CHAPTER 3 – WATER BUDGET

3.1 Introduction

Water resources play a fundamental role in the evolution of indigenous cultures and the development of subsequent societies. Guam, like the islands of Hawaii, enjoys plentiful and dependable supplies of fresh water. Although it is only about 200 square miles in size, the island already sustains a population of approximately 168,000 people. It is estimated there may be sufficient capacity to provide for a population of up to 300,000; however, this estimate may be tempered by potential threats to groundwater and a ruling on Ground Water Under the Direct Influence (GWUDI) of surface water. This topic is addressed in more detail in this volume in Chapter 2 – Water Regulatory Issues..

Guam is essentially composed of two different islands sutured together along a geological contact extending from Pago Bay on the Pacific Ocean to Adelup on the Philippine Ocean. Each unit is about 100 square miles in area and, because of their geological differences; each may be treated as a separate entity. The geology of the northern, downthrown side of the fault is dominated by fossil lagoonal limestone, which in most areas reaches far below sea level. It contains the great, highly permeable limestone aquifers that are the principal sources of water supply for the whole island. The southern, upthrown side is dominated by poorly permeable volcanics, for which the most voluminous output is stream flow. The first comprehensive study of the island's geology was undertaken by the USGS (Tracey et al., 1964)[1] and numerous studies have been conducted since then. Although interest in the occurrence and development of water resources started with the earliest Chamorro society, only after World War II did the need to understand the behavior of such resources become apparent. An extensive review of available literature and data sources was carried out to support development of this WRMP. The information and conclusions presented in this chapter were drawn from a variety of sources listed in the References Section at the end of this chapter, in addition to numerous technical reports of the Water Environmental Research Institute (WERI): Western Pacific University of Guam. Information has also been extracted from less comprehensive reports, which are referred to in the text when appropriate. In addition, data have been obtained from the GEPA management reports and from GWA files. Other sources include Earth Tech Corporation data and data obtained during development of several golf courses on the island.

3.2 Background

This chapter is divided into six major divisions:

- Hydrologic Budgets
- Water Resources Occurrence and Behavior
- Water Development
- Status of the Water Resources
- Quality of the Water Resources
- Water Resources Monitoring

In Section 3.3, Hydrologic Budgets, the rate of recharge to the northern Guam aquifers is derived based on the assumption that no runoff occurs in the limestone geology, whereas in the volcanic geology of the South very little recharge takes place and virtually all of the rainfall is converted to direct runoff or to evapotranspiration.

Section 3.4, Water Resources Occurrence and Behavior, describes the basal and parabasal limestone aquifers of the North, the limestone, volcanic aquifers and the river flow of the South.

Section 3.5, Water Development, emphasizes that the total average daily withdrawal from the northern aquifers considerably exceeds presumed consumption by all users. The best estimate of total production by all pumping entities—the former Earth Tech system, U.S. Navy, U.S. Air Force, golf course developments and miscellaneous uses—is approximately 46 million gallons per day (mgd). Actual consumption should amount to less than 25 mgd. Unaccounted-for water or water loss in the distribution system is very high, far in excess of the usual allowance for a standard system of about 15%. As part of the WRMP project, water loss was estimated to be approximately 22.5 mgd.

Section 3.6, Status of the Water Resources, notes that to date there have been no irreversible, detrimental impacts associated with development of groundwater in the North and surface water in the South. Salinity has risen in some wells as a result of seawater intrusion, but it may be controlled by reducing pumping rates and, perhaps by reducing the depth of the well below sea level. In the North, three Aquifer Sectors are responsible for most of the GWA groundwater supply. The most important is the Yigo-Tumon Sector, followed by the Finegayan, Tarague and Agana Sectors. To the best of current knowledge, the Yigo-Tumon Sector may be at the limit of its safe development. WERI has and will continue to model this sector in order to more accurately determine its sustainable yield. If new wells are necessary, the first should be restricted to the Ordot Aquifer System and the Agafo Gumas Aquifer System and also to the portion of the Mt. Santa Rosa-Andersen Sector accessible by GWA. In the South, consideration should be given to expanding the diversion at Ugum River and to investigating the feasibility of diversions at other rivers. Opportunities to utilize some of the limestone wells in the South should also be re-examined.

Section 3.7, Quality of the Water Resources, stresses that the groundwater of the North has been contaminated due to the high degree of porosity and permeability of the limestone from the surface through the phreatic zone to the zone of saturation. Recharge is voluminous and travels rapidly from the surface downward. Instances of contamination have been noted and are detailed in Chapter 2 of this volume. In addition to including low levels of oil/grease and methylene-blue active substances in some areas, instances of exceeding either half or the whole MCL or levels for specific contaminants are also detailed in Chapter 2. The occurrence in groundwater of relatively high concentrations of nitrogen (NO_3-N) is problematic, however. As discussed in Section 3.7.2, Water Resources Monitoring, GEPA has a Well Head Protection Program (WHPP) that is designed to control surface activities within 1,000 feet of a well, but it is not enforced consistently. The current well locations relative to development reflect the lack of enforcement as a large number of wells are concentrated over short distances, especially in the Yigo-Tumon Aquifer Sector. Capture zones are narrow but nevertheless overlap because of the proximity of the wells.

3.3 Hydrologic Budgets

In 1991, the Barrett Consulting Group (with J.F. Mink)[2] revisited previous efforts to arrive at a satisfactory hydrologic budget for northern Guam. Their study, *Groundwater in Northern Guam: Sustainable Yield and Groundwater Development,* offered somewhat different, higher values than those stated in the 1982 Northern Guam Lens Study[3] (hereafter referred to as NGLS). Much of the following text and analyses are based on the 1991 study. Additional analyses are provided in Exhibit

3A at the end of this chapter. In 1999, WERI composed a budget for northern Guam in Technical Report 88 [4] (TR 88) a discussion of which is included in the following text.

Islands, with their finite terminal boundaries, are good candidates for computing hydrologic budgets on a global scale because input flows across boundaries are absent, leaving atmospheric moisture as the sole input parameter. In the case of Guam, the only atmospheric moisture of significance is rainfall.

The goal of hydrologic budgeting is to determine a mass balance among input and output variables in the hydrologic cycle. Input variables include rainfall, together with other atmospheric moisture sources and fluxes (surface water and groundwater) across boundaries in the area of interest. Output variables consist of direct surface runoff, evapotranspiration, deep percolation and boundary fluxes. Total runoff, which includes direct surface runoff, groundwater seepage and rainfall, are often known with some degree of accuracy as a result of detailed measurements. Evapotranspiration is approximated from theoretical and empirical models, in particular equating it to measured pan evaporation. Infiltration is normally solved for as the unknown variable that closes the balance equation.

3.3.1 Northern Guam

Hydrological mass balances for northern Guam have been proposed by numerous investigators employing a variety of methods. Results have ranged from 8 to 15 mgd available from wells in the North.

In a study completed in 1976 for the Public Utility Agency Guam (PUAG), the predecessor to GWA, two hydrologic budgets were calculated, one using evaporation as the equivalent of evapotranspiration and the other deducing evapotranspiration from the water budget for southern Guam [J.F. Mink, *Groundwater Resources of Guam: Occurrence and Development*, University of Guam Water Resources Research Center Technical Report 1 (TR 1)].[5] In the 1982 NGLS, a budget was derived based on a theoretical determination of evapotranspiration; and as part of the study, WERI produced a partial budget in which infiltration was computed by relating the gain in salinity in groundwater compared to salinity in rainfall and attributing the difference to the effects of evapotranspiration. Each method is an approximation based on assumptions combined with a body of measured data for rainfall, pan evaporation and stream flow.

Table 3-1 summarizes previous attempts to create a global hydrologic budget for northern Guam. The budget taken from TR 1 is based on a total limestone area of 94.6 square miles, which is virtually the entire northern half of the island. The NGLS budget refers to only 67.92 square miles, which is the area inland of a 4,000-foot-wide buffer zone, which assumes that groundwater in the buffer zone is non-potable. This restriction of total area understates total input. The alternate balances were recomputed from the TR 1 budgets by altering some parameters and employing the total area of North Guam (100.3 square miles), or the area inland of a zone 0.5 mile in width from the coast, leaving an input area of 80.1 square miles. The most recent attempt at budgeting was performed by WERI (Jocson, Jenson and Contractor, 2002, Recharge and Aquifer Response: Northern Guam Lens Aquifer, Guam, Mariana Islands, Journal of Hydrology, 260, pp. 231-254)[6]; also TR 88 in which the probable recharge to groundwater is calculated as 67% of the rainfall and for which the authors noted that this value is consistent with the most probable estimate given in TR 1.

Table 3-1 – Summary of Attempts to Develop a Global Hydrologic Budget

Source	Area (sq.mi.)	P (in./yr)	ET (in./yr)	R (in/yr)	I (mgd/sq.mi.)
TR 1	94.6	94.7	42.8	0	2.45
NGLS	67.2	94	59	0	1.67
TR 88	100	94.0	31	0	3.00

P = average rainfall; ET = evapotranspiration, R = runoff; I = infiltration to groundwater

The TR 1 budgets are developed and explained in detail in that report. The minimum budget assumes the most conservative conditions wherein evapotranspiration is equated to measured pan evaporation. This, of course, is not realistic because moisture is not constantly available to plants. Much of the wet season rainfall quickly transits the thin soil to infiltrate rapidly, while in the dry season rainfall is insufficient to support potential evapotranspiration.

The "probable" budgets in TR 1 are a considerable improvement on the minimum budgets and they are the most reliable of the postulated budgets in that report because of the straightforward methodology employed. Reworking the basic premise that evapotranspiration is the difference between rainfall and runoff in southern Guam, the updated values for recharge in the North are not greatly different from the original estimates (see Exhibit 3A). In northern Guam, infiltration for the probable budget is 232 mgd when no allowance is made for loss by surface runoff, and it is 212 mgd when runoff is taken as five percent of the rain. These values refer to a total area of 94.6 square miles.

In the budgets discussed above, the calculated infiltration rates range from 1.67 to 3.00 mgd per square mile for northern Guam. The rate of 1.67 mgd per square mile is given in the 1982 NGLS report, which is unreasonably low. More reasonable values approach or exceed 2.3 mgd per square mile.

3.3.2 Southern Guam

In southern Guam, recharge to groundwater is small while direct surface runoff is high because of the low permeability of the predominant volcanic geology. Where limestone occurs along stretches of the coast and in the highlands of Mt. Alifan, Mt. Almagosa and Mt. Lamlam, as well as, in the upper reaches of the Talofofo River valley, infiltration may be as high as in northern Guam. However, the area covered by limestone is small compared with the volcanic terrain, and most of the accumulated groundwater eventually percolates as springs that flow to rivers. The hydrologic budgets for the balance in southern Guam are explained in Exhibit 3A.

Groundwater resources in the South constitute only a small fraction of the island's developable water supply, but stream flow is large. Good records of rainfall and stream flow measurements are available from which hydrological principles that are applicable to the whole island can be extracted. In computing hydrologic budgets, the input variable (rainfall) and the output variable (evapotranspiration) are treated as being about the same for North and South Guam; however, the output variables of surface runoff and groundwater flux are vastly different.

Assuming an average rainfall of 88.9 inches per year (based on rainfall measurements at Inarajan) and an evapotranspiration total of 38 inches per year (see Exhibit 3A for derivation), the combination of infiltration plus direct surface runoff is 50 inches.

Conversion of the Inarajan River data results in a total overland flow of 52.3 inches per year (average flow is 11 mgd). Subtracting average flow during the dry season of 6.2 inches per year yields an average direct surface runoff of 48.5 inches per year. Because the volcanic rock mass is saturated virtually to the ground surface at low places in the volcanic topography, not much infiltration to groundwater can accumulate as storage. The 6.2 inches per year flow during the dry season may be considered as the probable infiltration during the wet season.

3.4 Water Resources Occurrence and Behavior

The Adelup-Pago fault, which geologically and topographically divides the island, is also the boundary between two distinct suites of water resources. To the north, the occurrence of fresh water is limited to groundwater in permeable limestone aquifers; there are no streams, although there are a few small springs. In the South, surface runoff in the form of springs, streams and rivers is the dominant sources of fresh water. Some small areas of limestone contain groundwater but in trivial amounts compared with the aquifers of the North. The cost of developing the groundwater of the North and distributing it to consumers, the greatest number of whom live in the North, is far less than would be the cost of storing, treating and distributing the surface waters of the South. The groundwater of the North supplies the public demand except for parts of the sparsely populated regions of the South that are mostly served by the Ugum River and a few smaller diversions.

Groundwater occurs in two ways, basal and parabasal. In basal groundwater, a lens of fresh-to-brackish water floats on salt water because of the difference in their densities Parabasal groundwater is hydraulically continuous with basal groundwater, but it rests on the virtually impermeable volcanic basement rather than on salt water. Basal groundwater constitutes most of the freshwater resources but is subject to degradation by salt water if developed improperly. Parabasal groundwater resources are less voluminous, but they resist mixture with salt water until or unless overall groundwater extraction exceeds a safe limit.

3.4.1 Northern Guam

The hydrologic budget for northern Guam is estimated to have an average rate of recharge to groundwater of two to three mgd per square mile, or a total of 200 to 300 mgd for the 100 square miles of the North. Not all of it is safely developable, however. A fraction of this amount, perhaps as little as 30%, may be extracted without deteriorating either the quality or quantity of the water extracted. The rate of removal that meets this constraint is called the “sustainable yield.” Assuming an average recharge rate of 2.5 mgd per square mile, at a 30% extraction rate over the 100 square miles, the sustainable yield may be as high as 75 mgd. The most recent attempt to deduce sustainable yield for the North resulted in an average value of 70 mgd[2].

The above estimates of sustainable yield have been determined by regarding the entirety of the groundwater resources in the North. More accurate determinations on regional scales can be derived through methods such as numerical modeling. WERI has developed and continues to create numerical models that describe the behavior of groundwater in the North, especially in the Yigo-Tumon and Finegayan Regions.

Sustainable yield never equals recharge. Under average steady state conditions, recharge that accumulates in the aquifers is balanced by discharges from the aquifers. Discharge is a combination of draft (pumpage) and seepage to the sea in the vicinity of the coastline. If draft were to equal recharge, seepage would deplete storage until the lens vanished.

Parabasal groundwater is restricted to areas where the volcanic basement rises above the theoretical Ghyben-Herzberg depth of the lens. Substantial parabasal resources occur in the Yigo area, where the Mataguac Hill volcanics surface above the limestone terrain, and in the Ordot-Chaot region near Agana, where the basement rises toward the Adelup-Pago fault.

3.4.1.1 Aquifer Classification

The proposed aquifer categories follow the methodology created for Hawaii and other Pacific Islands. The divisional hierarchy starts with the Aquifer Sector, which is divided into Aquifer Systems, which in turn are subdivided into Aquifer Types. At this stage, only the Sectors and Systems have been identified for northern Guam. The Aquifer Type is defined by specific hydrogeological conditions within an Aquifer System. The Aquifer Sectors are the same as the Sub-basins referred to in the NGLS report, but each Aquifer System embraces several of the NGLS Management Zones. The Sector-System arrangement allows for a simpler and more direct discussion and allocation of the groundwater resources.

The most comprehensive review of northern Guam's water resources, the NGLS, was conducted almost 25 years ago. That study organized and evaluated existing hydrogeologic data, made analyses relevant to groundwater production, and subdivided all of northern Guam into Subbasins and Management Zones. This classification formed the basis for GEPA management decisions about the expansion of groundwater development.

In the NGLS, only 67 square miles of the total of 100 square miles in northern Guam were considered favorable for the production of potable water. This production area was divided into 47 Management Zones, each having an average area of somewhat more than 1 square mile. The outlines of the zones reflect hydrogeological and topographic features, but each is too small to be uniquely identified by these parameters. Strict adherence to a zone as a management unit inhibits flexibility in taking advantage of groundwater conditions.

Figure 3-1 is a map showing Aquifer Sectors and Systems on Guam. The correspondence between the NGLS divisions and the proposed classification is presented in Table 3-2.

Figure 3 -1 – Sectors and Systems

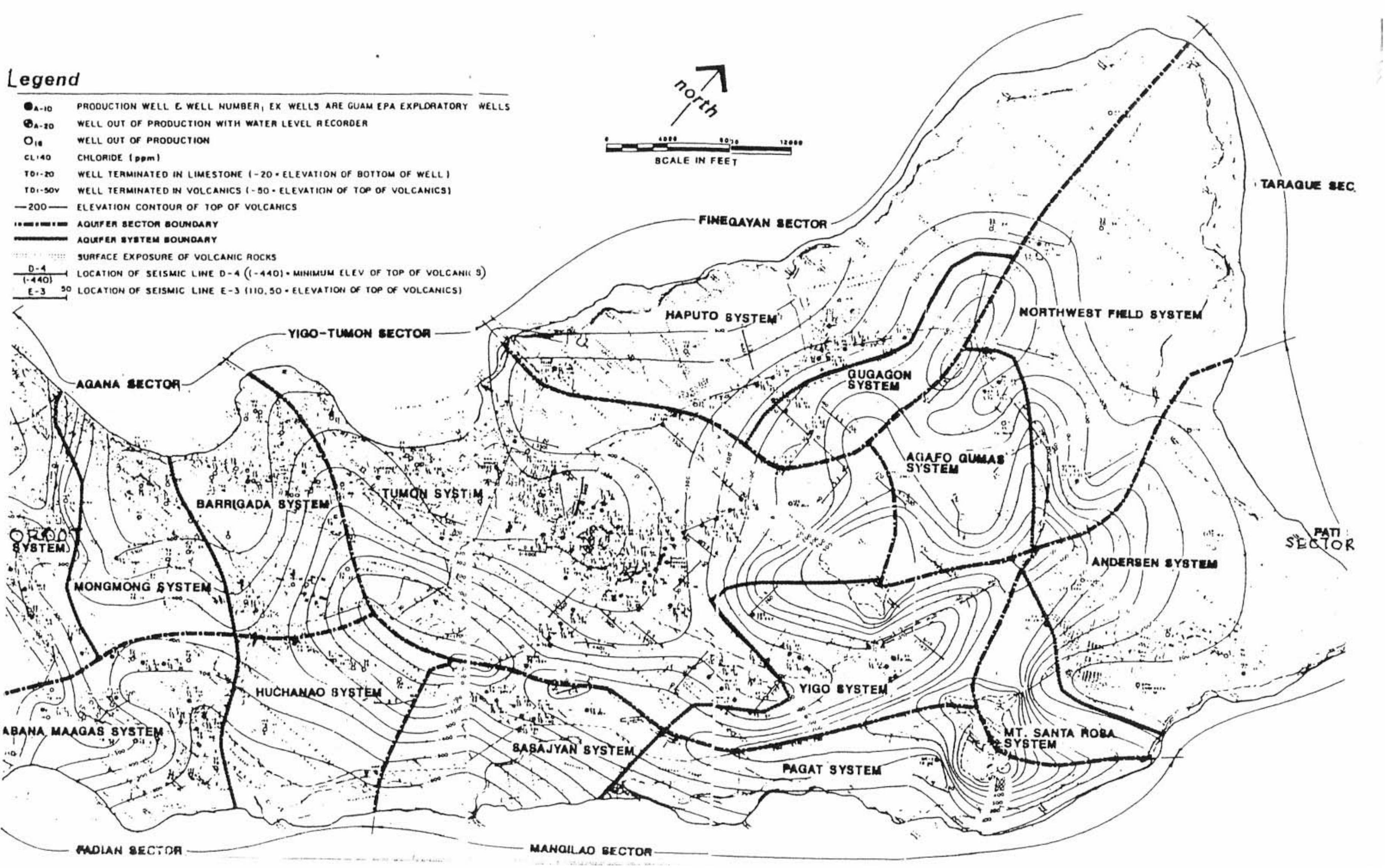
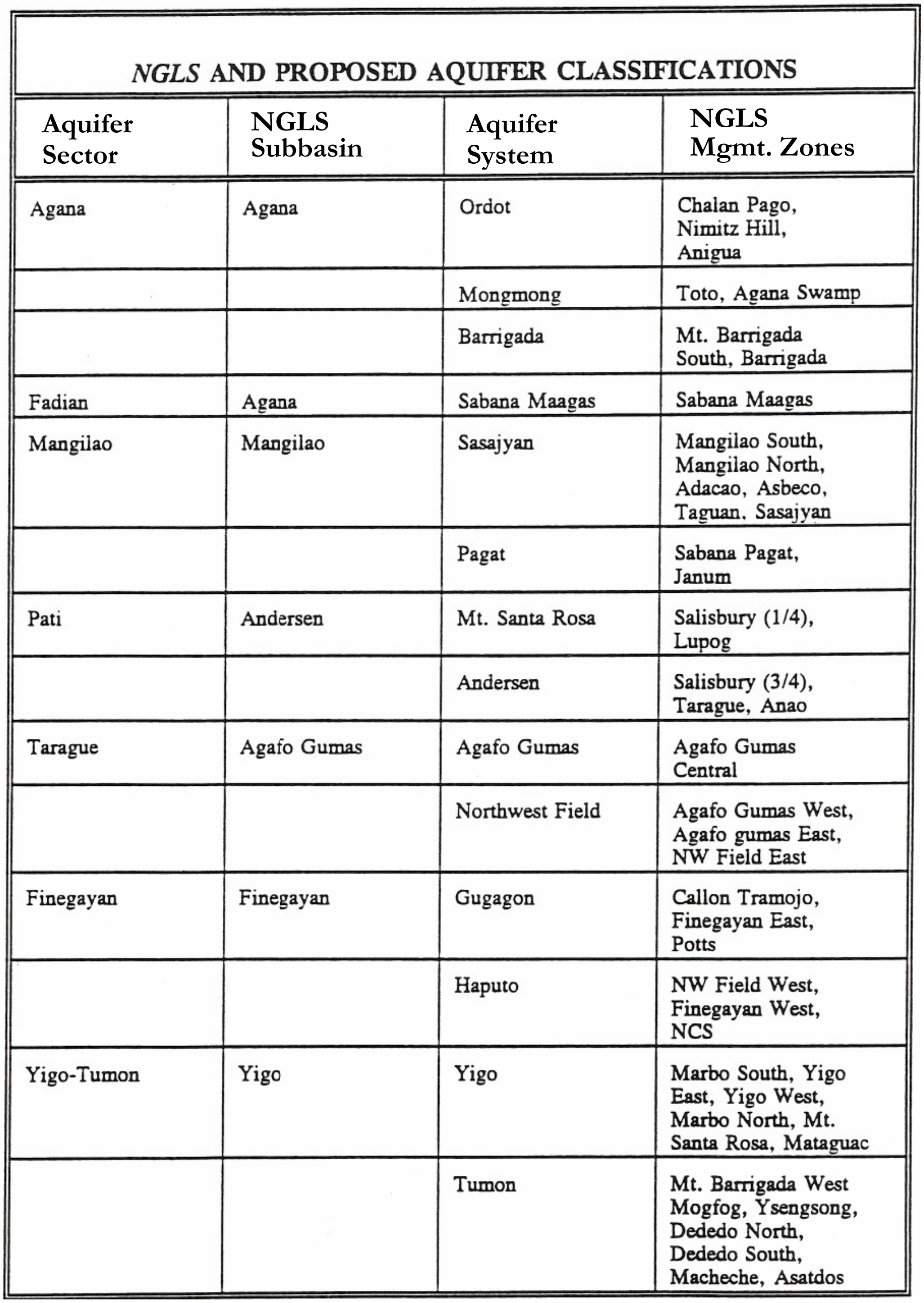


Table 3-2 – NGLS and Proposed Aquifer Classifications



NGLS AND PROPOSED AQUIFER CLASSIFICATIONS

Aquifer Sector	NGLS Subbasin	Aquifer System	NGLS Mgmt. Zones
Agana	Agana	Ordot	Chalan Pago, Nimitz Hill, Anigua
		Mongmong	Toto, Agana Swamp
		Barrigada	Mt. Barrigada South, Barrigada
Fadian	Agana	Sabana Maagas	Sabana Maagas
Mangilao	Mangilao	Sasajyan	Mangilao South, Mangilao North, Adacao, Asbeco, Taguan, Sasajyan
		Pagat	Sabana Pagat, Janum
Pati	Andersen	Mt. Santa Rosa	Salisbury (1/4), Lupog
		Andersen	Salisbury (3/4), Tarague, Anao
Tarague	Agafo Gumas	Agafo Gumas	Agafo Gumas Central
		Northwest Field	Agafo Gumas West, Agafo gumas East, NW Field East
Finegayan	Finegayan	Gugagon	Callon Tramojo, Finegayan East, Potts
		Haputo	NW Field West, Finegayan West, NCS
Yigo-Tumon	Yigo	Yigo	Marbo South, Yigo East, Yigo West, Marbo North, Mt. Santa Rosa, Mataguac
		Tumon	Mt. Barrigada West Mogfog, Ysengsong, Dededo North, Dededo South, Macheche, Asatdos

3.4.2 Southern Guam

3.4.2.1 Groundwater

Groundwater is not as dominant a freshwater resource south of the Adelup-Pago fault as it is to the north. Nevertheless, virtually the whole of southern Guam is saturated with fresh groundwater and a small quantity has been successfully exploited. The groundwater occurs in the limited areas of limestone as well as in the far larger areas of volcanics.

