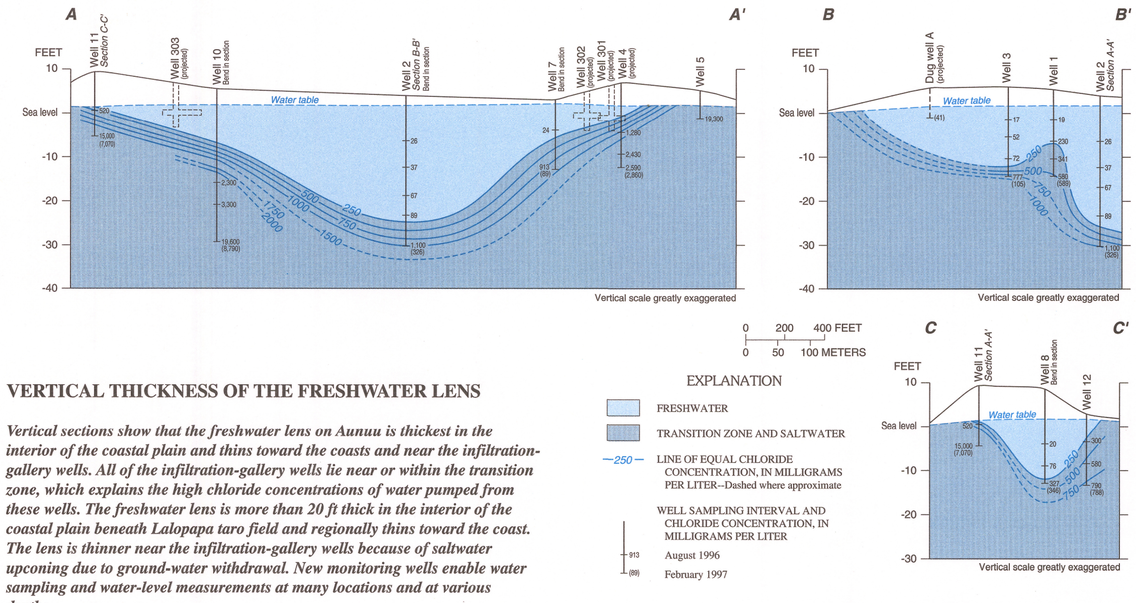

Figure 7. Thickness of freshwater lens (to a depth of 250 mg/L) and upper transition zone, August 1996, Aunuu Island, American Samoa. Lines of section are shown in figure 8.

VERTICAL THICKNESS OF THE FRESHWATER LENS

Vertical sections show that the freshwater lens on Aunuu is thickest in the interior of the coastal plain and thins toward the coasts and near the infiltration-gallery wells. All of the infiltration-gallery wells lie near or within the transition zone, which explains the high chloride concentrations of water pumped from these wells. The freshwater lens is more than 20 ft thick in the interior of the coastal plain beneath Lalopapa taro field and regionally thins toward the coast. The lens is thinner near the infiltration-gallery wells because of saltwater upconing due to ground-water withdrawal. New monitoring wells enable water sampling and water-level measurements at many locations and at various depths.

SECTIONAL VIEW

The vertical thickness of the freshwater (less than or equal to 250 mg/L) of the Aunuu coastal plain is shown in vertical sections along three transects (fig. 7). The section along transect *A-A'* through the length of the coastal plain shows that the freshwater is thickest in the center near well 2 and thins toward the northern and southern coasts. The maximum thickness attained by the freshwater is about 27 ft. The freshwater is thinner in the south than in the north, which indicates that saltwater upconing in the vicinity of wells 301 and 302 is greater than upconing near well 303. This pattern is consistent with the higher combined withdrawal from wells 301 and 302 compared with the withdrawal at well 303 (fig. 6).

