Hydrogeology and Quality of Ground Water on Guemes Island, Skagit County, Washington

By S.C. Kahle and T.D. Olsen

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
square mile (mi^2)	259.0	hectare
gallon (gal)	3.785	liter
acre-foot (acre-ft)	1,233	cubic meter
inch per day (in/d)	25.4	millimeter per day
foot per day (ft/d)	0.3048	meter per day
square foot per day (ft^2/d)	0.09290	square meter per day
cubic foot per day (ft^3/d)	0.028317	cubic meter per day
gallon per minute (gal/min)	0.06308	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
degree Celsius (^oC)	$^oF = 1.8 \times (^oC + 32)$	degree Fahrenheit (^oF)

Sea level: In this report "sea level" refers to the 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 Datum of 1929.

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ABSTRACT

Guemes Island is an 8.2-square-mile island in the northern part of Puget Sound in western Washington State. The population of the island is increasing, as is the demand for ground water, which is the island's sole source of freshwater.

The island consists of unconsolidated Pleistocene deposits and bedrock. A net of five hydrogeologic sections and a map of surficial geology were constructed and used to delineate six hydrogeologic units. The Double Bluff, Vashon, and beach aquifers are the most productive hydrogeologic units on the island. The thickness of the unconsolidated deposits under most of the island is unknown.

Discharge to pumping wells was estimated to be 64.6 acre-feet during 1992, and virtually all the water was used for public supply and domestic purposes. An approximate water budget indicates that of the 21-29 inches of precipitation that falls on the island in a typical year, 0-4 inches runs off as surface water, 12-22 inches evaporates or transpires, and 2-10 inches recharges the ground-water system. Only 0.1-0.3 inch of the recharge is withdrawn by wells; the remainder recharges deeper aquifers or discharges from the ground-water system fairly rapidly to drainage ditches or the sea.

Water samples were collected from 24 wells to determine the chemical quality of ground water on the island. All samples were analyzed for concentrations of common ions, iron, manganese, arsenic, and fecal-streptococci and fecal-coliform bacteria. The median dissolved-solids concentration was 236 mg/L (milligrams per liter). The secondary maximum contaminant level (SMCL) for dissolved solids, 500 mg/L, was exceeded in four samples. Twelve water samples were classified as moderately hard, the remainder as hard or very hard. Although calcium-magnesium/bicarbonate water types were most common, samples with relatively high amounts of sodium and chloride also were found. The median chloride concentration was 21 mg/L; two samples had chloride concentrations above the chloride SMCL of 250 mg/L. The median nitrate concentration of 0.08 mg/L indicates that there is no widespread contamination from septic systems or from livestock. More samples did not meet the SMCL for manganese than for any other constituent; 11 samples exceeded the 50 µg/L (micrograms per liter) limit. Similarly, nine samples did not meet the SMCL of 300 µg/L for iron. Arsenic was detected in 5 of 24 samples and concentrations ranged from 1 to 14 µg/L. Fecal-streptococci bacteria were detected in one sample; fecal-coliform bacteria were not detected at all.

Water from five wells was analyzed for concentrations of volatile organic compounds, and trace concentrations of a single but different compound were detected in three samples; trichloromethane, 1,1,1-trichloroethane, and benzene were each present in one sample. All samples containing a volatile organic compound were collected from wells less than 70 feet deep. Of the five water samples analyzed for radon, one sample exceeded the proposed radon maximum contaminant level of 300 picocuries per liter.

Several coastal wells in West Beach, North Beach, and Indian Village yielded water with chloride concentrations exceeding 100 mg/L, possibly indicating early stages of seawater intrusion. Chloride concentrations appeared to vary seasonally in wells that had chloride concentrations greater than 100 mg/L; the higher values occurred from April through September and lower values occurred from October through March.

INTRODUCTION

Ground water is the sole source of freshwater for Guemes Island in the northern part of Puget Sound in Washington State, and there is no potential for local surface-water development. Because the population of the island is increasing rapidly, there is concern that the fresh ground-water resource is not adequate to support continued growth and that increased pumpage will adversely affect its availability and quality. The potential for seawater intrusion on Guemes Island is great because parts of the island's two major aquifers are below sea level, the rates of recharge to the aquifers are low, and most wells are in near-shore areas. Seawater intrusion along some of the more densely populated coastal areas of the island has been documented in previous studies (Walters, 1971; Dion and Sumioka, 1984). Arsenic in ground water also is a concern because it has been found at high concentrations in ground water on nearby Lummi Island.

Although some water-quality information was available, a comprehensive assessment of the island's hydrogeology and water chemistry had not been made. Realizing the importance and need for this type of information to properly manage, protect, and (or) develop the local ground-water resource, a group of island residents coordinated efforts to initiate such a study. Consequently, in 1991 the U.S. Geological Survey (USGS) began a ground-water investigation on Guemes Island in cooperation with the Guemes Island Environmental Trust and the Skagit County Conservation District. The results of that study are presented in this report.

The objectives of the study are to:

(1) describe and quantify the ground-water system using existing or readily collectable data;

(2) determine the general chemical characteristics of waters in the major hydrogeologic units;

(3) describe any apparent widespread ground-water-quality problems, including seawater intrusion;

(4) prepare a generalized water budget of the island; and

(5) discuss options for monitoring ground-water quantity and quality based on the results of this study.

Purpose and Scope

This report summarizes the findings of the objectives listed in the Introduction. The topics covered in this report include regional and local geologic history; areal distribution and physical properties of significant hydrogeologic units; basic principles of the hydrologic cycle and ground-water occurrence; precipitation; recharge and discharge of ground water on the island; water-level fluctuations and trends; water budget of the island; seawater intrusion; general chemistry of ground water; and the need for monitoring and additional studies.

Description of the Study Area

Guemes Island is one of numerous islands located in the coastal waters of Washington State. The island covers 8.2 mi^2 in western Skagit County, just north of the city of Anacortes (fig. 1). Other islands in the immediate vicinity include Lummi Island to the north and Cypress Island to the west. The mainland is located to the east and south of Guemes Island. Public access to the island is limited to a county-operated ferry, which runs between Anacortes and Guemes Island.

The southeastern part of Guemes Island is hilly and composed of bedrock; the remainder is a gently rolling plain that is underlain by glacial drift (plate 1). The highest point on Guemes Island, located at the southeastern end of the island, is a bedrock hill 690 feet above sea level. The highest point on the glacial drift plain is about 190 feet.

Precipitation on the island averages about 25 in/yr (U.S. Department of Agriculture, 1965). A small perennial stream flows down the island's steep eastern bedrock slope and discharges into Square Harbor. An intermittent stream, located in a north-south trending valley just west of the bedrock part of the island, flows southward during wet periods. Wetlands exist locally, in poorly drained depressions or in low-lying coastal areas.

The year-round population of the island is about 540, and the summer population nears 2,200. Much of the island has a rural setting with most of the population concentrated along the coast. The more densely populated

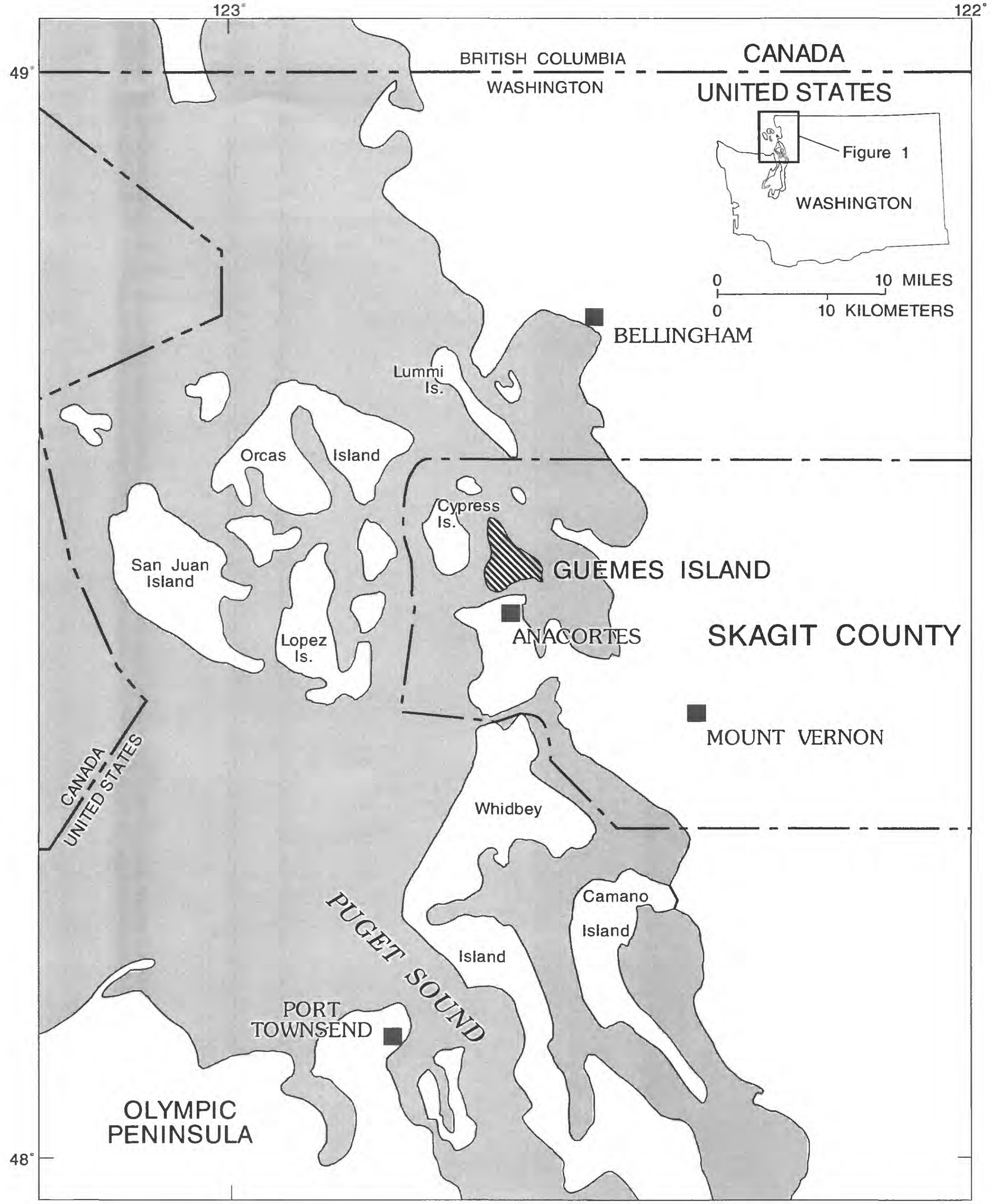


Figure 1.--Location of the study area.

areas on the island, labeled on plate 1, are West Beach, Indian Village, North Beach, Seaway Hollow, Holiday Hideaway, South Shore, and Kelly's Point. Commerce and industry are mostly limited to a small resort at North Beach, a gravel pit, and several small businesses related to arts and crafts, construction trades, or livestock. Domestic water supplies are provided by privately owned wells and 14 small public-supply systems. There are no central sewer systems on the island; waste water is returned to the ground by way of septic tanks and drain fields.

Well- and Spring-Numbering System

In Washington, wells and springs are assigned numbers that identify their location within a township, range, section, and 40-acre tract. Number 35N/01E-12R02 (fig. 2) indicates that the well is in township 35 North (N) and range 1 East (E) of the Willamette base line and meridian. The numbers immediately following the hyphen indicate the section (12) within the township; the letter following the section gives the 40-acre tract of the section, as shown on figure 2. The two-digit sequence number (02) following the letter indicates that the well was the second one inventoried by USGS personnel in that 40-acre tract. An "S" following the sequence number indicates that the site is a spring. In some parts of this

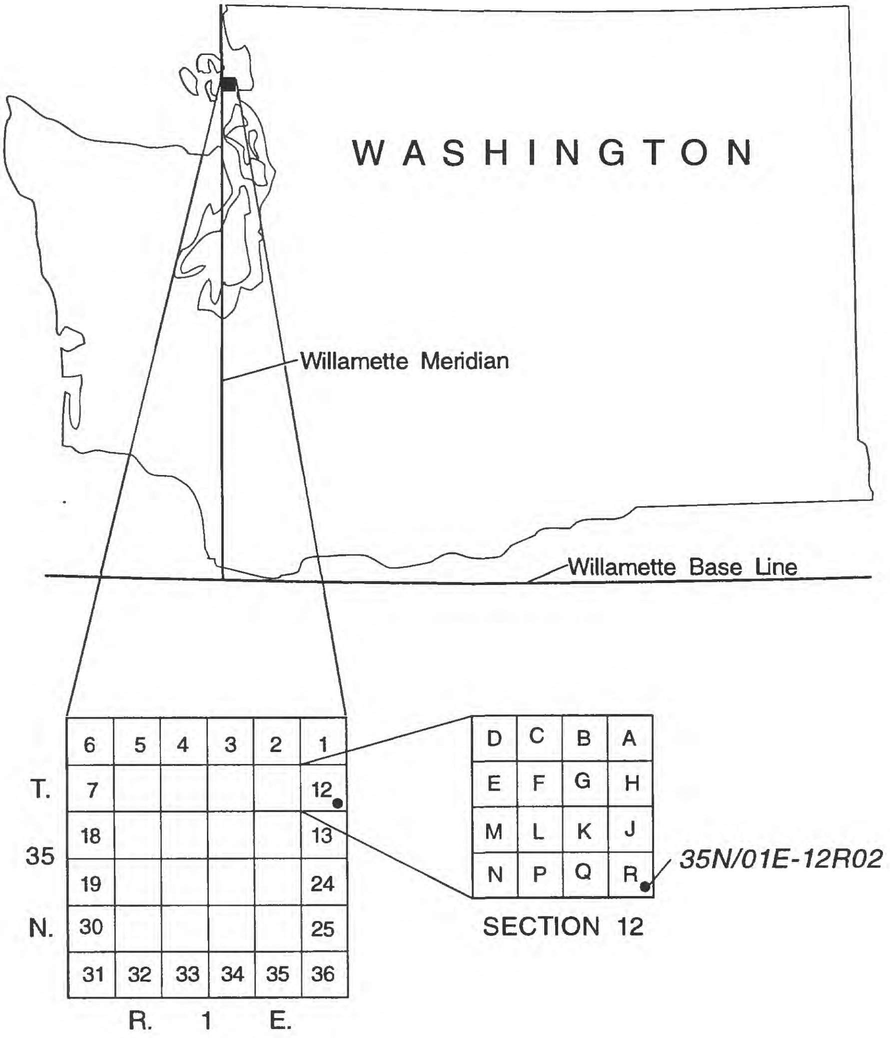


Figure 2.--Well- and spring-numbering system used in Washington.

report, wells and springs are identified individually by only the section and 40-acre tract, such as 12R02, and township and range are shown as a grid.

Acknowledgments

The authors wish to acknowledge the cooperation of the many well owners and tenants who supplied information and allowed access to their wells and land during the field work, and the owners and (or) managers of various water systems who supplied well and water-use data. Geologic interpretations were aided by information provided by Patrick T. Pringle and Connie J. Manson of the Washington Department of Natural Resources Division of Geology and Earth Resources. Two drilling companies, Hayes Drilling, Inc., and Dahlman Pump and Drilling, Inc., were also of assistance in providing and clarifying well logs and records.

STUDY METHODS

The methods used to study and interpret the occurrence and quality of ground water on Guemes Island are discussed in this section. The general approach used to achieve the study objectives included the following items:

(1) inventory wells and principal springs on the island;

(2) construct a net of hydrogeologic sections based on drillers' logs of inventoried wells and existing geologic maps;

(3) delineate vertical and areal extents of hydrogeologic units on the basis of the hydrogeologic sections and drillers' logs of inventoried wells;

(4) estimate hydraulic conductivity values for the hydrogeologic units;

(5) construct water-level contour maps for the principal aquifers and determine general ground-water flow directions;

(6) estimate the annual quantity of ground water withdrawn from the island and describe the uses of that water;

(7) determine an approximate water budget for the island;

(8) describe the general chemical characteristics of the ground water;

(9) identify areas of widespread water-quality problems; and

(10) describe a possible long-term network to monitor ground-water quantity and quality.

Field Inventory

A comprehensive well and spring inventory was conducted in order to locate existing wells and springs with accuracy, to measure the depth to the water surface inside the well, and to make a preliminary assessment of the quality of the water. During October 1991, 111 wells and 1 spring were inventoried, the locations of which are shown on plate 1. Physical and hydrologic data for these sites are contained in Appendix 1. Criteria for site selection included availability of driller's report (obtained from Washington Department of Ecology) having lithologic information and vertical distribution of well openings, and permission from the owner or tenant to inventory the well. All sites were plotted on 1:24,000-scale topographic maps. Altitudes of the land surface at each well head, accurate to plus or minus 10 feet, were determined from those maps. Other information gathered at each site included the name of the landowner or tenant, primary use of the water, the owner's comments about water quality and well yield, surrounding land use, and construction details of the well. The depth to water was measured using a graduated steel tape and is accurate to plus or minus 0.02 foot. Buried well heads or otherwise difficult access precluded water-level measurement in some wells. Water-level altitudes (well-head altitude minus depth to water) presented in this report are accurate only to plus or minus 10 feet because of the uncertainty in the well-head altitudes. A water sample was collected from most sites at the time of inventory and analyzed in the field for chloride concentration and specific conductance. Chloride concentrations were determined using titrimetric tests using mercuric nitrate titrant in acid solution with diphenylcarbazone as the end-point indicator. Specific conductance values were determined with a field conductance meter that was calibrated daily. Out of the 111 wells and 1 spring inventoried, 83 water levels were measured and 83 water samples were analyzed.

Hydrogeology

The generalized map of surficial geology for Guemes Island, shown on plate 1, is based on geologic maps in the Coastal Zone Atlas of Washington, Vol. 2 Skagit County (Washington Department of Ecology, 1978), soil survey maps of Skagit County (U.S. Department of Agriculture Soil Conservation Service, 1989), and lithologic descriptions in drillers' logs from 85 inventoried wells. Descriptions follow of each source of information and evaluations regarding its usefulness and possible limitations.

Geologic mapping for the Coastal Zone Atlas was done in order to evaluate geologic materials along Washington's shorelines for engineering properties, structural relations, and resource potential. The intent of the mapping was to provide land-use planning information in order to avoid land uses incompatible with the area's geology. The mapping was done by geologists of the Washington State Department of Natural Resources (DNR) largely by inspection of shoreline bluffs by boat (G. Thorsen, retired, Washington Department of Natural Resources, oral commun., 1993). Regional geologic maps, aerial photographs, and well drillers' logs also were used. The resulting maps provide a good description of geologic units along and near the coast.

Soil Surveys are maps of surficial soil types that are classified by the steepness of slopes on which the soil occurs, general pattern of drainage, natural or introduced vegetation growing on the soil, and type of bedrock or deposit on which the soil occurs. Although geologic formation names are not part of the classification scheme, it is helpful to know the type of parent material from which the soil has weathered. If, for example, a soil has developed on a clay-rich parent material of glacial origin, the source may be a lacustrine or glaciomarine deposit. On the other hand, soil derived from sand and gravel could indicate glacial outwash as the parent material. It was in this manner that the soil survey of Skagit County was used as an aid in extending the geologic mapping of the Coastal Zone Atlas.

Lithologic logs for field-located drilling sites provided subsurface information on the geologic unit(s) encountered. In most cases the logs verified existing geologic mapping. However, where numerous logs indicated a different type of deposit than was previously mapped, the logs were used to modify the existing maps.

Five hydrogeologic sections (plate 1) were constructed on the basis of lithologic data from drillers' logs and the surficial geologic map. Geologic units were identified and correlated on the basis of grain size, sorting, stratigraphic position, outcrop pattern, and color. The hydrogeologic sections were used to delineate six hydrogeologic units. Using the sections and additional logs of inventoried wells, maps of top (altitude), thickness, and extent of the principal hydrogeologic units were constructed. The lithologic logs of wells used in constructing the hydrogeologic sections are presented in Appendix 2.

Water Quality

Water samples were collected from 24 of the inventoried wells during June 1992. The sampled wells were selected to provide broad geographic coverage and an equal representation of the hydrogeologic units. All samples were analyzed for concentrations of the major constituents, iron, manganese, arsenic, and fecal-coliform and fecal-streptococci bacteria. In addition, field measurements of temperature, specific conductance, pH, alkalinity, and dissolved-oxygen concentration were made at all sites. The sampling and analytical methods used in the water-quality part of this study follow guidelines presented in U.S. Geological Survey Techniques of Water-Resources Investigations (Fishman and Friedman, 1985; Friedman and Erdmann, 1982; Greeson and others, 1977; Wershaw and others, 1987; and Wood, 1981). With the exception of the field parameters, the samples were analyzed at the U.S. Geological Survey's National Water Quality Laboratory (NWQL) in Arvada, Colo.

Of the 24 sampled wells, a subset of 5 samples was analyzed for the trace constituents barium, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc. A second subset of five samples was analyzed to determine concentrations of selected volatile organic compounds. A third subset of 12 samples, collected mostly from wells situated in more populated areas, was analyzed for boron and methylene blue active substances (MBAS), which are constituents found in household waste water. Finally, a fourth subset of samples from five wells was analyzed for concentrations of radon. A sampling matrix, indicating which subset(s) were included for each well and the hydrogeologic unit designation for each well, is shown in table 1. Water-quality data for the June 1992 sampling are contained in Appendixes 6-8.

In addition, water samples from 12 coastal wells were collected monthly from December 1991 through December 1992 to determine seasonal differences or trends in chloride concentration. Samples from this monthly network were analyzed for dissolved chloride concentration and specific conductance at the U.S. Bureau of Reclamation Water Quality Laboratory in Boise, Idaho. Water-quality data for the monthly network are contained in Appendix 5.

***Table 1.**--Sampling matrix indicating analyses performed and hydrogeologic unit of each sample site on Guemes island*

[Hydrogeologic unit: Qsc, Surficial confining unit; Qva, Vashon aquifer; Qw, Whidbey confining unit; Qdb, Double Bluff aquifer; and Br, Bedrock]

Local well number	Hydro-geo-logic unit	Common constituents, iron, manganese, arsenic, and fecal-coliform and fecal-streptococci bacteria	Selected trace constituents	Selected volatile organic compounds	Boron and methylene blue active substances	Radon
35N/01E-01C02	Qva	X				
35N/01E-01D01	Qdb	X				
35N/01E-01M01	Qdb	X	X		X	
35N/01E-01R01	Qdb	X				X
35N/01E-02L01	Qva	X		X	X	
35N/01E-12F01	Qva	X		X	X	
35N/01E-12P03	Qdb	X				
35N/01E-12R02	Qdb	X				
35N/01E-14B02	Qdb	X	X	X	X	X
35N/02E-06E01	Qdb	X				
35N/02E-06G01	Br	X				X
35N/02E-07A01	Qw	X				
35N/02E-07G01	Qsc	X				
35N/02E-07H04	Qw	X			X	
35N/02E-08E02	Br	X	X		X	X
36N/01E-26H01	Qdb	X			X	X
36N/01E-26J01	Qdb	X	X		X	
36N/01E-26P01	Qva	X		X	X	
36N/01E-35F01	Qdb	X				
36N/01E-36C01	Qva	X			X	
36N/01E-36C05	Qva	X		X	X	
36N/01E-36Q01	Qdb	X	X			
36N/02E-31M01	Qdb	X				
36N/02E-31P01	Qdb	X			X	

HYDROGEOLOGY

Geologic Setting

The interpretation of the geologic framework of Guemes Island was based largely on existing data contained in geologic or soil maps (Washington Department of Ecology, 1978, and U.S. Department of Agriculture Soil Conservation Service, 1989), scientific publications (McLellan, 1927; Easterbrook and others, 1967; Easterbrook, 1969; Blunt and others, 1987; Brandon and others, 1988; Brandon, 1989; and M. A. Jones, U.S. Geological Survey, written commun., 1994), and drillers' lithologic descriptions. The geologic units recognized during this study are referred to by formal geologic names, and corresponding map symbols, or by informal names of most common usage (Easterbrook, 1968; Dion and others, 1994; and Turney and others, 1995). The reader is referred to Kruckeberg (1991) for a description of the regional geology and natural history of the Puget Sound region in general, and to Oldow and others (1989) for a thorough description of the geologic evolution of the western part of the North American continent.

The geology of Guemes Island is illustrated on plate 1 by hydrogeologic sections and a map of surficial geology. Eight geologic units were identified: consolidated bedrock (Br), Double Bluff Drift (Qdb), Whidbey Formation (Qw), Vashon advance outwash (Qva), Vashon till (Qvt), Everson drift (Qe), peat (Qp), and beach deposits (Qb). The hydrogeologic sections indicate that there is considerable variation in the thickness of individual units, and that not all units are necessarily present at any one location. In general, younger unconsolidated deposits are more easily recognized and correlated because of surface or near-surface exposures and the fact that they have not undergone as much erosion and (or) burial as older deposits.

Bedrock is exposed only on the southeastern end of the island and is composed of locally fractured igneous and fine-grained marine sedimentary rocks of Middle Jurassic to Early Cretaceous age. Depth to bedrock (thickness of unconsolidated deposits) is largely unknown, but ranges from 0 feet to greater than 300 feet according to a map of thickness of unconsolidated deposits in the Puget Sound Lowland (M. A. Jones, U.S. Geological Survey, written commun., 1994).

The Double Bluff Drift is composed of till, glaciomarine drift, glaciofluvial sand and gravel, and glaciolacustrine silt and is named for an exposure at Double Bluff on Whidbey Island. It is the oldest and deepest unconsolidated deposit that has been encountered by drilling on Guemes Island. The Double Bluff Drift was deposited during the Pleistocene, from about 250,000 to 100,000 years ago. It is exposed at or near sea level in sea cliffs on the northern tip of the island and at two locations along the southern shoreline.

The Whidbey Formation consists of floodplain clay, silt, peat, and lenses of sand that accumulated on top of the Double Bluff Drift during the last major interglacial period in the Puget Sound Lowland. This Pleistocene unit was deposited during a time characterized by a warm climate, from about 100,000 to 90,000 years ago. On Guemes Island the unit is exposed only in sea cliffs.

The next youngest deposits found on Guemes Island are considerably younger than the Whidbey Formation. About 18,000 years ago, the final and most recent glaciation, referred to as the Vashon Stade of the Fraser Glaciation, began when ice slowly advanced southward from Canada and blanketed the entire Puget Lowland. This glaciation resulted in three deposits on Guemes Island: Vashon advance outwash, Vashon till, and Everson drift. Vashon advance outwash consists of sand and gravel and is exposed along the western edge of Guemes Island and in a small gravel pit located near the north-central part of the island where overlying till has been removed. Vashon till is a compact mixture of clay, silt, sand, gravel, and boulders that occurs at land surface over much of the island.

Everson drift consists of pebbly clay and silt referred to as glaciomarine drift. It was deposited about 13,000 years ago when the ice of the final glaciation had thinned sufficiently to allow marine water back into the Puget Lowland and float the remaining ice; the progressive melting of the ice resulted in the deposition of the unit. On Guemes Island, Everson drift occurs mostly in low-lying areas.

At the end of the Pleistocene Epoch, about 10,000 years ago, the melting glacier had retreated back to near the United States-Canada border. Geologic processes dominating the Puget Lowland since that time include erosion and (or) deposition by wind, waves, and flowing water.

Two units are still being deposited on Guemes Island: peat and beach deposits. Peat, composed of partially decomposed and disintegrated organic matter, occurs in poorly drained low-lying areas. Beach deposits consist of sand and gravel that are weathered from sea bluffs or that have accumulated above high tide as a result of longshore drift, the wave-generated movement of sand or gravel parallel to the shore. Considerable amounts of beach deposits have accumulated at North Beach and West Beach.

Conceptual Model of the Hydrogeologic System

Water circulates continuously between the ocean, the atmosphere, and the earth's surface in a process known as the hydrologic cycle (fig. 3). Water in the atmosphere condenses to form clouds and eventually falls to the earth's surface as rain or snow. Part of the rain and snowmelt runs off to roadside drainage ditches, streams, ponds or marshes, or directly back to the sea; part infiltrates the ground, and part is evaporated back to the atmosphere from the soil and from free-water surfaces such as ponds. Some of the water entering the soil is drawn up by plant roots and is returned to the atmosphere by transpiration from leaves. Some of the water that enters the ground continues to percolate downward to the water table. A part of the ground water may return to the land surface by seepage to ponds, marshes, streams, and springs located along coastal bluffs. A small quantity is also withdrawn by wells. The rest of the ground water discharges by sub-sea outflow.

On islands, fresh ground water commonly occurs as a lens-shaped body that "floats" above the denser, more saline ground water (fig. 3). The thickness of this lens usually decreases from the center of an island toward its coast. Areally, ground water in an island environment generally moves radially from its area of recharge toward the coast; the approximate directions of ground-water flow are shown with arrows in figure 3. The bounding surface between the fresh and salty ground water, commonly referred to as the freshwater-seawater interface, actually is a zone of diffusion, or mixing.

The simplified conceptual model of the ground-water system of Guemes Island shown in figure 3 includes an assemblage of permeable units (sand and gravel) and less-permeable units (till, clay, silt, bedrock, and fine-grained bottom deposits of Puget Sound). Older unconsolidated material (undifferentiated deposits) may occur beneath these units and above bedrock. Bedrock is not considered a principal transmitter of water because it is poorly permeable compared with the sand or gravel deposits.

Occurrence of Ground Water

Saturated geologic materials can be considered either as water yielding or non-water yielding. An aquifer is defined as a saturated geologic material that is sufficiently permeable to yield water in significant quantities to a well or spring. Generally, well-sorted, coarse-grained deposits have higher permeabilities than do fine-grained or poorly sorted deposits. In the Puget Lowland, saturated glacial outwash and coarse-grained alluvium yield water to wells at high rates (10 to more than 1,000 gal/min), whereas glacial till, lacustrine deposits, glaciomarine drift, and bedrock generally yield water at much lower rates.

The manner of occurrence of ground water in consolidated bedrock differs greatly from that in unconsolidated deposits. In dense consolidated rock such as that found on Guemes Island, the principal movement of water is through interconnected fractures. In unconsolidated materials, such as sand or gravel, water moves through pore spaces separating the individual particles. Water moves more easily through the larger spaces within deposits of well-sorted sand or gravel than through the much smaller spaces between clay and silt particles or through poorly sorted materials such as till.

