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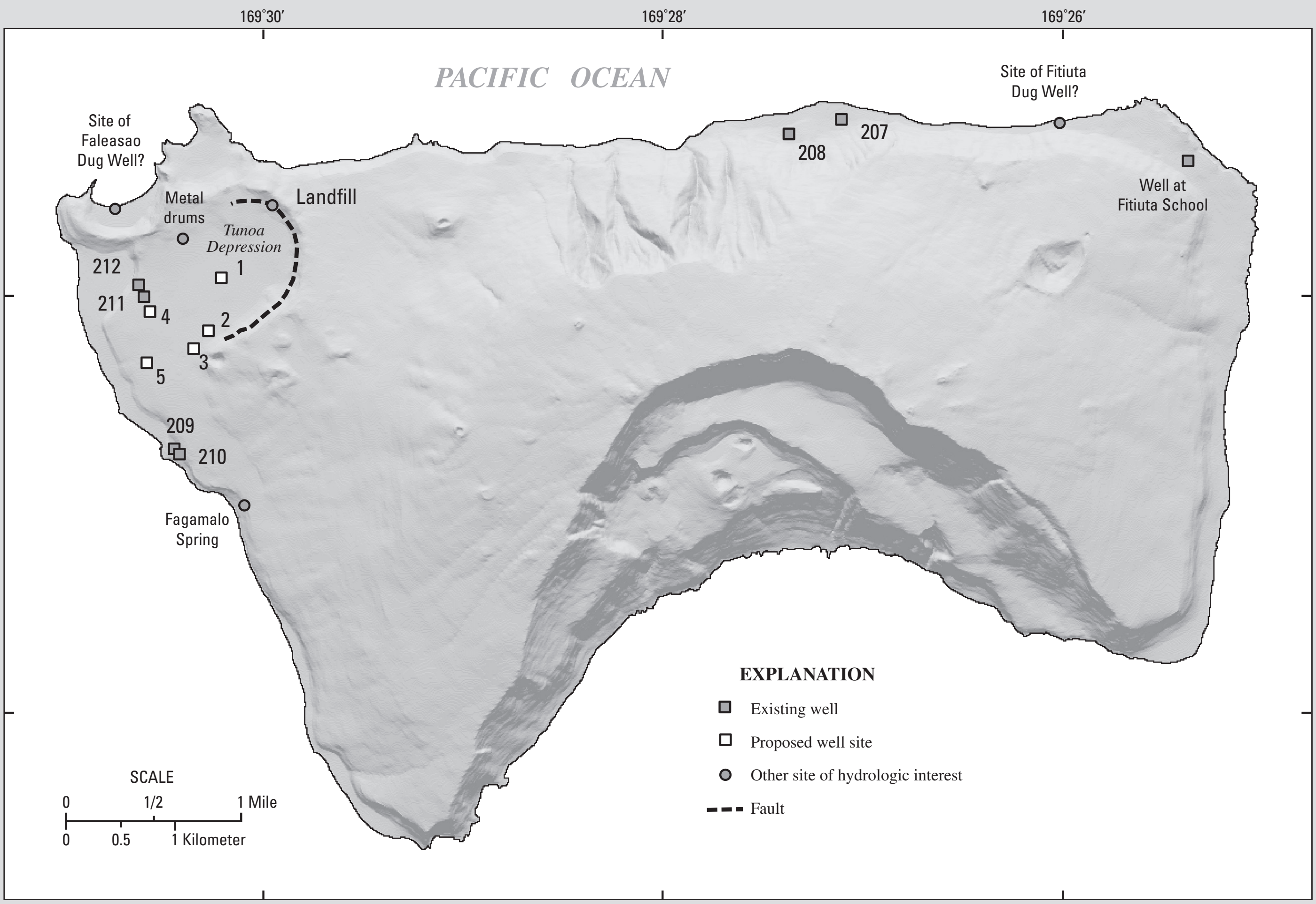
Reconnaissance of the Hydrogeology of Ta'u, American Samoa



Scientific Investigations Report 2004-5240

U.S. Department of the Interior
U.S. Geological Survey

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By Scot K. Izuka

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Gale A. Norton, Secretary

U.S. Geological Survey
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Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Elevations are referenced to mean sea level.

Horizontal coordinate information is referenced to World Geodetic System of 1984 (WGS84)

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Reconnaissance of the Hydrogeology of Ta'u, American Samoa

By Scot K. Izuka

Abstract

Analysis of existing data and information collected on a reconnaissance field visit supports a conceptual model of ground-water occurrence in Ta'u, American Samoa, in which a thin freshwater lens exists in a predominantly high-permeability aquifer that receives high rates of recharge. Because the freshwater lens is thin throughout most of the island, the productivity of wells, especially those near the coast where the lens is the thinnest, is likely to be limited by saltwater intrusion.

The landfill in northwestern Ta'u is closer to the north coast of the island than to any of the existing or proposed well sites. Although this may indicate that ground water beneath the landfill would flow away from the existing and proposed well sites, this interpretation may change depending on the hydraulic properties of a fault and rift zone in the area. Of four plausible scenarios tested with a numerical ground-water flow model, only one scenario indicated that ground water from beneath the landfill would flow toward the existing and proposed well sites; the analysis does not, however, assess which of the four scenarios is most plausible. The analysis also does not consider the change in flow paths that will result from ground-water withdrawals, dispersion of contaminants during transport by ground water, other plausible hydrogeologic scenarios, transport of contaminants by surface-water flow, or that sources of contamination other than the landfill may exist.

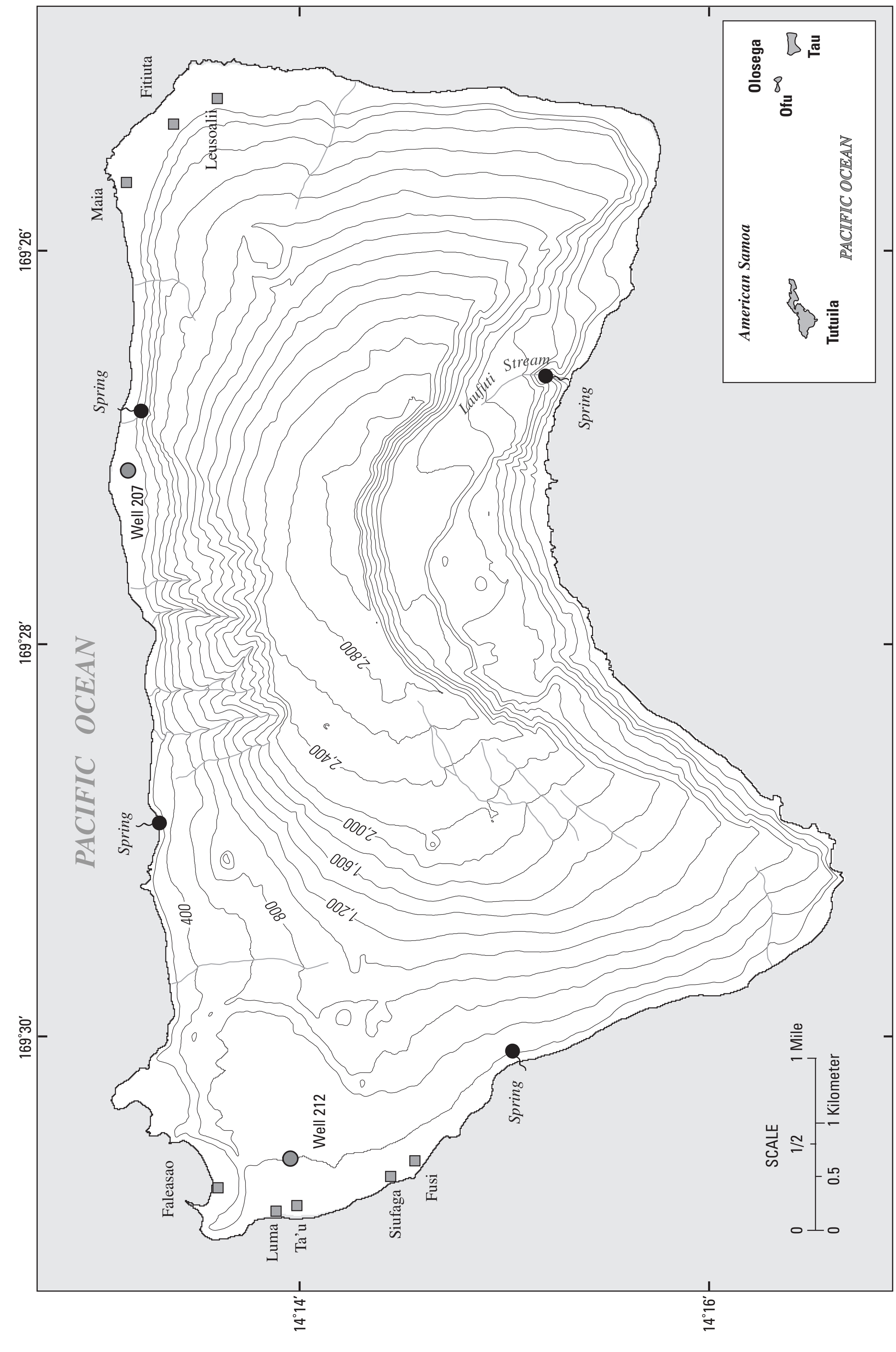
Accuracy of the hydrologic interpretations in this study is limited by the relatively sparse data available for Ta'u. Understanding water resources on Ta'u can be advanced by monitoring rainfall, stream-flow, evaporation, ground-water withdrawals, and water quality, and with accurate surveys of measuring point elevations for all wells and careful testing of well-performance. Assessing the potential for contaminants in the landfill to reach existing and proposed well sites can be improved with additional information on the landfill itself (history, construction, contents, water chemistry), surface-water flow directions, spatial distribution of ground-water levels, and the quality of water in nearby wells. Monitoring water levels and chemistry in one or more monitoring wells between the landfill and existing or proposed wells can provide a means to detect movement of contaminants before they reach production wells. Steps that can be implemented in the short term include analyzing water in the landfill and monitoring of water chemistry and water levels in all existing and new production wells.

Placing future wells farther inland may mitigate saltwater intrusion problems, but the steep topography of Ta'u limits the feasibility of this approach. Alternative solutions include distributing ground-water withdrawal among several shallow-penetrating, low-yield wells.