In section *C-C'*, the freshwater lens is about 13 ft thick at well 8 and thins seaward to zero thickness before reaching well 11 but also thins landward to about 4 ft thick at well 12. This landward thinning may be the result of upconing caused by pumping at well 303 or differences in permeability of the coastal plain sediments. Pumping at well 301 and 302 may be the cause of the upconing of the transition zone in the vicinity of well 1 apparent in the section *B-B'*.

Relation to chloride concentrations at the infiltration-gallery wells.-- The chloride concentration of water pumped at wells 301, 302, and 303 depends on the position of the transition zone relative to the infiltration galleries in the wells. The transition zone (with a chloride concentration greater than 250 mg/L) will rise when the wells are pumped (fig. 6). As the transition zone rises to the level of the infiltration galleries (or the sump, if the sump leaks), chloride concentration of the pumped water will increase. If the initial distance between the infiltration galleries and the transition zone is short, even small withdrawal rates can raise the transition zone far enough to adversely affect water quality in the well.

The galleries for well 301 are located within the transition zone (below the 250 mg/L line in figure 7), which explains the high chloride concentration in the water pumped from this well. The sump extends into even saltier water. Although the intakes of wells 302 and 303 appear to be above the transition zone in figure 7, this is probably because of the effects of their projections onto the transects. The high chloride concentrations of water pumped from the wells indicate that the galleries lie in or near the transition zone.

MAP VIEW

The freshwater lens is thickest in the interior of the plain near the tuff cone and generally thins toward the coast (fig. 8). The maximum thickness measured was about 27 ft at well 2, located seaward of the western margin of the Lalopapa taro field, but the lens is probably even thicker beneath the marsh. Toward the coast, the locations of the dug wells control the position of the line of zero thickness of freshwater, because all of the dug wells provide water with chloride concentrations less than 250 mg/L (table 2). The freshwater lens is nonexistent beneath the northeastern section of the coastal plain near the mangrove swamp and Pala Lake, both of which contain brackish water. A sample of the lake water collected on August 8, 1996 had a chloride concentration of 12,400 mg/L. The chloride concentration of seawater typically is about 19,000 mg/L (Thurman, 1990).

Superposed on the regional pattern of seaward thinning of the freshwater lens are two areas of localized thinning: (1) in the north surrounding the infiltration galleries of well 303, and (2) in the south surrounding the infiltration galleries of wells 301 and 302. The historical chloride-concentration data from the infiltration-gallery wells (fig. 6) indicate that this thinning is the result of saltwater upconing caused by the withdrawal of ground water at the wells.

Preparation of the freshwater-thickness plots.--During August 1-9, 1996, 12 monitoring wells were hammer driven into the coastal plain (fig. 4). Each well consists of one to seven 5-ft sections of 2-in. (interior diameter) galvanized steel pipe joined with threaded stainless-steel couplings. At the bottom of each well is a 3-ft long well point with a 2.2-ft long stainless-steel internal screen (fig. 9, table 2). During installation, the monitoring wells were purged by bailing and sampled at 5-ft depth intervals as the screened sections of the wells were driven through the freshwater lens and into the transition zone. The chloride concentration of each sample was measured by titration and was considered to represent the concentration in the aquifer at the elevation of the midpoint of the screened interval of the monitoring well.

To estimate the thickness of the freshwater lens below sea level at each monitoring well, the chloride concentration was plotted against sampling depth and the depth to water with a chloride concentration of 250 mg/L was picked off a smooth line drawn through the data. At some wells, the positions of the deeper lines of equal chloride concentration were estimated by extrapolating beyond the maximum depth to provide a more complete picture, but the positions of these lines are speculative (fig. 7). The map of freshwater thickness (fig. 8) was constructed by measuring the distance between the water table and the 250 mg/L contour at all monitoring wells and selected vertical transects between monitoring wells on the sectional plots. These thicknesses were transferred to the areal map of monitoring wells and contoured. The map represents the estimated thickness of the freshwater lens for the period August 1-9, 1996.

