UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# HYDROLOGY AND THE EFFECTS OF INDUSTRIAL PUMPING IN THE NIKISKI AREA, ALASKA

By Gordon L. Nelson

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JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
Water Resources Division
733 West 4th Avenue, Suite 400
Anchorage, Alaska 99501

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## INCH-POUND UNITS AND SI METRIC UNIT EQUIVALENTS

| Multiply | By | To obtain |
|---|---|---|
| inches (in.) | 25.4 | millimeters (mm) |
| feet (ft) | 0.3048 | meters (m) |
| miles (mi) | 1.609 | kilometers (km) |
| square feet ($ft^2$) | 0.0929 | square meters ($m^2$) |
| square miles ($mi^2$) | 2.589 | square kilometers ($km^2$) |
| cubic feet ($ft^3$) | 0.0283 | cubic meters ($m^3$) |
| inches per year (in./year) | 25.4 | millimeters per year (mm/year) |
| feet per day (ft/d) | 0.3048 | meters per day (m/d) |
| cubic feet per second ($ft^3$/s) | 1699.3 | liters per minute (L/min) |
| gallons per minute (gal/min) | 3.785 | liters per minute (L/min) |
| gallons per day (gal/d) | 3.785 | liters per day (L/d) |
| cubic feet per second per square mile [($ft^3$/s)/$mi^2$] | 0.0109 | cubic meters per second per square kilometer [($m^3$/s)/$km^2$] |

## GLOSSARY

Base flow - Sustained streamflow that continues several days or months after precipitation or snowmelt ends.

Drawdown cone - A conical depression of the potentiometric surface caused by pumping from a well.

Fluvial - Produced by the action of a stream.

Gradient - The slope of the potentiometric surface; the difference in head between two points divided by the distance between the points.

Head - Potential; the height to which water will rise in a well above a reference datum.

Hydraulic conductivity - The amount of water that will be conducted through a 1-square-foot section of materials under a hydraulic gradient of one at prevailing temperature.

Lacustrine - Produced in or relating to a lake.

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 "Sea Level of 1929."

Potentiometric surface - The surface defined by water levels in all tightly cased wells open to a particular aquifer. The water table is the potentiometric surface of the unconfined aquifer.

Steady state - A condition under which both stresses and effects (water levels) do not change with time.

Storage coefficient - The volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity - The amount of water transmitted through a 1-foot-wide section of an aquifer under a unit hydraulic gradient, at the prevailing temperature. (Section is perpendicular to flow.)

# HYDROLOGY AND EFFECTS OF INDUSTRIAL PUMPING IN THE NIKISKI AREA, ALASKA

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## ABSTRACT

Ground-water consumption for industrial use at Nikiski increased from about 1 million gallons per day in 1968 to 4.2 million gallons per day in 1979. Water managers and local citizens are concerned that industrial pumping may reduce the esthetic and recreational value of local lakes. Some lake levels have declined as much as 8 feet since pumping began; the greatest declines occurred in lakes nearest the center of pumping.

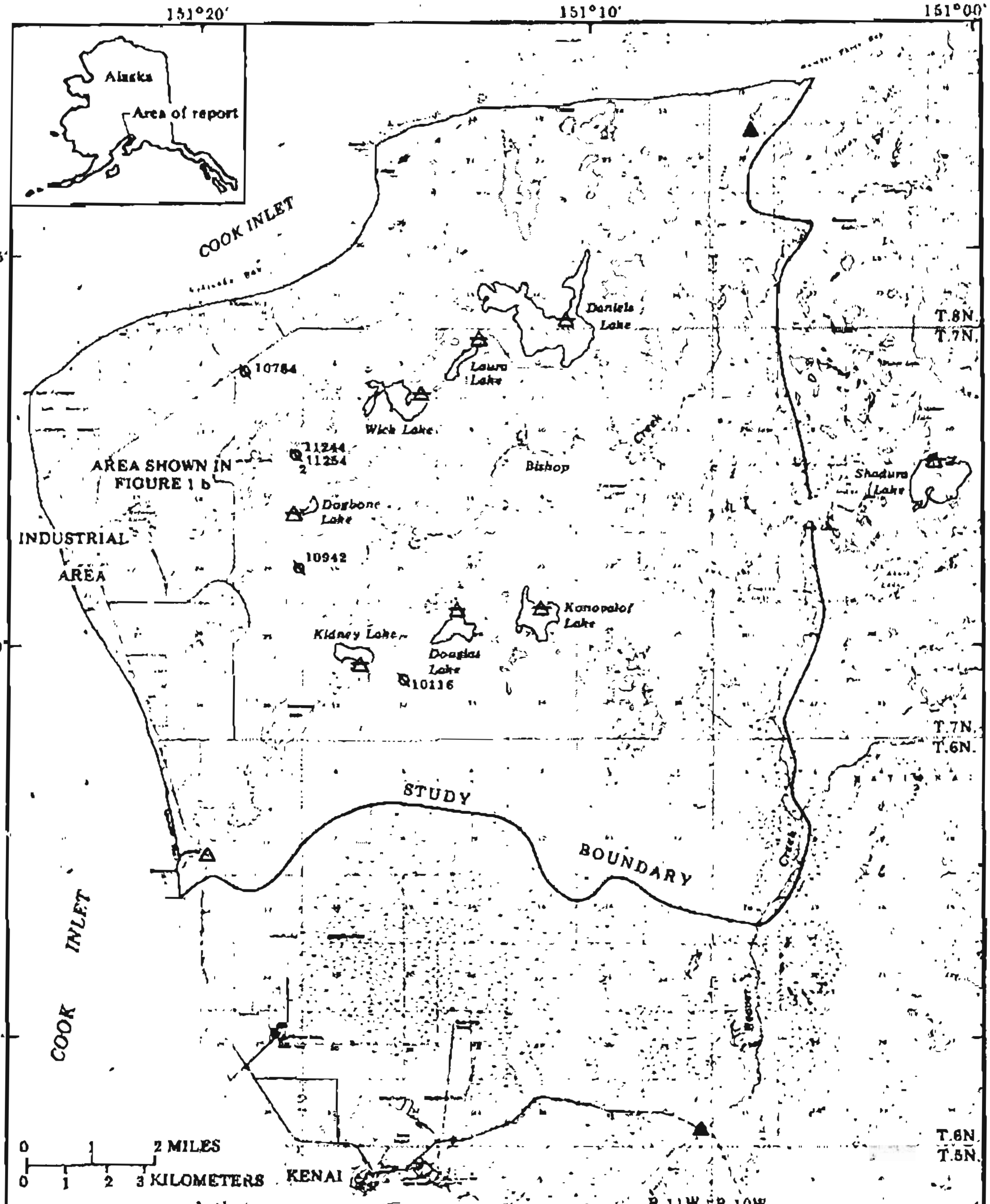
Ground water occurs in three aquifers. The upper aquifer is unconfined and is hydraulically connected to most lakes and streams in the area. The upper two aquifers are hydraulically connected through a leaky confining layer, and water levels in the two aquifers fluctuate synchronously with changes in precipitation and changes in pumping from either aquifer. The hydraulic connection of the lower confined aquifer, the deepest of the three aquifers, to the other two aquifers is poor. Drawdowns caused by pumping have stabilized in all three aquifers. This indicates that the pumping is in equilibrium with the hydrologic boundaries. In the lower two aquifers, the potentiometric surfaces near some production wells are below sea level; however, no salt water has intruded the aquifers as far as the pumped wells. If intrusion occurs or if additional water supplies are needed, another potential site for ground-water development is the middle Beaver Creek basin, 7-10 miles east of the industrial area.

## INTRODUCTION

The Nikiski area (figs. 1a and b) has undergone rapid industrial, commercial, and residential development since the discovery of oil on the Kenai Peninsula in the early 1960's. Owing to its proximity to both a deep-water port and oil and gas fields, Nikiski has been the center of industrial growth. Commercial growth has occurred along the North Road from Kenai to Bishop Creek, and residential development has taken place throughout the Nikiski area.

