WATER-TABLE CONFIGURATION AND DIRECTIONS OF GROUND-WATER FLOW

The water table reaches its highest points in the volcanic rocks that are above sea level. Ground water flows from the north-central highlands and the southeastern ridge, where the water-table elevation is highest, towards the coast. A depression in the water table due to ground-water withdrawal may be causing ground-water flow patterns to change in the vicinity of the Municipal well.

The water table defines the top surface of the freshwater lens. Water-table contours for July 4, 1997 (fig. 5) show two mounds in areas where low-permeability pyroclastic rocks are above sea level and a localized zone of water-table depression in the vicinity of the Municipal well which was withdrawing water at the time of the measurements. Over most of the island, the water table is relatively flat and water levels are less than 2 ft above mean sea level. Water-level measurements made on other dates help determine where water-level contours are drawn. The highest measured water level in the limestone was 3.42 ft above mean sea level on December 7, 1997 in well M02 which is directly west of the north-central highland. The highest measured water level on the island was in the pyroclastic rocks on the southeastern ridge where water level was about 90 ft above mean sea level on May 29, 1997 in well TH19 (see table 1). The water table is expected to be similarly high in the pyroclastic rocks of the north-central highland but no wells are available there to provide water-level data.

On Tinian, 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 (fig. 5). The water-table contours indicate that ground water moves radially from the north-central highland and the southeastern ridge and flows generally oceanward.

The water-table map reflects pumping conditions in the aquifer because withdrawal from the production well had been steady during the preceding months (fig. 8). Different water-table configurations would reflect different patterns of ground-water flow than that shown in figure 5. Drawdown from pumping diverts some of the oceanward ground-water flow to wells. To what degree the water-table configuration represents the long-term average configuration is not known. A longer-term 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-level map.--Measuring-point elevations at each well were surveyed by turning-point leveling to an accuracy of about 0.02 ft and referenced to the mean sea-level datum benchmark at the Tinian harbor. The average sea level, measured at the Tinian tide gage was 0.35 ft below mean sea level during the water-level survey. On July 4, 1997 between 7:00 a.m. and 11:00 a.m., the depth to water in each well was measured and subtracted from the measuring-point elevation at each well to obtain the height of water above mean sea level. At two wells, the Ushi well and the Municipal well, electronically recorded, 30-minute water-level data were available for the day of the survey. Because ocean tides caused water levels to fluctuate about 0.08 ft in the Ushi well and about 0.04 ft in the Municipal well during the 4 hours of the survey, the measurements from these wells were averaged over that time range. Other wells on Tinian are expected to have less daily variation from tidal fluctuations because they are much farther from the coast. Electronically recorded 30-minute water-level data from wells M02, M21, M29, and TH07 show less than 0.01 ft of daily tidal variation. Therefore, the shape of the water table shown in figure 5 probably is not significantly different than the shape of the water table with tidal fluctuations removed.

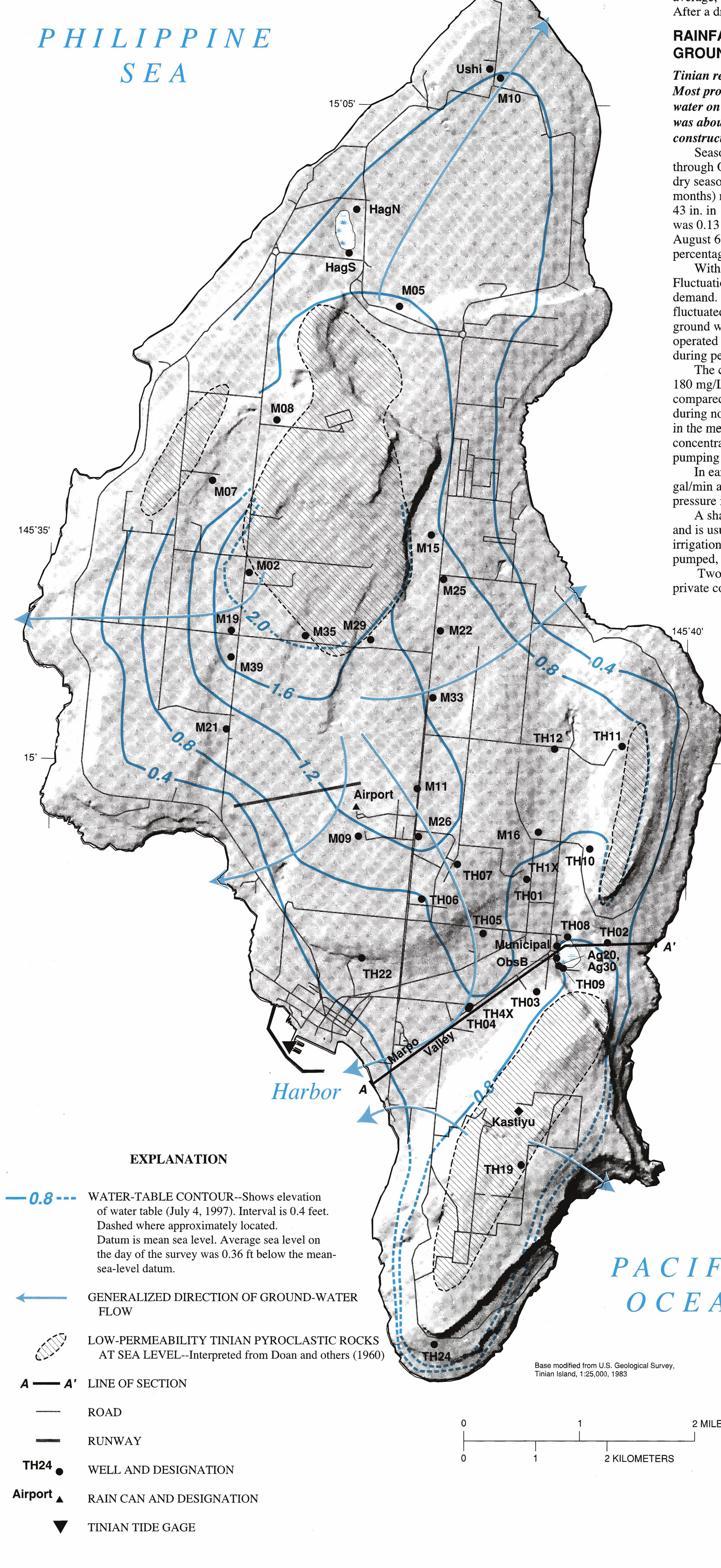

Figure 5. Configuration of the water table, July 4, 1997 with selected wells, and rain stations, Tinian.

