UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY SURVEY OF GROUND-WATER RESOURCES FOR ISLAND COUNTY, WASHINGTON

By D. R. Cline, M. A. Jones, N. P. Dion,
K. J. Whiteman, and D. B. Sapik

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JAMES G. WATT, Secretary

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METRIC (SI) CONVERSION FACTORS

Multiply	By	To obtain
inches (in.)	2.54	centimeters (cm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilomters (km^2)
acre-feet (ac-ft)	1,233.0	cubic meters (m^3)
gallons (gal)	0.003785	cubic meters (m^3)
degrees Fahrenheit (°F)	0.5556, after subtracting 32	degrees Celsius (°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

Increased ground-water withdrawals associated with the population increase in Island County, Washington, have caused concern about ground-water availability and potential seawater intrusion. The most widespread and widely used aquifer lies near sea level. Available data indicate that, locally, one or more water-bearing zones lie above the sea-level aquifer.

Pumpage in 1979 totaled about 1.6 billion gallons; about 90 percent was pumped from the sea-level aquifer. Most large producing wells in the county have pumping water levels near or below sea level, so that if pumping continued for a long enough time, seawater intrusion would result.

Sampling of chloride concentrations in July 1978, April 1980, and August 1980 indicated problem areas mainly in northeastern and southern Camano Island and in central Whidbey Island.

INTRODUCTION

Island County, Washington, is an area of rapidly increasing population, growing from 6,700 in 1940 to 22,000 in 1964 and to 40,200 in 1979 (fig. 1). Ground water is the primary source of water used in the county; however, water is imported from the Skagit River on the mainland to supply Ault Field (U.S. Navy) and to supplement Oak Harbor's ground-water supply. Increased ground-water withdrawals associated with the population increase have caused concern about ground-water availability and potential seawater intrusion. To plan for further growth in the county, the quantity and chemical quality of available ground water must be known. In an effort to provide planners with information on the quantity and chemical quality of ground water in Island County, the U.S. Geological Survey conducted an investigation in cooperation with Island County and the Washington State Department of Ecology.

Purpose and Scope

The objectives of this preliminary investigation were to: (1) review and summarize existing data and, to the extent that these data allow, describe the geohydrologic setting of the county, identifying areas of potentially serious ground-water quality problems; and (2) identify areas where overdraft is evident or appears imminent. Additional data on water levels and chloride concentrations in wells were collected during the study to assist in problem identification.

This report presents the results of the preliminary study, defining the specific ground-water problems confronting Island County. It also outlines a more comprehensive approach for a study that would provide the information needed to resolve the problems identified during this study.

Previous Work

The ground-water resources of Island County were first discussed by Anderson (1968) and Van Denburgh (1968). Later ground-water reports by Walters (1971) and Dion and Sumioka (written commun., 1981) discussed the occurrence of seawater intrusion in the coastal areas of Washington and in Island County.

At the time of this report, the geology of Island County is being mapped by the Washington Department of Natural Resources as part of the Port Townsend 1:100,000 mapping project being done by the U.S. Geological Survey.

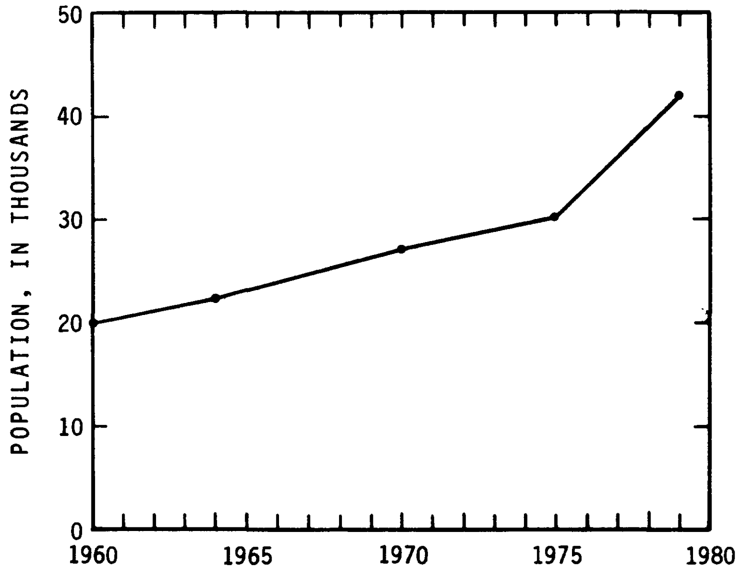

FIGURE 1.--Population increase in Island County, 1960-1979.

Acknowledgments

Appreciation is expressed to the well owners, users, and drillers who supplied information and well records. Special acknowledgment is given the Washington Department of Social and Health Services for laboratory analysis of the ground-water samples.

DESCRIPTION OF THE AREA

Geographic Setting

Island County is located in the Puget Sound lowland northwest of Seattle and east of the Strait of Juan de Fuca (fig. 2). The major islands of the county are Whidbey and Camano.

The land area of Whidbey and Camano Islands is approximately 210 square miles. Whidbey, the larger of the two islands, is about 40 miles long and 1 to 10 miles wide. Camano Island is about 15 miles long and 1 to 7 miles wide. Because of indentations in the shoreline, no point on either island is more than 2½ miles from shore.

The land surface consists of rolling uplands, generally ranging from 100 to 300 feet above sea level, but in a few places as high as 600 feet.

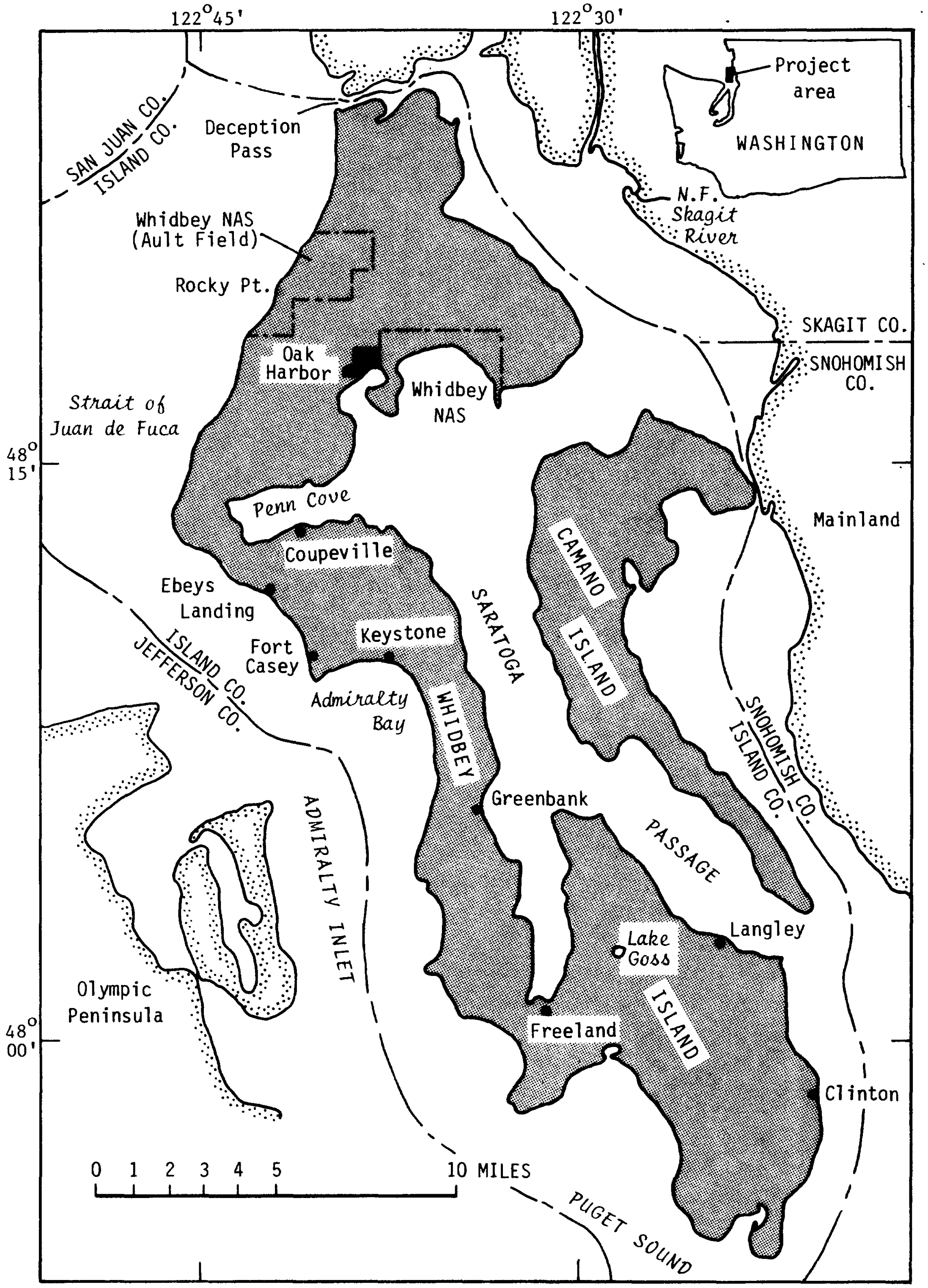

FIGURE 2.--Towns and principal geographic features of Island County (modified from Anderson, 1968).

Climate

Island County has a temperate marine climate with dry summers and wet winters. The mean annual temperature is 50°F. The coolest month of the year is January, with an average temperature of 38°F, and the warmest are July and August, with an average temperature of 61°F.

Precipitation in Island County ranges from 18 inches per year at Coupeville to 42 inches at Lake Goss. The seasonal precipitation patterns at five weather stations on Whidbey Island are similar (fig. 3), and precipitation is lowest in the summer months. The total amount of precipitation varies among stations, and this variation is influenced by two factors, the rain shadow cast by the Olympic Mountains on the west and the land-surface altitude. The rain-shadow effect can be observed in the central and northern parts of Whidbey Island, where the average annual precipitation is less than in the southern part of the island. The land-surface-altitude effect can be seen by comparing the altitudes at Greenbank (80 ft), Langley (135 ft), and Lake Goss (290 ft) with the average annual precipitation at each station (fig. 3). This suggests a general increase in precipitation with increasing altitude. The rain-shadow effect of the Olympic Mountains masks the effect of the land-surface altitude at Coupeville and Ault Field (Anderson, 1968).

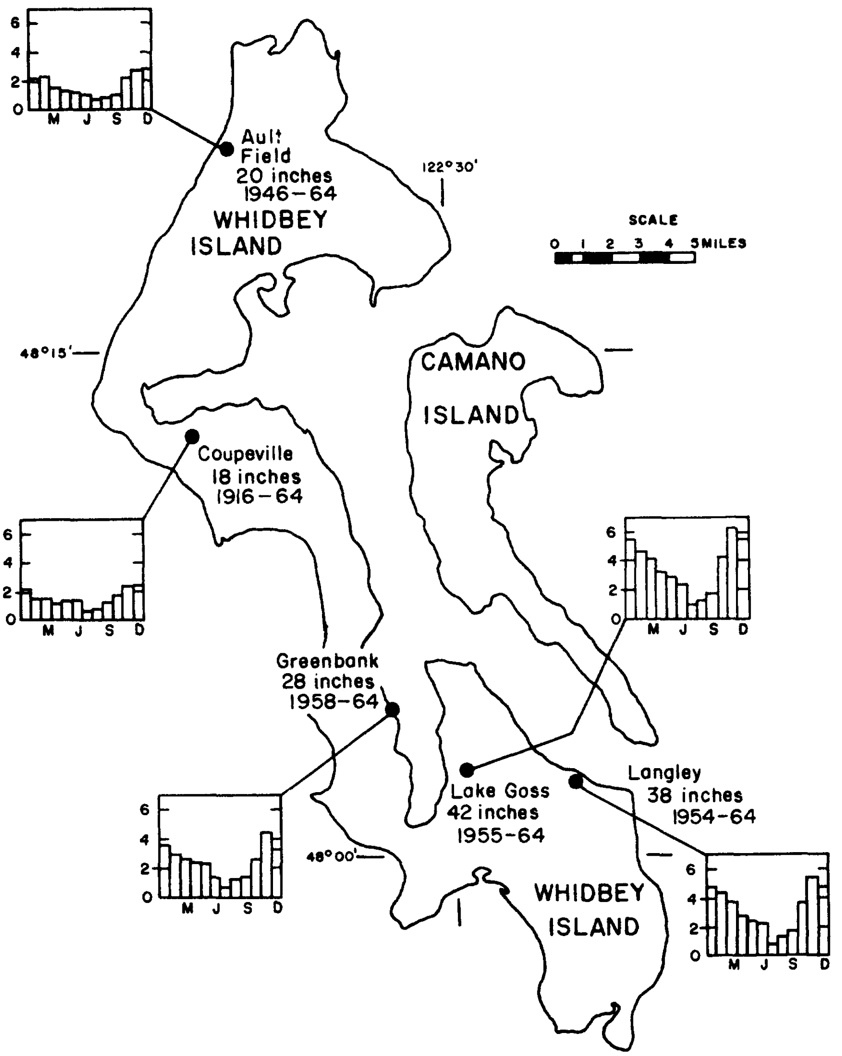

FIGURE 3.--Average annual and monthly precipitation at five weather stations in Island County (modified from Anderson, 1968).

Geohydrologic Setting

Whidbey and Camano Islands are composed of unconsolidated glacial and interglacial Quaternary deposits that overlie Tertiary and older bedrock in most places. Pre-Tertiary metamorphic bedrock is exposed at Deception Pass and at a point 5 miles to the south in the low tidal zone at Rocky Point (fig. 4). This bedrock is a hard, dense, dark rock that generally yields little or no water to wells.

The Quaternary deposits, hereinafter called unconsolidated deposits, consist of clay, silt, sand, and gravel. These deposits extend only a few hundred feet below sea level in northern and southern Whidbey Island; however, they are much thicker in the central part of the island - about 3,000 feet at well 30/2-17K2 (Weldon Rau, Washington Department of Natural Resources, oral commun., May 1980) - where bedrock is nearly 2,700 feet below sea level (fig. 4). Although the configuration of the bedrock is largely unknown, Gower (1978) indicated that the unconsolidated deposits are thick where a downthrown fault block is inferred (between the possible fault zones shown in figure 4). Although bedrock in this area is inferred to be relatively shallow at well 32/1-12C1, several factors may account for the apparent discrepancy, such as a large amount of erosional relief on the bedrock surface, a tilted fault block, or the possibility that the fault zone(s) has a different location than that shown in figure 4. As indicated in figure 4, Camano Island lies within this downthrown fault block, and thus Quaternary sediments there are probably thick. The areal extent and thickness of individual gravel, sand, and clay units varies, and it is difficult to correlate these units between wells. Correlation is complicated by the presence of faults in the unconsolidated deposits (Jerry Thorsen, Washington Department of Natural Resources, written commun., February 1980).