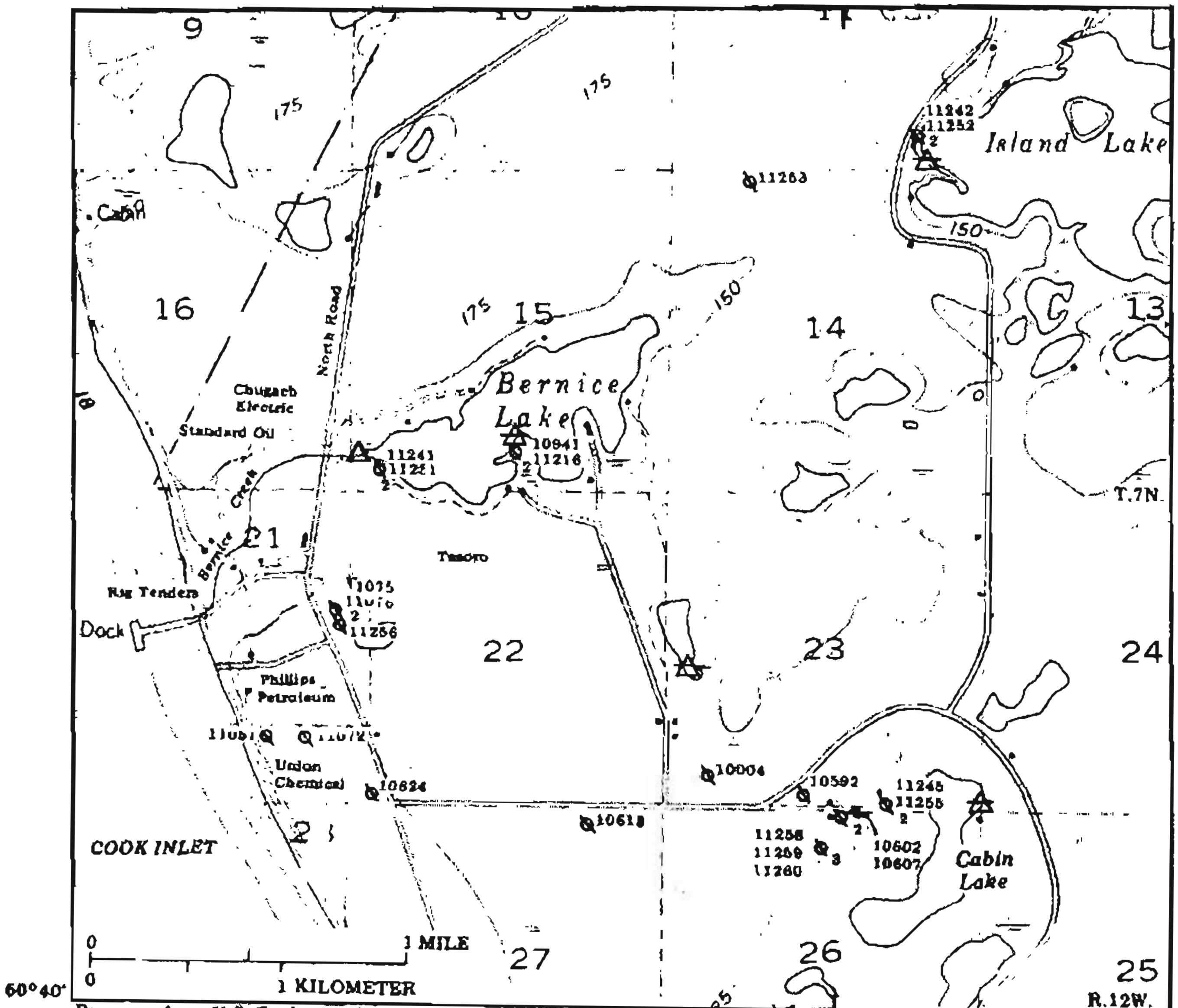
The water resources of the Nikiski area have many uses. These include industrial, commercial, and domestic consumption, esthetic and recreational use, and wildlife habitat. During the period of development, the stresses on the water resources have increased, and conflicts have arisen regarding the most beneficial use of the available water.

The study area has the following boundaries (fig. 1b): Cook Inlet to the north and west, Bishop and Beaver Creeks to the east, and the area of coastal plain sediments (Anderson and Jones, 1972, plate 1) on the south. The coastal plain sediments are not a true hydrologic boundary. However, they probably represent a southern limit to the area of intensive ground-water development because they are too fine grained to be suitable for large-capacity wells.



Base map from U.S. Geological Survey, Kenai Area, Alaska, 1:63,360

Figure 1 a.--Location and natural features of the Nikiski study area.




Base map from U.S. Geological Survey, Kenai Area, Alaska, 1:63,360

**EXPLANATION FOR FIGURES 1 a and 1 b.**

- 10116 / 2 — Observation well; five-digit number is station number; one-digit number is number of wells represented by symbol
- ▲ — Continuous-record gaging station
- △ — Streamflow-measurement site without gage
- Lake-level measuring site
- Contour line (50 ft interval)
- Intermediate contour line
- Tidal flats
- Wetlands

Figure 1 b.–Locations of data-collection sites and principal industries in the Nikiaki study area.

## Previous Studies

The first detailed investigation of ground-water resources of the Nikiski area was released in 1967 for Union Chemical Company (formerly Collier Carbon and Chemical Corporation) by Dames and Moore (written commun., 1967). Subsequently Dames and Moore (written commun., 1976), working for Union Chemical Company, analyzed aquifer properties and interactions between ground water and surface water in the Nikiski area and reported on the results of several pumping tests for the company.

The U.S. Geological Survey has published a number of studies on the hydrology of the Kenai Peninsula that include information on the Nikiski area. These studies were summarized by Anderson and Jones (1972) as part of a hydrologic analysis of the Nikiski-Kenai-Soldotna area. Subsequently, Scully, Leveen, and George (1978) compiled surface-water records for the Cook Inlet basin. Records of stream discharge and of water levels in several observation wells in the Kenai-Nikiski area have been published annually in the Survey's Water-Data Reports (U.S. Geological Survey, 1977-79).

## Purpose and Scope

The purposes of this study are:

1. To define the hydrologic system, particularly the hydraulic communication among aquifers, based on data available through September 1, 1979.
2. To evaluate the effects of industrial pumping.
3. To appraise the potential for obtaining ground water from areas east of the 1979 area of concentrated pumping.

The study included an expansion of the previously existing data base by test drilling, monitoring of lakes, wells, and streams, updating well inventories, and laboratory and field tests of the hydraulic properties of materials. Wells were drilled at 16 sites and ranged in depth from 65 to 355 ft. Continuous water-level records were collected from 10 wells, and periodic measurements were made in 18 others. Streamgaging stations were maintained on Beaver Creek during 1967-77 and on Bishop Creek during 1977-79. Lake-level stations were maintained on 12 lakes. The locations of the data-collection stations are shown in figures 1a and b. The datum for all stations except Konovalof Lake is the National Geodetic Vertical Datum of 1929 (NGVD). NGVD of 1929 is referred to as sea level in this report. The vertical control for the Kenai C-4 map (1951, minor revisions 1972) used in this report is 30-50 ft in error in the industrial area. Altitudes for geologic sections in this report are from surveyed levels and topographic mapping by North Pacific Aerial Surveys, Inc.

This report contains only a small part of the information collected during the Survey's study of the Nikiski area. The hydrographs, well logs, and other forms of data used in this report were selected to illustrate the major concepts developed during the study. Other data are available on request from the District Chief at the address on the reverse side of the title page of this report.

## WATER USE

Most of the ground water consumed in the Nikiski area is for industrial use. Industrial pumpage has increased from about 1 million gal/d in early 1968 to more than 4 million gal/d in 1979 (fig. 2). Figure 3 shows locations and rates of pumping from the major industrial wells during 1968, 1970, and 1977. Some consumers have two or more wells within 1,000 ft of each other, and such well fields are plotted on the figure as a single point. Chugach Electric and Standard Oil of California are considered a single user because their water systems are combined. In early 1968 Chugach Electric-Standard Oil and Rig Tenders were the only industrial consumers of ground water. In late 1968 Union Chemical Company began to pump water, primarily from a well near Cabin Lake. In June 1969, Phillips Petroleum's Kenai Plant began pumping, and in November 1969, the Tesoro-Alaskan refinery began pumping water. The rates and areal pattern of pumping were nearly constant from 1970 until 1977 when Union Chemical Company increased pumping for expansion of their plant. Also in 1977, Union Chemical Company began utilizing three wells that were nearer their plant than the one near Cabin Lake. Since 1978, when the Union Chemical Company expansion was completed, the rate of industrial pumping in the Nikiski area has remained at about 4.2 million gal/d.

An estimated 350,000 gal/d of ground water are used for domestic purposes in the Nikiski area. This estimate is based on a 1978 population of 3,485 (Kenai Peninsula Borough, written commun., 1978) and a per capita use of 100 gal/d. Less than 25 percent of the water for domestic use is drawn from public-supply wells; most is supplied by wells serving single-family residences. Virtually all the domestically used ground water in the Nikiski area is discharged back to the ground through on-site sewage systems. Domestic pumpage therefore has minimal effect on the net ground-water balance.

## GEOLOGIC SETTING

### Bedrock

Bedrock consists of moderately indurated sandstone, siltstone, claystone, and coal. No wells penetrate bedrock within the study area, and it is presumed to be deeper than 500 ft below land surface. Oil and gas wells near the eastern edge of the study area have penetrated bedrock at a depth of approximately 590 ft.

The potential for producing ground water from bedrock is much less than from the overlying unconsolidated materials. Although bedrock provides up to 50 gal/min to wells in other parts of the Kenai Peninsula, it is not a significant aquifer in the Nikiski area.

