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GROUND WATER IN THE TAFUNA-LEONE PLAIN

The Tafuna-Leone Plain is the area of greatest ground-water production on Tutuila. The 18 wells in this area that were in production in 1996 combined for a total average pumpage of about 6.2 Mgal/d, which is about 70 percent of the total pumpage on the island (Izuka, 1997); individual wells were pumped at rates between 0.2 and 0.5 Mgal/d (fig. 8). Most of these production wells are located in four areas: (1) Tafunafou, (2) Iliili, (3) Malaeloa, and (4) Malaeimi Valley.

Water-level elevations in Tafunafou and Malaeloa are about 1 to 5 ft and have a gentle seaward gradient of less than 4 ft/mi (fig. 4). Variations in chloride concentrations in the water pumped from these wells correspond inversely with monthly rainfall (figs. 8 and 3). Peaks in the chloride-concentration record show a sawtooth pattern, rising gradually during dry periods and dropping quickly when rainfall returns.

Wells in Iliili have water levels that are a few feet higher than in Tafunafou and Malaeloa (fig. 4). Despite being closer to the ocean, drilled to about the same depth, and pumped at about the same rates as the Tafunafou and Malaeloa wells, most wells in Iliili (with the exception of well 84) have chloride concentrations less than 250 mg/L and do not show the sawtooth pattern of chloride-concentration peaks (fig. 8). This indicates that either the fresh ground-water body in Iliili is thicker (which is consistent with the higher water levels), or that upconing is slow and has not yet affected the wells, or both.

The higher water table and slower response of chloride concentrations to pumpage and rainfall in Iliili wells indicate that the rocks in Iliili are less permeable than rocks in Tafunafou and Malaeloa, assuming recharge is about the same in the two areas. Wells in Tafunafou are in highly permeable, young lava flows of the Leone volcanics, and drilling records (Bentley, 1975) indicate that wells in Malaeloa penetrated permeable lava flows and reef material beneath surficial pyroclastic rocks. In contrast, wells in Iliili penetrated lava flows interfingered with layers of low-permeability pyroclastic rocks that probably extend from the nearby cinder and ash cones (figs. 2 and 8; Bentley, 1975).

Wells 67, 88, and 89 in Malaeimi Valley differ from wells in the rest of the Tafuna-Leone Plain because they penetrate the Older Volcanics (figs. 2 and 8). The water table in Malaeimi Valley is also higher than in most of the Tafuna-Leone Plain (fig. 4). Chloride concentrations in wells 67 and 89 remained less than 50 mg/L even during periods when the wells were pumping 0.4 to 0.5 Mgal/d each. In contrast, chloride concentrations from well 69 at the mouth of Malaeimi Valley exceeded 500 mg/L when the well was pumping at a rate of only 0.01 to 0.02 Mgal/d, and varied with rainfall in a manner similar to the chloride concentrations in wells in Tafunafou. This indicates that well 69 penetrates Leone Volcanics, as do the Tafunafou wells, rather than the Older Volcanics, as do the other Malaeimi wells.

Relation of chloride concentration to well depth and distance from ocean.--Chloride concentrations in wells in Tafunafou show a decreasing trend with distance from shore and an increasing trend with depth. This indicates a gradual landward thickening of the fresh ground-water body in the Tafuna-Leone Plain (fig. 9). The low chloride concentrations and higher water levels of the deeper Malaeimi wells indicate a more rapid landward thickening of the fresh ground-water body beneath Malaeimi Valley. The difference in freshwater thickness between Malaeimi Valley and Tafunafou is consistent with the contrast between the low-permeability Older Volcanics in Malaeimi Valley and the high-permeability Leone Volcanics in Tafunafou.

GROUND WATER IN VALLEYS AND ALONG THE COAST OF THE MOUNTAINS FORMING THE MAIN PART OF TUTUILA

Most wells in this region are in valleys or other low-lying areas near the coast. The wells develop water from the Older Volcanics. Most wells produce less than 0.2 Mgal/d each and commonly have high drawdowns and high chloride concentrations. Unlike chloride concentrations in wells on the Tafuna-Leone Plain, chloride concentrations in wells in the Older Volcanics, once elevated, do not return quickly to low levels when rainfall is high or pumpage is reduced.