THICKNESS OF THE FRESHWATER LENS

A vertical section through the median valley shows that the freshwater lens beneath the valley is thickest in the interior of the island and thins toward the coasts. The freshwater lens is about 40 ft thick in the middle of the island. The lens is slightly thinner near the Municipal well and the Marpo marsh possibly because of saltwater upconing due to ground-water withdrawal and evaporation.

Sectional view.--The thickness of the potable part (less than or equal to 250 mg/L) of the freshwater lens beneath the median valley (fig. 5, *A-A'*) is shown in a vertical section (fig. 6). The section shows that the freshwater lens is thickest in the center near well TH04 and thins toward the east and west coasts. The maximum thickness attained by the freshwater is about 40 ft. The freshwater lens is slightly thinner in the east than in the west, which indicates that saltwater may be upconing in the vicinity because of ground-water withdrawal at the Municipal well and evapotranspiration at the Marpo marsh.

Relation of transition zone to chloride concentrations at the Municipal well.--The chloride concentration of water pumped at the Municipal well depends on the position of the transition zone relative to the infiltration galleries in the well. The transition zone will rise when the wells are pumped (fig. 2). At the time of these measurements, the distance between the infiltration galleries and the transition zone was relatively large and the transition zone did not rise into the infiltration galleries at the maintained pumping rate. Chloride concentrations of pumped water remained relatively steady between 1990 and 1997 (fig. 8). Increased pumping rates may cause the transition zone to rise to the level of the infiltration galleries causing chloride concentrations in the pumped water to rise. Available data is insufficient for estimating the maximum withdrawal rate that will maintain acceptable chloride concentrations in the pumped water.

Preparation of the vertical sections.--Each well shown in the vertical section (fig. 6) was sampled at about 10-ft depth intervals starting at the water table using a 3-ft long bailer lowered to the desired depth in the open hole. Field measurements of the sampled water included temperature, specific conductance, and chloride-concentration. Where field measurements indicated that the salinity of the sample was higher than the sample from 10 ft above, the sample was submitted to the USGS Hawaii District laboratory in Honolulu for a more accurate chloride-concentration determination using titration. Therefore, several depth intervals having the same field chloride concentration as the next higher sample are not shown on the vertical section. The chloride concentration of a sample was considered to represent the chloride concentration in the aquifer at the elevation the sample was collected in the well. Water samples were collected from wells TH04X, TH08, and TH09 on March 5-6, 1997 and from well TH02 on May 23, 1997.

SEASONAL CHANGES IN THICKNESS OF THE FRESHWATER LENS

The thickness of the freshwater lens changed only slightly as a result of seasonal recharge and ground-water withdrawal. Freshwater thickness increased by about 3 to 5 ft during the wet season of 1993, a period of typical rainfall. Freshwater thickness decreased 1 to 2 ft during the dry season of 1994, when rainfall was higher than average.

Chloride concentrations deeper than 35 ft below sea level in monitor wells TH08 and TH09 (fig. 7) at the end of the 1993 wet season (July to October) were slightly lower than after the 1993 dry season (fig. 8), indicating that the freshwater lens had become slightly thicker. The number of sampling points in the wells is limited so the interpretation of the data is speculative. The thickening of the freshwater lens results from an increase in the amount of recharge to the aquifer relative to discharge during the wet season. In both wells, the base of potable water (250 mg/L chloride concentration) and the midpoint of the transition zone (9,500 mg/L chloride concentration) lowered only 3 to 5 feet between May and November 1993. Rainfall during this period was about 57 in. and the average rainfall for this same period during 1988-97 was also about 57 in. Therefore, the increase in thickness of the freshwater lens shown in figure 7 probably is typical of the average yearly change due to wet season recharge.

During the dry season (February to May), the thickness of the freshwater lens would be expected to decrease in response to a decrease in recharge. But the chloride-depth profiles (fig. 7) show only a slight thinning (1 to 2 ft) of the lens from November 1993 to May 1994. Rainfall during this period was about 28 in., 126 percent of the average rainfall during this same 6-month period for the years 1988-97. Because the 1994 dry season was wetter than average, the freshwater lens would not be expected to shrink to the same size as that measured the previous year. After a dry season of more typical rainfall, the lens would be expected to shrink slightly more.

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

Tinian receives about 79 in. of rainfall annually and has distinct wet and dry seasons. Six wells produce water. Most production comes from the Municipal well which pumps about 1 Mgal/d and was the sole source of potable water on Tinian for more than 50 years. The chloride concentration of pumped water from the Municipal well was about 180 mg/L during 1992-97, which is about 100 mg/L higher than initially measured after well construction in 1945.

Seasonal differences in rainfall define distinct wet and dry seasons on Tinian (fig. 8). The months of July through October (the wet season) receive about 61 percent (48 in.) of the annual rainfall; February through May (the dry season) receive 12 percent (10 in.) of the rainfall; and November, December, January, and June (transitional months) receive 27 percent (21 in.) of the rainfall. From 1988 to 1998, the total annual rainfall ranged from a low of 43 in. in 1998 to a high of 97 in. in 1994. The lowest amount of monthly rainfall recorded for the period of record was 0.13 in. in March 1995. The highest amount of daily rainfall recorded for the period of record was 12.9 in. on August 6, 1993 during tropical storm Steve. Rainfall from tropical storms and typhoons make up a significant percentage of the total annual rainfall and a lack of storms can significantly contribute to drought conditions.