Throughout southern Guam, the entire volcanic rock mass to an unknown but substantial depth is saturated with groundwater. Although of low permeability, the volcanics constitute a nearly continuous aquifer. A few attempts to exploit the aquifers by drilling wells have succeeded in yielding low rates of production in the range of 25 to 60 gallons per minute (gpm); however, some attempts have failed to yield even a few gpm from very deep borings.

3.4.2.2 Surface Water

A comprehensive study of potential surface water development in the South was performed for PUAG by the Barrett Consulting Group in 1994[7]. Eighteen of more than 40 rivers and streams were evaluated as potential sources of fresh water. The other water bodies were considered too small to be worth considering.

Development of surface water would be by means of storage reservoirs or simple diversions, such as currently in place on the Ugum River. The construction of storage reservoirs would be very destructive of the environment, as well as extraordinarily costly, for the reliable amount of water that could be captured for potable use. Diversions, on the other hand, would be far less expensive and would require a minimum of construction that would not severely affect the environment. The report concluded that diversions would be preferable to storage reservoirs although the amount of water gained would be small. Nevertheless, in the report both storage reservoirs and diversions are fully analyzed.

The only storage reservoir in southern Guam is the U.S. Navy Fena Reservoir, which collects drainage from three rivers–Almagosa, Imong and Maulap. Fena can sustain a draft of 11.5 mgd. A 1991 memorandum of understanding with the U.S. Navy allots 4.39 mgd to GWA and the remainder serves Navy demand.

Numerous studies have been performed relating to the construction of a dam and reservoir on the Ugum River that would yield available draft of 11 mgd. Studies have also been made for a dam/reservoir on the Inarajan River that would allow for available draft of about 6 mgd. The cost of construction and the environmental degradation that would accompany these projects have relegated them to a low priority on the list of water development schemes.

Diversion of stream flow is more acceptable from both a cost and environmental perspective, but the potential quantity of available water is far less than for dam/storage reservoirs. Numerous diversion structures have been installed in the past. Some are still active; others have been abandoned. The most productive diversion is on the Ugum River, which was designed to reliably yield 2 mgd of finished water. Diversions on small streams serve the Umatac and Merizo areas. At one time the Tinago River was diverted to serve the Malojloj region, but it has been abandoned and the supply now comes from the Ugum River. A well in Malojloj also contributed to the supply, but it is not active at the moment.

Should all of the potential reservoirs listed in the Barrett study[7] be constructed, the total available draft would be 64 mgd. This total does not include the current available draft of the Fena system but does include yield made available by improving that system. For all of the potential diversions, excluding the present yield from the Ugum River, the available draft would be 10.3 mgd. If the 2 mgd from the Ugum River is included, the total would be 12.3 mgd.

These total available drafts are fractions of total surface runoff. Average surface runoff is estimated at 2.5 mgd per square mile (see Chapter 2 on Hydrologic Budgets in this volume), which over the approximately 100 square miles of the south totals 250 mgd. If all the reservoirs were constructed and Fena Reservoir improved, the available draft of 64 mgd would amount to 26% of total runoff; adding the current Fena yield of 11 mgd raises the fraction to 30%. If all of the diversions were implemented, the fraction of average runoff would be approximately five percent.

Surface water in the South is a substantial resource that may have to be exploited more intensively should population demand in the future exceed the sustainable yield of the northern aquifers.

3.5 Water Development

Guam, with an estimated population of 168,564 (U.S. Census Bureau International Data Base for mid-year 2005), should consume about 21 mgd, assuming a per capita usage of 125 gallons per capita per day (gpcd). Allowing for an additional 5 to 10 mgd for miscellaneous purposes, total consumption should be about 26 to 31 mgd. If a typical water system leakage rate of 15% of production is applied, the gross demand should be approximately 30 to 36 mgd. Total current production from surface and groundwater, however, approaches 60 to 65 mgd. This amount includes pumpage from the northern aquifers (approximately 46 mgd), the Ugum diversion (2 mgd), Fena Reservoir (yield 11 mgd) and miscellaneous springs. Evidently the water distribution systems lose a substantial share of the water developed.

Under current production rates in the North, the unused sustainable yield available to GWA totals about 13 mgd. The most readily developable additional sources are in the Ordot Aquifer System of the Agana Aquifer Sector (approximately 2.7 mgd) and the Agafo Gumas Aquifer System (approximately 2.9 mgd). The sustainable yield assigned to the Yigo-Tumon Aquifer Sector (approximately 20 mgd) has already been reached, yet the basal lens in the Tumon System appears to be stable.

No wells are used by GWA in the South although, before the Ugum diversion came on line, two wells at Malojloj provided local supply. These wells, along with several others (Asalonso, GORCO, Talofofo), may have use in the future.

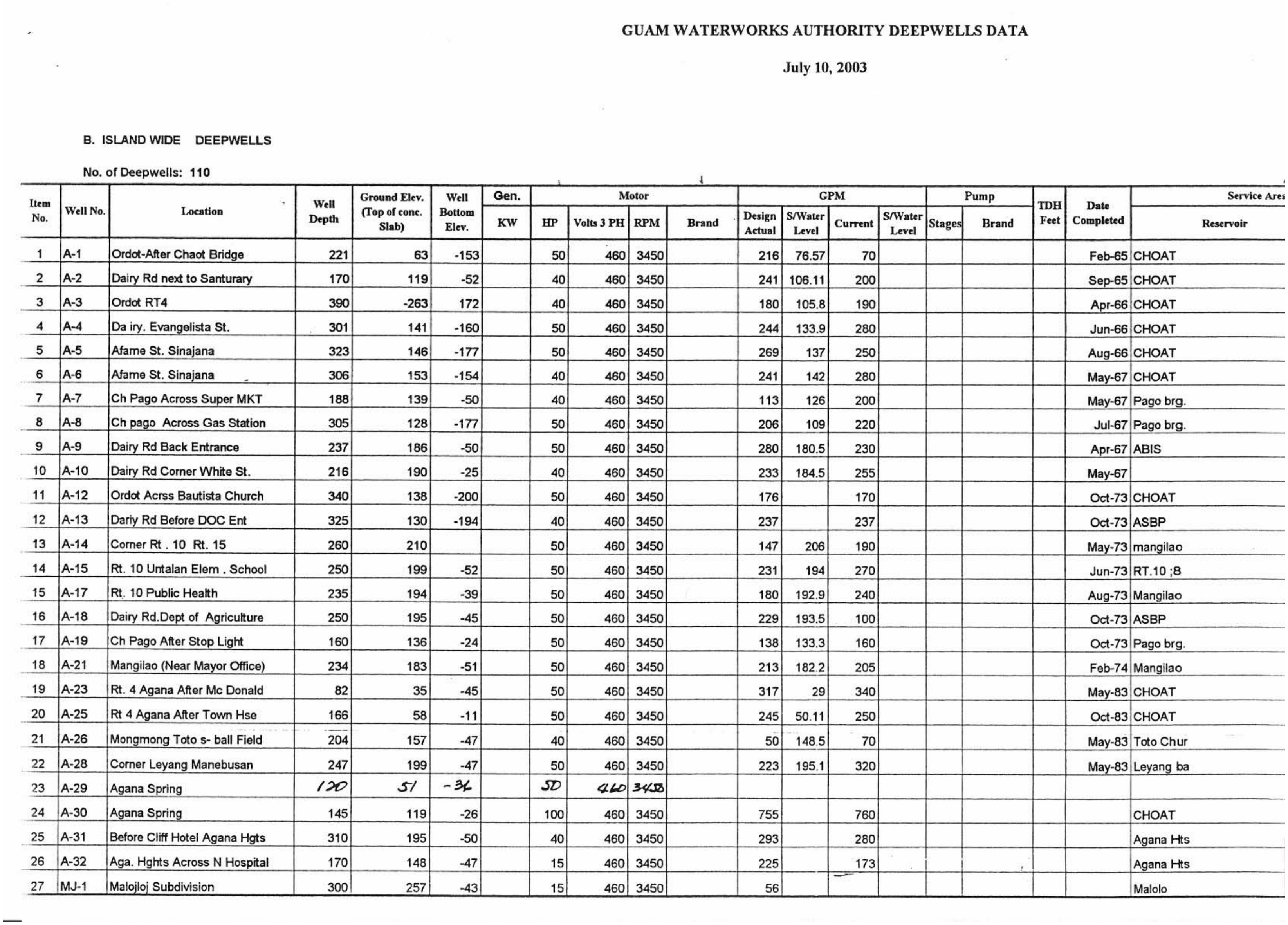
GWA is allowed 4 mgd of the 11 mgd reliable yield from the Fena Reservoir system. The Ugum diversion belongs to GWA and supplies an average of up to 2 mgd finished water to southern Guam.

Pumpage from the northern Guam limestone aquifers is of greatest concern. GWA depends on production from about 110 wells, in addition to 10 wells formerly managed by Earth Tech

Corporation. It also obtains a small quantity from Air Force wells. Based on a GWA Production Data Report (July 10, 2003), GWA wells in combination with U.S. Navy wells account for approximately 39 mgd, Table 3-3 – GWA Production Data Report. Former Earth Tech wells supply an additional 3.3 mgd Table 3-4 – Earth Tech Water System. The combined total of these wells amounts to 42.3 mgd. The U.S. Air Force also pumps about 2.5 mgd for its own use, and private users pump about 1 mgd, resulting in a total groundwater production of approximately 46 mgd. This figure cannot be treated as truly accurate because of the approximations made in assigning yield values to each well. Even if the entire population of Guam was served by northern groundwater, per capita consumption would be 273 gpcd for a population of 168,564. The difference between 273 gpcd and the expected average consumption of 125 gpcd implies a system loss of approximately 55%, far in excess of the 15% experienced by most systems in good order.

Exhibit 3B approaches the disparity between pumpage and consumption by comparing consumption based on revenue collected by GWA with reported pumpage. The average revenue collected over the 5-year period from October 1999 to September 2004, when converted to consumption, totaled 23 mgd (see data and details in Exhibit 3B). A total of 6.5 mgd was derived from surface water sources that included Fena Reservoir, the Ugum diversion, and Santa Rita and Asan Springs. Total GWA recorded pumpage was 42 mgd for a total of water source of 48.5 mgd. Thus, it is clear that leakage in the system is a serious problem because the analyses above demonstrate about 50% loss of potable water.

Table 3-3 – GWA Production Data Report



GUAM WATERWORKS AUTHORITY DEEPWELLS DATA

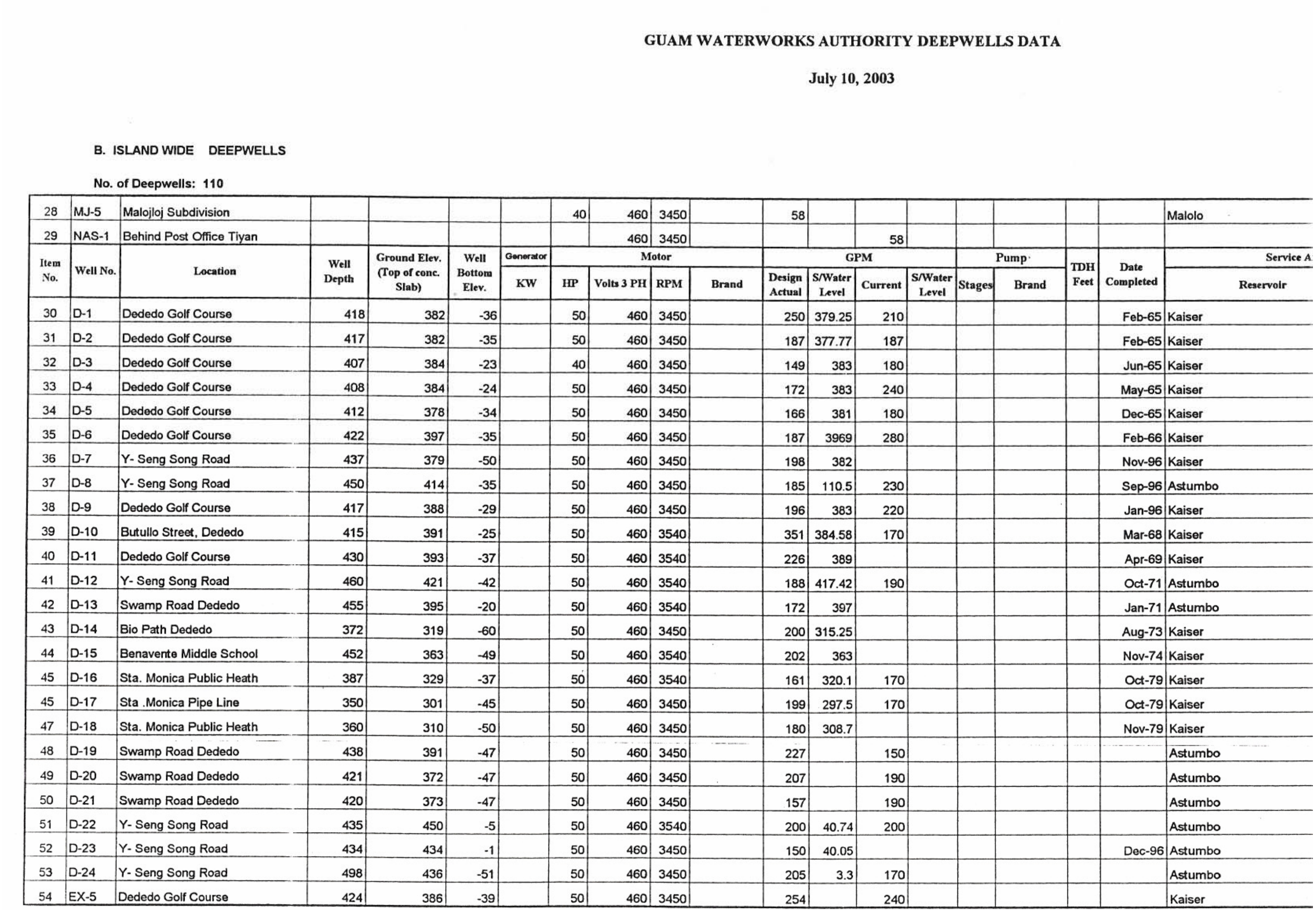
July 10, 2003

B. ISLAND WIDE DEEPWELLS

No. of Deepwells: 110

Item No.	Well No.	Location	Well Depth	Ground Elev. (Top of conc. Slab)	Well Bottom Elev.	Gen.	Motor				GPM				Pump		TDH Feet	Date Completed	Service Are
						KW	HP	Volts 3 PH	RPM	Brand	Design Actual	S/Water Level	Current	S/Water Level	Stages	Brand			Reservoir
1	A-1	Ordot-After Chaot Bridge	221	63	-153		50	460	3450		216	76.57	70					Feb-65	CHOAT
2	A-2	Dairy Rd next to Santurary	170	119	-52		40	460	3450		241	106.11	200					Sep-65	CHOAT
3	A-3	Ordot RT4	390	-263	172		40	460	3450		180	105.8	190					Apr-66	CHOAT
4	A-4	Da iry. Evangelista St.	301	141	-160		50	460	3450		244	133.9	280					Jun-66	CHOAT
5	A-5	Afame St. Sinajana	323	146	-177		50	460	3450		269	137	250					Aug-66	CHOAT
6	A-6	Afame St. Sinajana	306	153	-154		40	460	3450		241	142	280					May-67	CHOAT
7	A-7	Ch Pago Across Super MKT	188	139	-50		40	460	3450		113	126	200					May-67	Pago brg.
8	A-8	Ch pago Across Gas Station	305	128	-177		50	460	3450		206	109	220					Jul-67	Pago brg.
9	A-9	Dairy Rd Back Entrance	237	186	-50		50	460	3450		280	180.5	230					Apr-67	ABIS
10	A-10	Dairy Rd Corner White St.	216	190	-25		40	460	3450		233	184.5	255					May-67	
11	A-12	Ordot Acrss Bautista Church	340	138	-200		50	460	3450		176		170					Oct-73	CHOAT
12	A-13	Dariy Rd Before DOC Ent	325	130	-194		40	460	3450		237		237					Oct-73	ASBP
13	A-14	Corner Rt . 10 Rt. 15	260	210			50	460	3450		147	206	190					May-73	mangilao
14	A-15	Rt. 10 Untalan Elem . School	250	199	-52		50	460	3450		231	194	270					Jun-73	RT.10 ;8
15	A-17	Rt. 10 Public Health	235	194	-39		50	460	3450		180	192.9	240					Aug-73	Mangilao
16	A-18	Dairy Rd.Dept of Agriculture	250	195	-45		50	460	3450		229	193.5	100					Oct-73	ASBP
17	A-19	Ch Pago After Stop Light	160	136	-24		50	460	3450		138	133.3	160					Oct-73	Pago brg.
18	A-21	Mangilao (Near Mayor Office)	234	183	-51		50	460	3450		213	182.2	205					Feb-74	Mangilao
19	A-23	Rt. 4 Agana After Mc Donald	82	35	-45		50	460	3450		317	29	340					May-83	CHOAT
20	A-25	Rt 4 Agana After Town Hse	166	58	-11		50	460	3450		245	50.11	250					Oct-83	CHOAT
21	A-26	Mongmong Toto s- ball Field	204	157	-47		40	460	3450		50	148.5	70					May-83	Toto Chur
22	A-28	Corner Leyang Manebusan	247	199	-47		50	460	3450		223	195.1	320					May-83	Leyang ba
23	A-29	Agana Spring	120	51	-34		50	460	3450										
24	A-30	Agana Spring	145	119	-26		100	460	3450		755		760						CHOAT
25	A-31	Before Cliff Hotel Agana Hgts	310	195	-50		40	460	3450		293		280						Agana Hts
26	A-32	Aga. Hghts Across N Hospital	170	148	-47		15	460	3450		225		173						Agana Hts
27	MJ-1	Malojloj Subdivision	300	257	-43		15	460	3450		56								Malolo

Table 3-3 – GWA Production Data Report (continued)