### Unconsolidated Sediments

The unconsolidated sediments overlying bedrock consist of mixed deposits of glacial, fluvial, lacustrine, and estuarine origin. The distribution of surficial materials within the study area has been mapped by Anderson and Jones (1972) and is shown in figure 4. The till is poorly sorted and yields little water to wells. However, thin beds and stringers of fluvial sand and gravel within the till provide water to some wells. Undifferentiated drift is composed of mixed till, outwash deposits, and lacustrine sediments. Deposits of coarse sand and gravel within this

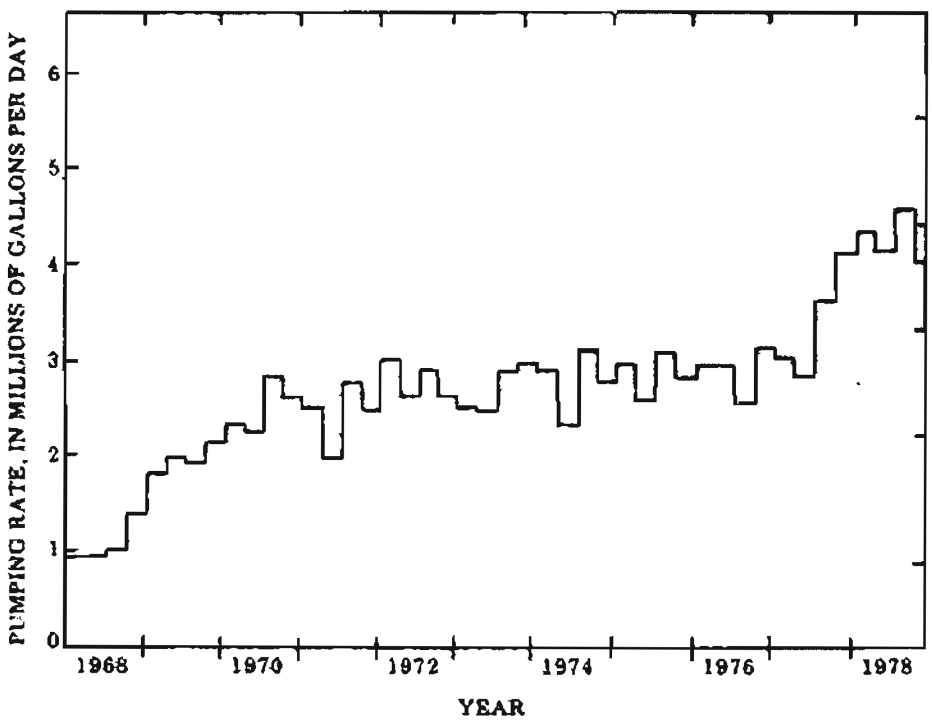
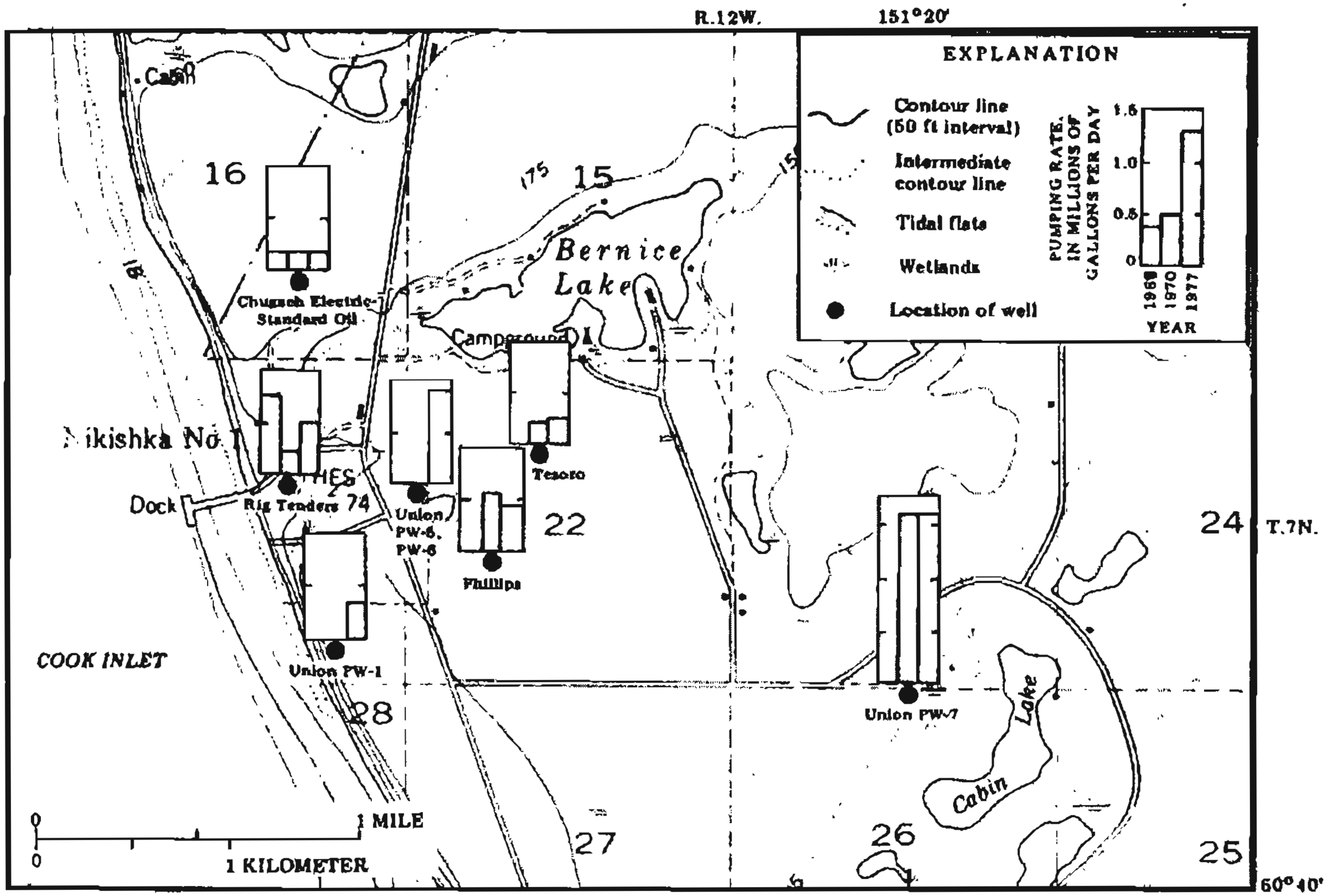



Figure 2.--Quarterly average rates of industrial pumping, 1968-78.

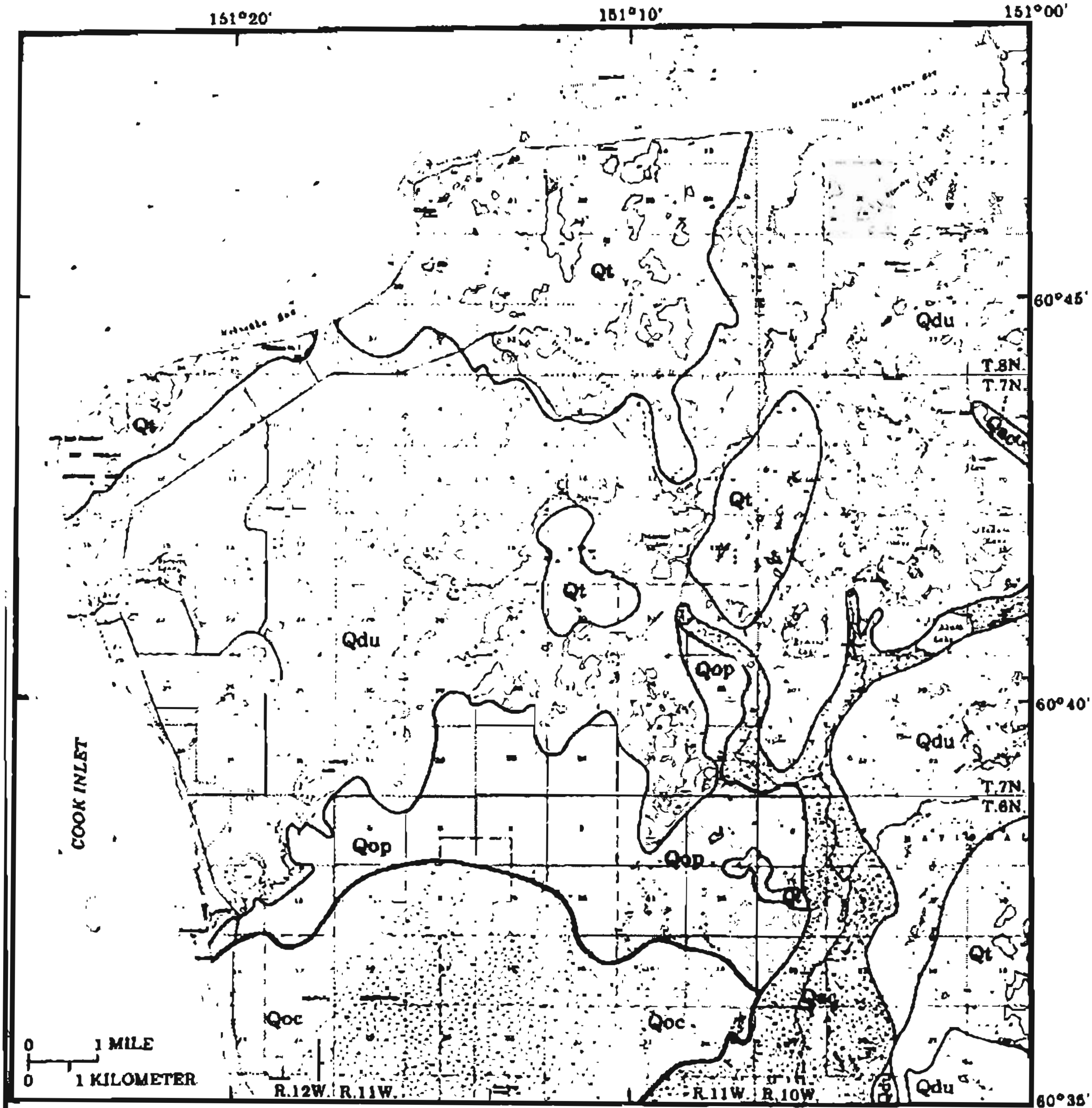
unit provide more than 1,000 gal/min to some wells in the area. Outwash-plain deposits are materials that were deposited in front of ancient glaciers. They are composed of well-sorted sand and gravel and have good permeability and porosity. Coastal-plain deposits occur in areas of low relief. They are composed primarily of sand and grade to stratified clay, silt, and fine sand at depth. The water table in areas of coastal plain deposits is generally within a few feet of land surface. Abandoned-channel deposits are composed of fluvial sand and gravel entrenched in older sedimentary deposits. The generally high porosity and permeability of abandoned-channel deposits give them a high potential for producing water to wells.