Withdrawal and chloride-concentration data from the Municipal well for 1990-97 are shown in figure 8. Fluctuations in withdrawal correlate to changes in system condition or design, the pump efficiencies, and water demand. From 1990-97, ground-water withdrawal from this well has averaged about 1.2 Mgal/d and has typically fluctuated by about 10 percent over a year. Three 50-horsepower motors have been used since 1990 to extract ground water from this well. In March, 1996, one motor was upgraded to 75 horsepower. Pumps are typically operated at maximum capacity 24 hours per day, except when one or more pumps are turned off for maintenance or during periods of lower demand in the wet season.

The chloride concentration at the Municipal well did not change significantly during 1992-97, averaging about 180 mg/L, and ranging from 160 to 220 mg/L. Chloride concentration was usually slightly lower in the wet season as compared to the dry season. The average chloride concentration is about 100 mg/L higher than initially measured during non-pumping conditions after construction in 1945 (Lawlor, 1946), and 100 mg/L higher than at other wells in the median valley. Monitor wells TH08, TH09, and TH03 are near the Municipal well and show similar chloride concentrations, near 180 mg/L, indicating that the chloride concentration at these wells may be elevated from pumping at the Municipal well.

In early 1999, wells TH04 and TH06 were put into operation. Well TH06 is capable of producing about 60 gal/min and well TH04 can produce about 50 gal/min. These wells are used during peak demand hours to maintain pressure in the distribution system (Greg Castro, CUC Deputy Director, oral commun., 1999).

A shallow, 30-ft diameter well (well Ag30) is used seasonally to supply irrigation water to cooperative farms, and is usually operated for about 10 hours on alternate days of the dry season. When operated, withdrawal from the irrigation well is estimated to be about 500 gal/min. Chloride concentrations increase significantly when the well is pumped, from pre-pumping values of 180 mg/L to post-pumping values more than 500 mg/L.

Two other wells that are currently in use are wells M25 and M26. These wells were rehabilitated in 1987 by a private corporation and are each pumped at about 25 gal/min for ranch uses.

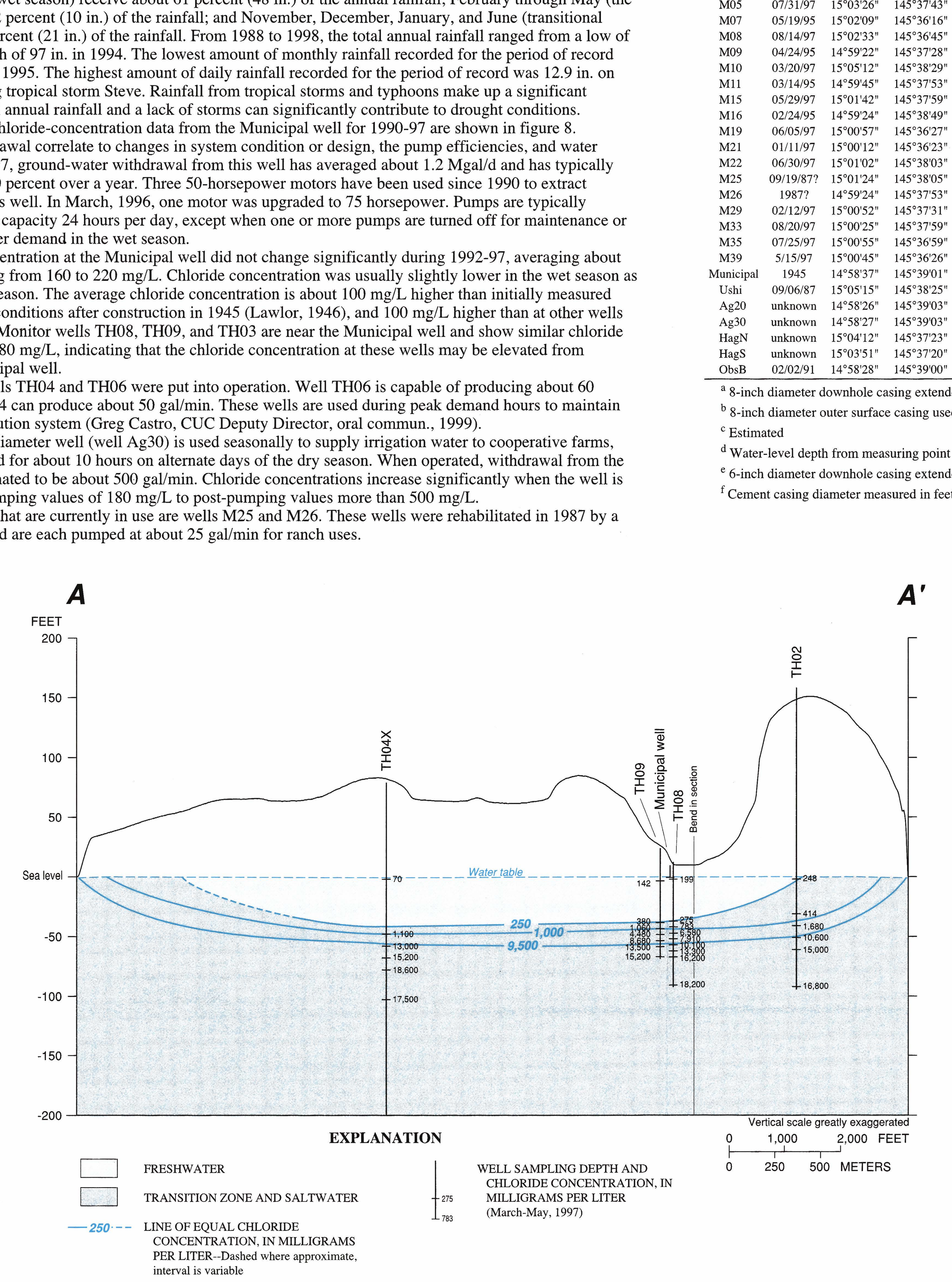

Figure 6. Thickness of freshwater lens (to a depth of 250 mg/L chloride concentration) and upper transition zone, Tinian, March 5-6 and May 23, 1997. Line of section is shown in figure 5.

