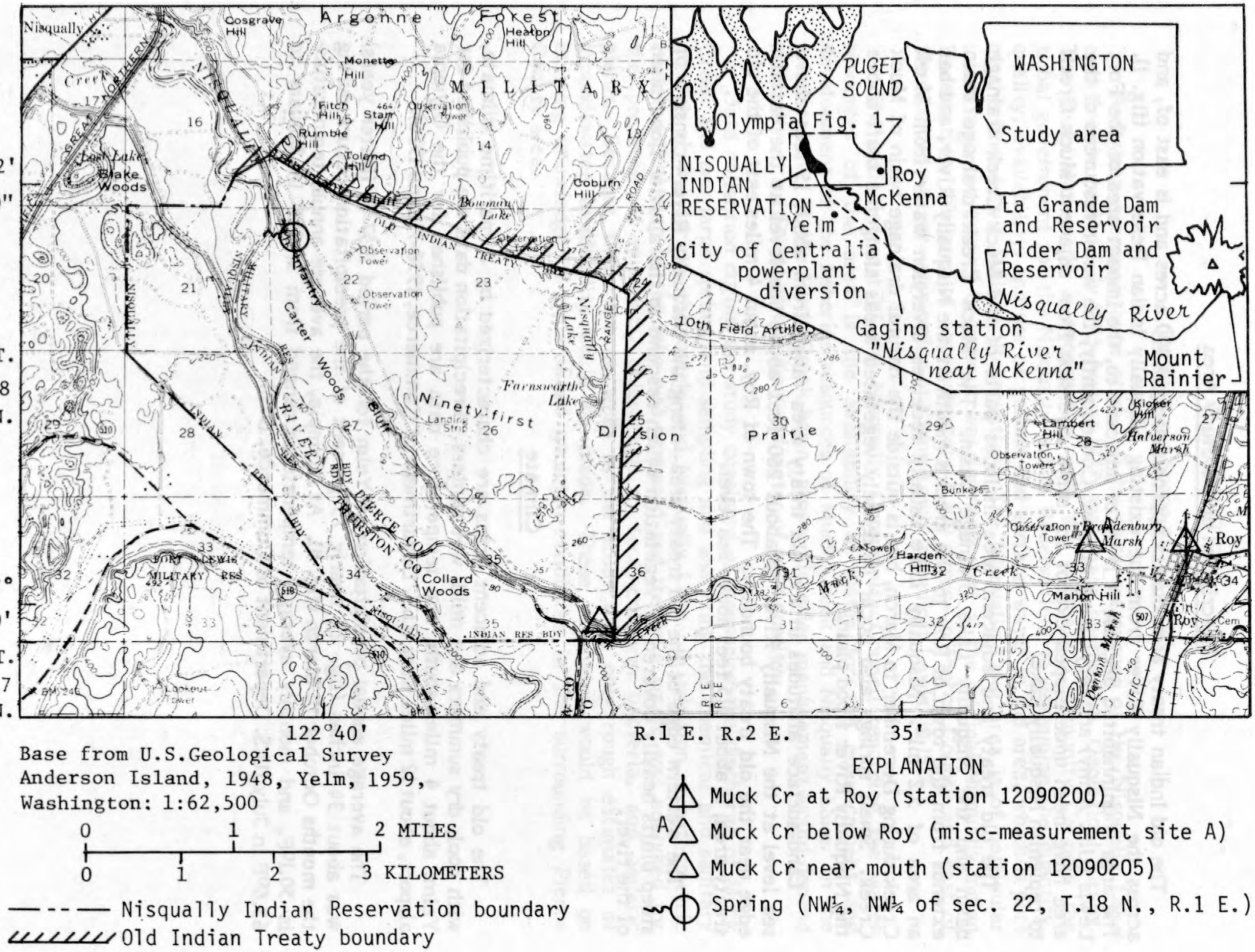


FIGURE 1.--Location of data-collection sites in the old treaty area and adjacent area.

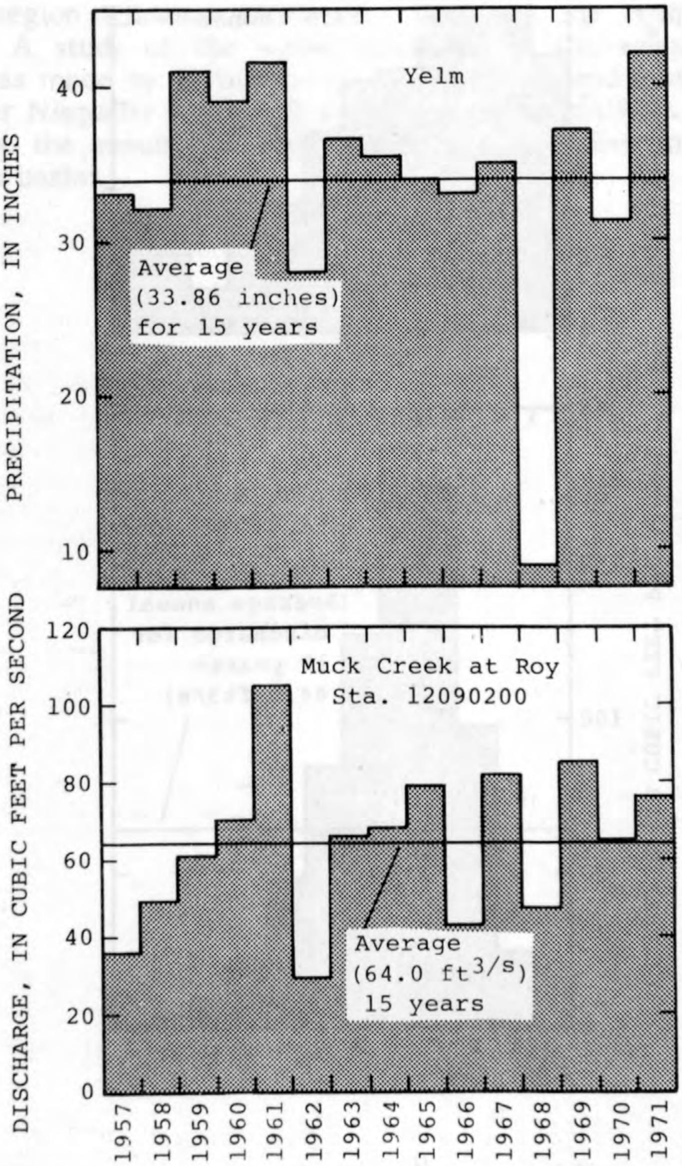


FIGURE 2.--Mean annual precipitation at Yelm and mean annual discharge of Muck Creek at Roy, for water years 1957-71. Precipitation data from U.S. Department of Commerce (1957-71).