Introduction

Ta'u is a small (15 mi^2) island in the tropical South Pacific island group of American Samoa (fig. 1). The interior of the island is steep and densely forested, and most of the island's population of 873 (U.S. Bureau of the Census, 2000) is concentrated in two coastal areas: (1) the northeast corner of the island, which includes the villages of Fitiuta and Leusoalii; and (2) the northwest corner of the island, which includes the villages of Ta'u, Faleasao, and Luma. In the mid-20th century, residents obtained their water from small spring- or stream-fed reservoirs, dug wells, and rain catchments (Davis, 1963). By the late 1970s, a few deep wells had been drilled, but some of these wells yielded salty water (U.S. Army Engineering District, Honolulu, 1977). Because wells, like the villages they serve, are near the coast, they are susceptible to saltwater intrusion if the wells are too deep or pumping rates are high. Ta'u currently has two functioning production wells. Well 207 serves the villages in the northeast, and well 212 near Manua High School serves the villages in the northwest. The well serving the eastern villages currently produces water having relatively low salinity, but water pumped from the well in the west currently has such high salinity that it must be processed through reverse osmosis to make the water potable. The reverse-osmosis unit currently produces about 2,500 gallons per day (Wilfredo Carreon, American Samoa Power Authority, oral communication, 2004).

The American Samoa Power Authority (ASPA), the agency responsible for providing water in American Samoa, plans to drill new wells in search of better-quality water, but



Base from U.S. Geological Survey,
Manua Islands, American Samoa, 1:24,000 scale.

Figure 1. Location and topography of Ta‘u, American Samoa.

ground-water exploration is hindered because basic hydrologic information such as rainfall, streamflow, ground-water levels, and water quality are either lacking, sparse, or dispersed in unpublished files and documents. Only a few wells have been drilled into the volcanic rock of the island (fig. 2). All of these wells are near or within coastal villages, thus the ground-water hydrology of the island's interior is virtually unknown. Also, because the wells are near villages, the potential for contamination of existing and proposed wells by human activities is a concern. Initial motivation for this study came from concern that some of the proposed sites for new wells in northwestern Ta'u are close to an existing landfill. To address this concern, and to identify needs for the collection and analysis of additional data to guide the development and management of water resources on the island, the U.S. Geological Survey (USGS), in cooperation with ASPA, conducted a reconnaissance study of the hydrogeology of Ta'u.

Purpose and Scope

This report describes a conceptual hydrogeologic model that will aid in the exploration for and management of water resources on Ta'u, with emphasis in the northwestern part of the island, where new wells have been proposed and concerns about ground-water contamination from a landfill have been raised. The model is based on compilation, analysis, and hydrologic interpretation of existing data and data collected during a reconnaissance survey of the existing fresh-water resources on Ta'u. The model is tested with a simplified island-wide numerical ground-water model. Four scenarios of plausible hydrogeologic conditions in northwestern Ta'u were simulated in the numerical model to study possible ground-water flow paths beneath the landfill. This report also discusses limitations to hydrologic interpretations owing to the limited data available, and identifies additional information that is needed to improve the conceptual model and its utility in ground-water exploration, development and management on Ta'u.

Acknowledgments

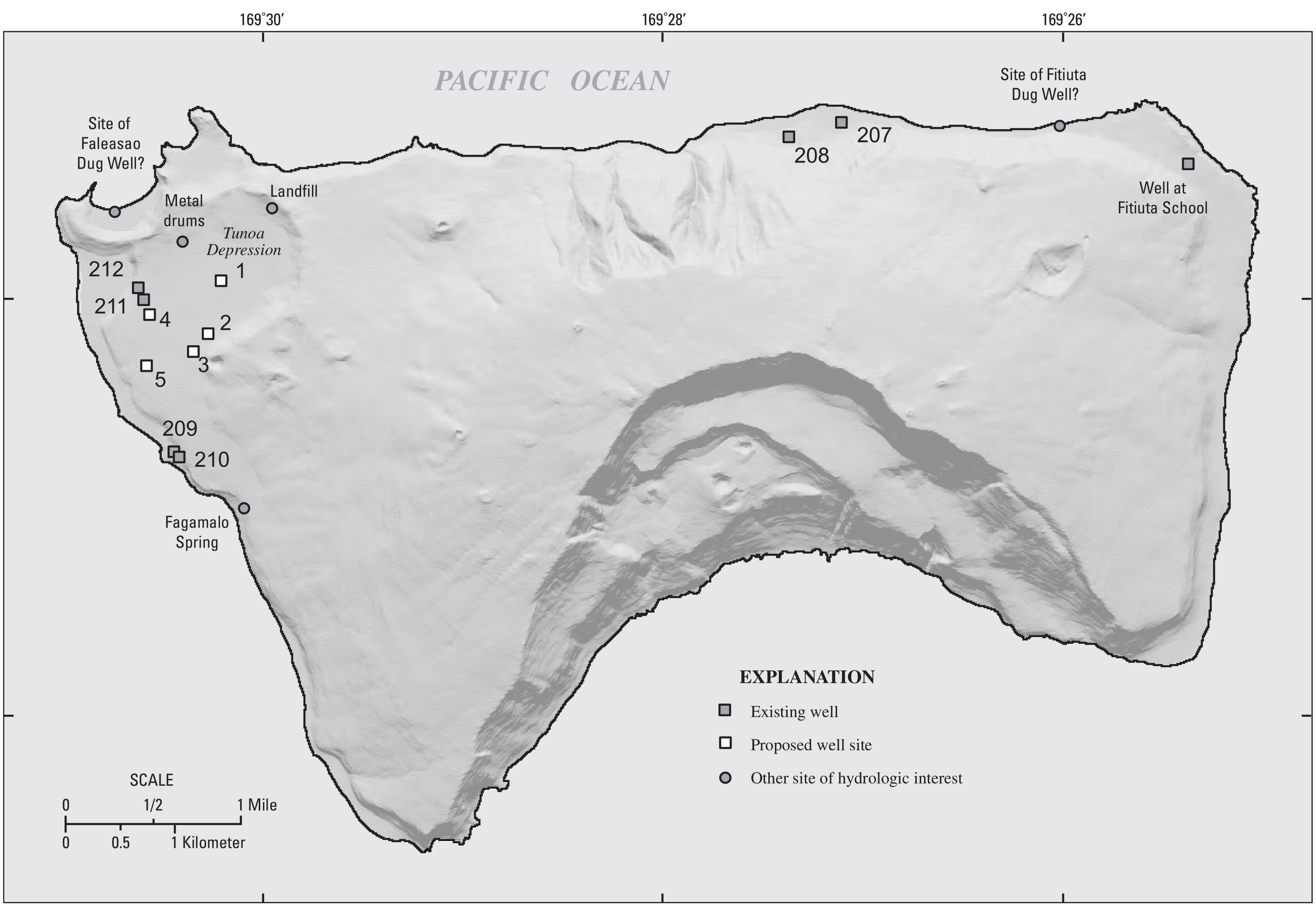
The author is grateful to the staff of ASPA, its Executive Director, Abe Malae, and Wilfredo Carreon, for their assistance in this project. ASPA employees Fola Tanielu, Aloalii Maui, Pauono Saiana, and Junior Faaitu assisted the author during fieldwork on Ta'u. Maatifa Eleasaro and Peter Peshut of the American Samoa Environmental Protection Agency (ASEPA) also provided background information and assistance. This report has benefited from the contributions of Charles D. Hunt, Deborah J. Parliman and Luis Menoyo of the USGS.

Setting

Ta'u has a broad dome-shape profile and a rectangular outline in plan view (fig. 1). Despite its small size, the island has high relief, with a maximum elevation of more than 3,000 ft. Rainfall records for Ta'u are meager, but data from the National Climate Data Center (2002) for the villages of Luma and Faleasao indicate that the northwestern end of the island receives about 150 to 200 in. of rain per year. Long-term rainfall data from the airport on Tutuila (about 70 mi to the west of Ta'u) indicate that the periods over which the data for Luma (July 1969 through October 1975), and Faleasao (November 1975 through December 1986) were collected were about average for the American Samoa archipelago. The spatial variation of rainfall on Ta'u is not known, but it is likely that as on other islands in American Samoa, rainfall on Ta'u is higher at higher elevations than it is at lower elevations (Izuka, 1999).

Previous studies indicate that Ta'u has the geologic structure and plate-tectonic setting of a young, basaltic, shield-volcano island that has been modified by erosion, collapse, and renewed volcanism (Stearns, 1944; Stice, 1966; Stice and McCoy, 1968). According to these studies, Ta'u was formed by mid-oceanic-plate volcanism. The main shield volcano that built Ta'u, the Lata Shield (fig. 3), formed by the accumulation of fluid lavas emanating from weakly explosive summit and rift-zone eruptions. At some point during shield building a caldera was formed, but volcanic activity continued. Rift-zone eruptions formed smaller satellite shield volcanoes that built out the northwest (Tunoa Shield) and northeast (Lautele Shield) coasts of the island (fig. 3). Erosion created stream gullies and sea cliffs, some of which were buried by subsequent eruptions, and large-scale collapse or slope failure resulted in the removal of the southern half of the original shield volcano.

Volcanic dikes (near-vertical sheets of dense igneous rock that intrude into the lava flows that form the shield volcano) are likely to be associated with the caldera and rift zones of the Lata Shield, although few dikes are exposed on Ta'u. Stice and McCoy (1968) described dike exposures in Laufuti Stream on the south-facing cliffs of Ta'u (fig. 1). More dikes probably exist within the Ta'u shield, especially along the principal rift zones. Although Stice and McCoy (1968) do not delineate rift zones in their geologic map of Ta'u, they describe a rift zone that extends to the northeast through the Lautele Shield and another rift zone that extends northwest through the Tunoa Shield. Stice and McCoy (1968) also describe caldera deposits in the cliffs of the central south coast of Ta'u (fig. 3). A gravity survey by Machesky (1965) shows a Bouguer anomaly that is consistent with the caldera interpretation. Stice and McCoy (1968) also describe a central depression (the Tunoa Depression, fig. 1) on the satellite Tunoa Shield, but this depression is smaller than a caldera and whether it has rocks similar to those of a caldera is unknown.



Base from U.S. Geological Survey,
Manua Islands, American Samoa, 1:24,000 scale.

Figure 2. Wells and other sites of hydrologic interest on Ta‘u, American Samoa.