GUAM WATERWORKS AUTHORITY DEEPWELLS DATA

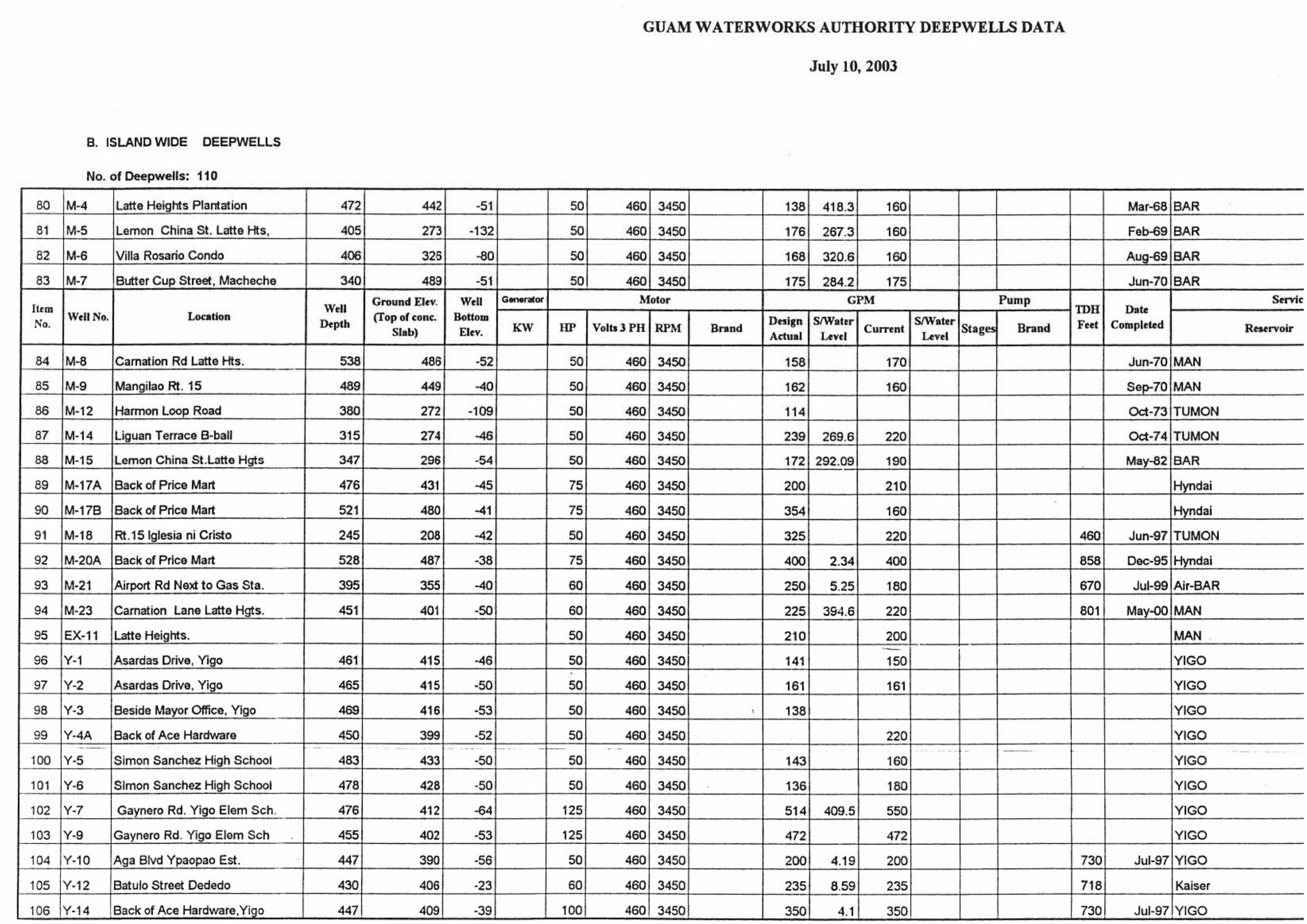
July 10, 2003

B. ISLAND WIDE DEEPWELLS

No. of Deepwells: 110

28	MJ-5	Malojloj Subdivision					40	460	3450		58								Malolo
29	NAS-1	Behind Post Office Tiyan						460	3450				58						
Item No.	Well No.	Location	Well Depth	Ground Elev. (Top of conc. Slab)	Well Bottom Elev.	Generator	Motor				GPM				Pump		TDH Feet	Date Completed	Service A
						KW	HP	Volts 3 PH	RPM	Brand	Design Actual	S/Water Level	Current	S/Water Level	Stages	Brand			Reservoir
30	D-1	Dededo Golf Course	418	382	-36		50	460	3450		250	379.25	210					Feb-65	Kaiser
31	D-2	Dededo Golf Course	417	382	-35		50	460	3450		187	377.77	187					Feb-65	Kaiser
32	D-3	Dededo Golf Course	407	384	-23		40	460	3450		149	383	180					Jun-65	Kaiser
33	D-4	Dededo Golf Course	408	384	-24		50	460	3450		172	383	240					May-65	Kaiser
34	D-5	Dededo Golf Course	412	378	-34		50	460	3450		166	381	180					Dec-65	Kaiser
35	D-6	Dededo Golf Course	422	397	-35		50	460	3450		187	3969	280					Feb-66	Kaiser
36	D-7	Y- Seng Song Road	437	379	-50		50	460	3450		198	382						Nov-96	Kaiser
37	D-8	Y- Seng Song Road	450	414	-35		50	460	3450		185	110.5	230					Sep-96	Astumbo
38	D-9	Dededo Golf Course	417	388	-29		50	460	3450		196	383	220					Jan-96	Kaiser
39	D-10	Butullo Street, Dededo	415	391	-25		50	460	3540		351	384.58	170					Mar-68	Kaiser
40	D-11	Dededo Golf Course	430	393	-37		50	460	3540		226	389						Apr-69	Kaiser
41	D-12	Y- Seng Song Road	460	421	-42		50	460	3540		188	417.42	190					Oct-71	Astumbo
42	D-13	Swamp Road Dededo	455	395	-20		50	460	3540		172	397						Jan-71	Astumbo
43	D-14	Bio Path Dededo	372	319	-60		50	460	3450		200	315.25						Aug-73	Kaiser
44	D-15	Benavente Middle School	452	363	-49		50	460	3540		202	363						Nov-74	Kaiser
45	D-16	Sta. Monica Public Heath	387	329	-37		50	460	3540		161	320.1	170					Oct-79	Kaiser
45	D-17	Sta .Monica Pipe Line	350	301	-45		50	460	3450		199	297.5	170					Oct-79	Kaiser
47	D-18	Sta. Monica Public Heath	360	310	-50		50	460	3450		180	308.7						Nov-79	Kaiser
48	D-19	Swamp Road Dededo	438	391	-47		50	460	3450		227		150						Astumbo
49	D-20	Swamp Road Dededo	421	372	-47		50	460	3450		207		190						Astumbo
50	D-21	Swamp Road Dededo	420	373	-47		50	460	3450		157		190						Astumbo
51	D-22	Y- Seng Song Road	435	450	-5		50	460	3540		200	40.74	200						Astumbo
52	D-23	Y- Seng Song Road	434	434	-1		50	460	3450		150	40.05						Dec-96	Astumbo
53	D-24	Y- Seng Song Road	498	436	-51		50	460	3450		205	3.3	170						Astumbo
54	EX-5	Dededo Golf Course	424	386	-39		50	460	3450		254		240						Kaiser

Table 3-3 – GWA Production Data Report (continued)



GUAM WATERWORKS AUTHORITY DEEPWELLS DATA

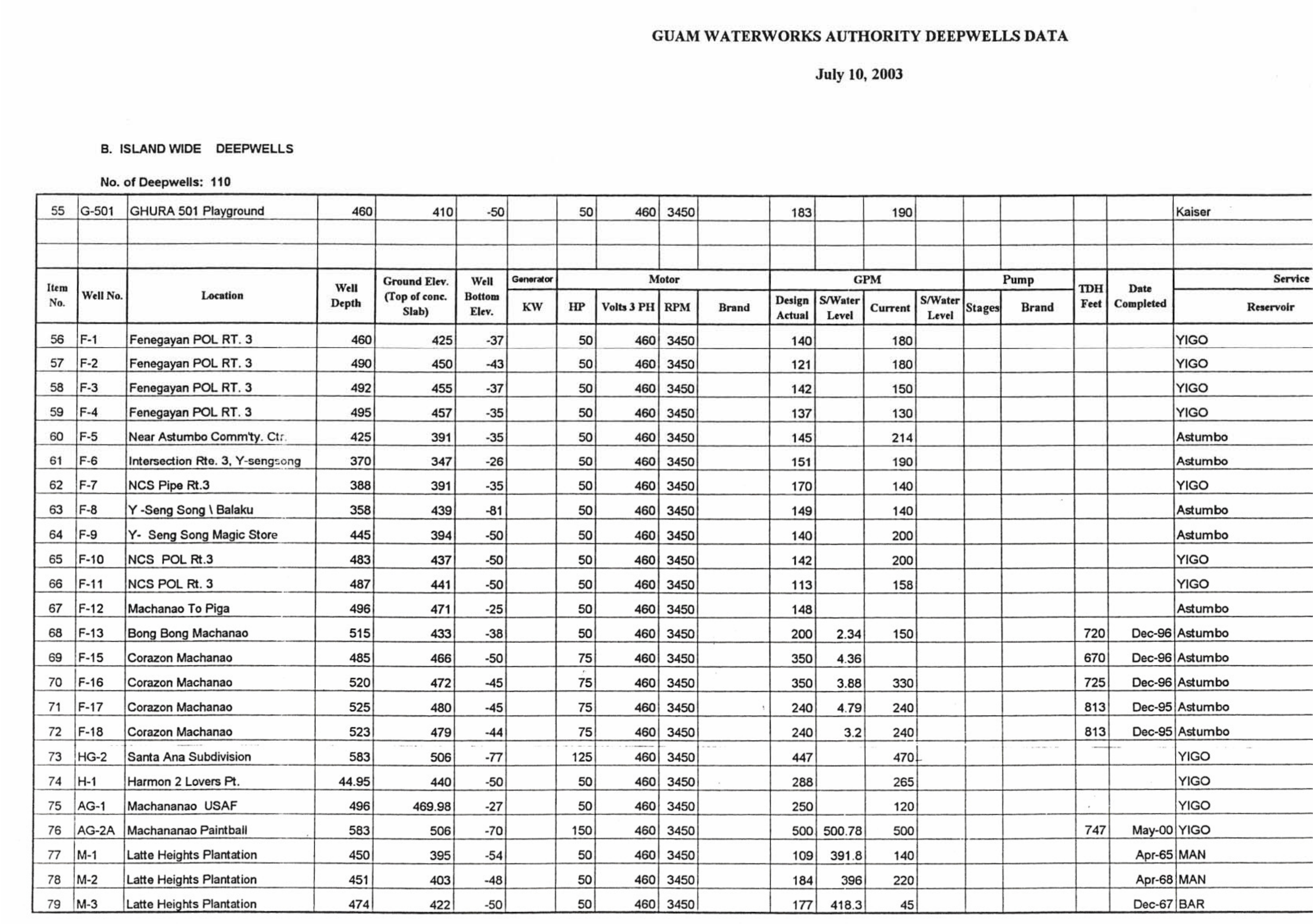
July 10, 2003

B. ISLAND WIDE DEEPWELLS

No. of Deepwells: 110

80	M-4	Latte Heights Plantation	472	442	-51		50	460	3450		138	418.3	160					Mar-68	BAR
81	M-5	Lemon China St. Latte Hts,	405	273	-132		50	460	3450		176	267.3	160					Feb-69	BAR
82	M-6	Villa Rosario Condo	406	326	-80		50	460	3450		168	320.6	160					Aug-69	BAR
83	M-7	Butter Cup Street, Macheche	340	489	-51		50	460	3450		175	284.2	175					Jun-70	BAR
Item No.	Well No.	Location	Well Depth	Ground Elev. (Top of conc. Slab)	Well Bottom Elev.	Generator	Motor				GPM				Pump		TDH Feet	Date Completed	Servic
						KW	HP	Volts 3 PH	RPM	Brand	Design Actual	S/Water Level	Current	S/Water Level	Stages	Brand			Reservoir
84	M-8	Carnation Rd Latte Hts.	538	486	-52		50	460	3450		158		170					Jun-70	MAN
85	M-9	Mangilao Rt. 15	489	449	-40		50	460	3450		162		160					Sep-70	MAN
86	M-12	Harmon Loop Road	380	272	-109		50	460	3450		114							Oct-73	TUMON
87	M-14	Liguan Terrace B-ball	315	274	-46		50	460	3450		239	269.6	220					Oct-74	TUMON
88	M-15	Lemon China St.Latte Hgts	347	296	-54		50	460	3450		172	292.09	190					May-82	BAR
89	M-17A	Back of Price Mart	476	431	-45		75	460	3450		200		210						Hyndai
90	M-17B	Back of Price Mart	521	480	-41		75	460	3450		354		160						Hyndai
91	M-18	Rt.15 Iglesia ni Cristo	245	208	-42		50	460	3450		325		220				460	Jun-97	TUMON
92	M-20A	Back of Price Mart	528	487	-38		75	460	3450		400	2.34	400				858	Dec-95	Hyndai
93	M-21	Airport Rd Next to Gas Sta.	395	355	-40		60	460	3450		250	5.25	180				670	Jul-99	Air-BAR
94	M-23	Carnation Lane Latte Hgts.	451	401	-50		60	460	3450		225	394.6	220				801	May-00	MAN
95	EX-11	Latte Heights.					50	460	3450		210		200						MAN
96	Y-1	Asardas Drive, Yigo	461	415	-46		50	460	3450		141		150						YIGO
97	Y-2	Asardas Drive, Yigo	465	415	-50		50	460	3450		161		161						YIGO
98	Y-3	Beside Mayor Office, Yigo	469	416	-53		50	460	3450		138								YIGO
99	Y-4A	Back of Ace Hardware	450	399	-52		50	460	3450				220						YIGO
100	Y-5	Simon Sanchez High School	483	433	-50		50	460	3450		143		160						YIGO
101	Y-6	Simon Sanchez High School	478	428	-50		50	460	3450		136		180						YIGO
102	Y-7	Gaynero Rd. Yigo Elem Sch.	476	412	-64		125	460	3450		514	409.5	550						YIGO
103	Y-9	Gaynero Rd. Yigo Elem Sch	455	402	-53		125	460	3450		472		472						YIGO
104	Y-10	Aga Blvd Ypaopao Est.	447	390	-56		50	460	3450		200	4.19	200				730	Jul-97	YIGO
105	Y-12	Batulo Street Dededo	430	406	-23		60	460	3450		235	8.59	235				718		Kaiser
106	Y-14	Back of Ace Hardware,Yigo	447	409	-39		100	460	3450		350	4.1	350				730	Jul-97	YIGO

Table 3-3 – GWA Production Data Report (continued)



GUAM WATERWORKS AUTHORITY DEEPWELLS DATA

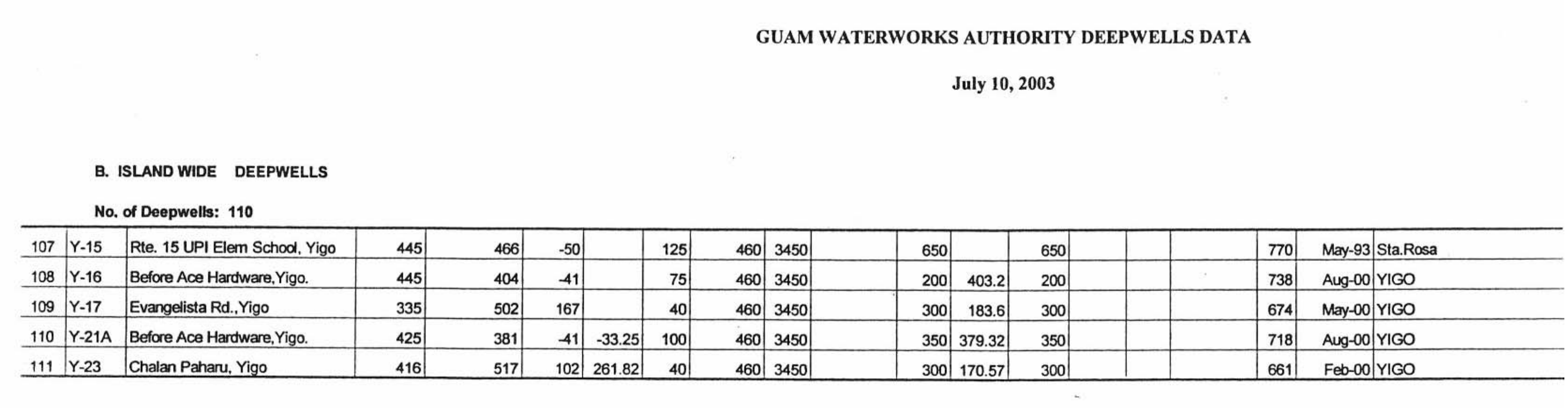
July 10, 2003

B. ISLAND WIDE DEEPWELLS

No. of Deepwells: 110

55	G-501	GHURA 501 Playground	460	410	-50		50	460	3450		183		190						Kaiser
Item No.	**Well No.**	**Location**	**Well Depth**	**Ground Elev. (Top of conc. Slab)**	**Well Bottom Elev.**	**Generator**	**Motor**				**GPM**				**Pump**		**TDH Feet**	**Date Completed**	**Service**
						KW	**HP**	**Volts 3 PH**	**RPM**	**Brand**	**Design Actual**	**S/Water Level**	**Current**	**S/Water Level**	**Stages**	**Brand**			**Reservoir**
56	F-1	Fenegayan POL RT. 3	460	425	-37		50	460	3450		140		180						YIGO
57	F-2	Fenegayan POL RT. 3	490	450	-43		50	460	3450		121		180						YIGO
58	F-3	Fenegayan POL RT. 3	492	455	-37		50	460	3450		142		150						YIGO
59	F-4	Fenegayan POL RT. 3	495	457	-35		50	460	3450		137		130						YIGO
60	F-5	Near Astumbo Comm'ty. Ctr.	425	391	-35		50	460	3450		145		214						Astumbo
61	F-6	Intersection Rte. 3, Y-sengsong	370	347	-26		50	460	3450		151		190						Astumbo
62	F-7	NCS Pipe Rt.3	388	391	-35		50	460	3450		170		140						YIGO
63	F-8	Y -Seng Song \ Balaku	358	439	-81		50	460	3450		149		140						Astumbo
64	F-9	Y- Seng Song Magic Store	445	394	-50		50	460	3450		140		200						Astumbo
65	F-10	NCS POL Rt.3	483	437	-50		50	460	3450		142		200						YIGO
66	F-11	NCS POL Rt. 3	487	441	-50		50	460	3450		113		158						YIGO
67	F-12	Machanao To Piga	496	471	-25		50	460	3450		148								Astumbo
68	F-13	Bong Bong Machanao	515	433	-38		50	460	3450		200	2.34	150				720	Dec-96	Astumbo
69	F-15	Corazon Machanao	485	466	-50		75	460	3450		350	4.36					670	Dec-96	Astumbo
70	F-16	Corazon Machanao	520	472	-45		75	460	3450		350	3.88	330				725	Dec-96	Astumbo
71	F-17	Corazon Machanao	525	480	-45		75	460	3450		240	4.79	240				813	Dec-95	Astumbo
72	F-18	Corazon Machanao	523	479	-44		75	460	3450		240	3.2	240				813	Dec-95	Astumbo
73	HG-2	Santa Ana Subdivision	583	506	-77		125	460	3450		447		470						YIGO
74	H-1	Harmon 2 Lovers Pt.	44.95	440	-50		50	460	3450		288		265						YIGO
75	AG-1	Machananao USAF	496	469.98	-27		50	460	3450		250		120						YIGO
76	AG-2A	Machananao Paintball	583	506	-70		150	460	3450		500	500.78	500				747	May-00	YIGO
77	M-1	Latte Heights Plantation	450	395	-54		50	460	3450		109	391.8	140					Apr-65	MAN
78	M-2	Latte Heights Plantation	451	403	-48		50	460	3450		184	396	220					Apr-68	MAN
79	M-3	Latte Heights Plantation	474	422	-50		50	460	3450		177	418.3	45					Dec-67	BAR

Table 3-3 – GWA Production Data Report (continued)



GUAM WATERWORKS AUTHORITY DEEPWELLS DATA

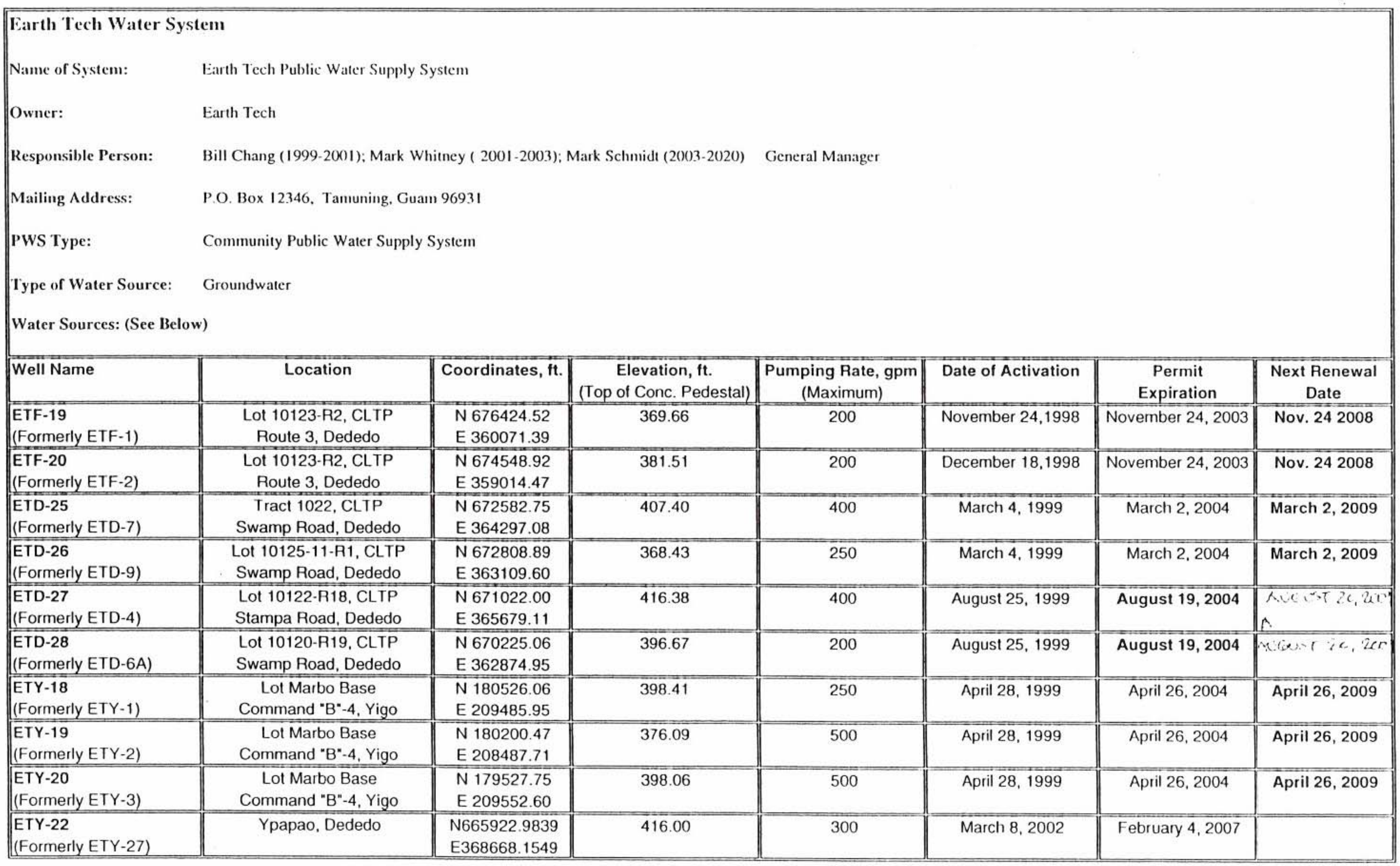
July 10, 2003

B. ISLAND WIDE DEEPWELLS

No. of Deepwells: 110

107	Y-15	Rte. 15 UPI Elem School, Yigo	445	466	-50		125	460	3450		650		650				770	May-93	Sta.Rosa
108	Y-16	Before Ace Hardware,Yigo.	445	404	-41		75	460	3450		200	403.2	200				738	Aug-00	YIGO
109	Y-17	Evangelista Rd.,Yigo	335	502	167		40	460	3450		300	183.6	300				674	May-00	YIGO
110	Y-21A	Before Ace Hardware,Yigo.	425	381	-41	-33.25	100	460	3450		350	379.32	350				718	Aug-00	YIGO
111	Y-23	Chalan Paharu, Yigo	416	517	102	261.82	40	460	3450		300	170.57	300				661	Feb-00	YIGO

Table 3-4 – Earth Tech Water System



Earth Tech Water System

Name of System:	Earth Tech Public Water Supply System
Owner:	Earth Tech
Responsible Person:	Bill Chang (1999-2001); Mark Whitney (2001-2003); Mark Schmidt (2003-2020) General Manager
Mailing Address:	P.O. Box 12346, Tamuning, Guam 96931
PWS Type:	Community Public Water Supply System
Type of Water Source:	Groundwater

Water Sources: (See Below)

Well Name	Location	Coordinates, ft.	Elevation, ft. (Top of Conc. Pedestal)	Pumping Rate, gpm (Maximum)	Date of Activation	Permit Expiration	Next Renewal Date
ETF-19 (Formerly ETF-1)	Lot 10123-R2, CLTP Route 3, Dededo	N 676424.52 E 360071.39	369.66	200	November 24,1998	November 24, 2003	**Nov. 24 2008**
ETF-20 (Formerly ETF-2)	Lot 10123-R2, CLTP Route 3, Dededo	N 674548.92 E 359014.47	381.51	200	December 18,1998	November 24, 2003	**Nov. 24 2008**
ETD-25 (Formerly ETD-7)	Tract 1022, CLTP Swamp Road, Dededo	N 672582.75 E 364297.08	407.40	400	March 4, 1999	March 2, 2004	**March 2, 2009**
ETD-26 (Formerly ETD-9)	Lot 10125-11-R1, CLTP Swamp Road, Dededo	N 672808.89 E 363109.60	368.43	250	March 4, 1999	March 2, 2004	**March 2, 2009**
ETD-27 (Formerly ETD-4)	Lot 10122-R18, CLTP Stampa Road, Dededo	N 671022.00 E 365679.11	416.38	400	August 25, 1999	**August 19, 2004**	AUGUST 26, 200
ETD-28 (Formerly ETD-6A)	Lot 10120-R19, CLTP Swamp Road, Dededo	N 670225.06 E 362874.95	396.67	200	August 25, 1999	**August 19, 2004**	AUGUST 26, 20
ETY-18 (Formerly ETY-1)	Lot Marbo Base Command "B"-4, Yigo	N 180526.06 E 209485.95	398.41	250	April 28, 1999	April 26, 2004	**April 26, 2009**
ETY-19 (Formerly ETY-2)	Lot Marbo Base Command "B"-4, Yigo	N 180200.47 E 208487.71	376.09	500	April 28, 1999	April 26, 2004	**April 26, 2009**
ETY-20 (Formerly ETY-3)	Lot Marbo Base Command "B"-4, Yigo	N 179527.75 E 209552.60	398.06	500	April 28, 1999	April 26, 2004	**April 26, 2009**
ETY-22 (Formerly ETY-27)	Ypapao, Dededo	N665922.9839 E368668.1549	416.00	300	March 8, 2002	February 4, 2007	

3.5.1 Northern Guam

The groundwater in northern Guam is the most voluminous supply source for the island's population and its activities. Pumpage has steadily increased since large-scale exploitation began in the 1960s. Since 1990, total pumpage has risen from about 31 mgd[2] when the island's population was 133,000 to about 46 mgd in 2003. The common statement that just 26 to 31 mgd is pumped must be erroneous because it is likely based only on GWA production. The data sources for the higher estimate of 46 mgd are the compilation of records included in a Master's Thesis by M.Q. McDonald (University of Guam–WERI (2001)[8]; the GWA Deep Well data printout of July 2003 (see Table 3-3); and Earth Tech records.