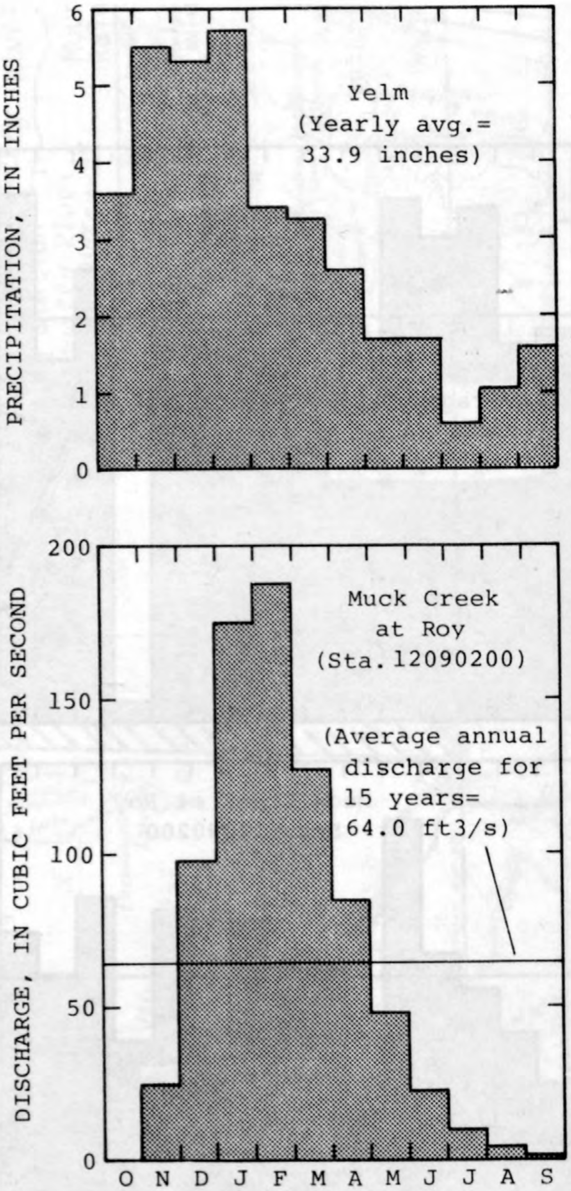


FIGURE 3.--Mean monthly precipitation at Yelm, and mean monthly discharge of Muck Creek at Roy, during 1957-71 water years. Monthly precipitation data from U.S. Department of Commerce (1956-71).

Previous Studies in the Area

Previous studies that deal primarily with the water resources of the old treaty area and nearby areas are as follows: the availability and quality of water in the Tacoma area (Griffin and others, 1962); ground-water occurrence in central Pierce County (Walters and Kimmel, 1968); low-flow characteristics of streams in the Puget Sound region (Hidaka, 1973), which includes the Nisqually and Deschutes River basins. A study of the water resources of the existing Nisqually Indian Reservation was made by Myers and Cummans (1973), and a study of flood profiles along the lower Nisqually River was made by Cummans (1974). A report by Nelson (1974) presents the results of sediment-transport studies in the Deschutes and Nisqually River basins.

THE HYDROLOGIC CYCLE

The hydrologic cycle is the system in which water evaporates into the atmosphere from the earth's surface and then condenses to return to earth as precipitation to replenish the surface and underground supplies of water. Precipitation as rain and snow is the source of all fresh water. The amount of water from precipitation that is available for use as streamflow, ground water, or storage in lakes and reservoirs is reduced by evaporation from soil and water surfaces and by transpiration of plants. A large part of the precipitation runs off the land surface in streams and rivers. Water that is neither lost through evaporation, transpiration, nor surface runoff infiltrates into the ground and percolates downward to the water table and recharges the ground-water reservoir. In turn, most of the ground water returns to the surface as seepage to springs, lakes, streams, and the sea. The hydrologic cycle in the study area is illustrated diagrammatically in figure 4.

The rate at which water infiltrates into the ground is dependent upon the permeability and degree of saturation of the soil and underlying materials. Because the soil and underlying gravel (Walters and Kimmel, 1968) of the study area are highly permeable, infiltration is rapid. The saturated rock materials (gravels) which yield usable amounts of water to wells or springs are termed aquifers. In the aquifer, ground water flows from points of recharge (higher head) towards points of discharge (lower head), at rates which vary directly with the hydraulic gradient and the permeability of the deposits. The occurrence of ground water is discussed further in the section on ground-water availability, page 30.

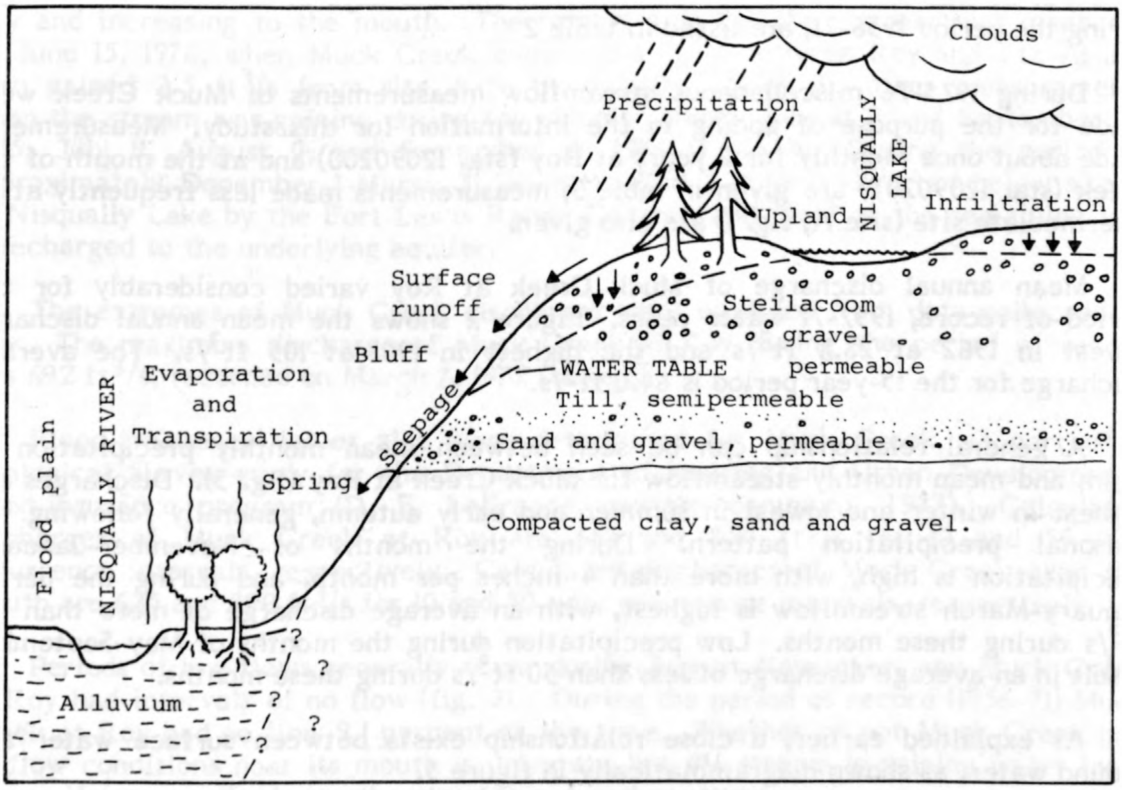


FIGURE 4.--Diagrammatic sketch of the hydrologic cycle and generalized geologic section, looking to the north, showing relation of water and rock materials in the old treaty area.

