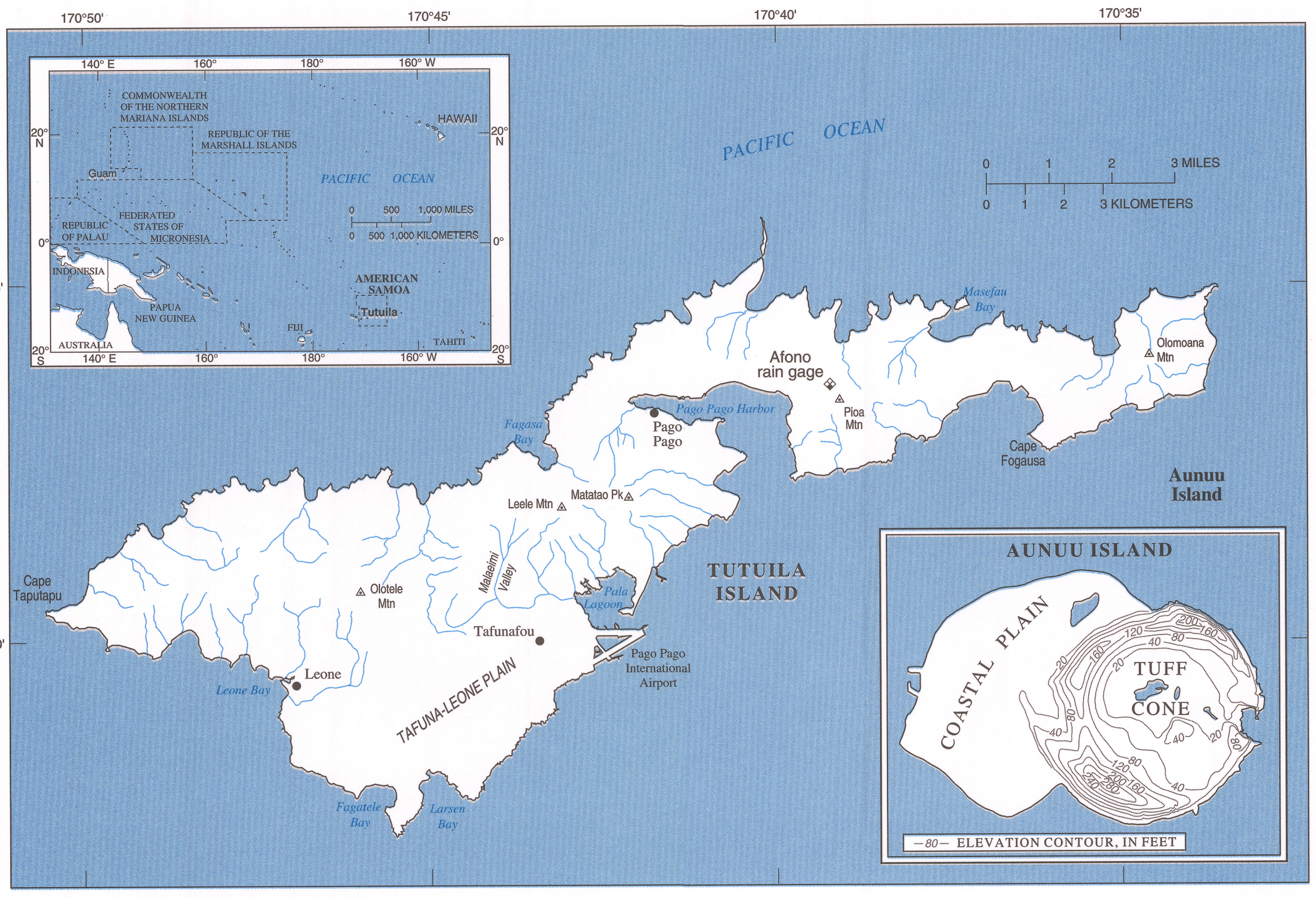

Figure 1. Tutuila and Aunuu Islands, American Samoa.