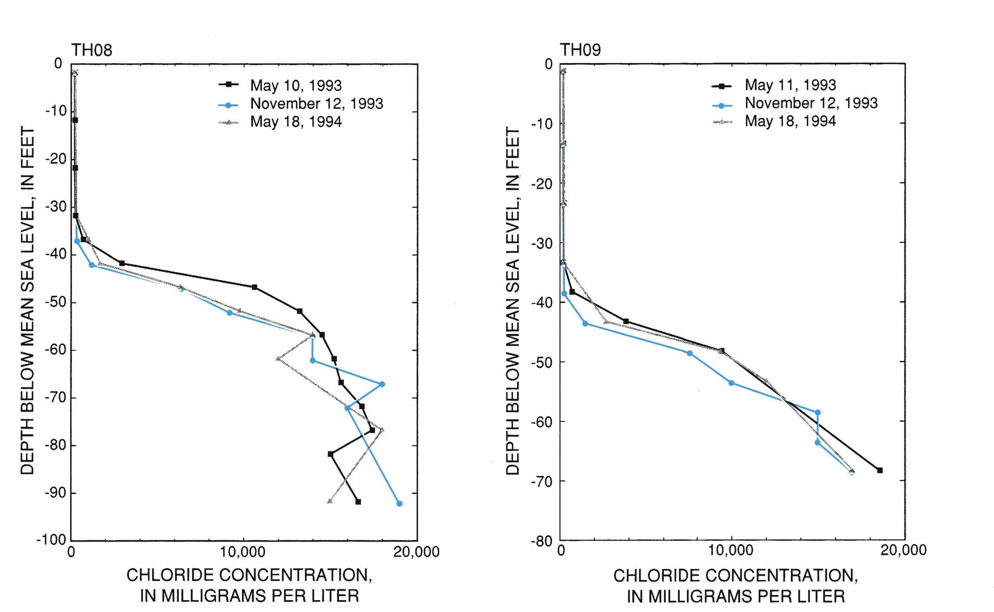

Figure 7. Seasonal changes in chloride concentrations with depth at wells TH08 and TH09, Tinian.

LOCATION AND WELL CONSTRUCTION OF SELECTED WELLS

Well-construction details of 40 wells that were drilled, rehabilitated, or monitored during the USGS ground-water study, 1990-97, are shown in table 1. The wells can be divided into three groups, defined by the periods of construction: USGS-drilled wells, 1993-97; U.S. military-drilled wells, 1944-45; and dug wells, 1930's. The Ushi well is an exception, drilled by the U.S. military in 1987.

The USGS drilled 17 monitoring wells (TH-designated well numbers, fig. 5 and table 1) during 1993-97 in the median valley and adjacent southeastern ridge and central plateau. Of the 17 wells, 12 are open holes and 5 are cased with PVC pipe and screened below the water table. All wells were drilled into the top of the freshwater lens except wells TH02, TH04X, TH08, and TH09 (fig. 5) which were drilled into the transition zone. These transition zone wells are important because they provide information about the temporal changes in thickness of the freshwater lens and underlying transition zone due to seasonal rainfall and ground-water withdrawal.

The U.S. military drilled 40 wells, mostly on the central plateau and north-central highland, and constructed one Maui-type horizontal well (presently known as the Municipal or Marpo well) on the northern edge of the Marpo marsh during 1944-45. All drilled wells were abandoned shortly after World War II. The USGS rehabilitated 16 of the 40 wells (M-designated well numbers, fig. 5) during 1995-97. The rehabilitated wells originally extended into the freshwater lens and were cased from land surface to well bottom with solid steel casing, perforated throughout the bottom 10 to 20 ft. Rehabilitation involved retrieving the old pump and pipe, re-drilling if necessary, and cleaning the hole to near the original depth. The well casing remains intact although some parts are heavily corroded. Well M29 was deepened into the transition zone. Two other military wells (M25, M26) were rehabilitated by a private corporation about 1987.

The Municipal well is a Maui-type infiltration gallery constructed by the U.S. military in 1945 (fig. 9). This well is the only well that was not abandoned after World War II, and supplied all of the potable water for Tinian until 1999 when two additional vertical wells were added to the system. The well withdraws about 1 Mgal/d from the limestone aquifer in a depression of the median valley. The well withdraws water from the upper part of the aquifer over a large area, which tends to maximize the amount of freshwater that can be withdrawn from an area while minimizing upconing of the transition zone. The infiltration gallery lies in a trench and consists of dual drainage tunnels 300 ft in length, covered with 1-1/2-in. graded coral gravel (Lawlor, 1946). The tunnels were made of 240 steel cylindrical bomb crates, connected end to end with hinged couplings and perforated. A sump at the midpoint of the tunnels constructed of two steel pontoons collects water from the tunnels and houses the pumps used to extract the water.

The Japanese administration dug more than 100 wells during the occupation of Tinian in the 1930's. All but a few were abandoned and filled. Four shallow wells ranging in diameter from 10 to 30 ft that penetrate the freshwater lens are included in table 1: Ag20, Ag30, HagN, and HagS (fig. 5). Wells Ag20 and Ag30 are both located on the southern edge of the Marpo marsh. The Ag30 well continues to be used seasonally as a source of irrigation water. Wells HagN and HagS are located on the north and south edge, respectively, of Hagoi Lake.

Table 1. Location and construction of selected wells, Tinian

[TH, USGS test hole; M, U.S. military well; Ushi, Ushi Point well; Ag20, Ag30, agricultural dug wells; HagN, HagS, Hagoi Lake, north and south dug wells; date well drilled is last day of rehabilitation for military wells (M) and last day of drilling for all other wells; measuring point is top of well casing except TH06, M25, M26 is top of PVC sounding tube, and Ag20, Ag30, HagN, HagS is top of cement wall; N/S, not surveyed. For military wells: hole bottom elevation is bottom of rehabilitated hole; casing bottom may extend below hole bottom elevation; top of open interval not known; casing bottom elevation and open interval elevation interpreted from Doan and others, 1960; open, open hole; perf, perforated casing; screen, screened casing]