MUCK CREEK

The only stream of significance in the old treaty area is Muck Creek. As part of this study the flow of the creek, which is a tributary to the Nisqually River, was measured at three sites (fig. 1). The mean annual and monthly discharges of Muck Creek at Roy, compared to precipitation at Yelm during the 1957-71 water years, are shown in figures 2 and 3, respectively. The annual maximum discharges (1957-76) at this station are listed in table 1, and the days of no flow of the creek during the period 1956-71, are listed in table 2

During 1975-76 miscellaneous streamflow measurements of Muck Creek were made for the purpose of adding to the information for this study. Measurements made about once monthly for 2 years at Roy (sta. 12090200) and at the mouth of the creek (sta. 12090205) are given in table 3; measurements made less frequently at an intermediate site (site A, fig. 1) are also given.

Mean annual discharge of Muck Creek at Roy varied considerably for the period of record, 1957-71 water years. Figure 2 shows the mean annual discharge lowest in 1962 at 28.8 ft^3/s and the highest in 1961 at 105 ft^3/s. The average discharge for the 15-year period is 64.0 ft^3/s.

A general relationship can be seen between mean monthly precipitation at Yelm and mean monthly streamflow for Muck Creek at Roy (fig. 3). Discharges are highest in winter and lowest in summer and early autumn, generally following the seasonal precipitation pattern. During the months of November-January, precipitation is high, with more than 4 inches per month, and during the period January-March streamflow is highest, with an average discharge of more than 125 ft^3/s during these months. Low precipitation during the months of May-September result in an average discharge of less than 50 ft^3/s during these months.

As explained earlier, a close relationship exists between surface water and ground water, as shown diagrammatically in figure 5.

A general streamflow pattern may be inferred from the monthly measurements. Between Roy and the Nisqually River, Muck Creek was losing water during November 1975-January 1976 (fig. 5A), and gaining water during February 1976-December 1976 (fig. 5B). Because of the abnormally dry winter of 1976-77, the usual recharge of the aquifer by precipitation probably was minimal, if any, and Muck Creek was dry at Roy in August 1977 (fig. 5C).

Measurements at Roy and at site A (table 3) indicate that on December 11, 1975, Muck Creek gained 38 ft^3/s between Roy and site A, and then lost 51 ft^3/s downstream from site A. Other intermittent measurements at both stations also indicate either the gaining stream or losing stream situation. On March 24, 1976, Muck Creek gained 45 ft^3/s; between Roy and site A, and then lost 23 ft^3/s between site A and the mouth. However, during the summer months, June to September, measurements indicate a gain of water along the 3 sites, starting at Roy and increasing to the mouth. The largest gain for the summer was measured on June 15, 1976, when Muck Creek gained 13.5 ft^3/s between Roy and site A; and then gained 2.5 ft^3/s from site A to the mouth. Dates for other measurements when the stream was gaining during the summer were: August 8 and September 12, 1975; July 9, August 9, and September 10, 1976 (table 3). During the period of approximately December 1-March 31, an estimated 5 ft^3/s is diverted below site A to Nisqually Lake by the Fort Lewis Range Control, and most of the remaining loss is recharged to the underlying aquifer.

The extremes of Muck Creek discharges were obtained from data collected at Roy. The maximum discharge of Muck Creek at Roy during the period of record was 692 ft^3/s, recorded on March 7, 1972 (table 1).

Flood-frequency values also were determined for Muck Creek, as part of a Geological Survey study for the Department of Housing and Urban Development's flood-insurance program (D. E. LaFrance, written commun., 1977). Calculated discharges of Muck Creek at Roy are 610 and 850 ft^3/s for 10 and 50-year recurrence intervals, respectively. Calculated discharges of Muck Creek near the mouth are 635 and 890 ft^3/s for 10 and 50-year recurrence intervals, respectively.

Periods of low flows generally occur during August-November, and Muck Creek at Roy had intervals of no flow (fig. 2). During the period of record (1956-71) Muck Creek at Roy had no flow 9.1 percent of the time. Whether or not Muck Creek had no-flow conditions near its mouth is unknown, but the stream is gaining water from the aquifer generally during the summer and early autumn.

TABLE 1.--Annual maximum discharges of Muck Creek at Roy, (sta. 12090200) for period 1957-76

Water year	Annual peak discharge (ft^3/s)	Date of event
1957	332	3-11-57
1958	308	2-27-58
1959	351	1-25-59
1960	226	2-16-60
1961	428	2-26-61
1962	94	1-07-62
1963	267	2-05-63
1964	500	1-27-64
1965	584	2-01-65
1966	193	3-23-66
1967	453	1-30-67
1968	325	2-24-68
1969	551	1-09-69
1970	569	1-28-70
1971	606	1-27-71
1972*	692	3-07-72
1973*	288	12-26-72
1974*	464	1-18-74
1975*	584	1-13-75
1976*	502	12-05-75

*Operated as crest-stage gage only.

TABLE 2.--Days of no flow of Muck Creek at Roy, (sta. 12090200) for period 1956-71

Month	Number of days of record	Number of no-flow days	Percent of no-flow days
October	465	191	41.1
November	450	74	16.4
December	465	7	1.5
January	465	0	0.0
February	423	0	0.0
March	465	0	0.0
April	450	0	0.0
May	465	0	0.0
June	480	0	0.0
July	496	12	2.4
August	496	55	11.1
September	480	170	35.4
Total	5600	509	9.1

TABLE 3.--Discharge measurements of Muck Creek near mouth, at site A, and at Roy, for period 1975-77

Date	Discharge, in cubic feet per second		
	Muck Creek near mouth	Site A	Muck Creek at Roy
8-8-75	8.06	5.46	0.90
9-12-75	4.72	3.16	.86
10-21-75	2.40	--	1.30
11-17-75	1.45	--	24.6
12-11-75	362.	413.	375.*
1-14-76	344.	--	367.*
2-13-76	138.	--	114.*
3-24-76	145.	168.	123.*
4-23-76	116.	--	91.*
5-14-76	61.5	--	11.*
6-15-76	24.9	22.4	8.9*
7-9-76	15.0	13.9	4.97
8-9-76	10.2	6.77	2.26
9-10-76	6.91	5.36	3.32
10-13-76	5.19	--	.65
11-11-76	2.32	--	.63
1-11-77	.61, ice	--	1.51, ice
3-18-77	30.5	--	34.0
5-12-77	13.8	--	6.78
6-9-77	15.1	--	13.0
7-8-77	9.84	--	1.43
8-8-77	7.12	--	dry

*Computed discharge from Gage Height and rating table.