A comparison of the GWA and McDonald data sets, by Aquifer Sectors and Aquifer Systems, is presented in Table 3-5. All pumpage (as mgd) is included. The Earth Tech and Navy data are summed with the original McDonald and GWA data, respectively.

Table 3-5 – GWA and McDonald Data Set Comparison

Sector	Aquifer System	McDonald	GWA
Agana Aquifer Sector	Ordot	4.95	4.84
	Mongmong	1.50	1.12
	Barrigada	.83	.82
	Total	7.28	6.78
Fadian Aquifer Sector	Sabana Maagas	2.97	2.79
	Huchunao	1.22	1.23
	Total	4.19	4.02
Mangilao Aquifer Sector	Sasajayan	1.54	1.57
	Pagat	0.0	0.0
	Total	1.54	1.57
Pati Aquifer Sector	Mt. Santa Rosa	.81	.94
	Andersen	0.0	0.0
	Total	.81	.94
Tarague Aquifer Sector	Agafo Gumas	1.94	2.07
	Northwest Field	0.0	0.0
	Total	1.94	2.07
Finagayan Aquifer Sector	Guagon	2.75	3.07
	Haputo	4.74	4.65
	Total	7.49	7.72
Yigo-Tumon Aquifer Sector	Yigo	4.51	5.12
	Tumon	15.04	14.13
	Total	19.55	19.25
Total		*42.8*	*42.35*
Air Force		2.5	2.5
Private		1.0	1.0
TOTAL		*46.3*	*45.85*

Groundwater withdrawals in the northern aquifers already surpass the early estimates of sustainable yield and are approaching the most recent estimates of about 70 mgd. Not all of this total estimate is available to GWA, however, because a significant portion is located on federal land, in particular the Andersen Air Base complex. The NGLS sustainable yield available to GWA was estimated at 60 mgd.

The total average draft of nearly 50 mgd satisfies a demand which is, at most, 35 mgd. The difference is lost in the distribution network by leakage, most of which presumably returns to the aquifers. If so, the net loss to the aquifers by pumping may be closer to 35 mgd than to 50 mgd. Nevertheless, a prime goal for GWA is to reduce system leakage. Pumping costs would be reduced, and mismanagement of the aquifers would be avoided.

The sustainable yield given in the NGLS for each Management Zone was adjusted in the Barrett Consulting Group–Mink study[2] for each Aquifer System. The NGLS estimate of 60 mgd for northern Guam was increased to 75 mgd, but 15 mgd of this amount was assigned to federal property and thus considered not available to GWA. This leaves an accessible sustainable yield of 60 mgd, the same amount proposed in the NGLS. Table 3-6 summarizes the revised sustainable yield and the portions available to GWA, together with the current draft and the unused sustainable yield, for each Aquifer System (all values in mgd).

Table 3-6 – Summary of Revised Sustainable Yields (SY) in MGD

Sector	System	Total SY	Non-Fed SY	Draft	Unused Non-Fed SY
Agana Aquifer	Ordot	7.5	7.5	4.84	2.7
	Mongmong	2.8	2.8	1.12	1.7
	Barrigada	3	3	.82	2.2
	Total	13.3	13.3	6.78	6.6
Fadian Aquifer	Sabana Maagas	3	3	2.79	.2
	Huchunao	4.2	4.2	1.23	3
	Total	7.2	7.2	4.02	3.2
Mangilao Aquifer	Sasajyan	3.3	3.3	1.57	1.7
	Pagat	3.3	0	0	0
	Total	6.6	3.3	1.57	1.7
Pati Aquifer	Mt. Santa Rosa	2.3	2.3	.94	1.4
	Andersen	7.5	0	0	0
	Total	9.8	2.3	.94	1.4
Tarague Aquifer	Agafo Gumas	5	5	2.07	2.9
	Northwest Field	7	0	0	0
	Total	12	5	2.07	2.9
Finegayan Aquifer	Gugagon	5	5	3.07	1.9
	Haputo	6.6	4	4.65	-.65
	Total	11.6	9	7.72	1.25
Yigo-Tumon Aquifer	Yigo	6.4	6.4	5.12	1.3
	Tumon	13.6	13.6	14.13	-.59
	Total	20	20	19.25	.71
Total		*80.5*	*60.1*	*42.35*	*17.76*
Miscellaneous Draft	Air Force + Private			4.5	
TOTAL				*47*	*18*

The total of unused, nonfederal sustainable yield accessible by GWA is about 18 mgd. This value should be treated as a simple estimate that probably underestimates the remaining sustainable yield developable by optimal means. Not all of the remaining sustainable yield will be easy to access, however.

The first well, designated Well D-1, was simple in design and fitted with a pump to provide 200 gpm (Figure 3-2). It became the standard design used throughout northern Guam. Recognition that parabasal groundwater could sustain higher pump rates led to the installation of pump capacities as high as 755 gpm (Well A-30, Agana Swamp, Mongmong Aquifer System). Most of the wells pump an average of 150 to 200 gpm, and the parabasal wells pump 200 to 700 gpm. Tables 3-3 and 3-4 list the GWA wells (as of July 2003) and the former Earth Tech wells, respectively.

Should GWA decide to further exploit the upgradient areas of the parabasal aquifer, a monitoring network needs to be in place to monitor chloride concentrations in the adjacent basal sections of the aquifer. In addition, a comprehensive continuous data collection system must be in place to measure actual lens geometry response to present pumping conditions, and modified pumping schemes must be designed to maximize yield while preserving freshwater integrity. This monitoring effort would be well coordinated among GEPA, GWA and WERI.

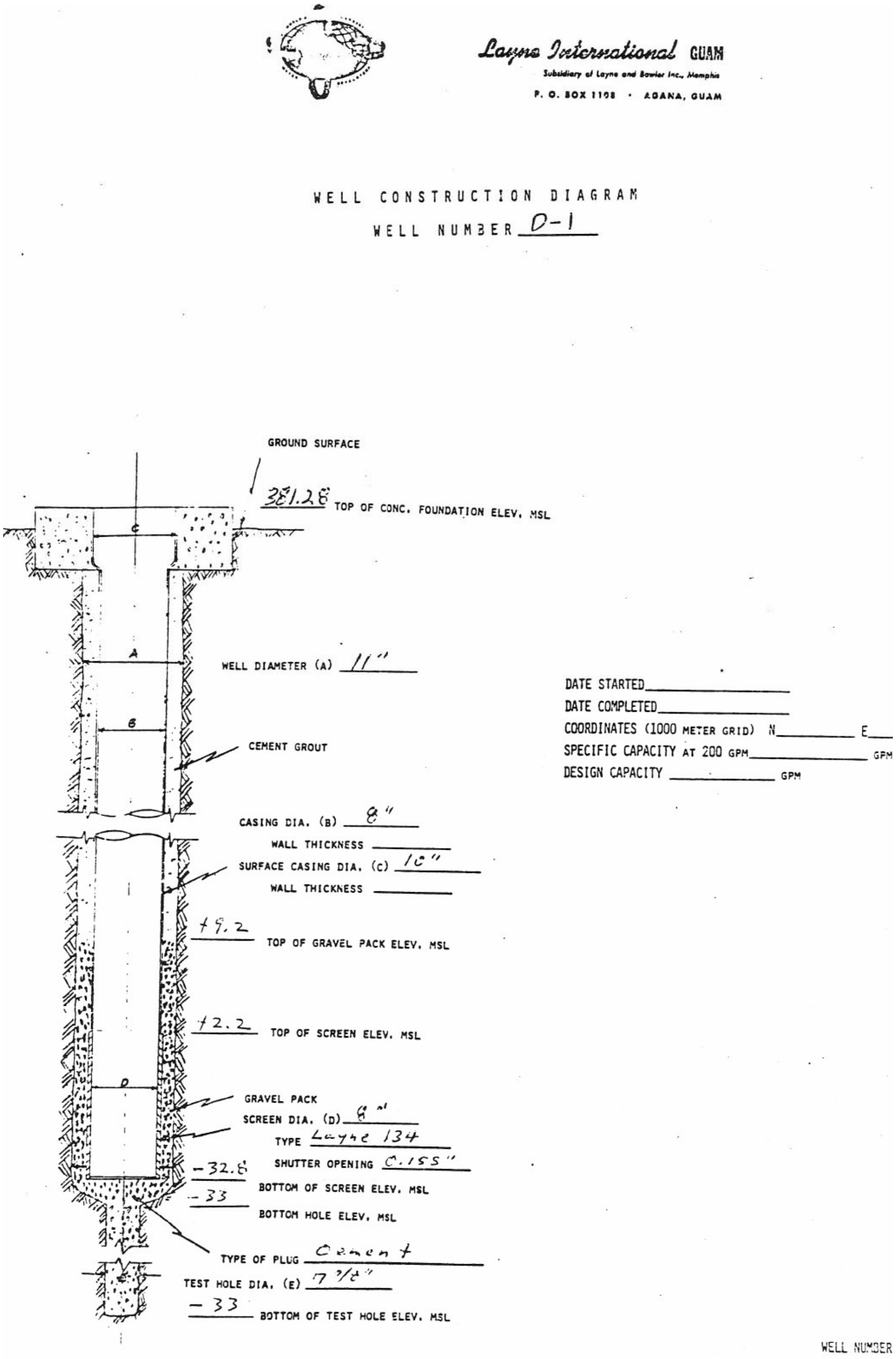
3.5.2 Southern Guam

Both groundwater and surface water are developed in southern Guam, but surface water offers the most voluminous source of supply. Surface water is already extensively exploited in the Fena Reservoir system and, to a lesser extent, as a diversion from the Ugum River. Numerous wells have been drilled, but only one—at the old GORCO Refinery—can be pumped at a rate similar to the typical northern Guam well (i.e., 150 to 200 gpm). The importance of the surface water opportunities in southern Guam will increase as island population continues to grow. Groundwater development will always be limited, but it may help in supplying local demands.

3.5.2.1 Surface Water

The surface water resources of southern Guam and proposals for developing them are thoroughly discussed in the surface water development study by the Barrett Consulting Group[7]. The study concluded that although a dam/reservoir on several rivers would provide the greatest reliable yield, the most practical way to capture stream flow for use is by means of diversions. Tables 3-7 and 3-8, taken from the Barrett report, summarize the expectation of reliable draft for potential reservoir sites and for diversion. Figures 3-3 and 3-4, also from the Barrett report, show the locations of the potential reservoirs and diversions.

Figure 3-2 – Well Number D-1



Layne International GUAM
Subsidiary of Layne and Bowler Inc., Memphis
P. O. BOX 1198 · AGANA, GUAM

WELL CONSTRUCTION DIAGRAM
WELL NUMBER D-1

GROUND SURFACE

381.28 TOP OF CONC. FOUNDATION ELEV. MSL

WELL DIAMETER (A) 11"

CEMENT GROUT

CASING DIA. (B) 8"
WALL THICKNESS ______
SURFACE CASING DIA. (C) 10"
WALL THICKNESS ______

+9.2 TOP OF GRAVEL PACK ELEV. MSL

+2.2 TOP OF SCREEN ELEV. MSL

GRAVEL PACK
SCREEN DIA. (D) 8"
TYPE Layne 134
SHUTTER OPENING 0.155"
-32.8 BOTTOM OF SCREEN ELEV. MSL
-33 BOTTOM HOLE ELEV. MSL

TYPE OF PLUG Cement
TEST HOLE DIA. (E) 7 7/8"
-33 BOTTOM OF TEST HOLE ELEV. MSL

DATE STARTED ______
DATE COMPLETED ______
COORDINATES (1000 METER GRID) N ______ E ______
SPECIFIC CAPACITY AT 200 GPM ______ GPM
DESIGN CAPACITY ______ GPM

WELL NUMBER

Table 3-7 – Summary of Potential Reservoir Sites

Reservoir	Available Draft (mgd)	Reservoir Volume (ac-ft)	Reservoir[1] Depth at Dam (ft)	Minimum Down-stream Base Flow (cfs)	Shortage Index	Remarks
Cetti	1.0	854	46	0.50	0.04	
Fena [2]	4.0	10,740	20	0.00	0.03	Raise existing dam
Finile	0.15	88	50	0.23	NF[3]	
Geus	0.15	90	60	0.13	NF	Replace existing dam
Inarajan	5.9	4,090	72	2.37	0.17	
La Sa Fua	0.5	96	35	0.74	NF	
Lonfit	3.3	2,270	78	0.31	0.00	
Pago	9.6	7,010	50	0.93	NF	
Sigua	5.4	5,200	78	0.45	0.02	
Tarzan	7.5	4,915	76	0.83	0.02	
Tinago	1.8	2,350	42	0.19	0.02	
Ugum	11.0	5,010	68	5.17	0.02	
Umatac	0.15	101	40	0.2	NF	Supplemented by La Sa Fua River
Windward Hills	2.1	1,215	60	1.11	0.02	Supplemented by Ylig River
Ylig	11.4	7,720	70	1.26	0.02	

[1] Does not include sediment or storm flow volume.
[2] Values show increase above existing conditions.
[3] Determined not feasible (NF).

Table 3-8 – Summary of Potential Diversion Sites

Diversion	Available Draft (mgd)	Minimum Down-stream Base Flow (cfs)	Shortage Index	Remarks
Cetti	0.15	0.50	4.74	
Finile	0.15	0.23	7.86	
Geus	0.15	0.13	6.16	Rehabilitate existing facility
Inarajan	2.00	2.37	9.68	
La Sa Fua	0.15	0.2	0.39	
Lonfit	0.15	0.31	4.82	
Sigua	0.15	0.45	3.66	
Talofofo	2.00	2.95	4.71	
Tarzan	1.0	0.83	5.57	
Tinago	0.15	10.19	4.81	
Tolaeyuus	1.0	1.10	3.52	
Tolaeyuus/Fena	0.9	1.10	0.05	Supplement existing Fena Reservoir
Umatac/La Sa Fua	0.30	0.20	2.96	Supplement existing Umatac Facility
Ylig	2.0	1.48	5.24	Rehabilitate abandoned plant
Janum	1.00	0.00		Maui-type tunnel intercept

Figure 3-3 – Potential Reservoir Sites

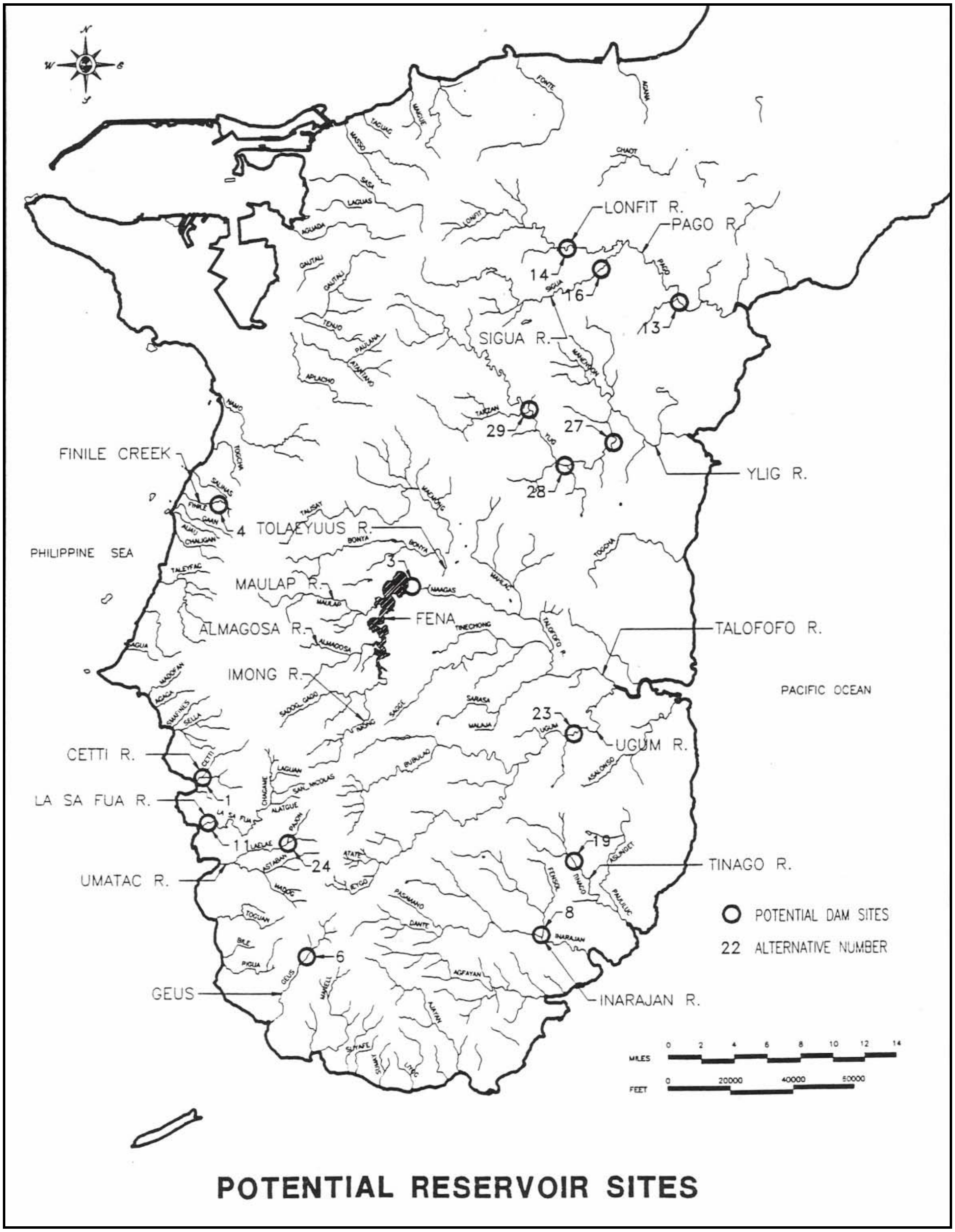
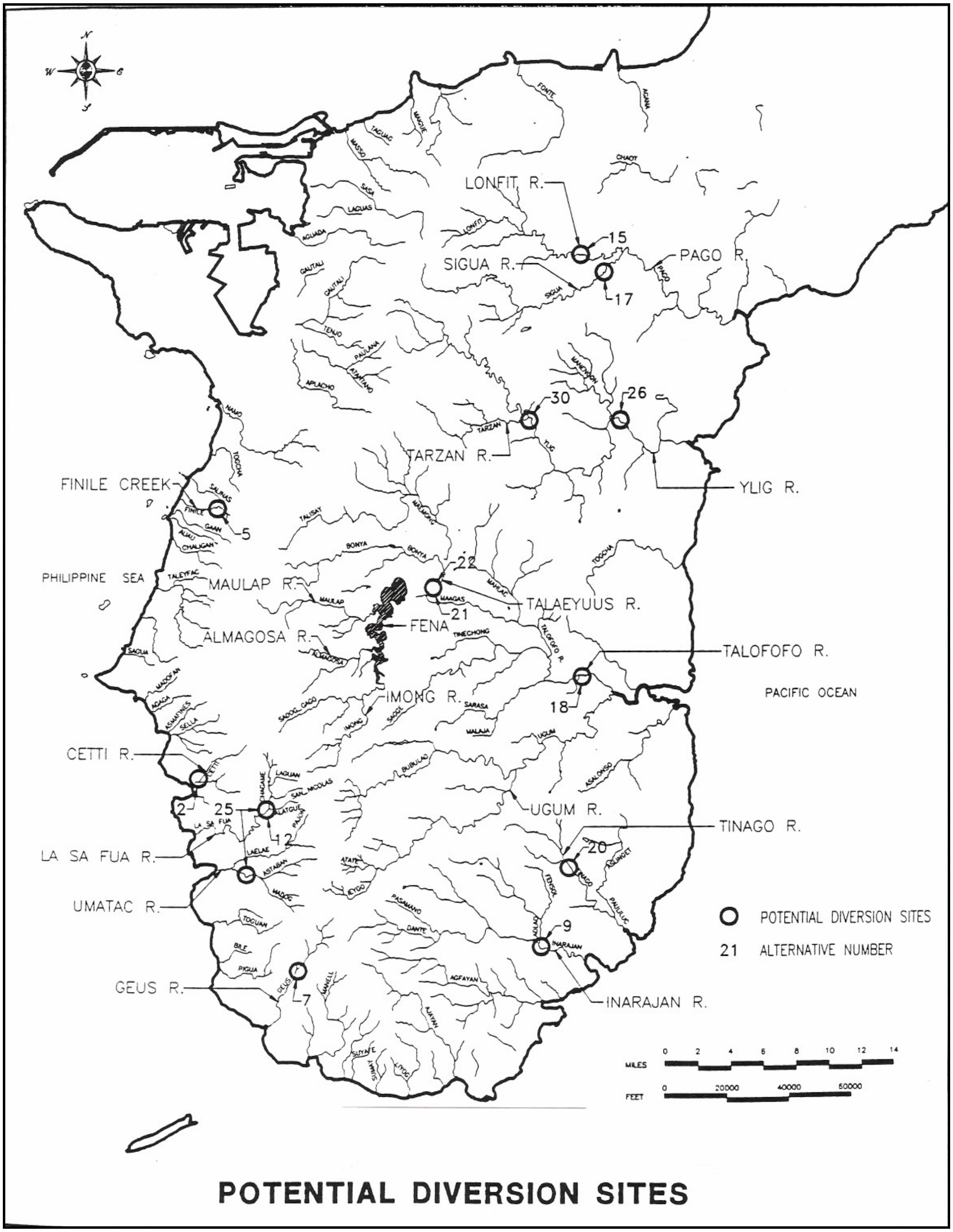


Figure 3-4 – Potential Diversion Sites



At present one large-scale dam/reservoir, a moderate river diversion and several springs constitute water development in the South. The dam/reservoir is the U.S. Navy Fena system, completed in 1952. Its average yield is about 11.5 mgd, of which about 4 mgd is sold to GWA. The Fena Reservoir is large, having a surface area of 196 acres, a length of 1.9 miles, a maximum width of 0.4 mile and a maximum depth of 66 feet near the spillway. The dam is 125 feet high and 1,500 feet long. Surface runoff, plus some spring flow from a watershed area of 6 square miles, drains to the reservoir, whose storage volume is approximately 7,500 acre-feet. The water is treated before it is distributed for potable use.