Figure 8. Thickness of the freshwater lens, Aunuu Island, American Samoa, August 1996.

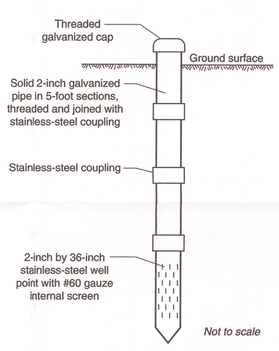

Figure 9. Schematic diagram of monitoring-well construction.

Table 2. Monitoring-well and selected dug-well data, Aunuu Island, American Samoa, 1997

[ft, feet; mg/L, milligrams per liter; --, not available; na, not applicable; elevations relative to mean sea level for February 26, 1997; screened-interval length is 2.2 feet; water-level elevation measured February 26, 1997; chloride-concentration samples collected February 25, 1997; water-level elevation corrected for density of water on the basis of chloride concentration; datum is mean sea level]

Well number	Latitude	Longitude	Approximate ground-surface elevation (ft)	Measuring-point elevation (ft)	Elevation of top of screen (ft)	Elevation of bottom of screen (ft)	Elevation of midpoint of screen (ft)	Average water-level elevation (ft)	Chloride concentration (mg/L)
Well 1	14° 17' 20" S	170° 33' 26" W	5.4	7.08	-13.4	-15.6	-14.5	1.90	589
Well 2	14° 17' 20" S	170° 33' 23" W	4.0	6.12	-29.4	-31.6	-30.5	1.91	326
Well 3	14° 17' 21" S	170° 33' 28" W	6.0	7.02	-13.5	-15.7	-14.6	1.82	105
Well 4	14° 17' 30" S	170° 33' 20" W	6.9	9.17	-11.3	-13.5	-12.4	1.78	2,860
Well 5	14° 17' 34" S	170° 33' 21" W	5.1	5.56	0.1	-2.1	-1.0	1.81	18,800
Well 6	14° 17' 27" S	170° 33' 25" W	4.5	6.09	-14.4	-16.6	-15.5	1.80	396
Well 7	14° 17' 27" S	170° 33' 23" W	3.0	3.77	-11.7	-13.9	-13.8	2.34	89
Well 8	14° 17' 08" S	170° 33' 22" W	8.6	10.43	-12.6	-14.8	-13.7	1.83	346
Well 9	14° 17' 27" S	170° 33' 25" W	4.6	7.11	1.2	-0.6	0.1	--	--
Well 10	14° 17' 11" S	170° 33' 26" W	5.6	6.88	-28.6	-30.8	-29.7	--	8,790
Well 11	14° 17' 05" S	170° 33' 23" W	9.4	12.35	-3.2	-5.4	-4.3	1.57	7,070
Well 12	14° 17' 09" S	170° 33' 20" W	2.9	5.71	-12.3	-14.5	-13.4	1.83	788
Dug well A	14° 17' 23" S	170° 33' 31" W	5.8	5.85	na	na	na	1.72	41
Dug well B	14° 17' 20" S	170° 33' 33" W	4.9	4.96	na	na	na	1.71	10
Dug well D	14° 17' 31" S	170° 33' 27" W	5.9	5.90	na	na	na	1.76	45
Dug well E	14° 17' 15" S	170° 33' 28" W	4.3	4.31	na	na	na	1.81	20

SEASONAL CHANGES IN VERTICAL THICKNESS OF THE FRESHWATER LENS

The vertical thickness of the freshwater lens changed seasonally in response to changes in recharge and withdrawal rates. Freshwater thickness increased by as much as 8 ft near well 7. Increased withdrawal at wells 301 and 302 raised the salinity at well 4.