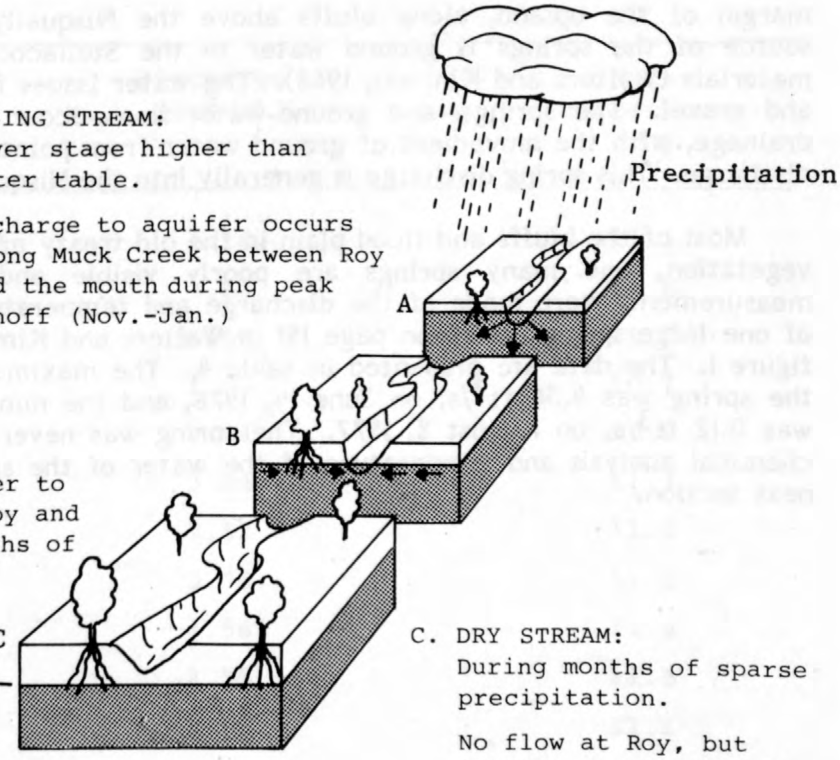


FIGURE 5.--Diagrammatic sketch showing relationships of surface water and ground water in the Muck Creek basin.

SPRINGS

The only other surface-water bodies in the old treaty area besides Nisqually Lake and Muck Creek are channels below natural springs that occur along the margin of the upland, along bluffs above the Nisqually River flood plain. The source of the springs is ground water in the Steilacoom Gravel and underlying materials (Walters and Kimmel, 1968). The water issues from the base of the sand and gravel. The springs--and ground-water flow--occur as a result of subsurface drainage, with the movement of ground water from points of recharge to points of discharge. This spring discharge is generally into the Nisqually River flood plain.

Most of the bluffs and flood plain in the old treaty area are heavily covered by vegetation, and many springs are poorly visible and inaccessible. However, measurements were made of the discharge and temperature and samples collected of one large spring (listed on page 191 in Walters and Kimmel, 1968) as indicated in figure 1. The data are presented in table 4. The maximum measured discharge of the spring was 4.56 ft^3/s, on June 14, 1976, and the minimum measured discharge was 0.12 ft^3/s, on August 8, 1977. The spring was never observed to be dry. The chemical analysis and temperature of the water of the spring are discussed in the next section.

TABLE 4.--Discharge and water temperature of spring for period 1975-77

Date	Discharge (ft^3/s)	Water temperature (°C)
8-9-75	1.10	11.1
9-12-75	.83	11.4
11-17-75	.68	10.6
12-11-75	1.05	10.7
1-14-76	3.44	10.8
2-13-76	3.94	11.7
3-24-76	3.52	11.2
4-23-76	3.36	11.1
5-14-76	4.56	11.4
6-15-76	2.55	11.2
7-9-76	2.07	11.1
8-9-76	1.74	11.1
9-10-76	1.45	10.8
10-13-76	.82	10.8
11-11-76	.79	10.8
6-9-77	.22	10.8
7-8-77	.20	11.1
8-8-77	.12	11.1

QUALITY OF STREAM AND SPRING WATER

To determine the quality of the stream and spring water in the old treaty area, samples were collected quarterly for 1 year from Muck Creek near its mouth and from the spring. In addition, tables 4 and 5 list water temperatures of the spring and of 3 sites on Muck Creek, respectively, for a 2-year period (Aug. 1975-Aug. 1977). Table 6 lists the data on chemical quality for waters sampled from Muck Creek near the mouth and from the spring.

The quality of water in Muck Creek near the mouth and in the spring are generally similar and of excellent quality for most purposes. Chemical and biological characteristics of lake water are discussed in detail in sections concerning Nisqually Lake, see page 24.

The temperature of the spring water was fairly constant, ranging from 10.6°C (on November 17, 1975) to 11.7°C (on February 13, 1976). The temperatures in Muck Creek were generally lower near the mouth than at the other two sites, probably because of ground water entering the streamflow and moderating the temperature at low discharges in warm weather. The range of water temperatures at Muck Creek near the mouth was from 1.1°C (on January 11, 1977) to 14.0°C (on August 8, 1977).

Chemical analysis of the water from Muck Creek near the mouth and from the spring also indicate the waters are soft and contain relatively little dissolved solids. Hardness between 0 and 60 mg/L (milligrams per liter) is considered soft. Specific conductance values less than 100 µmho/cm (micromhos per centimeter) indicate that the water does not contain much dissolved solids. These specific conductance and hardness values are typical of western Washington streams.

Moderately high concentrations of coliform bacteria may be a potential problem depending on the use of the water. The results of analyses for total coliform bacteria (table 6) show that the highest concentration in Muck Creek was 370 col/100 mL (colonies per 100 milliliters) on December 11, 1975 and the highest concentration in the spring water was 250 col/100 mL (on June 15, 1976). Livestock or wildlife droppings upstreams or near the spring may account for these moderately high counts. For public water supplies the total coliform densities in raw surface-water sources should not exceed 20,000 col/100 mL (National Academy of Sciences, National Academy of Engineering, 1973).

TABLE 5.--Temperatures of Muck Creek near mouth, at site A and at Roy, 1975-77

Date	Muck Cr near mouth		Site A		Muck Cr at Roy	
	Local time	Temperature (°C)	Local time	Temperature (°C)	Local time	Temperature (°C)
8-8-75	1630	12.2	1530	16.7	1415	18.9
9-12-75	0917	9.4	1320	18.3	1357	21.1
10-21-75	1240	9.0	--	--	--	--
11-17-75	0935	5.6	--	--	1035	5.6
12-11-75	0940	7.2	1230	7.0	1315	7.2
1-14-76	1000	7.2	--	--	1300	6.7
2-13-76	0950	7.5	1230	7.5	1250	7.2
3-24-76	1030	7.8	1130	6.6	1000	7.0
4-23-76	1050	9.2	1140	9.4	1215	10.3
5-14-76	1045	10.6	1200	12.2	1300	15.0
6-15-76	0930	9.7	1230	13.2	1310	16.1
7-9-76	0930	10.0	1015	14.8	1050	17.8
8-9-76	1130	10.0	1220	15.0	1310	16.7
9-10-76	1042	9.4	1132	15.0	1232	16.7
10-13-76	1000	8.0	1040	10.6	1230	11.7
11-11-76	0915	8.3	--	--	1010	8.6
1-11-77	1140	1.1	--	--	1255	.6
3-18-77	0906	7.8	--	--	0945	7.5
5-12-77	1402	12.6	--	--	1500	16.6
6-12-77	0920	9.7	--	--	1015	14.4
7-8-77	0825	10.0	--	--	0920	17.5
8-8-77	1330	14.0	--	--	1410	dry

TABLE 6.--Chemical analyses of water from Muck Creek near mouth and from spring (sec.22, T.18 N., R.1 E.)