Well number	Date well drilled	Latitude	Longitude	Measuring point altitude (feet)	Hole bottom altitude (feet)	Casing bottom altitude (feet)	Casing inside diameter (inches)	Type of open interval	Open interval altitude (feet)	Water-level altitude (feet)	Water-level date	Water-level time
TH01	09/17/96	14°59'03"	145°38'47"	117.46	-13	107	12	open	107 to -11	1.00	12/28/97	1200
TH1X	10/01/96	14°59'04"	145°38'47"	116.99	-15	107	6	open	107 to -15	0.78	07/04/97	0825
TH02	04/28/97	14°58'40"	145°39'25"	158.86	-94	149	8	open	149 to -94	0.52	07/04/97	0755
TH03	10/24/96	14°58'12"	145°38'48"	109.05	-22	99	8	open	992 to -22	0.71	07/04/97	0725
TH04	12/13/93	14°58'05"	145°38'18"	72.18	-18	51	8[a]	open	51 to -18	0.79	07/04/97	0720
TH4X	05/05/94	14°58'06"	145°38'18"	71.89	-268	52	8	open	52 to -268	1.26	03/06/97	1600
TH05	06/21/95	14°58'42"	145°38'24"	120.85	-18	111	8	open	11 to -18	0.94	07/04/97	0830
TH06	03/02/95	14°58'53"	145°37'55"	309.07	-13	-12	6	screen	8 to -12	0.79	07/04/97	0835
TH07	01/20/95	14°59'12"	145°38'11"	343.84	-20	-20	6[b]	screen	0 to -20	0.84	07/04/97	0840
TH08	01/29/93	14°58'39"	145°39'04"	8.24	-92	-92	4	screen	8 to -92	0.83	07/04/97	0745
TH09	02/03/93	14°58'25"	145°39'03"	6.70	-92	-68	4	screen	2 to -68	0.80	07/04/97	0730
TH10	10/09/96	14°59'20"	145°39'12"	163.74	-16	154	8	open	154 to -16	0.78	07/04/97	0750
TH11	02/25/97	15°00'03"	145°39'30"	339.66	-19	-17	6[b]	screen	3 to -17	0.85	07/04/97	0810
TH12	01/08/97	15°00'06"	145°38'53"	146.41	-13	136	8	open	136 to -13	0.90	07/04/97	0800
TH19	07/26/95	14°56'57"	145°38'45"	550[c]	-29[c]	543[c]	8	open	543[c] to -29[c]	90[c]	05/29/97	1025
TH22	10/16/96	14°58'26"	145°37'27"	96.61	-16	87	8	open	87 to -16	0.69	07/04/97	0715
TH24	04/10/97	14°55'35"	145°38'06"	N/S	-9[c]	302[c]	8	open	302[c] to -9[c]	311.39[d]	07/04/97	0700
M02	08/05/97	15°01'24"	145°36'32"	264.56	-12	-12	6	perf	? to -12	2.76	08/22/97	1040
M05	07/31/97	15°03'26"	145°37'43"	108.80	-13	-14	6[e]	perf	? to -13	0.88	07/31/97	1820
M07	05/19/95	15°02'09"	145°36'16"	241.35	-19	-17	6	perf/open	? to -19	0.98	07/04/97	1000
M08	08/14/97	15°02'33"	145°36'45"	266.07	-16	-16	6	perf	? to -16	1.09	08/22/97	0925
M09	04/24/95	14°59'22"	145°37'28"	265.08	-15	-13	6	perf/open	? to -15	0.94	07/04/97	0850
M10	03/20/97	15°05'12"	145°38'29"	95.00	-16	-14	6	perf/open	? to -16	0.42	07/04/97	1015
M11	03/14/95	14°59'45"	145°37'53"	292.03	-14	-14	6	perf	? to -14	1.25	07/04/97	0900
M15	05/29/97	15°01'42"	145°37'59"	193.84	-9	-7	6	perf/open	? to -9	0.81	07/04/97	0925
M16	02/24/95	14°59'24"	145°38'49"	153.39	-17	-15	8	perf/open	? to -17	0.82	07/04/97	0820
M19	06/05/97	15°00'57"	145°36'27"	247.92	-14	-16	6	perf	? to -14	1.76	07/04/97	0950
M21	01/11/97	15°00'12"	145°36'23"	243.29	-17	-14	6	perf/open	? to -17	1.07	07/04/97	0940
M22	06/30/97	15°01'02"	145°38'03"	222.73	-8	-15	6	perf	? to -8	0.98	07/04/97	0905
M25	09/19/87?	15°01'24"	145°38'05"	211.94	-88	-10	6	perf/open	? to -88	0.88	07/04/97	0915
M26	1987?	14°59'24"	145°37'53"	340.83	-30	330	6	open	330 to -30	1.32	07/04/97	0855
M29	02/12/97	15°00'52"	145°37'31"	247.04	-168	-17	6	perf/open	? to -168	1.26	07/04/97	0930
M33	08/20/97	15°00'25"	145°37'59"	235.63	-10	-12	6[e]	perf	? to -10	1.41	08/22/97	1055
M35	07/25/97	15°00'55"	145°36'59"	257.23	-13	-14	6	perf	? to -13	2.26	07/31/97	1725
M39	5/15/97	15°00'45"	145°36'26"	238.93	-11	-13	6	perf	? to -11	1.62	07/04/97	0945
Municipal	1945	14°58'37"	145°39'01"	9.76	-1	-1	20	perf	1 to -1	0.58	07/04/97	1000
Ushi	09/06/87	15°05'15"	145°38'25"	98.47	-19	-19	6	screen	-7 to -17	-0.09	07/01/97	1537
Ag20	unknown	14°58'26"	145°39'03"	7.10	-1	-1	20[f]	open	-1	1.57	07/02/97	1110
Ag30	unknown	14°58'27"	145°39'03"	5.08	-5	-5	30[f]	open	-5	0.80	07/04/97	0735
HagN	unknown	15°04'12"	145°37'23"	4.40	-2	-2	20[f]	open	-2	0.61	07/04/97	1030
HagS	unknown	15°03'51"	145°37'20"	7.54	-1	-1	10[f]	open	-1	0.67	07/04/97	1100
ObsB	02/02/91	14°58'28"	145°39'00"	7.45	-0.5	?	4	?	?	0.78	07/04/97	0740