Sand-and-gravel units below the water table yield water to wells. The majority of wells in the county tap sand-and-gravel deposits that range from about 30 feet above sea level to 200 feet below (fig. 5 and 6). Sand-and-gravel deposits in this zone appear to be more continuous than in the sand-and-gravel deposits above. This zone, presently the most productive in the county, is hereafter called the sea-level aquifer. Its boundaries are tentative because they are based on insufficient data. Available data suggest that the sea-level aquifer is continuous across the major tectonic features in the county. Sand-and-gravel units are also found at greater depths; however, few wells penetrate deeper than 200 feet below sea level, and little is known about the extent or hydrologic character of these deeper units.

Sand-and-gravel water-bearing units that are above the sea-level aquifer occur primarily in northeastern and southeastern Whidbey Island (fig. 7). These shallow water-bearing units appear to be of limited vertical and areal extent.

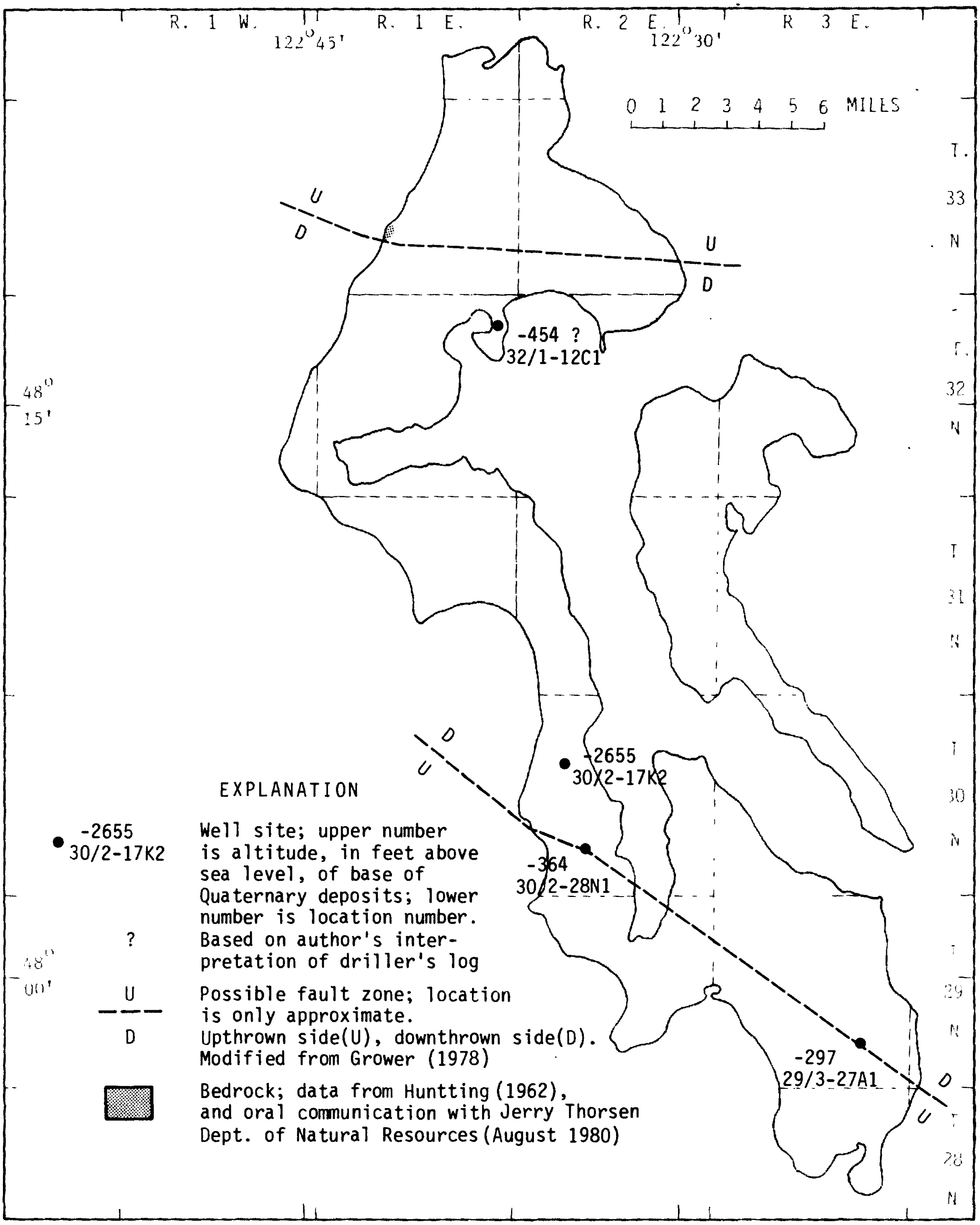

FIGURE 4.--Altitude of base of Quaternary deposits and probable tectonic features in Island County.

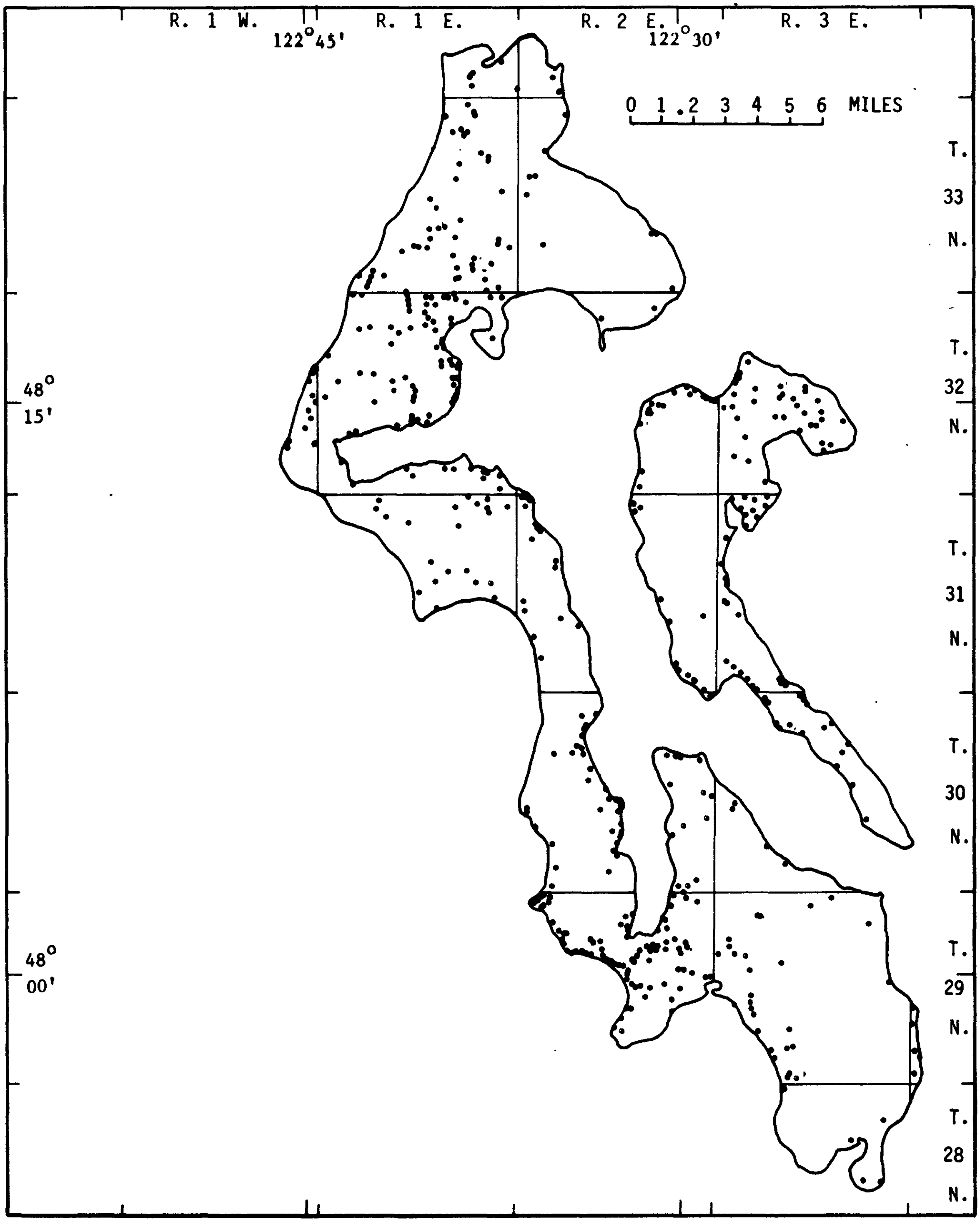

FIGURE 5.--Location of wells drilled to depths between sea level and 200 feet below sea level.

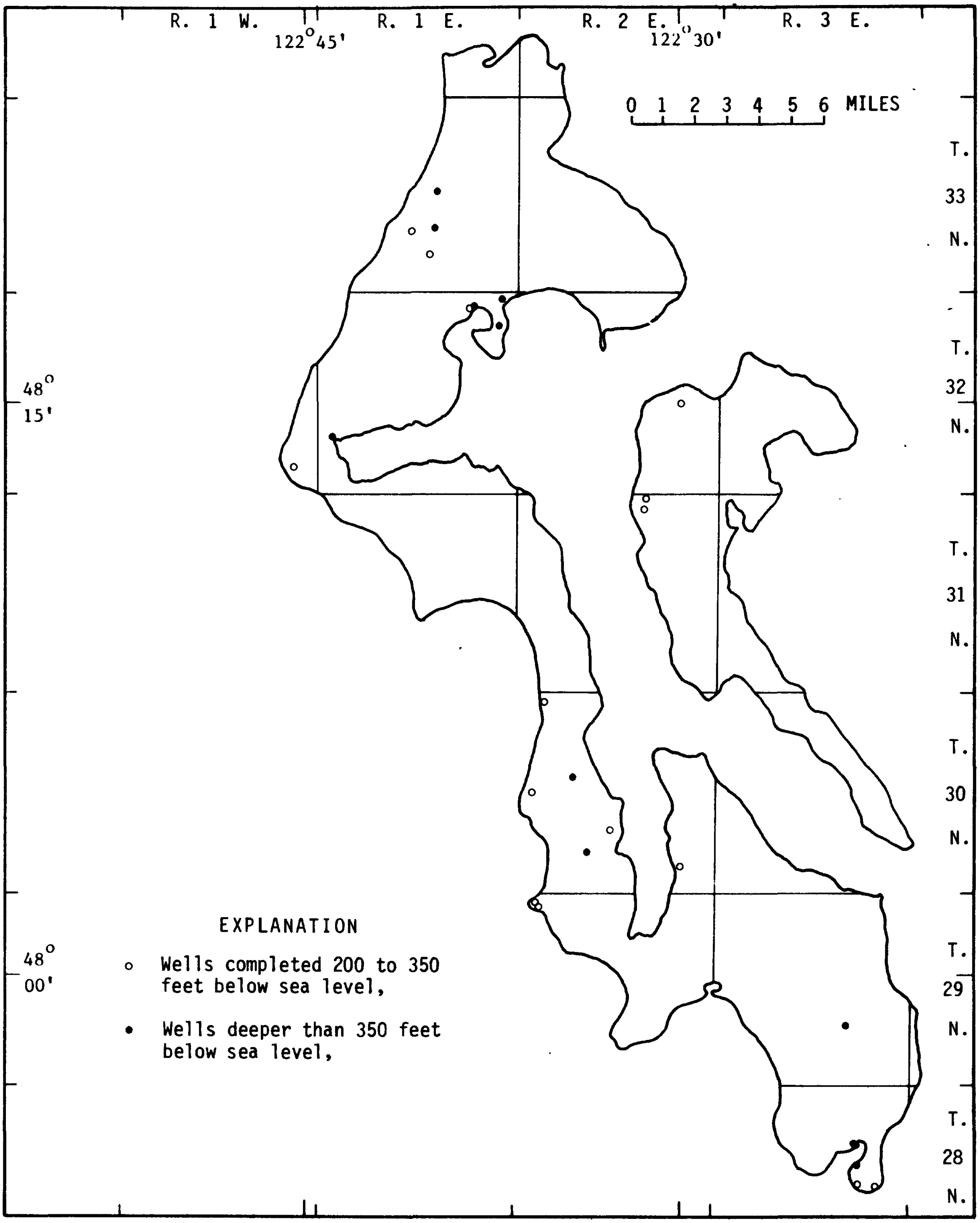

FIGURE 6.--Location of wells drilled to depths more than 200 feet below sea level.

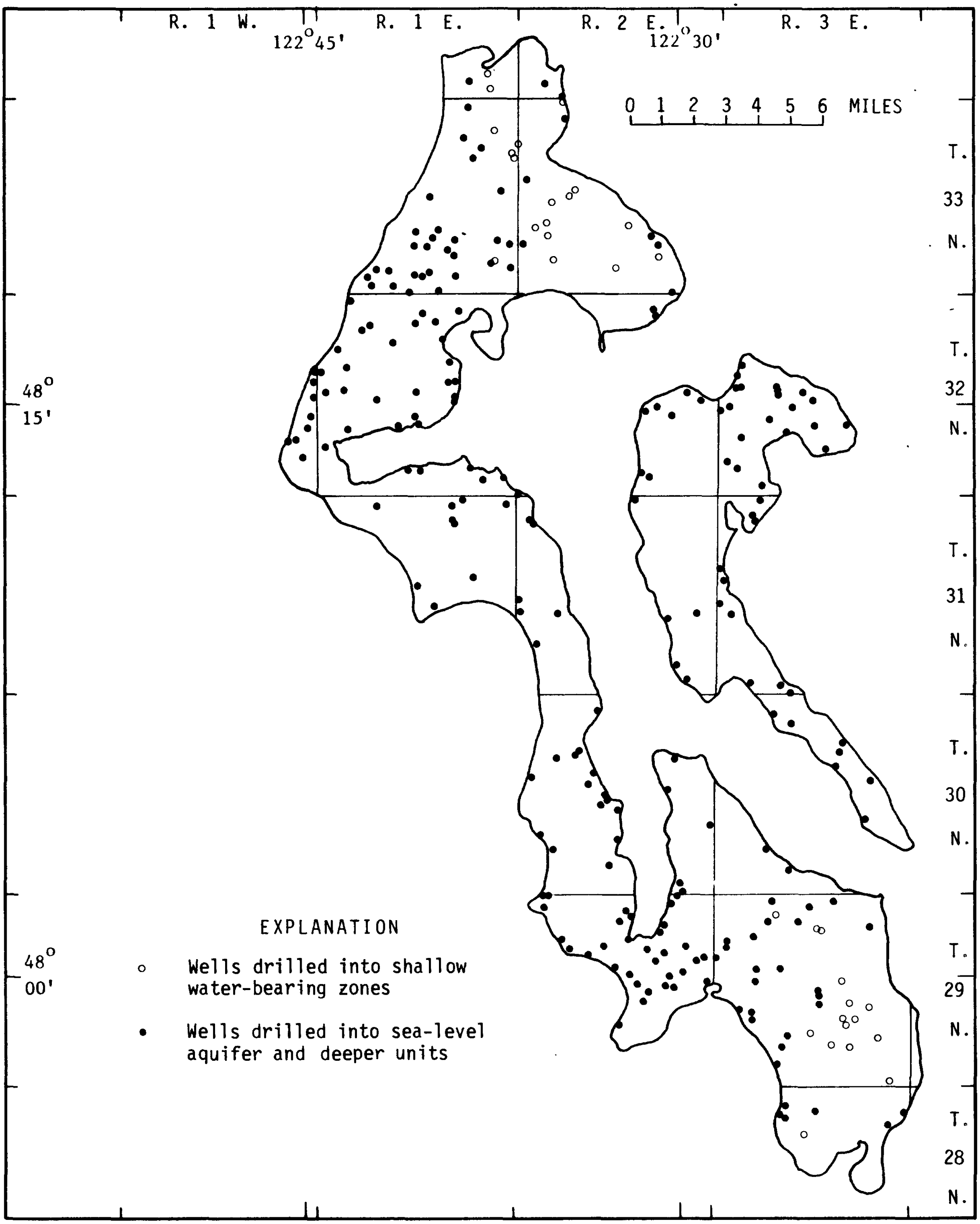

FIGURE 7.--Location of wells inventoried in April 1980.