[Data in milligrams per liter unless otherwise indicated]

	Muck Creek near mouth (sta. 12090205)				Spring			
	Date of collection				Date of collection			
	9/12/75	12/11/75	3/24/76	6/15/76	9/12/75	12/11/75	3/24/76	6/15/76
Discharge (ft^3/s)	4.72	362	145	24.9	0.83	1.05	3.52	2.55
Dissolved silica (SiO_2)	19	16	16	18	22	20	20	21
Dissolved iron (Fe) (µg/L)	--	--	110	10	--	--	10	0
Dissolved manganese (Mn) (µg/L)	10	0	0	7	10	10	0	50
Dissolved calcium (Ca)	7.7	7.5	7.7	8.0	7.7	8.0	7.9	8.3
Dissolved magnesium (Mg)	3.3	2.7	3.6	3.1	3.1	3.2	4.0	2.7
Dissolved sodium (Na)	45	4.1	4.1	3.9	4.5	4.6	4.3	4.0
Dissolved potassium (K)	1.0	1.6	1.2	.8	.7	.7	.7	.7
Bicarbonate (HCO_3)	36	33	39	44	41	45	42	43
Alkalinity as $CaCO_3$	30	27	32	36	37	34	34	35
Dissolved sulfate (SO_4)	3.5	4.8	3.7	3.5	5.4	3.7	3.3	5.3

Dissolved chloride (Cl)	2.7	3.4	3.4	3.0	2.4	2.4	2.5	1.3
Dissolved fluoride (F)	.1	.1	.0	.6	.0	.1	.1	.1
Total nitrate (N)	.48	.60	.45	.32	.23	.30	.30	.22
Total nitrite (N)	.011	.006	.008	.01	.001	.005	.005	.00
Total ammonia (N)	.03	.10	.08	.02	.03	.02	.02	.01
Hardness (Ca,Mg)	33	30	34	33	32	36	36	32
Noncarbonate hardness	3	3	2	0	0	2	2	0
Percent sodium	22	22	20	20	23	20	20	21
Sodium adsorption ratio	.3	.3	.3	.3	.3	.3	.3	.3
Specific conductance (μmho/cm)	76	90	84	72	81	98	83	76
pH (units)	7.4	6.6	7.2	7.4	7.2	7.4	6.9	7.1
Water temperature (°C)	9.4	7.1	7.8	9.6	11.4	10.7	11.2	11.2
Color (platinum-cobalt scale)	1	40	20	1	1	1	0	1
Turbidity (Jtu)	0	1	1	0	0	1	0	0
Dissolved oxygen	12.3	11.2	11.3	11.2	11.0	11.0	10.7	10.9
Total coliform bacteria (col/100 mL)	145	370	60	100	21	131	4	250
Fecal coliform bacteria (col/100 mL)	2	14	14	<1	<1	<1	<1	<1

NISQUALLY LAKE

Nisqually Lake is located on the Fort Lewis Military Reservation (within the old reservation boundaries), in the northeastern corner of the study area (fig. 1). Water is imported into the lake from Muck Creek, which is outside the lake's natural drainage basin.

The part of the drainage basin immediately adjacent to the lake is underlain by pebble- to-cobble-size gravel and boulders, and compact till (Walters and Kimmel, 1968). The soils of the same area are gravelly sandy loam with some loamy sand (Anderson and others, 1955).

Lake Basin

The shape of a lake is best described using a detailed bathymetric map. The map of Nisqually Lake (fig. 6) was prepared by the U.S. Geological Survey by combining the shore outline, as depicted on aerial photographs, with lines of depth soundings made from a boat on June 11, 1976. From the bathymetric map a number of physical aspects of the lake basin can be determined. Shown below are some physical characteristics of the lake.

Altitude (from topographic map):	229 feet
Surface area:	89 acres.
Lake volume:	594 acre-feet
Mean depth:	7 feet
Maximum depth:	9 feet
Shoreline length:	11,100 feet

Hydrology

Nisqually Lake has no natural surface-water inflow or outflow. The only surface-water input to the lake is that diverted from Muck Creek during the winter and spring. According to military authorities, this annual diversion of water into the lake raises its stage 5-8 feet. When the diversion is stopped, usually in late spring, the lake stage declines 5-6 feet in a period of 2-3 weeks. The rapid decline in stage is probably due to the seepage of lake water into the coarse gravels underlying the lake and its banks.

Measurements of lake stage were made by U.S. Geological Survey personnel each time the lake was sampled. The lake stage declined 2.62 feet during the period May 21-July 26, 1976. In 1976, the diversion of water into the lake had been terminated prior to May 21, the first sampling date.