At a depth of about 100 ft below land surface, there is an extensive layer of clay and silt that may have been deposited in a proglacial lake (Karlstrom, 1964) or in Cook Inlet. This clay layer is underlain by a complex and poorly defined unit of mixed glacial, fluvial, and lacustrine sediments. Much of this unit is composed of fine sand that yields little water to wells. However, it also contains significant deposits of well-sorted sand and gravel that constitute the major confined aquifers of the Nikiski area. Some wells completed in these aquifers yield more than 1,000 gal/min of water.




Base map from U.S. Geological Survey, Kenai Area, Alaska, 1:63,360

Figure 3.--Locations of major production wells and their pumping rates in June 1968, June 1970, and November 1977.




Base map from U.S. Geological Survey, Kenai Area, Alaska, 1:63,360

Figure 4.–Surficial geology of the Nikiski area (from Anderson and Jones, 1972).

## EXPLANATION FOR SURFICIAL GEOLOGY MAP

(Modified from Anderson and Jones, 1972)

| MAP UNIT | LITHOLOGY AND STRATIGRAPHY | LANDFORMS AND OCCURRENCE | SURFICIAL DRAINAGE AND INFILTRATION | OCCURRENCE OF GROUND WATER |
|---|---|---|---|---|
| Qac<br>Abandoned-channel deposits | Gravelly sand, well stratified to lenticular, 30-100 feet thick, overlying stratified clay, silt, fine sand, and gravel. | Broad, flat valleys entrenched in older sediments. Appear to be former meltwater channels that were formed during the melting of glaciers that covered the Kenai lowland. | Surficial drainage poor because of low relief; infiltration poor because of shallow water table. | Ground-water availability moderate to good. Water-table aquifer yields 20 to 300 gal/min to individual wells. Artesian aquifers occur 200 to 300 feet below land surface. Artesian aquifer developments in these deposits in Beaver Creek valley near Kenai yields as much as 1,000 gal/min to individual wells. |
| Qcp<br>Coastal-plain deposits | Gravelly sand, well stratified to lenticular, 50-100 feet thick; overlying stratified clay, silt, and fine sand as much as 400 feet thick. | Broad, level plain north of Kenai. | Surficial drainage poor because of low relief; infiltration poor because of shallow water table. | Ground-water availability poor to moderate. Water-table aquifer capable of producing 100 to 200 gal/min. Discontinuous artesian aquifers occur from 100 to 400 feet below land surface but are not known to produce more than 100 gal/min. |
| Qop<br>Outwash-plain deposits | Sand and gravel, coarse, well sorted, 100 feet thick, grading down to stratified clay, silt, fine sand, and gravel. | Broad, level plain north of Kenai. | No developed surficial drainage; infiltration excellent. | Ground-water availability believed to be good. Limited exploration has shown ground-water potential to be good in the water-table aquifer. Because of its similarity with other areas, good artesian aquifers may occur from 100 to 300 feet below land surface. |
| Qdu<br>Glacial drift undifferentiated | Sand, gravel, and silt, well stratified to lenticular and interfingering with an overlying heterogeneous mixture of clay, silt, sand, and gravel 100-400 feet thick; upper 100 feet are generally well-stratified sand and gravel, below which the unit grades to fine sand, silt, and clay. | Rolling to steep hills and broad, nearly level plains. Occurs most extensively in the northern part of the study area. Contains many lakes. | Surficial drainage good on slopes, poor in depressions and broad, flat areas; infiltration good except in low areas where water table is shallow. | Ground-water availability moderate to good. In Nikiski area, individual wells produce as much as 1,500 gal/min, both from water-table aquifers and from artesian aquifers 100 to 3[illegible] feet below land surface. |
| Qt<br>Till | Clay, silt, sand, and gravel, heterogeneous mixture, some areas thinly and irregularly veneered with sorted sand and gravel of glacio-fluvial origin, 100-400 feet thick, grades to predominantly fine sand, silt, and clay below 100 feet. | Steep hilly terrain near East Foreland and Boulder Point and a northeast-trending belt along the eastern side of the study area. Contains numerous closed-basin lakes. | Surficial drainage good on slopes, poor in depressions; infiltration ranges from poor to good, depending on soil texture. | Ground-water availability poor to moderate because of low permeability. |

## HYDROLOGIC SYSTEM

### Hydrologic Setting

Figure 5 depicts the hydrologic setting for the Nikiski area. Water falling to the land surface as precipitation flows overland into lakes and streams and infiltrates into the soils. Of the water that infiltrates, some returns to the atmosphere by evaporation and transpiration, and some percolates down to the water table where it recharges the unconfined aquifer. Ground water in the unconfined aquifer flows toward streams and toward springs on the coastal bluffs where it discharges. Ground water in the unconfined aquifer also leaks downward through the clay units to recharge the deeper confined aquifers. Ground water in the confined aquifers flows toward the coast and discharges under Cook Inlet. Lakes in the Nikiski area are recharged by precipitation and by ground-water inflow. Lakes lose water to evaporation, to ground-water outflow, and to outlet streams.

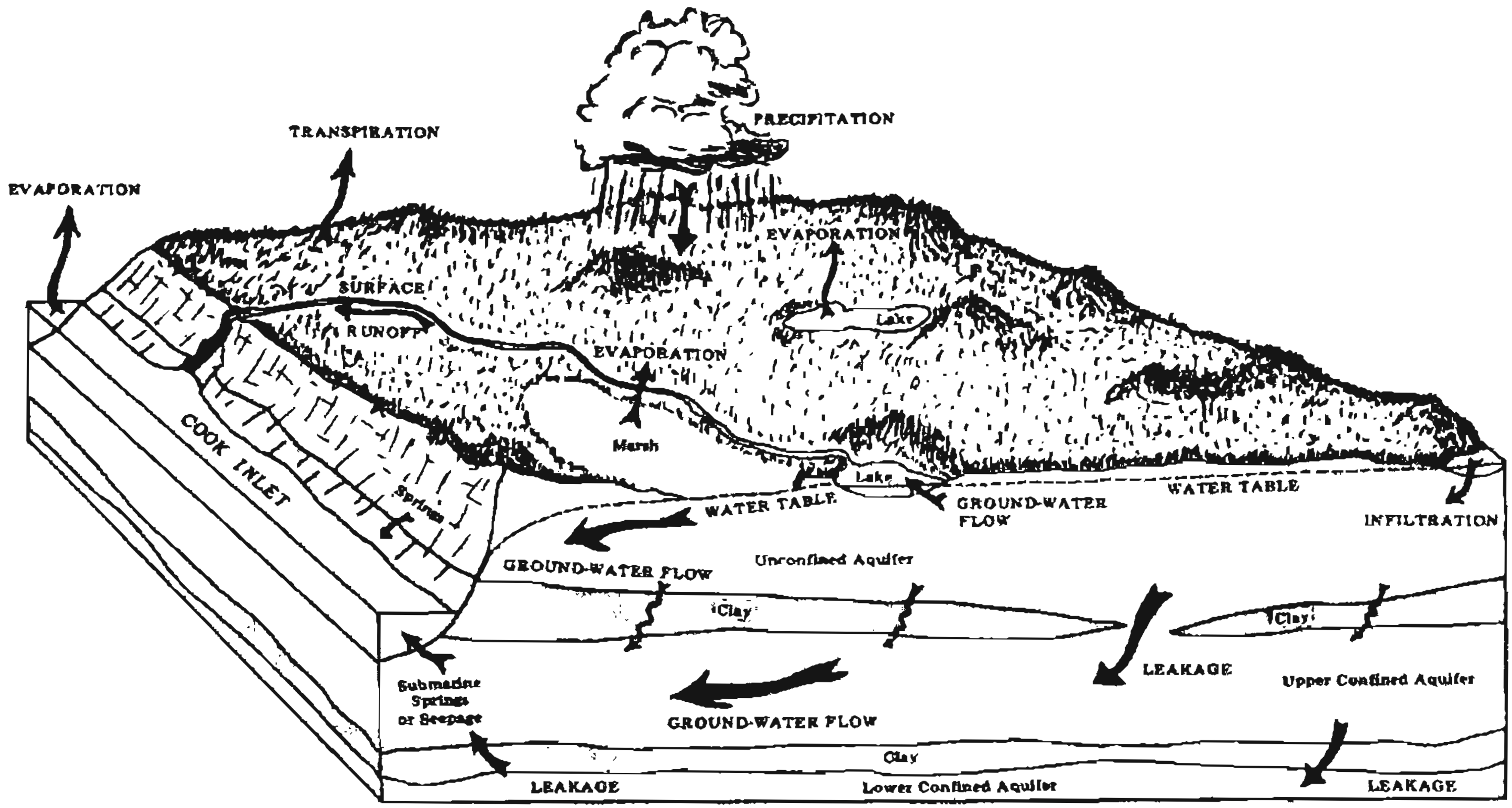



Figure 5.--Schematic diagram of the hydrologic setting of the Nikiski area.