[a] 8-inch diameter downhole casing extended above ground with 6-inch casing
[b] 8-inch diameter outer surface casing used as measuring point
[c] Estimated
[d] Water-level depth from measuring point
[e] 6-inch diameter downhole casing extended above ground with 8-inch casing
[f] Cement casing diameter measured in feet

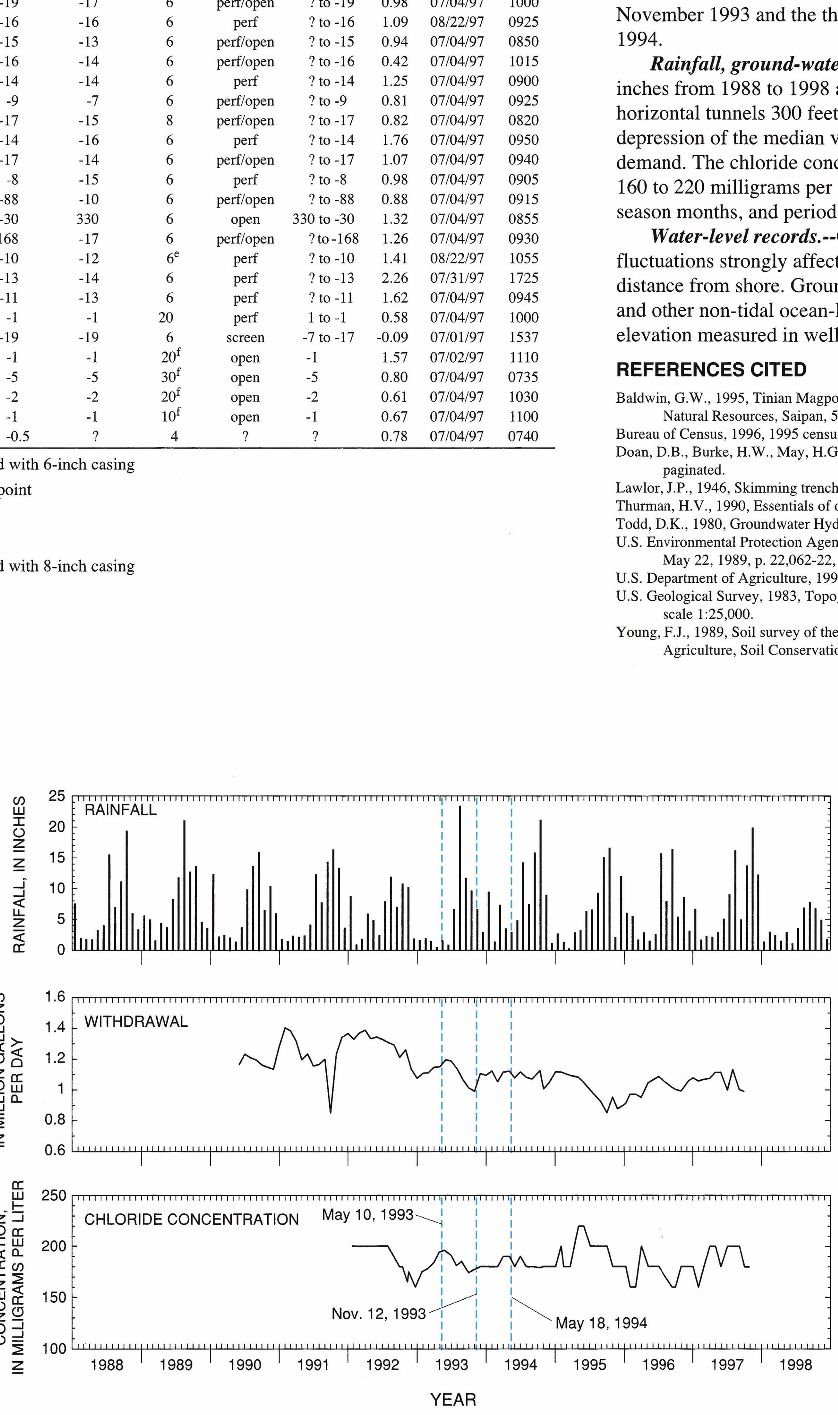

Figure 8. Rainfall, ground-water withdrawal, and chloride concentration at Municipal well, Tinian.

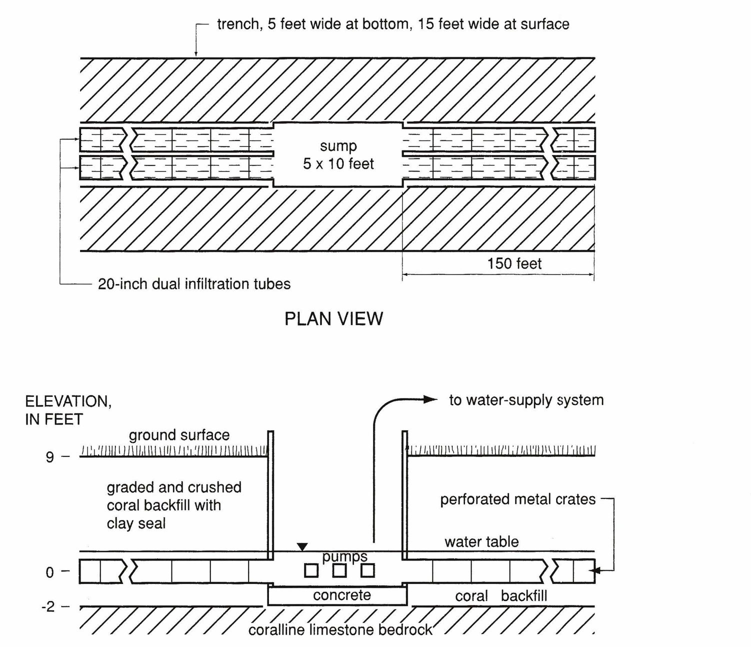

Figure 9. Plan and section views of Municipal well construction, Tinian.