Chloride concentrations from most of the monitoring wells decreased between August 1996 and February 1997 (fig. 7) indicating that the freshwater lens became thicker. The thickening of the freshwater lens probably results from a large amount of recharge to the aquifer from the unusually high rainfall in December 1996 and January 1997 (fig. 6). Because the completed monitoring wells can be sampled only at their lowest depth interval, the vertical distribution of chloride-concentration data from February 1997 is insufficient to accurately delineate the freshwater lens but is sufficient to indicate the general nature of the changes to the freshwater lens and transition zone since the first set of chloride-concentration samples was collected. At wells open to an interval of the aquifer containing freshwater, the largest decrease in chloride concentration was measured at wells 7 and 3. In these wells, the chloride concentration decreased from more than 770 mg/L to about 100 mg/L indicating a thickening of the freshwater of about 5 ft. The freshwater probably became thicker also near wells 10 and 11 where the largest overall chloride-concentration decreases, about 8,000 mg/L, were measured. In spite of the high rainfall, the chloride concentration at well 4 increased by about 300 mg/L since August 1996 indicating that the freshwater thickness probably decreased. This decrease likely resulted from the increased withdrawal rate at well 301 for February 1997 when the pumping rate was at the highest level reported (fig. 6).

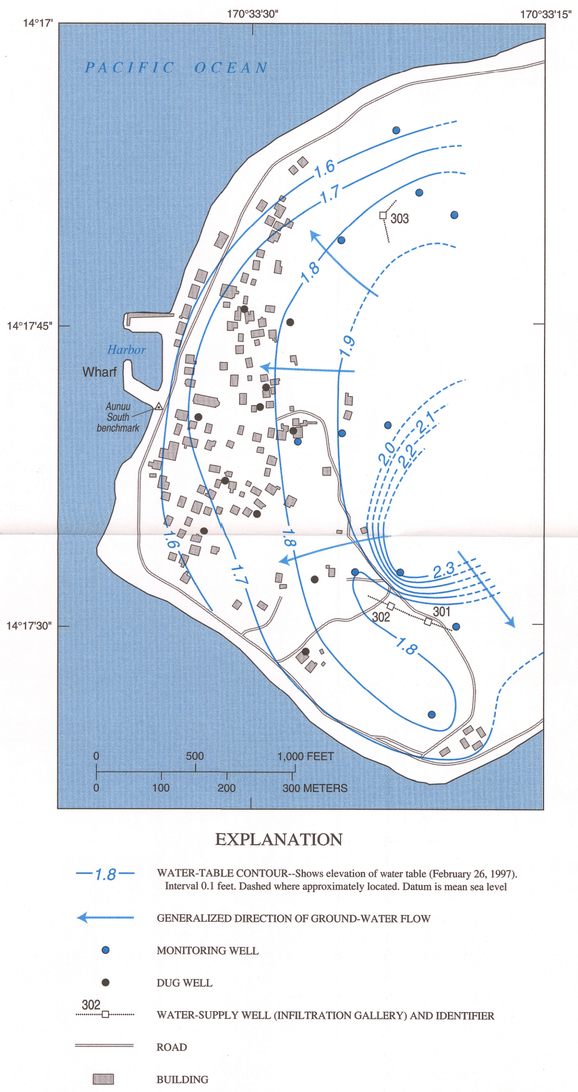

Figure 10. Configuration of the water table, Aunuu Island, American Samoa, February 26, 1997.

WATER-TABLE CONFIGURATION AND DIRECTIONS OF GROUND-WATER FLOW

The water table forms a broad mound near the center of the coastal plain on Aunuu. Ground water flows from the interior of the coastal plain, where the water-table elevation is highest, toward the coast. In the vicinity of the pumping wells, ground-water withdrawals cause a depression in the water table thereby changing the natural ground-water flow patterns.