Wells in which initial chloride concentrations were high.--In Fagaitua and Alofau, initial chloride concentrations in production wells were high at the beginning of pumping and climbed higher as pumping continued (fig. 8). Chloride concentrations in Alofau started near 1,000 mg/L, rose to more than 2,000 mg/L, then returned to about 1,000 mg/L when pumpage decreased. Chloride concentrations in Fagaitua were in excess of 1,000 mg/L throughout most of its short pumping period. The data indicate that these wells penetrated through the fresh ground-water body and into the freshwater/saltwater transition zone. With continued pumping, the transition zone rose even higher into the well, thus increasing the chloride concentrations (fig. 10).

Wells in which chloride concentrations were initially low but rose during pumping.--In Fagasa, Aua, Alao, Tula, and Sailele, chloride concentrations in production wells were low at the onset of pumping, but increased as pumping continued (fig. 8). This trend indicates that the bottom of the wells had not penetrated the transition zone initially, but the transition zone rose to the well during pumping. These wells were either drilled close to the transition zone or pumpage was excessive given the proximity of the wells to the transition zone (fig. 11). The time between initiation of pumpage and the initial rise in chloride concentrations ranged from a few months to several years.

The time required for the transition zone to reach a well depends, in large part, on the depth of the well relative to the depth of the transition zone. For example, the chloride concentration in well 104 in Tula remained low for 5 years before rising to about 400 mg/L, whereas chloride concentrations in nearby well 40, which is about 40 ft deeper than well 104, rose to about 900 mg/L within the first 3 months of pumping (fig. 8). Because the depth of the transition zone increases with distance from shore, a well near the coast will be closer to the transition zone than a well of the same depth farther inland. In Aua, for example, chloride concentrations in well 99 were generally lower than in the more seaward well 97 and also appear to be more responsive to control by reduction in pumpage.

The rate of movement of the transition zone in response to pumping also depends in part on hydraulic properties of the aquifer. Movement of the transition zone in response to pumping is apparently a slower process in places such as Aua where rocks have low permeabilities. Chloride concentrations in all of the production wells in Aua were below 100 mg/L initially, but after 1 to 2 years of pumping each well at 0.3 to 0.4 Mgal/d, chloride concentrations rose sharply (fig. 8). In well 99, chloride concentrations declined after the initial rise when the pumping rate was reduced, but did not return to the same concentrations as before the initial rise. In well 97, chloride concentrations remained high throughout most of the period of record after the initial rise, despite lowered pumping rates. Whereas pumping in Aua took years to cause a rise in chloride concentrations, mitigation of the high chloride concentrations has also taken years.

The response to rainfall variations is also slower in the low-permeability Older Volcanics than in the high-permeability Leone Volcanics. None of the wells in the Older Volcanics shows the sawtooth pattern of rapid fluctuations in chloride concentration characteristic of the wells in the high-permeability rocks in Tafuna and Malaeloa. Fluctuations in chloride concentrations in some wells, such as wells 104 and 108 in Tula, appear to correspond to fluctuations in rainfall, but the response is not as rapid as in Tafunafou or Malaeloa (fig. 8).

Because upconing and drawdown are related, impending saltwater contamination caused by excessive pumping may be preceded by high drawdowns in pumping and monitor wells. In Aua, for example, during the 1 to 2 years of pumping preceding the initial rise in chloride concentrations, water levels in wells dropped as far as 60 ft below sea level (fig. 8).

Wells with low chloride concentrations.--Chloride concentrations in wells in Pago Pago, Fagaalu, Fagatogo, and Laulii have remained less than 250 mg/L for several years of pumping (fig. 8). The average production at individual wells in 1996 ranged from about 0.1 Mgal/d from the well in Fagaalu to about 0.5 Mgal/d in some wells in Pago Pago.