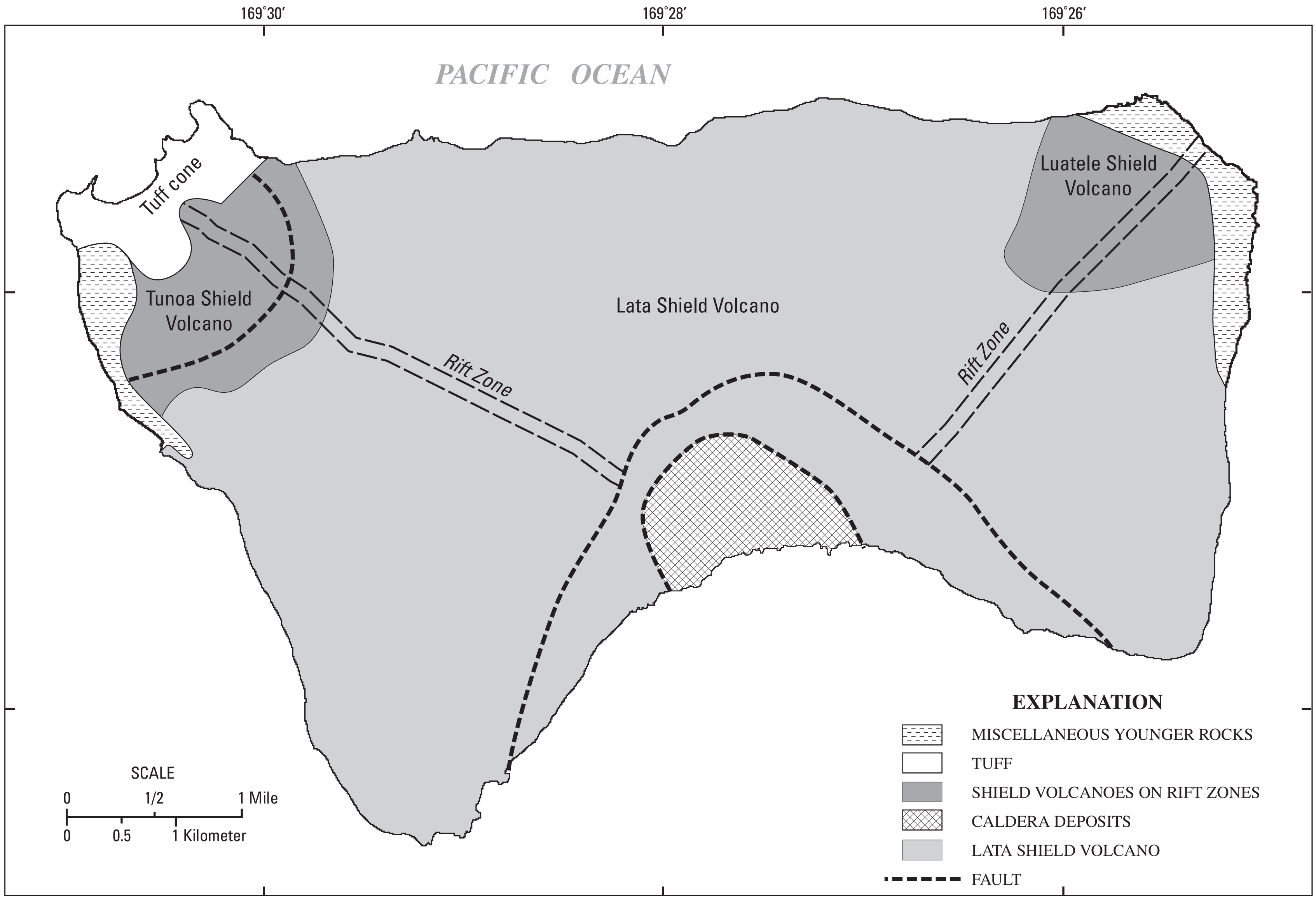


Figure 3. Major geologic features of Ta'u, American Samoa (modified from Stice and McCoy, 1968).

Ground-Water Hydrology

Current understanding of the ground-water hydrology of Ta'u is based on scattered and relatively sparse data. The main published sources are reports by Davis (1963), the U.S. Army Engineering District, Honolulu (1977), and Bentley (1975). Additional information is contained in files at the USGS office in Honolulu, Hawaii, including field notes, memoranda, and correspondence of USGS hydrologists R.H. Dale, K.J. Takasaki, and P.R. Eyre who visited the island several times in the 1960s –90s.

To supplement the existing published and unpublished data, a field reconnaissance was conducted from October 23 to 25, 2003 as part of this study. The field reconnaissance included (1) visits to all existing wells and, where possible, springs, former well sites, proposed well sites, and sites of potential contamination that may present a threat to ground-water resources (fig. 2); (2) using a global positioning system (GPS) instrument to obtain accurate geographic coordinates of all sites; (3) measurement of water levels in wells, where possible; (4) recording present well pumping rates and spring discharge rates; and (5) testing the chloride concentrations of the water from springs and wells.

Wells, Springs, and Sources of Possible Contamination

Accurate location, using GPS, of wells, springs, and sources of possible ground-water contamination, is considered one of the more important contributions of the reconnaissance field survey conducted for this study. Accurate location of wells, springs, potential sources of contamination, and geologic structures is essential to the analysis of ground-water resources in any area.

Information in the files of the USGS indicates that as many as 10 wells have been constructed on Ta'u, but in the field reconnaissance for this study, only nine sites of existing or former wells were found (table 1). Of these wells, two were destroyed, so their locations were only approximated from the recollection of island residents; three were plugged; two were unused but accessible for water-level measurements; and one was being used and could be sampled but had no access for water-level measurements. In only one well could both a sample and water-level measurement be taken. Of the wells visited, only two had surveyed measuring-point elevations. Measuring-point elevations were surveyed for three other wells during the field reconnaissance.

Well 207. – Well 207 is the easternmost of a pair of wells in Faga (wells 207 and 208, table 1, fig. 2). Well 207 is synonymous with well 92-1327-01 in the USGS files and well 129 in older notes, and because it provides water to the villages in northeastern Ta'u, including Fitiuta, this well is commonly referred to as the "Fitiuta Well." The well is 579 ft inland from the northwest coast of Ta'u. Records in the USGS files indicate that the well was drilled in 1981 and report a "well slab elevation" of 28.33 ft. During the reconnaissance field visit for this study, a two-tiered concrete slab surrounded this well; it is not clear whether the 28.33 ft elevation corresponds to the upper or lower tier of the slab. The top of the upper tier of the slab surrounding the casing is 0.60 ft above the lower tier, and the top of the measuring tube is 0.33 ft above the top of the upper tier. Assuming that the lower tier of the slab has an elevation of 28.33 ft, the elevation of the top of the measuring tube is 29.26 ft. Depth-to-water measurements in the USGS files indicate that the pre-pumping water-level elevation was about 2 to 3 ft. The depth of this well is not clear from the data in the USGS files, but it is apparently at least 36.67 ft, which was the reported depth of the pump used during testing. The USGS files also contain data from a pumping test (not dated) which ran for 375 min (6 hours, 15 minutes). During this test, the pumping rate was variable (40 to 150 gal/min), the maximum recorded drawdown was 5.92 ft, and chloride concentrations of the pumped water were less than 200 mg/L. During another test (dated April 14, 1981), which ran for 238 minutes (about 4 hours) at a variable pumping rate of 60 to 100 gal/min, the maximum recorded drawdown was 6.25 ft.

During the field reconnaissance for this study (October 24, 2003), the well was being pumped at a rate of 55 gal/min (the duration of pumping prior to the visit is unknown), the water-level elevation was -0.3 ft (assuming the elevation of the top of the measuring tube is 29.26 ft), and the water had a chloride concentration of 57 mg/L.

Well 208. – Well 208 is the westernmost of a pair of wells in Faga (table 1, fig. 2). Well 208 is synonymous with well 92-1327-02 in the USGS files. The USGS files indicate that the well was drilled in 1985 at an elevation of about 49 ft (no precise surveyed elevation was given) at a location about 700 ft from the coast, is 61 ft deep with 52 ft of solid casing above and 10 ft of slotted casing below, and had a "static water" level (probably depth-to-water) of 49.42 ft. At the time of the reconnaissance field visit for this study, the well was not being used. The well casing was surrounded by a two-tiered concrete pad; the lower tier was about 1.10 ft above ground, the second tier was 0.5 ft above the first tier, and the top of the casing was 0.10 ft below the top of the upper tier. The water level at the time of the reconnaissance visit (October 24, 2003) was 49.90 ft below the top of the casing.

Well 209. – Well 209 is the northernmost of a pair of wells drilled near the boat harbor on the western side of the island of Ta'u (table 1, fig. 2). The well is synonymous with well TA-1430-03 in the files of the USGS, and well 130 in older notes. According to information in the USGS files, the well was drilled in 1981 at an elevation of about 40 ft and is 52 ft deep, and produced brackish water. A level survey conducted during the field reconnaissance visit for this study indicated the elevation of the top of the casing, which was flush with the upper tier of the surrounding concrete slab, was 40.24 ft (elevation surveyed from the USGS "Tide Gage" bench mark south of the boat harbor). The well is 328 ft from the coast, according to the well location determined by GPS.

Table 1. Characteristics of wells and other important hydrologic sites visited during the October 2003 reconnaissance survey of Ta'u, American Samoa

[latitude and longitude in degrees:minutes:seconds in the WGS 84 datum, determined by hand-held global positioning system (GPS) instrument; all elevations are relative to mean sea level; NA, data not available or not applicable; ft, feet; Q, well discharge; gal/min, gallons per minute; ASPA, American Samoa Power Authority]

Hydrologic site	Latitude and longitude	Total depth (feet)	Water level-measurement				Notes
			Measuring point elevation (feet)	Depth below measuring point (feet)	Date and time (Samoa)	Elevation relative to mean sea level (feet)	
Well 207	14:12:49 S 169:27:13 W	>37	29.26	29.56	10/24/03 16:25	-0.30	Q = 55 gal/min at time of water-level measurement
Well 208	14:12:52 S 169:27:28 W	61	NA	49.90	10/24/03 16:08	NA	Unused. Difficulty getting GPS reading at well site
Well 209	14:14:26.1 S 169:30:31.2 W	52	40.24	40.50	10/24/03 13:30	-0.26	Unused; water level fluctuates with tides
Well 210	14:14:27.6 S 169:30:29.9 W	51	NA	NA	NA	NA	Plugged at depth of 24.88 ft
Well 211	14:13:42.2 S 169:30:40.5 W	250	NA	NA	NA	NA	Plugged at depth of 189 ft
Well 212	14:13:38.5 S 169:30:42.1 W	223	201.29	NA	NA	NA	Measuring tube blocked, water meter not working, ASPA technician said pumping rate is about 60 gal/min.
Faleasao dug well	14:13:15.8 S 169:30:49.7 W	NA	NA	NA	NA	NA	Not located (destroyed?)
Fitiuta School well	14:13:00.5 S 169:25:30.2 W	NA	NA	NA	NA	NA	Plugged to near top of casing
Fitiuta dug well	14:12:49.8 S 169:26:08.6 W	NA	NA	NA	NA	NA	Not located (destroyed?)
Fagamalo Spring	14:14:44.6 S 169:30:08.5 W	NA	NA	NA	NA	NA	
Ta’u landfill	14:13:15.3 S 169:30:02.6 W	NA	NA	NA	NA	NA	
Proposed well site 1	14:13:36.3 S 169:30:17.6 W	NA	NA	NA	NA	NA	
Proposed well site 2	14:13:51.7 S 169:30:21.5 W	NA	NA	NA	NA	NA	
Proposed well site 3	14:13:56.9 S 169:30:25.8 W	NA	NA	NA	NA	NA	
Proposed well site 4	14:13:46.3 S 169:30:38.8 W	NA	NA	NA	NA	NA	North end of old airfield
Proposed well site 5	14:14:01.3 S 169:30:39.6W	NA	NA	NA	NA	NA	South end of old airfield

Because no pump was installed in the well, an opportunity was available to set a pressure transducer and data logger to monitor water-level fluctuations over the two-day period of the reconnaissance visit. The water-level monitoring data shows a semi-diurnal cycle corresponding to the fluctuation of ocean tides (fig. 4). The range of the water-level fluctuation during the two-day monitoring period was about 2.8 ft, which is 75 percent of the concurrent tidal range recorded at the tide gage at Pago Pago Harbor on Tutuila (National Oceanic and Atmospheric Administration, 2003). The relatively strong tidal signal in this well indicates that the rock penetrated by the well has high permeability.