The Ugum River diversion, a GWA project, was put on line in 1993 to supply about 2 mgd for the Malojloj-Inarajan region. The water is treated and then it is delivered to a 1-million-gallon steel reservoir for distribution. The Ugum project has been a success and is a model for future diversion projects.

Several springs provide water for communities in the South. Asan Spring south of Hagatna has an estimated reliable flow of 298 gpm. Santa Rita Spring near Agat yields about 165 gpm. Further south, the village of Merizo is supplied by flow in the Geus River (about 53 gpm) and Siligin Spring (about 10 gpm). Umatac depends on Laelae Spring, also called Piga Spring with a flow of about 37 gpm.

The role of surface water as a supply source may increase in the future as the population demand approaches the sustainable yield of the northern Guam aquifers.

3.5.2.2 Groundwater

Numerous attempts have been made to extract groundwater from both the limestone and volcanic aquifers in the South. By and large, the efforts have not yielded sufficient water to justify extensive development of the resources. Table 3-9 is an inventory of wells drilled in southern Guam since 1965. Approximately 50 test wells were drilled, but only GORCO exceeded a pump rate of 100 gpm for more than several hours. Table 3-10 lists wells drilled in limestone aquifers, and Table 3-11 lists those drilled in volcanic aquifers since 1965.

None of the Southern wells currently serves potable demand. Before the installation of the Ugum diversion, a limestone well in Malojloj was a source of supply, and tests of at least one other well in the area suggests that a reliable groundwater resource exists. The unusually productive well in the volcanics at the former GORCO refinery was never connected to a distribution system. It may be a source of potable water for local demand in the future. Many of the other volcanic wells were drilled to supply water for irrigation of golf courses. Some were successful, others were abandoned as failures.

Test wells were drilled for PUAG in Ylig valley, the Asalonso coastal plain, Malojloj and Ipan. Several of the Ylig wells were proved to be potential sources, as were the Asalonso wells and two of the Malojloj wells. The Ipan wells yielded high-chloride water.

Table 3-9 – Inventory of Wells Drilled in Southern Guam Since 1965

Location	Sponsor	Number	Aquifer	Pump Rate (gpm)	Comments
Ylig	GovGuam	5	Limestone	55-105	Abandoned
Togcha	Private	11	Limestone	25	Inactive
Talofofo	GovGuam	1	Limestone	115	Inactive
Asalonso	GovGuam	2	Limestone	60-80	Inactive
Ipan	GovGuam	1	Limestone	60	Failure
Malojloj	GovGuam	7	Volc/Lime	68-170	3 Fail. Inactive
Lonfit	Private	3	Volcanics	10-55	Failures
Pulantat	Private	5	Volcanics	35-65	Abandoned
RCA	Private	1	Volcanics	20	In Use
Leo Palace	Private	1	Volcanics	30	Unknown
Cascada	Private	4	Volcanics	30-60	Abandoned
Talofofo	Private	6	Volcanics	25-90	Golf course use
GORCO	Private	1	Volc/Lime	218	Inactive
Windward Hills	Private	3	Volcanics		Failure
Dandan	GovGuam	1	Volcanics		Failure
Geus River	GovGuam		Volcanics		Failure

Table 3-10 – Wells Drilled in the Limestones of Southern Guam Since 1965

Location	Name	Ground Elev. (ft)	Depth (ft)	Head Elev. (ft)	Chloride (mg/L)	Pump (gpm)	Draw down (ft)	Hyd. Con ft/day	Note
Ylig (GovGuam)	YL-1	21	105	8.5		55	12	23	
	YL-2	32	150	6.0	<100	55	17		
	YL-3	24	140	6.0	<100	55	10	15	(1)
	YL-4	20	94	9	206	95	16		
	YL-5	22	130	9		105	14		
Togcha (Golf Course/Country Club)	TG1-11	100	154	~3	100	25			(2)
Talofofo (GovGuam)	T-1			18	<250	115		60	(3)
Asalonso (GovGuam)	AL-1	43	70	4.3	30	60	12		
	AL-2	38	70	4.5	141	82	14		
Ipan (GovGuam)	IP-1	105	117	1	625	60	2		
Malojloj (GovGuam)	ML-1	257			35			60	(4)
	ML-2	257			35			70	
	ML-3	315				170		37	
	ML-4	340	365	77		<5	98		
	ML-5	320	267	215		68	65		
	ML-6	280	220	83					
	ML-7								

Column Headings:

Location: general area of drilling. Sponsoring entity is in parentheses.
Name: Identification of well at time of drilling.
Ground Elev. (ft): ground elevation above mean sea level.
Depth (ft): depth of drilling.
Head Elev. (ft): elevation of water table above sea level.
Chloride mg/L: chloride content in milligrams per liter.
Pump gpm: Test pumping rate in gallons per minute.
Drawdown (ft): water table drawdown during pumping.
Hyd.Con. (ft/day): Local hydraulic conductivity derived from pump test data.

Notes:

(1) YL-3 was completed for production but is now lost.
(2) For the golf course at Togcha 10 successful wells were drilled. They are now inactive because the golf course now uses GWA water.
(3) This well was drilled post-World War II, used by the Military, abandoned, then reclaimed by PUAG and provided water for several years. It is now inactive.

(4) ML-1, ML-2, ML-3 and ML-5 were successful. The others were failures.

Table 3-11 – Wells Drilled in the Volcanics of Southern Guam Since 1965

Location	Name	Ground Elev. (ft)	Depth (ft)	Head Elev. (ft)	Chloride (mg/L)	Pump (gpm)	Draw down (ft)	Hyd. Con ft/day	Note
Lonfit (Private)	1	270	270	245		55	163	.022	(1)
	2	280	385	218		10	139		
	3	330	380	284		23	170	.05	
Pulantat (Private)	W-1	236	305	210	25	67	32	.55	(2)
	W-2	232	310	99	20	60	33	.54	
	W-3	223	300	205	25	60	34	.57	
	W-4	225	285	206	48	35	6.3		
	Y-1	225	300	110	22				
(RCA)		362	360	342		20	250	.04	
Leo Palace (Private)	1	427	585	367	23	30	100		
Cascada (Private)	1				2475	30	100	.27	(3)
	2	410		Dry					
	3	112		69	14	60	19	1.6	
	4			86		40	50	1.6	
Talofofo (Private)	E-1					90	100		(4)
	E-2					48	161	.61	
	E-3					25	100		
	E-4							.15	
	E-5								
	E-6								
GORCO (Private)		134	200			218	118	2.6	(5)
Windward Hills (Private)	Y-1, Y-2, Y-3								(6)
Dandan (GovGuam)		242						.034	
Geus River (GovGuam)		169	375			Bail dry			

Column Headings:
Location: general area of drilling. Sponsoring entity in parentheses.
Name: Identification of well at time of drilling.
Ground Elev. (ft): ground elevation above mean sea level.
Depth (ft): depth of drilling.
Head Elev. (ft): elevation of water table above sea level.
Chloride mg/L: chloride content in milligrams per liter.
Pump gpm: Test pumping rate in gallons per minute.
Drawdown (ft): water table drawdown during pumping.
Hyd.Con. ft/day: Local hydraulic conductivity derived from pump test data.

Notes:
(1) Drilled for Lonfit New Town, but project not undertaken.
(2) Drilled for First Green Golf Course, which was not developed.
(3) Test wells for a golf course, which was not developed. Water from Well 1 is unusually warm and saline.
(4) Active wells for Talofofo Golf Course.
(5) The GORCO well may derive some of its water from limestone. The well served the refinery for several years, but is now inactive.
(6) Test borings for a golf course, which was not developed.

3.6 Status of the Water Resources

Several instances of groundwater contamination have been noted in the northern aquifers. In northern Guam, increases in salinity in some wells imply saltwater intrusion. A number of wells have had to be abandoned, and others may have to be reconfigured. Permanent loss of head over time is not evident, even in the Tumon Aquifer System, which has been especially exploited. In southern Guam, the only water development of consequence besides the Fena Reservoir complex is GWA's Ugum River diversion. As the population grows and the demand on the northern Guam aquifers increase, additional surface water development opportunities in the South will have to be explored

3.6.1 Northern Guam

A recent study, Chloride History and Trends of Water Production Wells in the Northern Guam Lens Aquifer, by M.Q. McDonald and J.W. Jenson, 2003[9] (WERI TR 98) examined and commented on the changes in salinity, expressed as chloride (Cl) content in milligrams per liter (mg/L), of 128 wells in northern Guam since the 1970s. The chloride content has increased in 64 wells: in 21 wells it now exceeds 150 mg/L, and in eight it exceeds the suggested maximum concentration level of 250 mg/L. WERI TR 98 categorizes salinities as follows:

- Acceptable at less than 150 mg/L with no upward trend
- Acceptable but suspect, upward trend
- Unacceptable but remediable, greater than 150 mg/L
- Unacceptable and irremediable, greater than 150 mg/L

The analyses of the change in salinity by WERI TR 98 affirm that salinity of basal groundwater is primarily a function of well depth and rate of draft. As a general rule, which is consistent with expectations, the deeper the well boring and the higher the rate of draft, the greater will be salinity as a result of seawater intrusion caused by upconing. McDonald and Jenson's work brings together in a single volume data that appear in a variety of separate reports, such as those of the EPA, the U.S. Geological Survey (USGS) and various consultants. Note, additional chloride level data for 1996 to 2005 are presented in this volume in Chapter 1, Tables 1-4 and 1-5.

The following discussions about the status of groundwater in the Aquifer Sectors incorporate much of McDonald and Jensons' work. The salinity benchmarks listed in that report are basically the same as those previously employed: parabasal, less than 30 mg/L; boundary between parabasal and basal, 30 to 70 mg/L; normal basal not seriously impacted by seawater intrusion, 70 to 150 mg/L; and basal affected by upcoming, greater than 150 mg/L. Heads associated with the limestone aquifer types, as stated in the NGLS, are: parabasal, greater than five feet; basal (clean limestone), less than four feet; and basal (argillaceous limestone), less than eight feet.

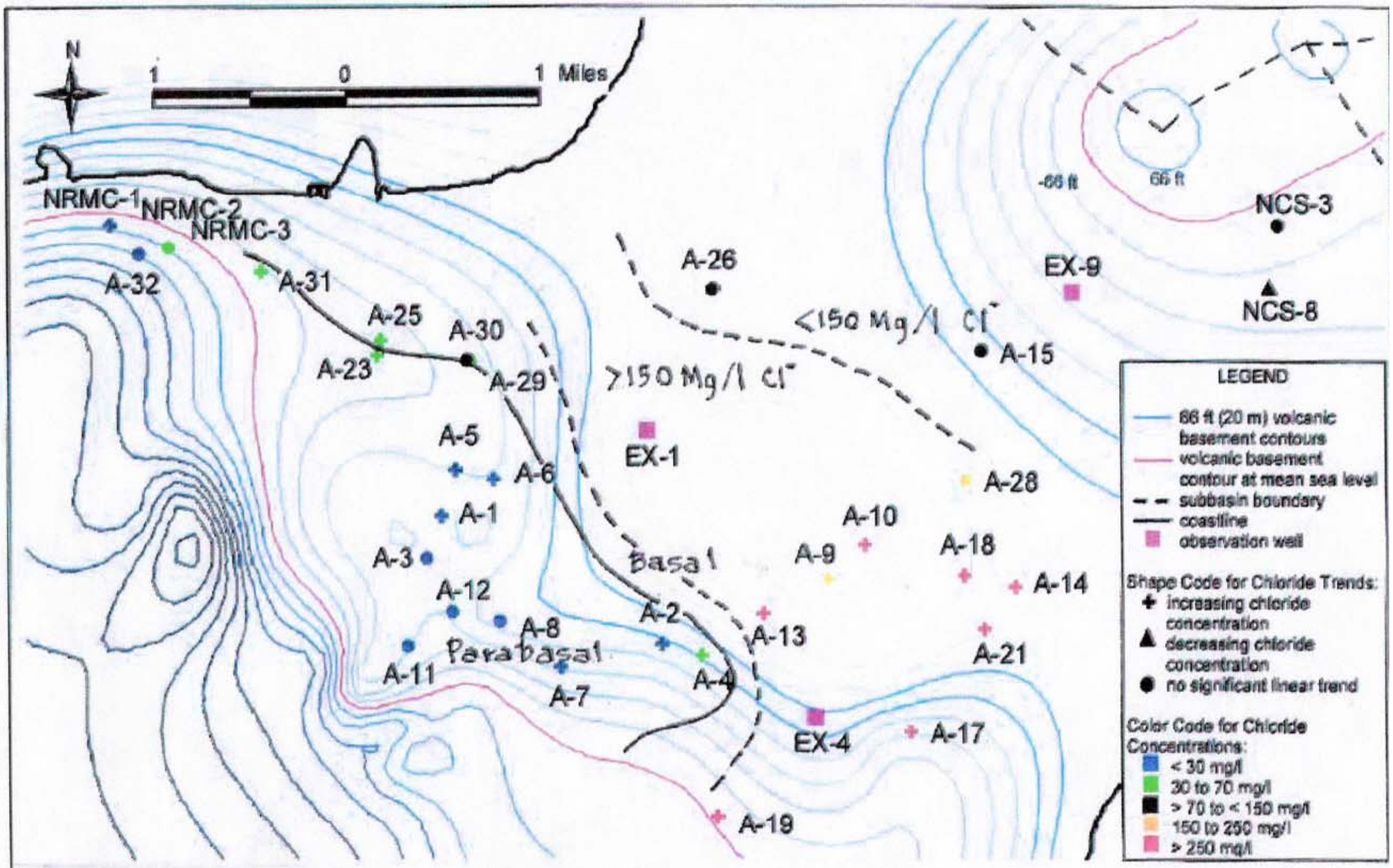
3.6.1.1 Groundwater Status by Aquifer Sectors

Three Aquifer Sectors yield most of the groundwater for GWA. The most important is the Yigo-Tumon Sector, followed by the Finegayan and Agana Sectors. Each of these sectors is already heavily exploited.

The Agana Sector serves much of the southern half of Northern Guam. Its Ordot Aquifer System is especially important because the resource is parabasal and, therefore, free of seawater intrusion. The basal groundwater has already been affected by seawater intrusion, and many A series wells produce water with greater than 150 mg/L, and some exceed 250 mg/L. The probability of successfully withdrawing additional potable water from the basal wells is poor at best, but production from the parabasal resource can be expanded.

Figure 3-5 (from WERI TR 98, amended) depicts the parabasal and basal portions of the Aquifer Sector. The wells near the old Navy pump station at Agana Springs are on the boundary between basal and parabasal conditions.

Figure 3-5 – Agana Sector



AGANA Sector production wells, observation wells, volcanic basement contours, and average chloride concentrations from 1990 to 1999. Chloride trends are based on regression analysis over a well's complete chloride sampling record.

The Yigo-Tumon Aquifer Sector is the most productive potable groundwater provider in the island. Average head at 3.5 feet has not varied significantly; depth to the 50% isochlor has been virtually invariant; and in most wells the salinity of the water has not risen significantly.

A large region, the Yigo Aquifer System contains parabasal aquifers. Down gradient toward Tumon, where basal conditions prevail, the flow of groundwater is very high. Figure 3-6 (from WERI TR 98, amended) illustrates the trough-like subsurface topography in which the groundwater flows toward Tumon Bay. In the parabasal region and at the boundary between the parabasal and basal regions, wells of greater than 200-gpm capacity successfully yield low salinity water.

The Yigo-Tumon Aquifer Sector, because of its productivity and its reasonably well-defined boundaries, has been numerically modeled by WERI and will be the subject of more advanced models. Its importance for the supply of potable water to northern Guam cannot be overemphasized. Although it is a robust hydrogeological system, it may be at the point of excessive development. The future WERI models should signal whether additional groundwater can be withdrawn without affecting either the quality or quantity of water pumped.

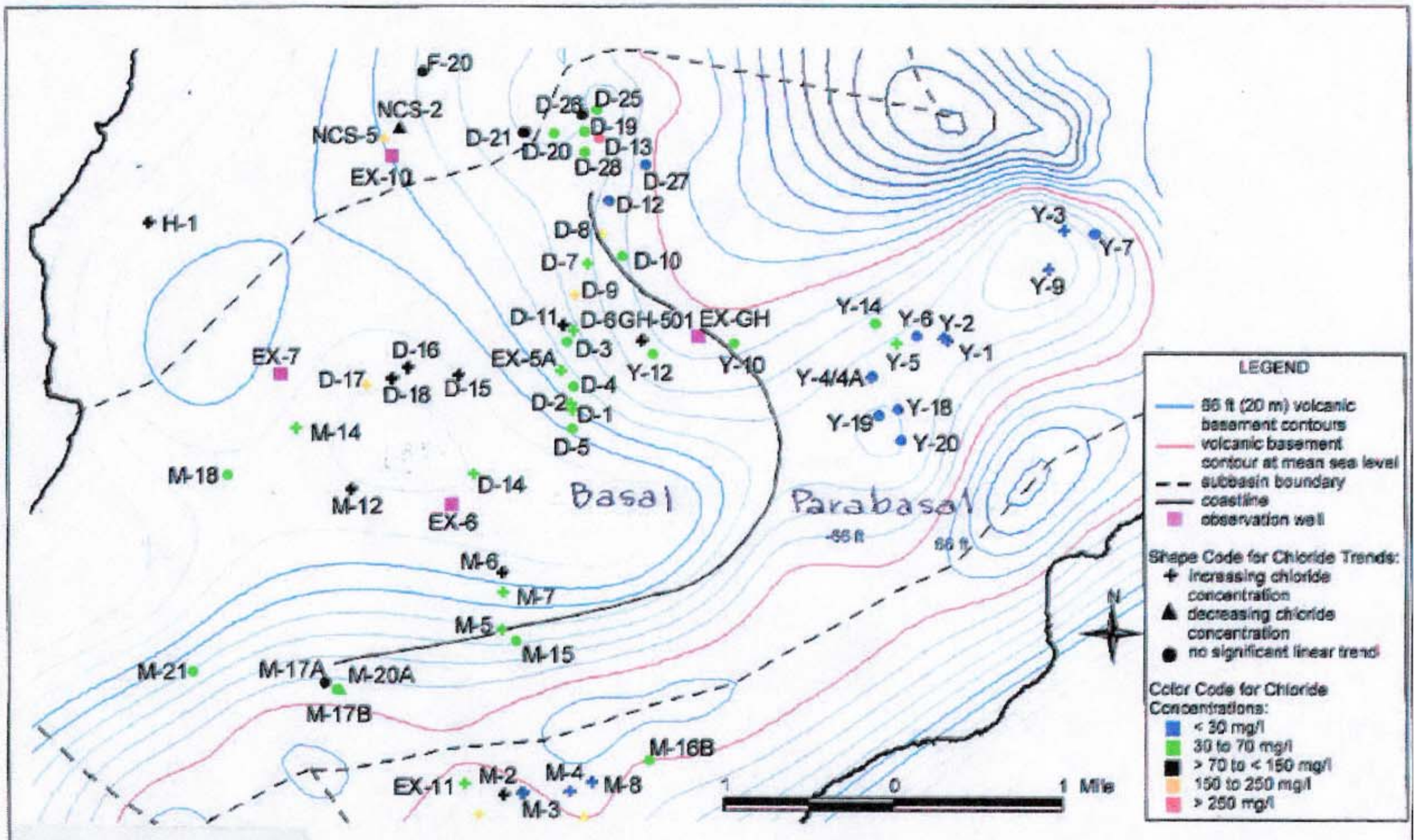
The Finegayan Aquifer Sector is also crucial to the water supply of Guam. The parabasal and the transitional basal-to-parabasal regions include 13 wells yielding water with less than 70 mg/L chloride (Figure 3-7, from WERI TR 98, amended). Thirteen basal wells have retained their low salinity, while six have risen above 150 mg/L.

In the Mangilao Aquifer Sector three parabasal and two near-parabasal wells contribute potable water to GWA. Several basal wells also are active (Figure 3-8, WERI TR 98, amended). Additional water having less than 150 mg/L chloride will be difficult to extract from the sector.

In the Pati Aquifer Sector, one parabasal well produces water for GWA. One parabasal well in the Agafo Gumas Aquifer System of the Tarague Aquifer Sector also contributes low salinity water. In both sectors, additional low salinity water can be developed, but much of the area of the sectors is within federal lands.

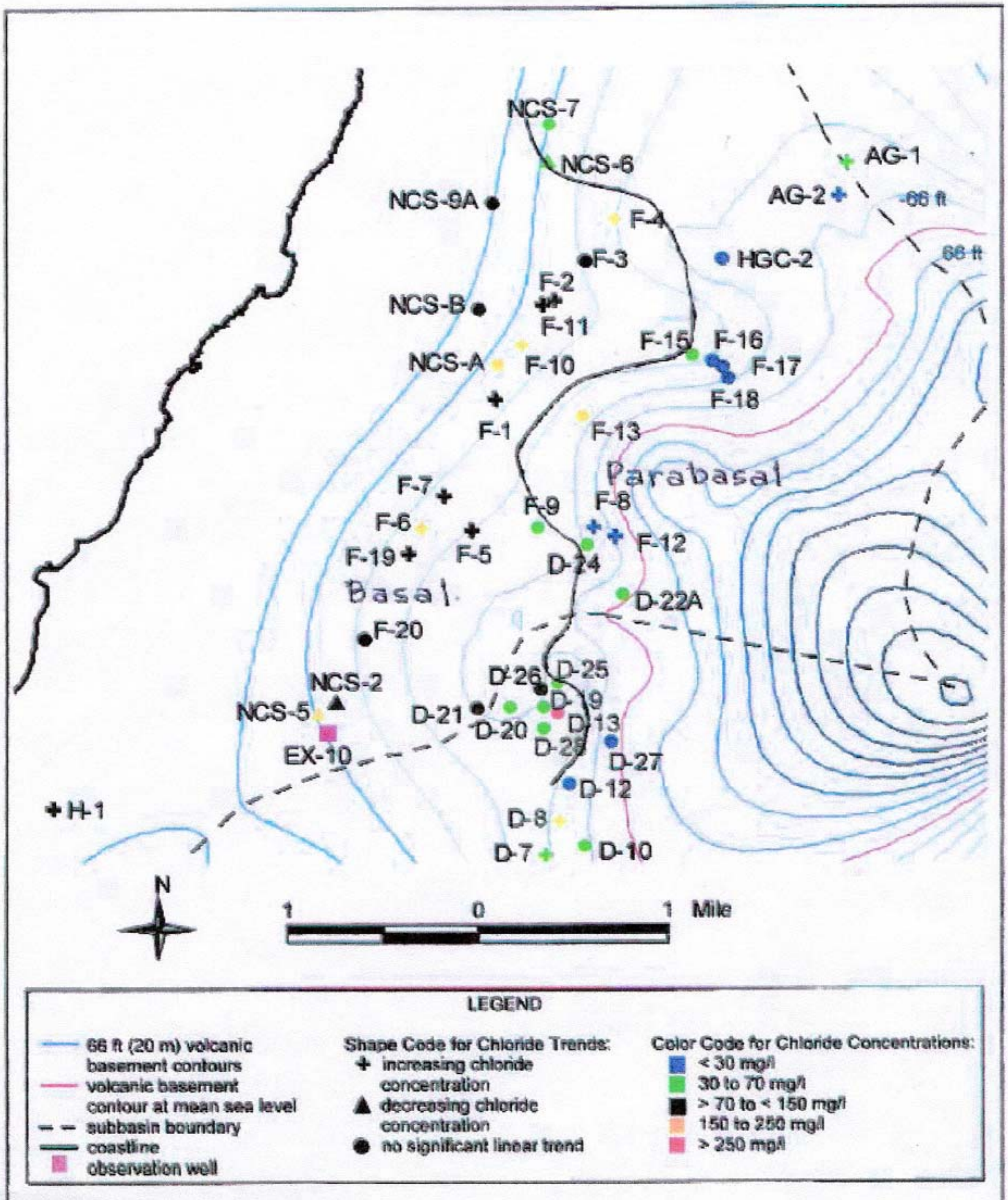
The tendency to drill more wells to increase water supply, especially in the Yigo-Tumon Aquifer Sector, can be curbed once improvements in the distribution system are undertaken. In a nearly ideal production-distribution system supplying water at a rate of 125 gpcd accompanied by 15% leakage for a total of 144 gpcd, the current draft on the northern Guam aquifers should be able to supply the needs of approximately 300,000 people. Current island population is around 168,564. It is clear that the emphasis on system improvements should focus on repairs and reconfiguration.