GROUND WATER

Movement of Ground Water

The general movement of fresh water within the ground-water reservoir is illustrated in figure 8. As indicated by the arrows, ground water moves downward from recharge areas and upward to discharge areas. Recharge comes from precipitation that infiltrates the ground. Ground water discharges naturally through stream baseflow, the sea bottom, springs, evapotranspiration, and by pumping from wells.

Recharge

Recharge to the ground-water reservoir comes from precipitation that falls on the islands, infiltrates the ground, and percolates downward to the water table; some recharge, probably small, may come from water piped in to northern Whidbey Island. Most recharge occurs during winter and spring months when precipitation is high. Preliminary calculations indicate that about 94,000 acre-feet per year, or about 40 percent of the yearly estimated precipitation, is available to run off in streams or to recharge the ground-water reservoir. This number was derived by calculating the difference between average monthly precipitation and calculated monthly potential evapotranspiration for the year. Precipitation figures used were based on the U.S. Weather Bureau isohyetal map (1965), which includes one weather station in Island County, at Coupeville. Calculations for the quantity of water used by evapotranspiration were based on the growth-coefficient curve for a deciduous orchard with ground cover and for a 2.5-inch moisture-holding capacity of the soil using the Blaney-Criddle method as modified by the U.S. Department of Agriculture (1970). Of the 94,000 acre-feet per year of water available for runoff and recharge, about 55,000 acre-feet per year (59 percent) is estimated to recharge the ground-water reservoir underlying the 210-square-mile area of Whidbey and Camano Islands. This quantity was determined from the cross-sectional digital model (see Seawater-Freshwater Interface section).

There is not sufficient information at present (1980) to determine the areas where high recharge occurs in the county. Areas with sand and gravel at the surface (fig. 9) have higher infiltration rates than areas of silt and clay; however, it is difficult to relate infiltration to recharge because recharge to the ground-water system depends on many factors, including subsurface lithology, depth to the water table, slope of the land surface, and amount of precipitation. Recharge is reduced in areas covered by manmade structures such as buildings and paved roads.

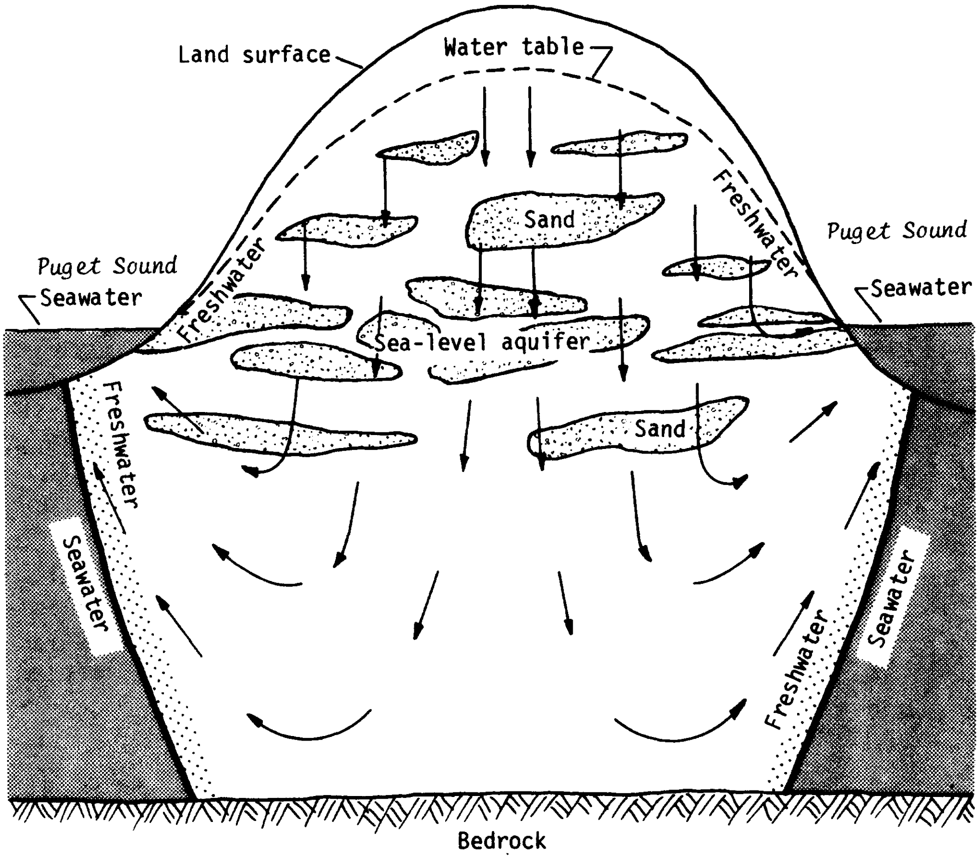

FIGURE 8.--Idealized movement of ground water in a vertical section, with arrows indicating direction of movement.

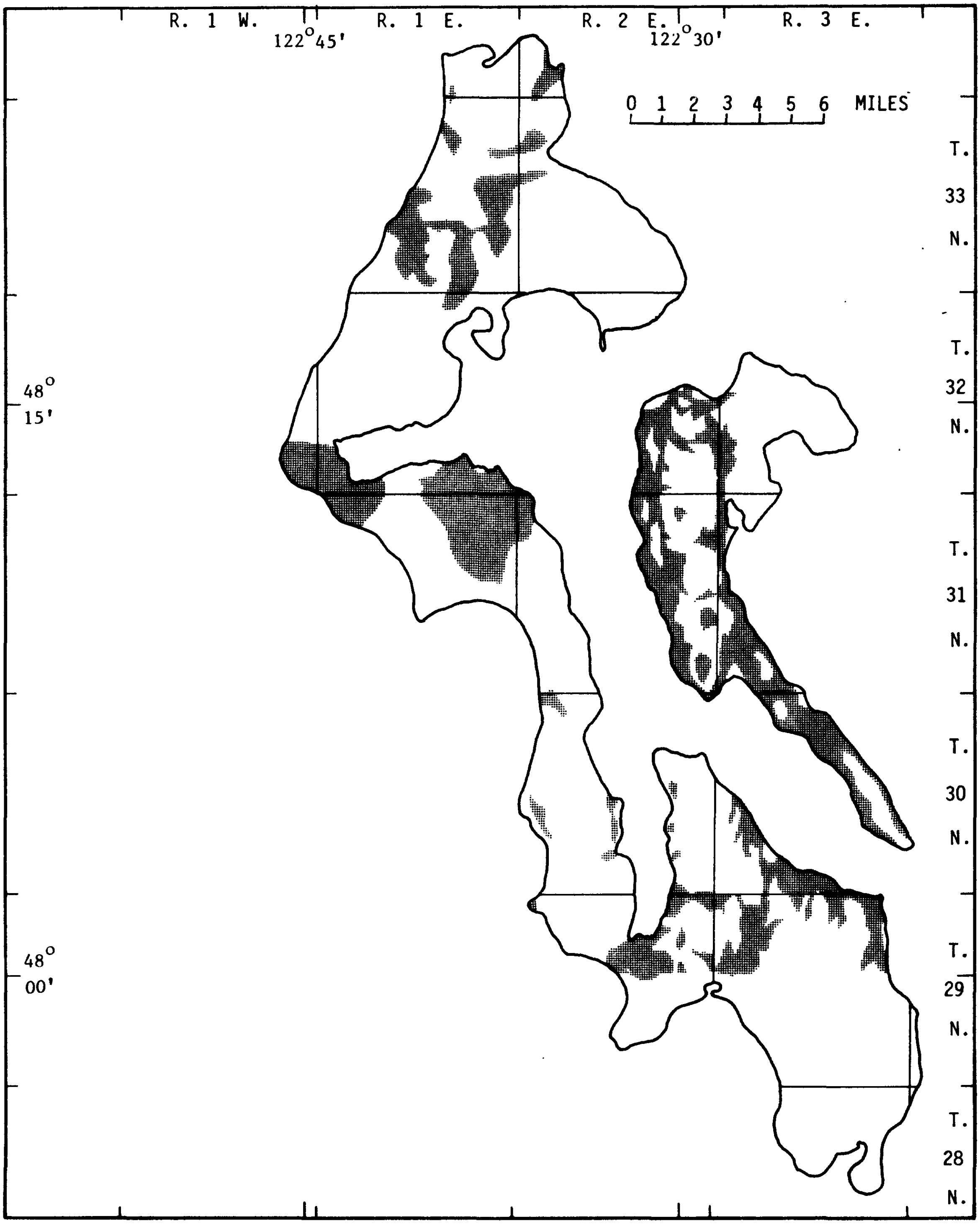

FIGURE 9.--Location of surficial sand-and-gravel deposits (shaded areas). Data from Fred Pessl, USGS (written commun., May 1980).

Discharge

Ground-water outflow to the sea probably accounts for most of the natural discharge in Island county. There are few streams in the county and no stream discharge data are available. Most of the perennial streams which are sustained by ground-water discharge are less than 2 miles long. Many springs are found in the county along the sea cliffs and shoreline, but little information exists on the amount of spring discharge.

Most of the ground water pumped from wells in Island County is used for public supply, some for irrigation, and the remainder for domestic and industrial purposes. The location and amount of pumpage are shown in figures 10a and b.

Total ground-water pumpage in Island County from all sources for 1979 was estimated to be 1.67 billion gallons, most of it from the sea-level aquifer. This withdrawal represents a 60-percent increase in the water use estimated by Anderson (1968) for 1963. Of the 1.67-billion-gallon total, 1.65 billion gallons were pumped for domestic and public supplies and irrigation. Domestic and public supplies accounted for 74 percent of the annual water use, irrigation 25 percent, and industrial 1 percent. Figure 11 shows the amount of water used for public supply and irrigation by island and by aquifer. A similar breakdown for domestic pumpage was not possible. Industrial use was negligable and is not shown. There is a marked seasonal variation in pumpage rates, as shown in figure 12. Heavy irrigation and peak public-supply pumping occur simultaneously during the summer months.

Domestic and public-supply systems pumped an estimated 1.23 billion gallons of ground water in 1979. Anderson (1968) reported that the total annual ground-water pumpage for domestic and public supplies in 1963 was about 652 million gallons (fig. 13). Thus, during the period 1963-79 the population has doubled and water use has about doubled.

For the purposes of this investigation, all water-supply systems serving 30 or more people were designated public supply. Island County has more than 150 public supplies, of which very few have water meters or available estimates of water use. Pumpage was based on an estimated consumption rate of 100 gallons per day per person. This estimate was derived by averaging the consumption rates of the few larger systems in the county that do have water meters. Average daily water-use information provided by the Washington Department of Social and Health Services supports this estimate. Public-supply systems pumped an estimated 1.1 billion gallons of ground water in 1979.

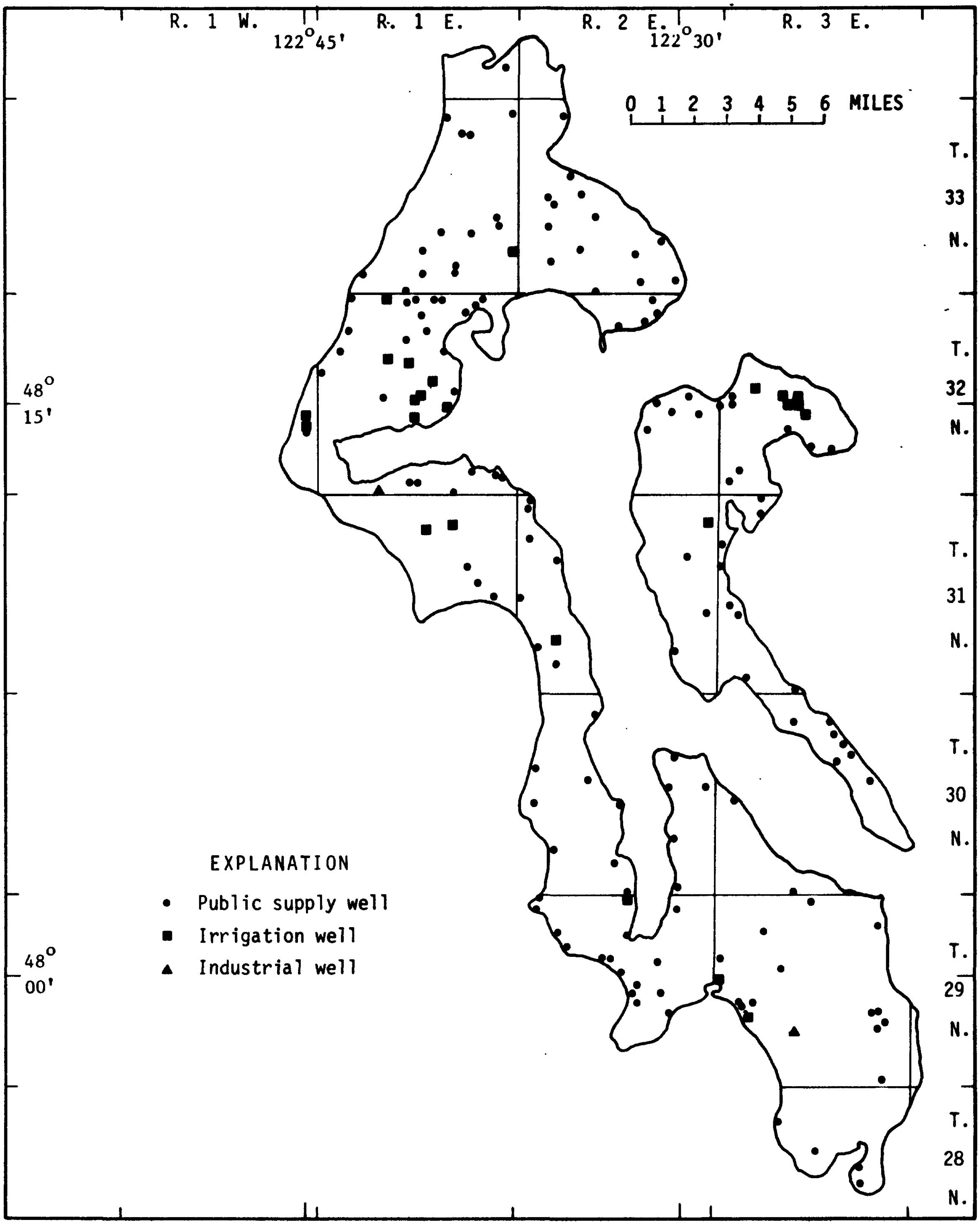

FIGURE 10a.--Type and distribution of wells in Island County, 1979.