INTRODUCTION

Aunuu Island, a 0.6 mi^2 tuff (consolidated volcanic ash) cone and coastal plain, is located less than 1 mile off the eastern coast of Tutuila Island, American Samoa, which lies in the south-central Pacific Ocean at latitude 14°S and longitude 170°W (fig. 1). Fresh ground water is obtained from shallow wells that tap a coastal-plain aquifer. The coastal-plain aquifer is composed mainly of coralline and volcanic debris. The existing water-supply wells withdraw water with chloride concentrations as high as 1,960 mg/L (Izuka, 1996), yet current pumping rates are too low to adequately supply the island residents. To better understand the ground-water resources of the island, the U.S. Geological Survey (USGS) entered into a cooperative study with the American Samoa Environmental Protection Agency (ASEPA) in conjunction with the American Samoa Power Authority (ASPA). The objective of the study, conducted between July 1996 and February 1997, was to determine the geometry of the freshwater lens in the coastal plain at Aunuu by (1) measuring water levels relative to sea level, (2) determining tidal influence on water levels, and (3) determining the depth of the transition zone. In addition, a rainfall-data collection program was initiated.

This report presents the results of the study including a description of the vertical thickness and areal extent of the freshwater lens, the water-table configuration, and directions of ground-water flow. The report also discusses the relation of the lens geometry to the existing distribution of ground-water withdrawal and to seasonal changes in rainfall.

Acknowledgments.--This report was produced under a cooperative agreement with the ASEPA. The authors gratefully acknowledge Togipa Tausaga (Director, ASEPA), Abe Malae (Director, ASPA), Sheila Wiegman (ASEPA), and Wilfredo Carreon (ASPA) for their assistance. Help during field activities was provided by Asomuamua Ito and Taylor Wilson of ASPA and Francis Huber of ASEPA.

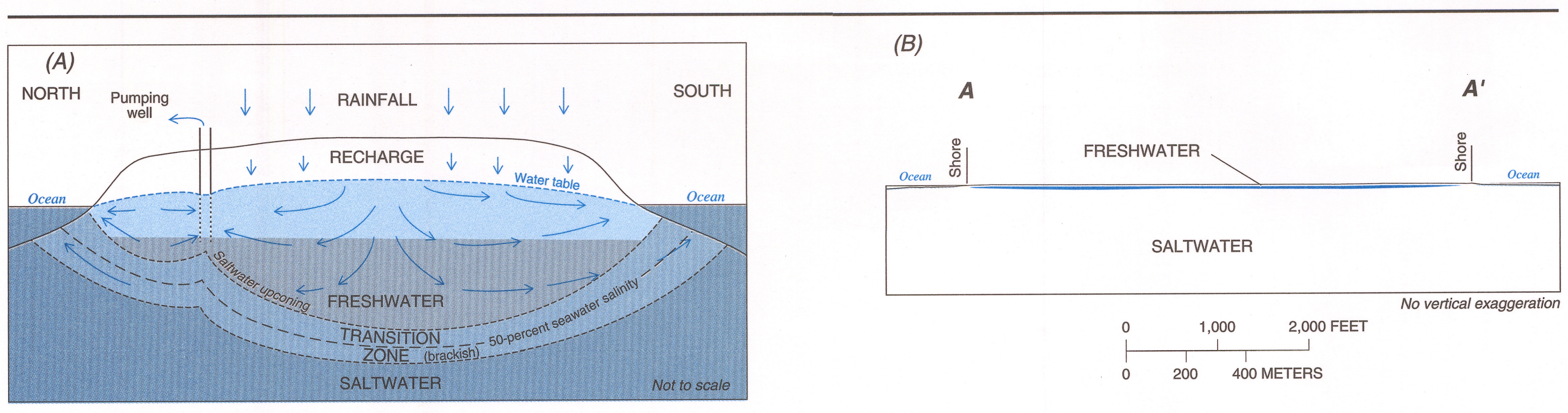

Figure 2. Diagrams of Aunuu Island freshwater lens. A, Salinity structure and ground-water flow pattern, vertical dimension greatly exaggerated, B, freshwater lens, no vertical exaggeration. Line of section shown in figure 8.

GROUND-WATER RESOURCE: THE FRESHWATER LENS

Rainwater infiltrates and maintains a freshwater lens within the island. Some fraction of the infiltration can be withdrawn by wells, but high salinity can result from overpumping or dry weather.