The water table defines the top surface of the freshwater lens. Contour lines showing the elevation of the water table for February 26, 1997 (fig. 10) define a mound rising toward the interior of the coastal plain on Aunuu. The location of the mound is influenced by several factors, most notably the shape of the island and the spatial distributions of recharge, discharge, aquifer properties, and ground-water withdrawal. The high point of the water table, 2.34 ft above mean sea level, is located to the south side of the mound, not in the center as might be expected. This water-table distribution might be the result of localized permeability differences in the coastal plain sediments, but existing data are insufficient to confirm this. The map also shows a localized zone of water-table depression in the vicinity of wells 301 and 302, which were withdrawing about 15 gal/min of water at the time of the survey.

On Aunuu, the shape of the water table can be used to infer directions and rates of ground-water flow as well as the movement of contaminants dissolved in the flowing ground water. Fresh ground water will flow from areas of higher water level to areas of lower water level, in directions roughly perpendicular to the water-table contours. The water-table contours indicate that ground water flows radially from the interior of the coastal plain toward the coast.

The water-table map reflects hydrologic conditions on February 26, 1997. Rainfall and ground-water withdrawal from the production wells had been higher than normal during the preceding months (fig. 6). Changes in rainfall and ground-water withdrawal rates will alter the water-table configuration shown in figure 10. Drawdown from pumping diverts some of the oceanward ground-water flow to wells, and recharge modifies flow directions locally causing mounds in the water table, perhaps even temporarily reversing flow in some areas. To what degree the measured water-table configuration represents general conditions or approximates some average configuration is not known. An average configuration could be determined by operating continuous water-level recorders at numerous wells and averaging the data over the desired time period, such as a year.

Preparation of the water-table map.--A water-level survey was made on February 26, 1997. Measuring-point elevations at each monitoring well and dug wells A, B, D, and E (fig. 4) were determined by turning-point leveling to an accuracy of about 0.02 ft and referenced to the mean sea-level elevation measured at a temporary tide gage established at the wharf in the Aunuu harbor. The depth to water in each well was measured and subtracted from the measuring-point elevation to obtain the height of water above mean sea level. Because ocean tides can cause water levels in some wells to fluctuate several feet daily on Aunuu, measurements were synchronized with the tides. The water-level survey was done twice, once each for a consecutive high and low tide about 6 hours apart and the maximum and minimum water levels were averaged to obtain an average water level over the tidal half-cycle. Average water levels were corrected for water density, where necessary, to convert them to equivalent freshwater levels (in a freshwater-saltwater system, water levels depend on the salinity and density of the water and will not provide an accurate indication of hydraulic head and ground-water flow direction unless corrected: Lusczynski, 1961). The tidally averaged, density-corrected water levels were plotted on maps and contour lines were hand-drawn by visual interpolation.

WATER-LEVEL RECORDS

Water levels in well 9 were recorded electronically between October 1996 and February 1997. Water levels in the well respond to daily tidal fluctuations in the ocean and to rainfall on the island.

The record of the water level between October 30, 1996 and February 25, 1997 in well 9 shows how the water-table elevation fluctuates over time (fig. 11). The water level in the well fluctuates daily because of the effects of the ocean tide and over a longer time period because of recharge from rainfall. The daily water-level fluctuations due to the ocean tides average about 0.25 ft. The largest water-level change due to recharge was about 1.3 ft following several days of heavy rainfall beginning on January 5, 1997. Periods of heavy rainfall caused a rapid rise in the water table followed by a gradual decline as the water table returned to a more stable configuration.