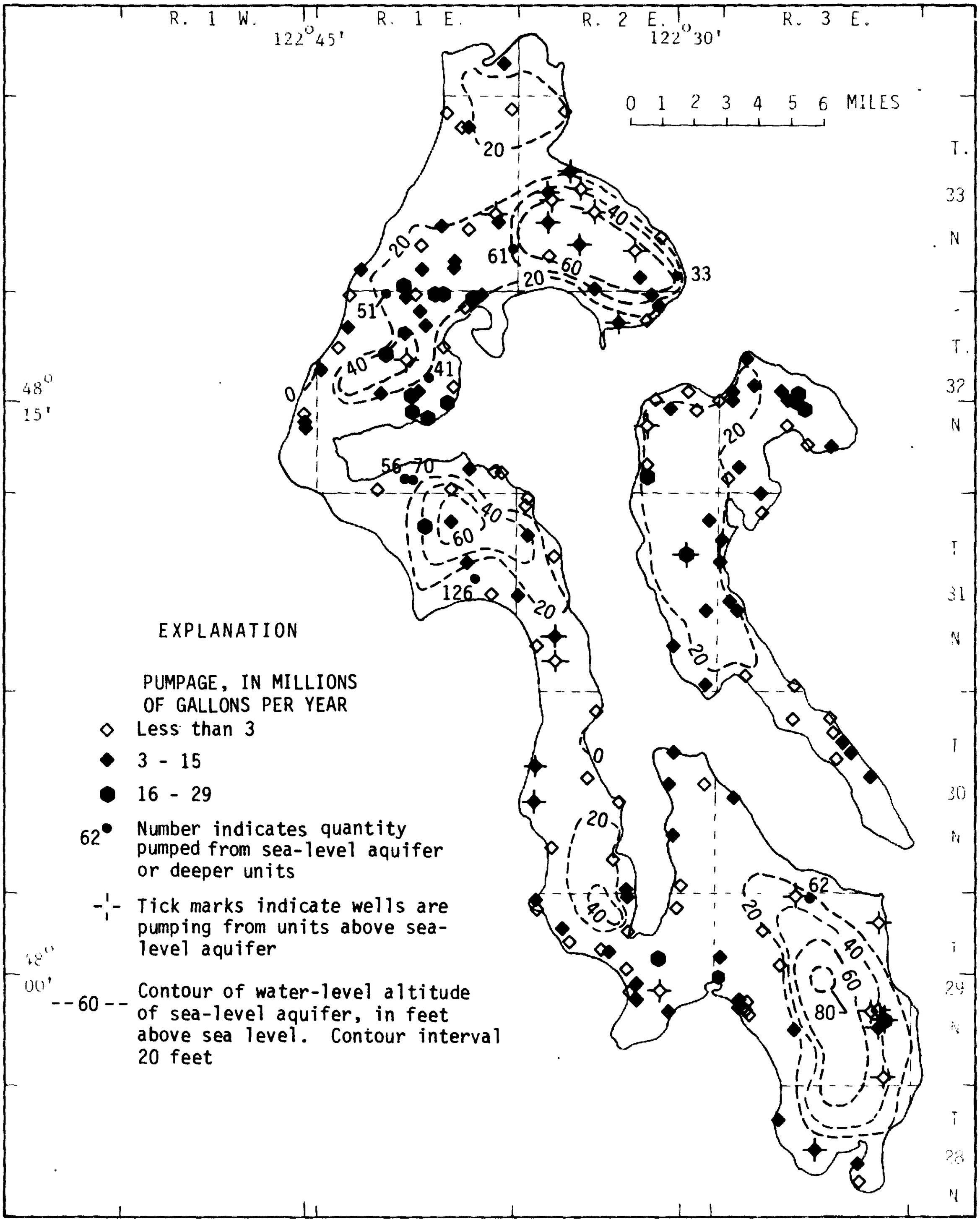

FIGURE 10b.--Water-level altitudes for the sea-level aquifer, and pumpage rates in Island County, 1979.

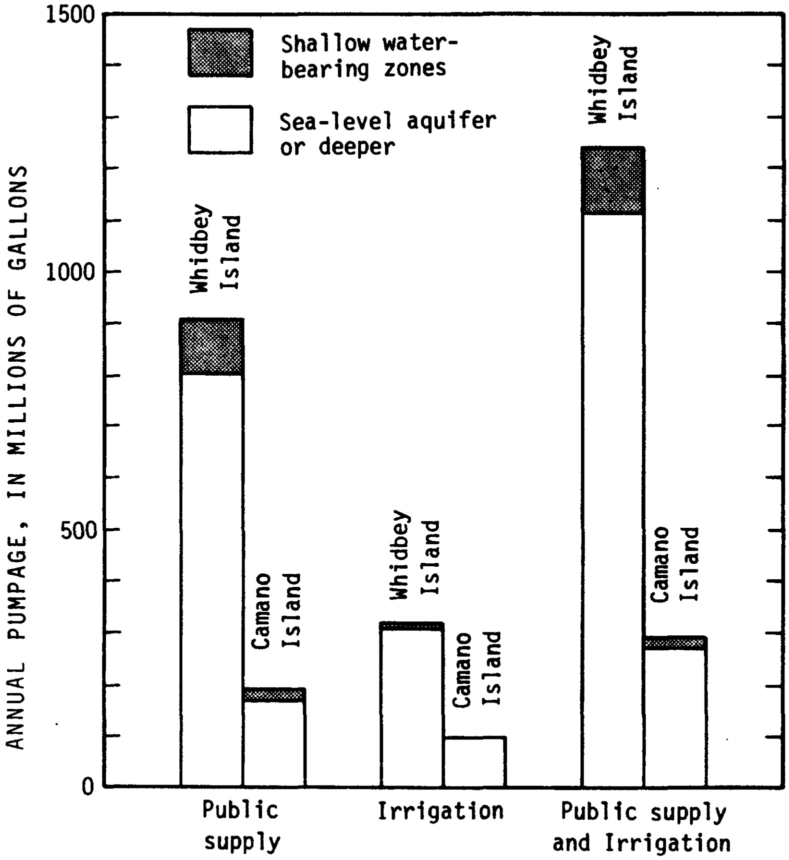

FIGURE 11.--Pumpage in Island County by island and aquifer, 1979.

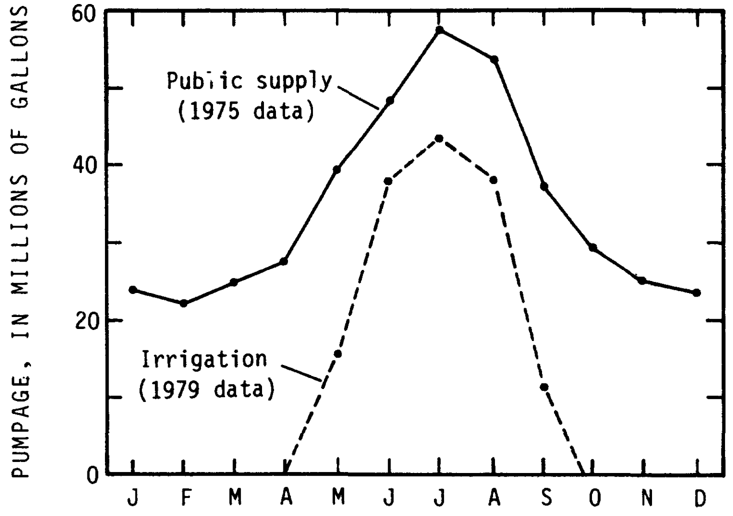

FIGURE 12.--Seasonal variation in pumpage rates in Island County.

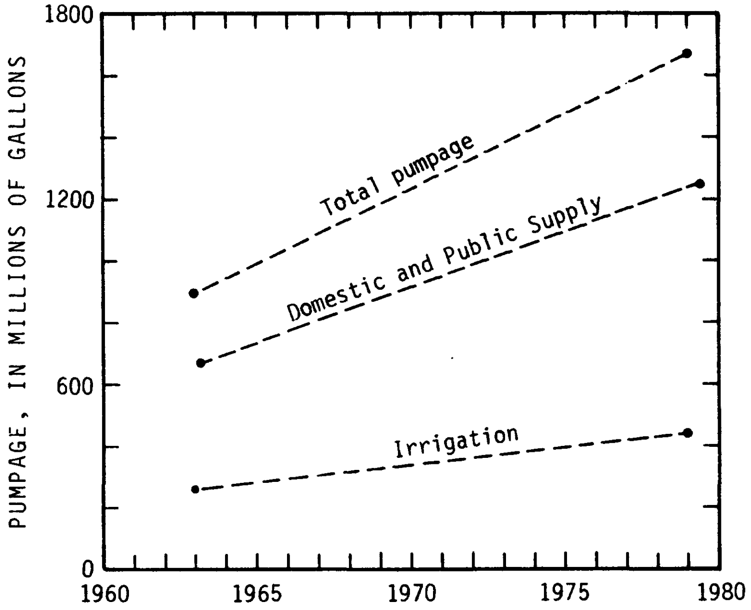

FIGURE 13.--Increase in pumpage in Island County, 1963-79.

The amount of ground water withdrawn for domestic use from privately owned wells in 1979 was 130 million gallons. This estimate was computed by taking the total Island County population of 40,200 for 1979, subtracting those served by public supply systems (including the Skagit River pipeline service area), and multiplying by 100 gallons per day per person. The 1979 domestic and public-supply ground-water pumpage was not as large as it might have been because residents in the Oak Harbor-Ault Field area were (and are now) using water piped in from the mainland.

In 1979, an estimated 420 million gallons of irrigation water were pumped, an increase of 160 million gallons over that reported by Anderson (1968) for 1963 (fig. 13). The number of irrigation permits issued for the same period increased from 22 to 79. The major irrigation areas were on northern Camano Island and on northern Whidbey Island in the Oak Harbor-Coupeville area (fig. 10a).

Most irrigators in Island County begin pumping in mid-May and pump an average of 12 days a month through the middle of September (fig. 12). The majority of wells pump 200 to 300 gallons per minute, and the average application rate is 1 acre-foot of water per acre per year.

Industrial activities in Island County in 1979 were small, and, therefore, no exhaustive search for industrial pumpage was made during this investigation. Anderson (1968) estimated the total water used for commercial and industrial purposes to be 33 million gallons. An estimated 10 million gallons of water were used in 1979 for sand and gravel washing, chicken raising, and egg processing.

Water Levels

The water table, which is the top of the ground-water reservoir, is generally near the land surface in Island County, and in places it is more than 500 feet above sea level (Anderson, 1968). Depth to the water table is generally greater in the central part of the islands than along the coast. Throughout most of Whidbey and Camano Islands, water is moving both laterally and downward (fig. 8). Where water is moving downward, water levels decrease with depth. In discharge areas, ground water moves upward and the water-level altitude increases with depth. The water-level altitude in wells tapping the sea-level aquifer is less than 30 feet above sea level in most areas (fig. 10b).

Water levels fluctuate in response to changes in recharge, pumping, discharge into springs and streams, and tidal fluctuations. Generally, one would expect that water levels are lower in the summer when recharge from precipitation is low and pumping and evapotranspiration are greatest and, corresponding, water levels are highest in early spring when pumping and evapotranspiration are lowest. Monthly water-level observations taken from 1963-1965 at four wells located away from the coast to reduce tidal effects indicate that the water-level fluctuations in the sea-level aquifer were approximately 3 feet. Isolated water-level measurements taken in 1977, 1978, and 1980 at these wells fell within the same range as previous water levels (fig. 14). A comparison of water-level data for the sea-level aquifer collected in April and August of 1980 revealed a net decline of about 1 foot in August. Water-level extremes for this period ranged from a 4.8-foot rise to an 8.0-foot decline. (Tidal effects have not been removed from data.)

Water levels in shallow wells that tap water-bearing zones of sand and gravel above the sea-level aquifer may have considerably larger fluctuations in response to seasonal changes in recharge (Anderson, 1968) than wells tapping the sea-level aquifer.

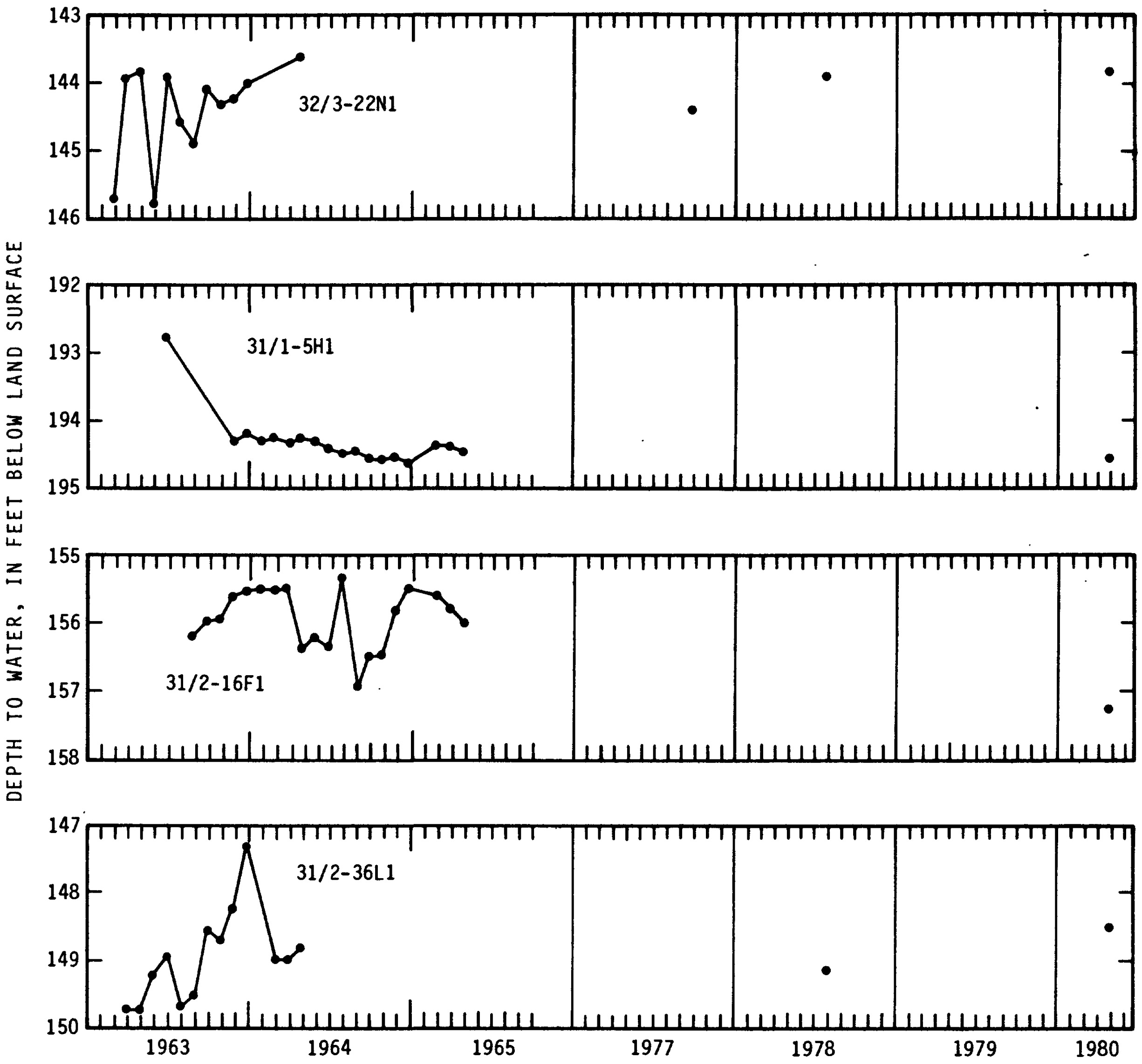

FIGURE 14.--Water levels in selected sea-level wells in Island County.