Pre-pumping water levels in these areas are higher than water levels in most other small valleys. Pre-pumping water levels were 45 ft to 50 ft above sea level in Pago Pago, and 70 ft above sea level in Fagaalu. Pre-pumping water levels in Laulii are not known, but water levels in a monitor well 500 ft from the pumping well vary between 15 and 27 ft above sea level. Pre-pumping water levels were also relatively high (about 20 ft) in the Fagatogo wells. The higher water levels indicate that the fresh ground-water body is thicker in these areas and the transition zone was initially far below the bottom of the wells, which is consistent with the low chloride concentrations measured at these wells.

Wells in Fagatogo have produced water with low chloride concentrations for several years, but between 1988 and 1992 pumpage of 1.0 Mgal/d, from well 101 caused water levels of nearby monitor well 102 to drop to a few feet below sea level; water levels in the pumping well (102) must have been even farther below sea level. The high drawdown indicates that a pumpage of 1.0 Mgal/d may have resulted eventually in contamination by saltwater. Chloride concentrations remained low during this period, but effects of saltwater upconing may not yet have become apparent because upconing is slow in the low-permeability Older Volcanics. Pumpage in Fagatogo was reduced in 1992, but water levels have not been monitored since then.

The water-level data are not adequate enough to assess whether the cones of depression for wells in Pago Pago, Fagaalu, Fagatogo, and Laulii are still growing. All of the wells are near streams that could have halted or slowed the growth of the cones of depression, but the water-level data are not adequate enough to assess whether this has happened. The rate of decline in water levels monitored in pumping well 107 in Pago Pago has slowed during the 8 years of record, but this may be the result of the logarithmic decline of the drawdown/time curve (see fig. 7), rather than an indication that drawdown has stopped increasing. If the cones of depression are still growing and drawdowns are still increasing, the possibility of future contamination from saltwater remains.

GROUND WATER IN THE HIGH-ELEVATION INTERIOR OF TUTUILA

Two wells in Aoloaufou pump water from near the crest of Olotele Mountain (fig. 8). The wells were put into production in 1994 and pumped at about 0.03 to 0.05 Mgal/d each. Chloride concentrations have remained near 20 mg/L throughout the short pumping history of these wells. Water levels were not monitored in any wells in this area so it is not known whether drawdowns are continuing to increase or the cones of depression caused by the pumping of these wells have stopped growing. Water levels in these wells and elevations of nearby springs indicate that the pre-pumping water table in this area was more than 1,100 ft above sea level.

The elevations of the bottoms of the wells in Aoloaufou are hundreds of feet above sea level and thus are unlikely to be affected by saltwater upconing. However, pumping of the wells is likely to eventually cause a reduction in flow of nearby springs.

GROUND-WATER AVAILABILITY

The data presented here show that pumping-induced upconing of the transition zone is a major constraint on the pumping rate of wells and hence the ground-water availability on Tutuila. The data show that aquifer permeability, pumping rate, thickness of the fresh ground-water body, and the depth of the well relative to the transition zone determine whether upconing will cause saltwater to enter a well.

Many wells in the Older Volcanics have had persistent high chloride concentrations despite low pumping rates, whereas most wells in the Tafuna-Leone Plain have been pumped at high rates with only occasional, brief rises in chloride concentrations during dry weather. The high productivity of the Tafuna-Leone Plain has been possible, even though the fresh ground-water body is thin throughout most of the plain, because drawdowns and saltwater upconing are less in the high-permeability rocks of the Leone Volcanics. In contrast, even though the freshwater in most of the Older Volcanics is thicker than in the Tafuna-Leone Plain, many wells in the Older Volcanics have high chloride concentrations because (1) they are near the coast where the fresh ground-water body is thinnest, and (2) drawdowns and saltwater upconing are greater in rocks with low permeability such as the Older Volcanics.