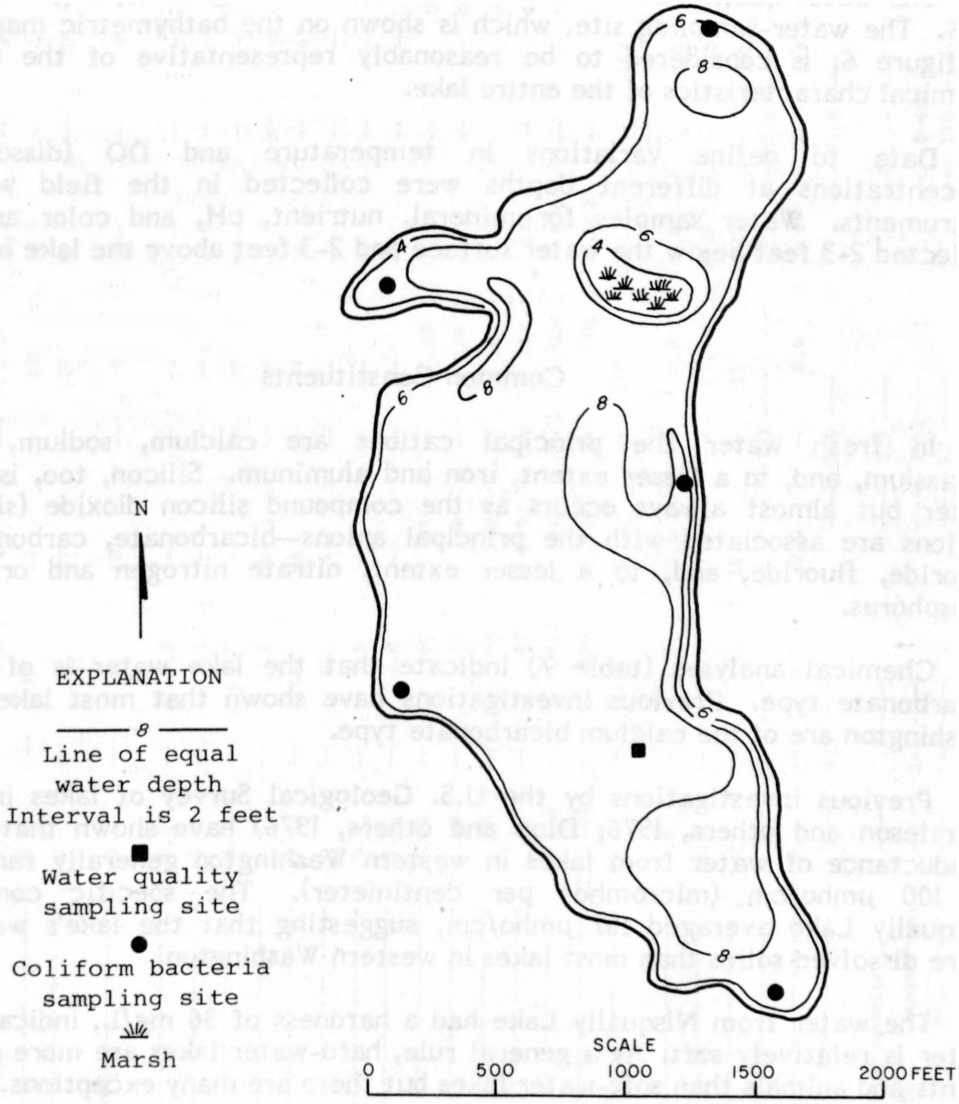


FIGURE 6.--Bathymetric map of Nisqually Lake. Prepared from measurements by the U.S. Geological Survey, June 11, 1976.

Water Quality

The water-quality field data were collected during the spring and summer of 1976. The water-sampling site, which is shown on the bathymetric map of the lake in figure 6, is considered to be reasonably representative of the physical and chemical characteristics of the entire lake.

Data to define variations in temperature and DO (dissolved-oxygen) concentrations at different depths were collected in the field with portable instruments. Water samples for mineral, nutrient, pH, and color analyses were collected 2-3 feet below the water surface and 2-3 feet above the lake bottom.

Common Constituents

In fresh water the principal cations are calcium, sodium, magnesium, potassium, and, to a lesser extent, iron and aluminum. Silicon, too, is abundant in water but almost always occurs as the compound silicon dioxide (silica). These cations are associated with the principal anions--bicarbonate, carbonate, sulfate, chloride, fluoride, and, to a lesser extent, nitrate nitrogen and orthophosphate phosphorus.

Chemical analyses (table 7) indicate that the lake water is of the calcium bicarbonate type. Previous investigations have shown that most lakes in western Washington are of the calcium bicarbonate type.

Previous investigations by the U.S. Geological Survey of lakes in Washington (Bortleson and others, 1976; Dion and others, 1976) have shown that the specific conductance of water from lakes in western Washington generally ranges from 25 to 100 µmho/cm (micromhos per centimeter). The specific conductance of Nisqually Lake averaged 107 µmho/cm, suggesting that the lake's water contains more dissolved solids than most lakes in western Washington.

The water from Nisqually Lake had a hardness of 36 mg/L, indicating that the water is relatively soft. As a general rule, hard-water lakes are more productive of plants and animals than soft-water lakes but there are many exceptions.

The pH of water in Nisqually Lake was slightly basic and averaged 7.7 near the surface and 7.8 near the bottom.

Color is one control of light transmission through water. High color values in many lakes result from the decomposition of vegetation, which gives the water a brown, tealike color. Color is determined by a comparison of the water with standardized colored-glass discs and is reported in platinum-cobalt units. The water in Nisqually Lake had color values of 15 in June and 20-25 in July, indicating slightly more color than found in most western Washington lakes.

TABLE 7.--Water-quality data from Nisqually Lake, 1976

[Data in milligrams per liter unless otherwise indicated]

Station: Nisqually Lake	Date of collection								
	May 21			June 11			July 26		
Water depth (ft)	3.0	--	5.0	2.0	--	5.0	2.5	--	4.5
Silica (SiO_2)	13	--	13	12	--	12	8.9	--	8.9
Dissolved iron (Fe), (in ug/L)	0	--	0	20	--	20	30	--	20
Dissolved manganese (Mn), (in ug/L)	0	--	0	10	--	0	0	--	0
Calcium (Ca)	9.0	--	9.0	--	--	--	--	--	--
Magnesium (Mg)	3.4	--	3.5	--	--	--	--	--	--
Sodium (Na)	4.7	--	4.7	--	--	--	--	--	--
Potassium (K)	.8	--	.8	--	--	--	--	--	--
Bicarbonate (HCO_3)	43	--	48	44	--	44	58	--	57
Carbonate (CO_3)	0	--	0	--	--	--	--	--	--
Sulfate (SO_4)	5.4	--	5.5	--	--	--	--	--	--
Chloride (Cl)	2.8	--	2.8	--	--	--	--	--	--
Nitrate nitrogen (as N)	.02	--	.00	.01	--	.00	.00	--	.00
Nitrite nitrogen (as N)	.00	--	.01	.00	--	.00	--	--	.00
Ammonia nitrogen (as N)	.06	--	.06	.05	--	.05	.09	--	.08
Organic nitrogen (as N)	.30	--	.42	.39	--	.35	.48	--	.47
Total phosphorus (as P)	.018	--	.037	.023	--	.020	.036	--	.033
Orthophosphate (as P)	.001	--	.001	.000	--	.001	.002	--	.002
Specific conductance (μmho/cm at 25°C)	105	--	110	110	--	110	104	--	103
pH (pH units)	7.6	--	7.7	7.6	--	7.6	7.8	--	8.1
Water temperature (°C)	16.5	--	16.2	17.0	--	17.0	22.8	--	22.8
Color (Pt-Co scale)	--	--	--	15	--	15	20	--	25
Secchi-disc visibility (ft)	----	>8.0	----	----	>7.2	----	----	3.8	----
Dissolved oxygen (DO)	9.2	--	9.2	9.0	--	8.9	9.4	--	9.4
Chlorophyll _a_ in photic zone (in μg/L)	----	4.2	----	----	5.4	----	----	9.8	----
Algal growth potential (composite)	----	.6	----	----	1.9	----	----	--	----
Fecal coliform bacteria (col/100 mL) Range	----	<1-1	----	----	1-57	----	----	6-468	----
Mean	----	<1	----	----	12	-----	----	110	----
Alkalinity total (as $CaCO_3$)	35	--	39	36	--	36	48	--	47

Nutrients

A nutrient is any chemical element, ion, or compound that is required by an organism for the continuation of growth, reproduction, and other life processes. Many elements and compounds act as nutrients to supply the food needed by aquatic plants. However, nitrogen and phosphorus usually are considered the limiting nutrients for aquatic-plant growth--algae in particular--and as such received the most emphasis in this study. Whatever nutrient is limiting algal growth, the concentrations of nitrogen and phosphorus--in particular the inorganic forms--are useful in evaluating the trophic conditions of a lake (Lee, 1972).