The water level in a pumping well is lower than the static level, and, as discussed later in the section Quality of the Water, wells drilled below sea level can be affected by seawater intrusion. On the basis of water-level measurements made in April and August of 1980, at least 43 wells have pumping or static water levels below sea level. Of those wells tapping the sea level aquifer for which water-level measurements were not made, reported specific capacity and pumpage data that were collected indicated that an additional seven wells probably have pumping levels below sea level. On the basis of reported depth, specific capacity and estimated pump capacity obtained from well logs, an additional 21 wells constructed in the sea-level aquifer could have pumping levels below sea level, assuming the wells are pumped at 65 percent of their estimated rates (fig. 15).

The long-term effect of pumping on ground-water levels in the county is presently unknown. Data on water levels dating back to 1963 are available for a limited number of wells. For selected wells, water levels measured in April 1980 were generally within 1 or 2 feet of water levels measured in the early 1960's. Although there were no consistent water-level changes observed for the period 1963-80 in most of the county, there is an area of heavy pumping just west of Oak Harbor where water levels have dropped 4 to 5 feet since 1964.

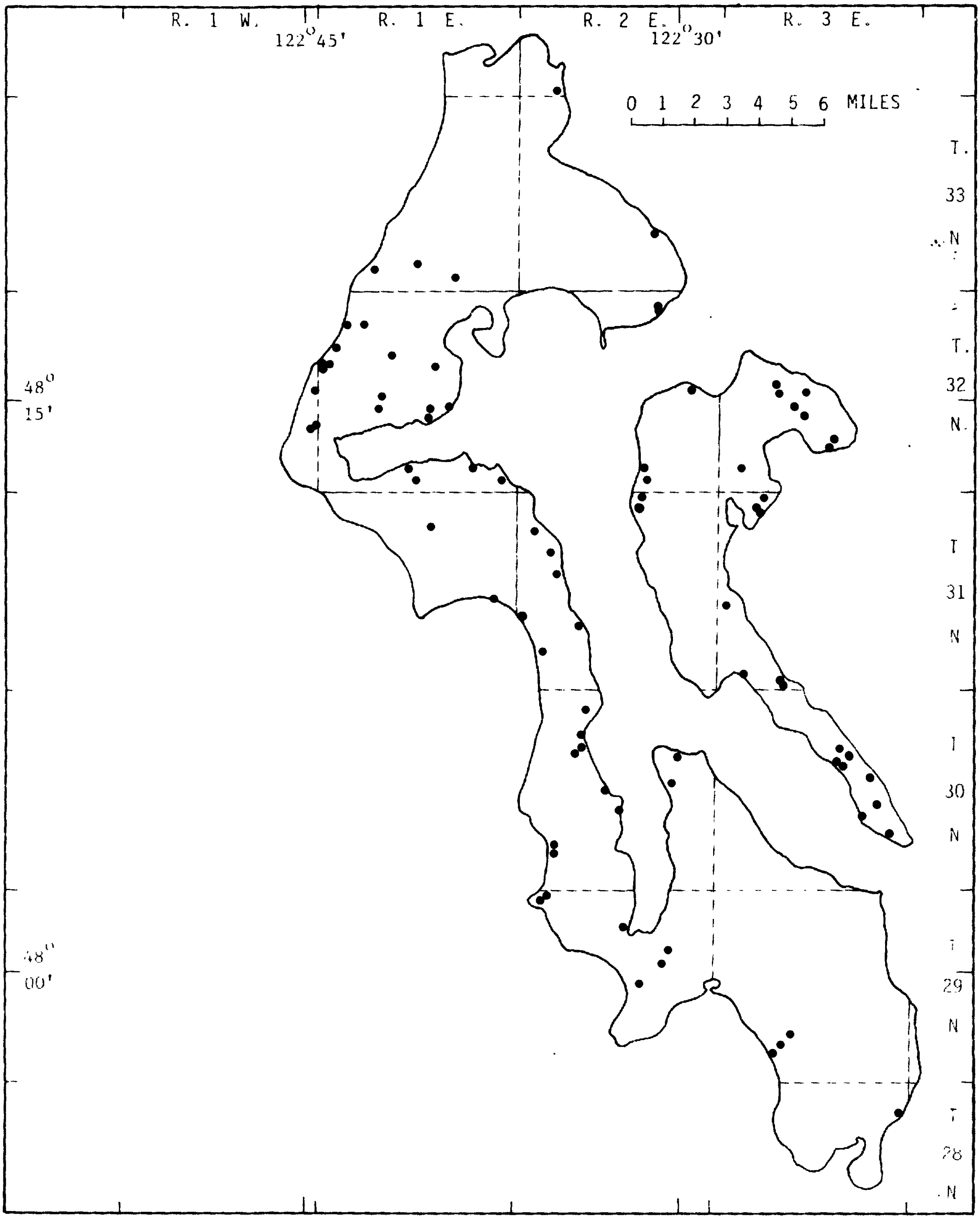

FIGURE 15.--Wells whose static and(or) pumping water level is at or below sea level.

Quality of the Water

A small amount of water-quality information for Island County is available from previous studies conducted by Van Denburgh (1968) and Walters (1971), from unpublished data collected by Washington Department of Ecology and Washington Department of Social and Health Services, and from unpublished data collected by the U.S. Geological Survey during the late 1960's, 1978, and 1980. Some of these studies involved collecting water samples for standard chemical analysis; however, many analyses consist only of specific conductance and chloride determinations. The following summary has considered all the above chemical data.

The principal dissolved chemical constituents in ground water in the county are calcium and magnesium. In areas where aquifers are intruded by seawater, however, sodium and chloride ions predominate. Because of the naturally high concentrations of calcium and magnesium in much of the ground water, the hardness of water sampled from many wells exceeds 300 mg/L, classified as very hard by U.S. Environmental Protection Agency (EPA) criteria (U.S. Environmental Protection Agency, p. 75, 1976). On the basis of the limited data, there does not appear to be any discernible areal pattern to the occurrence of hard water in the county; however, the principal areas of hard water are between Keystone and the U.S. Navy's Ault Field on Whidbey Island and the northeast part of Camano Island (fig. 2).

Many wells in the county produce water that contains iron and manganese in concentrations exceeding the EPA criteria of 0.3 mg/L for iron and 0.05 mg/L for manganese. There does not appear to be any pattern to this occurrence.

High concentrations of dissolved chloride can be detected by taste and can, consequently, lead to rejection of a given source or supply of domestic water. On the basis of taste, which varies widely due to a wide taste-perception range in humans, a secondary maximum contaminant level of 250 mg/L has been established. This criterion is not enforceable, but rather pertains to the esthetic quality of drinking water and, thus, is meant to serve as a guideline. Water Quality Criteria, 1972 (National Academy of Sciences/National Academy of Engineering, 1974, p. 61) recommends that sources exceeding 250 mg/L should not be used for public drinking water if sources of lower levels are available.

From the chloride data collected in previous studies and during this investigation, it is apparent that specific problem areas exist in Island County (fig. 16). For this report, locations where the chloride concentrations exceeded 190 mg/L but were less than 250 mg/L are considered to be potential problem areas. Chloride in ground water can be caused by seawater intrusion or by the disposal of manmade wastes that percolate to the ground-water system. Data are not available to determine the specific sources of chloride in the problem wells; however, it is assumed that seawater surrounding the islands is a major source, as it contains approximately 16,000 mg/L of chloride.

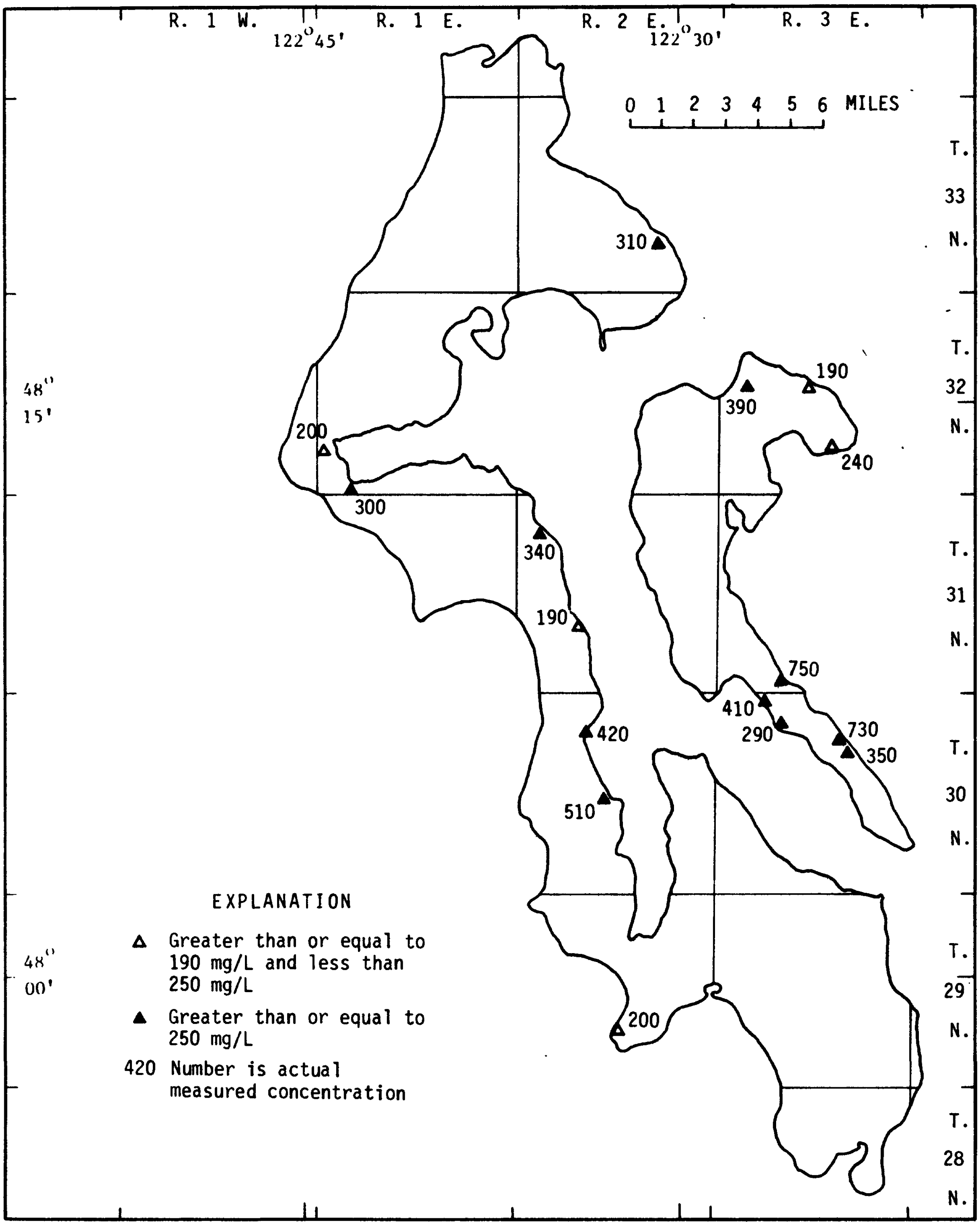

FIGURE 16.--Chloride concentrations greater than 190 mg/L in wells tapping the sea-level aquifer, July 1978.

As part of a 1978 Geological Survey investigation to determine areas of potential seawater intrusion into the sea-level aquifer (Dion and Sumioka, written commun., 1981), 209 wells, all within 1 mile of the shoreline, were sampled to determine specific conductance and chloride concentration. The observed concentrations of chloride ranged from 1.4 to 13,000 mg/L in July 1978. Of the wells sampled in 1978, chloride concentrations equaled or exceeded 190 mg/L in 16 wells that penetrate the sea-level aquifer (fig. 16). Chloride concentrations were less than 190 mg/l in the remaining wells (fig. 17).

To assess the present distribution of chloride, 235 wells were sampled in April 1980 and 330 wells were sampled in August 1980. Samples were obtained from wells in the sea-level aquifer and from those in the sand-and-gravel units above the sea-level aquifer. Chloride concentrations ranged from 5 to 970 mg/L in April 1980 and from 10 to 1,240 mg/L in August. Of the 235 wells sampled in April 1980, 229 were sampled again in August, and 121 of the wells sampled in August had also been sampled in July 1978.

The locations of wells having chloride concentrations in excess of 190 mg/L and penetrating the sea-level aquifer in April 1980 are shown on figure 18, and wells where chloride concentrations were less than 190 mg/L are shown on figure 19. The concentration of chloride was greater than 190 mg/L in eight wells.

The locations of wells penetrating the sea-level aquifer where chloride exceeded 190 mg/L in August 1980 are shown in figure 20, and wells where chloride was less than 190 mg/L are shown in figure 21. The concentration of chloride was greater than 190 mg/L in 32 wells.

For wells pumping from above the sea-level aquifer, chloride concentrations were generally less than 50 mg/L in April and August 1980.

Areas of seawater intrusion may be found where ground water is high in chloride and pumping levels in wells are below sea level. An examination of available data indicates that high chloride (concentration equals or exceeds 190 mg/L) occurs in areas of low pumping levels on north and south Camano Island (figs. 20 and 15).