Figure 3-6 – Yigo-Tumon Sector



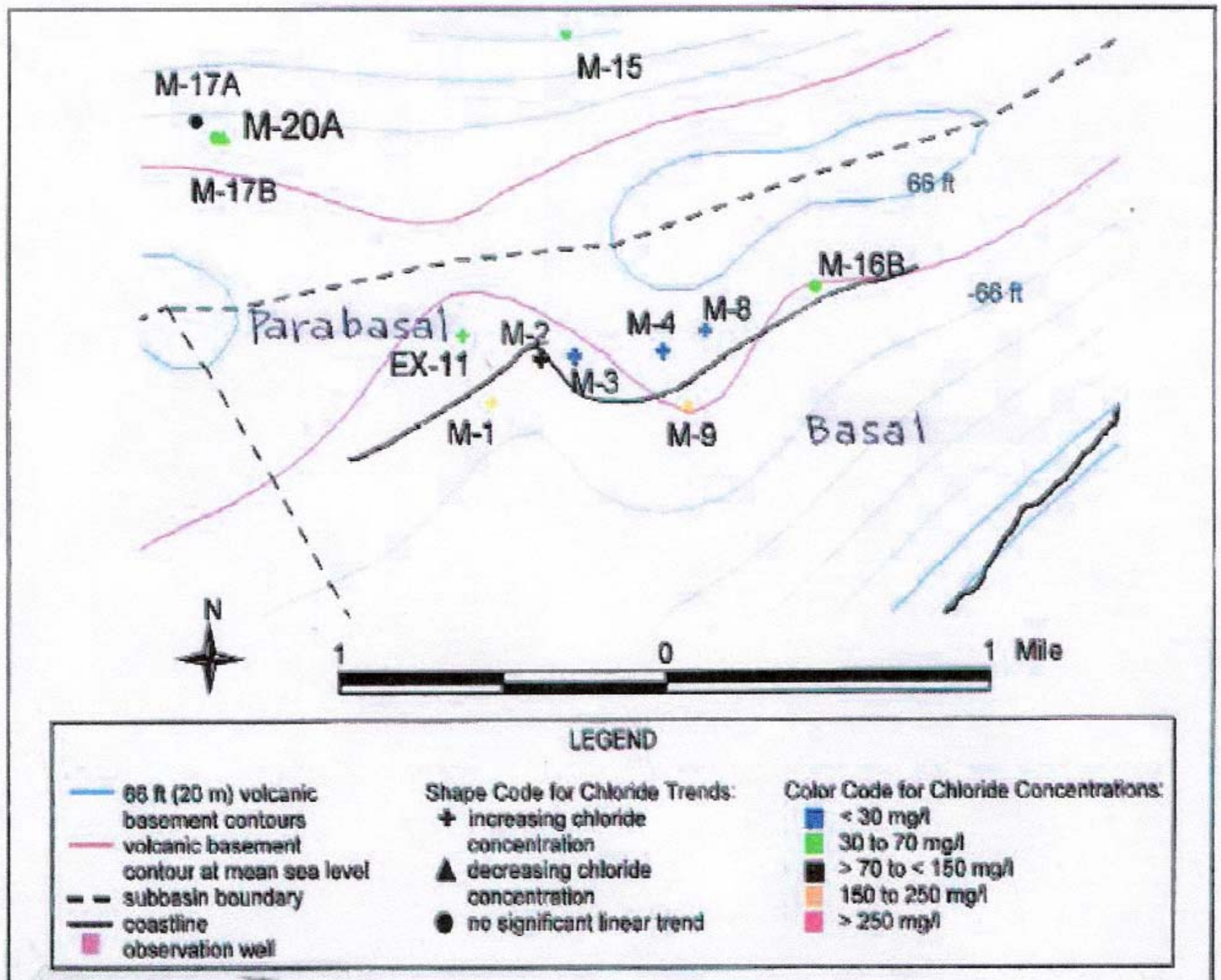
YIGO Sector production wells, observation wells, volcanic basement contours, and average chloride concentrations from 1990 to 1999. Chloride trends are based on linear regression analysis over a well's complete chloride sampling record.

Figure 3-7 – Finegayan Sector



FINEGAYAN Sector production wells, observation wells, volcanic basement contours, and average chloride concentrations from 1990 to 1999. Chloride trends are based on linear regression analysis over a well's complete chloride sampling record.

Figure 3-8 – Mangilao Sector



MANGILAO Sector production wells, volcanic basement contours, and average chloride concentrations from 1990 to 1999. Chloride trends are based on linear regression analysis over a well's complete chloride sampling record.

Future wells that may be needed should preferentially exploit the parabasal resources of the Ordot Aquifer System of the Agana Aquifer Sector, the Agafo Gumas Aquifer System of the Tarague Aquifer Sector, and the Mt. Santa Rosa – Andersen Aquifer Systems of the Pati Aquifer Sector. The sustainable yield of the Yigo-Tumon Aquifer Sector must be more accurately determined before additional development takes place. The WERI numerical models are also necessary to establish a proper sustainable yield.

3.6.2 Southern Guam

The GEPA Annual Data Management Report for 1995 listed the total groundwater pumpage from 20 wells in southern Guam as 0.4 mgd. Many of those wells are no longer active. Only two GWA wells were included, MJ 1 and MJ 2 at Malojloj, but these wells are used as backup. Their production has been replaced by the Ugum River diversion. The remaining active wells provide golf course irrigation. Total current pumpage averages no more than about 0.2 mgd. The economically exploitable groundwater resources of southern Guam are not nearly as voluminous as those of the North, but they may be adequate to supply remote localities.

The major surface water development in the South is the Navy's Fena catchment, storage and treatment complex. This system has a reliable yield of 11 to 11.5 mgd, which is approximately equivalent to 15% of the sustainable yield of the northern Guam aquifers. About 4 mgd is diverted to GWA. The next most productive GWA source is the Ugum River diversion, with a capacity of 2 mgd. Prior to the startup of the Ugum WTP, the communities of Merizo and Umatac were served by springs and stream flow. The Geus River supplied about 51 gpm and Siligin Spring provided another 10 gpm to Merizo. Umatac received water from Piga Spring at a rate of about 37 gpm. The most productive spring in southern Guam available to GWA is Asan (not in service), which has an average flow of about 298 gpm. Santa Rita Spring, which is the next most productive source, averages about 165 gpm. Both of these springs drain limestone; the others drain volcanics. Spring yields are already maximized, so additional water resources will be required as population grows in the South.

3.7 Quality of the Water Resources: Potential Contamination

The water resources of Guam developed for public consumption have not met EPA drinking water standards in many instances. Specific information on contaminants is presented in the preceding chapter (Chapter 2 – Water Regulatory Issues), as are details regarding compliance with drinking water regulations. It is incumbent on GWA to deal with potential contamination issues because of the mode of occurrence in the water resources. The groundwater in northern Guam occurs in highly porous limestone that extends from the ground surface through the vadose zone into the saturated aquifers. All recharge must first encounter conditions at the surface before infiltrating into the subsurface. In the South, groundwater in the limestone formations and volcanic soils follow a similar path, but far less activity that might affect groundwater quality takes place. The surface water exploited in the South drains areas that are free of significant anthropomorphic sources of potential contamination.

3.7.1 Groundwater Contamination Observations

The quality of the pristine groundwater of northern Guam is dominated by hardness (calcium carbonate content) and, where seawater intrusion occurs, by salinity. The "clean" limestone north of the Agana Aquifer Sector is composed of 98 to 99% calcium carbonate, while the argillaceous limestones in the Agana Aquifer Sector are 80 to 90% calcium carbonate. Salinity depends on the degree of seawater intrusion. Groundwater free of intrusion has a chloride content of less than 30 mg/L.

Drinking water sources are analyzed frequently by GWA and GEPA for evidence of contamination, such as heavy metals, organic compounds, oil and grease, detergents, nitratenitrogen (NO_3-N) and bacteria. Metals, organic compounds and bacteria have appeared in concentrations that equal or exceed the EPA allowable MCL on several occasions. In 2000 and 2001, chlordane was measured in Well M-14 at a concentration greater than one-half of the MCL. In 2004, chlordane exceeded the MCL in Well M-14 and the well was physically disconnected from the system. Data from GWA's Water Quality Reports for the years 2000 through 2004 show that six regulated VOCs have been detected in GWA's water. Data from GWA's Water Quality Reports from 2000 through 2004 show that six regulated volatile organics have been detected in GWA's water. Table 2.11 in Volume 2, Chapter 2 summarizes the VOCs by water source.

In 2000 and 2001, the concentration of tetrachloroethylene (PCE) in Well A-5 exceeded the MCL. In 2000, the concentration of trichloroethylene (TCE) in Well NAS exceeded the MCL. In 2004, the concentration of trihalomethanes in the Northern Water System exceeded the MCL. Well NAS had a concentration of 266 parts per billion. It was taken out-of-service and will not be put back in service until the granular activated carbon system is placed on-line.

Historically, persistent groundwater contaminant plumes in the Northern Guam Lens include the MARBO area and Tiyan. The MARBO plume has been present for at least 30 years since groundwater sampling began during the 1970s, and it probably predates the onset of sampling. The MARBO area is located in the Yigo trough portion of the aquifer, where infiltration is focused by the configuration of the volcanic basement. Despite the considerable amount of flushing that the aquifer undergoes as a result of Guam's high rainfall, especially in the MARBO area, these plumes have not shown a steady decrease in contaminant levels over time. The persistent nature of such contamination in the aquifer is enigmatic and significant in terms of ensuring that all available measures are taken to stop contaminants from entering the aquifer. Much like saltwater intrusion, once contaminants enter the aquifer it is extremely difficult to reverse the process.

Other significant contaminant plumes have been present in the aquifer, and some still exist. Those plumes consist of a third TCE/PCE plume, numerous gasoline component plumes, one ethylene di-bromide plume and various plumes resulting from sewage leaks and/or spills. The third TCE/PCE plume lies beneath a portion of the Harmon industrial park, Upper and Lower Tumon and Tumon Bay. It has resulted in the shutdown of the Tumon Maui production well since 1997 and the remediation of the Guam Plaza Hotel wells. The contaminants are being discharged into Tumon Bay. No source has been identified.

A comparison of concentrations at wells for 1976 and 2003 suggests that groundwater in the Agana Aquifer Sector and the Yigo-Tumon Aquifer Sector, the main water producing sectors, have remained stable over the span of 27 years. Table 3-12 lists concentrations for the two periods (data for 1976 are from TR 1; data for 2003 are from the GWA laboratory).

Table 3-12 – Comparison of NO_3-N Concentrations at Wells for 1976 and 2003 (mg/L)

Agana Aquifer Sector Well	1976	2003	Change
A1	1.8	1.3	-0.5
A2	2.1	3.3	+1.2
A3	1.5	0.9	-0.6
A4	2.0	3.4	+1.4
A5	2.7	1.7	-1.0
A6	2.7	2.3	-0.4
A7	2.9	2.7	-0.2
A8	1.9	2.1	+0.2
Yigo-Tumon Sector Well	1976	2003	Change
D1	2.5	2.1	-0.4
D2	2.5	2.2	-0.3
D4	2.5	2.1	-0.4
D5	2.5	2	-0.5
D6	1.8	2.2	+0.4
D7	2.0	2.1	+0.1
D8	2.2	1.5	-0.7
D9	1.8	2.2	+0.4
Y1	2.1	3.3	+1.2
Y2	2.2	3.4	+1.2

In the Mangilao Aquifer Sector, six wells for which 1976 and 2003 records were available had an average NO_3-N content of 1.9 mg/L in 1976 and 3.7 mg/L in 2003; this represents an increase of 1.6 mg/L. The increase is probably the result of heavy fertilization of a nearby golf course that was built after 1976.

Among the major sources of potential contamination are fertilizers and pesticides used in farming and on golf courses, as well as urban runoff collected in ponding basins. In the early 1990s, questions were raised about the fertilizers and pesticides used on the Guam International Golf Course near Dededo being possible pollutants. The golf course overlies the Tumon Aquifer System in which the D series wells are located. The results of a WERI investigation of the fate of the pesticide chlorpyrifos spread on the golf course indicated that the pesticide undergoes relatively rapid degradation and its chance of leaching to the aquifer is slight, except perhaps during heavy rainfall. The report noted, however, that more mobile degradation products associated with other pesticides were not evaluated.

Golf courses are heavily fertilized, and some of the fertilizer is lost to leaching below the root zone. According to a record of fertilizer applications for the golf course at Dededo dating from December 1992 through May 1993, NO_3-N at the rate of 95 pounds per acre per year was applied. Assuming a normal irrigation rate of 1.5 inches per week (78 inches per year) and a recharge rate of 53 inches per year (2.5 mgd per square mile), and further assuming that all of the NO_3-N was lost to leaching, the concentration of the percolate would be 3.3 mg/L. This amount is about 1 mg/L greater than that found in the aquifer. Of course, not all of the NO_3-N would be entrained in the percolate.

3.7.2 Well Head Protection

In 1986, the Federal Safe Drinking Water Act was amended to protect groundwater resources from contamination. The amendments were translated by EPA into the Well Head Protection Program (WHPP), which states that "the surface and subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or well field should be protected." The zone of contamination is determined from the following criteria: (1) distance, (2) drawdown, (3) time of travel, (4) flow boundaries and (5) assimilative capacity. In the highly permeable limestones of northern Guam, drawdown is an impractical criterion because the cone of depression is unrecognizable not far from the pumping well, even though it may extend outward a great distance. Each of the other criteria may be applicable to some degree. The most adaptable criterion is specification of flow boundaries.

Although GEPA has a WHPP that is designed to control surface activities within 1,000 feet of a well, it is not enforced consistently. The current well locations relative to development reflect the lack of enforcement (i.e., a large number of wells are concentrated over short distances) especially in the Yigo-Tumon Aquifer Sector. Capture zones are narrow but nevertheless overlap because of the proximity of the wells.

GEPA established a reasonably effective groundwater monitoring system after completion of the NGLS in 1982. That system lasted through 1995. The most instructive data were the measurements of salinity with depth at a number of exploratory wells, which penetrated through the freshwater core of the lens and through the transition zone until sea water was encountered. Revival of this program should be a priority.

A new arrangement for data collection has been agreed upon by GEPA, USGS and WERI, with WERI serving as the data archivist. Data will include rainfall, stream flow, groundwater water table elevation and groundwater salinity. These data will play a vital role in monitoring the status of Guam's groundwater resources and updating the respective models.

Flow boundaries, which outline the "capture zone" of a pumping well, are normally computed for a highly idealized version of a well or well field. The assumptions are that flow to the well is horizontal and steady, that the aquifer is homogeneous and isotropic, that drawdown is small compared to depth of flow and that depth of flow extends throughout the depth of the aquifer. The simplest equations yield the maximum width of the capture zone upgradient of the well and the distance to the "stagnation point" down gradient of the well. The stagnation point marks the farthest down gradient point of separation between the aquifer flow field and flow toward the well.

In a coordinate system in which $x = 0$, $y = 0$, and the x axis bisects the width of the capture zone, the maximum full width up gradient of the well is given by

$$2y = Q/(bq)$$

in which 2y (feet) is the maximum width; Q is pumpage (cubic feet/day); b is depth of flow (feet); and q is the Darcy flux, or ki, where k is hydraulic conductivity (feet/day) and i is groundwater gradient (dimensionless). In a basal lens, the depth of flow is taken as either the depth of penetration of the well below the water table or the depth from the water table to the top of the transition zone. For the stagnation point, the equation is

$$x = -Q/2\pi bq$$

in which x is down gradient distance to the stagnation point and the other symbols are as noted above.

For a typical D series well in the Tumon Aquifer System pumping at 200 gpm and having a depth of 50 feet below the water table while constrained by the aquifer parameters, k = 20,000 feet/day (regional) and i = .00025, the maximum width of the capture zone is 154 feet. If the depth to the top of the transition zone is taken as b (120 feet), the maximum width would be just 64 feet. Distance to the stagnation point for b = 50 feet would be 24.5 feet, and for b = 120 feet it would be 10.2 feet. On the other hand, if a local hydraulic conductivity of 200 feet/day were employed, the width would be too great to reasonably reflect flow behavior.

The narrow width of each capture zone and the short distance to each stagnation point explains why so many wells in the Yigo-Tumon Aquifer Sector that are sited not far apart can sustain pumpage of low salinity water. The density of existing well locations, however, precludes the establishment of surface zones in which activities that may lead to pollution are forbidden. Capture zones have not been taken into account when locating wells in the past; their shape and extent should be one of the criteria governing the location of new wells.

3.8 Water Resources Monitoring

A structured monitoring program for the groundwater resources of northern and southern Guam was not set in place until completion of the NGLS in 1982. Before that time, water levels were sporadically measured, although salinity was determined on a regular basis. In the South, stream and river, flows were continuously recorded by the USGS at many sites starting in about 1952. Eventually many of the gauging stations were discontinued, but several have been retained.

The USGS, in cooperation and an agreement with GEPA and WERI, will continue to monitor water levels in a set of wells in the North, surface water flows in several rivers in the South and rain gauges throughout the island. The sites at which the USGS will collect data are identified in Figure 3-9. The data and graphics are available online at: http://hi.water.usgs.gov/guam. At this time, GEPA data can be downloaded for only a few of the sites shown on Figure 3-9. Monthly water level measurements at eight wells are available from this site: EX-7, EX-10, M-10A, M-11, A-16, A-20, BMP-1 and ACEORP Tunnel.

As part of the NGLS, 11 deep borings (EX series) were drilled in northern Guam to collect information about hydrologic conditions in the basal lenses. Eight of the wells were successful in meeting the objectives of the program, which were to systematically collect water level and salinity data and to track changes in the thickness of the freshwater portion of the lens. The unsuccessful borings were dry either because of striking the volcanic basement well above sea level or because they were improperly drilled. In addition to the EX wells, another deep boring was drilled by Ghura-Dededo (referred to as EX GH). The successful wells, their depth below sea level (BSL), and their respective locations are listed in Table 3-15.

Figure 3-9 – USGS Data Collection Sites

Table 3-13 – Well Depth and Location

Well	Depth BSL (ft)	Aquifer Sector/System
EX1	-500	Agana/Mongmong
EX4	-246	Agana/Sabanna Maagas
EX6	-154	Yigo-Tumon/Tumon
EX7	-415	Yigo-Tumon/Tumon
EX8	-196	Tarague/Northwest Field
EX9	-274	Agana/Barrigada
EX10	-356	Finegayan/Haputo
EX GH	Unknown	Yigo-Tumon/Tumon

Water table elevations for these wells were recorded, and, more important, salinities were determined at depths through the freshwater core of the lens into the transition zone until sea water was reached. Of special concern was depth to the top of the transition zone (250 mg/L Cl) and to the middle of the transition zone (50% isochlor; 9,500 mg/L Cl, one-half seawater salinity). Depth to the middle of the transition is converted to "storage head" by dividing it by the Ghyben-Herzberg constant, which for Guam is 39 rather than the normal standard of 40 because of the warmth of both the fresh water and the underlying sea water. In a lens in perfect balance, the water table elevation equals the storage head. In Guam, the two values are virtually equal because the groundwater flow system is not impeded by geological barriers.

By agreement between GEPA and USGS, the USGS was responsible for collecting the data specified in the NGLS. This arrangement lasted from 1982 through 1995, at which time it was terminated, but USGS continued to make water table measurements at a number of wells and to include them in a database that is accessible on its Web site. These wells are plotted on Figure 3-9.

The cessation of perhaps the most important aspect of the data collection program, salinity and depth measurements to and within the transition zone, leaves a void in understanding the behavior of the lenses. A deep monitoring well designed to determine the position of the 50% isochlor should be established in each Aquifer Sector, at a minimum, and eventually in each Aquifer System. Currently, exploratory wells EX1, EX4 and EX9 are in the Agana Aquifer Sector; EX6, EX7 and EX GH are in the Yigo-Tumon Sector; EX10 is in the Finegayan Sector; and EX8 is in the Tarague Sector. Aquifer Sectors in which deep exploratory wells are not located are Fadian, Mangilao and Pati. Reclamation of the EX wells that yielded data during 1982–1995, plus the drilling of three new similar wells, should have the highest priority. Changes in the configuration of the two fundamental components of a basal lens - the freshwater core and the transition zone - need to be carefully tracked to ascertain whether or not over-exploitation is taking place.

In the period 1982–1995, the structure of the basal lens as evidenced by salinity-depth measurements was surprisingly stable in spite of the accelerating increase in pumpage. In Figures 3-10 to 3-16, the depth to the 50% isochlor and the corresponding storage head are plotted for EX1, EX4, EX6, EX7, EX9, EX10 and EX GH. In each case except for Well EX GH, the computed storage heads are nearly the same as the measured water table elevations, as listed below in Table 3-16 (values in feet).

Table 3-14 – Measured Water Table Elevations

Well	50% Isochlor	Storage Head	Water Table Elev.
EX1	250	6.4	6.2
EX4	228	5.9	5.7
EX6	136	3.5	3.4
EX7	131	3.4	3.3
EX9	120	3.1	3.0
EX10	118	3.0	2.6
EX GH	136	3.5	2.2

Note: Storage head = Depth to 50% Isochlor/39

The large difference in head for EX GH suggests that the elevation of the measuring point for obtaining depth to water is in error.