Among wells in the Older Volcanics, those that have persistently produced water with low chloride concentrations are farther inland where initial water levels were higher and the fresh ground-water body was thicker. In the low-permeability Older Volcanics, the water table rises steeply and the depth of the transition zone increases sharply toward the interior of the island. The greater freshwater thickness both above and below sea level allows room to accommodate the greater drawdowns and upconing expected in low-permeability rock. Wells farther inland are thus less susceptible to contamination by saltwater. For future ground-water development in the Older Volcanics, the constraints imposed by upconing can be minimized by locating wells farther inland where the fresh ground-water body is thicker and ensuring that the wells do not penetrate to a depth near the transition zone.

The ground-water data show that although excessive pumping rates in some wells may be maintained for one or more years before chloride concentrations begin to rise, once concentrations are high, they may not immediately return to the pre-pumping levels despite reductions in pumping rate. The rise in chloride concentrations in some of the overpumped wells was preceded by drawdowns that lowered water levels several tens of feet below sea level. In retrospect, the drawdowns could have served as an indicator of the impending salting of the wells. However, a more complete analysis of whether the pumping rate would have caused saltwater contamination would require consideration not only of drawdown, but also of well depth, depth of the transition zone, aquifer permeability, hydrologic boundaries, and locations and pumping rates of other wells.

SUMMARY

Analysis of records of water level, pumpage, and water quality show that ground-water availability on Tutuila is constrained by saltwater upconing. Whether saltwater will enter a well as a result of upconing depends on aquifer permeability, pumping rate, thickness of the fresh ground-water body, and the depth of the well relative to the freshwater/saltwater transition zone. The constraints imposed by upconing can be minimized by locating wells where the fresh ground-water body is thicker, ensuring that they do not penetrate to depths near the transition zone, and determining pumping rates that can be maintained without causing contamination by saltwater.

Water-level data indicate that the fresh ground-water body is thickest in the center of the Older Volcanics of the main mountainous part of Tutuila. The water table is several hundreds of feet high beneath the mountain crests, and declines sharply toward the coast, valleys, and the Tafuna-Leone Plain. The high water-table elevations and steep gradients in the Older Volcanics are consistent with the low permeability of this unit. In the Tafuna-Leone Plain, water-level elevations are mostly less than 20 ft and have a low gradient. The low water-table elevations and gradient are consistent with the higher permeability of the Leone Volcanics. Water levels in the pyroclastic parts of the Leone Volcanics are a few feet higher compared with those in Tafunafou and Malaeloa, indicating that the rocks have a lower permeability than the rocks elsewhere on the plain.

Most wells in the Tafuna-Leone Plain have been pumped at high rates with only occasional, brief rises in chloride concentrations. This high productivity has been possible because drawdowns and saltwater upconing are less in the high-permeability rocks of the Leone Volcanics. Chloride concentrations in wells in Tafunafou and Malaeimi show a decreasing trend with distance from shore and an increasing trend with depth, which is consistent with the concept of a landward-thickening fresh ground-water body.

Elsewhere on Tutuila where the low-permeability rocks of the Older Volcanics predominate, many wells have high chloride concentrations because drawdowns and saltwater upconing are greater in low-permeability rocks and the wells are located near the coast where the fresh ground-water body is thinnest. A few wells located farther inland, where the water levels are higher and the fresh ground-water body is thicker, have had persistently low chloride concentrations.