Density differences between freshwater and saltwater create a lens-shaped body of freshwater that floats on saltwater within the island (fig. 2), much the way an iceberg floats on the ocean. The shallow coastal-plain aquifer at Aunuu Island is composed mostly of reef-derived, calcium-carbonate sand and gravel and volcaniclastics eroded from the tuff cone (Davis, 1963). Water occupies small pores and spaces between the sand and gravel grains as well as larger voids which originated as openings in the growth structure of the coral reef or developed later by dissolution of the calcium carbonate.

Theoretical freshwater lens and actual conditions at Aunuu Island.--The Ghyben-Herzberg principle commonly is used to relate the vertical thickness of a freshwater lens in an ocean-island aquifer to the density difference between freshwater and saltwater. The principle states that an interface between freshwater and saltwater will be located at a depth below sea level that is 40 times the height of the water table above sea level (Todd, 1980). Instead of a sharp freshwater-saltwater interface, however, the freshwater is separated from the saltwater by a transition zone in which salinity grades from freshwater to saltwater. In many field studies of freshwater lenses, the Ghyben-Herzberg depth has been found to correspond to the depth of about a 50-percent mix of freshwater and saltwater. Under equilibrium flow conditions in permeable aquifer systems, the Ghyben-Herzberg principle may provide a reasonable estimate of freshwater depth if the transition zone is comparatively thin. In small islands such as Aunuu, however, the transition zone is comparatively thick and the freshwater layer is much thinner than estimated by the Ghyben-Herzberg principle.

Definition of potable freshwater.--Salinity in a freshwater lens is gradational, from an upper freshwater core through the underlying transition zone to saltwater. A chloride concentration of 250 mg/L is the maximum contaminant level recommended by the U.S. Environmental Protection Agency (USEPA) as a secondary standard for drinking water (U.S. Environmental Protection Agency, 1989). Secondary standards are not mandatory requirements, but instead establish limits for constituents that may affect the aesthetic qualities of drinking water (taste and odor, for example). In this report, freshwater is defined as water having a chloride concentration less than or equal to 250 mg/L. The transition zone between freshwater and saltwater contains brackish water with a chloride concentration greater than 250 mg/L.

Ground-water flow, recharge, and temporal variations in lens size.--Water flows continuously in a freshwater lens. Rainfall infiltrates and recharges the aquifer, where frictional resistance to flow causes the water to accumulate and a lens to form. Freshwater flows by gravity toward the shore, where it discharges as diffuse seepage and as springflow at shoreline and submarine springs. On small islands, mixing in the transition zone results mainly from tidal fluctuations and also from flow of freshwater toward the shore. Under conditions of steady recharge and no pumping, the lens would have a fixed size. In reality, rainfall is episodic and seasonal, and lens volume fluctuates naturally with time. The lens discharges continuously throughout the year, but shrinks during dry periods when recharge diminishes or ceases. The lens expands when recharge increases, commonly during a definable wet season.

Ground-water withdrawal from wells, saltwater upconing, and regional lens depletion.--Some fraction of the recharge can be withdrawn continuously by wells, in effect capturing a fraction of the natural discharge. The most efficient means of developing a thin lens is to scatter shallow wells where the lens is thickest and to maintain low pumping rates at each well. This spreads withdrawal over a wide area and skims freshwater from the lens. The more widespread the withdrawal, the greater the fraction of recharge that can be withdrawn with acceptable salinity for drinking. Saltwater upconing can contaminate wells if the lens is too thin, if wells are too deep, or if too much water is withdrawn from a small area. Even if wells are designed and placed to minimize local upconing, the lens will gradually shrink to a size that is in balance with the withdrawal. This regional shrinkage raises the transition zone closer to the wells, potentially close enough to raise the salinity of pumped water. Shrinkage due to dry weather can also contribute to high salinity in wells.

Freshwater lens at true scale.--Most sectional diagrams of a freshwater lens are drawn with the vertical scale greatly exaggerated (fig. 2A). If the section is drawn with no vertical exaggeration (fig. 2B), the extreme thinness of the freshwater lens on a small island is more evident as is the difficulty of withdrawing freshwater without causing saltwater upconing.