Ground water can occur under two general hydrologic conditions (fig. 4). Where water only partly fills an aquifer, the upper surface of the saturated zone (the water table) rises and falls with changes in recharge and discharge. In this situation, the ground water is said to occur under unconfined or water table conditions. The position of the water table is determined by measuring water levels in many wells open to the unconfined aquifer near the water table. Where water completely fills an aquifer that is overlain by a confining zone of less permeable materials, such as an extensive layer of clay, ground water is said to occur under confined or artesian conditions. Water levels in wells that tap a confined aquifer are above the top of the confined aquifer. The height to which water will rise in a well completed in a confined aquifer defines the water pressure or head at that location. The distribution of head defines the potentiometric surface. If the head is sufficient to raise the water level within the well above the top of the well, water will flow from the well and the well is called a flowing artesian well. Both the potentiometric surface and water table fluctuate in response to recharge and discharge of ground water. The direction of the slope (gradient) of the surfaces indicates the general direction of ground-water movement.

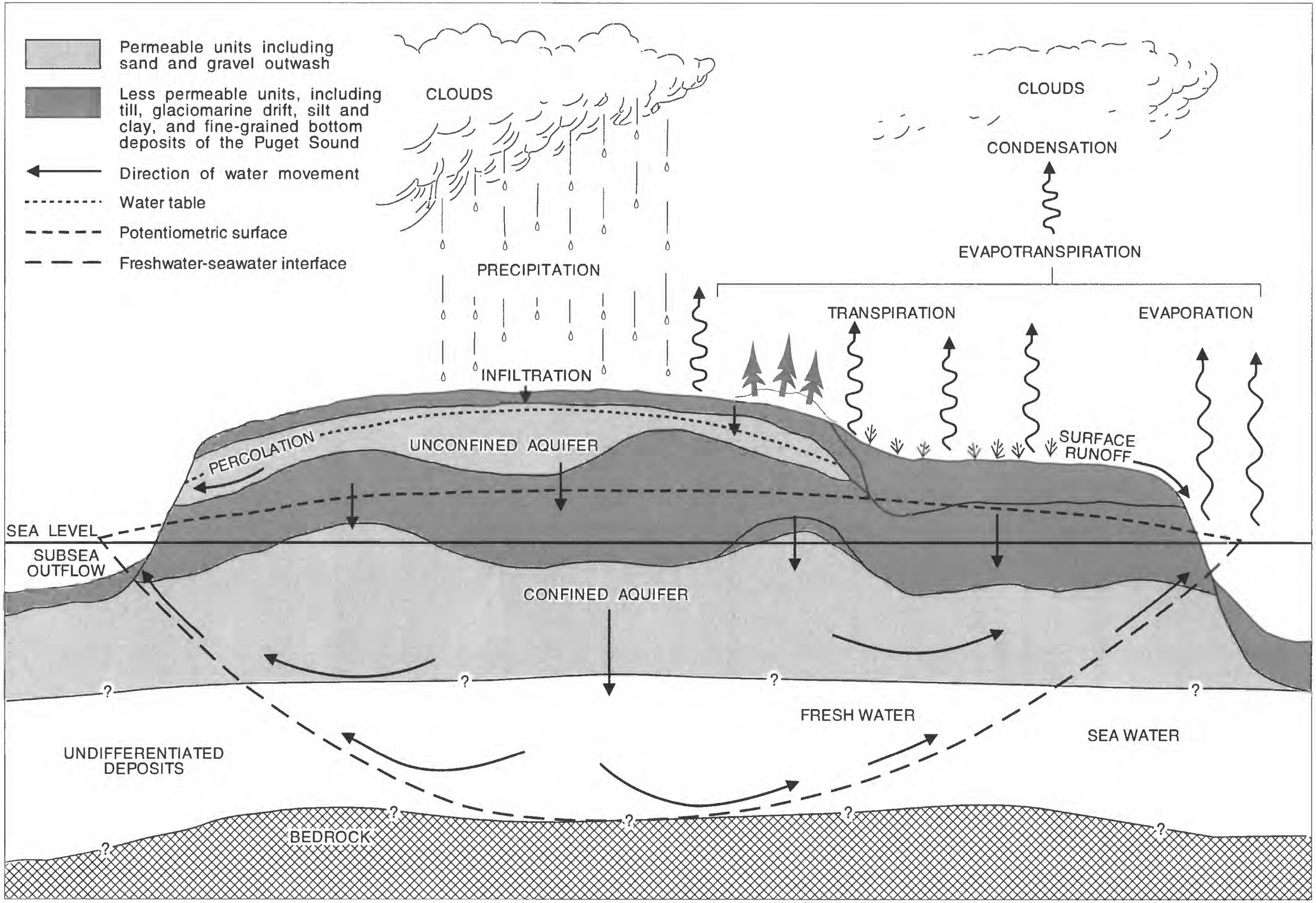


Figure 3.--Simplified conceptual model of hydrologic conditions on Guemes Island.

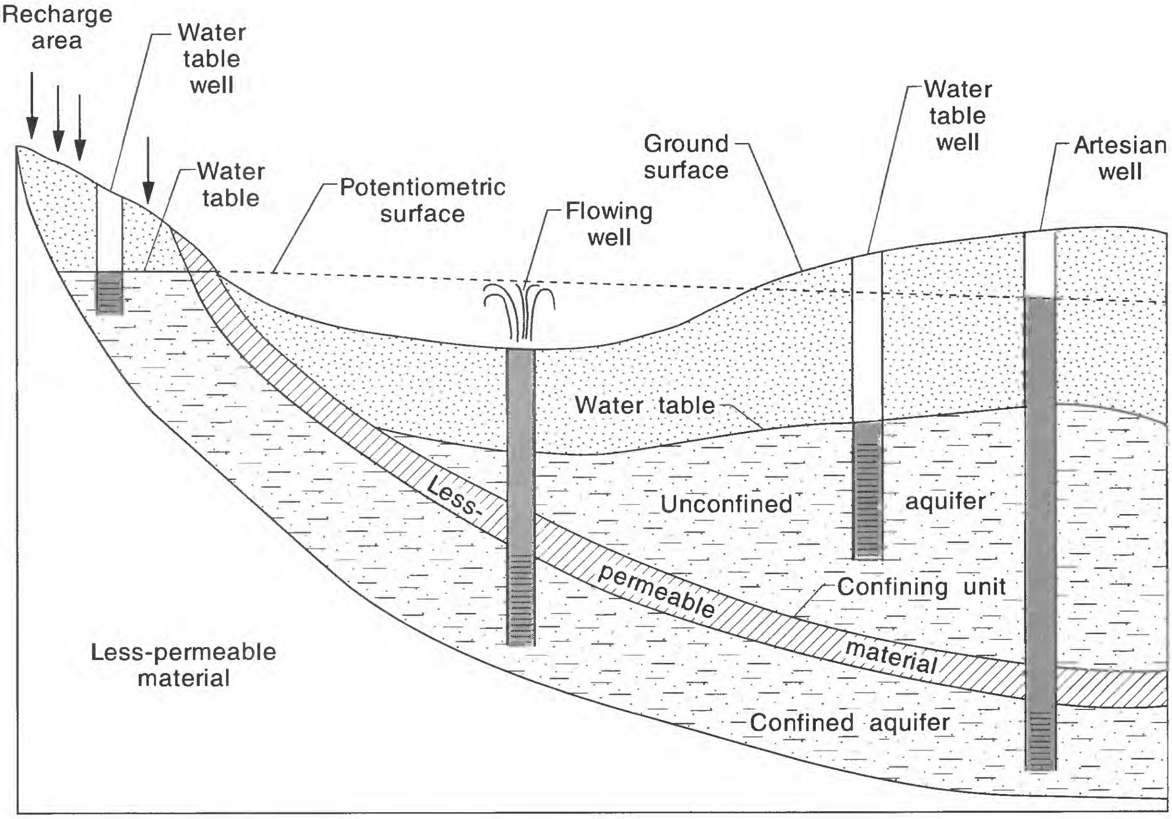


Figure 4.--Unconfined and confined ground-water conditions. (Modified from Todd, 1980.)

Hydrogeologic Units

The geologic units described previously were differentiated into six hydrogeologic units, based on their areal extent and general water-yielding properties. The hydrogeologic units identified on Guemes Island, and described in figure 5 are, from youngest to oldest:

Beach aquifer (Qb),

Surficial confining unit (Qsc),

Vashon aquifer (Qva),

Whidbey confining unit (Qw),

Double Bluff aquifer (Qdb), and

Bedrock confining unit (Br).

With the exception of the surficial confining unit (Qsc), the hydrogeologic units listed above are nearly equivalent to the geologic units for which they are named.

The Beach aquifer consists of sand and gravel that has accumulated at the coast as a result of longshore drift. Only two inventoried wells are completed in this unit. The thickness of the unit is estimated to be 10 to 20 feet.

The surficial confining unit is composed of the Vashon till and the Everson drift. Five inventoried wells, tapping productive lenses, are completed in this unit. This poorly permeable unit occurs at the surface over most of the island at altitudes ranging from near sea level to more than 280 feet (fig. 6). Its thickness ranges from about 20 feet to more than 200 feet in the south-central part of the island (fig. 7).

The Vashon aquifer consists of partly saturated sands and gravels. The top of the unit ranges from approximately 40 to 120 feet above sea level (fig. 8). As illustrated in figure 9, the unit occurs in two separate areas,

Hydrogeologic unit and unit label	Typical thickness (feet)	Lithologic and hydrologic characteristics	Number of inventoried wells completed in unit	Geologic unit and unit label	Epoch and age (age in Ma--million years before present)
Beach aquifer (Qb)	10-20	Discontinuous sand and gravel. Quality of water is mostly unknown, but may be affected by septic systems, organic matter in swampy areas, sea spray, or seawater intrusion. Unconfined aquifer.	2	Beach deposits (Qb)	Holocene (0.01 Ma to present)
Surficial confining unit (Qsc)	20-200	Low-permeability unit consisting of compacted sand, gravel, silt, and clay (till) and pebbly clay and silt (glaciomarine drift); overlain by peat in poorly drained depressions. Unit contains some water-bearing lenses.	5	Peat (Qp) Everson Drift (Qe) Vashon till (Qvt)	Pleistocene (1.6 to 0.01 Ma)
Vashon aquifer (Qva)	40-100	Sand and gravel, mostly under water-table (unconfined) conditions. Unit is not fully saturated in most areas. Springs occur where unit is exposed along coastal bluffs. Quality of water is affected by seawater intrusion in some areas.	28	Vashon advance outwash (Qva)	
Whidbey confining unit (Qw)	40-130	Generally clay, silt, fine-grained sand of low permeability and peat of floodplain origin with local occurrences of till at its base. Unit contains water-bearing lenses.	17	Whidbey Formation (Qw)	
Double Bluff aquifer (Qdb)	Unknown	Sand and gravel. Commonly occurs at or below sea level. Quality of water is affected by seawater intrusion in some areas. Confined aquifer.	54	Double Bluff Drift (Qdb)	
Bedrock (Br)	- -	Mostly igneous and fine-grained sedimentary rocks. Locally yields water where rocks are fractured. Well yields are small.	5	Bedrock (Br)	Middle Jurassic to Early Cretaceous (187 to 98 Ma)

Figure 5.--Lithologic and hydrologic characteristics of the hydrogeologic units on Guemes Island, Washington.

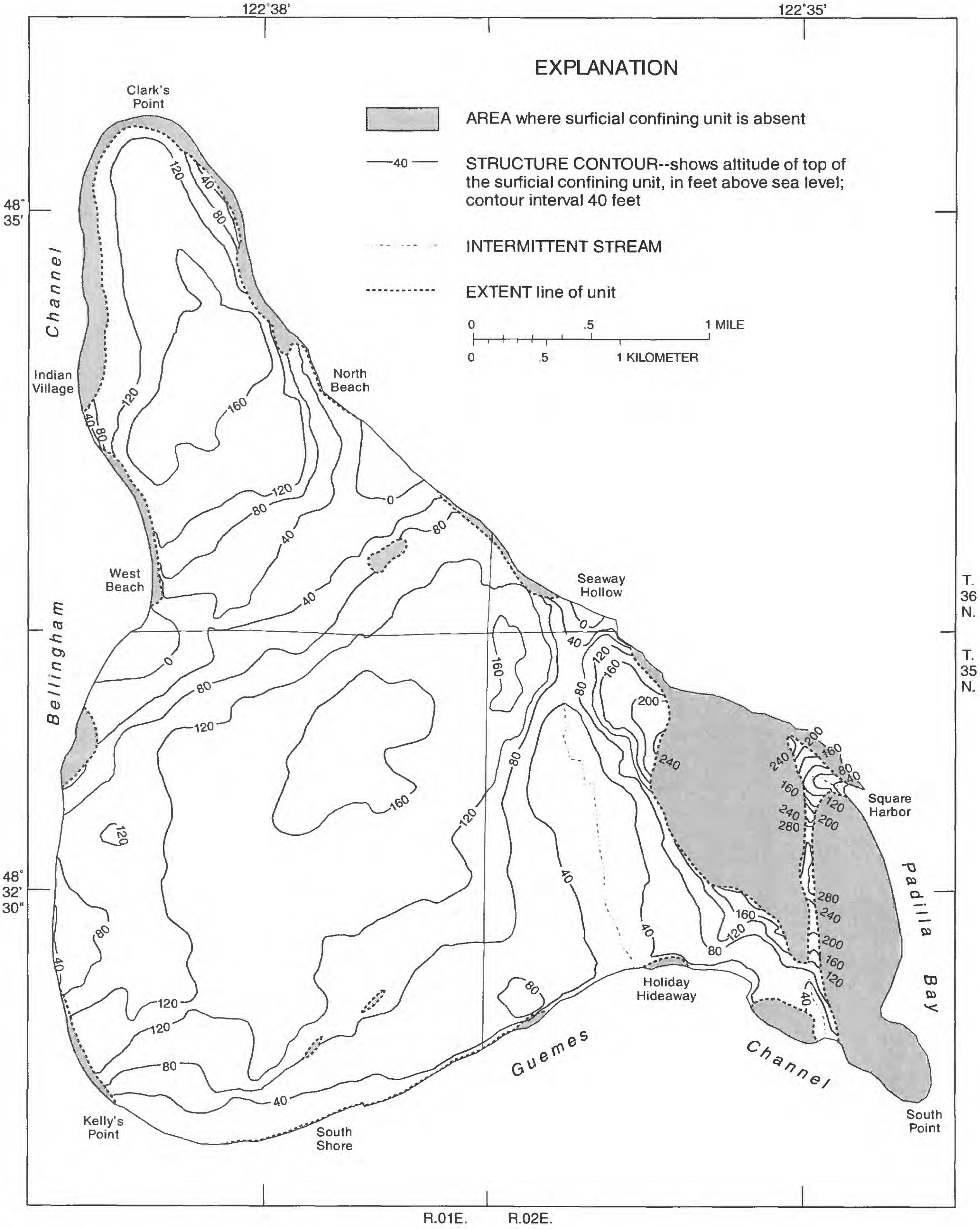


Figure 6.--Extent and altitude of the top of the surficial confining unit.

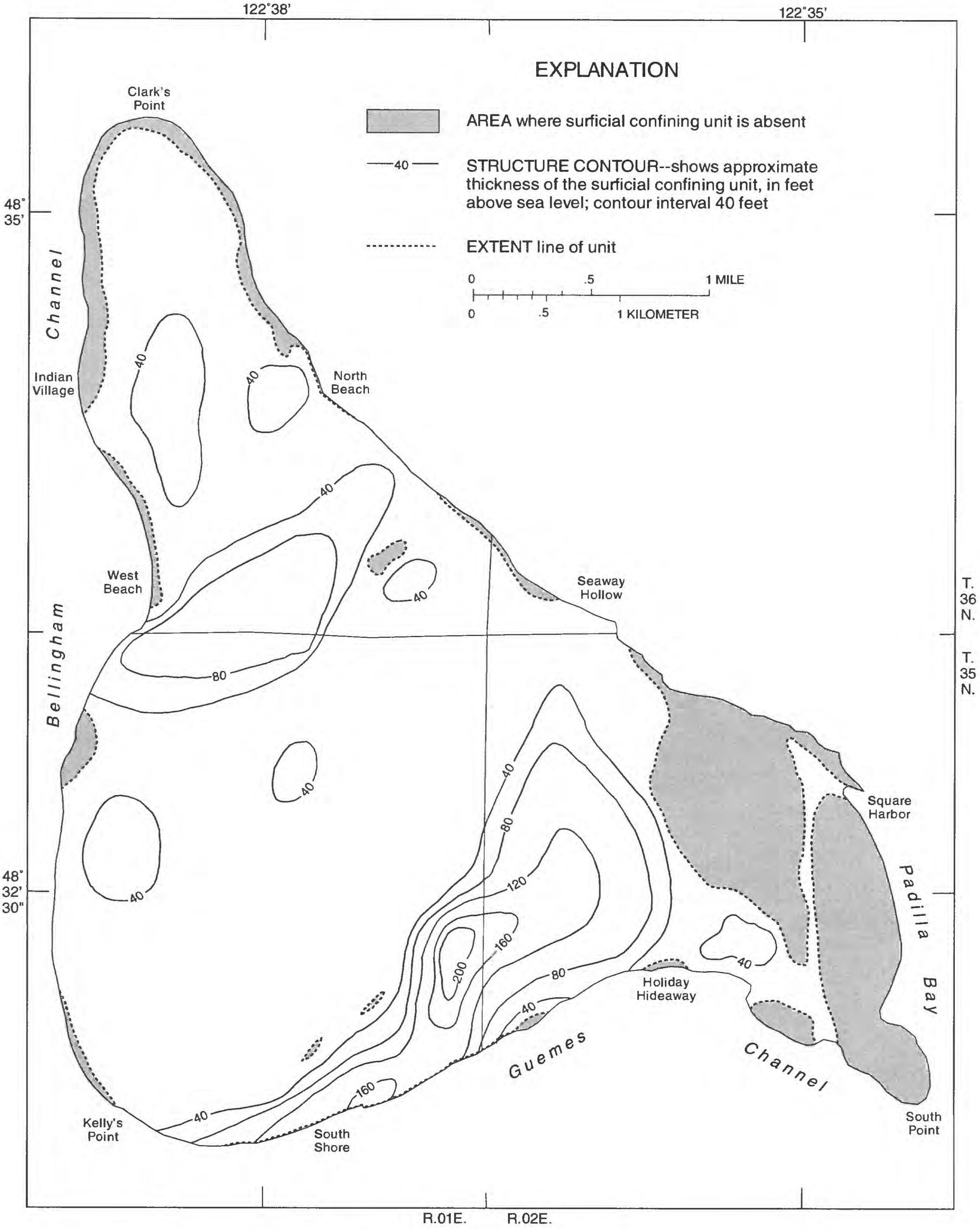


Figure 7.--Extent and thickness of the surficial confining unit.

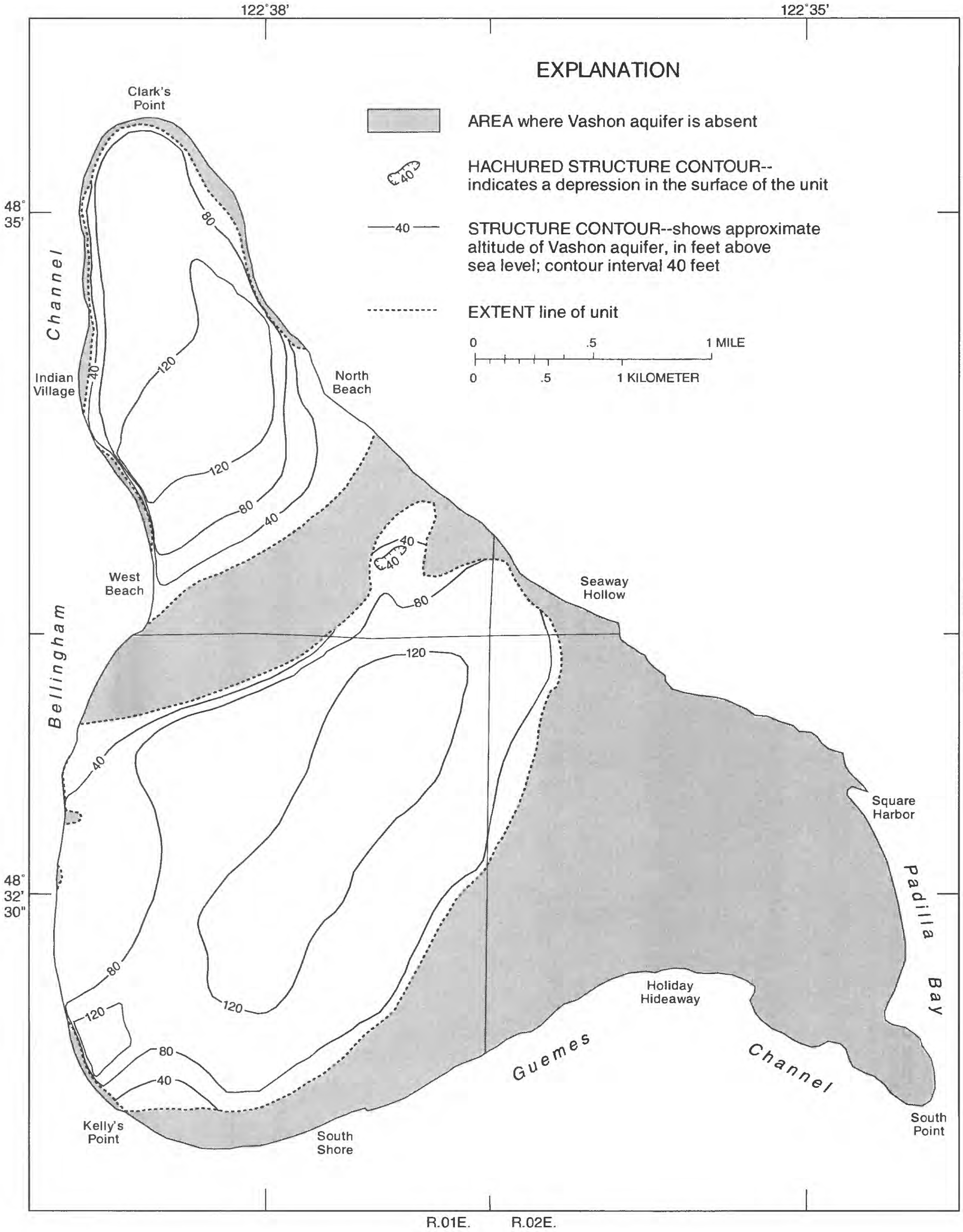


Figure 8.--Extent and altitude of the top of the Vashon aquifer.

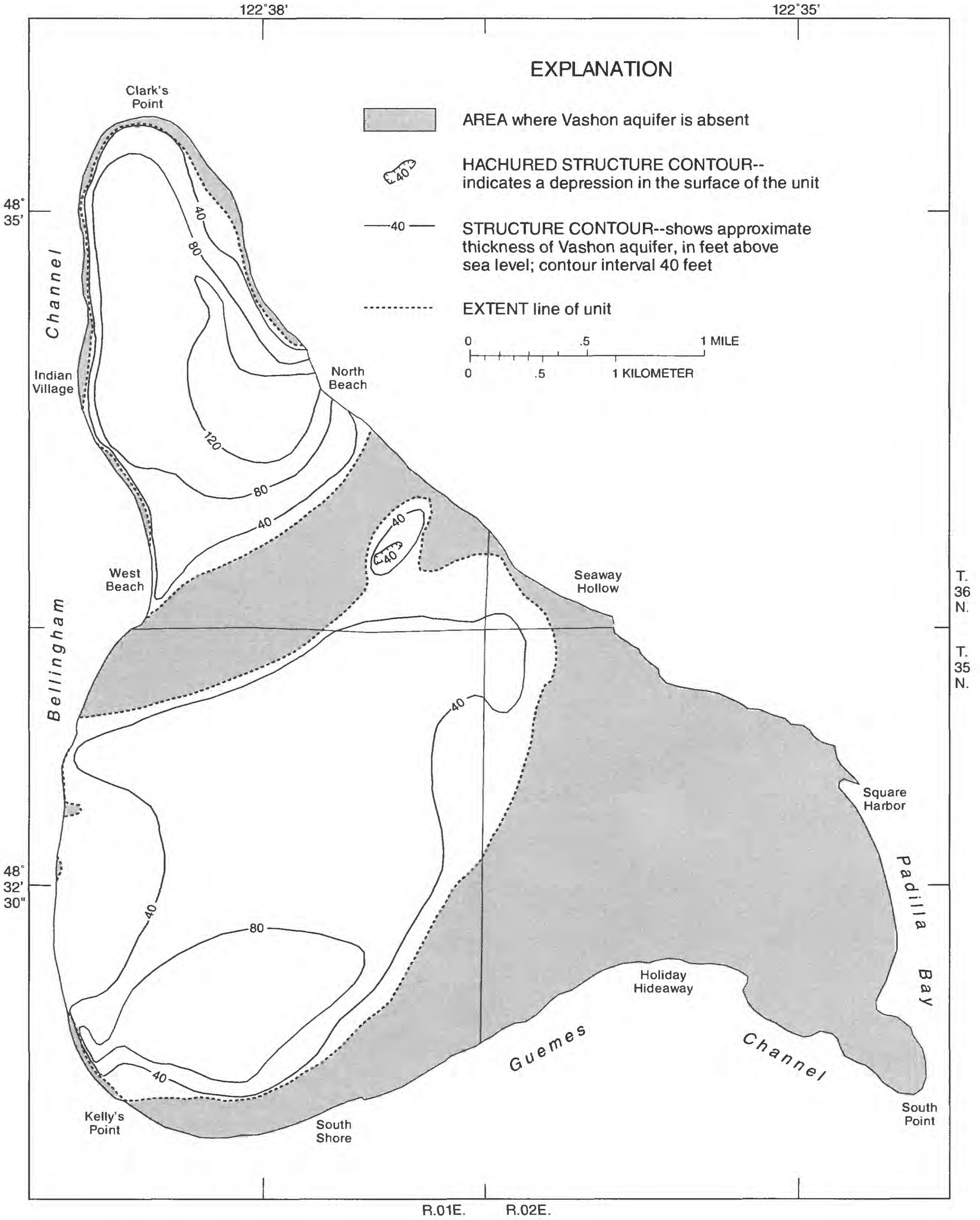


Figure 9.--Extent and thickness of the Vashon aquifer.

rather than islandwide. The thickness of the unit is commonly 40 to 80 feet, with a maximum thickness slightly greater than 120 feet on the northern part of the island (fig. 9).

The Whidbey confining unit is composed mostly of floodplain clay, silt, fine-grained sand, and peat. A poorly permeable layer of till at the top of the underlying Double Bluff Drift is included with this unit because it has similar hydrologic properties. Generally, the unit is poorly permeable, but it locally contains productive sand lenses; 17 inventoried wells tap productive zones within this unit. The top of the unit ranges from approximately 80 feet above sea level to 80 feet below sea level (fig. 10). The unit occurs at depth throughout much of the island and is commonly 40 to 130 feet thick (fig. 11).

The Double Bluff aquifer consists of sand and gravel outwash and underlies all but the eastern end of the island. In terms of use, the Double Bluff aquifer is the principal aquifer on the island--about half of the inventoried wells on the island obtain water from this unit. The top of the unit ranges from approximately 40 feet above sea level to approximately 160 feet below sea level (fig. 12). The total thickness of the unit is unknown because drilling generally stops once the unit is penetrated sufficiently to yield water at required rates--commonly 10 to 15 feet below the top of the unit.

The bedrock confining unit is composed of igneous and fine-grained marine sedimentary rocks. Locally it can yield water where the rocks are faulted or fractured, but yields are generally small. Only five inventoried wells, all located on the southeastern end of the island, are completed in this unit. They range in depth from 80 to 403 feet and their yields range from 0.25 to 7 gal/min.

An estimate of the horizontal hydraulic conductivity of each hydrogeologic unit is helpful in understanding the movement and availability of water within the unit. Hydraulic conductivity is a measure of a material's ability to transmit water and is dependent on the size, shape, and arrangement of the particles in unconsolidated materials, or on the degree of fracturing in consolidated bedrock. Because these characteristics vary greatly within each hydrogeologic unit on Guemes Island, hydraulic conductivity values also are expected to vary greatly.

Values of horizontal hydraulic conductivity were estimated for each unit on the basis of the specific capacity of wells completed in that unit. The specific capacity of a well is the ratio of its discharge (yield) to its total drawdown (static water level minus pumping water level). Although more precise methods are available, they require aquifer-test data and (or) analyses of core samples of the unit. Only data from those wells that had a driller's log containing discharge rate, time of pumping, drawdown, static water level, well-construction data, and lithologic log were used.

Two different sets of equations were used to estimate hydraulic conductivity, depending on how the well was finished. For wells that had a screened, perforated, or open-hole interval (a section of a well, usually in bedrock, where no casing or screen exists), the modified Theis equation (Ferris and others, 1962) was first used to estimate transmissivity values. The Theis equation is:

$$s = \frac{Q}{4\pi T} \ln \frac{2.25\ Tt}{r^2 S} \qquad (1)$$

where

s = drawdown in the well, in feet;

Q = discharge, or pumping rate, of the well, in ft^3/d;

T = transmissivity of the hydrogeologic unit, in ft^2/d;

t = length of time the well was pumped, in days;

r = radius of the well, in feet; and

S = storage coefficient, a dimensionless number.

A computer program was used to solve the equation for transmissivity (T) using Newton's iterative method (Carnahan and others, 1969). Next, the following equation was used to calculate horizontal hydraulic conductivity:

$$K_h = T/b \qquad (2)$$

where

K_h = horizontal hydraulic conductivity of the hydrogeologic unit, in ft/d;

T = transmissivity, as calculated above; and

b = thickness of the hydrogeologic unit, in feet, approximated using the length of the open interval as reported in the driller's report.