The Guam Hydrologic Survey, directed by WERI with the cooperation of EPA and USGS, is an essential step in establishing a functional Comprehensive Water Monitoring Program. Ever since its establishment more than 30 years ago, WERI has played a significant role in explaining the nature of the island’s water resource, and it is equipped and has the capacity to serve as the lead agency in tracking and interpreting changes that certainly will take place.

Figure 3-10 – Observation Well EX – 1

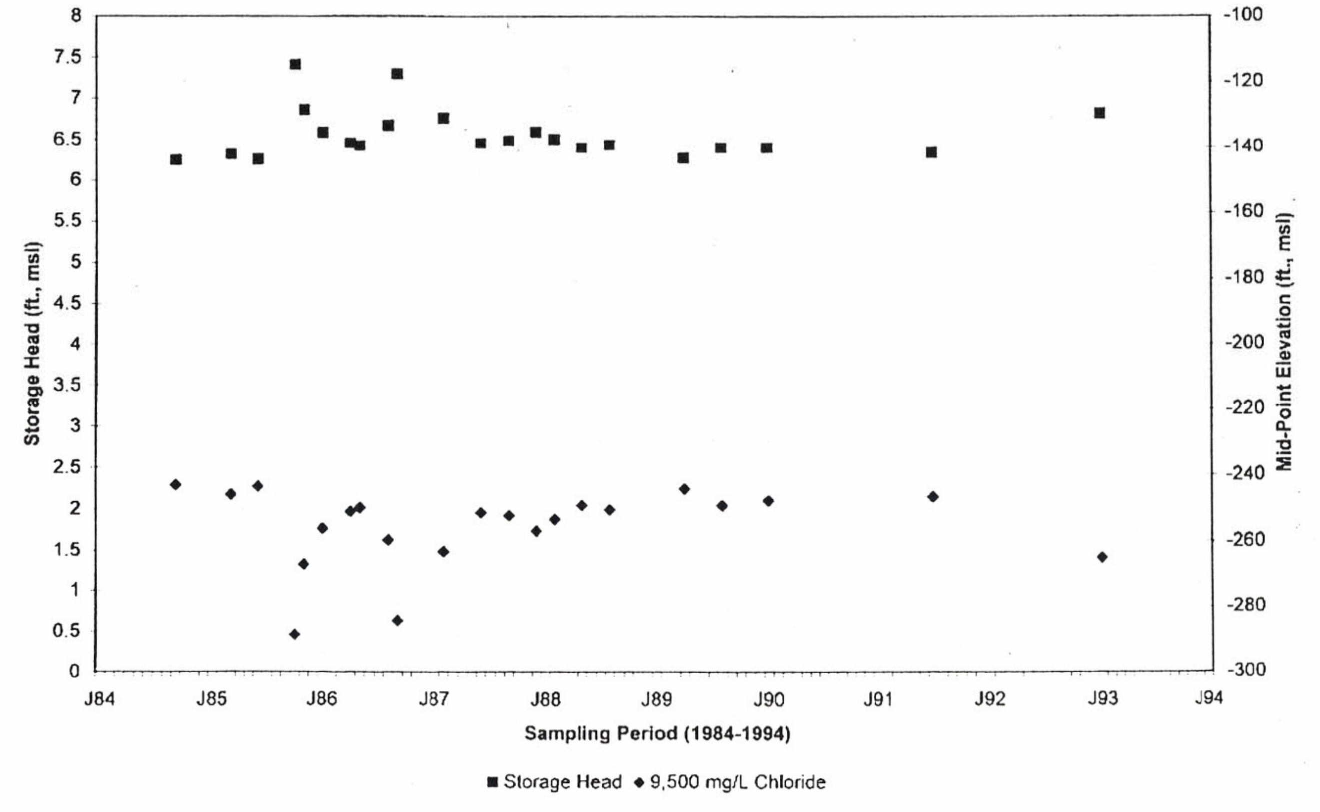


Figure 3-11 – Observation Well EX – 4

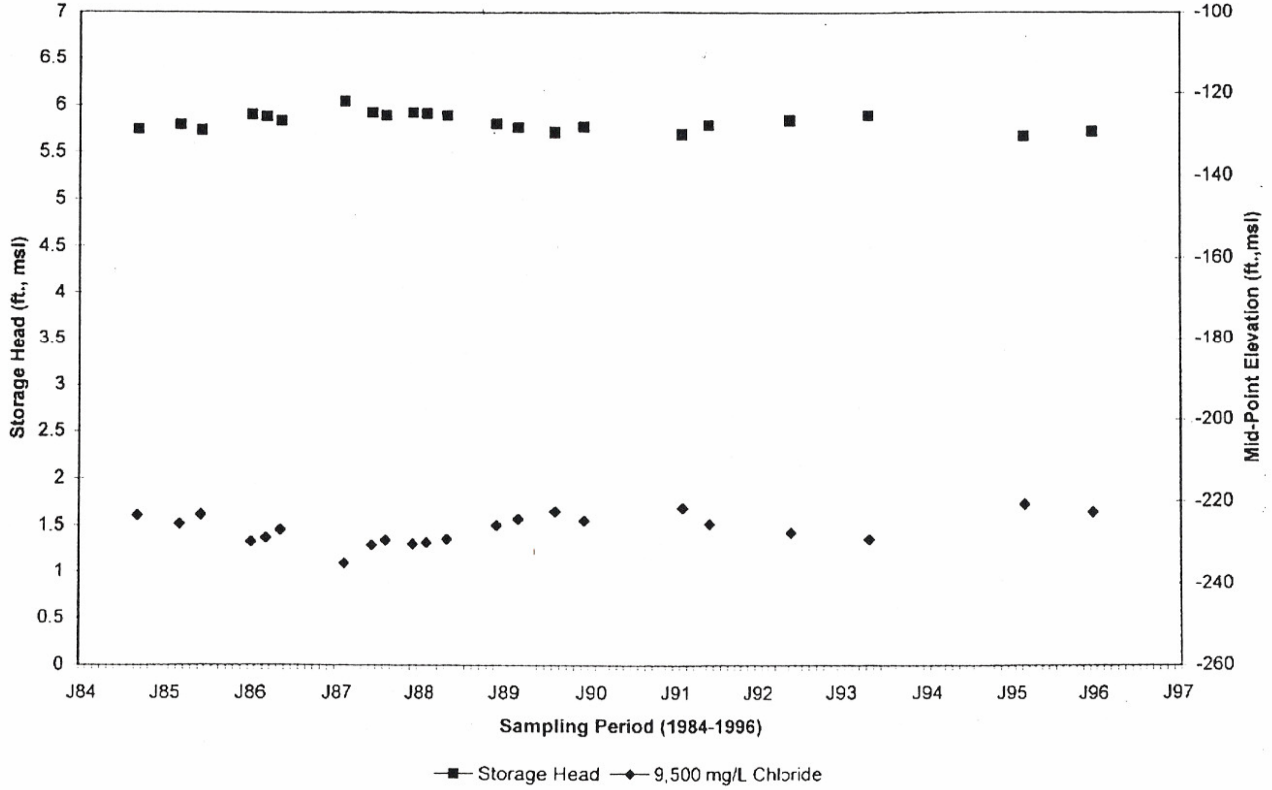


Figure 3-12 – Observation Well EX – 6

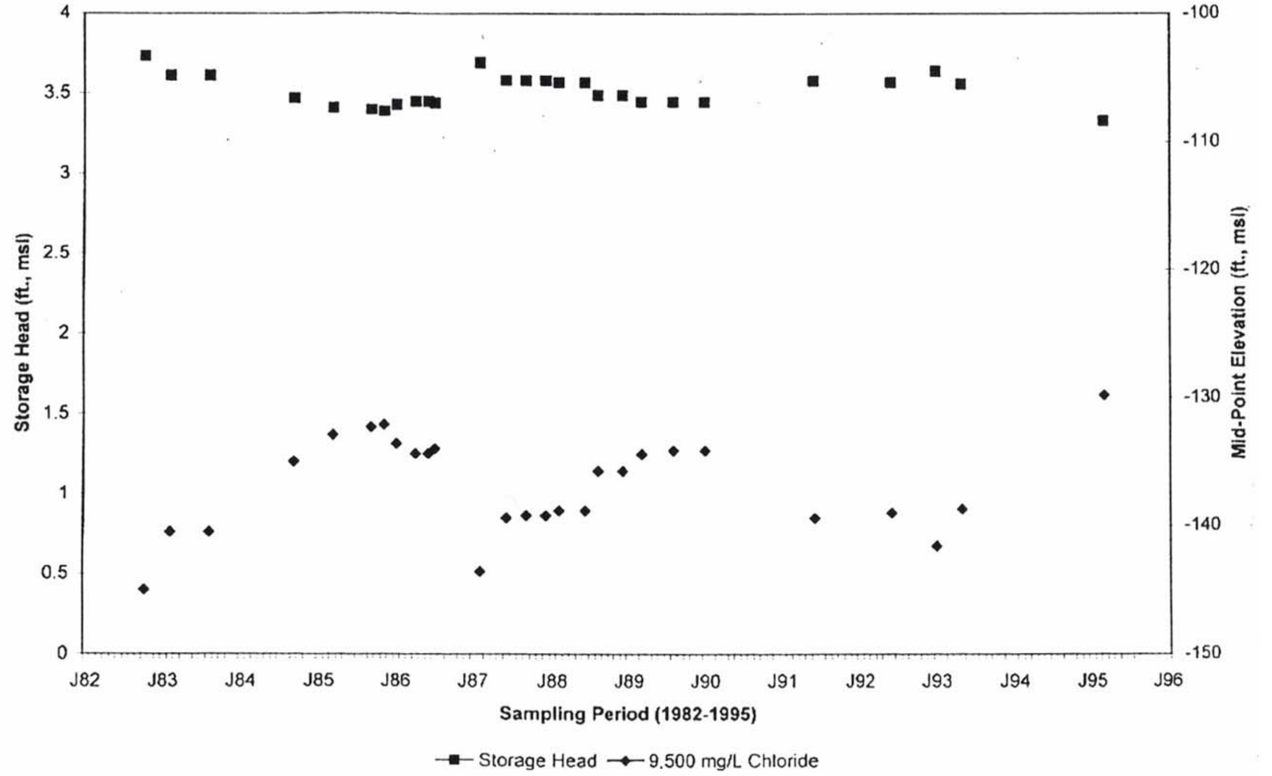


Figure 3-13 – Observation Well EX - 7

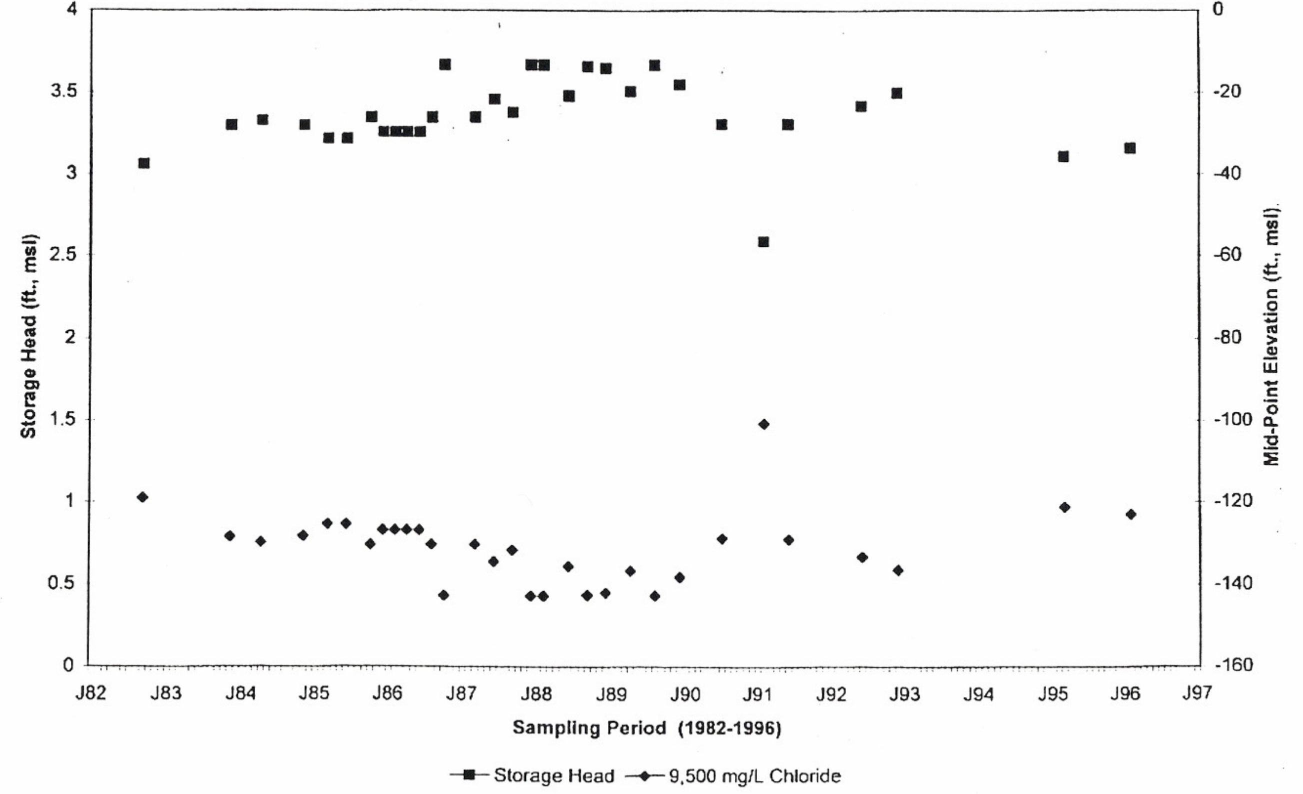


Figure 3-14 – Observation Well EX – 9

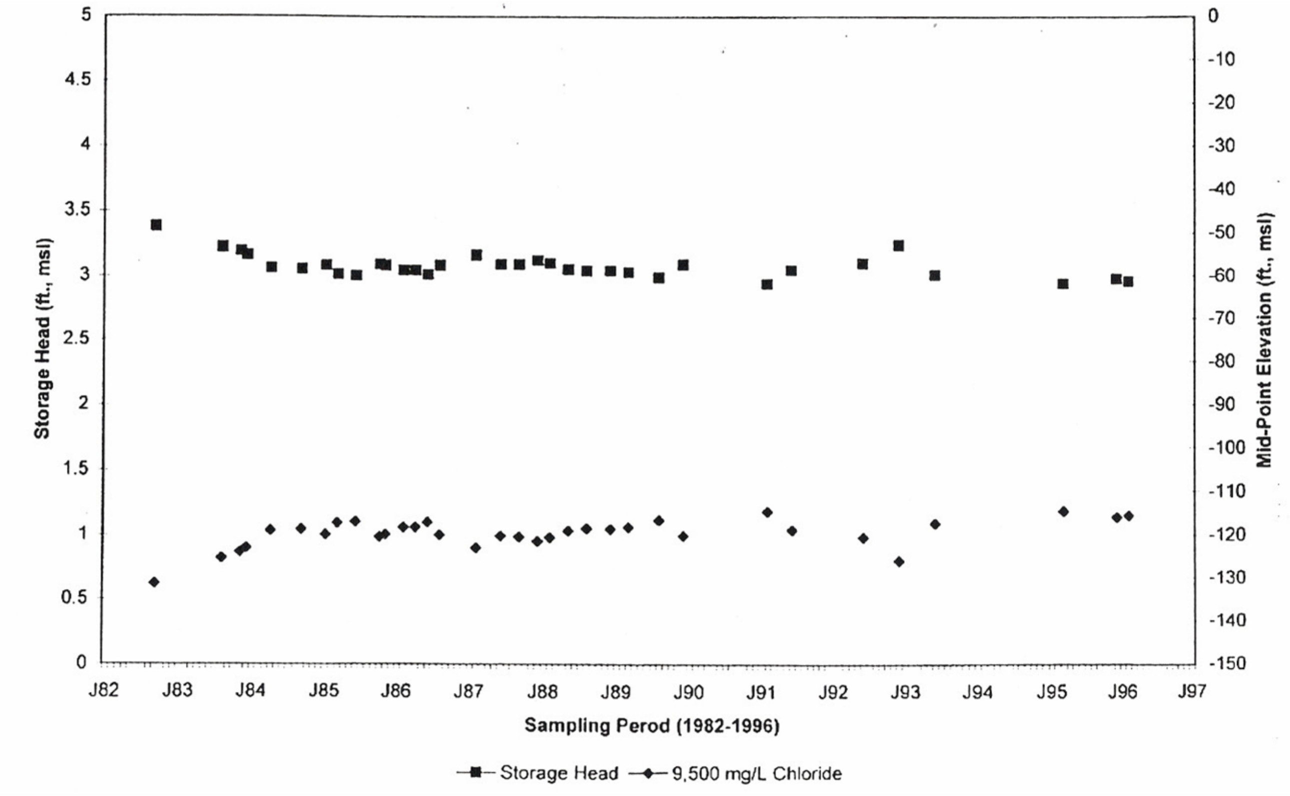


Figure 3-15 – Observation Well EX - 10

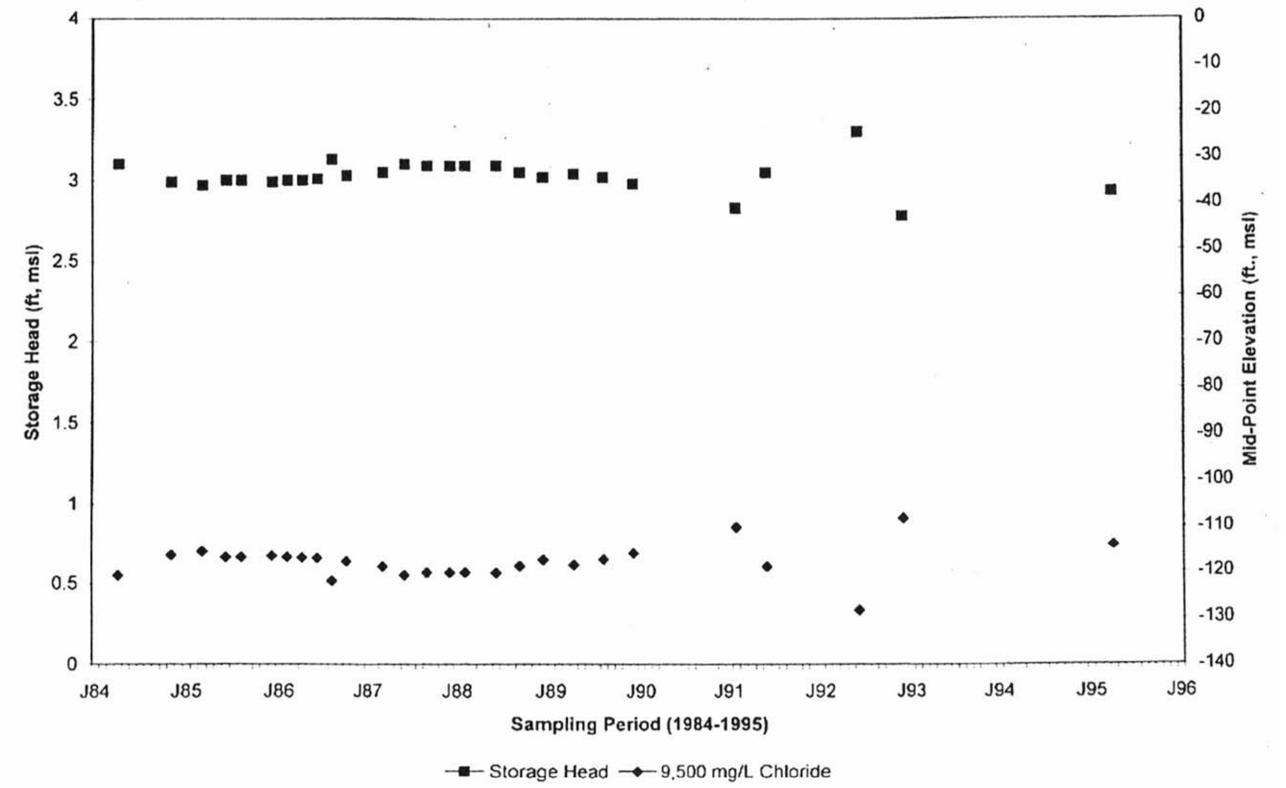
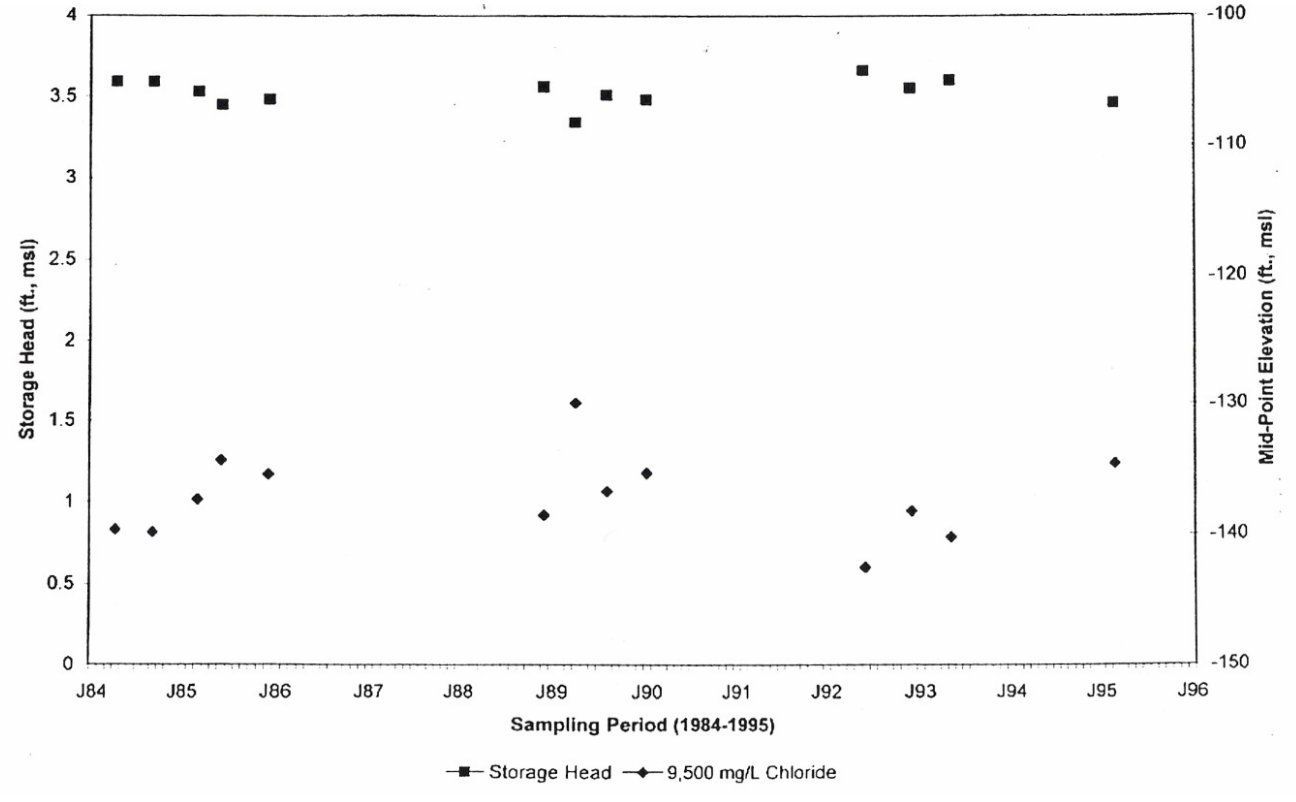


Figure 3-16 – Observation Well EX - Ghura



3.9 Conclusions

Key findings in this chapter are summarized below:

- It is estimated there may be sufficient capacity to provide for a population of up to 300,000; however, this may be tempered by potential threats to groundwater and a ruling on GWUDI of surface water.
- Although the hydrologic budget for northern Guam is estimated to have a rate of recharge to groundwater averaging 2 to 3 mgd per square mile, or a total of 200 to 300 mgd for the 100 square miles of the North, not all of this amount can be safely developed. A fraction, perhaps as little as 30%, may be extracted without deteriorating either the quality or quantity of the water extracted. Therefore, the sustainable yield assumes an average recharge rate of 2.5 mgd per square mile at a 30% extraction rate over the 100 square miles, resulting in a yield of 75 mgd. This is supported by a 1991 study performed by Barrett Consulting-Mink that resulted in an average yield of 70 mgd.
- The Adelup-Pago fault, which geologically and topographically divides the island, is also the boundary between two distinct suites of water resources. To the north, the occurrence of fresh water is limited to groundwater in permeable limestone aquifers; there are no streams, although a few small springs exist. In the South, surface runoff in the form of springs, streams and rivers is the dominant source of fresh water (small areas of limestone contain groundwater), but these are trivial in amounts compared with the northern aquifers.
- The cost of developing the groundwater in the North and distributing it to consumers (the greatest number of whom live in the North) is far less than the cost of storing, treating and distributing the surface waters of the South would be.
- The northern groundwater supplies public demand except for parts of the sparsely populated regions of the south that are mostly served by the Ugum River and a few smaller diversions.
- The sustainable yield given in the NGLS (1982) for each Management Zone was adjusted in the Barrett Consulting–Mink study (1991) for each Aquifer System. The NGLS estimate of 60 mgd for northern Guam was increased in the 1991 study to 75 mgd, but 15 mgd of this amount is assigned to federal property and considered unavailable to GWA. That leaves an estimated available yield of 60 mgd, the same as proposed in the NGLS.
- Of the estimated available yield, an average draft of nearly 50 mgd satisfies a demand that is, at most, 35 mgd. The difference is lost in the distribution network through leakage, most of which presumably returns to the aquifers. If so, the net loss to the aquifers by pumping may be closer to 35 mgd than to 50 mgd.
- Guam, with an estimated population of 168,564 (based on the U.S. Census Bureau International Data Base for mid-year 2005), should consume about 21 mgd, assuming a per capita usage of 125 gpcd. Allowing for an additional 5 to 10 mgd for miscellaneous purposes, total consumption should be 26 to 31 mgd. If a typical rate of water system leakage of 15% of production is applied, the gross demand should be approximately 30 to 36 mgd. Total current production from surface and groundwater, however,

approaches 60 to 65 mgd, which includes pumpage from the northern aquifers (approximately 46 mgd), the Ugum diversion (2 mgd), Fena Reservoir (yield 11 mgd) and miscellaneous springs. Evidently, the water distribution systems lose a substantial share of the water developed.