LAND USE

Particular types of land use (residential, agricultural, landfill) are concentrated in particular parts of the island. Land use influences the potential for ground-water contamination.

The land surface of Aunuu Island has been modified from its natural state, primarily for agricultural purposes (fig. 3). The total area of Aunuu is about 260 acres and the area of the coastal plain is about 170 acres. Part of the coastal plain is wetlands consisting of a freshwater marsh and a brackish mangrove swamp that surrounds a small saline surface-water body, Pala Lake (BioSystems Analysis, Inc., 1992). The freshwater marsh consists of the Palapalaloa, Taufusitele, and Lalopapa taro fields which together form the largest taro field in American Samoa. A small wetland is located along the southern edge of the coastal plain. The landfill currently in use (1997) is located on the edge of the mangrove swamp. The floor of the tuff cone contains a freshwater marsh (Faimulivai), about half of which is open water (BioSystems Analysis, Inc., 1992). The remaining area has some scattered agricultural use but is mostly unmaintained and covered with thick vegetation.

In the inhabited areas, sewer lines, septic tanks, livestock (mainly pigs), outdoor sinks and showers, abandoned dug wells, and grave sites may be potential sources of ground-water contamination. The landfill is also a potential source of contamination to the ground-water supply.

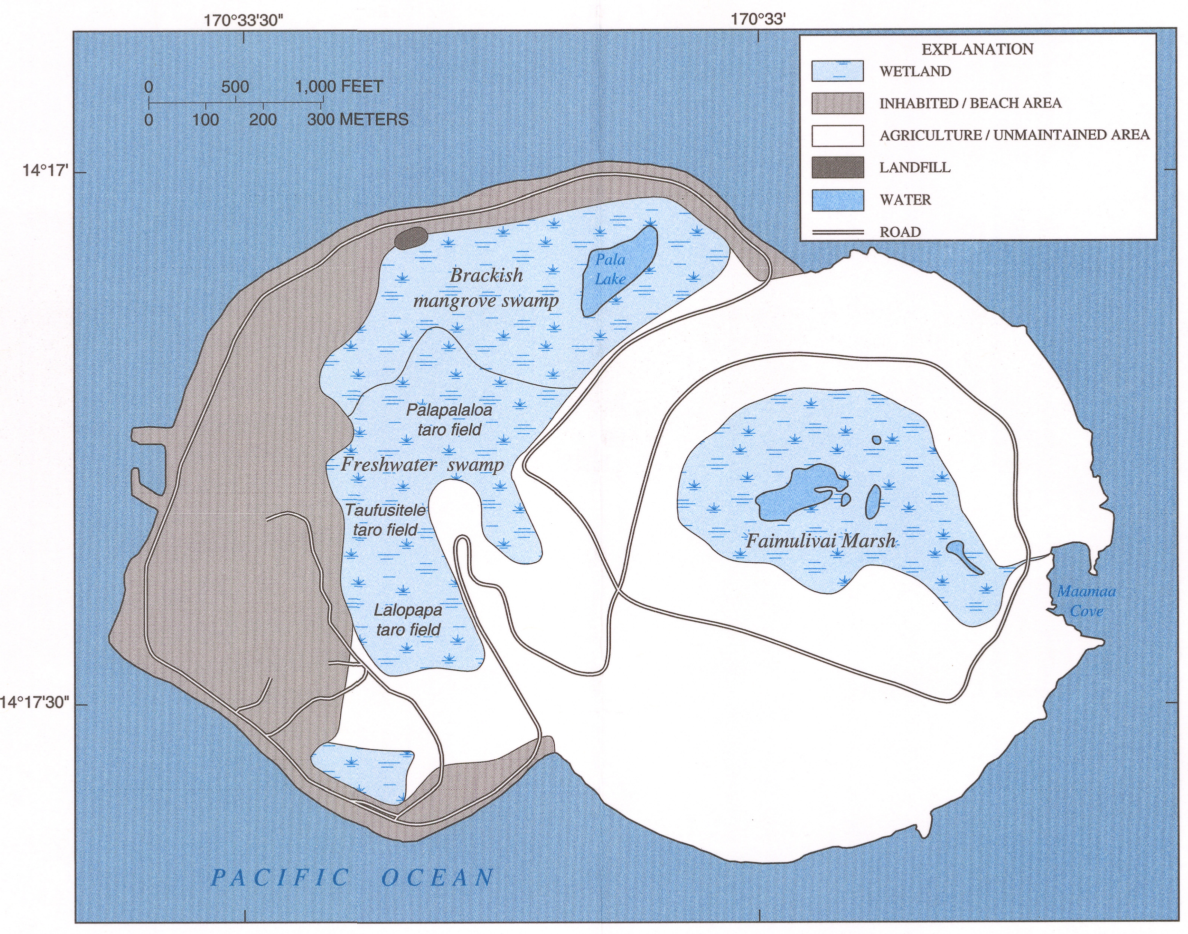

Figure 3. Land-use distribution, Aunuu Island, American Samoa (modified from BioSystems Analysis, Inc., 1992, fig. 2-13).

Figure 4. Water-supply wells, dug wells, and monitoring wells, Aunuu Island, American Samoa.

GROUND-WATER WITHDRAWAL WELLS

Ground-water withdrawal is primarily from horizontal wells which are designed to skim water from the thin freshwater lens without greatly raising salinity. Drinking water comes from rain catchments and shallow dug wells.