## Precipitation

The National Weather Service maintained a climatic data station at Nikiski from 1967 to 1977 and has maintained one at Kenai since 1944. The mean annual precipitation for Kenai is 18.98 in./yr. During the 10 water years, 1968-77, in which the stations were maintained concurrently, Kenai and Nikiski averaged 16.46 and 18.27 in./yr of precipitation, respectively. Nikiski received the greater precipitation in 8 of the 10 years.

Much of the precipitation that falls during the last 3 months of each calendar year is stored as snow and ice and is not available to recharge lakes, streams, and aquifers until it melts during the next spring. In order to relate precipitation to runoff and recharge, it is necessary to account for precipitation in the year during which it reaches the land surface in the liquid state. This is done by accounting by water years (October 1 - September 30).

Figure 6 is a histogram of the annual precipitation recorded at the Kenai airport during the water years 1945-79. Between 1955 and 1967, annual precipitation averaged 21.27 in./yr, about 2.5 in./yr more than the long-term average. Precipitation was below average in only 3 of the 13 years. Between 1968 and 1978, annual precipitation averaged 16.22 in./yr, about 2.6 in./yr less than the long-term average. Precipitation during this interval was above average only in 1977. The 1955-67 period of above-average precipitation coincides with the period of homesteading and residential development. The 1968-78 period of below-average precipitation coincides with the time of development of ground water for industrial use. The lower water levels in lakes and aquifers during the period 1968-78 are an effect of both pumping and reduced precipitation.

## Streamflow

The two major streams in the area are Bishop Creek and Beaver Creek. Salamatof Creek, B rnice Creek (fig. 1), and several other small creeks intermittently discharge water to Cook Inlet on the north and west margins of the study area. Gaging stations have been maintained on Bishop and Beaver Creeks, and a few miscellaneous discharge measurements have been made on Bernice Creek.

### Beaver Creek

The U.S. Geological Survey maintained a gage on Beaver Creek from October 1967 through September 1978. The maximum recorded discharge, as measured at the gage 4.5 mi downstream from the southeast corner of the study area, was 598 $ft^3/s$ on May 8, 1972. The minimum at that gage was 8.2 $ft^3/s$ on October 23, 1969. Average discharge for the period of record was 25.8 $ft^3/s$.

Much of the annual streamflow of Beaver Creek is derived from ground-water discharge to the creek from the unconfined aquifer. A hydrograph separation technique (DeWiest, 1967, p. 65) was used to separate the ground-water and surface-water components of streamflow. For the years 1971-78, the ground-water component averaged 21.2 $ft^3/s$, which was 82 percent of the annual discharge of Beaver Creek.

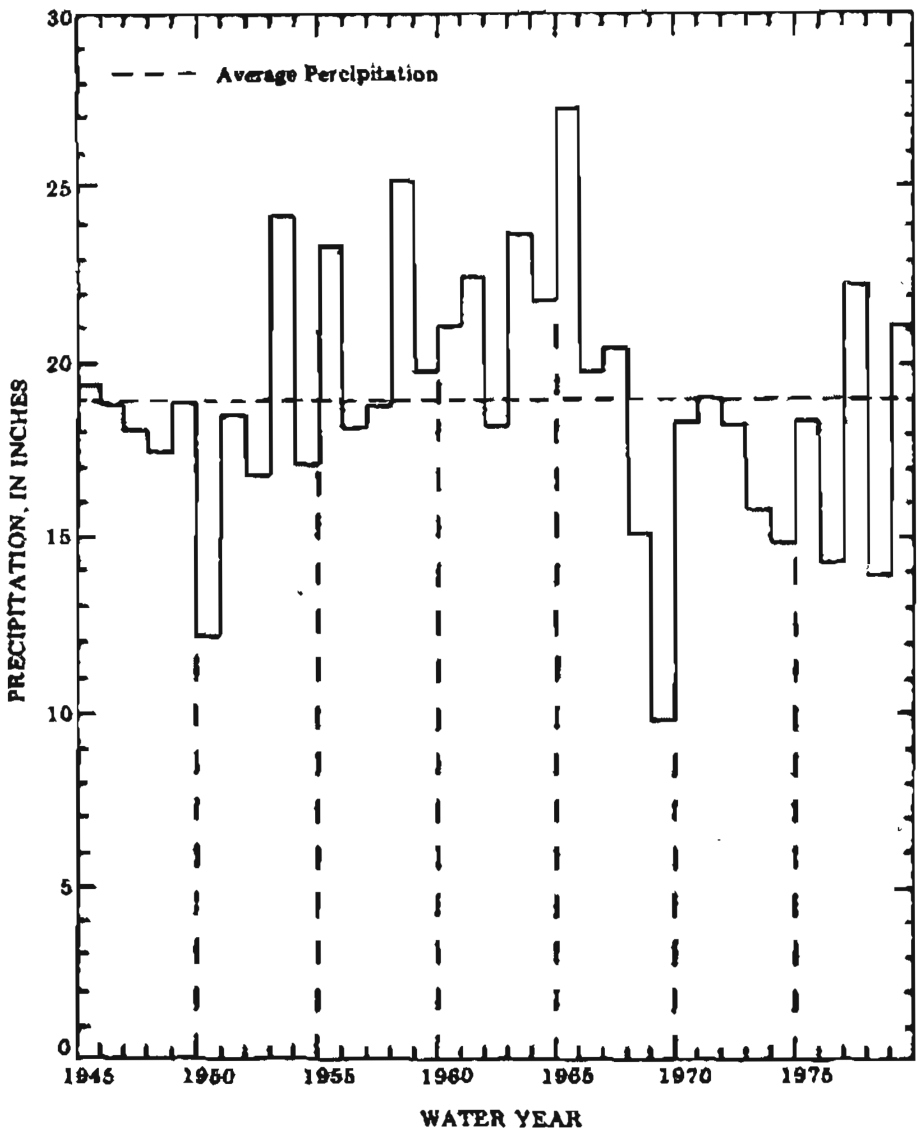



Figure 6.--Precipitation at Kenai airport. (Data provided by U.S. Department of Commerce, National Weather Service)

### Bishop Creek

The U.S. Geological Survey maintained a gage on Bishop Creek from October 1977 through September 1979. The maximum recorded discharge at the gaging station was 197 $ft^3/s$ on May 6, 1977. The minimum discharge was 4.2 $ft^3/s$ on June 11, 1978.

Nine lakes having a total area of 1.9 $mi^2$ are tributary to Bishop Creek. Base flow in the creek is derived from both ground water and lake water. Although much of the lake water is derived from ground-water inflow, part is composed of both surface runoff into the lake and precipitation that fell directly on the lake. Base flow is therefore not rigorously equivalent to ground-water discharge.

During 1978, the base flow for Bishop Creek averaged 17.5 $ft^3/s$, which was about 91 percent of the total discharge. In the same year the ground-water discharge to Beaver Creek was 17.8 $ft^3/s$, about 87 percent of the total discharge. It therefore appears that the amounts of ground-water runoff for the two basins are similar in magnitude and relative contribution to streamflow.

### Ground-Water Discharge from the Industrial Area

Ground-water discharge from the industrial area cannot be easily measured by a stream gage because discharge occurs through many small springs and streams. However, the industrial area is hydrologically similar to the basins of Beaver and Bishop Creeks. By anology with these areas, the ground-water discharge per unit area from the industrial area can be estimated.

The combined ground-water discharge to Beaver and Bishop Creeks in 1978 was 35 $ft^3/s$, and their combined drainage-basin area is about 70 $mi^2$. The ground-water discharge to the creeks is therefore about 0.5 $(ft^3/s)/mi^2$. The location of part of the divide between Beaver and Bishop Creeks is uncertain because it is in a area where gradients are slight. By combining the two basins, uncertainty in the location of their common boundary does not affect the accuracy of the calculations. By similar calculations, the ground-water discharged to the creeks in 1976 and 1977 averaged 0.5 and .7 $(ft^3/s)/mi^2$ respectively. The average for the three years was 0.6 $(ft^3/s)/mi^2$. Ground-water discharge from Beaver and Bishop Creeks is not significantly affected by pumping. By analogy, 0.6 $(ft^3/s)/mi^2$ is an estimate of the ground-water that would be discharged from the industrial area if there were no pumping.

## Aquifers

There are three major aquifers in the Nikiski area (fig. 7). The uppermost aquifer is unconfined; the lower two are confined.

The unconfined aquifer is the aquifer in which most domestic wells are completed. It is hydraulically connected to Beaver and Bishop Creeks and to many of the lakes in the area. The unconfined aquifer is recharged by precipitation, and it discharges water naturally to Cook Inlet, to creeks, and to underlying aquifers. Many springs occur along the Cook Inlet bluffs where the unconfined aquifer crops out above high tide level.