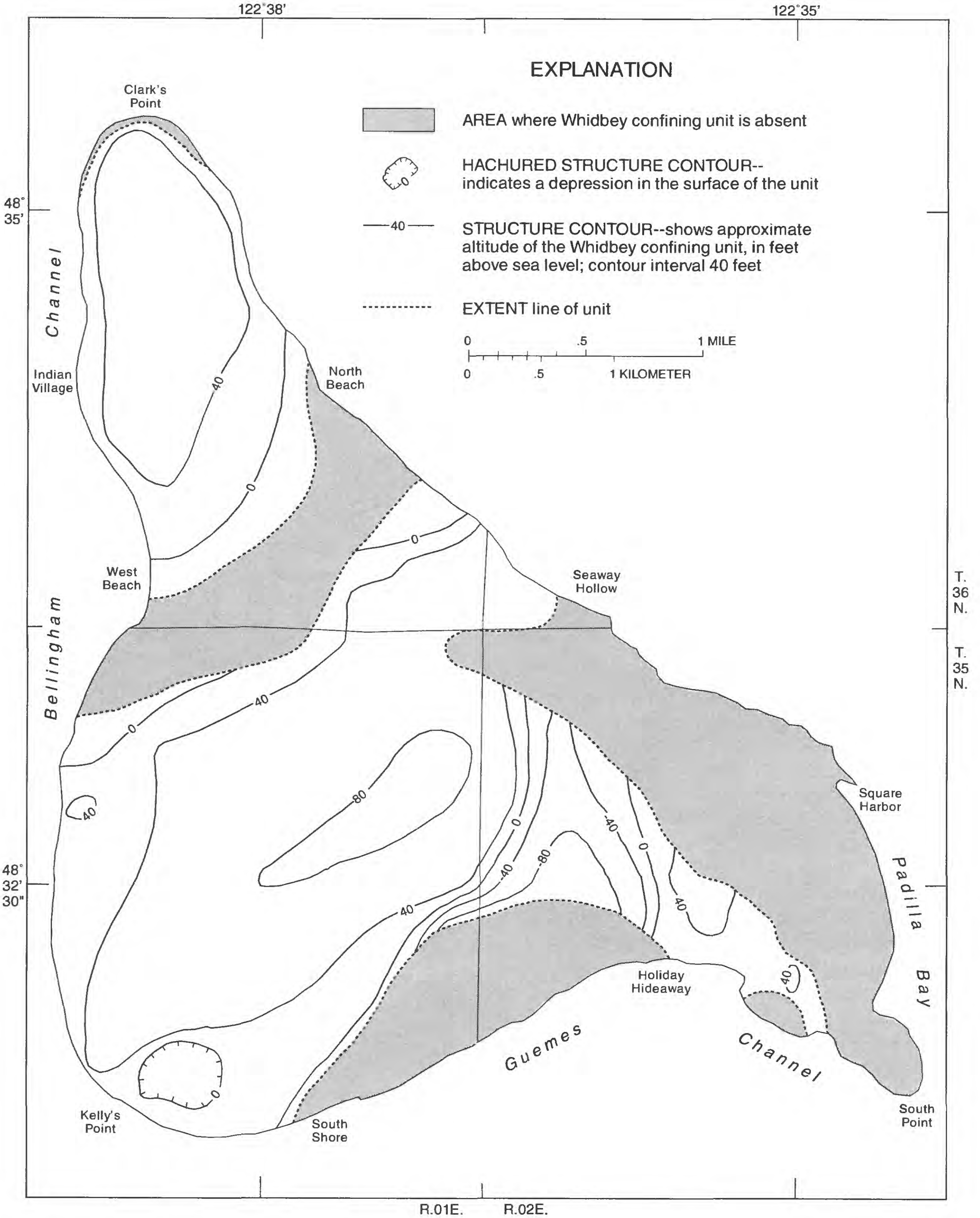


Figure 10.--Extent and altitude of the top of the Whidbey confining unit.

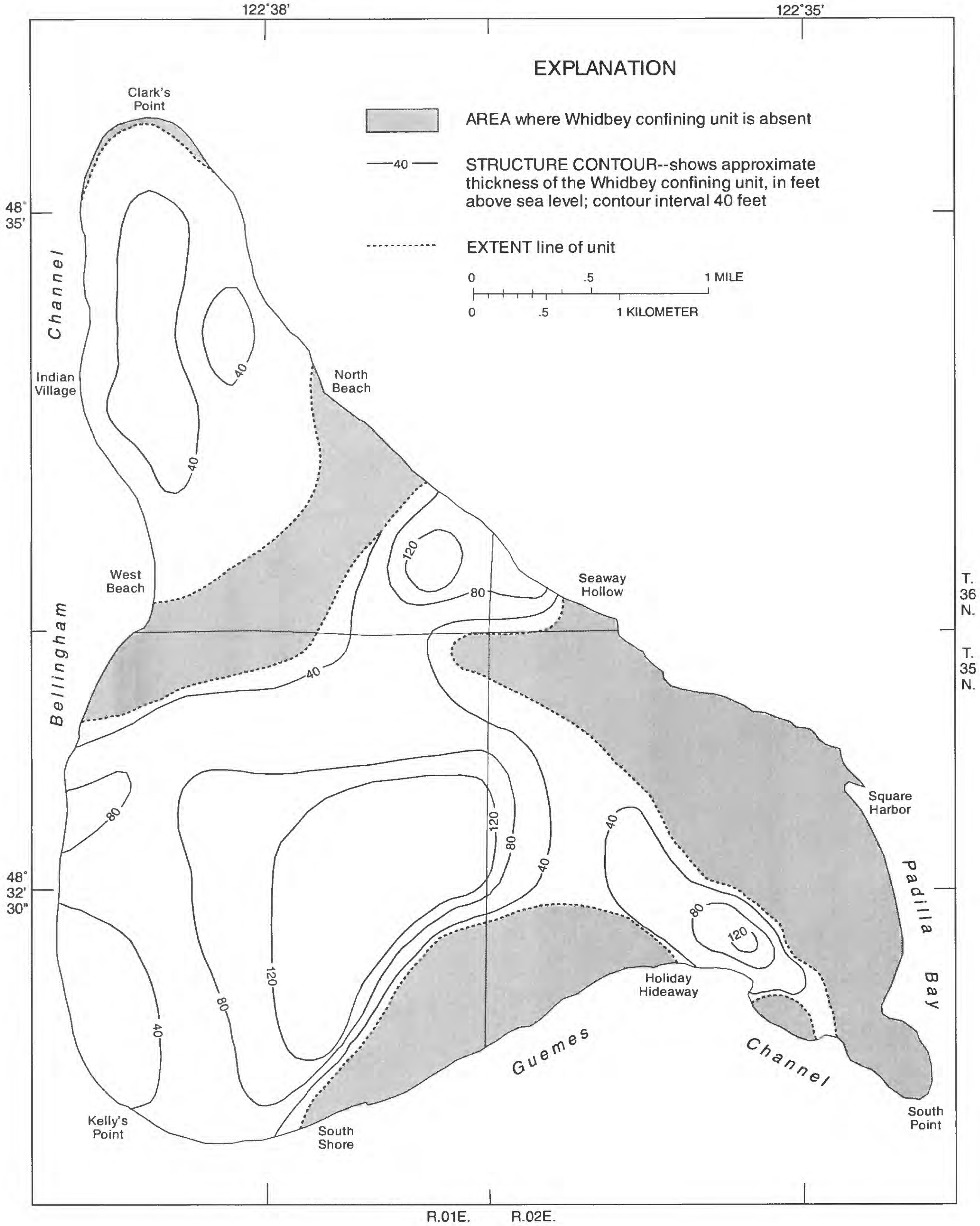


Figure 11.--Extent and thickness of the Whidbey confining unit.

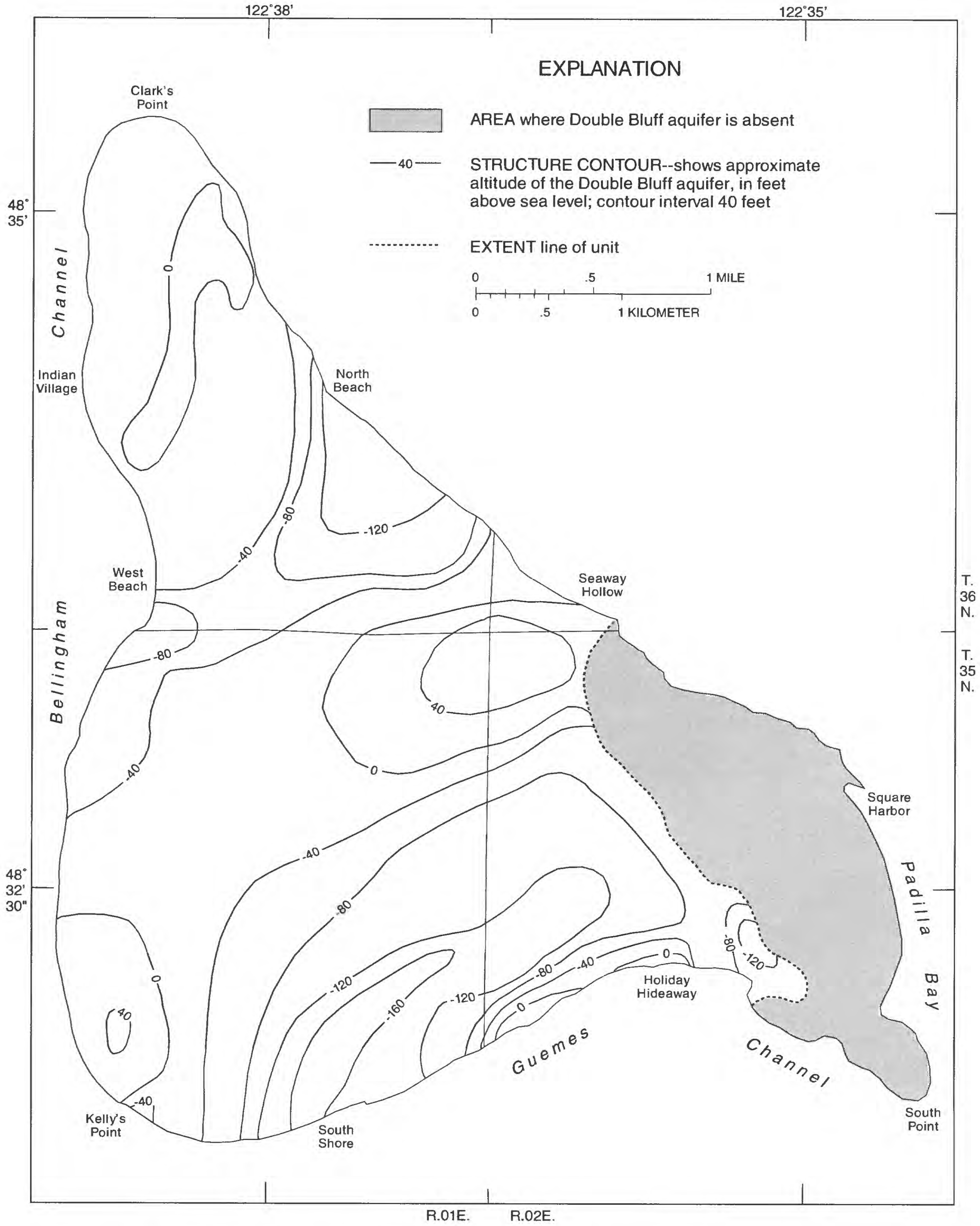


Figure 12.--Extent and altitude of the top of the Double Bluff aquifer.

The use of the length of a well's open interval to approximate the thickness of a hydrogeologic unit may overestimate values of K_h. Nevertheless, this approximation is necessary because the equations used assume that virtually all flow of water to the well is horizontal. Horizontal flow is much greater than vertical flow in most unconsolidated deposits because the materials typically are layered.

A second equation was used to estimate hydraulic conductivities for wells having only an open end, and thus no vertical dimension to the open interval. Bear (1979) provides an equation for hemispherical flow to an open-ended well just penetrating a hydrogeologic unit. When modified for spherical flow to an open-ended well within a unit, the equation becomes

$$K_h = \frac{Q}{4\pi sr} \qquad (3)$$

where

K_h = horizontal hydraulic conductivity of the hydrogeologic unit, in ft/d;

Q = discharge, or pumping rate of the well, in ft^3/d;

s = drawdown in the well, in feet; and

r = radius of the well, in feet.

Equation 3 is based on the assumption that flow can occur equally in all directions; specifically, that horizontal and vertical hydraulic conductivities are equal. As discussed above, this is not likely to be true for unconsolidated deposits. However, the errors associated with violating this assumption are likely to be less than those that would occur in trying to fit the Theis equation to the open-ended well geometry.

Individual values of hydraulic conductivity are reported in Appendix 1 and are summarized statistically for Qsc, Qva, Qw, and Qdb in table 2. Specific-capacity data were unavailable for Qb and Br. With the exception of Qsc, the median hydraulic conductivity values presented in table 2 are similar in magnitude to values reported by Freeze and Cherry (1979) for similar materials. Of significance in table 2 is the fact that the median values for the aquifers, 43 ft/d for Qva and 68 ft/d for Qdb, are similar. Although specific-capacity data were available for only one inventoried well completed in Qw, the estimated hydraulic conductivity value of 1.6 ft/d is reasonable for a semi-confining unit. The median value of 23 ft/d for Qsc, on the other hand, is probably skewed upward by the small data set (two wells) and the fact that data for confining beds are usually available only for areas where lenses of productive material exist. Hydraulic conductivity values for Qb would be expected to be similar to those for Qva and Qdb, whereas values for the bedrock would be expected to be much smaller. Median horizontal hydraulic conductivity values for bedrock have been found to be less than 1 ft/d in recent ground-water studies conducted in the Puget Lowland (S. E. Cox and G. L. Turney, USGS, written commun., 1993).

Precipitation and Recharge

In order to determine the areal and temporal distribution of precipitation, six precipitation gages were installed at various locations on the island in September 1991 and were visited and read weekly from October 1991 through

***Table 2.**--Summary of horizontal hydraulic conductivity values on Guemes Island, by hydrogeologic unit*

[--, not determined; Hydrogeologic unit: Qsc, Surficial confining unit; Qva, Vashon aquifer; Qw, Whidbey confining unit; and Qdb, Double Bluff aquifer]

		Hydraulic conductivity (feet per day)				
Hydrogeologic unit	Number of wells	Minimum	25th percentile	Median	75th percentile	Maximum
Qsc	2	16	--	23	--	30
Qva	10	9.5	25	43	130	900
Qw	1	--	--	1.6	--	--
Qdb	22	1.3	10	68	140	1,200

December 1992. Gage locations were selected in order to obtain good geographic and topographic distribution across the island. Precipitation during 1992 ranged from 26.47 to 31.88 inches for the six stations. The total precipitation for 1992 at the nearest established weather station, in Anacortes, Wash., was 30.17 inches (National Oceanic and Atmospheric Administration, 1992). Monthly precipitation values at the six Guemes Island stations, tabulated in Appendix 3, were generally similar to values from Anacortes (fig. 13).

Average annual precipitation across Guemes Island ranges from approximately 22 in/yr on the west-central part of the island to approximately 28 in/yr on the easternmost part of the island (fig. 14). Average annual precipitation for the island is about 25 inches.

Precipitation measured at the Anacortes station during 1992 was 14.7 percent higher than the station's 32-year mean (26.31 inches; J. Ashby, Desert Research Institute, Western Regional Climate Center, written commun., 1993). In order to prepare a map showing the areal distribution of precipitation during an average year, the total 1992 precipitation observed at each of the six island stations was reduced by 14.7 percent and plotted on the map, and then the values were contoured.

Recharge of freshwater to the ground-water system of Guemes Island is primarily from infiltration of rainfall. Recharge from septic-field leachate and excessive irrigation of lawns and gardens is relatively small. Precipitation recharges everywhere on the island except where ground water is discharging, such as from springs. Most of the recharge occurs in the wet winter months from November through February, when precipitation greatly exceeds evapotranspiration.

The approximate quantity of freshwater recharge to the hydrologic system of Guemes Island was estimated by using relations derived from work in southwestern King County, Wash., by D. G. Woodward (written commun., 1995). These relations are based on the application of a deep percolation (recharge) model developed by Bauer and Vaccaro (1987) that estimates percolation below the root zone. Regression equations determined for King County showed that precipitation and surficial geology were the most important variables in estimating recharge.

The relation of precipitation and ground-water recharge for outwash and till in King County is shown in figure 15. These curves are considered to apply to other areas of the Puget Lowland, including Guemes Island, where geology, vegetation, and climate are similar. The percentage of precipitation going to ground-water recharge decreases as average annual precipitation decreases. To estimate recharge for areas receiving less than 30 inches, the curves were extrapolated, as indicated by the dashed sections of the till and outwash curves in figure 15. Finally, because data existed only for generalized outwash and till in King County, estimates needed to be made for the specific geologic units exposed at land surface on Guemes Island. The Vashon outwash (Qva), the Double Bluff Drift (Qdb), and the Beach deposits (Qb) were assumed to have lithologic and hydrologic characteristics similar to the generalized outwash. Likewise, the Vashon till (Qvt) and Whidbey Formation (Qw) were assumed to have lithologic and hydrologic characteristics similar to the generalized till. Recharge to the Everson drift (Qe) and the overlying peat (Qp), however, was estimated to be half that of the till. Recharge to bedrock was estimated to be 0.5 in/yr, based on regional recharge maps developed during the Puget Sound Regional Aquifer System Analysis (J. J. Vaccaro, U.S. Geological Survey, written commun., 1993) that indicate recharge to bedrock in the Puget Lowland is typically less than 1 in/yr.

To calculate the areal distribution of recharge (fig. 16), the contour map of average annual precipitation (fig. 14) was overlaid on the map of surficial geology (plate 1). The total recharge on the island in an average year was calculated to be about 6 inches. This is the approximate quantity of water that percolates below the root zone; it is not indicative of the actual quantity of water that reaches the island's deeper hydrogeologic units.

Compared with estimates of recharge made in other areas of western Washington, the 6 inches of recharge for Guemes Island is relatively small because of the island's lower average annual precipitation and the lower permeabilities of its surficial geologic materials. For example, recharge in east King County using the same technique was estimated to be 31 in/yr (Turney and others, 1995) and in Thurston County recharge was estimated to be 28 in/yr (Dion and others, 1994). However, annual precipitation in the east King and Thurston County study areas is approximately 57 and 51 inches, respectively, and only 55 and 35 percent of the surficial geologic materials are considered to be of low permeability.

The map showing the distribution of recharge (fig. 16) indicates that the areas of the island receiving the largest quantities of recharge (greater than 10 inches) generally are located in near-shore areas where coarse-grained units are exposed. In terms of recharge to the island's ground-water system, however, relatively high recharge in near-shore areas will have little effect on

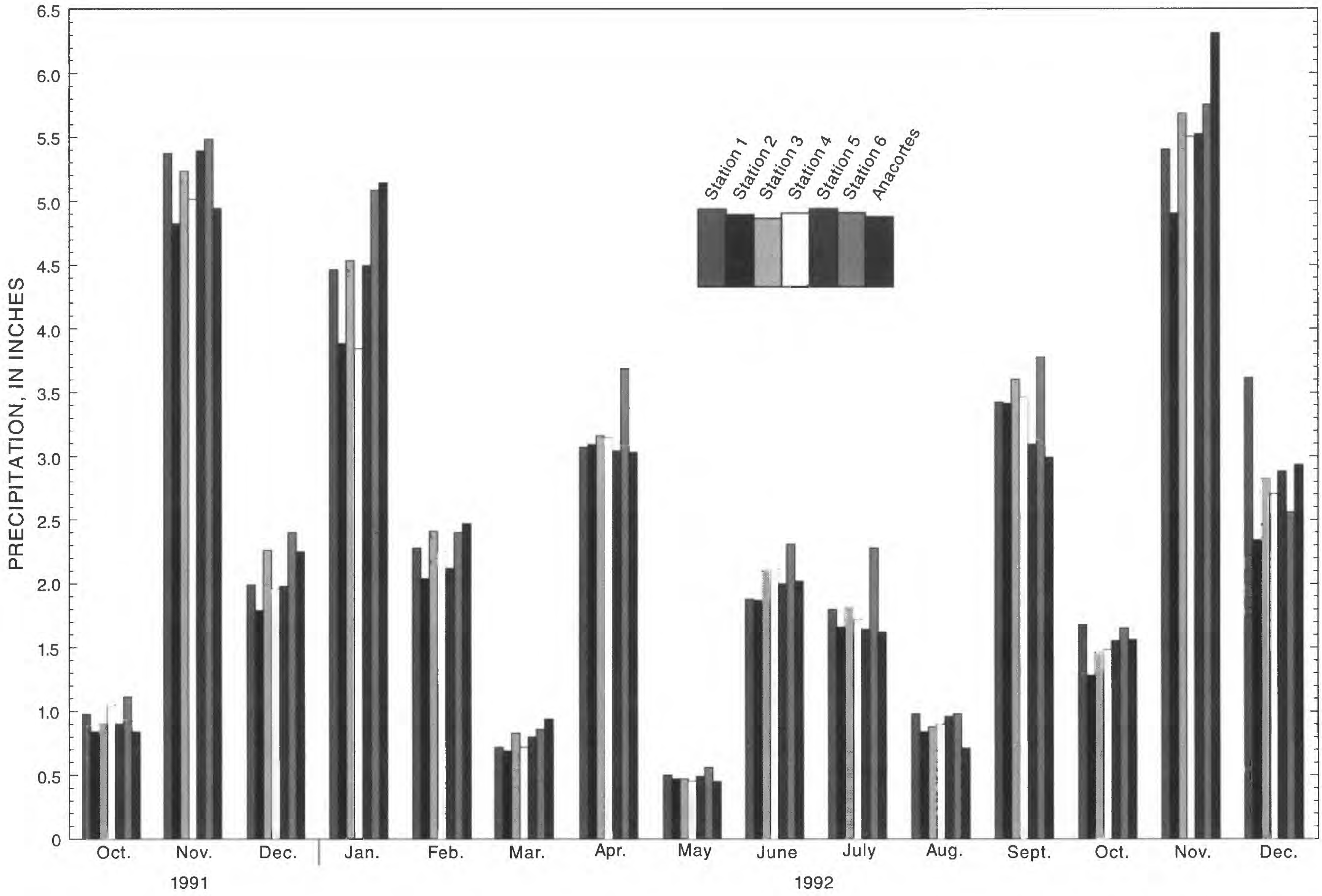


Figure 13.--Monthly precipitation measured on Guemes Island (stations 1-6; see figure 14 for locations) and at Anacortes, October 1991 through December 1992.

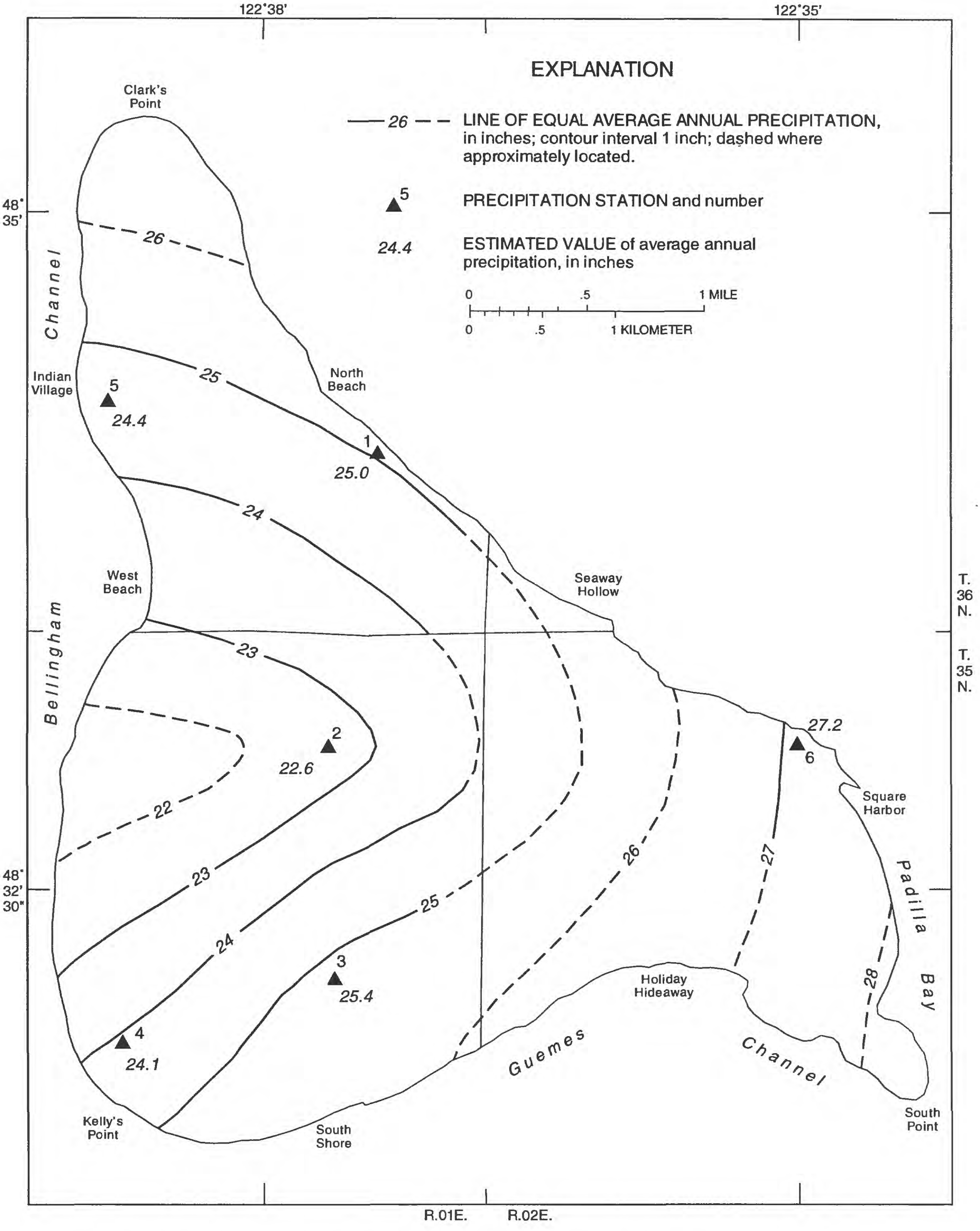


Figure 14.--Areal distribution estimate of average annual precipitation.

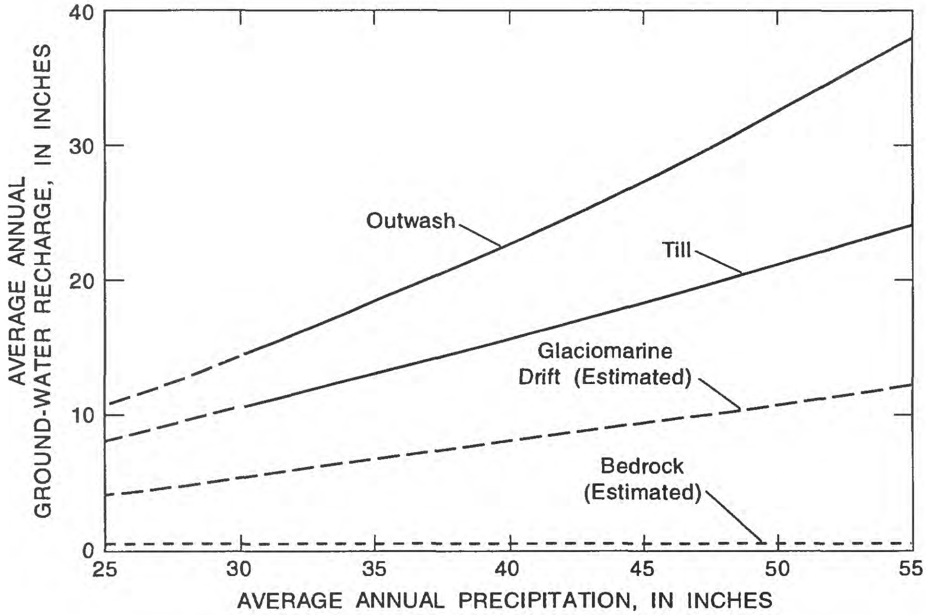


Figure 15.--Relation of precipitation to ground-water recharge on Guemes Island.

aquifers before the recharge water discharges to the sea. Areas receiving the smallest quantities of recharge (less than 6 inches) include the eastern end of the island where bedrock is exposed and the south-central and northwest-central parts of the island where fine-grained glaciomarine drift is exposed.

No attempt was made to determine the fate of recharge water in quantitative terms once it becomes part of the ground-water system. Some of the recharge water may immediately discharge to drainage ditches, and some may enter the deeper flow system to recharge the island's principal aquifers and not be discharged for months or years. Recharge to the island's principal aquifer (Qdb) would be dependent to a large extent on the vertical hydraulic conductivity values of overlying units. Such a determination would require a three-dimensional ground-water flow model.

Ground-Water Withdrawals

A summary of ground-water withdrawals during 1992 on Guemes Island, compiled by water-use category, is shown in table 3. Quantities of withdrawals were derived from information provided by the Skagit County Departments of Health, Planning, and Transportation, water system purveyors, U.S. Census Bureau, U.S. Department of Agriculture's Soil Conservation Service, and island residents. Water use was divided into three categories--livestock, public supply, and domestic self-supplied. Public supply and domestic self-supplied are further subdivided into year-round and seasonal use. Public supply has a third subdivision that includes ground water used for municipal purpose (fire department use, for example) or is lost due to pipe breakage, leaks, or flushing of lines. As shown in table 3, approximately 65 acre-feet of water was withdrawn through wells in 1992. About 70 percent of the total quantity was used for domestic self-supply, 28 percent for public supply, and 2 percent for livestock.

The livestock category includes ground-water withdrawals used for watering 178 cattle and 12 horses; these numbers were estimated on the basis of telephone surveys and actual field counts. Withdrawals for livestock were estimated by multiplying the cattle and horse populations by 7 and 12 gal/d, respectively, adding those numbers together, and then by multiplying the total by 365 days. Although the island's deer population and other wildlife consume water from stock troughs, the quantity was considered negligible for purposes of this study.