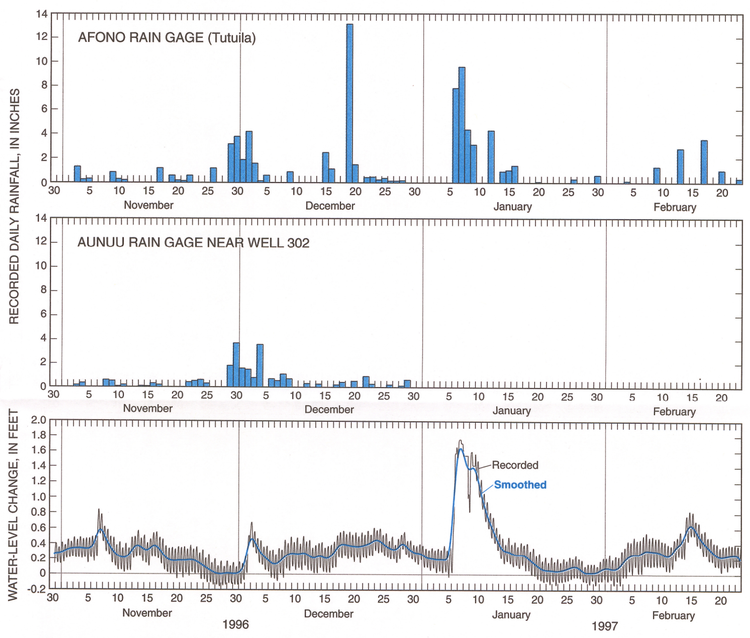

Figure 11. Rainfall data and water levels at well 9, Aunuu Island, American Samoa, October 30, 1996, through February 25, 1997.

SUMMARY AND CONCLUSIONS

This report presents findings of a study of ground-water resources in the coastal plain at Aunuu Island. The current water-supply system is insufficient to meet the needs of the island population and a study was undertaken to better delineate the fresh ground-water lens beneath the coastal plain. This report emphasizes results of field surveys made from July 1996 through February 1997.

Ground-water resources and development.--The ground-water resource in the coastal plain is a lens of freshwater that floats on saltwater. In most places, the zone of transition between freshwater and saltwater is thicker than the freshwater part of the lens. The freshwater lens is recharged by rainwater, and it shrinks and expands in response to variations in recharge and ground-water withdrawal by wells. The salinity of the water withdrawn from wells will rise if the withdrawal rate is too high or if rainfall is low for prolonged periods.

Water-production system.--Horizontal wells known as infiltration-gallery wells are used to skim water from the thin freshwater lens and are designed to reduce upconing of the transition zone, which would raise salinity. Brackish water is produced by a system of three infiltration-gallery wells and freshwater is withdrawn at numerous dug wells. Water production from the three infiltration-gallery wells has averaged about 53,000 gal/d since their installation in 1992. Ground-water withdrawal does not follow the seasonal pattern seen in rainfall. Since the start of monitoring of the infiltration-gallery wells in 1992, chloride concentrations of the pumped water have ranged between a few hundred to almost 2,000 mg/L.

Areal extent and vertical thickness of the freshwater lens.--The freshwater lens on the coastal plain of Aunuu reflects the general shape of the plain and attains a maximum thickness of at least 27 ft. The lens is thickest and widest in the interior of the coastal plain at the base of the tuff cone where the taro fields are located. The water pumped from wells 301, 302, and 303 has chloride concentrations above 250 mg/L because the freshwater lens is thin near the wells and the sump and infiltration galleries of the wells are located within the transition zone. Excessive pumping of the wells has caused the freshwater lens to become even thinner in these areas.

Changes in vertical thickness of the freshwater lens.--During the year of study, the lens shrank and expanded in a seasonal cycle, as much as 8 ft near well 7. Rainfall was heavier than normal during the study and as a result, observed changes in freshwater thickness were larger than expected. Smaller changes would be expected with an average seasonal rainfall pattern.

Directions of ground-water flow.--The top of the freshwater lens (the water table) forms a broad mound rising toward the interior of the coastal plain. Fresh ground water will flow from the mound and move oceanward and toward the withdrawal wells.

Potential for additional ground-water development.--On the basis of maps of freshwater thickness and areal extent, the central area of Aunuu near the taro fields holds the greatest potential for developing additional potable ground water with new wells. However, additional ground-water withdrawal in this area may raise the salinity of water in the taro fields and affect taro growth and cultivation. Outlying areas hold little potential for development of ground water, because of high salinity, except for irrigation or other nonpotable uses.

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

by
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