Well 210. – Well 210 is the southernmost of a pair of wells near the Ta'u boat harbor (table 1, fig. 2). It is synonymous with well TA-1430-04, and has also been called well 130a, and Ta'u Harbor Well 2. According to the USGS files, the well was drilled in 1982 at an elevation of about 40 ft, is 51 ft deep, and had rapid fluctuations (possibly caused by tides) in water level. At the time of the reconnaissance visit for this study, the well was not being used and was plugged at 24.88 ft below the top of the casing.

Well 211. – Well 211, at the back of the campus of Manua High School, was the first of two wells drilled near the school (table 1, fig. 2). This well is synonymous with well TA-1430-02 in the files of the USGS, and well M-1430-02 described in Bentley (1975). A level survey conducted during the reconnaissance visit of this study indicates that the top of the raised concrete slab that is flush with the top of the casing is at an elevation of 195.19 ft. This differs slightly from Bentley (1975) who reports that the top of the well casing is at an elevation of 194.9 ft. Bentley also reported that this well had an initial water-level elevation of 2 ft and a transmissivity of "about 50,000" ft^2/d. Notes in the files of the USGS indicate that the well is 250 ft deep, has a 6-in. solid casing to a depth of 200 ft, 40 ft of perforated casing, and 10 ft of open hole below that. Assuming horizontal flow and dividing Bentley's (1975) transmissivity by the 50 ft total of perforated casing and open hole yields an estimate of hydraulic conductivity of about 1,000 ft/d, which is comparable to the high hydraulic conductivities characteristic of the principal aquifers of Hawaiian shield volcanoes (Hunt, 1996). The files also indicate that in the 1980s, the well produced about 50 to 300 gal/min of water with chloride concentrations of about 140 to 300 mg/L. The well was abandoned in the 1980s when a pump was accidentally dropped into it. At the time of the reconnaissance visit of this study, the well was plugged at a depth of 189 ft below the top of the raised concrete pad.

Well 212. – Well 212 is the second of two wells near the Manua High School campus in northwestern Ta'u. This well is synonymous with well TA-1330-02 in the files of the USGS; ASPA employees commonly refer to this well as the "High School Well." The well is on the south side of the road that passes in front of the school, and is about 1,760 ft from the coastline (table 1, fig. 2). This well provides water to a reverse-osmosis unit in Faleasao Village. During the field reconnaissance for this study (October 24, 2003), the well was being pumped but the water level and pumping rate could not be determined because the water meter was not working and the access for the water-level measuring device was plugged. Technicians from ASPA indicated that the

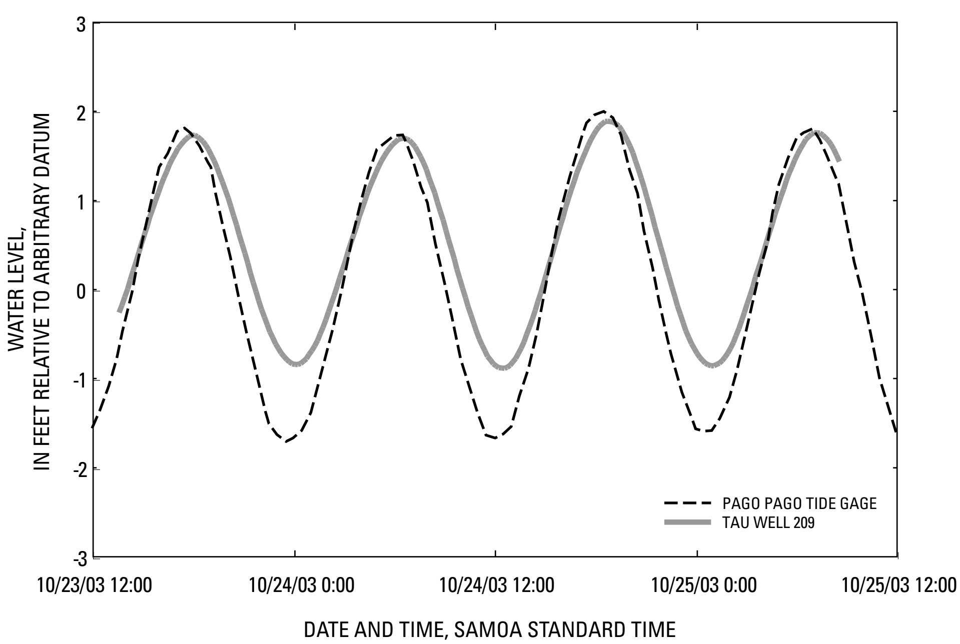


Figure 4. Water levels in well 209, near the boat harbor on Ta'u, American Samoa, and tidal records from Pago Pago Harbor, Tutuila, American Samoa (data for Pago Pago from the National Oceanic and Atmospheric Administration, 2003).

well is usually pumped at about 60 gal/min. A water sample from the well had a chloride concentration of 429 mg/L. A level survey was conducted during the reconnaissance visit of this study. With a starting reference elevation of 199.22 ft for the concrete base slab (reference elevation obtained from McConnell Dowell, the construction company that built the nearby road), the elevation of the top of the raised concrete slab surrounding the well casing was determined to be 200.70 ft, the top of the metal plate covering the well was determined to be 201.00 ft, and top of the existing (plugged) measuring tube was determined to be 201.29 ft. Information in the files of the USGS indicate that the well was drilled in 1986 and stopped at a depth of 223 ft when chloride concentrations of the water in the hole rose to 111 mg/L. The files also indicate that the pumping rate of this well was increased when well 211 became unusable.

***Faleasao Dug Well.* –** This well was not located during the reconnaissance visit for this study, and was apparently destroyed. The well's precise location is not known; the coordinates in table 1 and the location shown in figure 2 are based on recollection of an island resident. This well is probably synonymous with TA-1330-01 (also known as Ta'u Dug Well 2 in some old notes) in the USGS files, and M1330-1 in Bentley (1975).

***Fitiuta School Well.* –** During the reconnaissance field work for this study, an abandoned well was visited on the Fitiuta school grounds (table 1, fig. 2). Its location near (on the seaward side of) the main road, and the fact that it is plugged near the surface, indicates that this well is probably the same as the well that P. Eyre, in his 1982 field notes (in files at the USGS), called "well 128", which is synonymous with well TA-1325-03 in the files of the USGS. Notes and letters in the USGS files report that although the well reached water, the yield was not sufficient to develop.

***Fitiuta Dug Well.* –** Bentley (1975) lists a dug well (number M1325-1 in his report) near Fitiuta. Island residents questioned during the reconnaissance visit of this study recall a well on the north coast, but the precise location is not clear. The coordinates listed for this well in table 1, and the location shown in figure 2, are approximations based on the recollection of island residents.

***Fagamalo Spring.* –** Fagamalo Spring issues from a cliff on the western side of Ta'u (table 1, fig. 2). Davis (1963) reported that at the time of his reconnaissance study, which was before deep wells were drilled on Ta'u, Fagamalo Spring was used extensively for water supply in western Ta'u. At the time of the reconnaissance visit of this study, water was observed in a 17-ft long by 11-ft wide concrete catchment, out of which distribution pipes led. No flow from the catchment was observed, but water in the catchment was 5.3 ft deep, and a water sample taken from the catchment had a chloride concentration of 6.7 mg/L.

***Ta'u landfill.* –** The Ta'u landfill is on the eastern edge of the Tunoa depression in northwestern Ta'u (table 1, fig. 2), and is the primary site for disposal of solid waste on the island. Staff at the ASEPA and ASPA indicated that the landfill is not lined. The proximity of this landfill to existing and proposed wells was the primary motivation for this study.

***Proposed sites for new wells.* –** ASPA is proposing to drill a new well to serve northwestern Ta'u. During the reconnaissance visit for this study, resident ASPA employees indicated five possible well locations (table 1, fig. 2). At the time of this study, ASPA had plans to drill only one well.

***Large metal drums.* –** A stack of large metal drums was observed along the road between the landfill and Manua High School (table 1, fig. 2). The content of the drums was not determined, but island residents indicated that they once contained gasoline and that they are now empty. This study does not address whether these constitute a potential source of contamination.

Conceptual Model of Ground-Water Occurrence and Flow

Specific ground-water data for Ta'u is sparse, but consistent with the hypothesis that most of the ground water in Ta'u, as in other shield-volcano islands, forms a freshwater lens that floats on saltwater in an aquifer formed principally by permeable basaltic lava flows (fig. 5). The existence of a sizable freshwater lens in Ta'u was postulated by Davis (1963) and Bentley (1975). In the simplest conceptualization of a freshwater-lens system, the thickness of the freshwater lens below sea level is approximately 40 times the thickness of the lens above sea level. This relation, known as the Ghyben-Herzberg relation, is commonly used to estimate the thickness of the freshwater lens when the height of the water table above sea level is known. The Ghyben-Herzberg relation, however, has only limited accuracy in this regard because (1) the relation does not consider the thickness of the mixing zone between the freshwater lens and the underlying saltwater, and (2) the dynamics of the freshwater lens invalidates some of the assumptions of the relation.

Ground water constantly flows through the freshwater lens. The ground water originates as recharge from rainfall, and flows from high recharge areas in the interior of the island toward discharge sites (springs and seeps) at the coast (fig. 5). Only a few springs are shown on the topographic map of the Manua Islands (USGS, 1963, fig. 1), but historical accounts of spring use by villagers (Davis, 1963; U.S. Army Engineering District, Honolulu, 1977) indicate that ground-water discharge along the coast is widespread. There are also numerous references to coastal springs in unpublished notes in the well files of the USGS. Large springs that discharge at relatively high elevations have historically been used for drinking water, whereas springs at the coast (including those that are exposed only at low tide) have been used for bathing, washing, and in times of drought, drinking water (Davis, 1963).