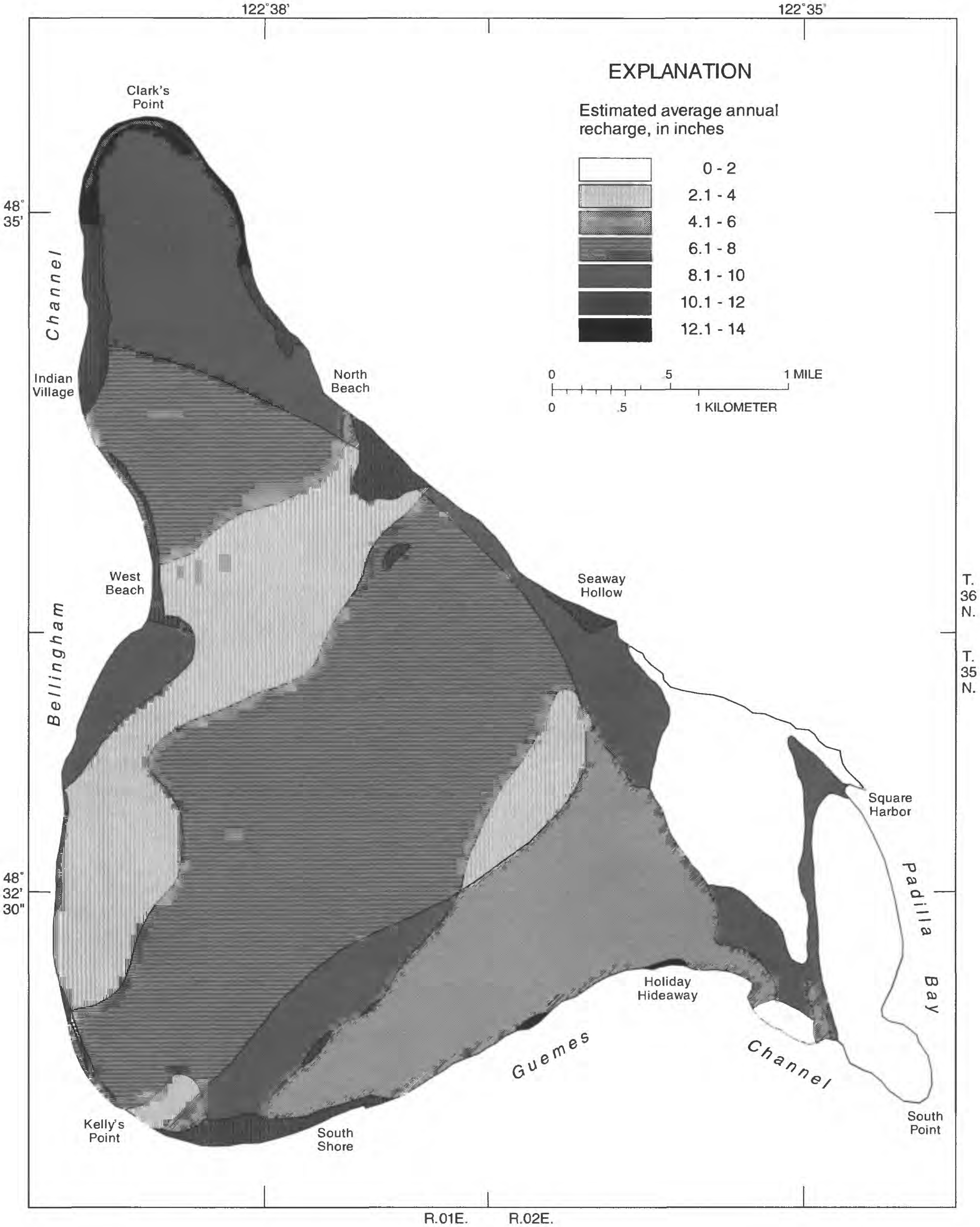


Figure 16.--Estimated areal distribution of recharge

Table 3.--Estimated ground-water withdrawals on Guemes Island during 1992

Use category	Quantity		Percent
	Gallons	Acre-feet	
LIVESTOCK	462,000	1.4	2
PUBLIC SUPPLY			
Year-round residents	3,818,000	11.7	18
Seasonal residents	1,584,000	4.9	8
Reported transmission losses and municipal use	552,000	1.7	2
Subtotal	5,954,000	18.3	28
DOMESTIC SELF-SUPPLIED			
Year-round residents	9,709,000	29.8	46
Seasonal residents	4,930,000	15.1	24
Subtotal	14,639,000	44.9	70
Total	21,055,000	64.6	100

Public supply on Guemes Island includes ground-water withdrawals by 12 single-well systems with 5 to 17 connections, a 2-well system with 32 connections, and a 3-well system with 85 connections. Four of the larger distribution systems are metered. Each water supplier provided data on ground-water withdrawals, population served, and how that population was divided between year-round and seasonal users.

Withdrawals for each non-metered public-supply system were determined by adding together the quantity of water used at each hookup (service) on each non-metered system during the year. The quantity used at each service was calculated using the following formula:

$$W = 70(nd) \qquad (4)$$

where

W = withdrawal for the year, in gallons,

n = the number of people using the service, and

d = the number of days per year the service was used.

Number of days of service was assumed to be 365 for year-round residents and an estimate provided by each water system was used for the number of days for seasonal users. The factor of 70 represents a gallons-per-day-per-capita value for Guemes Island based on records of water use provided by the purveyor of the island's largest water system.

The domestic self-supplied category includes ground-water withdrawals for the year-round and seasonal residents who are not served by one of the public-supply systems. The same equation (4) presented above was used to determine withdrawals. For seasonal residents, however, the number of days of service (d) was estimated to be 42 by consensus of water system purveyors. In order to determine the number of people served in this category, it was necessary to determine the island's seasonal and year-round populations first and then to subtract from those numbers the number of people served by public-supply systems.

A population figure reflecting seasonal shifts was estimated using several sources of information. The year-round population for 1992, estimated to be 535, was projected from the 1990 U.S. Census Bureau figure of 496 by adding the number of housing unit increases on the island from 1990 to 1992 (35) multiplied by the Census Bureau's factor (calculated for Guemes Island) for permanent residents per housing unit (1.12). According to public-supply system records, about 25 percent of the peak population served is year-round, indicating that 75 percent is seasonal. Therefore, if the island's year-round population is 535, the peak population is estimated to be 2,140 (4 x 535), and the difference of 1,605 is the seasonal population. Guemes Island ferry traffic data and monthly water-use data provided by various water systems indicate that the island's peak population occurs between Memorial Day and Labor Day.

Approximate Water Budget of the Island

An approximate water budget, or distribution of precipitation, for a typical year on the island is presented in table 4. It includes estimates of component values, possible errors associated with each component value, and a likely range of values for each component. This water budget serves as a simple illustration of the fate of precipitation by roughly quantifying the distribution of water in the island's hydrologic system: precipitation, evapotranspiration, recharge, and runoff. Because errors associated with estimation of component values may be considerable, likely ranges of values are presented.

Table 4.*--Approximate water budget of Guemes Island, reflecting uncertainties in estimation of component values*
[--, no value]

Hydrologic component	Estimated quantity (inches per year)	Possible error due to uncertainties in estimation (percent)	Likely range of component values reflecting uncertainties in estimation (inches per year)
Precipitation	25	[1]±15	21-29
Fate of precipitation:			
Evapotranspiration	17	[2]±30	12-22
Recharge (gross)	6	[3]±75	2-10
Runoff (residual)	2	[5]±120	0-4
Total	25	--	--
Fate of recharge:			
Withdrawal by wells	.2	[4]±40	.1-.3
Natural discharge (net recharge)	5.8	[5]±115	0-12
Total	6	--	--

[1] From Winter (1981).

[2] From H. Bauer (U.S. Geological Survey, written commun., 1994).

[3] From N. Dion and J. Vaccaro (U.S. Geological Survey, written commun., 1993).

[4] Estimated during this study.

[5] Accumulated errors.

A value for potential evapotranspiration was estimated by using the Thornthwaite energy-budget method as described by Dunne and Leopold (1978), and then actual-evapotranspiration was calculated by performing soil-moisture budget calculations as described in Jones (1992). Variables used for these estimations include average monthly precipitation and temperatures from Anacortes; estimated root depths for forest and grassland in the island's dominant soil types; and soil-moisture content. Average annual evapotranspiration was estimated to be 17 in/yr (table 4), or 12-22 in/yr based on estimation errors of as much as 30 percent (H. Bauer, U.S. Geological Survey, written commun., 1994).

The value of 2 inches for runoff (table 4) is a residual; that is, it represents the quantity that remains after evapotranspiration (17 inches) and recharge (6 inches) are subtracted from precipitation (25 inches). Similarly, the value of 5.8 inches for natural discharge from the ground-water system also is a residual; it represents the remainder when the estimated quantity withdrawn by wells (0.2 inches) is subtracted from recharge (6 inches). The large cumulative errors associated with the runoff and natural discharge are evident in their likely ranges of values: 0-4 and 0-12 in/yr, respectively (table 4).

The water budget indicates that a large quantity of precipitation goes to evapotranspiration and that a smaller quantity goes to recharging the island's ground-water system. The smallest quantity of precipitation goes to runoff. Of the water that goes to recharge, only a small fraction goes to pumped wells.

Although ground-water withdrawals account for only a small part of the annual recharge to the system, increased withdrawals could have significant impacts on the system for several reasons. Bredehoeft and others (1982) point out that any additional withdrawal or discharge superimposed on a previously stable system must be balanced by (1) an increase in recharge, (2) a decrease in discharge, (3) a loss of storage within the aquifer (reflected by lowering water levels in wells), or (4) by a combination of these factors. The possibility of increased natural recharge (increased infiltration of precipitation) is unlikely because it would involve major changes in regional weather patterns or increased infiltration rates. Likewise, a decrease in discharge (by pumping wells) is unlikely, because it would necessitate a decrease in water use. The third factor, a loss in fresh ground-water storage, is the one most likely to occur in response to increased withdrawals on the island. Long-term water-level data would be needed, however, in order to verify such changes in storage.

Ground-Water Levels

Several types of water-level data were collected during the course of this investigation, including (1) historical water-level measurements made in several wells as part of earlier seawater-intrusion studies; (2) water levels measured during the inventory phase of this study in October 1991; (3) monthly water-level measurements made in 20 selected observation wells across the island from December 1991 through December 1992; and (4) measurements of water levels in two coastal wells at 5-minute intervals for up to 48 hours to determine if water levels in those wells were affected by ocean tides.

Comparisons of historical and recent water-level measurements made in several wells on the island do not indicate any significant long-term water-level changes. However, earlier measurements made in 1967 and 1978 (Walters, 1971; Dion and Sumioka, 1984) are from too few wells (five total) to assess adequately the islandwide long-term water-level fluctuations.

Water-level measurements made during the inventory phase of this study were used to construct maps of generalized water-level altitudes for the island's two principal aquifers, Qdb (fig. 17) and Qva (fig. 18). For reasons pointed out in the Study Methods section, the water-level altitudes shown in figures 17 and 18 are probably only accurate to plus or minus 10 feet. This helps explain why some of the water levels shown are slightly below sea level, a condition that would not be expected under natural conditions. Because of this uncertainty, the water-level maps were constructed to show areas of similar water-level altitudes rather than trying to contour the available point data.

Water levels in aquifer Qdb were generally 13 to 30 feet above sea level in the central part of the island and generally less than 13 feet in near-shore areas (fig. 17). Water levels in overlying aquifer Qva were generally 61 to 80 feet above sea level near the central part of the island and less than 30 feet in near-shore areas (fig. 18). The wells in aquifer Qdb were distributed much more broadly than those in aquifer Qva.

Monthly water-level measurements were made in 20 selected wells to determine seasonal variations in hydraulic heads in the productive hydrogeologic units (Appendix 4). Representative hydrographs of ground-water levels for wells completed in Qdb and Qva are shown in figures 17 and 18. Hydrographs for wells completed in Qdb show

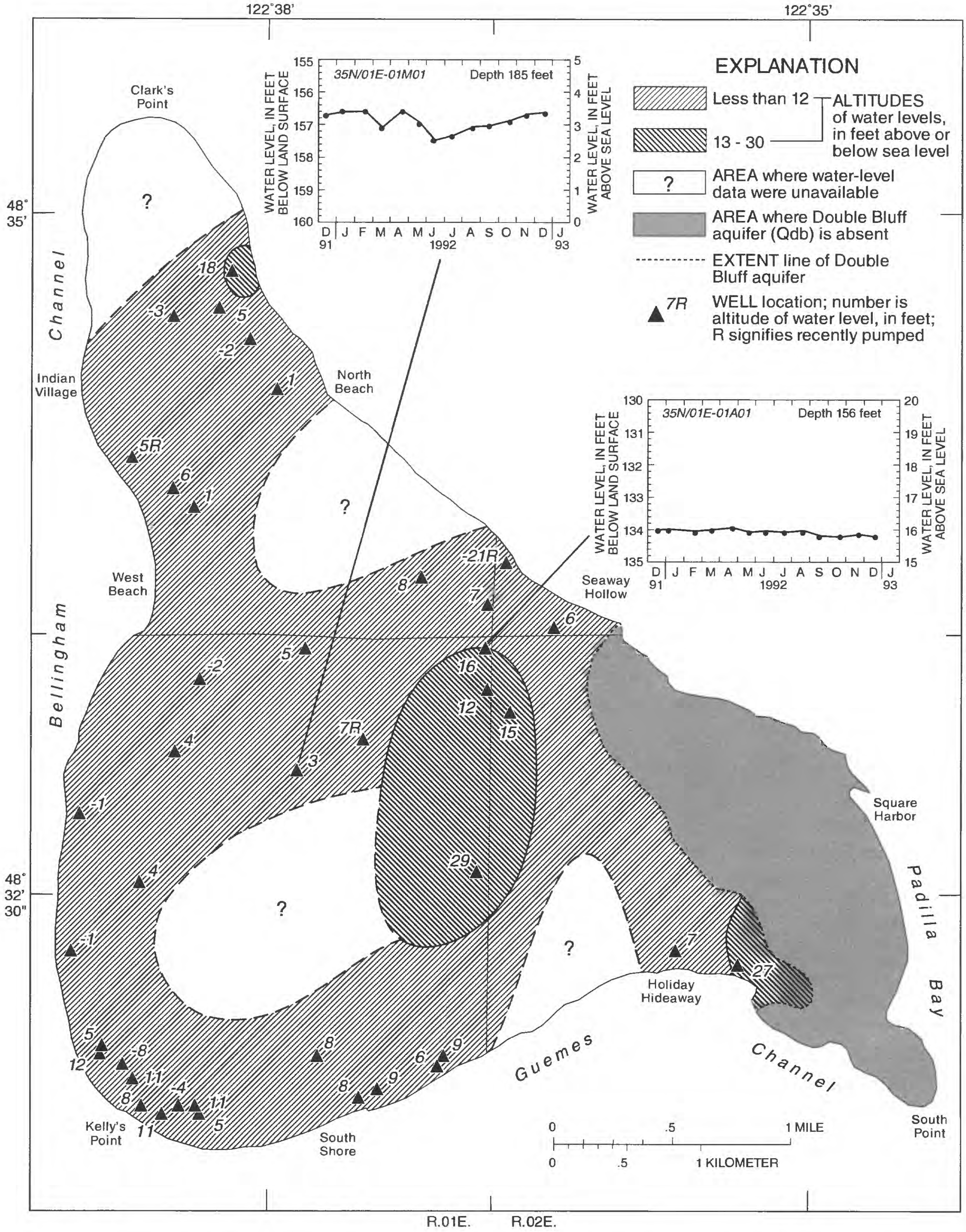


Figure 17.--Altitudes of water levels in wells completed in the Double Bluff aquifer (Qdb), and hydrographs of water levels in selected wells, October 1991.

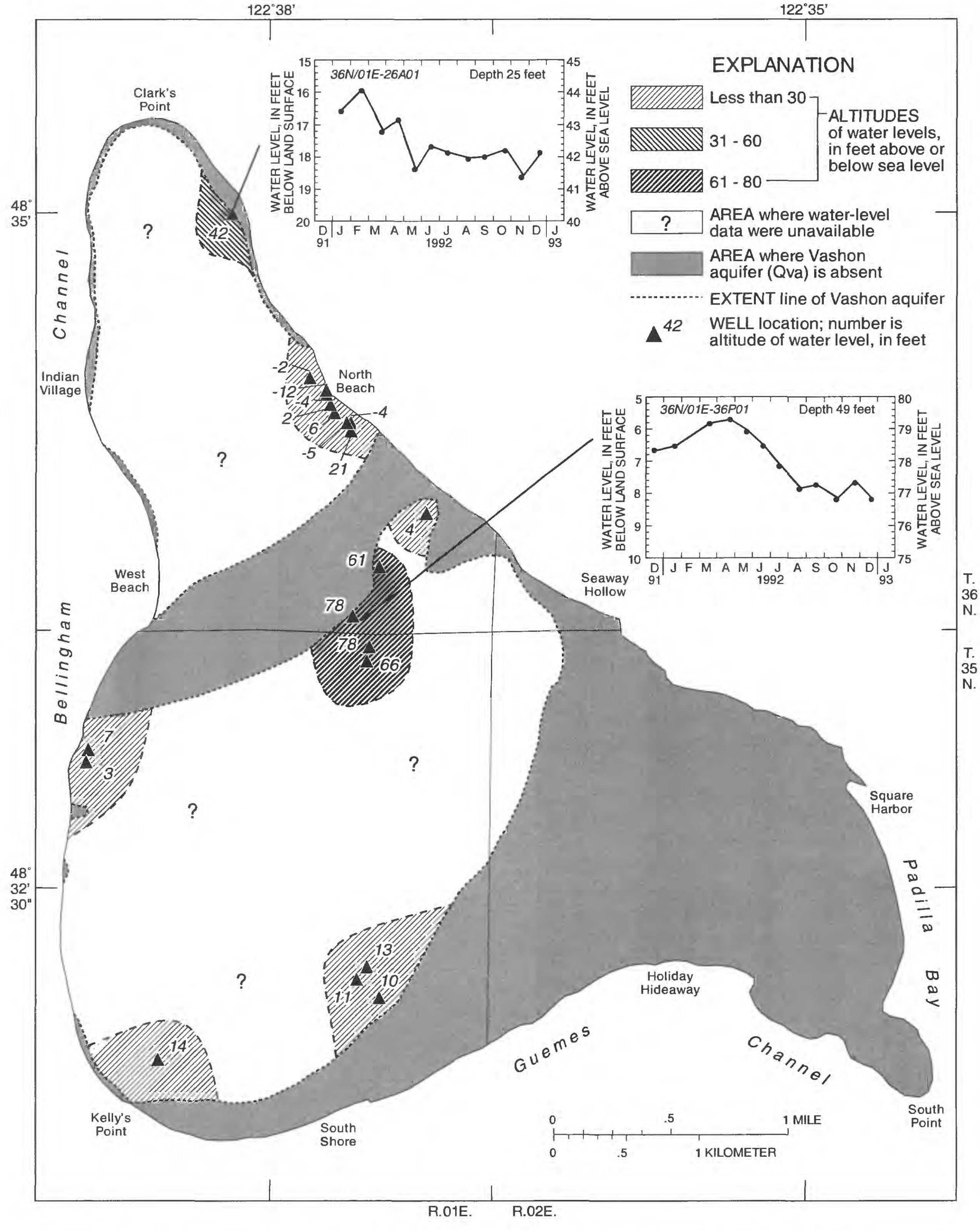


Figure 18.--Altitudes of water levels in wells completed in the Vashon aquifer (Qva), and hydrographs of water levels in selected wells, October 1991.

little seasonal fluctuation, generally less than 1 foot, with slightly higher water levels occurring in late spring or early summer. Hydrographs for wells completed in the shallower Qva show seasonal fluctuations of 2 feet or more. Water levels generally were highest in late winter and early spring and lowest in summer and early fall. When graphs of precipitation data (fig. 13) are compared to hydrographs of wells in Qva, a lag of several months between periods of highest precipitation (November through January) and highest water levels (February through April) is apparent; this is likely due to impedance of recharge water by the overlying till and (or) glaciomarine drift.

Water-level fluctuations caused by marine tidal influences were recorded in two coastal wells, 35N/01E-2L01 and 36N/1E-36C04, in late December 1992 when the difference between high and low tides was at a maximum (approximately 10 feet). Ground-water levels were recorded every 5 minutes and the values were graphed and then compared with a graph of tide levels for the same period of time. Both wells are completed in Qva, are within approximately 400 feet of the shoreline, and have similar depths--64 feet for 2L01 and 54 feet for 36C04. However, the altitudes of the open intervals of the wells differ considerably, being 45 feet below sea level in 2L01 but only 9 feet below sea level in 36C04. As illustrated in figure 19, water levels in 2L01 closely follow the tidal curve, showing a large tidal influence. Well 2L01 had a maximum water-level fluctuation of approximately 7 feet while the maximum tidal fluctuation was nearly 10 feet. The water-level curve for 36C04, on the other hand, shows almost no response to the tidal influence; fluctuations in this well were less than half a foot.

The observed responses of ground-water levels to tidal fluctuations on Guemes Island result from a hydraulic connection between the aquifer(s) and the seawater of the Puget Sound and (or) from tidal loading on top of less-permeable units above the aquifer(s). Direct hydraulic connection between the aquifer and the sea causes water levels in coastal wells to rise and fall--as tides rise and fall--due to increasing or decreasing pressure on the saturated zone of the aquifer. If the aquifer is overlain by a less permeable unit, water-level changes can be caused by pressure loading transmitted through the material overlying the aquifer. Apparently, the hydraulic connection and (or) tidal loading is much greater for well 2L01 than it is for well 36C04.

SEAWATER INTRUSION

Wells in many coastal areas are in a delicate balance between rates of ground-water pumping that safely provide freshwater supplies and increased pumping rates that might result in the intrusion of seawater into near-shore aquifers. Generally, prevention or detection of seawater intrusion is desirable. Excessive salts in drinking water supplies produce unpalatable tastes and possible adverse physiological effects, are corrosive to plumbing, and may increase the cost of water treatment. Moreover, once seawater intrudes a coastal aquifer, control or reversal of the condition can be difficult and expensive. Because ground water moves slowly, remedial measures may require years or decades to take effect.

Freshwater-Seawater Relations

In order for seawater intrusion to occur, an unconfined or confined aquifer must be in hydraulic connection with the sea, and the hydraulic head of the fresh ground water must be less than that of the saline water. Around 1900, hydrologists working along coastal areas of Europe observed that saline water occurred beneath freshwater at a depth below sea level of about 40 times the height of the freshwater surface above sea level. The freshwater appeared to "float" on the seawater as a lens-shaped body. This relation, known as the Ghyben-Herzberg relation after the two scientists who first described it, occurs because the density of freshwater (1.000) is slightly less than the density of seawater (1.025).

The Ghyben-Herzberg relation states that in an homogeneous unconfined aquifer, for every 1 foot of altitude of the water table above sea level, fresh ground water will extend about 40 feet below sea level. For example, if the water table at a site is 3 feet above sea level, the freshwater-seawater interface is about 120 feet below sea level and the thickness of the freshwater zone is about 123 feet. The relation also indicates that if the water table is lowered 1 foot, the interface will rise 40 feet, thereby reducing the total thickness of the freshwater lens by 41 feet. This relation is of primary importance when considering the effects that long-term pumping or drought could have on a coastal aquifer by reducing the quantity of fresh ground water.

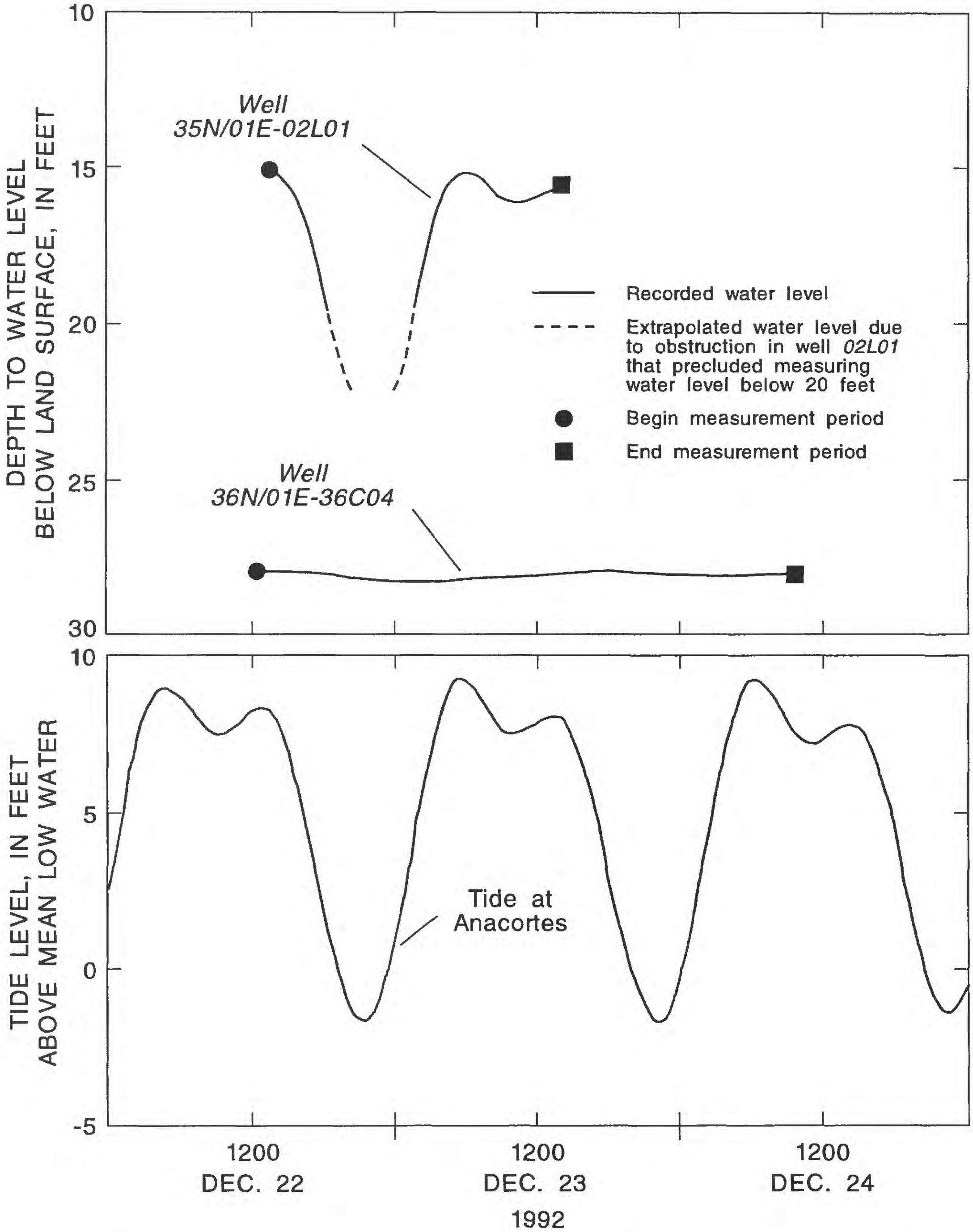


Figure 19.--Water levels in selected coastal wells on Guemes Island, and tidal fluctuations, December 22-24, 1992 (well locations shown on Plate 1).

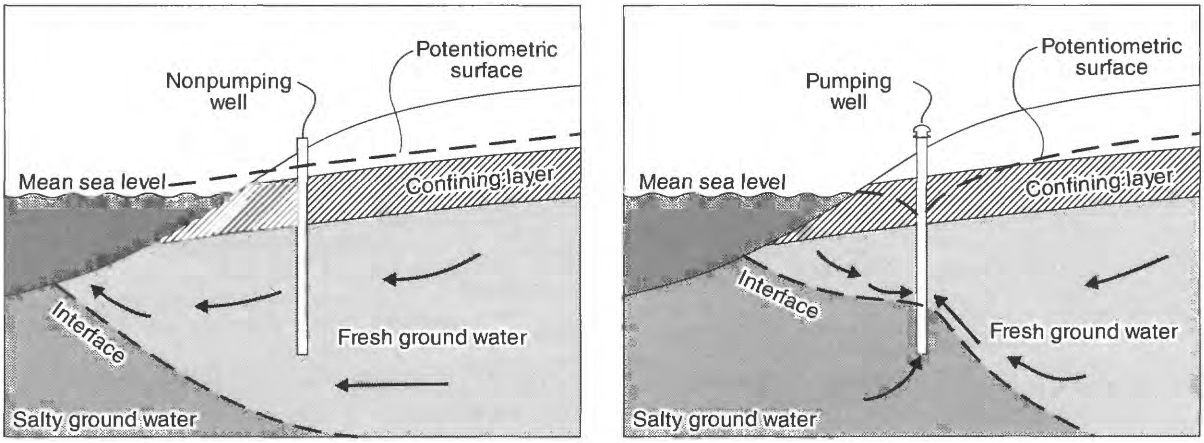
Sketches summarizing freshwater-seawater relations before and after seawater intrusion are shown in figure 20. In a confined aquifer under natural conditions, the altitude of the potentiometric surface in a coastal area is higher than sea level and decreases toward the shoreline (fig. 20a). Fresh ground water under these conditions moves downgradient toward the sea. When the potentiometric surface drops (such as from reduced rates of recharge or increased rates of pumping) and its gradient decreases (fig. 20b), the seaward flow of fresh ground water decreases and the interface moves landward and upward. Conversely, when the potentiometric surface rises, the interface moves seaward and downward.

Uncontaminated ground water in most coastal areas of Washington generally contains less than 10 mg/L of chloride, whereas seawater contains about 19,000 mg/L of chloride. For this study, chloride concentrations in excess of 100 mg/L were considered to represent seawater intrusion even though such high concentrations could actually be the result of contamination from surface sources, the presence of relict seawater, or sea spray.

Numerous wells on Guemes Island have been affected by seawater intrusion (Walters, 1971; Dion and Sumioka, 1984; D. P. Garland, Washington State Department of Ecology, written commun., 1992). The areal distribution of chloride concentrations in ground water on Guemes Island, based on field analyses of 83 samples collected during the inventory phase of this study, is shown in figure 21. Although field chloride analyses are not as precise or accurate as laboratory analyses, they give a good indication of where high chloride concentrations occur. The chloride concentrations varied from less than 20 mg/L to more than 200 mg/L. High chloride concentrations (greater than 100 mg/L) were found near West Beach, North Beach, and in the west-central part of the island. Chloride concentrations between 20 and 100 mg/L were detected near Kelly's Point, South Shore, and Holiday Hideaway.