Ground water is withdrawn from the coastal-plain aquifer. The primary ground-water withdrawal wells are three infiltration-gallery wells, which are located in the areas of banana and coconut cultivation away from residential areas (table 1, fig. 4). Wells 301 and 302 are connected, effectively making one long well with two pump locations. The infiltration galleries consist of perforated PVC pipes laid in a shallow, horizontal trench. The galleries are connected to deeper sumps that collect the water that is then pumped to the domestic water-supply system (fig. 5). Infiltration-gallery wells minimize the salinity of water pumped from a thin lens because they can be set near the water table where the water is freshest and because they are arranged horizontally. Withdrawal from infiltration-gallery wells creates a long, shallow trough of drawdown in the water table rather than a deep, localized cone centered around a conventional vertical well. This characteristic minimizes the uptake of water from the transition zone.

In addition to the infiltration-gallery wells, some residences have shallow, dug wells which penetrate only 1 or 2 feet below the water table. At least 11 dug wells are in use (labeled A-K in fig. 4), mainly for providing drinking water. Buckets dipped into the wells are the only means of withdrawal. Additional drinking water is supplied by individual rain-catchment systems.

Table 1. Withdrawal-well data, Aunuu, American Samoa, 1997
[ft, feet; gal/d, gallons per day; datum is mean sea level]

Well number	Number of horizontal galleries	Approximate elevation of bottom of vertical sump (ft)	Approximate elevation of mid-point of horizontal galleries (ft)	Approximate lengths of horizontal galleries (ft)	Average daily withdrawal since construction (gal/d)
301	2	-4.0	-1.1	108, 108	22,700
302	2	-4.0	-0.8	108, 108	16,400
303	2	-3.3	0.0	167, 63	13,700

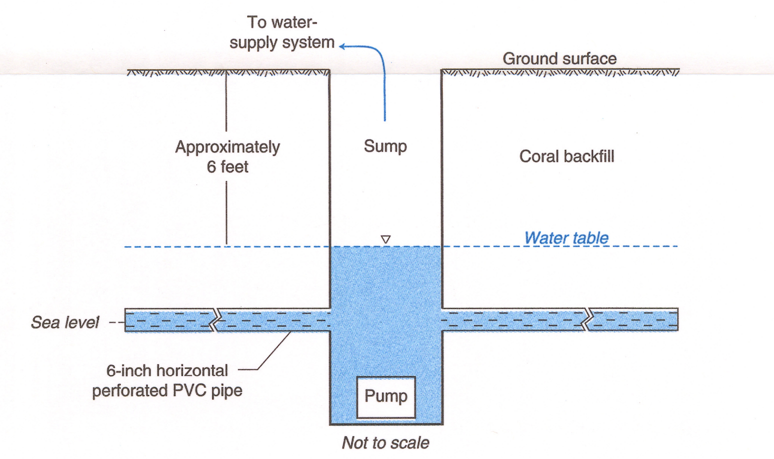

Figure 5. Schematic diagram of water-supply well (infiltration gallery) construction.