The freshwater lens is probably thickest in the interior of the island and thinnest at the coast where discharge occurs, but the overall thickness of the freshwater lens is a function of the rate of freshwater flow and the permeability of the rocks. In general, the freshwater lens will be thicker in an island

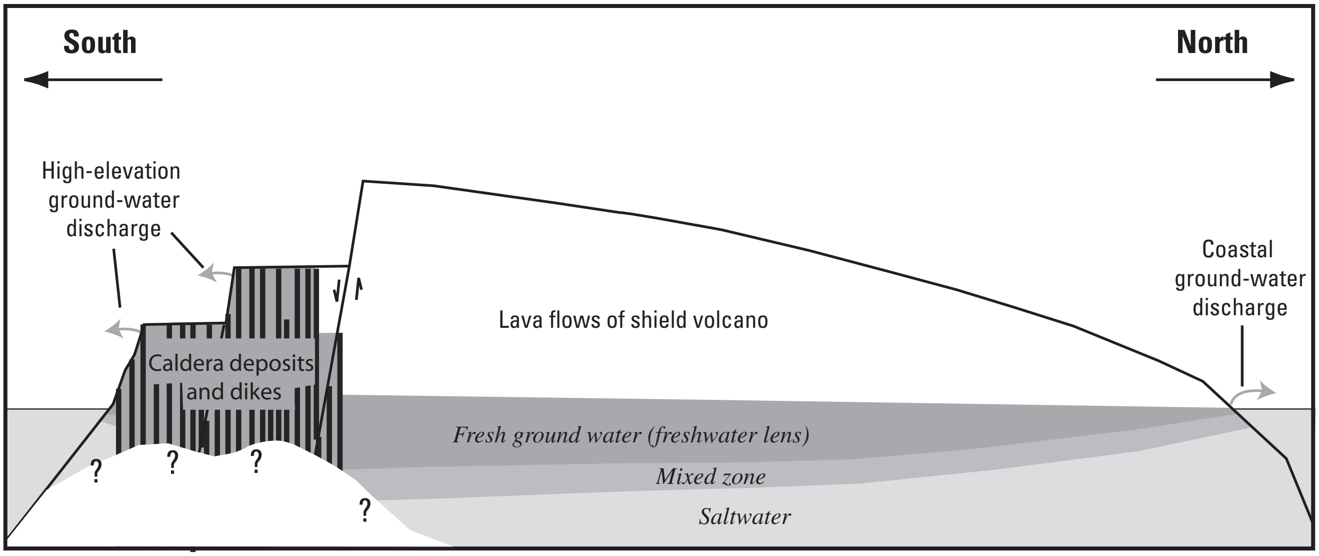


Figure 5. Diagrammatic representation of ground-water occurrence in Ta'u, American Samoa.

with lower permeability rocks or with a higher island-wide recharge. Because Ta'u has few wells, and even fewer wells for which accurate water-table elevations relative to sea level are known, the thickness of the freshwater lens in the island is for the most part unknown.

Volcanic dikes, which are common in shield volcanoes, tend to reduce the permeability of the lava-flow aquifers into which they intrude. This may result in local thickening of the freshwater lens or discharge of ground water at sites other than the coast (fig. 5). Laufuti Stream, which flows over a dike complex exposed in the benches and cliffs near the southeastern coast of the island (fig. 1), is perennial in its upper reaches down to an elevation of about 1,422 ft, and in its lower reaches below 121 ft elevation (Davis, 1963; Stice and McCoy, 1968; Cook 2001). The high-elevation perennial flow in Laufuti Stream indicates that the ground-water table is high in this area, despite its proximity to the coast, possibly as a consequence of the ground-water impounding effects of low-permeability geologic structures such as dikes or low-permeability caldera deposits.

Dikes can act as barriers to ground-water flow and thus limit the yield of nearby wells, but dikes also can create compartments in which large volumes of ground water are stored and water-table elevations are hundreds of feet above sea level. On Oahu, Hawaii, such high-level, dike-impounded ground-water bodies have been developed for water supply (Takasaki and Mink, 1985). Dikes are likely to be present in the rift zones of Ta'u (fig. 3), and Bentley (1975) postulated that Ta'u may also have high-level ground-water resources.

Rocks formed in calderas in Hawaii generally have lower permeability than the lava flows on the flank of the shield because in the caldera region, dikes are abundant, lava flows are generally thicker due to ponding, and hydrothermal alteration of the rocks reduces primary porosity. Analogous deposits from the caldera of the main Lata Shield of Ta'u (fig. 3) are also likely to have low permeability. Whether the rocks in the central depression of the satellite Tunoa Shield have the low-permeability characteristics of caldera rocks is, however, unknown.

Despite having similarities with other mid-ocean basaltic shield volcanoes such as Hawaii, Ta'u differs in certain hydrologically significant ways. Ta'u has an area above sea level that is only about a third of the area of the smallest of the major Hawaiian Islands. Such a small island likely offers only a small amount of ground-water storage, especially if the permeability of the rocks is high. Ta'u also has little or no coastal plain, which indicates that there is little to impede the discharge of ground water from the freshwater lens to the ocean. On Oahu, Hawaii, an extensive coastal plain of low-permeability sediments (locally known as caprock) impedes ground-water discharge from the major basalt aquifers to the ocean, thereby substantially increasing the thickness of the freshwater lens in the basalt even though the aquifer has high permeability. On Ta'u, where aquifer permeability is high but no caprock exists, the freshwater lens is likely to be thin even though recharge may be high.

An estimate of aquifer permeability. – The relatively low pre-pumping water levels (relative to sea level) in well 207 in northeastern Ta'u and well 211 in northwestern Ta'u, as well as the strong tidal signal at well 209, indicate that the aquifers penetrated by these wells have high permeability. The hydraulic conductivity of a coastal aquifer (a measure of its permeability) can be estimated by using equations developed by Glover (1964) for the steady-state shape of a freshwater lens discharging at a coast. Glover's equations describe the shape of the freshwater lens in terms of flow rate and aquifer hydraulic conductivity; the equations can be solved for hydraulic conductivity if freshwater flow rate and certain aspects of the shape of the freshwater lens are known. Glover's equation that approximates the water table height above sea level is:

$$h = (2\gamma Qx/K)^{0.5}, \quad \text{(eq. 1)}$$

where:
h = water table elevation at distance x from the shore [L],
γ = density difference between freshwater and saltwater divided by the density of freshwater, which for most oceanic islands is about 0.025 [dimensionless],
Q = freshwater flow per unit length of coast [L^2/T],
x = distance from shore where h is measured [L], and
K = hydraulic conductivity [L/T].

Solving for K gives:

$$K = (2\gamma Qx)/h^2. \quad \text{(eq. 2)}$$

Values for h and x can be obtained from records for well 211 (fig. 2), which indicate that the water level (h) at that location prior to pumping was about 2 ft above sea level. The distance (x) from well 211 to the nearest point on the coast is about 1,960 ft. An accurate value of Q is not available, but a reasonable range of estimates may be obtained by assuming that some proportion of rainfall becomes ground-water recharge, and dividing the recharge estimates by the 19.5-mi perimeter of the island. Although rainfall data for Ta'u are scarce, the records that do exist indicate that the island receives, on average, more than 100 in. of rain per year. For this study, a range of Q was computed using rainfall values of 100, 150, and 200 in. per year and assuming that 33 to 50 percent of the rainfall becomes ground-water recharge. Computations of K indicate that the hydraulic conductivity of the aquifer near well 211 could range from several hundreds to a few thousands of feet per day (table 2). Such high hydraulic conductivities are consistent with those measured from other shield volcanoes such as the Hawaiian Islands (Hunt, 1996), and consistent with the high transmissivity (which corresponds to a hydraulic conductivity of about 1,000 ft/d) reported for well 211 by Bentley (1975).

Numerical simulation of ground water – To test the validity of the conceptual model of ground-water occurrence and flow on Ta'u, a steady-state numerical model was constructed using the finite-difference modeling program SHARP (Essaid, 1990). Because SHARP allows the simulation of coupled freshwater and saltwater flow, it is ideal for simulating ground-water systems in oceanic islands where a freshwater lens overlies saltwater. The accuracy of the numerical model's representation of the ground-water system of Ta'u is limited by the general paucity of hydrologic data for Ta'u. Even so, the numerical model provides a means for (1) illustrating concepts of how ground-water flow and aquifer permeability are related to the size, shape, and geology of Ta'u, and (2) assessing whether the assumptions of the conceptual model are quantitatively consistent with the equations of ground-water flow.

Table 2. Estimates of hydraulic conductivity for shield-volcano lavas on Ta'u, American Samoa, using the equation in Glover (1964) over a range reflecting uncertainty in rainfall and recharge.

[in/yr, inches per year; %, percent; ft^3/s, cubic feet per second; ft/d feet per day; Q, ground-water flow per unit length of coastline; K, hydraulic conductivity]

Rainfall (in/yr)	Estimated Recharge		Q (ft^2/s)	K (ft/d)
	(% of rainfall)	(ft^3/s)		
100	33	36.47	0.000354	750
150	33	54.70	0.000531	1,125
200	33	72.93	0.000708	1,499
100	50	55.25	0.000537	1,136
150	50	82.88	0.000805	1,704
200	50	110.50	0.001073	2,272

Constants:
Island area = 15 square miles
Island coast = 19.5 miles
Distance of well from coast = 1960 feet
Water-table elevation = 2 feet

The numerical model encompasses the entire island of Ta'u as well as some of the surrounding sea floor so that the simulated freshwater lens is not artificially restricted by model boundaries (fig. 6). The model has a single layer, with 66 cells in the east-west direction and 67 cells in the north-south direction. In the northwest corner, the model cells were made smaller (277 ft by 277 ft) to increase resolution in the area where ASPA proposes to drill new wells (to be discussed in a later section).