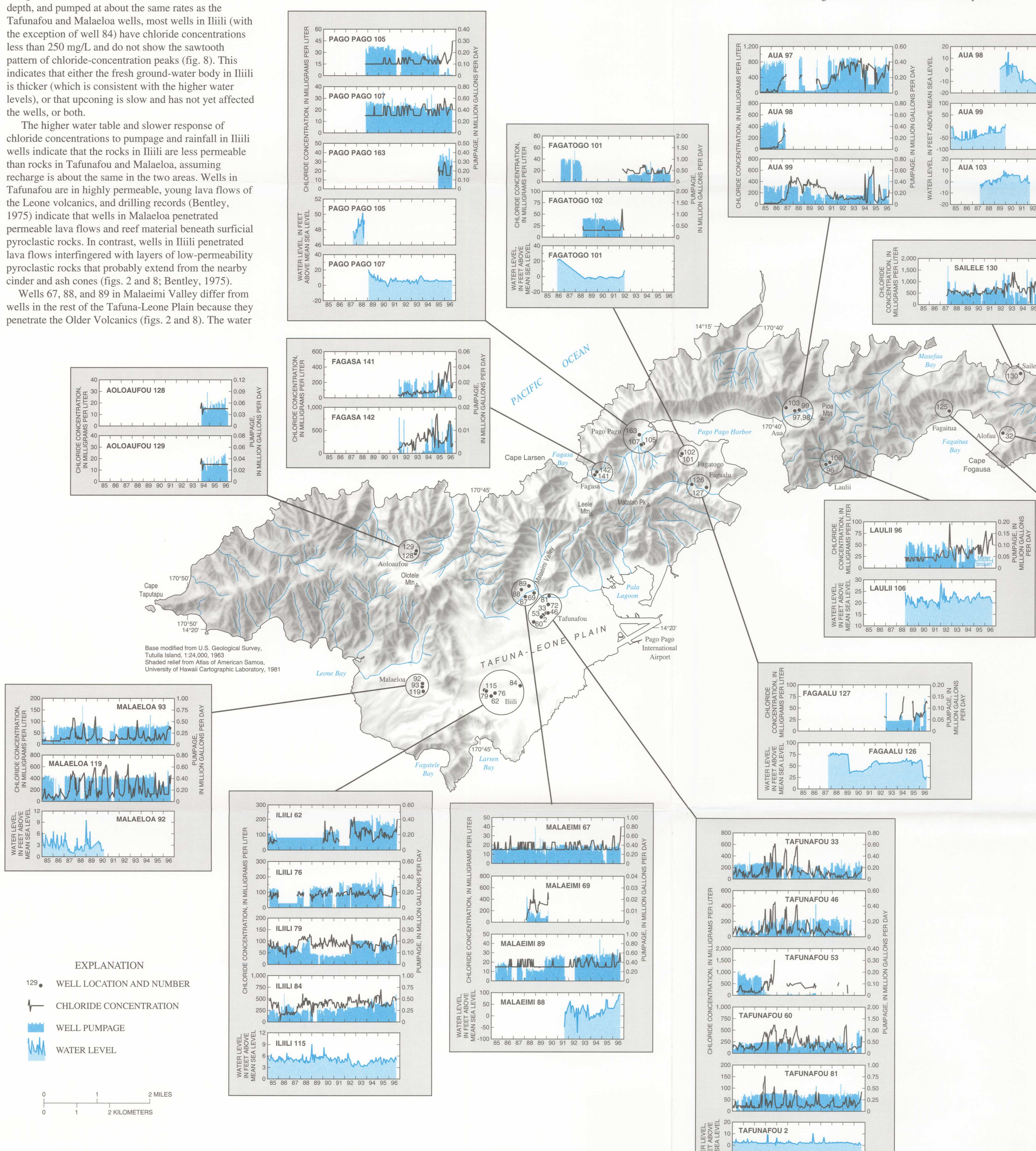

Figure 8. Well locations, pumpage, chloride concentrations, and water levels in selected wells in the Tutuila-Leone Plain, Tutuila, American Samoa though September, 1996. Compiled from data from the American Samoa Power Authority.