RAINFALL, GROUND-WATER WITHDRAWAL, AND CHLORIDE CONCENTRATIONS IN WELL WATER

Rainfall averages about 120 inches per year and varies seasonally. Three infiltration-gallery wells provide ground water for Aunuu, but the water from these wells has high chloride concentrations. Variations in chloride concentrations correspond with variations in rainfall and ground-water withdrawal rates. Excessive ground-water withdrawal rates are causing saltwater in the aquifer to rise and intrude the wells.

Rainfall.--Temporal variations in rainfall influence the availability of freshwater by causing variations in the volume of fresh ground water stored in the aquifer and the salinity of water withdrawn from wells. Not all rainfall on the island enters the aquifer as recharge because some water is lost to evaporation and transpiration by plants and some to runoff directly to the ocean. Rainfall data for Aunuu are sparse. Data from a rain gage near well 302 indicate that rainfall in 1993 was about 120 inches. Because the rain gage on Aunuu was visited at irregular intervals, the data are not adequate to show seasonal variations, but rainfall on Tutuila Island in 1993 was about 4 percent higher than average (Izuka, 1996). Continuous rainfall records from Tutuila show that rainfall in American Samoa varies seasonally with the peak of the wet season being March through May and the peak of the dry season being September through November (fig. 6). Rainfall on Aunuu probably follows a similar seasonal pattern, although Tutuila rainfall is influenced by orographic effects and Aunuu rainfall probably is more similar to open-ocean rainfall.

Ground-water withdrawal and chloride concentrations.--The infiltration-gallery wells (wells 301, 302, and 303) began withdrawing a combined total of about 53,000 gal/d (fig. 6) in 1992 (Izuka, 1996). Within a few months of the onset of withdrawal, chloride concentrations of the pumped water rose sharply, indicating that the pumping rates (about 15 gal/min) were excessive for these wells. The excessive withdrawal rates had caused saltwater in the aquifer to rise, move inland, and intrude the wells. Throughout most of the 5 years that the infiltration-gallery wells have been in use, chloride concentrations have remained higher than 250 mg/L.

Chloride concentrations of water pumped from wells 301 and 302 show a close correspondence because of the proximity of the wells to each other (fig. 6). The chloride concentration of the pumped water from both wells was 300 mg/L at the onset of pumping, rose to over 1,000 mg/L in 3 months, and has remained over 400 mg/L throughout most of the remaining period of record. Chloride concentrations do not closely correspond to the wells' respective individual pumpage records, but rather to the combined withdrawal from both wells (fig. 6), which indicates that withdrawal at one well affects the quality of water withdrawn at the other.

Chloride concentrations in pumped water from well 303 also correspond with variations in withdrawal rates at that well. The chloride concentration of pumped water from well 303 at the onset of withdrawal was 60 mg/L, rose to more than 1,000 mg/L after 2 months, and reached 1,920 mg/L after 5 months of withdrawal. Chloride concentrations dropped when withdrawal was reduced in 1993. Chloride concentrations rose again in late 1994 through early 1995 when withdrawal was high, decreased to as low as 40 mg/L in late 1995 when withdrawal was lowered, and rose again in late 1996 when withdrawal increased.

Neither withdrawal rates nor chloride concentrations in the pumped water from wells 301, 302, and 303 show a strong relation to rainfall amounts. Because the chloride concentration of the pumped water is high, water from the infiltration-gallery wells is used mostly for toilets and bathing. As a result, the use of water for these activities is not likely to increase or decrease with changes in rainfall. There are no withdrawal or chloride-concentration records for the dug wells.