All model cells representing the main shield volcano of Ta'u as well as all offshore areas were assigned a hydraulic conductivity of 1,200 ft/d, which is consistent with values estimated in the foregoing analysis using Glover's (1964) equation, as well as values reported for Ta'u (Bentley, 1975) and for Hawaii (Hunt, 1996). Using this value also results in a simulated water level of 2 ft at the location of well 212, which is the pre-pumping water level reported in nearby well 211. Rift zones, caldera deposits, and the tuff cone in the northwest, all of which are expected to have lower permeability than the main shield, were simulated with model cells having a hydraulic conductivity of 0.1 ft/d. The positions of the model-simulated tuff and caldera are based on the geologic maps and descriptions of Stice and McCoy (1968). No rift zones are delineated in the geologic map of Stice and McCoy (1968), but in the text of their paper, they describe northwest and northeast trending rift zones; these descriptions form the basis for the position for the simulated rift zones in the numerical ground-water model constructed for this study (fig. 6). Recharge for most of the model cells was set at a uniform 50 in/yr, which corresponds to an infiltration of 1/3 of a rainfall rate of

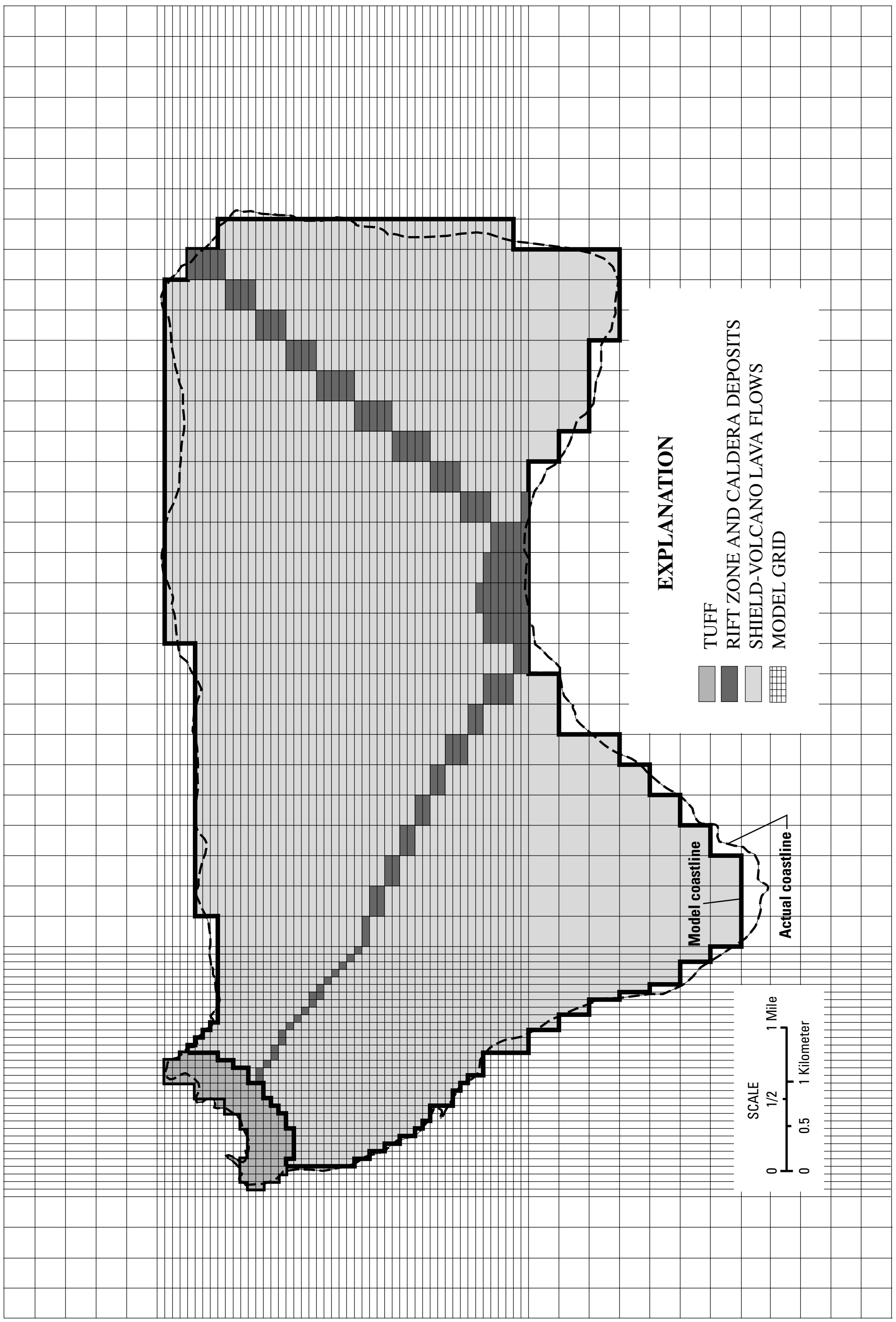


Figure 6. Extent of the numerical ground-water model of Ta‘u, American Samoa.

150 in/yr. Recharge at the tuff cone, caldera deposits, and rift zones was set at 7.5 in/yr because runoff from these low-permeability rocks and structures is likely to be high.

The model-simulated water table through most of the island (except the rift zones, caldera, and tuff cone) has a gentle convex slope, consistent with the shape of the upper surface of a freshwater lens (fig. 7). The low elevation of most of the water table indicates that the freshwater lens is thin in most areas. The continuity of the simulated water table is interrupted by the low-permeability rift zones that radiate to the northwest and northeast from the caldera. Water levels in the low-permeability caldera are higher than in the adjacent freshwater lens, but the geologic structure of this area is not known well enough to allow precise simulation of the high-elevation ground-water discharge to Laufuti Stream. These results support a conceptual model of ground-water occurrence in Ta'u, in which (1) recharge is high; (2) aquifer permeability is high except in the rift zones, caldera, and tuff cone; (3) the freshwater lens is thin throughout most of the island; and (4) water may exist at high elevations in areas such as calderas and rift zones where low-permeability geologic structures intrude into the otherwise high permeability rocks of the island.

Because the freshwater lens is thin throughout most of the island, the productivity of most wells is likely to be limited by saltwater intrusion. The freshwater lens is thinnest near the coast, therefore wells located near the coast are more likely to encounter production limitations due to salinity than wells located farther inland, where the freshwater lens is thicker. The history of high salinity and low water levels at wells 211 and 212 indicate that those wells were drilled too deep given the thin freshwater lens in that area. Using the Ghyben-Herzberg relation and the reported pre-pumping water-table elevation in well 211 gives a freshwater thickness of only 82 ft, part of which is brackish.

Ground Water in Northwestern Ta'u

To relieve the high demand on well 212 and the associated reverse-osmosis system that currently provides all the municipal drinking water for western Ta'u, ASPA has proposed the construction of a new well in the area inland from Ta'u and Siufaga Villages. Five potential locations for this new well were visited during the field reconnaissance phase of this study (fig. 8). Concern has been raised, however, that these proposed sites are so close to an active landfill that contamination from the landfill may threaten the quality of water from wells drilled at the proposed sites. In this section, the details of the hydrogeology of northwestern Ta'u are discussed, particularly as it bears on the existing well, proposed well sites, and the possibility of contamination from the landfill.

The geology of this area of Ta'u is dominated by the Tunoa Shield, a small shield volcano that was built on the northwestern flank of the main Ta'u shield volcano (fig. 3). The Tunoa Shield was formed by eruption of lava from the northwest rift zone of the main Ta'u shield, and is predominantly composed of thin-bedded pahoehoe lava flows. In the center of the Tunoa Shield is a large, fault-bounded, arc-shaped depression, known as the Tunoa Depression (fig. 2), which was partly filled by later lava flows and other volcanic rock. The Tunoa Shield, including part of its central depression, is truncated by a former sea cliff that was later partly covered by a complex of consolidated tuff. Remnants of the former sea cliff are still exposed behind Ta'u Village, but the present-day coastline is several hundred feet west of the cliff and is separated from it by a marsh and beach (Stice and McCoy, 1968).

Plots of the GPS data obtained during the field reconnaissance indicate that well 212, the proposed well sites, and the landfill all lie in the Tunoa Depression (fig. 8). Although the initial motivation for this study was a concern over the proximity of proposed new well sites to the landfill, the GPS data indicate that well 212 is closer to the landfill than some of the proposed new wells sites. The landfill also lies closer to the north coast of the island than to any of the existing or proposed well sites. Without consideration of geologic structures or the manner in which pumping wells can alter ground-water flow, the location of the landfill near the north coast suggests that ground-water from beneath the landfill would flow toward the north, away from the existing well and the proposed well sites. The landfill lies at the northern boundary of the Tunoa depression, however, and very close to the escarpment that Stice and McCoy (1968) interpreted to be a fault (fig. 8). The landfill is, in fact, so close to the fault that it is difficult to determine on which side of the fault the landfill lies. Depending on the hydraulic properties of the fault and a nearby rift zone relative to the surrounding rock, these structures may have a significant effect on ground-water flow directions in this area.

As discussed previously, the low water-table elevation at well 212 and the strong tidal signal at well 209 indicate that the permeability of the rocks in those areas is high. This is consistent with observations of Stice and McCoy (1968) that the Tunoa Shield is composed primarily of thin-bedded lava flows, as are the high-permeability aquifers in Hawaii (Hunt, 1996). The consolidated tuff, if analogous to similar deposits in Hawaii, is likely to have low permeability (Hunt, 1996). The hydraulic properties of faults in basaltic islands are virtually unknown. Whether the fault bounding the Tunoa Depression has a lower, equal, or higher permeability than the surrounding rocks can affect ground-water flow directions and hence whether the contaminants from the landfill, if they leach down to the water table, will flow toward the existing production well 212 and the proposed well sites, or away toward the north coast.

Which of these conditions is most likely to exist in northwestern Ta'u cannot be determined with the current knowledge of Ta'u geology and the hydraulic properties of faults in general, but a limited number of scenarios is