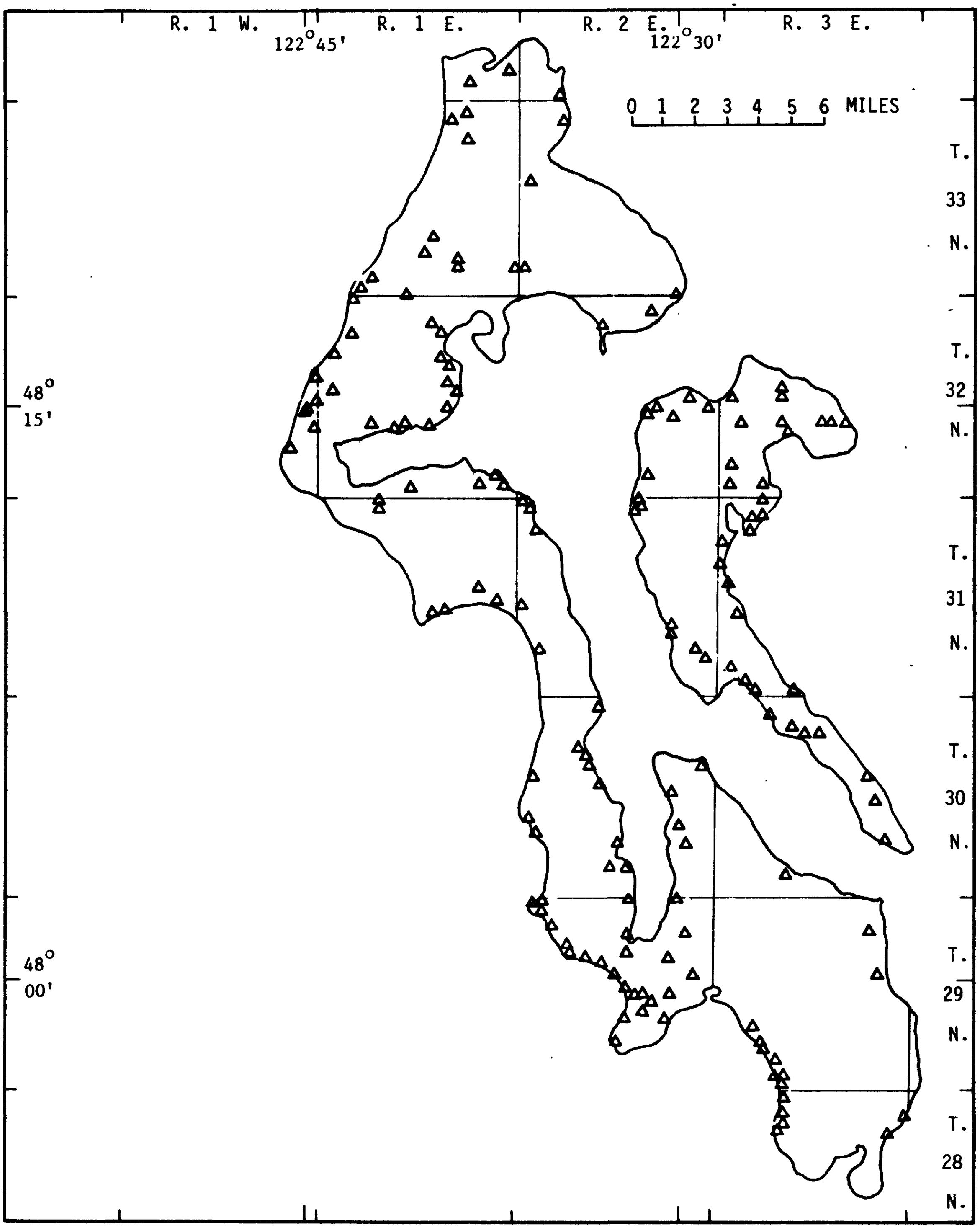

FIGURE 17.--Chloride concentrations less than 190 mg/L in wells tapping the sea-level aquifer, July 1978.

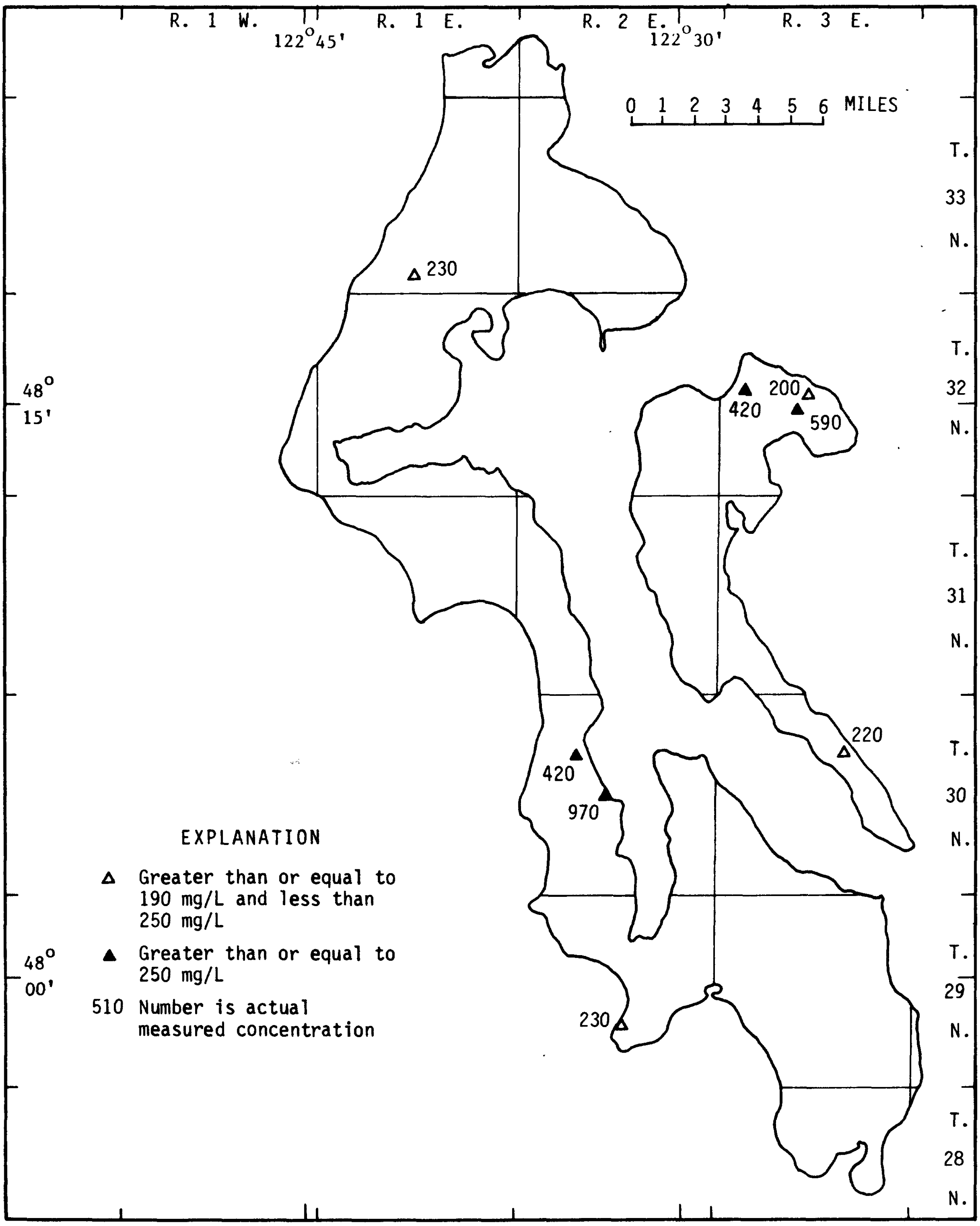

FIGURE 18.--Chloride concentrations greater than 190 mg/L in wells tapping the sea-level aquifer, April 1980.

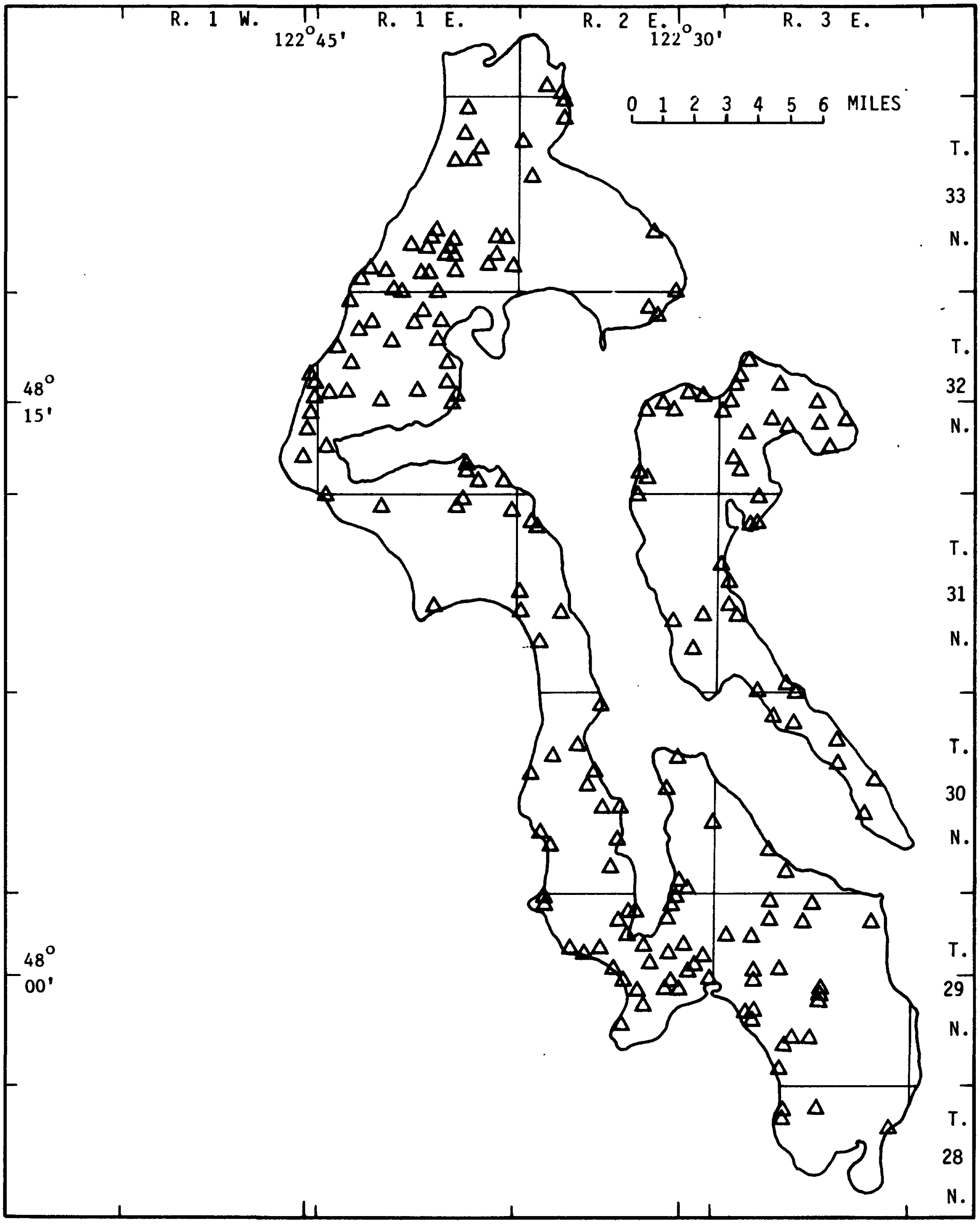

FIGURE 19.--Chloride concentrations less than 190 mg/L in wells tapping the sea-level aquifer, April 1980.

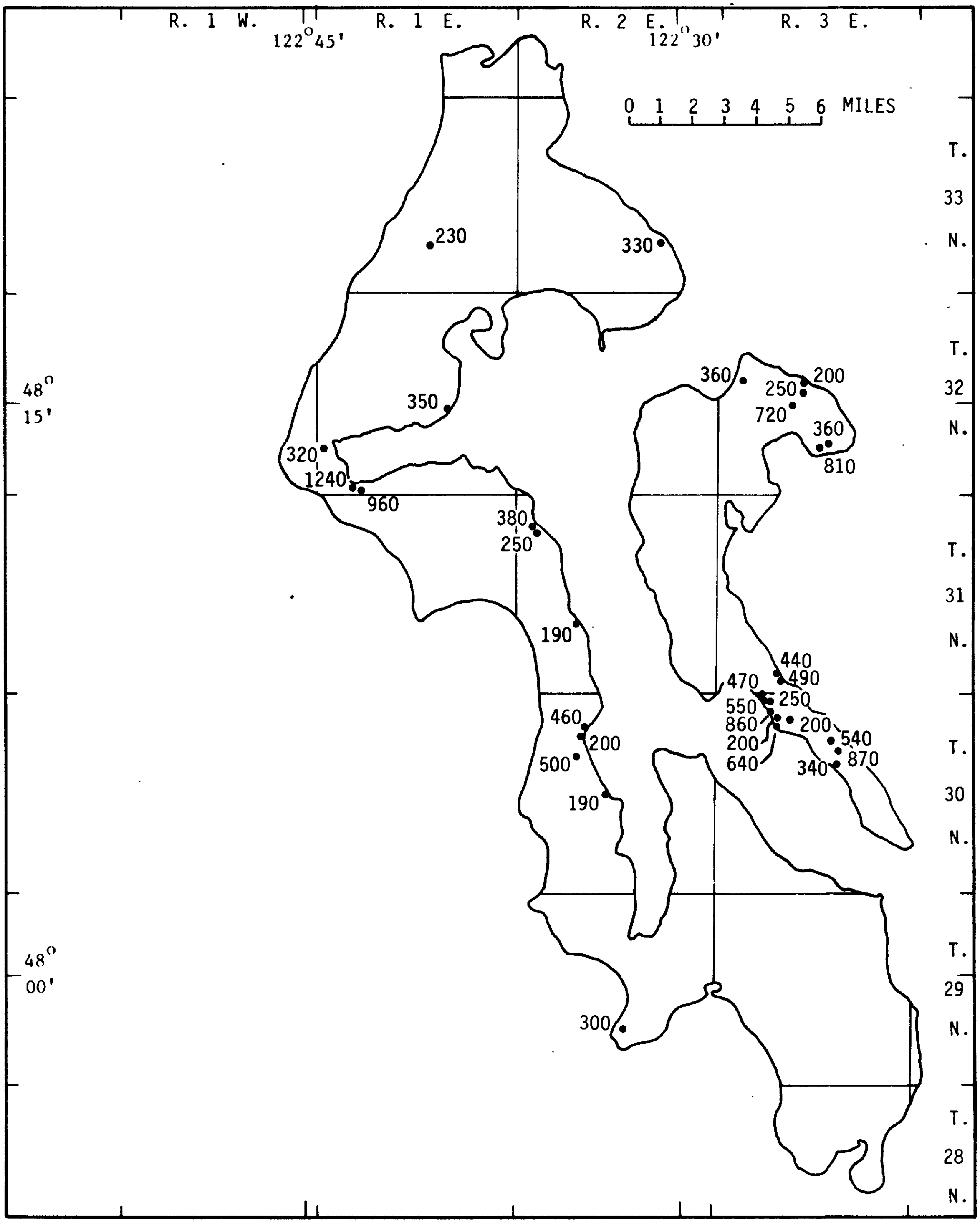

FIGURE 20.--High-chloride data points for August 1980.