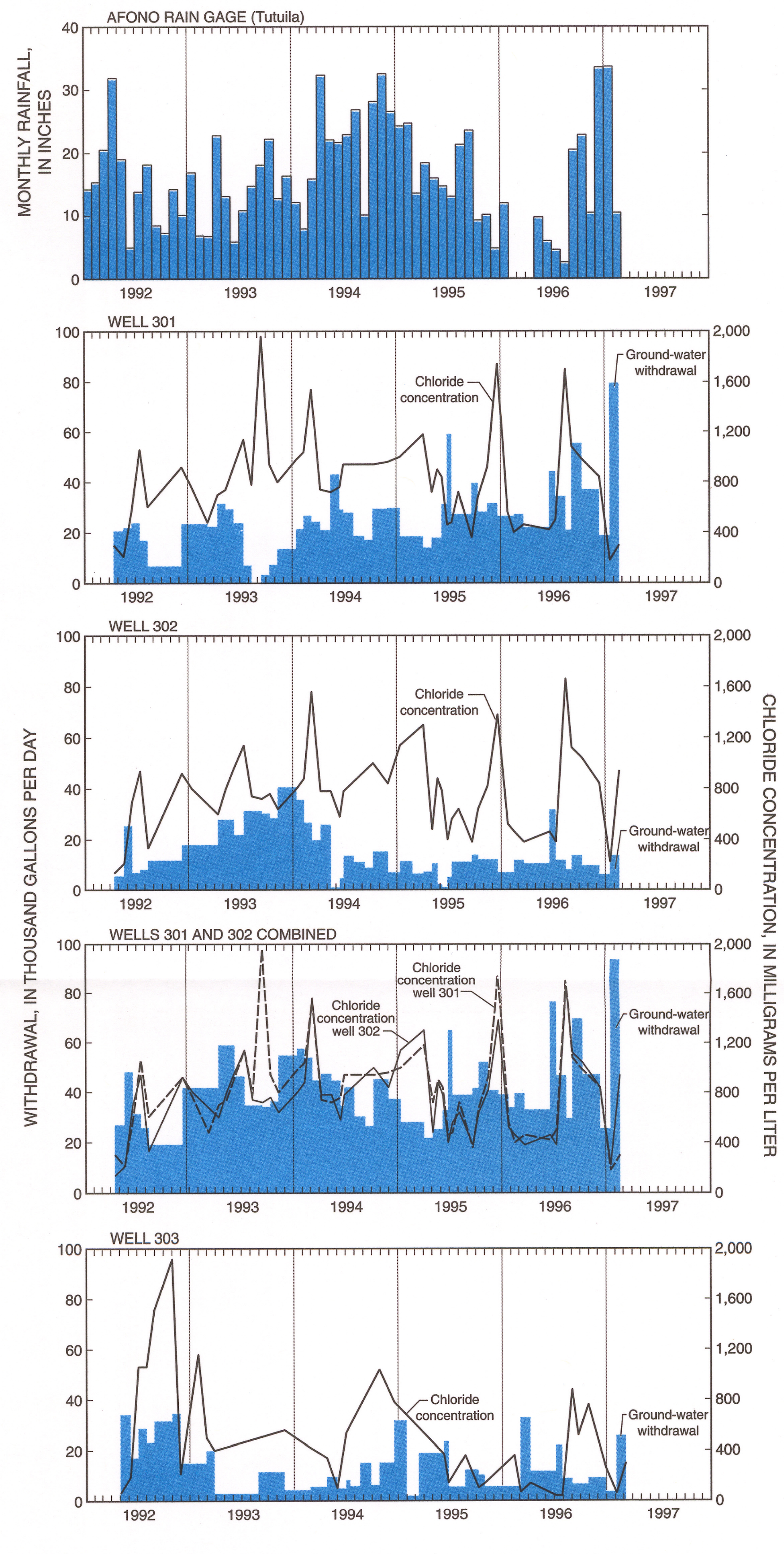

Figure 6. Rainfall (for Tutuila), and water-supply and chloride-concentration data, Aunuu Island, American Samoa.

ABBREVIATIONS

ft	feet
mi^2	square miles
gal/min	gallons per minute
gal/d	gallons per day
mg/L	milligrams per liter

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GROUND-WATER RESOURCES OF THE COASTAL PLAIN OF AUNUU ISLAND, AMERICAN SAMOA, 1996–97

by
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