The nutrient concentrations in water from Nisqually Lake included inorganic nitrogen (nitrate, nitrite, and ammonia), organic nitrogen, total phosphorus, and orthophosphate phosphorus. Chemical analyses indicate that the concentrations of inorganic nitrogen and of orthophosphate (the inorganic form of phosphorus) were low, averaging 0.07 and 0.001 mg/L, respectively, on the three sample dates. However, the concentrations of organic nitrogen and of total phosphorus were moderate to high, averaging 0.40 and 0.028 mg/L, respectively. The preceding nutrient concentrations are judged relative to levels found in similar western Washington lakes (Bortleson and others, 1976).

Transparency, Temperature, and Dissolved Oxygen

The transparency of lake water is commonly related to Secchi-disc visibility, the depth at which a white-and-black disc, 8 inches in diameter, disappears from view when lowered into the water. Because changes in biological production can cause changes in the color and turbidity of a lake, Secchi-disc visibility often is used as a gross measure of the plankton in the water.

The Secchi-disc visibility of Nisqually Lake in May and June was indeterminate; the disc was still visible when lying on the lake bottom at depths of 8.0 and 7.2 feet, respectively. By July, however, the visibility had decreased to 3.8 feet as a result of increased algal concentrations.

Water temperature in lakes, which varies with depth and time of year, is an important controlling factor for life processes and chemical reaction rates as well as many physical events that occur in the aquatic environment. The water temperature of Nisqually Lake indicates that the lake is too shallow to develop the summer thermal stratification common in deeper lakes. Water temperatures on the sampling dates in May, June, and July averaged 16.4°, 17.0°, and 22.8°C, respectively. Because of the lack of a cooler layer at depth, Nisqually Lake would probably be better suited for warm-water fish species than to cold-water species.

Dissolved-oxygen concentration in lake water varies with time of year and depth of water and is a function of many factors, including the water temperature, atmospheric pressure, and salinity of the water. Also, oxygen in water is continually being altered by life processes, such as photosynthesis and respiration, and by complex chemical reactions. For good growth and the general health of trout, salmon, and other cold-water species of aquatic life, the DO concentrations should not be less than 6.0 mg/L according to the Federal Water Pollution Control Administration (1968). In contrast, many warm-water species of fish and other aquatic life are tolerant of much lower DO concentrations.

Dissolved-oxygen concentrations in Nisqually Lake were high in May and June (9.2 and 9.0 mg/L, respectively) but below saturation values. In July, despite the higher water temperature, the DO concentrations averaged 9.4 mg/L, somewhat above the saturation value. This increase in daytime DO concentration was probably due to the increased algal concentrations observed in July. The opposite would probably be true at night when algae use oxygen, but nighttime measurements were not made.

Aquatic Plants

The rooted aquatic-plant growth of Nisqually Lake was assessed according to the percentage of the shoreline and water-surface area covered by emersed or floating plants and the percentage of the lake bottom covered by submersed plants. In this report, rooted aquatic plants with floating leaves, such as waterlilies, are considered emersed. The plants were identified to genus level according to the descriptions of Fassett (1969).

The composition of the littoral bottom is one of several factors that determine the suitability of the nearshore area for rooted aquatic-plant growth. For instance, littoral bottoms of muck or silt are conducive to plant growth, but bottoms of rock, gravel, or sand generally support fewer plants or none at all.

The littoral bottom of Nisqually Lake is composed predominantly of gravel, with local areas of muck and a gravel-muck mixture. This composition would be moderately conducive to the growth of rooted aquatic plants but other factors such as water depth, water temperature, water clarity, and nutrients also affect the extent of plant coverage.

About 75 percent of the shoreline of Nisqually Lake was covered by emersed plants, chiefly spike rush (Eleocharis sp.). Emersed plants, chiefly spike rush (Eleocharis sp.) and yellow lily (Nuphar sp.), covered about 42 percent of the lake surface. The entire lake bottom was covered by submersed plants, chiefly pondweed (Potamogeton sp.).

Chlorophyll a is a green photosynthetic pigment present in plant cells, including algae. The concentration of chlorophyll a in water is a commonly accepted indicator of algal biomass (Lee, 1972). The chlorophyll a concentrations in Nisqually Lake were low to moderate in May and June (4.2 and 5.4 µg/L; micrograms/liter, respectively) but moderate to high in July (9.8 µg/L). The algal flora on all three sampling dates was diversified, especially with respect to diatoms. In May and June, the dominant genus was the diatom Asterionella sp. By July, the dominant genera were the diatom Pinnularia sp. and the blue-green alga Anabaena sp; Asterionella sp. was not found in the July sample.

Fecal-Coliform Bacteria

Samples for the determination of fecal-coliform bacteria levels were collected at five stations approximately 100 feet offshore at a depth of 1 foot. The sample locations are shown in figure 6.

The fecal-coliform bacteria counts in Nisqually Lake were low to moderate in May and June; in July, however, one sample was high (468 col/100 mL), probably due to the presence of waterfowl.

Summary of Nisqually Lake Study

Nisqually Lake is located in the artillery impact zone of the Fort Lewis Military Reservation. The lake is shallow and has a relatively flat bottom. There are no natural surface-water inflows or outflows, although water is diverted into the lake during the winter and spring months.

The water in Nisqually Lake is generally of good quality but is higher in dissolved solids than most lakes in western Washington. The concentrations of inorganic nitrogen and of orthophosphate phosphorus were low; the concentrations of organic nitrogen and of total phosphorus were moderate to high.

Nisqually Lake is too shallow to stratify thermally; the warm surface-water temperatures observed in May, June, and July extended to the bottom of the lake. Dissolved-oxygen concentrations were high, but below saturation level, in May and June; however, in July the daytime DO concentration was above the saturation level, probably due to increased algal concentrations. Because of the lack of a cooler layer of water at depth, the lake would probably be better suited to warm-water fish species than to cold-water species.

The biological productivity of Nisqually Lake is high. This conclusion is based on the extent of algal and macrophyte growth observed in the lake in summer. Some possible reasons for the high productivity include shallow mean depth, moderate to high concentrations of total phosphorus, and warm-water temperatures, factors which previous studies have shown lead to increased productivity.

The basic data collected as part of this investigation are adequate to describe the water quality and overall status of Nisqually Lake, and the data will provide a base of reference for periodic appraisals of future lake conditions.

GROUND-WATER AVAILABILITY

Ground water occurring beneath the old treaty area comes from percolation of precipitation on the land surface. The water moves downward to the water table (top of the zone of saturation) and then westward toward the Nisqually River valley. Some of the ground water also derives as seepage from Muck Creek, particularly following periods of high streamflow.