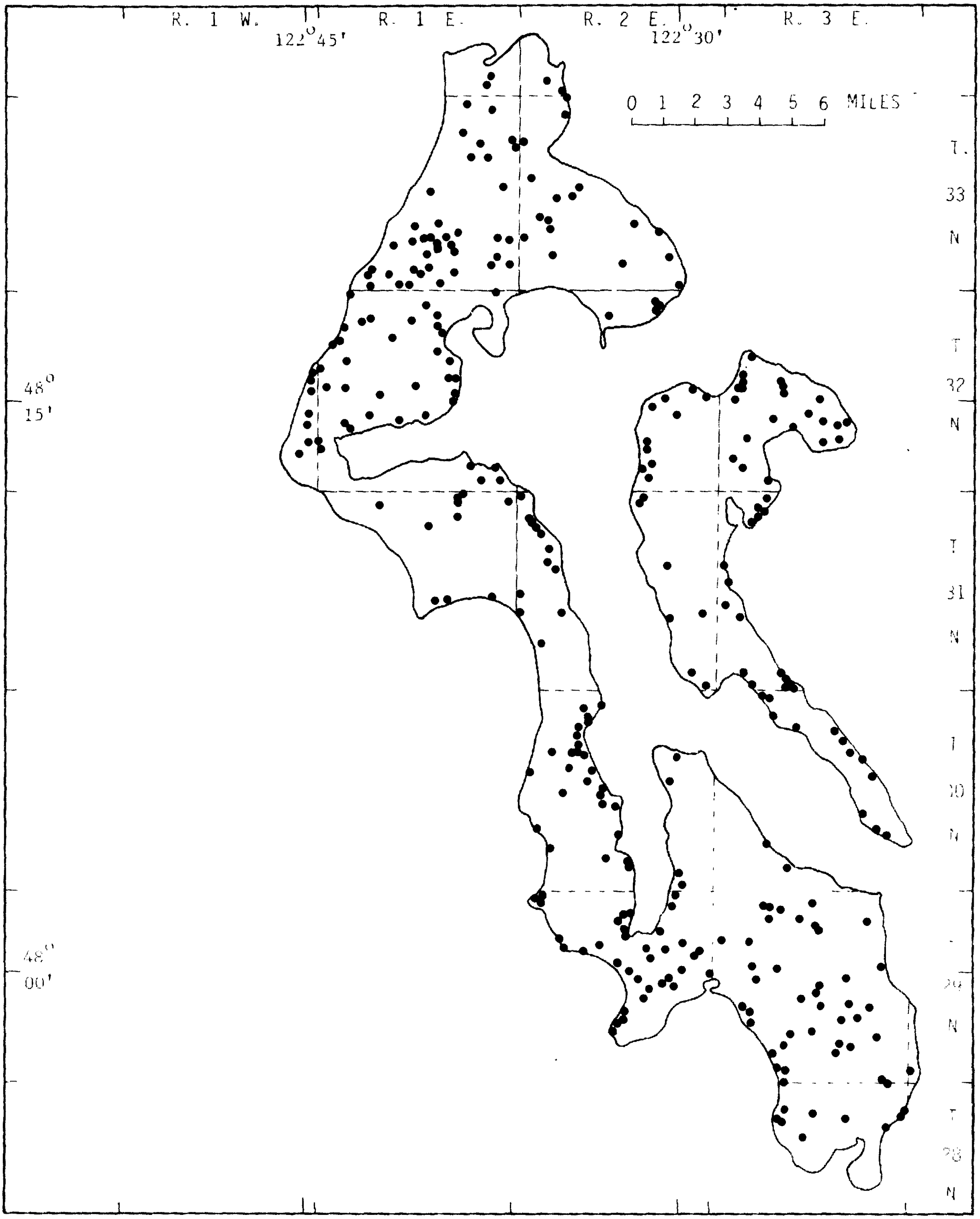

FIGURE 21.--Chloride data points less than 190 mg/L for August 1980.

Changes in Chloride Concentration

Changes in chloride concentration are caused by seawater intrusion due to movement of the freshwater-seawater interface in response to fluctuations in the water table. Changes in the water-table altitude are caused by changes in recharge, pumping from wells, discharge into springs and streams, and tidal fluctuations. Fluctuations in the water table (see discussion in Water Levels section) and resulting fluctuations in the freshwater-seawater interface may occur daily, monthly, seasonally, and annually. Annual changes in the freshwater-seawater interface cannot be determined from available chloride data. To detect changes in the freshwater-seawater interface, more data on water levels and chloride concentrations must be collected on a scheduled basis. It is expected that chloride concentrations would be low in winter and spring months, when water levels are usually up, and high in summer months, when water levels are usually down. The data to support these relationships are not yet available.

A direct comparison of the number of wells with high chloride concentrations for the 1978 and 1980 sampling periods is misleading because a different quantity of wells was sampled during each period. As stated earlier, the wells sampled in July 1978 were located within 1 mile of the shoreline, whereas in 1980 wells were sampled in all parts of the county. Most of the wells sampled in July 1978 were included in the April 1980 sampling. During the August 1980 sampling period, all but six of the wells sampled in April were resampled; however, when a field-determined specific conductance of a sample was high, additional wells were sampled in the immediate vicinity to better define the areal extent of high chloride concentrations.

Chloride concentrations were compared for 121 wells sampled in July 1978 and again in August 1980; 86 wells had higher chloride concentrations in August 1980, and 21 had lower concentrations (fig. 22). Fourteen had the same concentrations. The majority of the changes in chloride concentrations were in the range of 0-49 mg/L, as illustrated in the bar graph in figure 22.

A comparison of chloride concentrations measured in 229 wells sampled in April and August, 1980, showed that in August 46 wells had higher concentrations, 46 had lower concentrations (fig. 23), and 137 had the same concentrations. Most of the changes were in the range of 0-49 mg/L, as illustrated in figure 23. The areas where chloride values increased more than 10 mg/L were generally the same as the areas in which chloride concentrations equaled or exceeded 190 mg/L (fig. 24), particularly in northern and southern Camano Island.

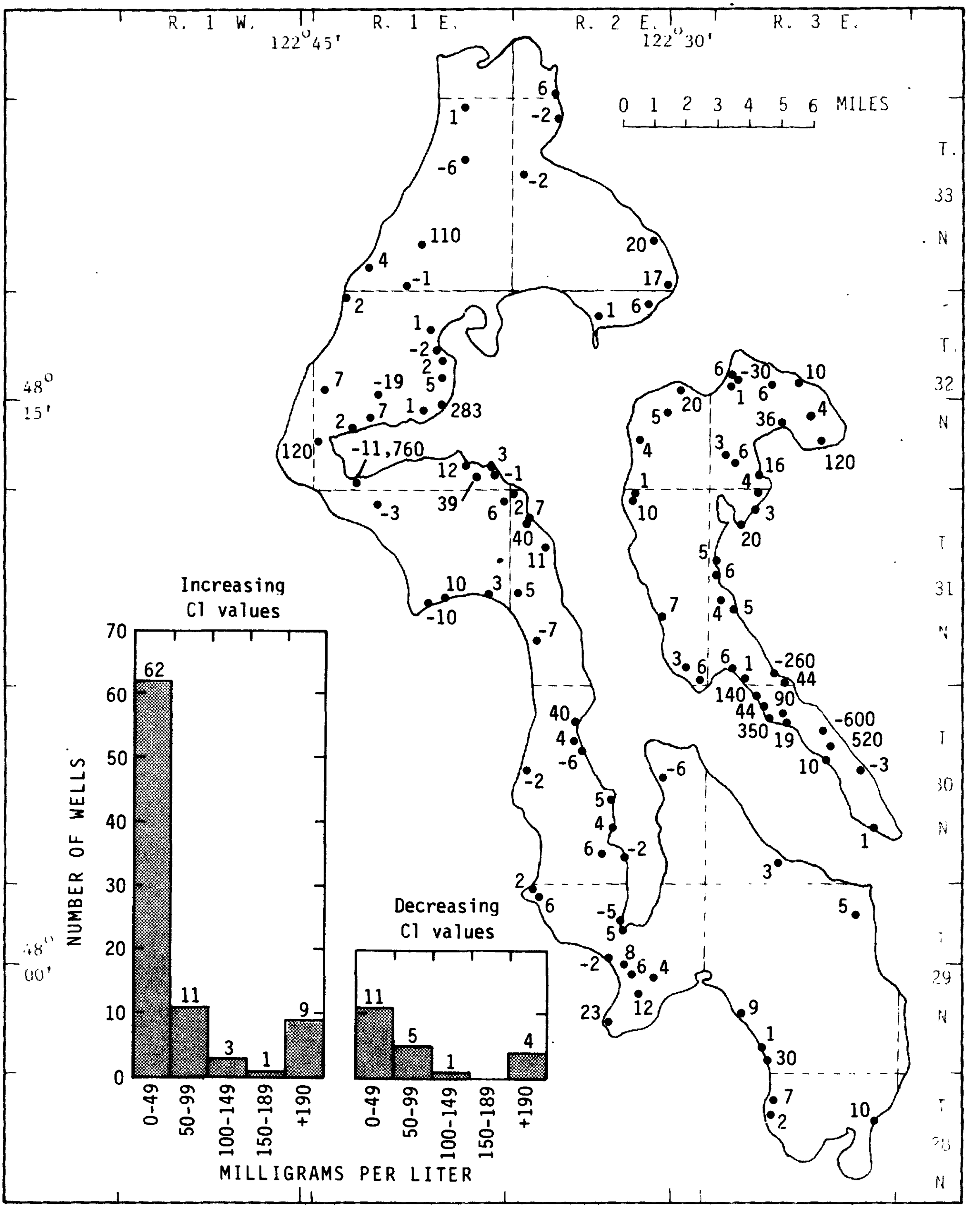

FIGURE 22.--Changes in chloride concentration, July 1978-August 1980.

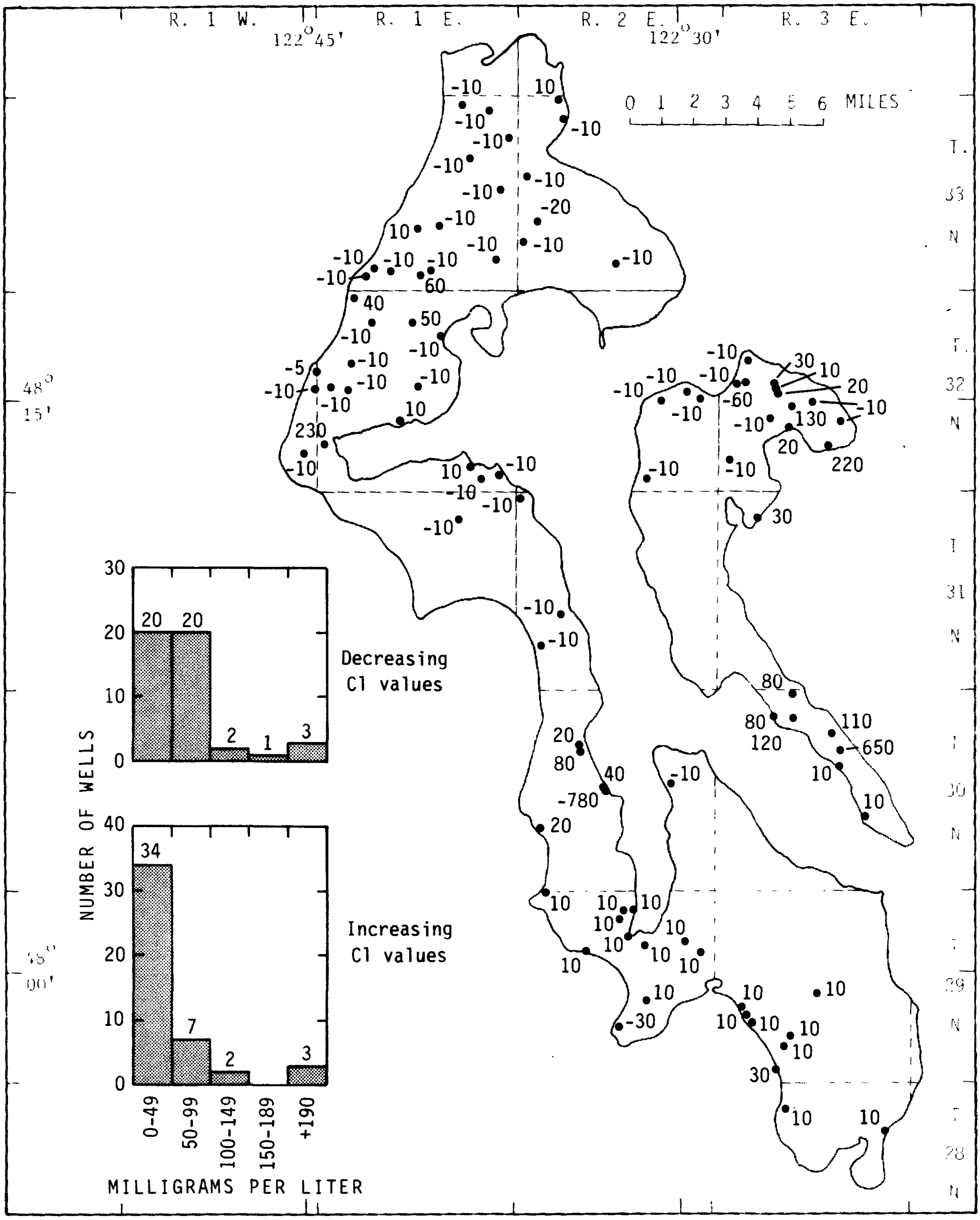

FIGURE 23.--Change in chloride concentration, April-August 1980.

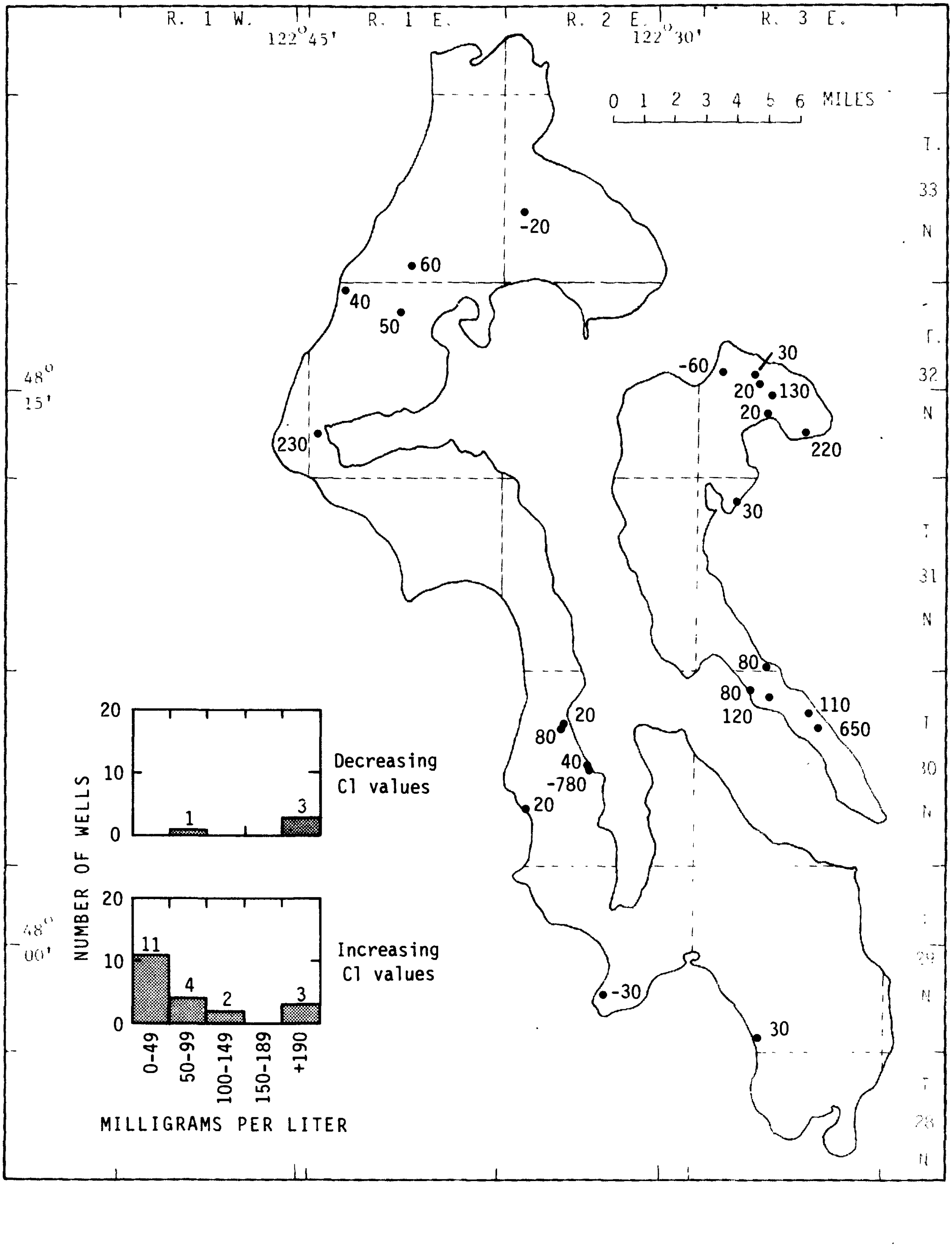

FIGURE 24.--Change in chloride concentrations greater than 10 mg/L, April-August 1980.