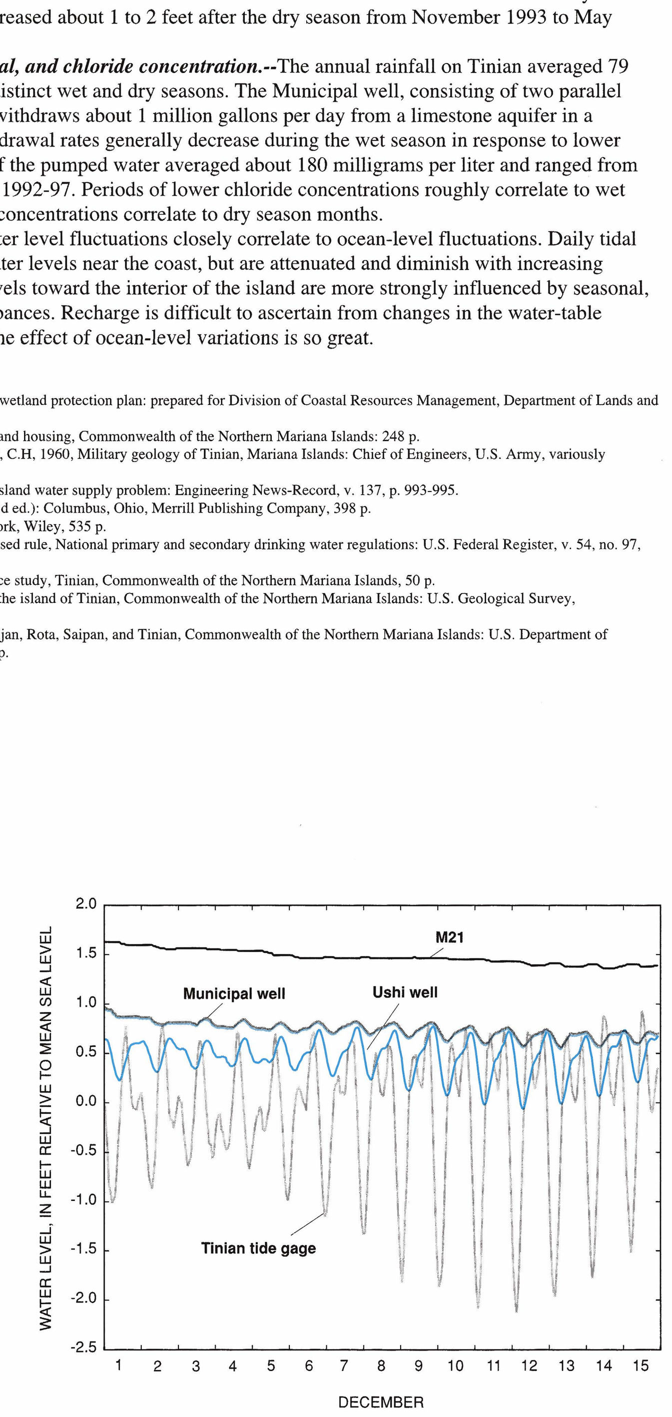

Figure 10. Selected ground-water levels and ocean level, Tinian, December 1–15, 1992.

WATER-LEVEL RECORDS

Water levels fluctuate daily as much as 0.5 ft in wells closest to the coast in response to ocean tides. Wells in the interior of the island typically do not show daily water-level fluctuations from ocean tides. Water levels in all wells rise and fall in response to non-tidal short- and long-term changes in ocean level and to changes in recharge. Water-table fluctuations caused by changes in recharge are difficult to evaluate because of the dominance of water-level changes caused by ocean-level variations.

The record of the water level in three wells between December 1 and December 15, 1992 shows how the water-table fluctuates in response to the ocean tide (fig. 10). The daily tidal signal from the ocean is attenuated as it travels through the aquifer and the daily fluctuation of the water table decreases with increasing distance from the ocean. The daily water-level changes in the Ushi well, 2,790 ft from the coast, averaged about 0.5 ft and the Municipal well, 4,080 ft from the coast, had daily water-level changes that averaged about 0.15 ft. Well M21, at 4,690 ft from the coast, had daily fluctuations that averaged about 0.01 ft. Three other wells (M02, M29, and TH07) that were monitored electronically by the USGS showed no daily tidal fluctuations; these wells are 7,660 ft, 9,630 ft, and 9,430 ft from the coast, respectively.

In addition to the daily fluctuation in water level caused by the ocean tides, water levels in wells also vary over longer time periods in response to non-periodic changes in ocean level and to rainfall (fig. 11). After removing tidal fluctuations, the ocean level at the Tinian harbor ranged from -0.4 ft to 0.5 ft altitude from January 1, 1997 to September 5, 1997, when the station was discontinued. During the entire period that the tide gage was operating (1990-97), the ocean-level record with the tidal fluctuations removed ranged from -0.7 ft to 1.2 ft altitude. The water-level records with the tidal fluctuations removed from the Ushi and Municipal wells show variations that correspond closely to the ocean-level record. Although the tide gage was discontinued in 1997, it is apparent that wells M29, M02, and TH07 also respond to the ocean level because the water-level records from these wells are similar to the Municipal well water-level record. The record from well M21 also corresponded to the ocean-level record but monitoring at this well was discontinued before the period shown on the plot, and therefore, is not shown.

The difficulty in determining the effects of recharge and withdrawal on the water table is illustrated in figure 11. For example, the decline in water level of nearly 0.7 ft in the Ushi well from January to March 1997 is due mainly to the decline in ocean level and cannot be reliably attributed to a decline in recharge during the annual dry season. With the exception of the water-level record from well M02, all of the variations in water level in the monitored wells appear to be directly in response to variations in ocean level with a little additional variation because of extreme rainfall. However, the effects of changes in recharge or withdrawal cannot be readily evaluated using these water-level records. The water-level rise of nearly 1 ft in well M02 during the end of December 1997 does not correlate with any of the other concurrent water-level records. The cause of this increase is unknown but is probably from recharge after an episode of extreme rainfall interacting with the nearby low-permeability volcanic rocks.

SUMMARY AND CONCLUSIONS

This report presents findings of a study of ground-water resources on Tinian, Commonwealth of the Northern Mariana Islands conducted from October 1990 through September 1997. The current water-supply system is expected to be insufficient for future population growth and development. The study was done to better understand and delineate the potable part of the fresh ground-water lens.