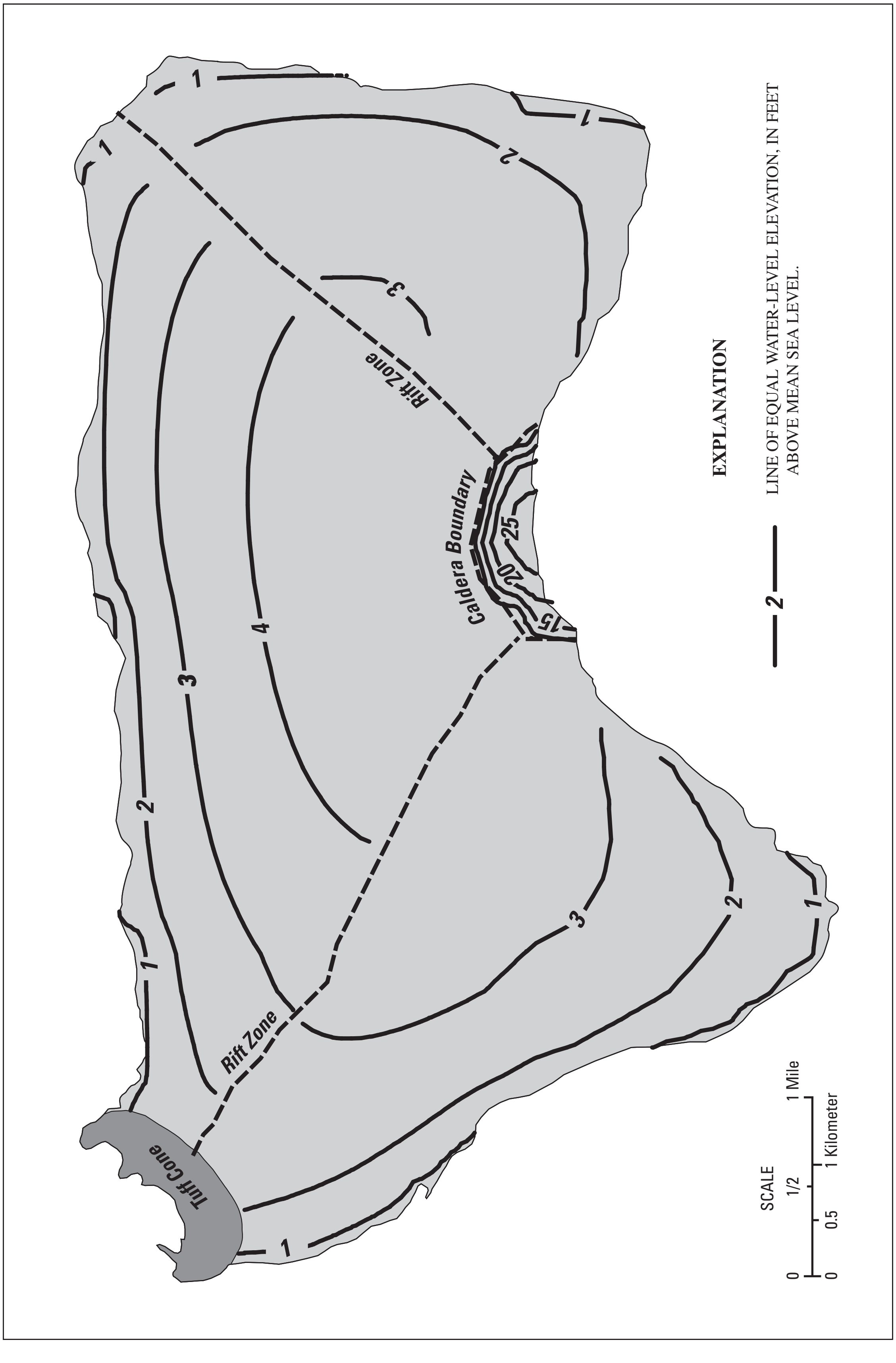


Figure 7. Model-simulated water-table elevations, in feet relative to mean sea level, for Ta‘u, American Samoa.

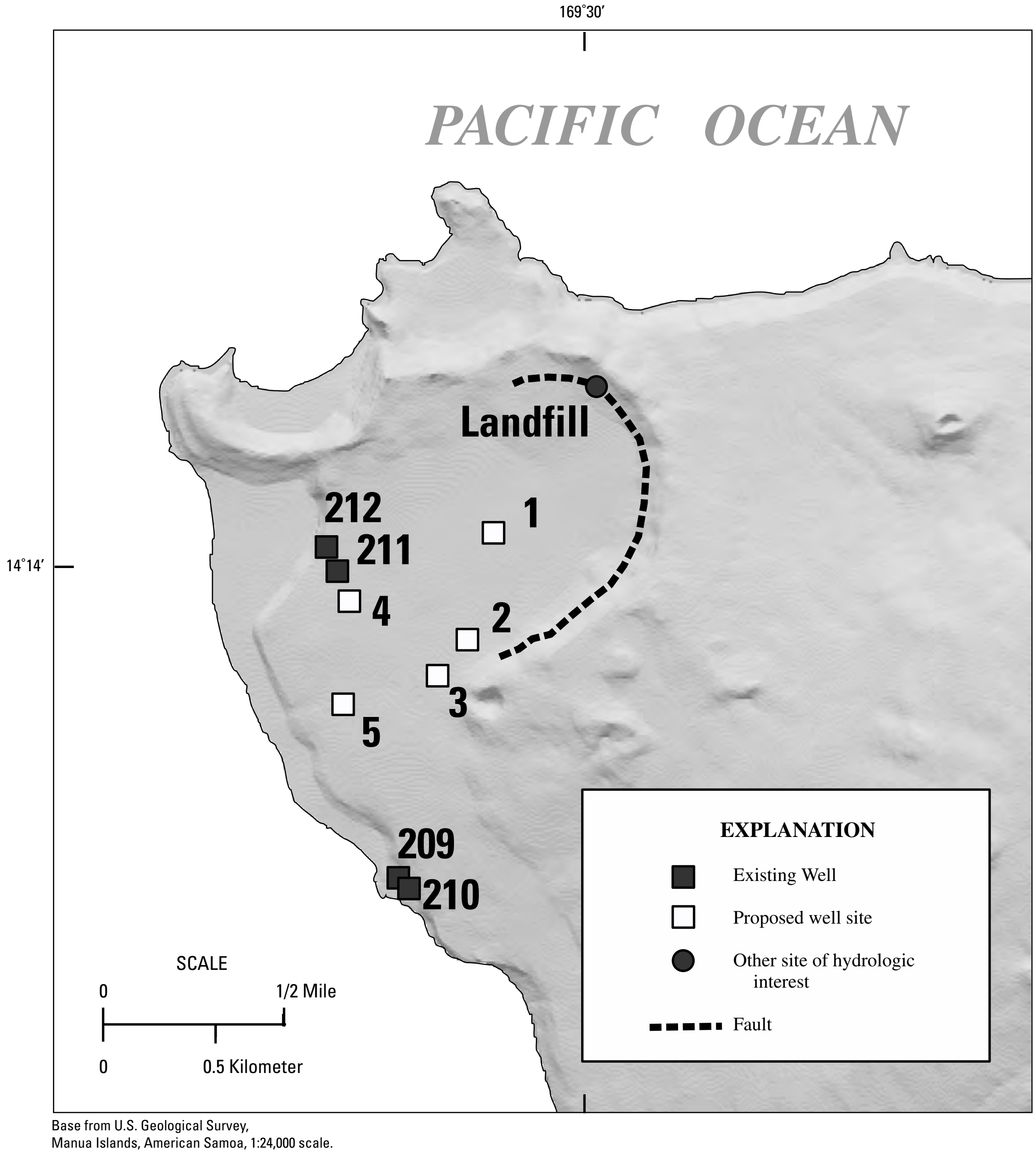


Figure 8. Existing wells, proposed well sites, and landfill in northwestern Ta'u, American Samoa (presence of the fault is based on Stice and McCoy, 1968; location of the fault as depicted here is based on topographic features).

plausible. These scenarios can be simulated with the numerical model to determine which, if any, present a situation in which water quality from wells in western Ta'u would be threatened by contaminants from the landfill. Four possible hydrogeologic scenarios were modeled: (A) the permeability of neither the fault nor rift zone is substantially different from that of the surrounding rock, (B) the rift zone has a lower permeability but the fault has a permeability that is the same as that of the surrounding rock, (C) the fault has a lower permeability but the rift zone has a permeability that is the same as that of the surrounding rock, and (D) both the fault and the rift zone have permeabilities that are substantially lower than that of the surrounding rock. In all of these scenarios, it is assumed that the landfill is on the same side of the fault as the well sites. This represents a higher probable effect (on the existing and proposed wells) than if the landfill and well sites were on opposite sides of the fault. The hydraulic conductivities of the simulated rock units for each scenario are shown in table 3.

In the two scenarios in which the permeability of the fault is not substantially different from the surrounding rock (fig. 9, A and B), the water table beneath the landfill slopes toward the north coast. Assuming horizontal aquifer homogeneity, ground water would flow in a direction perpendicular to the contour lines of the water table, as shown by the arrows in figure 9. Thus, results of the numerical simulation indicate that in these scenarios, ground water beneath the landfill would flow away from production well 212 and the proposed new well sites. If the rift zone has a lower permeability than the surrounding rock as shown in figure 9B, it may constitute an additional ground-water separation between the landfill and the existing and proposed well sites.

In the simulation in which the fault has a lower permeability but the rift zone has a permeability that is the same as the surrounding rock (fig. 9C), the water table beneath the landfill slopes toward the west, and the natural flow of ground water beneath the landfill will likewise be toward the west. The simulation results indicate that if this is true, the well most closely aligned with ground-water flow from the landfill is the existing production well 212. The proposed new well sites in the Tunoa Basin are not as closely aligned on a flow line from the landfill.

In the simulation in which both the fault and the rift zone have permeabilities that are substantially lower than the surrounding rock, the ground-water table between the fault and the rift zone reaches a substantially higher elevation than the surrounding area (fig. 9D). The low-permeability fault, rift zone, and tuff cone form a compartment in which ground water accumulates to form a mound. The landfill is on the northern side of the mound, indicating that ground water from beneath the landfill will probably flow to the north, away from well 212 and the proposed well sites.

The model simulations indicate that of the four scenarios tested, only one (fig. 9C) would result in ground-water flow paths that would bring water from beneath the landfill toward the wells. In all four scenarios tested, the proposed well sites 2, 3 and 5 are farthest from any ground-water flow lines originating at the landfill and are therefore least likely to be affected by contamination from the landfill. The available data are insufficient, however, to assess which of these scenarios is most likely, and these simulations do not consider the change in flow paths that could result from the withdrawal of water from any of the well sites, nor do the simulations consider other hydrogeologic conditions that may exist in this area.

Because at least one of the simulated possible scenarios indicates that water leaching from the landfill may reach the existing production well 212, testing of the water quality of this well and comparing it to the quality of water from the landfill may provide information on the movement through ground water of contaminants from the landfill. Analysis of a water sample collected from well 207 by the ASEPA in 2003 (data provided by Peter Peshut, ASEPA, written communication, 2004) indicates that except for sodium, concentrations of all inorganic constituents analyzed were below the maximum contaminant levels (MCLs) or secondary maximum contaminant levels (SMCLs) established by the U.S. Environmental Protection Agency (2003), and none of the organic constituents analyzed were above the detection limit of the analytical method. The high concentration (240 mg/L) of sodium in the water sample may reflect the known

Table 3. Hydraulic conductivities applied in numerical-model simulations of ground water in northwestern Ta'u, American Samoa.