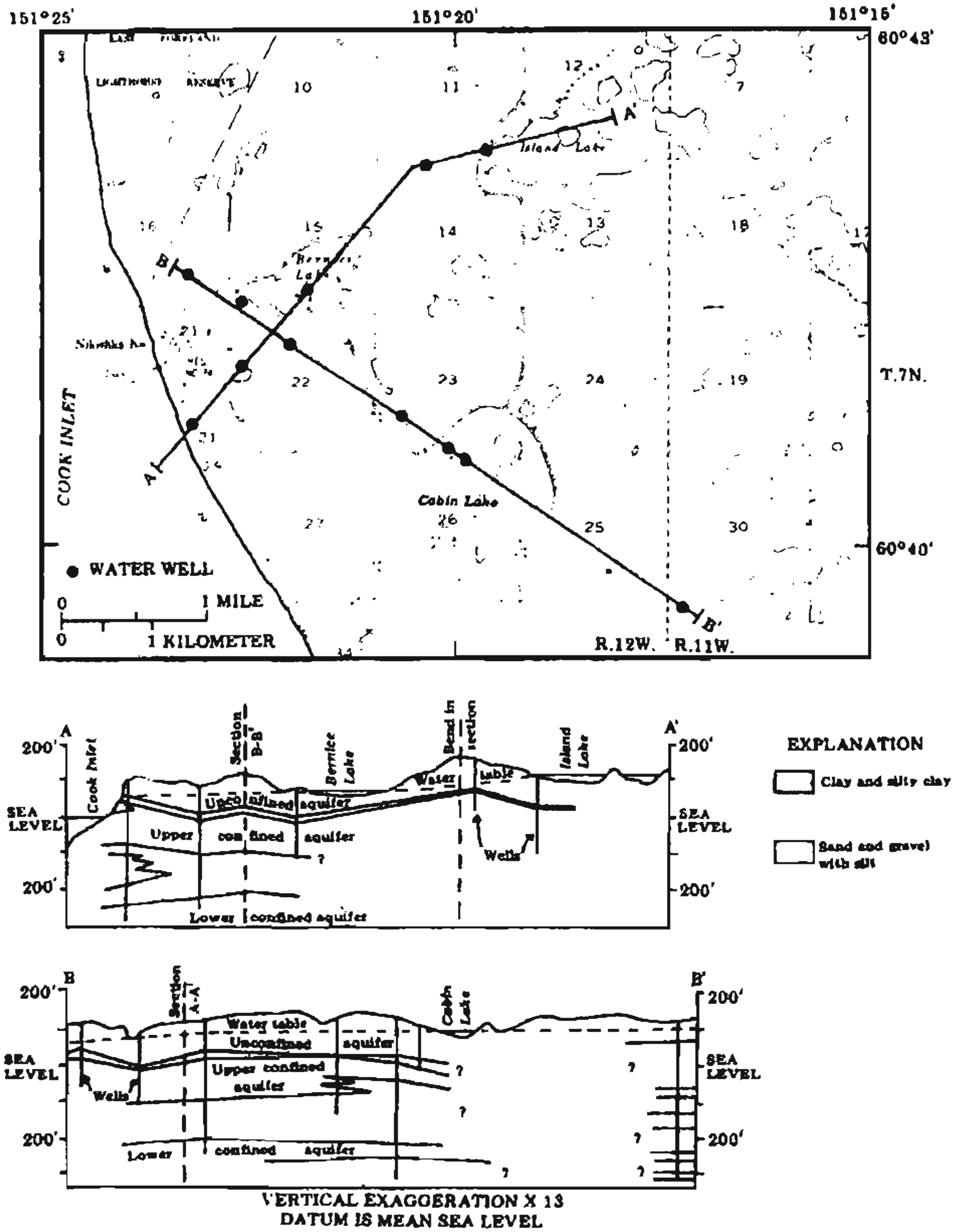



Figure 7.--Geologic sections A-A' and B-B' through the Nikiski area.

The base of the unconfined aquifer is an extensive layer of silt and clay that is termed the upper confining layer. Undulations in the upper confining layer generally conform to topography. No lakes are known to breach the upper confining layer. Locally, the low-permeability silt and clay grade laterally into fine sand having greater permeability.

The upper confined aquifer underlies the upper confining layer and is the aquifer in which most commercial and industrial wells are completed. It receives recharge from the overlying aquifer by leakage through the confining layer. It discharges water to Cook Inlet, to lower aquifers, and, in the vicinity of Bishop and Beaver Creeks, upward into the unconfined aquifer and then into the creeks. The aquifer probably crops out a short distance offshore in Cook Inlet. Rates of recharge to the upper confined aquifer may not be uniform over the entire area; recharge may be concentrated where the confining layer is most permeable.

Although the upper confined aquifer yields large quantities of water to wells west of Cabin Lake, it is not a productive aquifer throughout the Nikiski area. A 351-ft well drilled 1,000 ft northwest of Cabin Lake penetrated materials that were predominantly of low permeability in the depth-equivalent interval of the upper confined aquifer. Only a 2-ft-thick unit immediately below the confining layer yielded water to the well. Similarly, the well at the southeast end of section B-B' in figure 7 penetrated predominantly fine-grained materials in the interval that is the depth equivalent of the upper confined aquifer. The upper confined aquifer is poorly defined away from the industrial area.

The lower confined aquifer is separated from the upper confined aquifer by a silt and clay unit that is generally more than 100 ft thick. The lower confined aquifer is poorly defined throughout the study area. It may actually consist of many interconnected lenses and layers of sand and gravel at depths greater than 300 ft below land surface. The aquifer is probably recharged by slow leakage from the overlying aquifer. Natural flow is toward Cook Inlet. The top of the aquifer is about 200 ft below sea level, well below the floor of Cook Inlet within about 6 mi of Nikiski. The discharge area may therefore be many miles offshore.

## Lakes

The dominant control of the level of open lakes, lakes that have an outlet to a stream, is the altitude of the outlet. Changes in annual recharge or in pumping near such lakes cause the lake discharge to vary, but the lake level changes little. Daniels Lake (fig. 8) is an open lake. Bernice Lake (fig. 8) is open when the water level is above the altitude of the outlet, 77.2 ft above sea level. However, it was a closed lake from the time the U.S. Geological Survey began to monitor lake levels in 1970 until the outlet began flowing again in 1980.

The levels of closed lakes, those without an outlet stream, fluctuate several feet from year to year. Fluctuations are caused by changes in annual recharge and by ground-water pumping. The magnitude of the fluctuations is also related to lake size, distance from the lake to a hydrologic boundary (such as a creek, a ground-water divide, or a center of pumping), and properties of the aquifer that surrounds and underlies the lake.

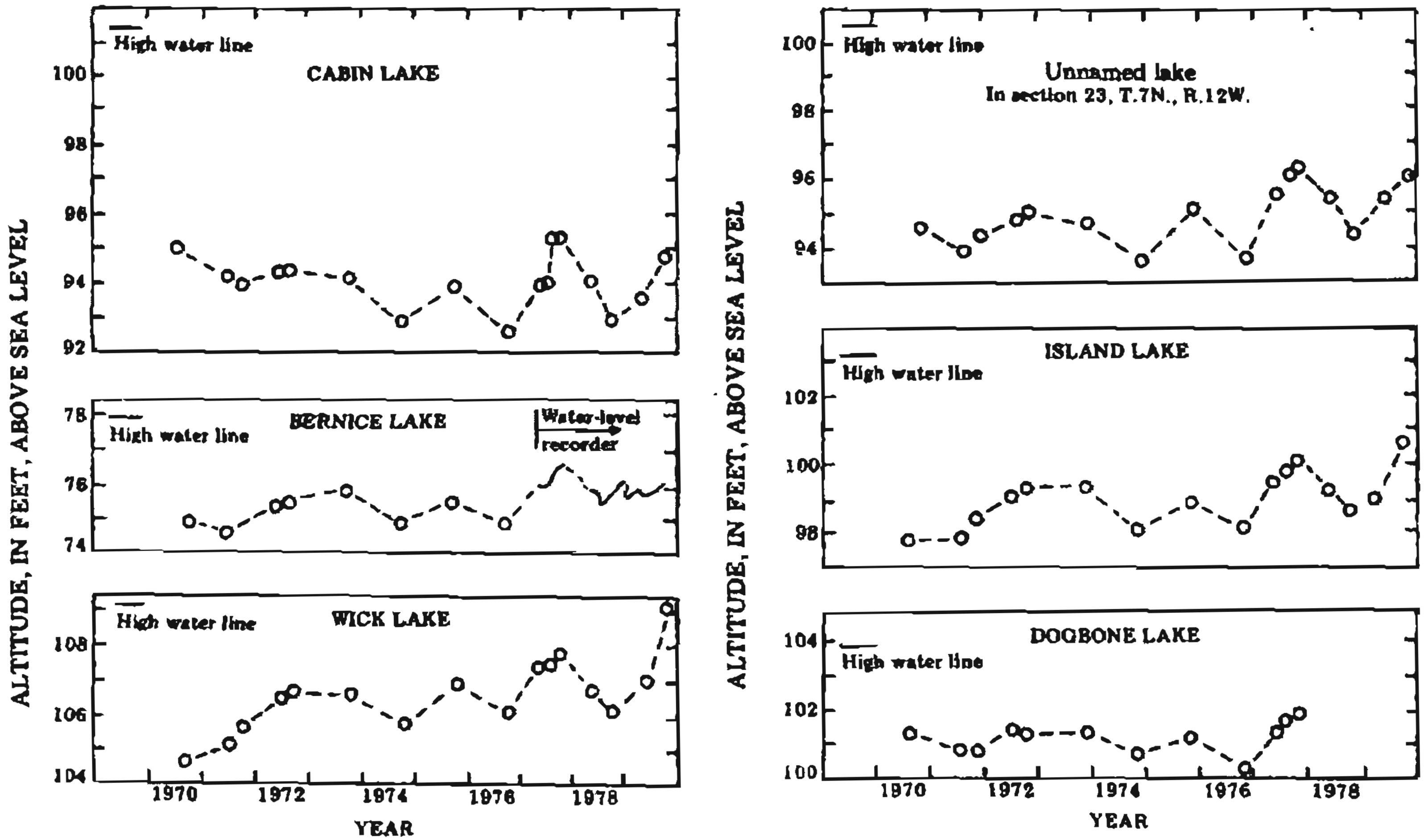



Figure 8.--Water levels and locations of lakes in the Nikiski area.