Ground-water resource.--The primary aquifer is coralliferous limestone and contains a freshwater lens that floats on saltwater near sea level. The freshwater lens is recharged by rain water, and the lens shrinks and expands in response to variations in recharge and ground-water withdrawal at wells. The salinity of water withdrawn from wells will rise if the withdrawal rate is too high or if rainfall is low for prolonged periods.

Geology, geography, and land use.--Limestone comprises about 98 percent of the surface exposures of the island, and dominates lithology above sea level, while volcanic rocks predominate below sea level and form the foundation of the island. The limestone rock commonly is coralliferous and highly porous, while the volcanic rock is composed of poorly sorted pyroclastic materials that have a lower porosity. The surface terrain is dominated by flat terraces and plateaus, separated by steep scarps. Five major land forms delineate the physiography: southeastern ridge, median valley, central plateau, north-central highland, and northern lowland. Most land-use activities are concentrated in 25 percent of the island within and adjacent to the median valley. Land use that may potentially contribute to ground-water contamination includes agricultural lots, septic fields, solid-waste dumps, and quarries.

Water-table configuration and ground-water flow.--The highest water levels occur in the vicinity of pyroclastic rocks that are above sea level. Water-table contours roughly parallel the perimeter of the north-central highlands and southeastern ridge. Water-table elevations are lowest at a depression in the median valley, and along the coast. Fresh ground water generally flows radially away from the north-central highlands and southeastern ridge, and flows toward the median valley and the coast, ultimately reaching the ocean.

Thickness of the freshwater lens.--The thickness of the freshwater lens is about 40 feet at the most inland well in a section through the median valley and near zero at the well closest to the coast. Withdrawal at the Municipal well and evaporation from the Marpo marsh may cause the potable part of the freshwater lens to be thinner and the transition zone to rise higher than would be expected under natural conditions in the vicinity of the well. The thickness of the freshwater lens at TH08 and TH09 increased about 3 to 5 feet after the wet season from May to November 1993 and the thickness decreased about 1 to 2 feet after the dry season from November 1993 to May 1994.

Rainfall, ground-water withdrawal, and chloride concentration.--The annual rainfall on Tinian averaged 79 inches from 1988 to 1998 and fell in distinct wet and dry seasons. The Municipal well, consisting of two parallel horizontal tunnels 300 feet in length, withdraws about 1 million gallons per day from a limestone aquifer in a depression of the median valley. Withdrawal rates generally decrease during the wet season in response to lower demand. The chloride concentration of the pumped water averaged about 180 milligrams per liter and ranged from 160 to 220 milligrams per liter during 1992-97. Periods of lower chloride concentrations roughly correlate to wet season months, and periods of higher concentrations correlate to dry season months.

Water-level records.--Ground-water level fluctuations closely correlate to ocean-level fluctuations. Daily tidal fluctuations strongly affect ground-water levels near the coast, but are attenuated and diminish with increasing distance from shore. Ground-water levels toward the interior of the island are more strongly influenced by seasonal, and other non-tidal ocean-level disturbances. Recharge is difficult to ascertain from changes in the water-table elevation measured in wells because the effect of ocean-level variations is so great.

REFERENCES CITED

Baldwin, G.W., 1995, Tinian Magpo watershed and wetland protection plan: prepared for Division of Coastal Resources Management, Department of Lands and Natural Resources, Saipan, 52 p.
Bureau of Census, 1996, 1995 census of population and housing, Commonwealth of the Northern Mariana Islands: 248 p.
Doan, D.B., Burke, H.W., May, H.G., and Stensland, C.H, 1960, Military geology of Tinian, Mariana Islands: Chief of Engineers, U.S. Army, variously paginated.
Lawlor, J.P., 1946, Skimming trench solves a coral island water supply problem: Engineering News-Record, v. 137, p. 993-995.
Thurman, H.V., 1990, Essentials of oceanography (3d ed.): Columbus, Ohio, Merrill Publishing Company, 398 p.
Todd, D.K., 1980, Groundwater Hydrology: New York, Wiley, 535 p.
U.S. Environmental Protection Agency, 1989, Proposed rule, National primary and secondary drinking water regulations: U.S. Federal Register, v. 54, no. 97, May 22, 1989, p. 22,062-22,160.
U.S. Department of Agriculture, 1994, Island resource study, Tinian, Commonwealth of the Northern Mariana Islands, 50 p.
U.S. Geological Survey, 1983, Topographic map of the island of Tinian, Commonwealth of the Northern Mariana Islands: U.S. Geological Survey, scale 1:25,000.
Young, F.J., 1989, Soil survey of the islands of Aguijan, Rota, Saipan, and Tinian, Commonwealth of the Northern Mariana Islands: U.S. Department of Agriculture, Soil Conservation Service, 166 p.

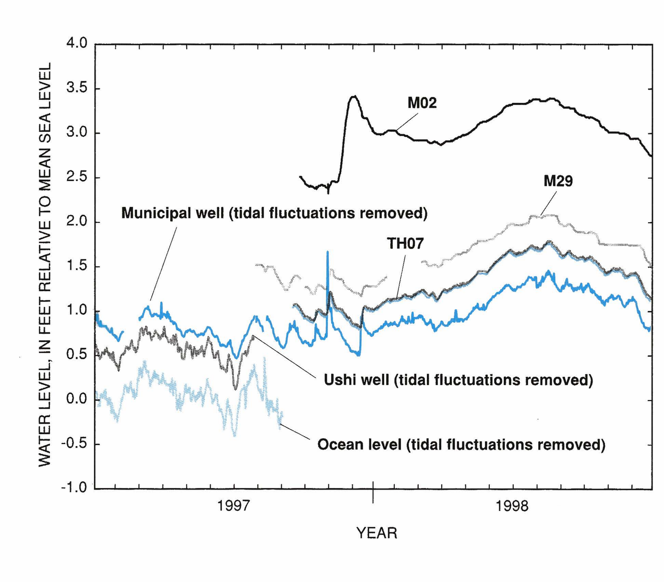

Figure 11. Ground-water levels and ocean level, Tinian, 1997–98.

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by

Stephen B. Gingerich and Daniel S. Yeatts