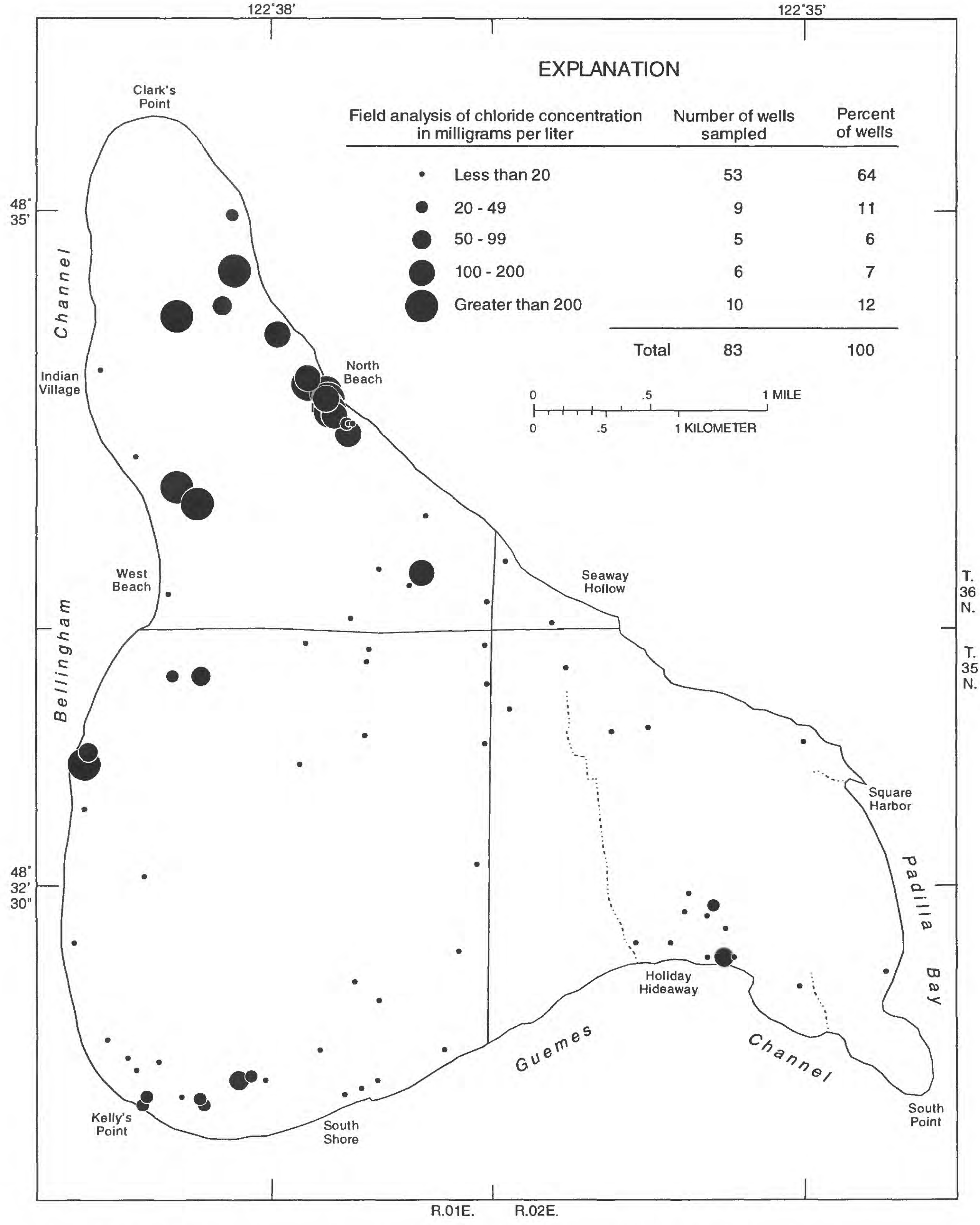
From an islandwide perspective, significant seawater intrusion is unlikely at the present time given the small quantity of ground-water discharge that goes to pumping wells. However, the geographic distribution of the pumping wells is a critical factor in seawater intrusion. Excessive ground-water withdrawal in a near-shore area can cause large local movement of the freshwater-seawater interface especially if the aquifer is thin. The degree of seawater intrusion depends on the proximity of the well's opening to the freshwater-seawater interface, the rates of recharge and pumping, and the local permeability of the hydrogeologic unit.

Another important factor in seawater intrusion, and in the availability and storage of fresh ground water, is the thickness of the unconsolidated deposits that overlie low-permeability bedrock. The thickness of the unconsolidated deposits, or depth to bedrock, is largely unknown for most of Guemes Island. A thick assemblage of unconsolidated deposits would result in a relatively thick freshwater lens and a freshwater-seawater interface located seaward. A thin assemblage of unconsolidated deposits would result in a thinner freshwater lens and a freshwater-seawater interface located landward. In terms of seawater intrusion, a thick freshwater lens would be less likely to be affected than a thin lens, given the same near-shore pumping


a. Non-pumping or moderate pumping conditions

b. Excessive pumping conditions

Figure 20.--Hypothetical hydrologic conditions (a) before and (b) after seawater intrusion (modified from Lum and Walters, 1976).



EXPLANATION

Field analysis of chloride concentration in milligrams per liter	Number of wells sampled	Percent of wells
• Less than 20	53	64
● 20 - 49	9	11
● 50 - 99	5	6
● 100 - 200	6	7
● Greater than 200	10	12
Total	83	100

Figure 21.--Areal distribution of chloride concentrations, measured during the well and spring inventory, October 1991.

conditions. Additionally, a thick freshwater lens would account for a greater availability of fresh ground water if the unconsolidated deposits are permeable.

Variability of Chloride Concentrations

Chloride concentrations in waters from coastal wells may vary in response to changes in the position of the freshwater-seawater interface. Factors affecting the position of the interface include the timing and quantities of pumping and recharge. Tides have a similar but much smaller effect on the position of the interface, by pushing it landward during high tide and seaward during low tide. Recent reconnaissance studies done on Lummi Island and Camano Island indicate that the differences in chloride concentrations at low and high tides are less significant than the overall increase in chloride due to the cumulative pumping duration (D. P. Garland, Washington State Department of Ecology, written commun., 1992 and 1993).

Seasonal variability of chloride concentration on Guemes Island was measured by sampling 12 coastal wells on a monthly basis from December 1991 through December 1992 (Appendix 5). Chloride concentrations varied seasonally in some wells but not in others (fig. 22). Wells yielding water with high chloride concentrations (above 100 mg/L) showed greater seasonal variability than those with low chloride concentrations. Most wells yielding water with concentrations less than 50 mg/L showed little or no seasonal variability. In general, the highest concentrations occurred from April through September, when water levels are typically declining. Similar seasonal chloride variability was observed in wells on Camano Island where chloride concentrations were highest in August and lowest from November through April (Garland and Safioles, 1988).

Chloride concentration and rate of pumping were measured by Ecology (D. P. Garland, Washington Department of Ecology, written commun., 1992) in a public-supply well (36N/01E-35G02) in West Beach, completed 20 feet below sea level, between April 1988 and October 1989. Chloride concentrations generally ranged from 400 to 600 mg/L and were highest during summer when pumping rates were highest.

QUALITY OF GROUND-WATER

In this section, the quality of the ground water on Guemes Island is described, on the basis of the results of chemical analyses of water samples collected in June 1992. Chemical concentrations and characteristics are discussed and related to hydrogeologic units, concentrations are compared with applicable U.S. Environmental Protection Agency (USEPA) drinking water standards, and causes of widespread or common water-quality problems are identified.

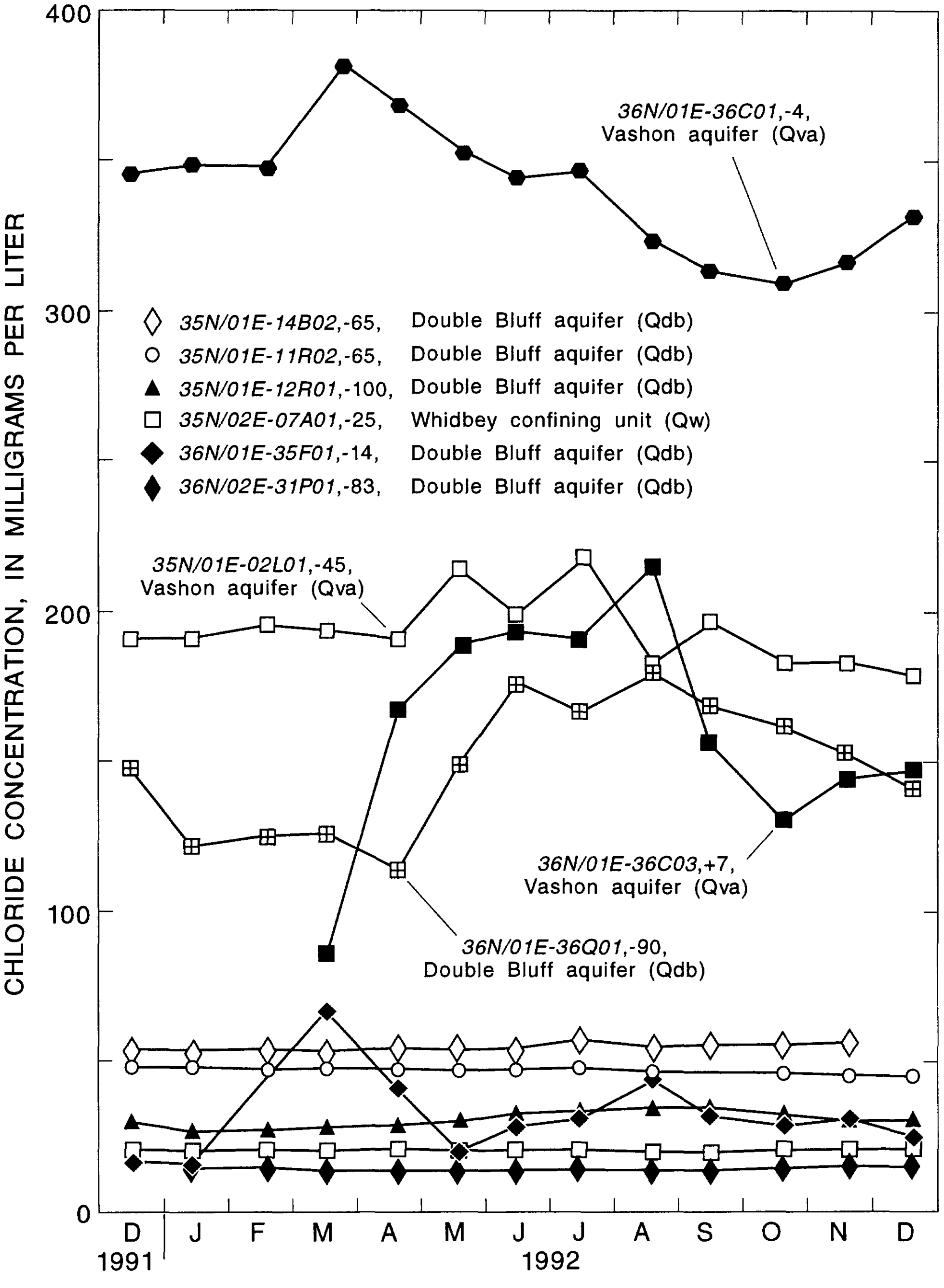
Ground-Water Chemistry

Most of the data that describe the general chemistry of the ground water are presented statistically in summary tables. Table 5 summarizes values of the common constituents determined; table 6 shows median concentration values for each of the common constituents, by hydrogeologic unit. Similar summary tables are presented for other constituents, as needed for the discussion. All supporting data are presented in Appendixes 6-8. Locations of the 24 wells from which samples were collected are shown on plate 1.

For many constituents, some concentrations may be reported as "less than" (<) a given value, where the value given is the detection limit of the analytical method. For example, the concentration of nitrate was often reported as <0.05 mg/L, where the detection limit is 0.05 mg/L. The correct interpretation of such a concentration is that the constituent was not detected at or above that particular concentration. The constituent may be present at a lower concentration, such as 0.01 mg/L, or it may not be present at all, but that is impossible to tell with the analytical method used.

Specific Conductance, pH, Dissolved Oxygen, and Hardness

Specific conductance is a measure of the water's ability to conduct an electric current and increases with the dissolved minerals content. The specific conductance values of the 24 samples, corrected for water temperature, ranged from 221 to 1,370 µS/cm (microsiemens per centimeter). The median specific conductance was 352 µS/cm (table 5).



EXPLANATION

36N/01E-36C01,-4, Vashon aquifer (Qva)	Local number, approximate altitude of top of open interval of well, in feet, hydrogeologic unit in which the well is open.

Figure 22.--Concentrations of chloride in water from selected wells on Guemes Island, December 1991 through December 1992.

Table 5.*--Summary of concentrations of common constituents, June 1992*

[Concentrations in milligrams per liter unless otherwise noted. All are dissolved concentrations. Values are for samples from 24 wells unless noted; µS/cm, microsiemens per centimeter at 25 °Celsius; <, not detected at the given concentration; µg/L, micrograms per liter]

	Concentrations				
Constituent	Minimum	25th percentile	Median	75th percentile	Maximum
pH (standard units)	6.2	6.8	7.2	7.9	8.5
Dissolved oxygen[1]	.0	<.1	.7	2.4	9.2
Specific conductance (µS/cm, field)	221	266	352	586	1,370
Hardness (as $CaCO_3$)	63	91	120	170	270
Calcium	10	16	20	31	53
Magnesium	7.5	12	16	22	33
Sodium	10	13	19	72	200
Percent sodium[2]	9	18	26	53	85
Potassium	.5	1.8	3.2	5.2	11
Alkalinity (as $CaCO_3$)	48	68	128	172	286
Sulfate	<.1	10	22	36	82
Chloride	13	16	21	59	330
Fluoride	<.1	<.1	<.1	.1	.3
Silica	13	28	30	35	50
Dissolved solids[1]	141	178	236	357	760
Nitrate (as nitrogen)[1]	<.05	<.05	.08	1.3	6.8
Iron (µg/L)	10	19	160	1,170	7,100
Manganese (µg/L)	1	6	34	150	1,500

[1] Based on 23 samples.

[2] Sodium as a percentage of total cation milliequivalents.

The acidity or basicity of water is measured by pH, and is gauged on a scale from 0 to 14. A pH of 7.0 is neutral; lower values are acidic and higher values are basic. The pH values of the samples collected ranged from 6.2 to 8.5 and the median was 7.2. Wells completed in Qva generally yielded acidic waters, whereas wells completed in Qdb yielded basic waters. The median pH of waters ranged from 6.5 in Qva to 8.2 in Qw (table 6).

Dissolved-oxygen concentrations help determine the types of chemical reactions that can occur in water. Small dissolved-oxygen concentrations indicate that a chemically reducing reaction can occur, and large concentrations indicate that a chemically oxidizing reaction can occur. Dissolved-oxygen concentrations ranged from less than 0.1 to 9.2 mg/L, and the median concentration was 0.7 mg/L. As shown in table 6, median concentrations varied considerably by unit, being largest in Qva and smaller in Qsc, Qw, and Qdb. However, there was much variation within individual units.

Hardness is primarily caused by the presence of calcium and magnesium and is expressed as milligrams per liter of $CaCO_3$. The most familiar effects of hard water are poor production of lather from soap and formation of scale deposits on plumbing.

Most water samples were classified as moderately hard or hard, as defined by the following scheme (Hem, 1989):

Table 6.--Median concentrations of common constituents by hydrogeologic unit, June 1992

[Hydrogeologic unit: Qsc, Surficial confining unit; Qva, Vashon aquifer; Qw, Whidbey confining unit; Qdb, Double Bluff aquifer; and Br, Bedrock. Concentrations in milligrams per liter (mg/L) unless otherwise noted. All are dissolved concentrations except pH, dissolved oxygen, and specific conductance; µS/cm, microsiemens per centimeter at 25° Celsius; <, not detected at the given concentration; µg/L, micrograms per liter]

	Hydrogeologic unit (Number of samples)				
	Qsc (1)	Qva (6)	Qw (2)	Qdb (13)	Br (2)
pH (standard units)	7.2	6.5	8.2	7.6	7.7
Dissolved oxygen	.4	2.4	<.1	.4	1.2
Specific conductance (µS/cm)	347	242	557	345	500
Hardness (as $CaCO_3$)	150	83	172	120	230
Calcium	38	18	33	19	42
Magnesium	13	10	21	18	30
Sodium	14	16	55	24	17
Percent sodium	17	29	38	27	14
Potassium	1.9	1.6	5.7	3.7	4.2
Alkalinity (as $CaCO_3$)	142	61	247	135	194
Sulfate	18	29	22	12	50
Chloride	13	18	24	27	20
Fluoride	<.1	<.1	.2	.1	<.1
Silica	13	30	29	32	30
Dissolved solids	199	165	341	[1]234	311
Nitrate (as nitrogen)	.55	1.0	<.05	[1]<.05	.06
Iron (µg/L)	33	19	971	500	157
Manganese (µg/L)	36	3	54	150	20
Arsenic (µg/L)	<1	<1	1	<1	<1

[1] Based on 12 samples.

Description	Hardness range (milligrams per liter of $CaCO_3$)	Number of samples	Percentage of samples
Soft	0-60	0	0
Moderately hard	61-120	13	54
Hard	121-180	6	25
Very hard	Greater than 180	5	21
		24	100

Dissolved Solids

The concentration of dissolved solids is the sum of the concentrations of all the minerals dissolved in the water. The major components of dissolved solids depend on many factors, but usually include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica. Other constituents, such as carbonate and fluoride, or metals such as iron and manganese, are also components but rarely are found in large enough concentrations to make a significant difference in comparison with the major components.

Dissolved-solids concentrations ranged from 141 to 760 mg/L, with a median concentration of 236 mg/L (table 5), and the concentrations tended to be larger in the deeper (older) units (table 6). Some of this variation is because of different geologic material in the units, but some is likely due to increased residence time of water in the deeper units. Water that has been in the ground for a longer time generally has had the opportunity to dissolve more minerals than water with a shorter residence time.

The areal distribution of dissolved-solids concentrations varied widely (fig. 23). A few wells near the shore had dissolved-solid contents greater than 400 mg/L, possibly because of seawater intrusion.

Major Ions

Most of the major components of dissolved solids are ions, meaning they have an electrical charge. Cations have a positive charge and include calcium, magnesium, sodium, potassium, and most metals. Anions have a negative charge and include bicarbonate, sulfate, chloride, nitrate, carbonate, and fluoride. Silica has no charge.

In Guemes Island ground water, the median concentration of dissolved calcium (table 5) was 20 mg/L, the largest of any of the cations. Magnesium and sodium had median concentrations of 16 and 19 mg/L, respectively, and account for most of the remaining cations. The median concentration of potassium was 3.2 mg/L.

The anion having the largest median concentration was bicarbonate, as indicated by the median alkalinity concentration of 128 mg/L (table 5). Alkalinity is attributed to the activities of bicarbonate, carbonate, and hydroxide, but the concentrations of each are dependent upon pH. At all pH values observed, bicarbonate is the major component of alkalinity. The largest alkalinity concentration observed in the study area was 286 mg/L, in a sample from well 35N/02E-07H04, which is completed in Qw. The median concentrations of sulfate, chloride, nitrate, and fluoride were small compared with alkalinity.

Chloride

Large chloride concentrations can indicate water-quality problems such as seawater intrusion, contamination from septic tank effluent, or the presence of connate water. Concentrations greater than about 250 mg/L commonly impart a salty taste. The distribution of chloride concentrations for June 1992 is shown in figure 24. Chloride concentrations in samples from wells in the central part of the island were generally less than 20 mg/L. Concentrations greater than 100 mg/L were found only in samples from wells in near-shore areas. Chloride concentrations islandwide ranged from 13 to 330 mg/L, with a median concentration of 21 mg/L (table 5). The range of median concentration by unit was small, from 13 mg/L in Qsc to 27 mg/L in Qdb (table 6). The chloride data from these 24 samples are consistent with the inventory data collected in October 1991. All of the chloride concentrations are above the background concentrations of 3 to 5 mg/L typically found in ground water in other parts of western Washington. A source of chloride other than seawater intrusion may be affecting ground water in Guemes Island wells not located in near-shore areas.

Chloride concentrations in water from some coastal wells in North Beach and West Beach exceeded 200 mg/L. Concentrations as large as 330 mg/L, in a sample from well 36N/01E-36C01, were found in these areas. Concentrations at Kelly's Point and along South Shore range from 17 to 100 mg/L.

Nitrate

Large concentrations of nitrate may indicate ground-water contamination from septic tanks, animal wastes, or fertilizer. Concentrations of nitrate greater than 10 mg/L may cause a sometimes fatal disease in infants. The actual analysis for nitrate includes both nitrite and nitrate; however, nitrite concentrations in ground water are usually much smaller than nitrate concentrations (National Research Council, 1978). The values determined, therefore, are considered to be mostly nitrate.

Concentrations ranged from less than 0.05 mg/L to 6.8 mg/L, but the median concentration was only 0.08 mg/L (table 5). Concentrations in most samples were 1.0 mg/L or less. Two areas appear to have nitrate concentrations generally exceeding 1.0 mg/L: near Indian Village and along North Beach (fig. 25); both areas are relatively densely populated. The values determined for the island are generally smaller than those reported for other parts of western Washington. Median nitrate concentrations have been reported as 0.16 mg/L in Clark County (Turney, 1990), 0.33 mg/L in Thurston County (Dion and others, 1994), and 0.10 mg/L or greater for much of the Puget Sound area (Turney, 1986).

The nitrate in the Guemes Island ground water probably originated from such local sources as septic tanks, lawn fertilizers, or domestic farm animals. Usually, shallow wells (less than 100 feet deep) are more susceptible to nitrate contamination than deeper wells. However, five of the seven wells where samples had nitrate

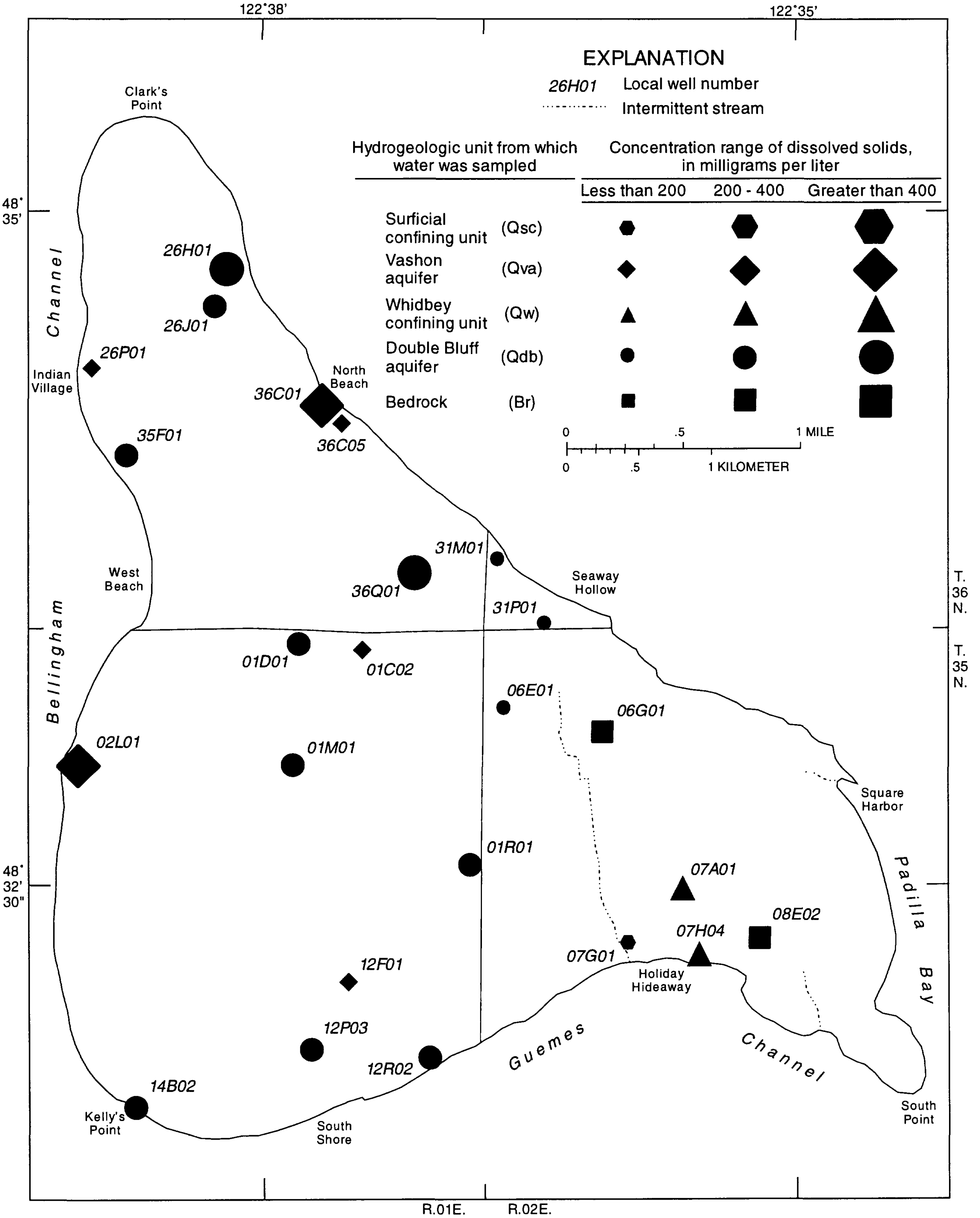


Figure 23.--Areal distribution of dissolved-solids concentrations, June 1992.

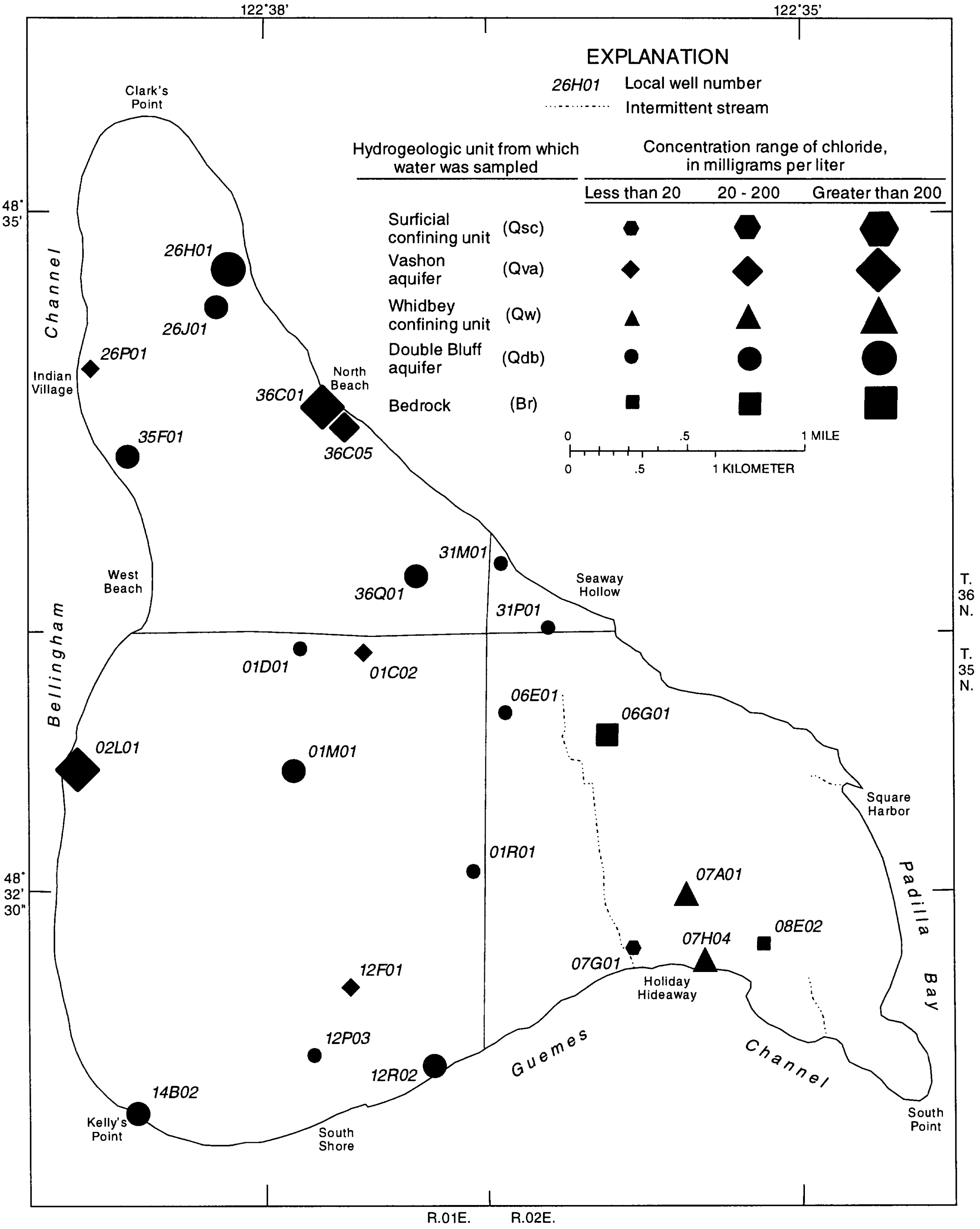


Figure 24.--Areal distribution of chloride concentrations, June 1992.