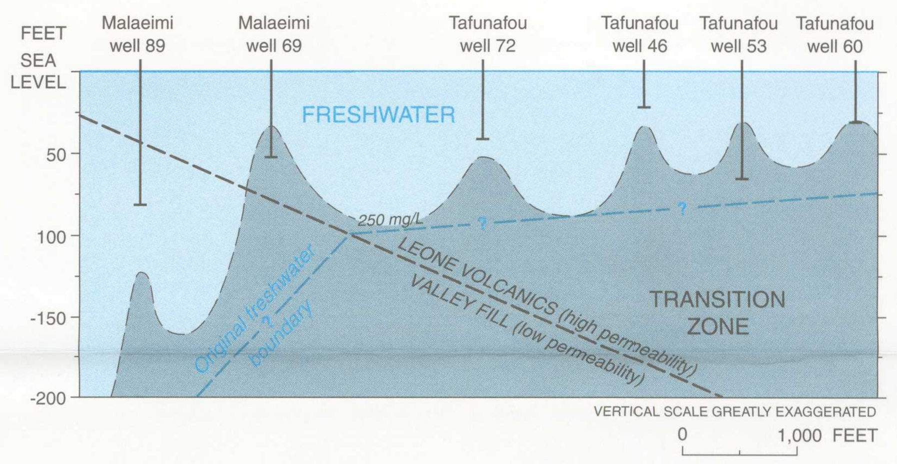

Figure 9. Hydrogeologic section through Malaeimi Valley and Tafunafou, Tutuila, American Samoa. Dashed lines are inferred. Lines with question marks are speculative.

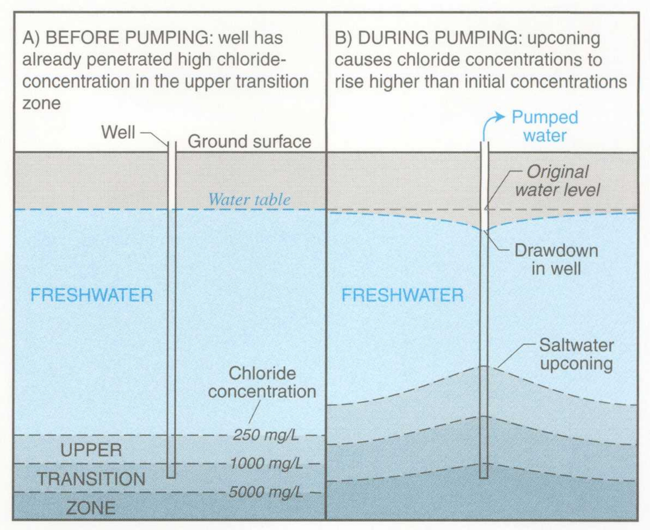

Figure 10. Diagram showing how high initial chloride concentrations result from a well that penetrates into the freshwater/saltwater transition zone.

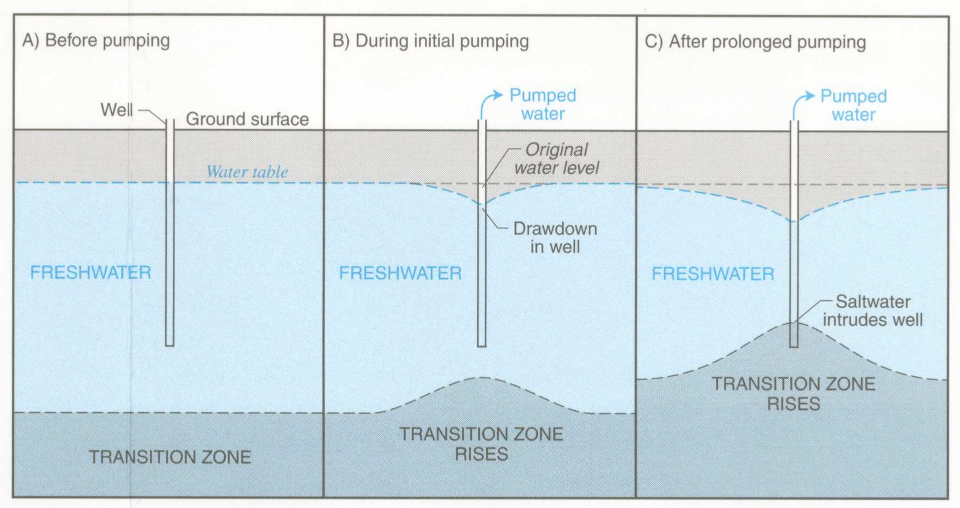

Figure 11. Diagram showing how chloride concentrations rise as a result of pumping from a well that penetrated close to the freshwater/saltwater transition zone.

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HYDROGEOLOGIC INTERPRETATIONS FROM AVAILABLE GROUND-WATER DATA, TUTUILA, AMERICAN SAMOA

by
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