Ground water beneath the old treaty area occurs in unconsolidated to poorly consolidated glacial drift or outwash consisting of gravel, sand, silt, and clay. These materials occur in several stratigraphic units, namely the highly permeable Steilacoom Gravel (uppermost unit), poorly permeable glacial till, permeable glacial advance outwash (mostly sand and gravel), and underlying impermeable materials consisting of compacted sand, gravel, and clay (fig. 4). The occurrence and availability of ground water in these materials depend on their permeability and position relative to the water table. Where the materials are permeable and saturated they will yield water to wells. Unfortunately, the absence of any wells in the old treaty area precludes any conclusions on the local availability of ground water. The following information therefore, is based on interpretations of the local geology and on data from wells drilled in the Roy area to the east.

The Steilacoom Gravel is widespread throughout southwestern Pierce County (Walters and Kimmel, 1968) and ranges in thickness from a few feet in some areas to 60 feet or more in other areas. Where it occurs below the water table it provides moderate to large supplies (100-250 gal/min or more) of water to wells. In the upland of the old treaty area and adjacent area (fig. 1) the gravel underlies the soil over an estimated 6,000 acres (about 9 mi^2). The thickness of the gravel in the old treaty area is unknown because of the lack of wells from which interpretations can be made. However, several wells less than 50 feet deep near the town of Roy tap the Steilacoom Gravel, and obtain yields of about 120 gal/min. Water levels in these wells range from 4 to 12 feet below land surface, with drawdowns reported from 2½ to 13 feet.

The Steilacoom Gravel would probably provide the principal source of ground water in the old treaty area. Till is probably beneath the Steilacoom Gravel. The advance outwash sand and gravel beneath the till is exposed at places in the bluffs overlooking the Nisqually River. The presence of springs along the face of the bluff also indicates the presence of ground water in the sand and gravel. The springs issue along the base of the sand and gravel which overlie impermeable semiconsolidated sand, gravel, silt, and clay.

In adjacent parts of Pierce County the advance outwash gravel is considered the most important source of ground water. Yields from wells tapping the material vary locally, but as much as 250 gal/min has been obtained from some wells.

Ground water also occurs in alluvial materials underlying the flood plain of the Nisqually River, as indicated by wells tapping these deposits beneath the present Nisqually Indian Reservation west of the river. According to Myers and Cummans (1973), gravel beneath the flood plain yields as much as 200 gal/min to wells. Such yields can presumably also be obtained in the present study area east of the river. Water levels in the alluvial material are probably slightly above river level.

More reliable determinations of the availability of ground water beneath the old treaty area will require the drilling of test wells. Several wells drilled to different depths would provide information on availability and depth to water, and the potential yields of the underlying water-bearing materials.

POTENTIAL FOR FUTURE WATER DEVELOPMENT

The old treaty area is currently under the control of the U.S. Army and is almost entirely inside the impact area and buffer zone of artillery ranges, therefore, development would appear unlikely under the present conditions of use and ownership of the land.

Uses of water, if development occurs in the old treaty area, would probably be in the form of fish and wildlife propagation. On the basis of data collected on the quantity and quality of water available in the old treaty area and adjacent area, a fish-rearing or hatchery facility of limited size would be possible next to Muck Creek in the vicinity of its mouth. Further studies could provide additional necessary information, such as more complete data on the availability of water in Muck Creek near its mouth during periods of low flow. Discharge data could be determined from a continuous-record gaging station placed there. Also, additional information could be obtained from studies by fisheries or wildlife agencies about the fish-spawning gravels, competition with other species, and physical barriers that might prevent migration. During the summer months the flow of Muck Creek through rearing ponds could be augmented by water pumped from the underlying aquifer. Investigation of the underlying aquifer, such as test-well drilling, would provide much-needed information on the aquifer's capacity for development.

REFERENCES CITED

Anderson, W. W., Ness, A. O., and Anderson, A. C., 1955, Soil survey of Pierce County, Washington: U.S. Soil Conservation Service, ser. 1939, no. 27, 88 p.

Bortleson, G. C., Dion, N. P., McConnell, J. B., and Nelson, L. M., 1976, Reconnaissance data on lakes in Washington: Washington Department Ecology Water-Supply Bulletin 43, v. 1-4, 1128 p.

Brown, Eugene, Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water Resources Investigations, book 5, chap. A1, 160 p.

Cummans, J. E., 1974, Flood profiles and inundated areas along the lower Nisqually River, Washington: U.S. Geological Survey Water-Resources Investigations 42-73, 9 p.

Dion, N. P., Bortleson, G. C., McConnell, J. B., and Nelson, L. M., 1976, Reconnaissance data on lakes in Washington: Washington Department Ecology Water-Supply Bulletin 43, v.5-7, 938 p.

Fassett, N. C., 1969, A manual of aquatic plants: Madison, Wisconsin University Press, 405 p.

Federal Water Pollution Control Administration, 1968, Water quality criteria: Report of the National Technical Advisory Committee to the Secretary of the Interior: Federal Water Pollution Control Administration, 234 p.

Griffin, W. C., Sceva, J. E., Swenson, H. A., and Mundorff, M. J., 1962, Water resources of the Tacoma area, Washington: U.S. Geological Survey Water-Supply Paper 1499-B, 101 p.

Hidaka, F. T., 1973, Low-flow characteristics of streams in the Puget Sound region, Washington: U.S. Geological Survey open-file report, 55 p.

Lee, G. F., 1972, Eutrophication: Transactions of the Northeast Fish and Wildlife Conference, p. 39-60.

Myers, D. A., and Cummans, J. E., 1973, Water resources of the Nisqually Indian Reservation, Washington: U.S. Geological Survey open-file report, 30 p.

National Academy of Sciences, National Academy of Engineering, 1973 (1974), Water quality criteria 1972: U.S. Environmental Protection Agency Ecological Research Series, R-3-73-033, 594 p.

Nelson, L. M., 1974, Sediment transport by streams in the Deschutes and Nisqually River basins, Washington, November 1971-June 1973: U.S. Geological Survey open-file report, 33 p.

Slack, K. V., Averett, R. C., Greeson, P. W., and Lipscomb, R. G., 1973, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A4, 165 p.

U.S. Department of Commerce, 1956-71, NOAA, Environmental Data Service, Annual summaries of hourly precipitation for Washington, annual reports for years indicated.

-----1976, NOAA, Environmental Data Service, Annual summary, Washington, Volume 80, Number 13.

U.S. Geological Survey, 1957-65, Surface water records of Washington: Tacoma, Wash., annual reports published for years indicated.

-----1966-71, Water resources data for Washington, Part 1, Surface water records: Tacoma, Wash., annual reports published for years indicated.

U.S. Weather Bureau, 1965, Mean annual precipitation, 1930-57, State of Washington: Portland, Oreg., U.S. Soil Conservation Service, map M-4430.

Walters, K. L., and Kimmel, G.E., 1968, Ground-water occurrence and stratigraphy of unconsolidated deposits, Central Pierce County, Washington: Washington Department Water Resources Water Supply Bull. 22.