Seawater-Freshwater Interface

The contact between fresh ground water beneath an island and seawater is called the interface and, to simplify mathematical computations for determining interface position, this interface is assumed to have a small width. The position of the interface underlying an island depends on the densities of the two fluids, the altitude of the water table, the hydraulic conductivities of both the aquifer material and the material surrounding the aquifer, and the recharge rate to the ground-water reservoir. The position of the interface will differ from one locality to another because of differences in these conditions. At any location, changes in the position of the interface are caused by changes in recharge (due to changes in climate and land use), discharge from wells, and tidal fluctuations.

The positions of the interface shown in figure 25 were determined along a vertical section near Coupeville, on Whidbey Island, using a digital computer model (Trescott, 1975) to simulate steady-state flow in horizontal and vertical directions and to compute the steady-state position of the interface. The sea-level aquifer was designated as the upper boundary of the model, and the interface between freshwater and seawater was designated as the lower boundary, with no flow across it. To compute the steady-state position of the interface for spring water levels, head in the sea-level aquifer was estimated from water-level measurements made in wells penetrating the sea-level aquifer during April 1980. In late summer, head is lower because of increased discharge from wells and less recharge from precipitation; therefore, head was assumed to be 5 feet lower in the center of the island, but unchanged at the shoreline. Horizontal hydraulic conductivities were estimated to be 100 feet per day for aquifer materials and 0.1 foot per day for materials surrounding the aquifers, and the ratio of horizontal to vertical hydraulic conductivity was estimated to be 10. These estimates were obtained from unpublished results of aquifer tests in materials hydrologically similar to those underlying Island County. A relative density of 1.021 was used for seawater in Puget Sound (U.S. Department of Commerce, 1954). The recharge rate to the ground-water reservoir was estimated to be 6.4 inches per year during the spring and 3.4 inches per year during late summer. These recharge rates were computed by the model for the spring and late summer positions of the interface. On the basis of an average recharge rate of 4.9 inches per year, the average annual recharge over the 210-square-mile area of Whidbey and Camano Islands was estimated to be 55,000 acre-feet per year (see discussion on Recharge).

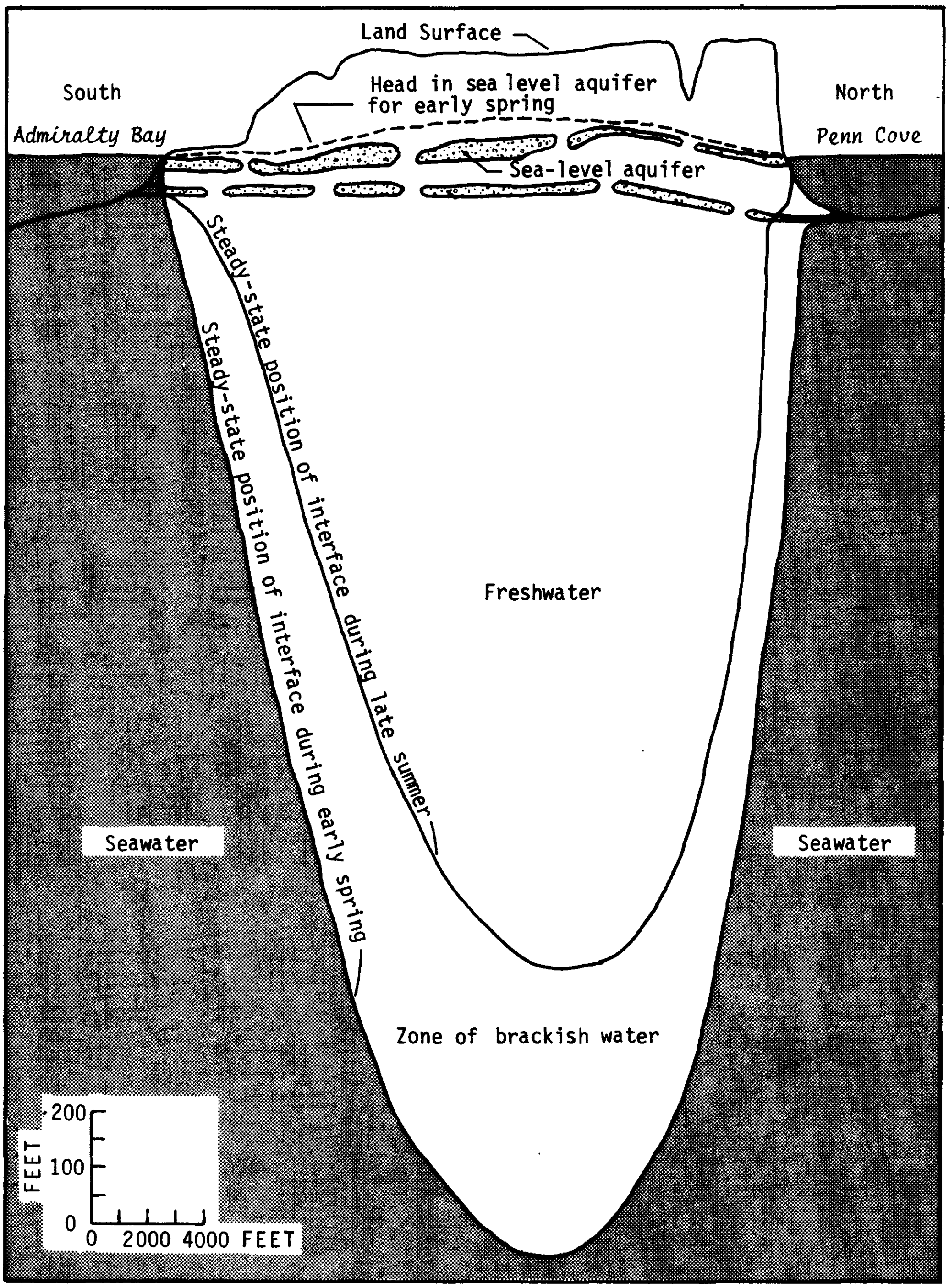

FIGURE 25.--Model-computed steady-state position of the freshwater-saltwater interface for early spring and late summer, 1980.

Results from the digital model (fig. 25) indicate that the April 1980 position of the interface is within 800 feet of the south shoreline, within 1,600 feet of the north shoreline, and approximately 1,950 feet below sea level at its maximum depth. The interface moves both laterally and vertically (see figure 25) in response to seasonal head changes in the sea-level aquifer. The maximum lateral movement of the interface is about 6,000 feet near the bottom of the interface and 1,600 feet near the top, and the maximum vertical movement is about 500 feet. The interface positions shown in figure 25 are the extreme positions achieved under steady-state conditions, and steady state may occur at a time when several years have elapsed after head in the sea-level aquifer is changed. Within 6 months after changing head in the sea-level aquifer, the interface will not move to either extreme position shown in figure 25. The error in computing the horizontal position of the interface is less than 800 feet, and the error in the vertical position is less than 50 feet.

The average chloride concentration in the zone of brackish water (fig. 25) is lower during early spring than in late summer because the interface is farther offshore during early spring. Within the zone of brackish water, chloride concentration varies laterally and, during early spring, is low near the late-summer position of the interface and high near the early-spring position.

The effects of pumping at a specific site on the position of the interface were not determined for this study; however, the idealized effects of pumping are illustrated in figure 26.

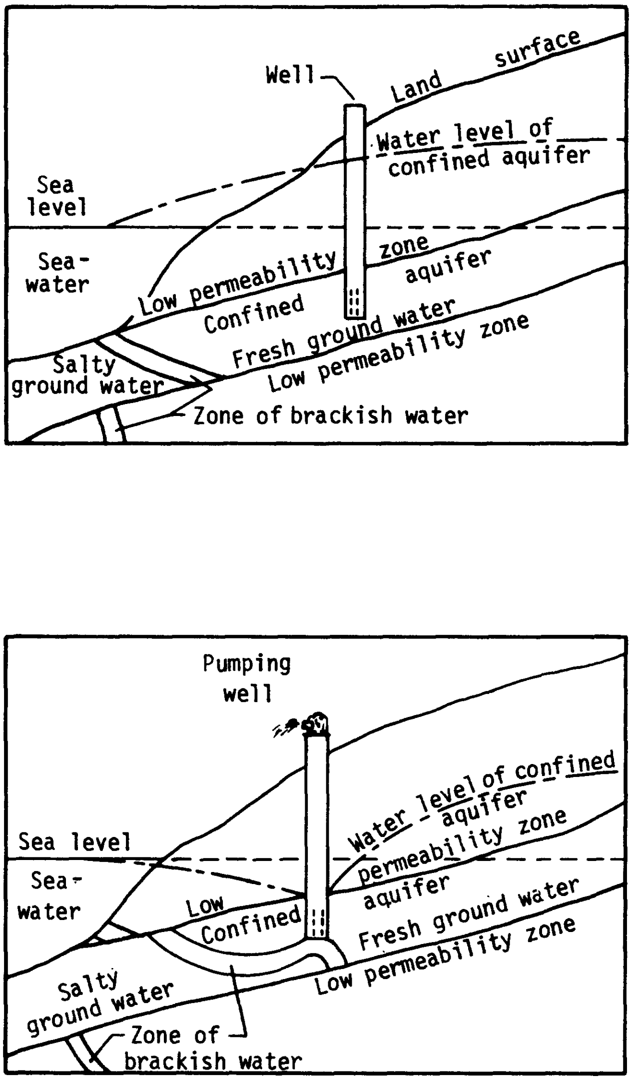

FIGURE 26.--Idealized effects of pumping on the saltwater-freshwater interface.

SUMMARY OF PRESENT GROUND-WATER CONDITIONS IN ISLAND COUNTY

Most of the wells in Island County obtain water from the sea-level aquifer located in the interval from about 30 feet above sea level to 200 feet below. The heaviest pumping occurs during the summer months, and indications are that pumping water levels are below sea level for most of the major wells. This suggests a threat to the quality of the water supply from lateral seawater intrusion into the sea-level aquifer, at least at locations near or seaward of the major wells.

A cross-section digital flow model was constructed during this study to determine the approximate steady-state position of the seawater-freshwater interface near Coupeville, on Whidbey Island, for water levels determined in April and August of 1980. The model indicated that the interface at this location is within 800 feet of the south shoreline and 1,600 feet of the north shoreline and is approximately 1,950 feet below sea level at its maximum depth. An assumed seasonal water-level drop of 5 feet at the center of the island caused the interface to move upward about 500 feet and inward laterally about 6,000 feet near the bottom of the interface and less than 1,600 feet near land surface. The precise amount of movement between interfaces computed by the model could not be determined because of model design constraints. The actual amount of interface movement due to head changes in the sea-level aquifer will be less than the distance between interfaces computed by the model.

Seawater intrusion would cause the chloride concentration in wells to increase beyond acceptable EPA limits for drinking water. Some data for July 1978 on chloride concentrations in wells indicated that chloride concentrations in 16 wells were near or exceeded the safe drinking-water criteria maximum of 250 mg/L. The highest recorded value was 13,000 mg/L. Sampling was extensive along the coast of the county, and was done as part of a cooperative program on seawater intrusion. Water-quality and water-level data were collected from a much more extensive network of wells in the county during April and August of 1980 as part of this study. Chloride concentrations in 1980 were found to be near or exceeding the safe drinking-water criteria in 8 wells in April and 31 wells in August; the highest chloride values were 970 mg/L in April and 1,240 mg/L in August.

As explained earlier, a direct comparison of the number of wells with high chloride concentrations for the 1978 and 1980 sampling periods is misleading because a different quantity of wells was sampled during each period.

Data are not presently available to determine if the effects of seawater intrusion are increasing with time. However, the fact that 86 of the 121 wells sampled during July 1978 and again in August 1980 showed an increase in chloride concentrations suggests that this may be occurring.

Analysis of data collected during the study shows that since 1963 the population of the county has doubled and total ground-water withdrawals for domestic and public supply have about doubled. Because population is expected to continue to increase, problems with seawater intrusion can be expected. There is, therefore, a need to more clearly define the extent and process of seawater intrusion and the availability of ground water in the county.

The degree to which the geologic framework of the county can presently be described is extremely limited because very few wells extend more than 200 feet below sea level. This in turn limits a complete assessment of the availability of ground water in the county and a definition of the threat of seawater intrusion associated with present or increased rates of ground-water withdrawal.

CONCLUSIONS

The sea-level aquifer is the most widespread aquifer in Island County. It lies between 30 feet above sea level and 200 feet below sea level. Locally, available data indicate that one or more water-bearing zones lie above the sea-level aquifer. Their lateral and vertical extent cannot be determined from available data.

Pumpage in 1979 totaled about 1.67 billion gallons, approximately 90 percent of which was pumped from the sea-level aquifer. Pumpage in 1979 was only 60 percent greater than in 1963, although the population nearly doubled. The 1979 ground-water pumpage was not as large as it might have been because some water was imported to supply part of northern Whidbey Island. In 1979, domestic and public supplies used 74 percent of the total pumped, irrigation 25 percent, and industrial 1 percent.

Chloride concentrations of 190 to 250 mg/L in water pumped from wells are considered in this report to represent potential seawater-intrusion problem areas. Sampling in July 1978, April 1980, and August 1980 indicated problem areas mainly in northeastern and southern Camano Island and in central Whidbey Island. No particular pattern of chloride change was apparent. Observation wells for chloride monitoring are needed so that seasonal and long-term trends can be determined.

Pumping wells in Island County can induce seawater intrusion by lateral movement and by vertical movement. Most of the large producing wells in the county have pumping water levels near or below sea level, so that if pumping continued for a long enough time seawater intrusion would result.

The most comprehensive method to describe quantitatively the effects of ground-water pumping and the probability of seawater intrusion in Island County is to conduct an investigation that includes modeling the ground-water flow system, using a three-dimensional digital model. Such an investigation would require test drilling and extensive data collection.

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