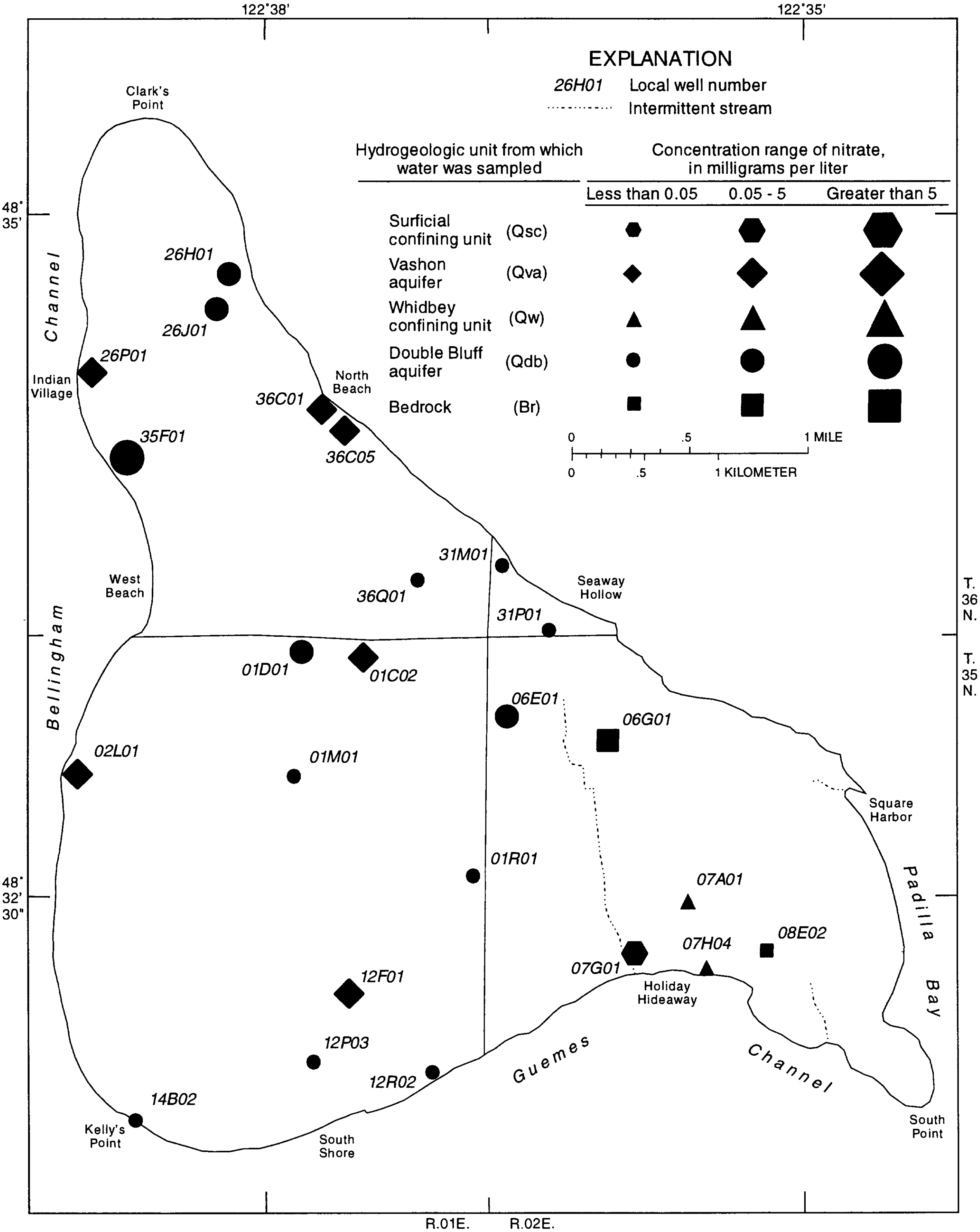


Figure 25.--Areal distribution of nitrate concentrations, June 1992.

concentrations exceeding 1.0 mg/L were more than 100 feet deep. In fact, the maximum concentration of nitrate (6.8 mg/L) was detected in a sample from well 36N/01E-35F01, which is 182 feet deep. Nitrate concentrations in samples from several nearby deep wells, such as wells 36N/01E-26H01, 36N/01E-26J01, and 36N/01E-35F01 at Indian Village and North Beach, indicate areal rather than point-source contamination. Deeper wells may contain nitrate from local sources, but the cause of contamination is often poor well construction that allows seepage of contaminated surface water into the ground along the well casing. This may be the case at wells 35N/01E-12F01 and 35N/02E-06E01 in the central part of the island. Overall, there was no strong correlation of nitrate concentration with either hydrogeologic unit or well depth on the island.

Iron and Manganese

Concentrations of iron and manganese greater than 300 µg/L and 50 µg/L, respectively, commonly stain plumbing fixtures and give water a poor taste. Iron concentrations ranged from 10 to 7,100 µg/L, with a median concentration of 160 µg/L (table 5). Median concentrations were smaller in Qsc, Qva, and Br, and larger in Qw and Qdb (table 6). All but one of the samples with iron concentrations greater than 300 µg/L were from wells completed in Qdb, whereas most samples from Qva had concentrations much lower than 300 µg/L (fig. 26).

Manganese concentrations ranged from 1 µg/L to 1,500 µg/L, and the median concentration was 34 µg/L (table 5). Like iron, the median concentration for individual units was largest for samples from Qw and Qdb. Manganese concentrations followed the same general pattern as iron concentrations.

The variation and range of iron and manganese concentrations seen on the island are typical of western Washington ground waters (Van Denburgh and Santos, 1965; Turney, 1986, 1990; Dion and others, 1994), although the median values are somewhat larger. Ground-water samples from studies in Thurston, east King, and Whatcom Counties had median iron concentrations of 23, 24, and 38 µg/L, and median manganese concentrations of 5, 17, and 10 µg/L (Dion and others, 1994; Turney and others, 1995; and S. E. Cox, U.S. Geological Survey, written commun., 1993). Large iron and manganese concentrations are due typically to natural processes. These processes depend closely upon ambient geochemical conditions, in particular the concentration of dissolved oxygen. Water that is depleted of oxygen will dissolve iron from the surrounding minerals as the chemically reduced ferrous (Fe^{2+}) form of iron. Iron is highly soluble under these conditions and large concentrations can result. If the water is reoxygenated, the iron is oxidized to the ferric (Fe^{3+}) form, which is much less soluble than the ferrous form and will precipitate as an oxide or a carbonate, resulting in a smaller dissolved-iron concentration. Manganese undergoes a similar set of reactions. Because these reactions are oxygen-sensitive and the oxygen content of the ground water may vary considerably in a given area, dissolved iron and manganese concentrations also may vary greatly.

Trace Constituents

Concentrations of most trace constituents were small. For all except barium and zinc, the median concentrations were less than 1 µg/L (table 7). Arsenic was detected in 5 of 24 samples, with concentrations of 1 µg/L in 4 samples and a concentration of 14 µg/L in the fifth sample, from well 36N/01E-36Q01. The sample from well 36Q01 also had one of the largest concentrations of dissolved solids (574 mg/L) and chloride (180 mg/L) on the island. The U.S. Environmental Protection Agency (USEPA) currently has set the maximum contaminant level (MCL) for arsenic at 50 µg/L; however, that value is being reviewed and may be lowered to 3 µg/L or less.

The source of the arsenic in the ground water is probably natural. Arsenic is present to some degree in many igneous rocks, which are the source material for much of the unconsolidated deposits in the Puget Lowland. Furthermore, arsenic tends to concentrate in aluminosilicate minerals and igneous rocks that contain iron oxides (Welch and others, 1988), both of which are present in the study area. Elevated concentrations of arsenic have been documented in nearby areas of western Washington and are thought to be due to natural conditions. In particular, on the north end of nearby Lummi Island, concentrations commonly ranging from 30 to 50 µg/L but as large as 465 µg/L were reported in water from numerous wells (D. P. Garland, Washington Department of Ecology, written commun., 1993; V. A. Stern, Washington Department of Health, written commun., 1993).

Barium, which occurs naturally, was present in five samples, ranging in concentration from 15 to 63 µg/L (table 7); the median concentration was 48 µg/L. Zinc was also present in all samples, but the concentrations varied greatly, ranging from 6 to 540 µg/L. A major anthropogenic source of zinc is the pipe used in wells and in home plumbing systems. Concentrations of barium and zinc were well within applicable drinking water regulations in all cases.

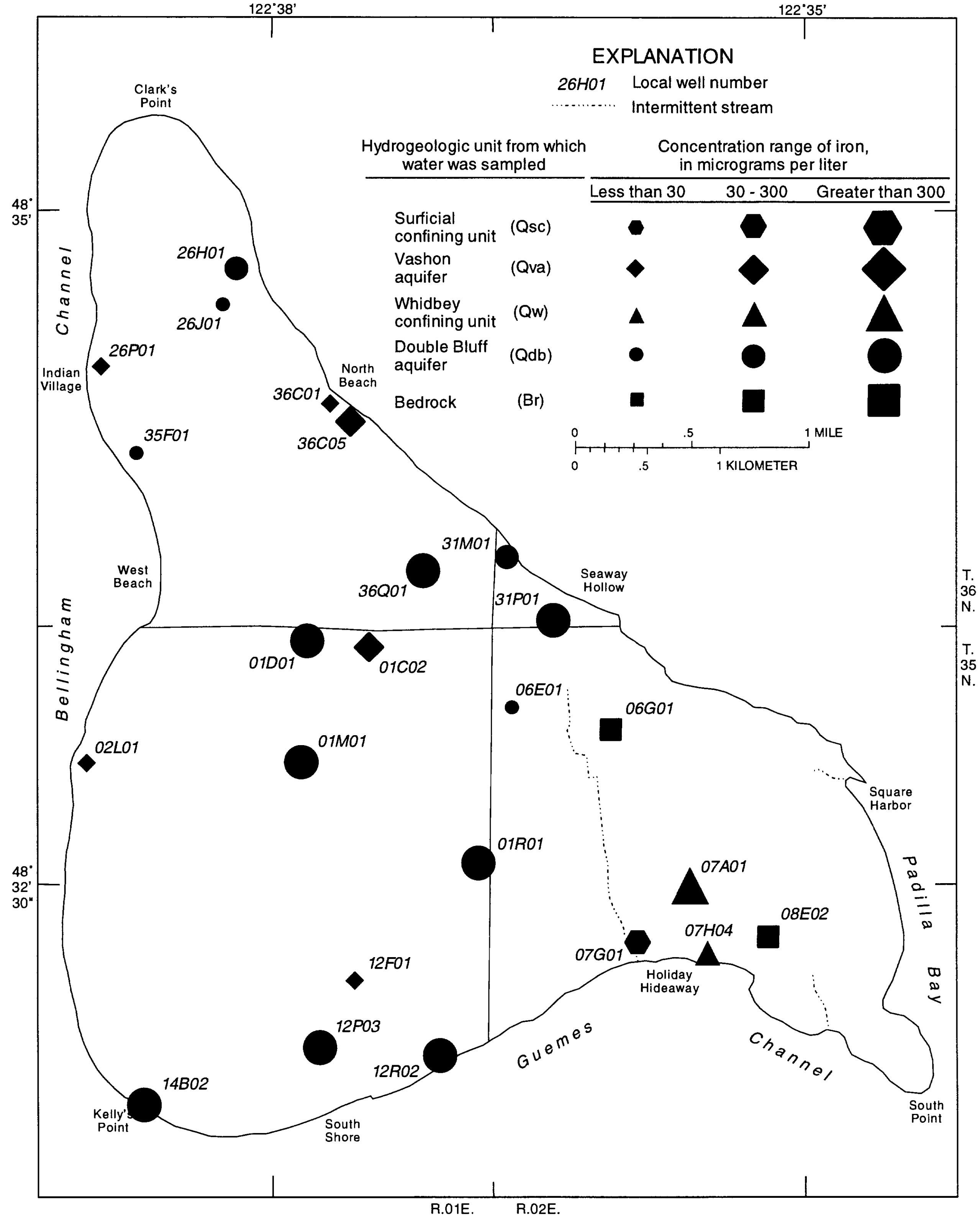


Figure 26.--Areal distribution of iron concentrations, June 1992.

Table 7.--Summary of concentrations of selected trace constituents, June 1992

[Concentrations in micrograms per liter unless otherwise noted. All are dissolved concentrations. <, not detected at the given concentration; pCi/L, picocuries per liter]

Constituent	Number of samples	Concentrations: Minimum	Concentrations: Median	Concentrations: Maximum	Wells with trace constituent present: Number	Wells with trace constituent present: Percent
Arsenic	24	<1	<1	14	5	21
Barium	5	15	48	63	5	100
Cadmium	5	<1	<1	<1	0	0
Chromium	5	<1	<1	1	1	20
Copper	5	<1	<1	4	1	20
Lead	5	<1	<1	<1	0	0
Mercury	5	<.1	<.1	<.1	0	0
Selenium	5	<1	<1	2	1	20
Silver	5	<1	<1	<1	0	0
Zinc	5	6	200	540	5	100
Radon (pCi/L)	5	<80	120	390	3	60

Radon concentrations ranged from less than 80 pCi/L (picocuries per liter) to 390 pCi/L, with a median concentration of 120 pCi/L. The picocurie is a measure of radioactivity, not mass. Radon is a naturally occurring element and is part of the radioactive decay chain of uranium. The USEPA has proposed an MCL of 300 pCi/L. However, the radon concentrations observed on Guemes Island are considerably less than those found in ground water in Thurston and King Counties, where median radon concentrations were 410 and 250 pCi/L, respectively (Dion and others, 1994; Turney and others, 1995).

The remaining trace elements are rarely present, and when present are not significant chemically or in terms of health. Chromium was present in one sample, from well 35N/02E-08E02, but at a concentration of only 1 µg/L. Such levels likely reflect the natural occurrence of chromium in the mineral matrix. Copper and selenium were present only in the sample from well 36N/01E-26J01, at concentrations of 4 and 2 µg/L, respectively. The source for copper is likely plumbing systems because, like zinc, it is commonly used in pipe and fixtures. Selenium, on the other hand, is probably naturally occurring and may be associated with seawater intrusion or connate water; selenium at small concentrations is a natural component of seawater. Finally, cadmium, lead, mercury, and silver were not detected in any samples.

Volatile Organic Compounds

The individual volatile organic compounds analyzed for are shown in table 8. The presence of any of these volatile organic compounds is generally considered to represent some type of anthropogenic source. The wells sampled for volatile organic compounds were selected because they are located in populated areas. Trace concentrations of volatile organic compounds were detected in three of the samples collected from five wells (table 9).

Trichloromethane and 1,1,1-trichloroethane, both commonly used as solvents, were detected at 0.2 µg/L in water from wells 36N/01E-36C05 and 35N/O1E-02L01, respectively (table 9). Benzene, which is present in gasoline, was detected in water from well 36N/01E-26P01 at 0.2 µg/L. Possible sources of these volatile organic compounds include sampling and laboratory contaminants, accidental spills, improper disposal, and in the case of benzene, leaking fuel storage tanks. All samples containing a volatile organic compound were taken from shallow wells ranging in depth from 26 to 64 feet. The two samples that had no volatile organic compounds detected were both from relatively deep wells (90 and 114 feet). It is important to recognize, however, that the compounds detected were at low concentrations and that resampling would be needed in order to verify their presence or absence.

Table 8.--Volatile organic compounds analyzed, June 1992

[Volatile organic compounds listed below are those analyzed for in samples from five wells. Except for those note
8, none was present at the detection limit of 0.2 micrograms per liter]

Constituents

Chloromethane
Dichloromethane
Trichloromethane
Tetrachloromethane
Bromomethane

Bromochloromethane
Dibromomethane
Tribromomethane
Bromodichloromethane
Dibromochloromethane

Trichlorofluoromethane
Dichlorodifluoromethane
Chloroethane
1,1-dichloroethane
1,2-dichloroethane

1,1,1-trichloroethane
1,1,2-trichloroethane
1,1,1,2-tetrachloroethane
1,1,2,2-tetrachloroethane
1,2-dibromoethane

Trichlorotrifluoroethane
Chloroethene
1,1-dichloroethene
Cis-1,2-dichloroethene
Trans-1,2-dichloroethene

Trichloroethene
Tetrachloroethene
Cyanoethene
1,2-dichloropropane
1,3-dichloropropane

2,2-dichloropropane
1,2,3-trichloropropane
1,2-dibromo,3-chloropropane
Propenol
1,1-dichloropropene

Cis-1,3-dichloropropene
Trans-1,3-dichloropropene
Hexachlorobutadiene
2-chloroethylvinylether
Tert-butylmethylether

Benzene
Chlorobenzene
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene

1,2,3-trichlorobenzene
1,2,4-trichlorobenzene
Bromobenzene
Toluene
o-chlorotoluene

p-chlorotoluene
Dimethylbenzene
Ethylbenzene
Ethenylbenzene
1,2,4-trimethylbenzene

1,3,5-trimethylbenzene
N-propylbenzene
Isopropylbenzene
N-butylbenzene
Sec-butylbenzene

Tert-butylbenzene
1,methyl-4-propylbenzene
Naphthalene

Concentrations of volatile organic compounds in wells where they were detected
geologic unit: Qva, Vashon aquifer]

Local well number	Depth of well (feet)	Hydrogeologic unit	Constituent	Concentration (micrograms per liter)
35N/01E-02L01	64	Qva	1,1,1-trichloroethane	0.2
36N/01E-26P01	26	Qva	Benzene	.2
36N/01E-36C05	41.5	Qva	Trichloromethane	.2

Septage-Related Compounds

Methylene blue active substances (MBAS) and boron are present in household waste water as detergent residues, and have been identified in septage-contaminated ground water (LeBlanc, 1984). Boron is also present in seawater and rocks, however, and its presence does not necessarily indicate septage contamination. The presence of MBAS or boron in ground water, if found in conjunction with nitrate, may indicate contamination from septic systems. Concentrations of MBAS and boron were determined for samples from 12 wells, mostly situated in the more populated areas of the island, and are included in Appendix 8.

MBAS was detected at small concentrations (0.02 and 0.03 mg/L) in water from two wells: 36N/01E-26P01 and 36N/01E-36C05. Nitrate was present in the same samples at the relatively high concentrations of 4.80 and 1.90 mg/L, respectively.

Boron concentrations ranged from 20 to 420 µg/L, with a median concentration of 50 µg/L. Boron concentrations measured during this study correlated poorly with MBAS and nitrate concentrations. In fact, small concentrations of boron (20 µg/L) were measured in samples from wells with detectable concentrations of MBAS (36N/01E-26P01 and 36N/01E-36C05). Samples with the three largest boron concentrations (420, 120, and 110 µg/L) were from wells 35N/02E-07H04, 36N/01E-26H01, and 36N/01E-36C01, respectively, which had MBAS concentrations below the 0.02 µg/L detection limit. Nitrate, however, although undetected in the sample from well 35N/02E-07H04, was detected in the other samples at 3.40 and 0.75 mg/L, respectively.

Bacteria

Fecal-streptococci bacteria were detected in water from 1 of the 24 wells sampled; fecal-coliform bacteria were not detected in any of the sampled wells. Both types of bacteria are indicators; that is, they are not pathogenic themselves, but can occur in conjunction with pathogenic bacteria. The only sample with bacteria present was from a 35-feet deep dug well (35N/02E-07G01).

Water Types

Another way to describe the composition of water is to determine the water types (or dominant ions) from the analytical results. First, concentrations of the major ions are converted from milligrams, which are based on mass, to milliequivalents, which are based on the number of molecules and electrical charge. A milliequivalent is the amount of a compound, in this case one of the ions, that either furnishes or reacts with a given amount of H^+ or OH^-. When expressed as milliequivalents, all cations or anions are equivalent for the purpose of balancing equations; a milliequivalent of sulfate will balance a milliequivalent of calcium. The milliequivalents of all the cations and anions are each summed to obtain a cation sum and anion sum, in milliequivalents. Because the water is electrically neutral, the cation and anion sums should be close in value. The contribution of each ion to the appropriate sum is then calculated as a percentage. The cation(s) and anion(s) that are the largest contributors to their respective sums define the water types.

To make the determination of water types easier, the percentages of cations and anions for a given sample, as milliequivalents, are plotted on a trilinear, or Piper, diagram, as shown in figure 27. The water type is then determined from the area of the diagram in which the sample is plotted. One plot defines the dominant cation, the other the dominant anion. Combined water types, where more than one cation or anion dominate, are possible and are actually common. An inspection of the explanation diagram in figure 27 shows that to be defined as a dominant ion, an ion must account for 50 percent or more of the cation or anion sum, and the analysis will be plotted near one of the corners. On the other hand, an ion that accounts for less than 20 percent of the sum will not be included in the water type. An exception to the latter case occurs when two ions, such as chloride and nitrate, are included on a single axis of the plot. If both together contribute 20 percent, then the sample will plot as though chloride is a dominant anion, even though chloride and nitrate contributions individually may be less than 20 percent. For this study, the actual percentages were used to determine the water type, and if both were less than 20 percent neither was considered dominant. Also, for combined water types, the ions were listed in order of dominance. For example, a calcium-magnesium bicarbonate type has more calcium than magnesium, and a magnesium-calcium bicarbonate type has more magnesium than calcium, but both plot in the same section of the diagram. It also should be noted that the diagram, which is based on percentages, does not show actual concentrations or milliequivalents.

All 24 samples were plotted on a single trilinear diagram (fig. 27) with a different symbol representing each hydrogeologic unit. Samples with magnesium and calcium as the dominant cations and bicarbonate as the dominant anion were fairly common throughout the study area. Such water types are common in aquifers made up of the glacial and interglacial deposits of western Washington (Van Denburgh and Santos, 1965; Turney, 1986; Dion and others, 1994). High percentages of sodium, chloride, and sulfate may indicate varying degrees of seawater intrusion, or possibly the presence of incompletely flushed connate water. Five samples, from wells 35N/01E-02L01, 36N/01E-26H01, 36N/01E-26J01, 36N/01E-36C01, and 36N/01E-36Q01, had sodium chloride water types, a possible indication of seawater intrusion.

Drinking Water Regulations

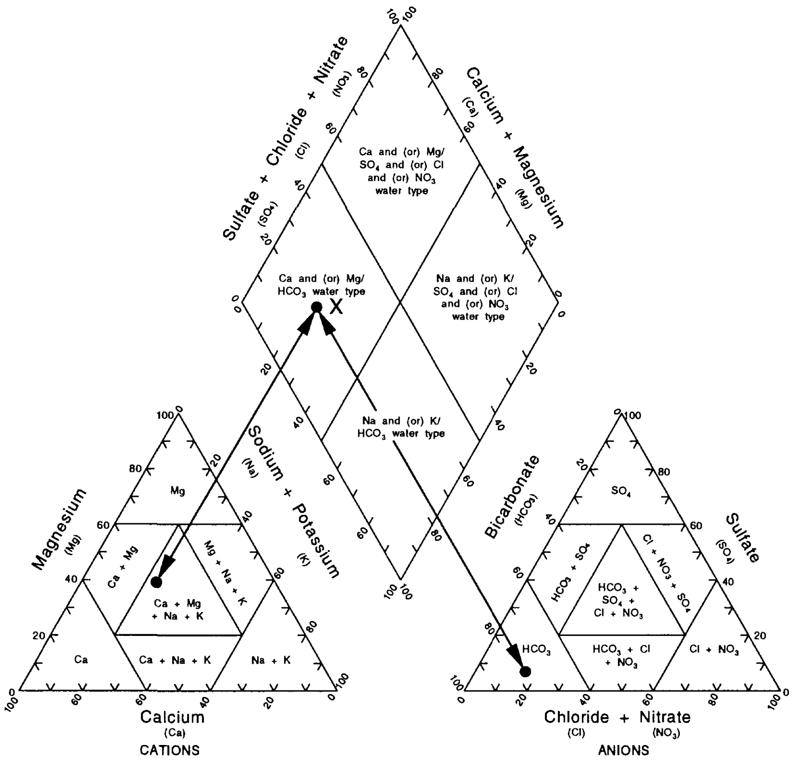
The USEPA establishes maximum concentrations of constituents allowed in public drinking water. Primary drinking water regulations concern constituents that affect human health. The maximum concentration allowed for each constituent is referred to by USEPA as the maximum contaminant level, or MCL (U.S. Environmental Protection Agency, 1988a, 1988b, 1989, 1991), and is legally enforceable by the USEPA or State regulatory agencies. Secondary drinking water regulations (U.S. Environmental Protection Agency, 1988c, 1991) pertain to the esthetic quality of water and are guidelines only. A secondary maximum contaminant level, or SMCL, is not enforceable by a Federal agency. Both sets of regulations legally apply only to public supplies, but also can be used to help assess the quality of water from private systems.

The drinking water regulations for all constituents analyzed in this study are shown in table 10. Because the standards are subject to revision, this report will use the MCL or SMCL in effect at the time the samples were collected. Along with each MCL or SMCL, the number of wells from which samples did not meet the standard is also shown in table 10.

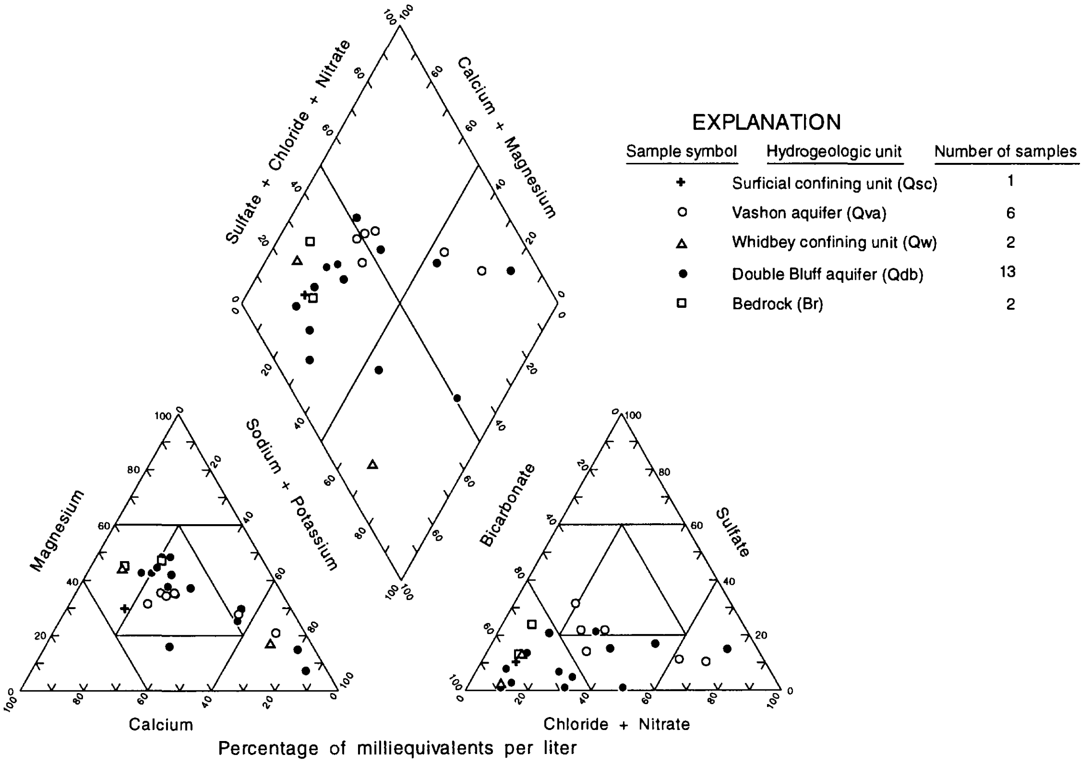
None of the primary MCLs was exceeded during this study. However, if the USEPA lowers the MCL for arsenic to 3 µg/L or less, as proposed, the sample from one well (36N/01E-36Q01) would exceed it. The current arsenic MCL of 50 µg/L is based on the concentration at which chronic arsenic poisoning can occur if continually ingested. The USEPA is considering lowering the current MCL because it does not take into account the carcinogenic effects of arsenic. Total-coliform bacteria were not analyzed for, but fecal-coliform bacteria, which are a subgroup of total coliform, were not detected in any of the samples.

Of 24 wells sampled, samples from 11, or 46 percent, did not meet the manganese SMCL of 50 µg/L. However, as described elsewhere, these large manganese concentrations occur naturally and are common in the ground waters of Puget Lowland. The SMCL for manganese is based on the level at which staining of laundry and plumbing fixtures may occur; the stain is usually black or purple. In addition, the taste of the water may be affected at concentrations greater than 50 µg/L. Extremely large concentrations of manganese may cause human health problems, but no such instances have ever been reported in the United States (U.S. Environmental Protection Agency, 1986).

Concentrations of iron in samples from nine wells (38 percent) did not meet the SMCL for iron of 300 µg/L. As with manganese, these large concentrations are likely due to natural causes. Iron concentrations exceeding the SMCL may cause an objectionable taste and may stain plumbing fixtures a characteristic red or brown color.



Example of a trilinear diagram, showing water types represented in each area. Numbers are percentages. Example "X" is a magnesium-calcium-sodium/bicarbonate water type



EXPLANATION

Sample symbol	Hydrogeologic unit	Number of samples
+	Surficial confining unit (Qsc)	1
○	Vashon aquifer (Qva)	6
△	Whidbey confining unit (Qw)	2
●	Double Bluff aquifer (Qdb)	13
□	Bedrock (Br)	2

Chemical character of ground water on Guemes Island based on percentage of major ions.

Figure 27.--Trilinear diagrams showing the chemical character of ground water from 24 wells on Guemes Island, June 1992.

Table 10.--Drinking water regulations and the number of samples not meeting them
[mg/L, milligrams per liter; µg/L, micrograms per liter; cols. per 100 mL, colonies per 100 milliliters]

Constituent	Maximum contaminant level (MCL) or secondary MCL (SMCL)	Number of wells with samples not meeting MCL or SMCL	Percentage of wells not meeting MCL	Total number of wells sampled
		Primary drinking water regulations		
Inorganic				
Fluoride	4 mg/L	0	0	24
Nitrate (as nitrogen)	10 mg/L	0	0	23
Arsenic	50 µg/L	0	0	24
Barium	2,000 µg/L	0	0	5
Cadmium	5 µg/L	0	0	5
Chromium	100 µg/L	0	0	5
Lead	50 µg/L	0	0	5
Mercury	2 µg/L	0	0	5
Selenium	50 µg/L	0	0	5
Silver	50 µg/L	0	0	5
Organic				
Trihalomethanes[1]	100 µg/L	0	0	5
Tetrachloromethane	5 µg/L	0	0	5
1,2-dichloroethane	5 µg/L	0	0	5
1,1,1-trichloroethane	200 µg/L	0	0	5
1,2-dibromoethane	.05 µg/L	0	0	5
Chloroethene	2 µg/L	0	0	5
1,1-dichloroethene	7 µg/L	0	0	5
Cis-1,2-dichloroethene	70 µg/L	0	0	5
Trans-1,2-dichloroethene	100 µg/L	0	0	5
Trichloroethene	5 µg/L	0	0	5
Tetrachloroethene	5 µg/L	0	0	5
1,2-dichloropropane	5 µg/L	0	0	5
Benzene	5 µg/L	0	0	5
Chlorobenzene	100 µg/L	0	0	5
1,2-dichlorobenzene	600 µg/L	0	0	5
1,3-dichlorobenzene	600 µg/L	0	0	5
1,4-dichlorobenzene	75 µg/L	0	0	5
Toluene	1,000 µg/L	0	0	5
Xylene	10,000 µg/L	0	0	5
Ethylbenzene	700 µg/L	0	0	5
Ethenylbenzene	100 µg/L	0	0	5
Microbiological				
Total coliform	0 cols. per 100 mL	0	0	24

Table 10.--Drinking water regulations and the number of samples not meeting them--Continued

Constituent	Maximum contaminant level (MCL) or secondary MCL (SMCL)	Number of wells with samples not meeting MCL or SMCL	Percentage of wells not meeting MCL	Total number of wells sampled
		Secondary drinking water regulations		
Inorganic				
pH	6.5-8.5 units	1	4	24
Sulfate	250 mg/L	0	0	24
Chloride	250 mg/L	2	8	24
Fluoride	2 mg/L	0	0	24
Dissolved solids	500 mg/L	4	17	24
Iron	300 µg/L	9	38	24
Manganese	50 µg/L	11	46	24
Copper	1,000 µg/L	0	0	5
Silver	100 µg/L	0	0	5
Zinc	5,000 µg/L	0	0	5
Organic				
MBAS (methylene blue active substances)	.5 mg/L	0	0	12

[1] Includes trichloromethane, tribromomethane, bromodichloromethane, and dibromochloromethane.