Aquifer	Hydraulic conductivity (feet per day)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Main shield volcano	1000	1200	1350	1250
Tuff cone	0.1	0.1	0.1	0.1
Fault	1000	1200	0.1	0.1
Rift zones and caldera	1000	0.1	1350	0.1
Offshore areas	1000	1200	1350	1250

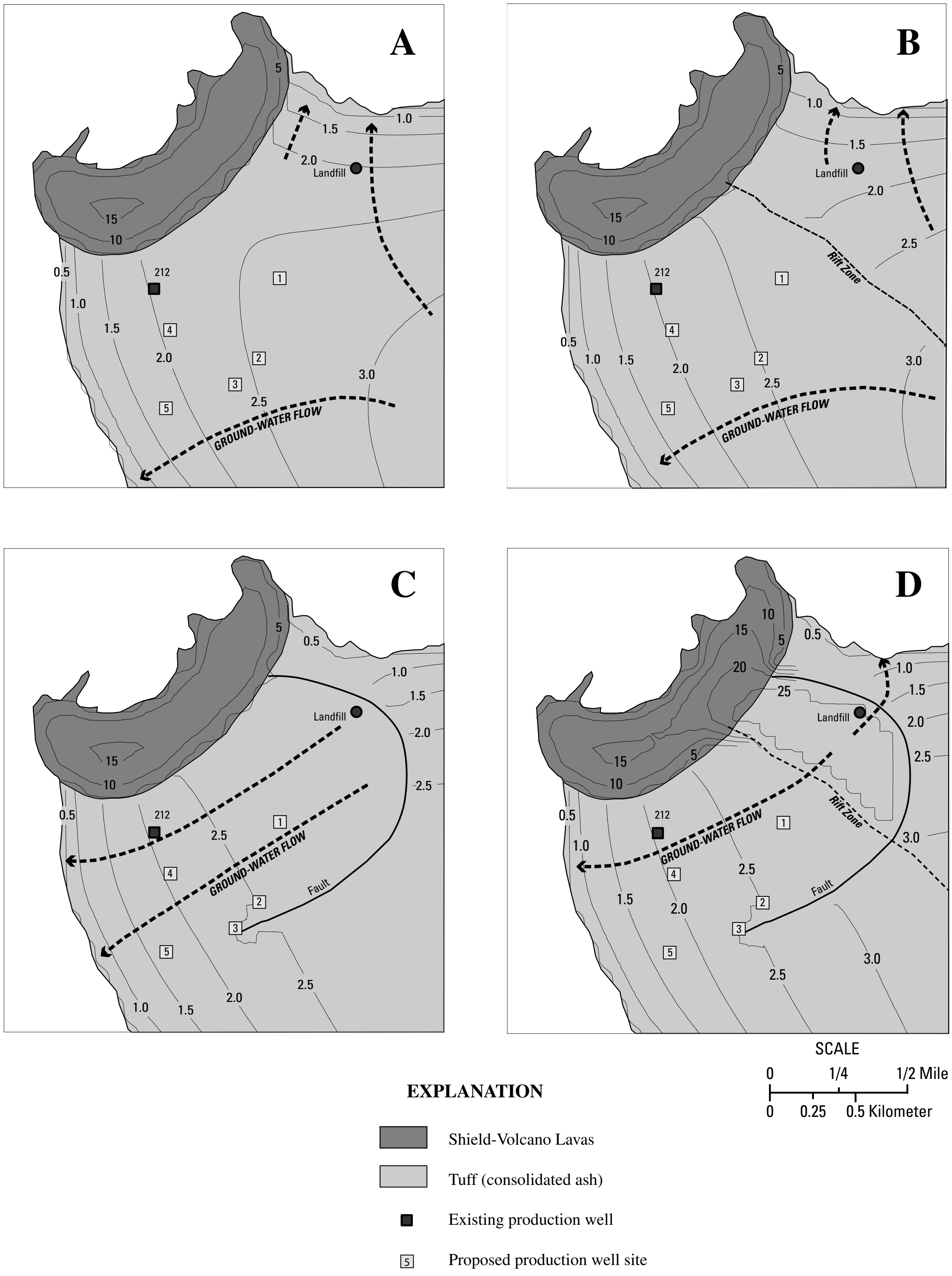


Figure 9. Model-simulated water-table elevations, in feet above sea level, and ground-water flow directions in northwestern Ta'u, American Samoa: (A) scenario in which the permeability of neither the fault nor rift zone is substantially different from that of the surrounding rock, (B) scenario in which the rift zone has a lower permeability but the fault has a permeability that is the same as that of the surrounding rock, (C) scenario in which the fault has a lower permeability but the rift zone has a permeability that is the same as that of the surrounding rock, and (D) scenario in which both the fault and the rift zone have permeabilities that are substantially lower than that of the surrounding rock.

relatively high salinity of water from this well. If all the sodium comes from sea salt (NaCl), a sodium concentration of 240 mg/L would correspond to a chloride concentration of 370 mg/L, which is consistent with the high chloride concentration of water sampled during the reconnaissance visit of this study (429 mg/L). The absence of any definitively high concentrations of any constituents other than sodium could indicate that (1) water from the landfill has not yet reached or will not reach the well, (2) the constituents are removed or diluted as they travel from the landfill to the well, or (3) water from the landfill does not carry any of the constituents analyzed. The analysis of water quality at well 212 or any other well that may be potentially affected by the landfill would be made more meaningful if the contents of the landfill or the water leaching from it were known.

Study Limitations and Additional Data Needs

Limitations of the island-wide conceptual and numerical models – The accuracy of the conceptual and numerical ground-water models presented in this study, and the hydrologic interpretations made from them, are limited by the relatively sparse hydrologic data that is available for Ta'u. Rainfall data are available only for the northwestern corner of the island, and does not cover a long period of time. There are currently no data to show how rainfall varies spatially on Ta'u, nor are there any long-term streamflow or evaporation data. Because these data are lacking, the recharge estimates used in the analytical computations and model simulations in this study are, at best, gross approximations. Precise water-level elevation data for Ta'u are difficult to obtain, in part because not many wells have been drilled, especially in the interior of the island, but also because accurate surveys of well elevations and measuring points are not available for most wells. Understanding of the water resources of Ta'u could be significantly advanced by (1) monitoring rainfall, streamflow, and evaporation data; (2) monitoring withdrawal, pumping schedules, pumping rates, and water quality at all wells; (3) establishing accurately surveyed measuring points for all wells, both used and unused, that are still open to the water table; and (4) testing for aquifer properties (i.e. pump tests or aquifer tests).

Because of the objectives of this study, the numerical model has greater detail in northwestern Ta'u than anywhere else on the island. All aspects of hydrology, including geology, recharge, and hydraulic properties for areas except the northwest are only grossly simulated. The numerical model is not intended for applications beyond the scope of this study.

Limitations of the analysis of northwestern Ta’u – This study has focused on the movement of ground water, and has not addressed the possibility that contaminants from the landfill may be carried by surface water to areas beyond the present-day limits of the landfill. If surface transport is significant, the potential for contaminants reaching wells may be greater than identified in this study. The study also has not considered the influence of well withdrawals, which can alter the direction of ground-water flow, or the possibility that contaminants will be dispersed as they are transported by ground water. This study has focused on the relation between the existing landfill, existing wells, and proposed sites for new wells as indicated by ASPA. It was beyond the scope of this reconnaissance study to identify other potential sources of contamination that may affect drinking-water wells. A survey of all potential sources of contamination, including sources from within villages and farms, would enable a more complete assessment of the steps needed to protect ground-water resources.

As with the island-wide conceptual and numerical models, the more focused analysis of the hydrogeology of northwestern Ta'u, and the assessment of the potential that contamination from the landfill may reach existing and proposed well sites, are limited by a paucity of data. The few water levels available for the area are insufficient to determine hydraulic gradients or the slope of the water table, which have a direct bearing on the movement of contaminants that may be carried in the ground water. There is little or no information on the historical dimensions, construction details, or contents of the landfill, nor the chemistry of the water running off the landfill.

In addition to the general hydrologic data needs discussed above, information that would improve assessment of the potential that contaminants in the landfill may reach existing and proposed well sites includes (1) history, construction details, and contents of the landfill; (2) surface-water flow directions in the vicinity of the landfill; (3) chemistry of the water flowing from the landfill; (4) spatial distribution of water levels in the area; and (5) the quality of water in wells that may be affected by the landfill. Because the landfill is likely to continue to be a concern for ground-water development, these unknowns must be addressed to allow a better assessment of the potential threat to both existing and proposed wells. Construction and operation (monitoring water levels and chemistry) of one or more monitoring wells between the landfill and existing or proposed wells would provide a means to detect movement of contaminants before they reach production wells. Steps that could be implemented in the short term include monitoring of water chemistry and water levels in all existing and new production wells. Determining the chemistry of water percolating through the landfill could help identify what contaminants to look for in the monitoring of the production wells.

For the long-term future of development of ground-water resources on Ta’u, drilling wells farther inland, away from the coast and up gradient from existing sources of contamination in and near villages, may solve some of the problems posed by high-salinity water and contamination from human activities. The feasibility of this strategy for Ta'u may be limited, however. Toward the interior of the island, the land surface rises steeply whereas the water table rises gently. Thus, the farther inland the wells are placed, the deeper the wells would have to be, yet the freshwater lens may be only a little thicker than it is at the coast. An alternative strategy to reduce the problem of saltwater intrusion would be to distribute the ground-water withdrawal among several small, low-yield wells, constructed so that they do not penetrate far into the freshwater lens.

Conclusions

Ta'u probably receives high rates of ground-water recharge, but the freshwater lens is thin throughout most of the island because aquifer permeability is high in most areas. Because the freshwater lens is thin, the productivity of most wells is likely to be limited by saltwater intrusion. The freshwater lens is thinnest near the coast, therefore wells near the coast are more likely to encounter high salinity than wells located farther inland, where the freshwater lens is thicker. High salinity and low water levels at wells 211 and 212 indicate that those wells were drilled too deeply into the thin freshwater lens in that area. Limited areas of high-level ground water may exist in areas such as calderas and rift zones where low-permeability geologic structures exist.

The landfill in northwestern Ta'u is closer to the north coast of the island than to any of the existing or proposed well sites. This suggests, if other hydrogeologic factors are not considered, that ground water beneath the landfill would flow away from existing and proposed well sites, but flow directions may differ depending on the hydraulic properties of a fault and rift zone in the area. Of four plausible scenarios tested with a numerical ground-water flow model, only one indicated that ground water from beneath the landfill would flow toward the existing and proposed well sites. There is, however, not enough data to assess which of the scenarios tested is most plausible, and the model simulations do not consider the influence of well withdrawals on ground-water flow directions, surface-water transport of contaminants, dispersion of contaminants as they are transported, or other sources of contamination besides the landfill.

Accuracy of the analyses and models in this study, and the hydrologic interpretations made from them, are limited by the relatively sparse data that is available for Ta'u. Understanding of the water resources of Ta'u could be significantly advanced by monitoring climate, streamflow, and well withdrawals, water levels and water quality. Hydrologic interpretations can also be improved with accurate surveys of measuring-point elevations of all wells and careful testing of well performance.

Assessing the potential for the movement of contaminants from the landfill to existing and proposed wells can be improved with better information on the landfill (history, construction, contents, water chemistry) and the surrounding area (surface-water flow, ground-water levels, water chemistry in wells near the landfill). Monitoring water levels and chemistry in wells between the landfill and production wells can provide a means to detect movement of contaminants before water supplies are affected. Steps that could be implemented in the short term include analyzing water in the landfill and continuous monitoring of water chemistry and water levels in all existing and new production wells.

For the long-term future development of ground-water resources on Ta'u, drilling wells farther inland may solve some of the problems posed by high-salinity water and contamination from human activities, but drilling very far inland may not be feasible given the steep topography of Ta'u. Alternatively, to mitigate the problem posed by saltwater, ground-water withdrawal could be distributed among several low-yield wells, constructed so that they do not penetrate far into the freshwater lens.

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