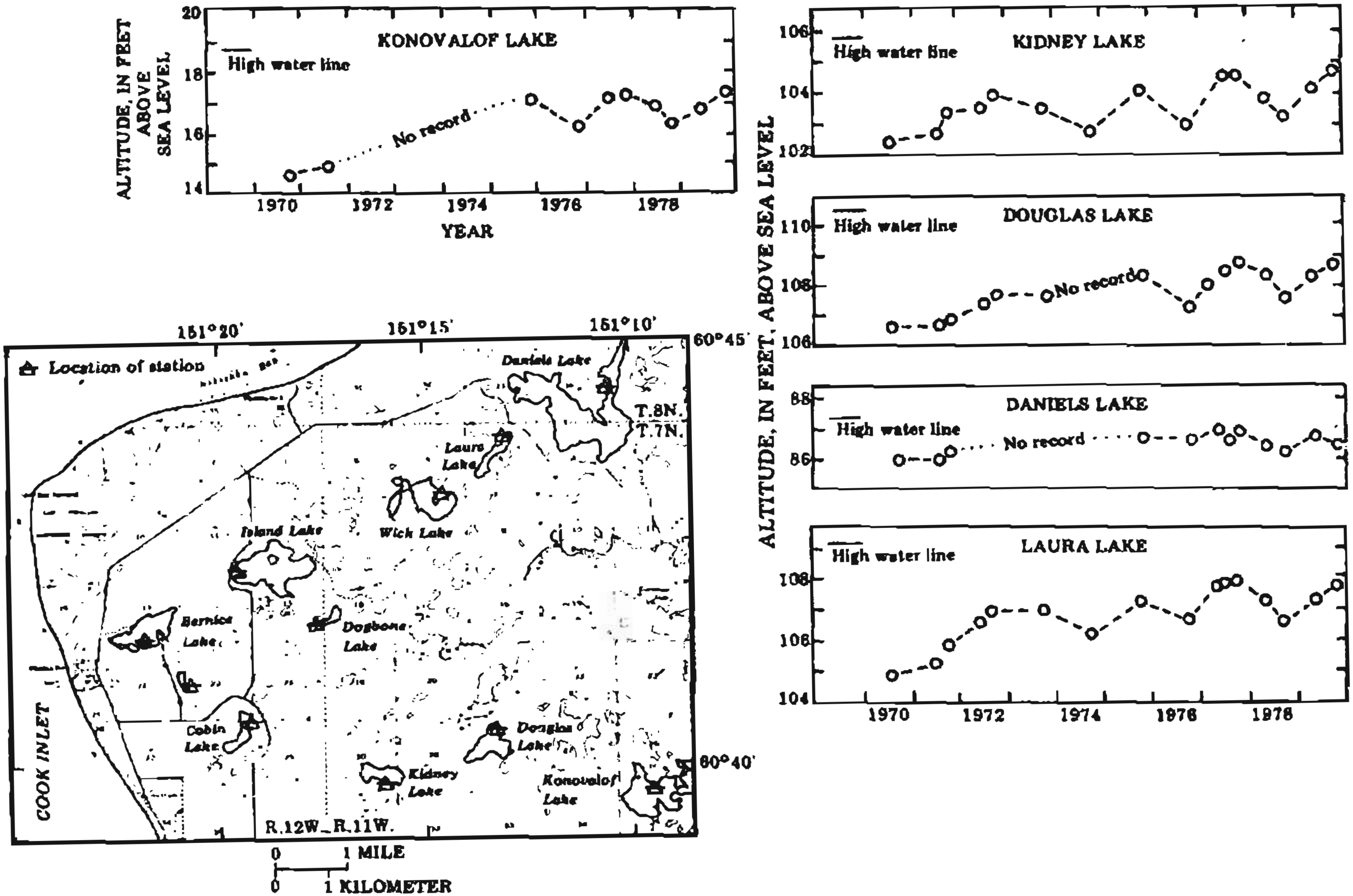



Figure 8.--Water levels and locations of lakes in the Nikiski area--Continued.

Figure 8 shows the 10-yr hydrographs for the lakes that have been monitored in the Nikiski area. The highest unvegetated beachline discernible at the time the lakes were first surveyed in 1970 is indicated on each hydrograph. Residents of the area generally indicate that these high-water lines reflect lake levels during the late 1960's. The greatest declines from the high-water lines have occurred in the two lakes nearest the center of industrial pumping. Cabin Lake declined more than 8 ft, and the unnamed lake in section 23, T. 7 N., R. 12 W. declined more than 6 ft.

## EFFECTS OF PUMPING

In the two upper aquifers, the drawdown caused by pumping reaches steady state within 6 months of a change in the rate of pumping. In the lower confined aquifer, drawdown reaches steady state within about a week of a change in the pumping rate. In the Nikiski area steady-state conditions occur when the rate of ground-water pumping is balanced by a decrease in the rate at which ground-water discharges naturally from the aquifer via creeks and coastal springs. Under steady-state conditions, drawdown is directly proportional to the rate of pumping (fig. 9). Although the potentiometric surface of the upper confined aquifer is drawn down, it is above sea level everywhere except within a few hundred feet of Union PW-6 (fig. 3). Near PW-6, the potentiometric surface is generally between 0 and 10 ft below sea level.

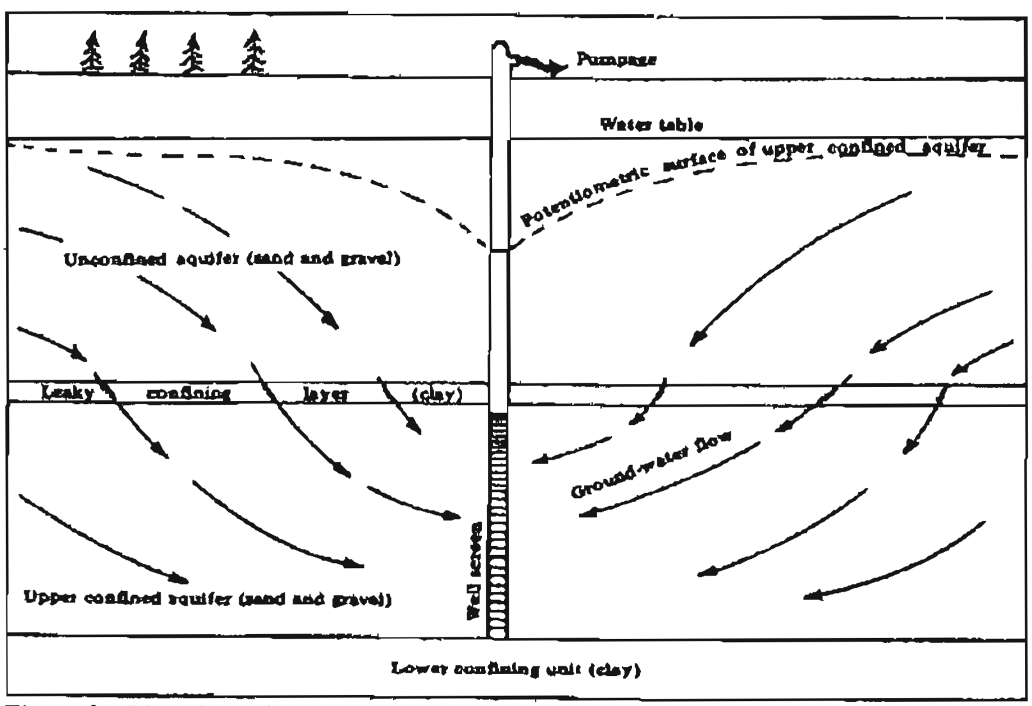



Figure 9.–Direction of ground-water flow when downward leakage through the confining layer equals pumpage from the well.

Too few data exist to define accurately the processes that stabilize drawdown in the lower confined aquifer, but drawdown is probably stabilized by a combination of increased leakage from the overlying aquifer and decreased outflow to Cook Inlet via diffuse seepage or submarine springs. The potentiometric surface is below sea level near the coast, and drawdowns may also be stabilized by movement of salt water toward the pumping wells. However, it is not possible to evaluate salt-water intrusion because there are no observation wells seaward of the most heavily pumped well in the lower confined aquifer.