Only 1 of the 24 samples had a pH value (6.2) outside the acceptable range of 6.5 to 8.5. The pH range used in the SMCL is based largely on the acceptable range for marine aquatic life, which is not readily applicable to ground-water systems. Water with a pH range from 5 to 9 is usually considered acceptable for domestic uses (U.S. Environmental Protection Agency, 1986). Water with small pH values may be corrosive to pipes and plumbing and can increase copper, lead, zinc, and cadmium concentrations. Water with large pH values may adversely affect the chlorination process and may cause carbonate deposits to form in pipes.

Samples from two wells (8 percent) had chloride concentrations above the SMCL of 250 mg/L: concentrations in wells 36N/01E-26H01 and 36N/01E-36C01 were 310 and 330 mg/L, respectively. The SMCL for chloride is the level at which a salty taste is discernible by most people.

Samples from four wells (17 percent) had dissolved-solids concentrations greater than the SMCL of 500 mg/L; the concentrations ranged from 543 to 760 mg/L. The SMCL for dissolved solids is based largely on taste, although other undesirable properties such as corrosiveness or hardness may be associated with large dissolved-solids concentrations.

The USEPA is in the process of establishing an MCL for radon of 300 pCi/L. Only one sample did not meet this proposed MCL.

For more information on drinking water regulations, the reader is referred to documents of the U.S. Environmental Protection Agency (1976, 1986, 1988a, 1988b, 1988c, 1989, 1991).

FUTURE MONITORING AND ADDITIONAL STUDIES

Long-term ground-water level and ground-water quality data for Guemes Island are generally sparse. Such data could be useful in detecting and characterizing natural or anthropogenic changes in the ground-water system. Measuring water levels in several wells monthly or bimonthly, with a representative number of wells in the major aquifers, Qva and Qdb, would allow the delineation of temporal trends. Declining water levels might indicate that the ground-water resource was being pumped faster than it was being recharged from rainfall.

A minimum level of water-quality monitoring would involve collecting samples periodically from selected wells for the analysis of chloride, nitrate, and bacteria. At the time of collection, perhaps quarterly, pH, specific conductance, dissolved-oxygen concentration, and temperature also could be measured in the field. Samples could be collected and analyzed for concentrations of common ions and trace elements at times of highest and lowest water levels. The resulting data could be compared to that collected during this and previous studies in order to identify cyclic or long-term changes in water chemistry. Degradation of ground-water quality might indicate inappropriate land-use practices or, in the case of seawater intrusion, overpumping of the ground-water resource. Long-term monitoring of chloride concentration and water levels in coastal wells finished below sea level would detect seawater intrusion.

Any monitoring efforts would need to be reviewed at least annually to ensure that the objectives of the data collection were being met. Modifications could be made as necessary, but should be kept to a minimum because the success of any monitoring program depends largely on its continuity.

The depth to bedrock on most of the island is mostly unknown, and therefore the total thickness of the potential water-bearing sediments above the bedrock is also unknown. Geophysical surveys and (or) drilling could help determine the geometry of the top of the underlying bedrock and of the island's most extensive and heavily used aquifer (Qdb).

The water-level maps constructed for this report could be refined with additional data, thereby allowing a better evaluation of ground-water flow directions. In the case of Qdb, which has a relatively flat potentiometric surface, more data points (water levels) and (or) more-accurate water-level altitudes would be useful in generating a water-level contour map of the unit. Refinement of water-level altitudes would involve determining the altitudes of the inventoried well heads more accurately than was done for this study. Additional data points could be gathered by locating and measuring water levels in new or previously uninventoried wells, preferably in areas where well coverage was limited at the time of this study.

The effects of additional ground-water development on the island's ground-water system cannot be accurately quantified at present. A mathematical ground-water model of the island is a tool that could help determine the effects of increased ground-water withdrawals.

SUMMARY AND CONCLUSIONS

The ground-water resource of Guemes Island provides all of the freshwater used by 535 year-round residents and an additional 1,605 seasonal residents. Population growth on the island is increasing the demand for ground water. Three water-use categories were recognized on the island: livestock (2 percent), public supply (28 percent), and domestic self-supplied (70 percent).

Guemes Island is composed of a sequence of unconsolidated glacial and interglacial deposits overlying consolidated bedrock. The unconsolidated deposits are lithologically variable and often are not present islandwide. Bedrock is exposed on the eastern end of the island; depth to bedrock on the remainder of the island is not known everywhere, but in places it may be greater than 300 feet. Six hydrogeologic units were identified on Guemes Island:

(1) Beach aquifer (Qb);

(2) Surficial confining unit (Qsc);

(3) Vashon aquifer (Qva);

(4) Whidbey confining unit (Qw);

(5) Double Bluff aquifer (Qdb); and

(6) Bedrock unit (Br).

The Double Bluff aquifer is the most laterally extensive hydrogeologic unit and is the unit from which most water is obtained. This unit generally occurs at or below sea level and the total thickness of the aquifer is unknown. The Vashon aquifer does not occur islandwide, ranges in thickness from zero to 100 feet, and is saturated only in places. The Beach aquifer occurs only in near-shore areas where beach deposits have accumulated to thicknesses of 10 to 20 feet.

Three less-permeable units, the Bedrock unit, the Whidbey confining unit, and the Surficial confining unit, occur on Guemes Island. The Bedrock unit is exposed in the southeastern part of the island and underlies the unconsolidated deposits throughout the rest of the island. Few wells are completed in the Bedrock unit, and those that are tend to have low yields of water. The Whidbey confining unit is generally fine-grained but has coarse-grained lenses that supply small yields of water to numerous wells. This unit is generally less than 120 feet thick and is found at depth over much of the island. The Surficial confining unit, which is composed of till and (or) glaciomarine drift, occurs on the surface of most of the island. The unit is commonly 20 feet thick where till alone occurs, but may be 200 or more feet thick where glaciomarine drift occurs. Few inventoried wells are completed in Qsc.

Hydraulic conductivity values of the hydrogeolgic units were estimated using specific-capacity data. Median values of hydraulic conductivity for the Double Bluff aquifer, the Vashon aquifer, the Whidbey confining unit, and the Surficial confining unit are 68, 43, 1.6, and 23, respectively. Data were unavailable for the Beach aquifer and the Bedrock unit.

An approximate water budget of the island indicates that of the 21-29 inches of precipitation falling on the island in a typical year, 0-4 inches runs off, 12-22 inches evapotranspires, and 2-10 inches recharges the groundwater system. Only 0.1-0.3 inch of the recharge is withdrawn (discharges) from wells. Discharge to springs and the sea was not quantified.

Although current (1992) withdrawals from wells may appear to be of little significance, the locations and density of pumping wells are critical factors affecting the ground-water system, especially in an island setting. Overpumping in near-shore areas could move the freshwater-seawater interface landward, thereby increasing the likelihood of seawater intrusion. Additionally, it is unknown how much of the recharge actually moves downward to the principal aquifer on the island, the Double Bluff aquifer. A significant part of this recharge water may be intercepted by pumping wells completed in overlying units, or part of the recharge water may leave the ground-water system at natural discharge points.

A water-level map for the Double Bluff aquifer illustrates that the unit has a fairly flat potentiometric surface, with hydraulic head varying less than 30 feet across the island. Water levels in wells completed in this aquifer generally had less than 0.5 foot of seasonal fluctuation. A water-level map for the Vashon aquifer shows that head ranges from 0 to 80 feet across the island. Water levels in wells completed in this unit generally showed slightly more than 2 feet of seasonal fluctuation. However, water-level fluctuations up to 7 feet were observed in coastal wells in response to tidal influences.

The chemical quality of ground water on the island is generally suitable for domestic use. Dissolved-solids concentrations ranged from 141 to 760 mg/L, with a median concentration of 236 mg/L. Dissolved-solids concentrations tended to be larger in the deeper units, and most water was moderately hard. Typically, magnesium, calcium, and bicarbonate were the dominant ions. Chloride concentrations ranged from 13 to 330 mg/L, with a median concentration of 21 mg/L. Nitrate concentrations were generally small, ranging from less than 0.05 to 6.8 mg/L, with a median concentration of 0.08 mg/L.

Iron and manganese concentrations varied greatly and in some cases were large. Iron concentrations ranged from 10 to 7,100 μg/L, with a median concentration of 160 μg/L. The largest concentrations of iron were found in the Double Bluff aquifer. Manganese concentrations ranged from 1 to 1,500 μg/L, with a median concentration of 34 μg/L. The largest concentrations of manganese were found in the Whidbey confining unit.

Arsenic was detected in 5 of 24 samples, at concentrations ranging from 1 to 14 μg/L. The arsenic probably occurs naturally and is present in ground water in other areas of western Washington. Radon concentrations ranged from less than 80 to 390 pCi/L, with a median concentration of 120 pCi/L.

Trace concentrations of volatile organic compounds were detected in three water samples. All of the samples with a volatile organic compound (VOC) present were collected from shallow wells. Possible sources of the VOCs (trichloromethane, 1,1,1-trichloroethane, and benzene) include sampling and laboratory contamination, accidental spills, improper disposal of fuels or solvents, or leaking storage tanks.

Concentrations of selected constituents were compared with maximum contaminant levels (MCLs) for applicable USEPA drinking water regulations. No primary MCLs were exceeded during this study. The secondary maximum contaminant level (SMCL) of 500 mg/L for dissolved solids was exceeded in four samples. Two of the four samples also had chloride concentrations larger than the chloride SMCL of 250 mg/L, suggesting seawater intrusion conditions. More samples did not meet the SMCL for manganese than for any other constituent; 11 samples exceeded the limit of 50 µg/L. Similarly, nine samples did not meet the SMCL of 300 µg/L for iron. Only one sample, with a pH of 6.2, exceeded the lower limit of the SMCL for pH. All other applicable drinking water regulations were met, including those for trace elements and organic compounds. However, one sample out of the five that were analyzed for radon would not meet the proposed radon MCL of 300 pCi/L.

Chloride concentrations in West Beach, North Beach, and Indian Village were generally above 100 mg/L, perhaps indicating the early stages of seawater intrusion. Chloride concentrations greater than 20 mg/L, but less than 100 mg/L, were found in water samples collected near Kelly's Point and along South Shore.

Chloride concentrations were determined monthly in water samples collected from 12 coastal wells. Water from wells with chloride concentrations generally in excess of 100 mg/L showed the greatest seasonal variation, with larger values occurring from April through September and smaller values occurring from October through March. Seasonal variations in chloride concentration are likely caused by shifting of the freshwater-seawater interface. This shifting most likely is due to seasonal changes in pumpage and in recharge to the ground-water system.

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Appendix 1.--Physical and hydrologic data for the inventoried wells

[Hydrogeologic unit: Qb, Beach aquifer; Qsc, Surficial confining unit; Qva, Vashon aquifer; Qw, Whidbey confining unit; Qdb, Double Bluff aquifer; and Br, Bedrock. Use of water: H, domestic; I, irrigation; P, public supply; and U, unused. Water level code indicates status of well at time of visit; R, recently pumped. Remarks: L, driller's (lithologic) log available; C, project observation well for chloride concentration; and W, project observation well for water level. --, not determined]

Local well number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Hydro-geo-logic unit	Altitude of land surface (feet)	Depth of well (feet)	Surface casing dia-meter (in.)	Well yield (gallons per minute)	Draw-down (feet)	Use of water	Water level below land surface (feet)	Date water level measured	Estimated horizontal hydraulic conductivity (feet per day)	Remarks
35N/01E-01A01	48°33’24”	122°36’48”	Qdb	150	156	6	20	10	H	134.25	10-12-91	110	L,W
35N/01E-01A02	48°33’15”	122°36’47”	Qdb	145	185	6	--	--	H	133.31	10-30-91	--	--
35N/01E-01C01	48°33’20”	122°37’28”	Qva	145	92	6	6	4	H	78.80	10-17-91	42	L
35N/01E-01C02	48°33’23”	122°37’27”	Qva	130	70	6	20	0	H	51.92	10-11-91	--	L
35N/01E-01D01	48°33’24”	122°37’48”	Qdb	70	90	6	30	13	H	65.30	10-29-91	140	L
35N/01E-01F01	48°33’04”	122°37’28”	Qdb	165	180	6	--	--	H	157.86 R	10-18-91	--	--
35N/01E-01H01	48°33’02”	122°36’47”	Qdb	140	166	6	--	--	H	--	--	--	--
35N/01E-01M01	48°32’57”	122°37’50”	Qdb	160	185	6	12	12	H	157.04	10-10-91	--	L,W
35N/01E-01R01	48°32’35”	122°36’50”	Qdb	120	228	6	12	66	H	90.85	10-18-91	7.4	L,W
35N/01E-02A01	48°33’17”	122°38’23”	Qdb	50	83	6	15	0	P	51.63	10-11-91	--	L
35N/01E-02B01	48°33’17”	122°38’33”	Qb	20	25	36	--	--	P	13.62	10-16-91	--	--
35N/01E-02G01	48°33’01”	122°38’31”	Qdb	122	158	6	--	--	--	117.68	10-17-91	--	L
35N/01E-02L01	48°32’57”	122°39’02”	Qva	19	64	6	--	--	P	15.65	10-10-91	--	--,C,W
35N/01E-02L02	48°33’00”	122°39’01”	Qva	16	43	6	--	--	P	8.96	10-10-91	--	--
35N/01E-02L03	48°32’59”	122°38’59”	Qdb	30	107	6	--	--	H	--	--	--	L
35N/01E-02P01	48°32’47”	122°39’02”	Qdb	85	130	6	--	--	H	85.71	10-12-91	--	L
35N/01E-11B01	48°32’32”	122°38’42”	Qdb	105	135	6	--	--	H	100.53	10-10-91	--	L
35N/01E-11E01	48°32’17”	122°39’05”	Qdb	65	120	6	--	--	P	65.47	10-16-91	--	--
35N/01E-11L01	48°31’56”	122°38’54”	Qdb	150	200	6	--	--	H	145.20	10-11-91	--	L
35N/01E-11P01	48°31’52”	122°38’47”	Qdb	100	128	6	--	--	H	107.58	10-29-91	--	L

***Appendix 1**.--Physical and hydrologic data for the inventoried wells--continued*

Local well number	Latitude (degrees)	Longitude (degrees)	Hydro-geo-logic unit	Altitude of land surface (feet)	Depth of well (feet)	Surface casing dia-meter (in.)	Well yield (gallons per minute)	Draw-down (feet)	Use of water	Water level below land surface (feet)	Date water level measured	Estimated horizontal hydraulic conductivity (feet per day)	Remarks
35N/01E-11P02	48°31’49”	122°38’44”	Qdb	72	112	6	45	10	H	61.03	10-10-91	--	L
35N/01E-11P03	48°31’54”	122°38’52”	Qdb	135	158	6	15	0	H	--	--	--	L
35N/01E-11P04	48°31’54”	122°38’55”	Qdb	145	177	6	15	4	H	132.76	10-10-91	180	L
35N/01E-11Q01	48°31’51”	122°38’37”	Qva	80	106	6	20	20	I	66.44	10-16-91	28	L
35N/01E-11Q02	48°31’43”	122°38’41”	Qdb	30	97	6	20	15	H	21.86	12-16-91	60	L,W
35N/01E-11Q03	48°31’43”	122°38’29”	Qdb	40	62	6	20	3	H	43.57	10-10-91	350	L
35N/01E-11R01	48°31’43”	122°38’23”	Qdb	50	60	6	--	--	H	39.30	10-17-91	--	L
35N/01E-11R02	48°31’47”	122°38’10”	Qw	90	114	6	--	--	H	79.62	10-10-91	--	L,C,W
35N/01E-11R03	48°31’48”	122°38’06”	Qw	110	132	6	--	--	H	95.21	10-11-91	--	L
35N/01E-12F01	48°32’09”	122°37’31”	Qva	110	114	6	--	--	H	99.15	10-17-91	--	L
35N/01E-12F02	48°32’12”	122°37’27”	Qva	110	120	6	--	--	H	97.23	10-30-91	--	L
35N/01E-12H02	48°32’16”	122°36’56”	Qdb	79	220	6	4	80	H	--	--	--	L
35N/01E-12K01	48°32’05”	122°37’23”	Qva	95	155	6	10	2	H	84.75	10-17-91	--	L
35N/01E-12L02	48°32’07”	122°37’26”	Qw	110	122	6	--	--	U	97.79	10-17-91	--	L,W
35N/01E-12N01	48°31’47”	122°38’01”	Qw	100	140	6	--	--	H	82.15	10-17-91	--	L
35N/01E-12P02	48°31’44”	122°37’34”	Qsc	30	80	6	--	--	H	--	--	--	--
35N/01E-12P03	48°31’54”	122°37’43”	Qdb	80	260	6	6	70	H	72.36	10-30-91	1.3	L,W
35N/01E-12P04	48°31’45”	122°37’29”	Qdb	25	164	6	45	45	H	16.62	10-17-91	51	L
35N/01E-12Q01	48°31’47”	122°37’23”	Qdb	37	171	6	--	--	H	27.70	10-17-91	--	L
35N/01E-12Q02	48°31’48”	122°37’25”	Qsc	40	65	6	8	23	H	30.67	10-17-91	16	L

Appendix 1.*--Physical and hydrologic data for the inventoried wells--continued*

Local well number	Latitude (degrees)	Longitude (degrees)	Hydro-geo-logic unit	Altitude of land surface (feet)	Depth of well (feet)	Surface casing dia-meter (in.)	Well yield (gallons per minute)	Draw-down (feet)	Use of water	Water level below land surface (feet)	Date water level measured	Estimated horizontal hydraulic conductivity (feet per day)	Remarks
35N/01E-12R01	48°31'54"	122°37'01"	Qdb	65	170	6	7.5	52	H	56.52	10-10-91	6.4	L,C
35N/01E-12R02	48°31'52"	122°37'03"	Qdb	61	158	6	--	--	H	54.80	10-29-91	--	L,W
35N/01E-13C01	48°31'41"	122°37'37"	Qdb	15	165	6	18	105	H	--	--	7.8	L
35N/01E-14A01	48°31'41"	122°38'22"	Qdb	40	65	6	--	--	H	34.97	10-17-91	--	--
35N/01E-14B01	48°31'41"	122°38'40"	Qdb	25	81	6	10	40	H	--	--	12	L
35N/01E-14B02	48°31'41"	122°38'42"	Qdb	20	90	6	15	12	H	--	--	56	L,C
35N/01E-14B03	48°31'41"	122°38'34"	Qdb	30	58	6	20	18	U	18.60	10-18-91	52	L
35N/01E-14B04	48°31'39"	122°38'33"	Qdb	20	63	6	20	22	H	--	--	46	L
35N/02E-05F01	48°33'03"	122°35'00"	Qsc	200	11.5	36	--	--	H	9.28	10-11-91	--	L
35N/02E-06C01	48°33'18"	122°36'12"	Br	90	80	--	--	--	-	--	--	--	L
35N/02E-06C02	48°33'19"	122°36'20"	Qdb	75	98	6	--	--	H	--	--	--	L
35N/02E-06E01	48°33'10"	122°36'39"	Qdb	161	175	6	--	--	H	146.03	10-10-91	--	--
35N/02E-06G01	48°33'05"	122°36'05"	Br	100	165	6	--	--	H	17.30	10-10-91	--	L,W
35N/02E-06G02	48°33'06"	122°35'52"	Br	210	264	6	--	--	H	43.03	10-10-91	--	L
35N/02E-07A01	48°32'29"	122°35'38"	Qw	75	110	6	--	--	H	62.61	10-10-91	--	L,C,W
35N/02E-07A02	48°32'24"	122°35'32"	Qw	85	118	6	--	--	P	--	--	--	L
35N/02E-07A03	48°32'25"	122°35'40"	Qw	65	123	6	--	--	H	52.86	10-09-91	--	L
35N/02E-07A04	48°32'26"	122°35'30"	Qw	90	109	6	--	--	H	76.83	10-09-91	--	L
35N/02E-07A05	48°32'21"	122°35'26"	Qw	130	116	6	2.5	0	H	109.32	10-10-91	--	L
35N/02E-07G01	48°32'18"	122°35'56"	Qsc	45	35	42	--	--	H	1.13	12-17-91	--	--

Appendix 1.--*Physical and hydrologic data for the inventoried wells--continued*

Local well number	Latitude (degrees)	Longitude (degrees)	Hydro-geo-logic unit	Altitude of land surface (feet)	Depth of well (feet)	Surface casing dia-meter (in.)	Well yield (gallons per minute)	Draw-down (feet)	Use of water	Water level below land surface (feet)	Date water level measured	Estimated horizontal hydraulic conductivity (feet per day)	Remarks
35N/02E-07H01	48°32'18"	122°35'44"	Qdb	45	72	36	40	52	H	38.45	10-09-91	80	L,C,W
35N/02E-07H02	48°32'15"	122°35'35"	Qw	45	104	6	--	--	H	38.72	10-11-91	--	L
35N/02E-07H03	48°32'15"	122°35'27"	Qw	50	81	6	--	--	H	42.16	10-11-91	--	L
35N/02E-07H04	48°32'15"	122°35'32"	Qw	50	158	6	--	--	H	--	--	--	--
35N/02E-08E01	48°32'15"	122°35'23"	Qdb	40	154	6	8	70	H	13.26	10-16-91	5.0	L
35N/02E-08E02	48°32'19"	122°35'12"	Br	80	189	6	--	--	H	--	--	--	L
35N/02E-08E03	48°32'19"	122°35'20"	Qw	75	206	6	11	164	-	14.95	10-11-91	1.6	L
35N/02E-08F01	48°32'09"	122°35'00"	Qw	58	140	8	--	--	P	--	--	--	--
35N/02E-08F02	48°32'09"	122°35'01"	Qw	57	120	6	--	--	P	27.21	10-14-91	--	L
35N/02E-08G01	48°32'12"	122°34'32"	Br	190	403	6	--	--	H	53.16	10-29-91	--	L,W
36N/01E-25N01	48°34'33"	122°37'58"	Qdb	120	125	6	--	--	H	--	--	--	--
36N/01E-25N02	48°34'23"	122°37'48"	Qva	55	69	6	--	--	H	57.43	10-29-91	900	L
36N/01E-25N03	48°34'21"	122°37'47"	Qva	60	77	6	10	2	H	--	--	170	L
36N/01E-25N04	48°34'22"	122°37'48"	Qva	60	72	6	10	3	H	--	--	110	L
36N/01E-25N05	48°34'21"	122°37'44"	Qdb	30	175	6	10	0	H	--	--	--	L
36N/01E-25N06	48°34'21"	122°37'58"	Qdb	150	167	6	5	2.3	H	149.31	10-16-91	130	L,W
36N/01E-26A01	48°34'59"	122°38'14"	Qva	60	25	36	--	--	P	17.98	10-17-91	--	--,C-W
36N/01E-26H01	48°34'47"	122°38'13"	Qdb	130	134	6	15	10	H	111.56	10-12-91	75	L
36N/01E-26J01	48°34'39"	122°38'17"	Qdb	163	180	6	10	1	H	158.28	10-09-91	610	L
36N/01E-26K01	48°34'37"	122°38'32"	Qdb	155	184	6	20	1	H	158.45	10-09-91	1,200	L

Appendix 1.--Physical and hydrologic data for the inventoried wells--continued

Local well number	Latitude (degrees)	Longitude (degrees)	Hydro-geo-logic unit	Altitude of land surface (feet)	Depth of well (feet)	Surface casing dia-meter (in.)	Well yield (gallons per minute)	Draw-down (feet)	Use of water	Water level below land surface (feet)	Date water level measured	Estimated horizontal hydraulic conductivity (feet per day)	Remarks
36N/01E-26K02	48°34’40”	122°38’39”	Qdb	135	180	--	--	--	-	--	--	--	L
36N/01E-26K03	48°34’41”	122°38’37”	Qw	135	105	6	--	--	H	90.63	10-16-91	--	L
36N/01E-26P01	48°34’25”	122°38’58”	Qva	75	26	48	--	--	H	--	--	--	--
36N/01E-26P02	48°34’30”	122°38’57”	Qva	38	23	6	10	14	H	--	--	44	L
36N/01E-26R01	48°34’32”	122°38’07”	Qdb	165	194	6	10	4	U	166.70	10-16-91	130	L
36N/01E-35C01	48°34’17”	122°38’52”	Qdb	100	140	6	--	--	-	--	--	--	--
36N/01E-35F01	48°34’06”	122°38’46”	Qdb	158	182	6	20	2	P	152.92 R	10-29-91	260	L,C,W
36N/01E-35G01	48°33’59”	122°38’32”	Qdb	150	168	6	--	--	P	143.94	10-08-91	--	L
36N/01E-35G02	48°33’55”	122°38’25”	Qdb	130	160	6	--	--	P	129.43	10-08-91	--	L
36N/01E-35Q01	48°33’36”	122°38’34”	Qb	15	10	48	--	--	H	1.22	10-09-91	--	--
36N/01E-35Q01S	48°33’35”	122°38’34”	Qva	30	--	--	--	--	-	--	--	--	--
36N/01E-36C01	48°34’17”	122°37’41”	Qva	45	54	6	--	--	H	43.16	10-09-91	--	L,C
36N/01E-36C02	48°34’15”	122°37’39”	Qva	48	70	48	--	--	P	41.70	10-10-91	--	--
36N/01E-36C03	48°34’11”	122°37’34”	Qva	35	28	8	--	--	P	14.19	10-09-91	--	--,C,W
36N/01E-36C04	48°34’13”	122°37’35”	Qva	25	43	6	10	9	H	30.05	10-11-91	29	L
36N/01E-36C05	48°34’13”	122°37’34”	Qva	25	41.5	6	7	9	H	28.84	10-11-91	21	L
36N/01E-36C06	48°34’13”	122°37’33”	Qva	20	37	6	10	4	H	--	--	150	L
36N/01E-36C07	48°34’19”	122°37’41”	Qva	20	55	--	--	--	H	--	--	--	--
36N/01E-36C08	48°34’16”	122°37’40”	Qva	40	54	8	2	1	H	--	--	--	--
36N/01E-36C09	48°34’20”	122°37’42”	Qva	30	58	6	--	--	H	41.64	10-16-91	--	--

Appendix 1.--Physical and hydrologic data for the inventoried wells--continued

Local well number	Latitude (degrees)	Longitude (degrees)	Hydro-geo-logic unit	Altitude of land surface (feet)	Depth of well (feet)	Surface casing dia-meter (in.)	Well yield (gallons per minute)	Draw-down (feet)	Use of water	Water level below land surface (feet)	Date water level measured	Estimated horizontal hydraulic conductivity (feet per day)	Remarks
36N/01E-36C10	48°34’19”	122°37’42”	Qva	25	--	--	--	--	H	29.42	10-17-91	--	--
36N/01E-36G01	48°33’53”	122°37’10”	Qva	50	71	6	--	--	-	--	--	--	L
36N/01E-36G02	48°33’53”	122°37’08”	Qva	50	71	6	--	--	H	46.12	10-09-91	--	L
36N/01E-36K01	48°33’41”	122°37’24”	Qva	70	12	45	--	--	H	8.64	10-17-91	--	--
36N/01E-36P01	48°33’30”	122°37’33”	Qva	85	49	6	8	35	H	7.47	10-17-91	9.5	L,W
36N/01E-36P02	48°33’35”	122°37’28”	Qsc	90	36	6	5	6	-	15.92	10-18-91	30	L
36N/01E-36Q01	48°33’40”	122°37’09”	Qdb	110	205	6	--	--	H	102.03	10-17-91	--	L,C,W
36N/01E-36Q02	48°33’37”	122°37’13”	Qw	114	69	6	--	--	H	49.43	10-17-91	--	L
36N/01E-36R01	48°33’34”	122°36’47”	Qdb	130	144	6	--	--	H	123.08	10-12-91	--	L
36N/02E-31M01	48°33’43”	122°36’41”	Qdb	90	144	6	--	--	H	111.11 R	10-17-91	--	L
36N/02E-31M02	48°33’44”	122°36’43”	Qdb	90	104	6	--	--	U	--	--	--	L
36N/02E-31P01	48°33’29”	122°36’25”	Qdb	85	168	6	--	--	P	79.20	10-29-91	--	--,C,W

Appendix 2.--Drillers' lithologic logs of wells used in the construction of hydrogeologic sections

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
35N/01E-01A01	Topsoil	6	6	Brown	1976
	Sandy loam	3	9		
	Tan clay	25	34		
	Coarse sand	44	78		
	Gravel	14	92		
	Coarse sand and fine gravel	41	133		
	Large rocks and gravel	4	137		
	Coarse sand	9	146		
	Fine gravel	7	153		
	Coarse gravel and fine sand; water bearing strata 153-156 feet	10	163		
35N/01E-01C02	Topsoil	1	1	Hayes	1990
	Boulder	1	2		
	Brown clay and gravel	18	20		
	Brown sand and gravel	35	55		
	Brown sand, gravel, and water	19	74		
	Gray clay	9	83		
	Brown peat	1	84		
	Brown clay	1	85		
	Gray clay	17	102		
35N/01E-01D01	Dirty sand and gravel	6	6	Dahlman	1990
	Brown clay	12	18		
	Blue clay	67	85		
	Water and gravel	5	90		
35N/01E-01M01	Dirty sand and gravel	8	8	Dahlman	1986
	Brown clay	7	15		
	Blue clay	35	50		
	Sand and gravel	53	103		
	Brown clay	15	118		
	Blue clay	60	178		
	Water and gravel	7	185		
35N/01E-01R01	Gravelly hard clay	31	31	Whidbey	1980
	Hardpan	9	40		
	Soupy sand	18	58		
	Clay	59	117		
	Gravelly hard clay	104	221		
	Water and sand	7	228		

***Appendix 2.**--Drillers' lithologic logs of wells used in the construction of hydrogeologic sections--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
35N/01E-02A01	Topsoil	2	2	Hayes	1988
	Brown sand	2	4		
	Tan clay	14	18		
	Gray clay and gravel	12	30		
	Tan clay	5	35		
	Tan clay, sand, and gravel	4	39		
	Gray dirty sand	2	41		
	Hard gray layered clay	28	69		
	Gray clay, wood, and silt	2	71		
	Gray silt, sand, clay, and seepage	4	75		
	Gray clay	1	76		
	Semi-consolidated gravel, sand, and water	5	81		
	Coarse gravel, sand, and water	2	83		
35N/01E-02G01	Topsoil	2	2	Hayes	1988
	Tan clay and gravel	15	17		
	Brown sand and gravel	38	55		
	Tan clay and gravel	2	57		
	Brown sand and gravel	13	70		
	Dirty gray fine sand and seepage	3	73		
	Hard peat	3	76		
	Gray clay and wood	7	83		
	Gray clay and silt	12	95		
	Tan clay, wood, and silt	22	117		
	Gray clay	16	113		
	Brown silt and sand and seepage	20	153		
	Gray clay	2	155		
	Consolidated brown gravel and water	2	157		
	Brown gravel and water	1	158		
35N/01E-02L03	Dirty sand and gravel	50	50	Dahlman	1989
	Brown clay	15	65		
	Blue clay	37	102		
	Gravel and water	5	107		
35N/01E-11B01	Brown clay	32	32	Dahlman	1988
	Blue clay and gravel	18	50		
	Brown clay and gravel	10	60		
	Sand and gravel	10	70		
	Brown clay	10	80		
	Blue clay	48	128		
	Water and gravel	7	135		

Appendix 2.--*Drillers' lithologic logs of wells used in the construction of hydrogeologic sections--Continued*

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
35N/01E-11P04	Topsoil	1	1	Hayes	1989
	Tan gravel, sand, and clay	15	16		
	Brown sand	14	30		
	Brown sand and gravel	65	95		
	Dark layered gray and brown clay and wood	19	114		
	Layered gray and brown clay	6	120		
	Dirty brown sand	15	135		
	Brown sand	25	160		
	Brown sand and water	19	179		
35N/01E-12H02	Topsoil	5	5	Dahlman	1983
	Brown clay	17	22		
	Blue clay	197	219		
	Water, sand, and clay	1	220		
35N/01E-12R01	Brown clay	10	10		
	Blue clay	140	150		
	Silt, sand, and water	5	155		
	Clay	3	158		
	Silt, sand, and water	12	170		
35N/01E-12R02	Topsoil	2	2	Dahlman	1990
	Brown clay	53	55		
	Blue clay	95	150		
	Fine sand and water	8	158		
35N/02E-05F01	Brown loam	1	1	Skagit	1990
	Sand and gravel	7.5	8.5		
	Sand, gravel, and water	3	11.5		
35N/02E-06C01	Topsoil	2	2	Hayes	1991
	Brown clay and gravel	8	10		
	Green basalt	70	80		
35N/02E-06C02	Brown sand and gravel	17	17	Hayes	1991
	Brown clay and gravel	16	33		
	Brown gravel and sand	42	75		
	Brown gravel and water	16	91		
	Gray gravel, sand, and water	8	99		
35N/02E-06G01	Brown clay	18	18	Dahlman	1981
	Rock	106	124		
	Soft shale with clay	2	126		
	Rock, water at 150 feet	39	165		

Appendix 2.--Drillers' lithologic logs of wells used in the construction of hydrogeologic sections--Continued

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
35N/02E-06G02	Dirty sand and gravel	20	20	Dahlman	1985
	Green granite; water at 183 feet	244	264		
35N/02E-07A02	Topsoil	3	3	Dahlman	1982
	Brown clay	27	30		
	Blue clay	60	90		
	Brown sand	20	110		
	Gray sand and water	8	118		
	Blue clay	22	140		
35N/02E-07A03	Topsoil	2	2	Dahlman	1978
	Clay and stone	78	80		
	Clay and sand	25	105		
	Water and gray sand	18	123		
35N/02E-07A05	Topsoil	1	1	Hayes	1990
	Tan sandy clay	14	15		
	Tan silty clay and gravel	9	24		
	Tan silty clay	30	54		
	Gray clay	13	67		
	Brown clay and scattered gravel	7	74		
	Gray clay	39	113		
	Gray fine sand and water	4	117		
	Gray clay and fine sand	1	118		
35N/02E-08E02	Topsoil	2	2	Olympic	1979
	Gravelly clay	18	20		
	Blue clay	5	25		
	Brown cemented sand and gravel	5	30		
	Gray cemented sand and gravel	23	53		
	Gray clay	88	141		
	Sand and clay	19	160		
	Gray hardpan	26	186		
	Shattered rock	3	189		
35N/02E-08E03	Topsoil	1	1	Hayes	1990
	Brown gravel, sand, and clay	11	12		
	Gray clay and gravel	46	58		
	Gray gravel, sand, and clay and seepage	3	61		
	Gray clay	5	66		
	Gray clay and gravel	4	70		
	Gray clay	29	99		
	Gray clay and little gravel	11	110		
	Gray clay	20	130		
	Gray clay and gravel	1	131		

Appendix 2.--Drillers' lithologic logs of wells used in the construction of hydrogeologic sections--Continued

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
35N/02E-08E03--cont	Gray clay	53	184		
	Gray clay and little gravel	16	200		
	Gray silty sand and water	5	205		
	Layered gray clay and water	12	217		
35N/02E-08G01	Brown clay and rock	12	12	Dahlman	1988
	Hard greenish rock	396	408		
36N/01E-26H01	Gravel	6	6	Whidbey	1976
	Hardpan	19	25		
	Gravel	44	69		
	Sandy clay	23	92		
	Hardpan	15	107		
	Sand	3	110		
	Dry gravel	6	116		
	Water and gravel	18	134		
36N/01E-26R01	Gravel	6	6	Whidbey	1976
	Gravelly clay	16	22		
	Gravel and sand	43	65		
	Gravel	33	98		
	Sand	26	124		
	Gravelly hardpan	16	140		
	Sand and clay	14	154		
	Clay	13	167		
	Hardpan	9	176		
	Gravel, hard	5	181		
	Gravel and water	13	194		
36N/01E-35G02	Topsoil	5	5	Dahlman	1985
	Brown clay	20	25		
	Blue clay	10	35		
	Brown sandy clay	15	50		
	Brown clay and gravel	35	85		
	Brown sand and clay	26	111		
	Blue clay	37	148		
	Water, sand, and gravel	12	160		
36N/01E-36R01	Dirty sand and gravel	10	10	Dahlman	1983
	Blue clay	12	22		
	Brown clay and gravel	21	43		
	Sand	12	55		
	Blue clay	20	75		
	Brown clay	59	134		
	Sand	3	137		
	Gravel and water	7	144		

Appendix 2.--Drillers' lithologic logs of wells used in the construction of hydrogeologic sections--Continued

Local well number	Driller's description of materials	Thickness (feet)	Depth of bottom (feet)	Driller's name	Year drilled
36N/02E-31M01	Sand	3	3	Kounkel	1973
	Gravel	12	15		
	Sand	7	22		
	Gravel	13	35		
	Yellow clay	15	50		
	Clayey sand	45	95		
	Blue clay	30	125		
	Gravel	10	135		
	Sand, gravel, and water	13	148		

Appendix 3.--Monthly precipitation totals

[Anacortes values were obtained from the National Oceanographic and Atmospheric Administration (1992); all units are inches]

	Guemes Island Station[1]						
Date	1	2	3	4	5	6	Anacortes
October 1991	0.98	0.84	0.90	1.05	0.90	1.11	0.84
November 1991	5.37	4.82	5.23	5.01	5.39	5.48	4.94
December 1991	1.99	1.79	2.26	1.96	1.98	2.40	2.25
January 1992	4.46	3.88	4.53	3.84	4.49	5.08	5.14
February 1992	2.28	2.04	2.41	2.25	2.12	2.40	2.47
March 1992	.72	.69	.83	.72	.80	.86	.94
April 1992	3.07	3.09	3.16	3.14	3.04	3.68	3.03
May 1992	.50	.47	.47	.45	.49	.56	.45
June 1992	1.88	1.87	2.10	2.11	2.00	2.31	2.02
July 1992	1.80	1.66	1.81	1.72	1.64	2.28	1.62
August 1992	.98	.84	.88	.90	.96	.98	.71
September 1992	3.42	3.41	3.60	3.46	3.09	3.77	2.99
October 1992	1.68	1.28	1.46	1.48	1.55	1.65	1.56
November 1992	5.40	4.90	5.68	5.50	5.52	5.75	6.31
December 1992	3.16	2.34	2.82	2.70	2.88	2.56	2.93

[1] See figure 14 for location of stations.

Appendix 4.--Monthly water-level measurements

Local well number	Date water level measured	Water level (feet below land surface)
35N/01E-01A01	12-17-91	134.01
	01-04-92	133.99
	02-19-92	134.05
	03-19-92	134.00
	04-21-92	133.95
	05-20-92	134.08
	06-16-92	134.05
	07-18-92	134.08
	08-20-92	134.04
	09-17-92	134.19
	10-21-92	134.23
	11-21-92	134.15
	12-21-92	134.22
35N/01E-01M01	12-16-91	156.72
	01-14-92	156.63
	02-19-92	156.62
	03-18-92	157.10
	04-21-92	156.59
	05-20-92	156.95
	06-16-92	157.50
	07-16-92	157.35
	08-20-92	157.08
	09-16-92	157.05
	10-21-92	156.89
	11-21-92	156.70
	12-21-92	156.64
35N/01E-01R01	12-17-91	90.15
	01-14-92	93.02
	02-19-92	89.62
	03-18-92	89.96
	04-21-92	89.82
	05-20-92	90.18
	06-16-92	90.30
	07-16-92	90.25
	08-20-92	90.36
	09-16-92	91.57
	10-21-92	90.15
	11-19-92	90.49
	12-21-92	90.03
35N/01E-02L01	12-16-91	15.73
	01-14-92	16.23
	02-19-92	16.52
	03-19-92	17.55
	04-21-92	19.17
	05-20-92	20.84
	06-16-92	21.50
	07-18-92	17.56
	08-20-92	17.36
	09-16-92	16.96

Appendix 4.--Monthly water-level measurements--Continued

Local well number	Date water level measured	Water level (feet below land surface)
	10-21-92	16.32
	11-20-92	15.41
	12-21-92	14.99
35N/01E-11Q02	12-16-91	21.86
	01-14-92	21.89
	02-19-92	21.57
	03-18-92	22.19
	04-21-92	21.85
	05-21-92	22.41
	06-16-92	22.34
	07-16-92	22.28
	08-20-92	22.31
	09-16-92	22.34
	10-21-92	22.25
	11-19-92	22.25
	12-21-92	21.96
35N/01E-11R02	12-16-91	79.41
	01-14-92	79.88
	02-19-92	79.82
	03-18-92	79.85
	04-21-92	79.77
	05-20-92	79.82
	06-16-92	79.85
	07-16-92	79.85
	08-20-92	79.90
	09-16-92	79.91
	10-21-92	79.98
	11-20-92	80.06
	12-21-92	80.08
35N/01E-12L02	12-16-91	97.58
	01-14-92	97.94
	02-19-92	97.70
	03-18-92	97.70
	04-21-92	97.28
	05-20-92	97.40
	06-16-92	97.48
	07-16-92	97.52
	08-20-92	97.60
	09-16-92	97.76
	10-22-92	97.90
	11-20-92	98.11
	12-22-92	98.04
35N/01E-12P03	12-16-91	71.40
	01-14-92	71.04
	02-20-92	70.72
	03-18-92	72.43
	04-23-92	70.99
	05-20-92	70.96
	06-16-92	71.31

Appendix 4.--Monthly water-level measurements--Continued

Local well number	Date water level measured	Water level (feet below land surface)
	07-16-92	71.16
	08-21-92	71.23
	09-16-92	72.08
	10-21-92	71.04
	11-21-92	73.99
	12-22-92	72.55
35N/01E-12R02	12-17-91	54.15
	01-14-92	55.02
	02-19-92	53.85
	03-18-92	54.55
	04-21-92	55.08
	06-15-92	55.46
	07-16-92	55.00
	08-20-92	54.90
	09-16-92	55.00
35N/02E-06G01	12-17-91	14.81
	01-14-92	13.36
	02-19-92	10.10
	03-18-92	9.45
	04-21-92	10.99
	05-20-92	13.77
	06-16-92	14.52
	07-16-92	15.03
	08-20-92	16.72
	09-17-92	16.15
	10-21-92	15.47
	11-21-92	13.60
	12-21-92	11.27
35N/02E-07A01	12-17-91	62.35
	01-14-92	62.64
	02-20-92	62.15
	03-18-92	62.50
	04-21-92	62.39
	05-20-92	62.65
	06-16-92	62.78
	07-16-92	62.80
	08-20-92	62.85
	09-17-92	63.10
	10-21-92	62.82
	11-21-92	63.08
	12-21-92	63.43
35N/02E-07H01	12-17-91	1.79
	01-14-92	1.40
	02-19-92	.75
	03-18-92	1.30
	04-21-92	1.18
	05-20-92	33.70
	06-16-92	37.61
	07-16-92	35.43

Appendix 4.--Monthly water-level measurements--Continued

Local well number	Date water level measured	Water level (feet below land surface)
	08-20-92	37.48
	09-16-92	37.70
	10-20-92	37.27
	11-23-92	10.37
	12-22-92	1.08
35N/02E-08G01	12-17-91	49.07
	01-14-92	49.76
	03-18-92	52.59
	04-27-92	30.87
	05-20-92	46.68
	06-16-92	59.54
	07-16-92	72.30
	08-20-92	54.08
	09-16-92	29.27
36N/01E-25N06	12-16-91	148.71
	01-14-92	150.49
	02-19-92	148.07
	03-18-92	148.83
	04-21-92	148.44
	05-22-92	148.86
	06-16-92	148.97
	07-16-92	148.87
	08-20-92	149.09
	09-16-92	149.20
	10-21-92	148.95
	11-20-92	148.92
	12-21-92	148.63
36N/01E-26A01	01-14-92	16.55
	02-19-92	15.91
	03-26-92	17.17
	04-21-92	16.84
	05-21-92	18.37
	06-16-92	17.67
	07-16-92	17.85
	08-20-92	18.02
	09-16-92	17.99
	10-22-92	17.75
	11-20-92	18.57
	12-21-92	17.86
36N/01E-35F01	12-17-91	151.76
	01-14-92	152.69
	03-18-92	152.80
	04-21-92	152.37
	05-22-92	153.34
	06-16-92	153.05
	07-16-92	153.05
	08-20-92	152.89
	09-16-92	152.69
	10-22-92	152.99

ix 4.--Monthly water-level measurements--
ued

Local well number	Date water level measured	Water level (feet below land surface)
	11-20-92	152.03
	12-22-92	152.38
36N/01E-36C03	03-18-92	14.15
	04-21-92	13.42
	05-22-92	13.86
	06-16-92	13.96
	07-16-92	13.87
	08-21-92	13.95
	09-16-92	14.10
	10-21-92	13.91
	11-20-92	13.88
	12-22-92	13.67
36N/01E-36P01	12-16-91	6.67
	01-19-92	6.53
	03-18-92	5.82
	04-21-92	5.71
	05-20-92	6.04
	06-16-92	6.50
	07-16-92	7.15
	08-20-92	7.85
	09-16-92	7.75
	10-22-92	8.15
	11-21-92	7.63
	12-21-92	8.19
36N/01E-36Q01	12-16-91	101.55
	01-14-92	101.38
	02-19-92	101.05
	03-18-92	101.42
	04-21-92	101.36
	05-20-92	101.80
	06-16-92	102.56
	07-16-92	101.88
	08-20-92	102.55
	09-16-92	101.90
	10-21-92	101.70
	11-19-92	101.60
	12-21-92	101.44
36N/02E-31P01	01-14-92	78.92
	02-19-92	78.79
	03-18-92	78.82
	04-21-92	78.70
	05-20-92	79.02
	06-16-92	79.00
	07-16-92	78.90
	08-20-92	78.81
	09-17-92	79.14
	10-21-92	79.06
	11-21-92	79.09
	12-22-92	79.00

Appendix 5.--Monthly values of chloride concentration and specific conductance
[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Local well number	Date	Chloride, dissolved (mg/L as CL)	Specific conductance (µS/cm)
35N/01E-02L01	12-16-91	191	865
	01-14-92	191	938
	02-19-92	196	959
	03-18-92	194	951
	04-21-92	191	941
	05-20-92	214	1,030
	06-16-92	199	972
	07-18-92	218	1,040
	08-20-92	183	917
	09-16-92	197	962
	10-21-92	183	930
	11-20-92	183	935
	12-21-92	179	912
35N/01E-11R02	12-16-91	48.4	441
	01-14-92	48.4	466
	02-19-92	47.5	466
	03-18-92	47.9	466
	04-21-92	47.5	466
	05-20-92	47.5	467
	06-16-92	47.5	467
	07-16-92	48.0	467
	08-20-92	47.0	467
	09-16-92	46.0	461
	10-21-92	46.0	463
	11-20-92	45.0	457
	12-21-92	45.0	456
35N/01E-12R01	12-16-91	30.3	377
	01-14-92	27.1	390
	02-19-92	28.0	394
	03-18-92	28.4	395
	04-21-92	29.1	397
	05-22-92	30.8	402
	06-16-92	33.0	409
	07-16-92	34.0	411
	08-20-92	35.0	418
	09-16-92	35.0	415
	10-21-92	33.0	408
	11-19-92	31.0	403
	12-21-92	31.0	402

Appendix 5.--Monthly values of chloride concentration and specific conductance--Continued

Local well number	Date	Chloride, dissolved (mg/L as CL)	Specific conductance (µS/cm)
35N/01E-14B02	12-16-91	54.2	444
	01-14-92	53.8	476
	03-18-92	53.5	476
	03-18-92	30.5	302
	05-21-92	51.0	530
	06-16-92	44.3	541
	08-20-92	37.0	525
	09-16-92	31.0	488
	10-23-92	32.0	499
	11-21-92	44.0	602
	12-23-92	35.0	352
35N/02E-07A01	12-17-91	21.1	442
	01-14-92	20.7	497
	02-19-92	20.9	505
	03-18-92	20.6	494
	04-21-92	20.9	507
	05-20-92	20.6	504
	06-16-92	20.9	502
	07-16-92	21.0	495
	08-20-92	20	483
	09-17-92	20	451
	10-21-92	21	487
	11-21-92	21	497
	12-21-92	21	447
35N/02E-07H01	12-17-91	49.4	399
	01-14-92	46.3	398
	02-19-92	31.9	298
	03-18-92	30.5	302
	05-21-92	51	530
	06-16-92	44.3	541
	08-20-92	37	525
	09-16-92	31	488
	10-23-92	32	499
	11-21-92	44	602
	12-23-92	35	352

Appendix 5.--Monthly values of chloride concentration and specific conductance--Continued

Local well number	Date	Chloride, dissolved (mg/L as CL)	Specific conductance (µS/cm)
36N/01E-26A01	01-14-92	32.0	457
	02-19-92	32.2	241
	03-18-92	39.0	285
	04-21-92	35.1	276
	05-21-92	37.2	279
	06-16-92	36.5	276
	07-16-92	35.0	267
	08-20-92	64.0	388
	09-16-92	48.0	329
	10-22-92	34.0	271
	11-20-92	41.0	291
	12-21-92	39.0	288
36N/01E-35F01	12-17-91	16.8	277
	01-14-92	15.9	285
	03-18-92	67.0	468
	04-21-92	41.1	378
	05-20-92	19.9	304
	06-16-92	28.4	335
	07-16-92	31.0	347
	08-20-92	44.0	395
	09-16-92	32.0	352
	10-24-92	29.0	345
	11-21-92	31.0	352
	12-23-92	25.0	333
36N/01E-36C01	12-16-91	345	1,310
	01-14-92	348	1,450
	02-19-92	347	1,470
	03-26-92	381	1,570
	04-21-92	368	1,530
	05-22-92	352	1,490
	06-16-92	344	1,450
	07-16-92	346	1,460
	08-20-92	323	1,380
	09-16-92	313	1,350
	10-21-92	309	1,350
	11-20-92	316	1,380
	12-21-92	331	1,430

Appendix 5.--Monthly values of chloride concentration and specific conductance--Continued

Local well number	Date	Chloride, dissolved (mg/L as CL)	Specific conductance (µS/cm)
36N/01E-36C03	03-18-92	86.9	530
	04-21-92	168	818
	05-22-92	189	891
	06-16-92	194	909
	07-16-92	191	892
	08-21-92	215	986
	09-16-92	157	769
	10-21-92	131	692
	11-20-92	144	735
	12-22-92	147	744
36N/01E-36Q01	12-16-91	148	865
	01-14-92	122	868
	02-19-92	125	864
	03-18-92	126	865
	04-21-92	114	845
	05-20-92	149	921
	06-16-92	176	1,020
	07-16-92	167	977
	08-20-92	169	1,030
	09-16-92	180	1,000
	10-21-92	162	963
	11-19-92	153	948
	12-21-92	141	917
36N/02E-31P01	01-14-92	15.6	260
	02-19-92	15.2	261
	03-18-92	14.9	261
	04-21-92	14.9	259
	05-20-92	14.5	257
	06-16-92	14.5	256
	07-16-92	14.0	253
	08-20-92	14.0	252
	09-17-92	14.0	254
	10-21-92	15.0	259
	11-21-92	16.0	261
	12-22-92	15.0	260

Appendix 6.--Values and concentrations of field measurements, common constituents, arsenic, and radon

[deg. C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; mg/L, micrograms per liter; <, not detected at the given concentration; cols. per 100 mL, colonies per 100 milliliters; pCi/L, picocuries per liter; --, not determined]

Local well number	Date	Time	Temperature water (deg. C)	Specific conductance (µS/cm)	Specific conductance lab (µS/cm)	pH, (standard units)	pH, lab (standard units)	Oxygen, dissolved (mg/L)	Hardness total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
35N/01E-01C02	06-15-92	1525	12.5	234	231	6.6	6.8	1.3	78	16
35N/01E-01D01	06-17-92	1205	10.0	358	352	7.4	7.7	.2	140	24
35N/01E-01M01	06-16-92	1300	12.5	345	383	7.7	7.6	.2	160	30
35N/01E-01R01	06-16-92	1705	10.5	334	347	8.1	7.8	<.1	120	25
35N/01E-02L01	06-16-92	1530	10.5	749	972	7.2	7.4	.9	200	31
35N/01E-12F01	06-16-92	1705	12.5	221	219	6.2	6.5	2.5	78	18
35N/01E-12P03	06-17-92	0830	12.0	336	329	7.9	7.9	.4	150	29
35N/01E-12R02	06-15-92	0920	11.0	511	488	8.2	8.2	.5	110	19
35N/01E-14B02	06-16-92	1200	11.0	481	485	7.1	7.1	<.1	180	34
35N/02E-06E01	06-17-92	0940	11.5	248	244	6.3	7.1	8.7	89	16
35N/02E-06G01	06-16-92	1135	15.0	555	549	7.2	7.5	2.3	270	53
35N/02E-07A01	06-15-92	1205	11.0	518	505	7.9	7.8	<.1	250	51
35N/02E-07G01	06-17-92	1040	14.0	347	341	7.2	7.4	.4	150	38
35N/02E-07H04	06-15-92	1405	11.5	597	593	8.5	8.5	<.1	94	16
35N/02E-08E02	06-16-92	1530	11.5	446	467	8.2	8.1	.1	190	31
36N/01E-26H01	06-16-92	0920	12.5	1330	1280	6.7	6.9	1.7	100	10
36N/01E-26J01	06-15-92	1655	10.5	707	679	7.2	7.4	9.2	140	20
36N/01E-26P01	06-15-92	1400	10.5	250	255	6.2	6.5	3.2	88	17
36N/01E-35F01	06-15-92	1230	10.0	318	335	6.9	7.0	8.9	100	17
36N/01E-36C01	06-15-92	1530	11.5	1370	1430	6.9	7.0	2.3	190	22
36N/01E-36C05	06-15-92	1700	11.0	222	225	6.4	6.6	5.3	74	15
36N/01E-36Q01	06-16-92	1000	11.5	970	1010	7.9	7.6	.1	63	13
36N/02E-31M01	06-16-92	1040	14.0	302	298	7.6	7.7	2.2	120	19
36N/02E-31P01	06-15-92	1000	10.5	254	254	7.6	7.6	<.1	99	15

Appendix 6.--Values and concentrations of field measurements, common constituents, arsenic, and radon--Continued

Local well number	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium, percent	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity lab (mg/L as $CaCO_3$)	Alkalinity field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)
35N/01E-01C02	9.2	12	25	0.6	1.7	55	--	35	14	0.1
35N/01E-01D01	19	21	24	.8	4.2	159	--	12	13	.3
35N/01E-01M01	20	17	19	.6	3.4	135	134	11	39	.1
35N/01E-01R01	15	25	30	1	3.7	165	--	.3	15	<.1
35N/01E-02L01	30	110	54	3	5.5	122	--	50	210	<.1
35N/01E-12F01	8.1	11	23	.5	1.5	53	--	22	16	<.1
35N/01E-12P03	18	13	16	.5	3.0	147	--	4.2	17	<.1
35N/01E-12R02	15	61	53	3	5.2	174	174	.1	57	.1
35N/01E-14B02	22	30	27	1	3.8	148	162	10	60	.1
35N/02E-06E01	12	10	19	.5	1.8	57	--	24	19	<.1
35N/02E-06G01	33	14	10	.4	1.6	197	--	68	21	<.1
35N/02E-07A01	30	12	9	.3	2.0	208	208	36	24	<.1
35N/02E-07G01	13	14	17	.5	1.9	142	--	18	13	<.1
35N/02E-07H04	13	99	67	4	9.4	286	--	7.1	24	.2
35N/02E-08E02	28	20	18	.6	6.9	191	--	32	19	<.1
36N/01E-26H01	19	190	78	8	11	51	--	82	310	.2
36N/01E-26J01	22	76	53	3	5.3	104	--	52	120	.1
36N/01E-26P01	11	18	31	.8	.50	67	--	17	16	<.1
36N/01E-35F01	14	24	34	1	2.2	72	--	21	27	<.1
36N/01E-36C01	32	200	69	6	8.8	115	--	67	330	<.1
36N/01E-36C05	8.8	13	27	.7	1.2	48	--	23	21	<.1
36N/01E-36Q01	7.5	180	85	10	4.3	247	247	<.1	180	.2
36N/02E-31M01	18	13	18	.5	3.1	116	--	19	15	<.1
36N/02E-31P01	15	13	22	.6	2.2	79	83	25	16	<.1

***Appendix 6.**--Values and concentrations of field measurements, common constituents, arsenic, and radon--Continued*

Local well number	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Arsenic, dissolved (µg/L as As)	Coliform, fecal (cols. per 100 mL)	Streptococci, fecal (cols. per 100 mL)	Radon 222 total (pci/L)
35N/01E-01C02	31	156	0.75	270	79	<1	<1	<1	--
35N/01E-01D01	44	234	--	770	890	<1	<1	<1	--
35N/01E-01M01	34	237	<.05	1,300	190	<1	<1	<1	--
35N/01E-01R01	39	223	<.05	480	190	<1	<1	<1	120
35N/01E-02L01	30	543	.75	10	3	1	<1	<1	--
35N/01E-12F01	27	141	1.3	18	12	<1	<1	<1	--
35N/01E-12P03	50	223	<.05	500	150	<1	<1	<1	--
35N/01E-12R02	23	286	<.05	1,300	150	<1	<1	<1	--
35N/01E-14B02	43	310	<.05	7,100	1,500	<1	<1	<1	<80
35N/02E-06E01	29	159	2.9	12	31	<1	<1	<1	--
35N/02E-06G01	29	338	.08	54	21	<1	<1	<1	170
35N/02E-07A01	36	318	<.05	1,900	96	1	<1	<1	--
35N/02E-07G01	13	199	.55	33	36	<1	<1	2	--
35N/02E-07H04	23	364	<.05	42	13	<1	<1	<1	--
35N/02E-08E02	32	284	<.05	260	19	<1	<1	<1	<80
36N/01E-26H01	25	693	3.4	140	26	<1	<1	<1	390
36N/01E-26J01	30	394	1.2	16	2	<1	<1	<1	--
36N/01E-26P01	34	175	4.8	20	2	<1	<1	<1	--
36N/01E-35F01	31	209	6.8	14	1	<1	<1	<1	--
36N/01E-36C01	28	760	.75	18	2	<1	<1	<1	--
36N/01E-36C05	30	149	1.9	39	4	<1	<1	<1	--
36N/01E-36Q01	41	574	<.05	1,400	280	14	<1	<1	--
36N/02E-31M01	32	189	<.05	180	120	1	<1	<1	--
36N/02E-31P01	29	167	<.05	1,900	150	1	<1	<1	--

Appendix 7.--Concentrations of trace metals
[µg/L, micrograms per liter]

Local well number	Date	Time	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Cadmium, dissolved (µg/L (as Cd)	Chrommium, dissolved (µg/L as Cr)
35N/01E-01M01	06-16-92	1300	<1	48	<1	<1
35N/01E-14B02	06-16-92	1200	<1	63	<1	<1
35N/02E-08E02	06-16-92	1530	<1	25	<1	1
36N/01E-26J01	06-15-92	1655	<1	15	<1	<1
36N/01E-36Q01	06-16-92	1000	14	50	<1	<1

Local well number	Copper, dissolved (µg/L as Cu)	Lead, dissolved (µg/L as Pb)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)
35N/01E-01M01	<1	<1	<0.1	<1	<1	7
35N/01E-14B02	<1	<1	<.1	<1	<1	220
35N/02E-08E02	<1	<1	<.1	<1	<1	6
36N/01E-26J01	4	<1	<.1	2	<1	540
36N/01E-36Q01	<1	<1	<.1	<1	<1	200

Appendix 8.--Concentrations of septage-related constituents
[mg/L, milligrams per liter; µg/L, micrograms per liter]

Local well number	Date	Time	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Boron, dissolved (µg/L as B)	Methylene blue active substance (mg/L)
35N/01E-01M01	06-16-92	1300	<0.05	30	<0.02
35N/01E-02L01	06-16-92	1530	.75	60	<.02
35N/01E-12F01	06-16-92	1705	1.30	20	<.02
35N/01E-14B02	06-16-92	1200	<.05	50	<.02
35N/02E-07H04	06-15-92	1405	<.05	420	<.02
35N/02E-08E02	06-16-92	1530	<.05	100	<.02
36N/01E-26H01	06-16-92	0920	3.40	120	<.02
36N/01E-26J01	06-15-92	1655	1.20	50	<.02
36N/01E-26P01	06-15-92	1400	4.80	20	.02
36N/01E-36C01	06-15-92	1530	.75	110	<.02
36N/01E-36C05	06-15-92	1700	1.90	20	.03
36N/02E-31P01	06-15-92	1000	<.05	20	<.02

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