The upper two aquifers are hydraulically connected by a leaky confining layer of clay. Pumping from the upper confined aquifer produces a drawdown cone in the upper confined aquifer. Within this drawdown cone, the downward hydraulic gradient across the clay layer is increased, thereby increasing the downward leakage from the unconfined aquifer. Within the area of the drawdown cone, the rate of downward leakage equals the rate of pumping except during a few days of adjustment after a change in the pumping rate. During this brief period of adjustment, water is taken from or added to aquifer storage while a new drawdown cone is being established.

The increased downward leakage from the unconfined to the upper confined aquifer produces a drawdown cone in the unconfined aquifer. This drawdown cone deepens and expands until it intercepts hydrologic boundaries that compensate the increased downward leakage. In the Nikiski area, the hydrologic boundaries that balance the increased downward leakage are ground-water divides and discharge boundaries near the streams and coast. It appears to take several months for these boundaries to balance fully the increased downward leakage, and the system achieves a steady state.

As the water table declines in response to increased downward leakage, it also fluctuates in response to precipitation changes. Lack of water-table and lake-level data prior to the onset of pumping precludes an accurate separation of pumping effects from precipitation effects. However, a comparison of levels of Cabin Lake and precipitation at Kenai (fig. 10) indicates that from 1972 to 1979 lake level fluctuations are related primarily to precipitation. Such a relation would not exist if the drawdown cone were continuously deepening and expanding. The precipitation data in figure 10 have been smoothed using a 2-year half-life-weighted averaging technique (L. R. Mayo, U.S. Geological Survey, written commun., 1978).

Pumping from the upper confined aquifer produces a drawdown cone that induces leakage over several square miles. Spreading the leakage over a large area produces a shallower drawdown cone in the unconfined aquifer than would occur if pumping were to be directly from the unconfined aquifer. A shallower drawdown cone will lower lake levels less than would a deeper drawdown cone such as might be produced by pumping directly from the unconfined aquifer.

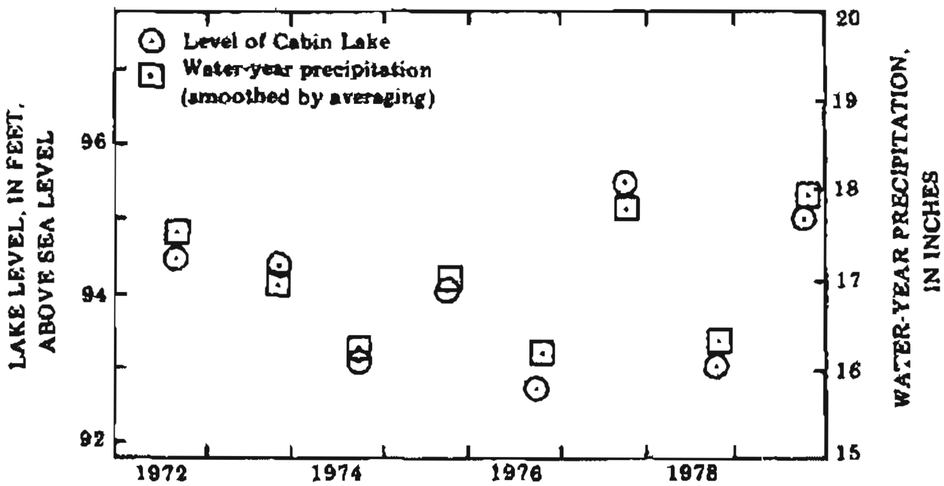



Figure 10.--Comparison of Kenai precipitation and levels of Cabin Lake. Precipitation data are smoothed by half-life-weighted average technique. Lake levels measured in October of each year.

## ALTERNATIVE AREA FOR INCREASED PUMPING

In the winter of 1978-79, the U.S. Geological Survey drilled test wells at three sites southeast of Nikiski in the Beaver Creek basin (fig. 11). Wells 1 and 2 penetrated coarse sand and gravel that appeared to be comparable to materials in which some of the industrial wells are completed near the industrial area. Both wells penetrated an unconfined aquifer and two confined aquifers. The upper confined aquifer contained the coarsest materials and appeared to have the best potential for producing large quantities of water. As the need for water in the Nikiski area increases, further exploration and testing of the area near wells 1 and 2 may be warranted. Well 3 penetrated fine-grained materials having little potential for large-capacity wells.

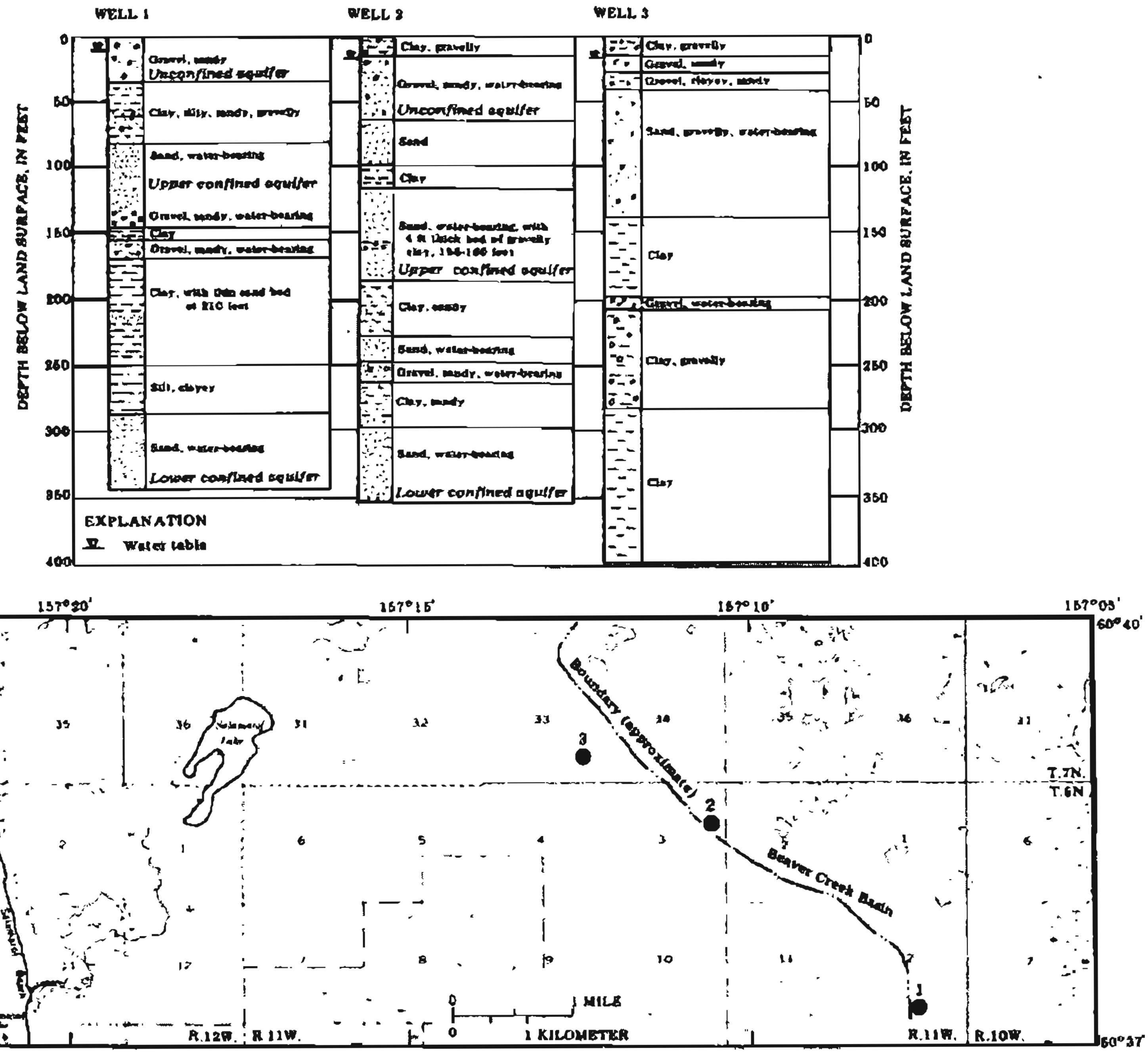


Figure 11.--Logs and locations of wells drilled during the winter of 1978-79.

## SUMMARY OF CONCLUSIONS

1. Ground-water discharge from Beaver and Bishop Creek basins combined, about 0.6 $(ft^3/sec)/mi^2$, is an estimate of ground-water discharge from the entire Nikiski area if there were no pumping.

2. The rate of ground-water pumping for industrial use was about 4.2 million gal/d in 1979.

3. The unconfined aquifer is recharged by precipitation and is hydraulically connected to many lakes.

4. The upper confined aquifer is hydraulically connected to the unconfined aquifer. Downward leakage from the unconfined aquifer is the source of recharge to the upper confined aquifer. Pumping from the upper confined aquifer increases the rate of downward leakage and lowers the water table and lake levels in the unconfined aquifer.

5. Pumping appears to be in equilibrium with recharge-discharge boundaries because drawdown does not continuously increase when pumping is constant.

6. There is good potential for ground-water development in the middle reach of Beaver Creek basin.

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