- Under current production rates in the North, the unused sustainable yield available to GWA totals about 18 mgd. The most readily developable additional sources are in the Ordot Aquifer System of the Agana Aquifer Sector (approximately 2.7 mgd) and the Agafo Gumas Aquifer System (approximately 2.9 mgd). The sustainable yield assigned to the Yigo-Tumon Aquifer Sector (approximately 20 mgd) has already been reached, yet the basal lens in the Tumon System appears to be stable.
- GWA wells in combination with U.S. Navy wells account for approximately 39 mgd of withdrawal. The total becomes 42.3 mgd when the former Earth Tech system wells are included. The U.S. Air Force also pumps about 2.5 mgd for its own use and private users pump about one mgd, resulting in total groundwater production of approximately 46 mgd. Even if the entire population of Guam was served by northern groundwater, per capita consumption would be 273 gpcd for a population of 168,564. The difference between 273 gpcd and the expected average consumption of 125 gpcd implies a system loss of approximately 55%. This amount substantially exceeds the 15% experienced by most systems in good order.
- Exhibit 3B approaches the disparity between production by pumpage/surface water sources and consumption rates by comparing consumption based on revenue collected by GWA with production. The average revenue collected over the 5-year period from October 1999 to September 2004, when converted to consumption, totaled 23 mgd. A total of 6.5 mgd was derived from surface water sources that included Fena Reservoir, the Ugum diversion, and Santa Rita and Asan Springs. Total GWA recorded pumpage was 42 mgd for a total of water source of 48.5 mgd. Thus, it is clear that leakage in the system is a serious problem because the analyses above demonstrate about 50% loss of potable water.
- Several instances of groundwater contamination have been noted in the northern aquifers. In northern Guam, increases in salinity in some wells imply saltwater intrusion. A number of wells have had to be abandoned, and others may have to be reconfigured. Permanent loss of head over time is not evident, even in the Tumon Aquifer System, which has been especially heavily exploited.
- In the South, the only water development of consequence besides the Fena Reservoir complex is GWA's Ugum River diversion. As the population grows substantially and the demand on the northern Guam aquifers increases, additional surface water development opportunities in the south may have to be explored. Surface water may become more important with substantial population increases if GWA does significantly reduce water losses from system leakage.
- The Yigo-Tumon Aquifer Sector is the most productive provider of potable groundwater on the island. Average head at 3.5 feet has not varied significantly, depth to the 50% isochlor has been virtually invariant, and in most wells the salinity of the water has not risen significantly.

- A large region, the Yigo Aquifer System, contains parabasal aquifers, and down gradient toward Tumon where basal conditions prevail, the flow of groundwater is very high. In the parabasal region and in the boundary between the parabasal and basal regions, wells of greater than 200-gpm capacity successfully yield low salinity water.
- Three Aquifer Sectors yield most of the groundwater for GWA. The most important is the Yigo-Tumon Sector, followed by the Finegayan and Agana Sectors. Each of these sectors is already heavily exploited.
- The Agana Aquifer Sector serves much of the southern half of Northern Guam. Its Ordot Aquifer System is especially important because the resource is parabasal and thus free of seawater intrusion. The basal groundwater has already been affected by seawater intrusion, and many A series wells produce water with greater than 150 mg/L and some exceed 250 mg/L. The probability of successfully withdrawing additional potable water from the basal wells is poor at best, but production from the parabasal resource can be expanded.
- The tendency to drill more wells to increase water supply, especially in the Yigo-Tumon Aquifer Sector, can be curbed once improvements in the distribution system are undertaken. In a nearly ideal production-distribution system that supplies water at a rate of 125 gpcd, accompanied by 15% leakage for a total of 144 gpcd, the current draft on the Northern Guam aquifers should be able to supply the needs of approximately 300,000 people. Current island population is about 168,564. It is clear that emphasis on improving the system should focus on repairs and reconfiguration.
- Historical persistent groundwater contaminant plumes in the NGL include the MARBO area and Tiyan. The MARBO plume has been present for at least 30 years since groundwater sampling began during the 1970s, and it probably predates the onset of sampling. Despite the considerable amount of flushing in by the aquifer resulting from Guam’s high rainfall, especially in the MARBO area located in the Yigo trough portion of the aquifer where infiltration is focused by the configuration of the volcanic basement, these plumes have not shown a steady decrease in contaminant levels over time. The persistent nature of such contamination in the aquifer is both puzzling and important in terms of ensuring that all available measures are taken to prevent contaminants from entering the aquifer. Much like saltwater intrusion, once contaminants enter the aquifer, it is extremely difficult to reverse the process.
- There are other significant contaminant plumes that have been present in the aquifer, and some still are. Those plumes consist of a third TCE/PCE plume, numerous gasoline component plumes, one ethylene di-bromide plume and various plumes resulting from sewage leaks and/or spills. The third TCE/PCE plume is beneath a portion of the Harmon industrial park, Upper and Lower Tumon and Tumon Bay. It has resulted in the shutdown of the Tumon Maui production well since 1997 and remediation of the Guam Plaza Hotel wells. The contaminants are being discharged into Tumon Bay. No source has been identified.
- Although GEPA has a WHPP that is designed to control surface activities within 1,000 feet of a well, it is not enforced consistently. The current well locations relative to development reflects the lack of enforcement as a large number of wells are

concentrated over short distances, especially in the Yigo-Tumon Aquifer Sector. Capture zones are narrow but nevertheless overlap because of the proximity of the wells.

- A reasonably effective groundwater monitoring system was established by GEPA after completion of the NGLS in 1982. The system lasted through 1995. The most instructive data were the measurement of salinity with depth at a number of exploratory wells that penetrated through the freshwater core of the lens and through the transition zone until sea water was encountered.
- A structured monitoring program for the groundwater resources of northern and southern Guam was not set in place until completion of the NGLS in 1982. Prior to that study, water levels were sporadically measured, although salinity was determined on a regular basis. In the South, stream and river flows were continuously recorded by the USGS at many sites, starting in about 1952. Eventually many of the gauging stations were discontinued, but several have been retained.
- By agreement between GEPA and USGS, the USGS was responsible for collecting the data specified in the NGLS. This arrangement lasted from 1982 through 1995, at which time it was terminated; however, USGS continued to make water table measurements at a number of wells and to include them in a database that is accessible on its Web site. The cessation of perhaps the most important aspect of the data collection program, salinity and depth measurements to and within the transition zone leaves a void in understanding the behavior of the lenses.

3.10 Recommendations

- A primary goal for GWA is to reduce system leakage. Pumping costs would be reduced and mismanagement of the aquifers would be avoided.
- It is incumbent on GWA to deal with potential contamination issues because of the mode of occurrence in the water resources. The groundwater of Northern Guam occurs in highly porous limestone that extends from the ground surface through the vadose zone into the saturated aquifers. All recharge must first encounter conditions at the surface before infiltrating into the subsurface. Groundwater in the limestone and volcanic soils of the south follows a similar path, but far less anthropomorphic activity that might affect groundwater quality takes place there. The surface water exploited in the South drains areas that are free of significant anthropomorphic sources of potential contamination.
- Creation of the Guam Hydrologic Survey, under the direction of WERI and with the cooperation of GEPA and USGS, is an essential step in establishing a functional Comprehensive Water Monitoring Program. WERI has played a significant role ever since its establishment more then 30 years ago in explaining the nature of the water resources of the island, and it is equipped and has the capacity to serve as the lead agency in tracking and interpreting changes that certainly will take place.
- GWA should work with GEPA and WERI to revive a reasonably effective groundwater monitoring system.

3.11 CIP Impacts

The water budget highlights the water loss that is currently occurring in GWA's system. Water loss control is a high priority. The CIP includes an annual allocation of $5.0 million for water line annual replacement to reduce water loss plus substantial water distribution system improvements. The full 4.0 mgd capacity of the Ugum WTP will be limited during low river flow months even after the upgrade to membrane filtration. The CIP does not include land purchase and construction of a raw water reservoir because of its estimated capital cost ($93 million).

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Exhibit 3A - Hydrologic Budgets

The steady state water balance equation for southern Guam may be expressed as

$$R=P-ET+GW-I$$

in which R is stream runoff, P is rainfall, ET is evapotranspiration, GW is groundwater contribution to the runoff, and I is infiltration to groundwater. Runoff and rainfall have been measured for some drainage basins while groundwater can be estimated by analysis of the stream flow records during the dry months of the year, January through June. Pan evaporation has been measured at WMSO and in one approach to the budget is put equal to evapotranspiration. Infiltration is likely to be small and transitory because the water table in the volcanic aquifers is either exposed at the ground surface or normally less than 15 feet below.

Assuming that GW and I cancel each other, the balance equation reduces to

$$P=R+ET$$

from which ET is determined from the two known values, ET=P-R.

Employing the Inarajan drainage basin as representative of hydrologic conditions in southern Guam, ET can be calculated from the excellent measurements of stream flow and rainfall in the basin. Average annual rainfall in Inarajan has been 88.92 inches, and average stream flow at the USGS gage (16835000) for the 30 year period of record (1952-1983) was 11 mgd from an area of 4.42 square miles. The table below is structured to derive an estimate of ET.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av. Rain,in	3.40	4.06	2.60	3.52	4.59	7.66	10.55	14.42	13.51	11.79	9.30	5.37
Av.Rain mgd	8.4	11.3	6.4	9.0	11.4	19.6	26.1	35.7	34.6	29.2	23.8	13.3
Av.Flow mgd	7.1	6.2	3.5	3.8	6.5	4.3	9.0	19.4	24.6	23.3	16.8	9.7
P-R=ET mgd	1.3	5.1	2.9	5.2	4.9	15.3	17.1	16.3	10.0	5.9	7.0	3.6
ET, in.	0.53	1.83	1.18	2.03	1.97	5.98	6.91	6.58	3.91	2.38	2.74	1.45

In the above, the annual ET totals 37.5 inches, which subtracted from the rainfall (88.92 inches) gives 51.4 inches. Assuming that ET in the north is the same as ET in the south and that no runoff occurs in the north, recharge in the north is 51.4 inches per year, equivalent to 2.45 mgd/sq.mi.

The minimum infiltration rate is calculated as the difference between rainfall and pan evaporation, which is assumed equal to evapotranspiration. For the WMSO at Taguac the rainfall and evaporation rates with the difference between them assumed equal to infiltration are as follows (these values are from TR-1).

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av.Rain, in	5.54	4.19	4.44	4.65	6.26	6.18	11.25	13.41	15.78	13.19	9.48	6.48
Av.Evap,in	5.49	5.93	7.23	7.64	7.68	6.52	5.84	5.15	4.85	5.12	5.22	5.74
Rain-Evap	0	0	0	0	0	0	5.41	8.26	10.93	8.07	4.26	0.74

The average annual difference between rain and evaporation is 37.67 inches, equal to 1.79 mgd/sq.mi, which is about 73% of the value determined by solving for ET.

Still another way to estimate recharge in the north by the balance equation in the south is to decompose the recorded runoff values into direct surface runoff, the immediate response to rainfall and the groundwater contribution. Once again employing the Inarajan River stream flow record coupled with rainfall data, and estimating the groundwater contribution to runoff from low flows in the record, the balance equation reduces to

$$DRO=R-GW$$

in which DRO is runoff responding to rainfall. Total runoff, R, is known, and the groundwater contribution is estimated from low stream flows during the dry period of the year, January through June. For Inarajan the average of the monthly minimum flows for the 30 year record was 1.31 mgd, equivalent to 6.2 in./yr. The average flow was 11 mgd, equivalent to 52.3 in./yr., and thus the DRO is 46.1 in./yr. Because in the North there is no direct surface runoff, DRO calculated for the South is equal to recharge in the North. Runoff of 46.1 in./yr. converts to 2.19 mgd/sq.mi.

The same method applied to the Ugum River above Talofofo Falls (USGS Gage 16854500) results in an estimate for the groundwater contribution to stream flow of 3.5 mgd of the average total of 16.8 mgd. Direct surface runoff is calculated as 48.5 in./yr., equivalent to 2.31 mgd/sq.mi.

In a report relating infiltration, recharge and discharge in the NGLA (J. Jocson, J. Jenson, and D. Contractor, 1999, Numerical Modeling and Field Investigation of Infiltration, Recharge and Discharge in the Northern Guam Limestone Aquifer: Univ. Guam WERI, TR 88), infiltration was estimated to amount to 67% of rainfall. For an average rainfall of 94 in./yr. in Northern Guam, the infiltration rate is 3.0 mgd/sq.mi. The authors speculate on the fate of infiltration, whether all of it recharges the lens or some escapes by traveling complicated pathways. They conclude the rate of 3.0 mgd/sq.mi. is a maximum.

The WERI budget was meticulously calculated by using daily pan evaporation as an estimate of daily potential evapotranspiration, then calculating daily minimum recharge estimates as measured daily rainfall minus daily pan evaporation. The daily data were then converted to monthly totals and a relationship between estimated recharge and monthly rainfall established. The relationship is statistically linear for which the equation is (values in cm.)

$$I = 0.87\ P - 4.24$$

in which I is monthly recharge and P is monthly rainfall. The equation applies only when monthly rainfall is greater than about 5 cm. For lesser monthly rainfall no recharge takes place. It is from the above analysis that the investigators concluded that recharge in northern Guam is 67% of rainfall.

The global approach to estimating recharge discussed above suggests that actual recharge in the north falls in the range 2 mgd/sq.mi. to 3 mgd/sq.mi.

Water Budget for Northern Guam.

The water budget for northern Guam is derived by employing the following variables.

1. P = rainfall; measured.
2. E = pan evaporation, measured.
3. ET = evapotranspiration; unknown.
4. R = stream runoff; measured in south.
5. GW = groundwater contribution to R in south.
6. I = Infiltration to groundwater; unknown.
7. DRO = direct surface runoff, derived from R.

Source	Pin/yr	Ein/yr	ETin/yr	Iin/yr	Imgd/sq.mi.	Asq.mi.	Imgd
WERI TR-1	95	70	36.4	58.6	2.78	94.6	263
NGLS	92	82	59.0	33.0	1.65	67.9	112
WERI TR-88	95	32	32	63	3.00	94.6	284
Current	89	72	37.5	51.4	2.45	94.6	232
Current	90	72	43.9	46.1	2.19	94.6	207

Method of computation

WERI TR-1: Equate runoff (R) in southern Guam with recharge (I) in northern Guam.
NGLS: Compute ET by Blaney-Criddle method. I = P – ET.
WERI TR-88: Compute recharge as difference between measured daily rainfall and measured daily pan evaporation.
Current I: Compute ET for river of southern Guam by P – R = ET; then, P – ET = I.
Current II: Compute DRO by DRO = R – GW, estimate GW from Inarajan River flow record (30 years). Equate DRO to recharge in north.

Exhibit 3B - GWA Revenue Summary
October 1999 – September 2004

GWA Water Distribution Budget

GWA distributes approximately 24 mgd for which it receives revenue. The annual revenue collection for the years October, 1999 through September, 2004 (a total of five years), is summarized by usage. The revenue volumes are converted to mgd by employing the rate schedule, which also is included in this Exhibit. For residential collections the two layer charges are converted to an average charge as follows:

1. Assume actual per capita consumption = 125 gal/day.

2. Assume 4 persons per household (meter) = 500 gal/day = 15,250 gal/month.

3. 5,000 gallons at $2.40/1,000 gal; 10,250 gallons at $2.85/1,000 gal. Average rate = $2.70/1,000 gal. All other categories at fixed rates.

The revenue values include both groundwater and surface water. The surface water components are:

1. 4.3 mgd provided by the US Navy (Fena Reservoir).

2. 1.3 mgd from Ugum diversion (recently in 2004 successfully raised to 2.4 mgd).

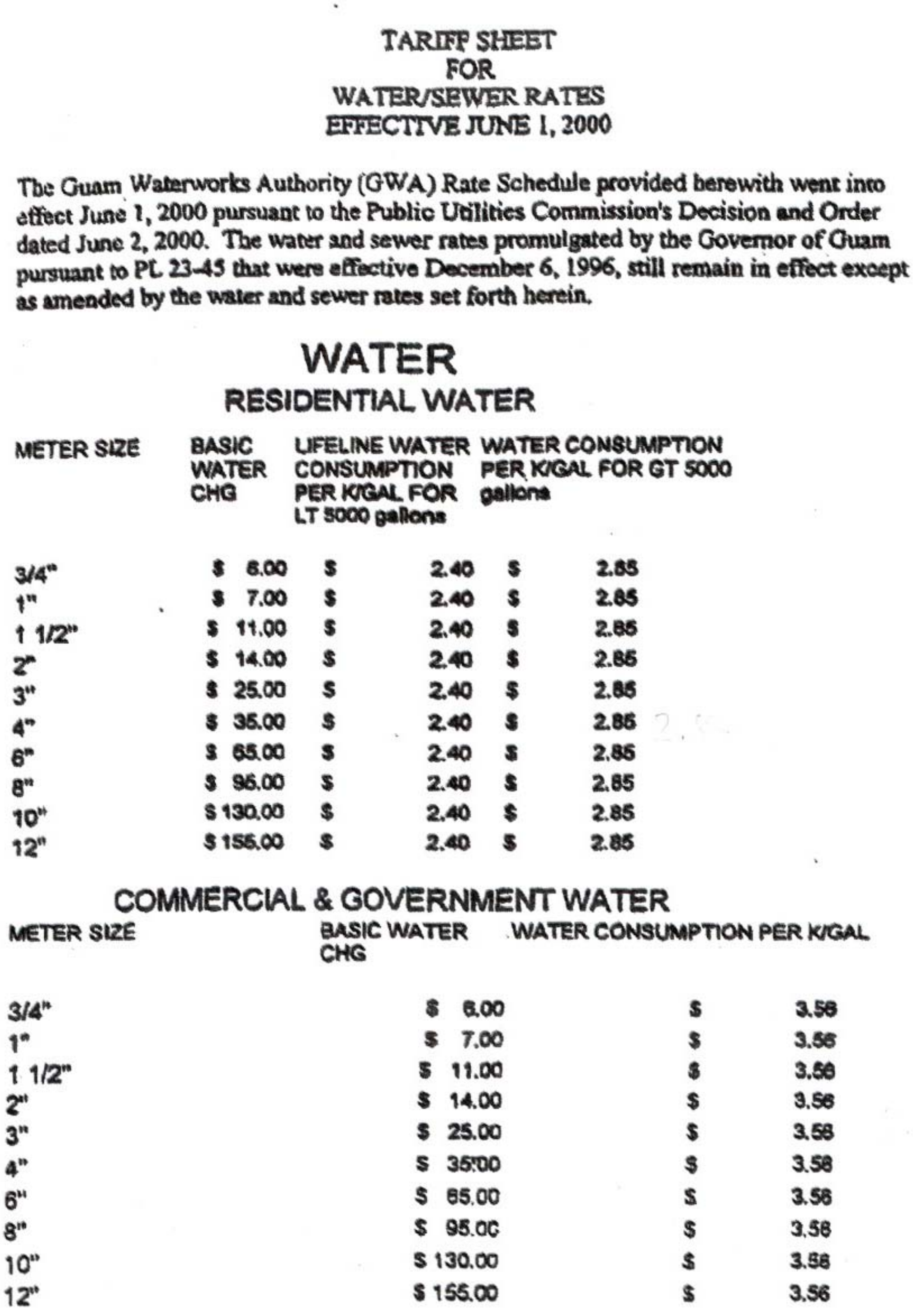
3. Approximately 0.5 mgd from Santa Rita Spring.

4. Approximately 0.4 mgd from Asan Spring (now out of production).

TOTAL 6.5 mgd.

The total revenue volume is 23 mgd. The total surface water supplied is 6.5 mgd, while actual GWA pumpage from northern Guam averages approximately 42 mgd as determined from well records provided by GWA and as derived from records in McDonald (2001). Consequently, the total volume of supplied water from the sources is 48.5 mgd. Thus, the quantity lost therefore is 25.5 mgd, or 53%% of total supplied water. If losses were limited to 15 % of supplied water, which is typical for most hydraulically competent systems, total water resource supplied from the source would be 26.5 mgd, which is 22 mgd less than currently extracted or supplied. .

	Category	Revenue	mgd	Revenue	mgd	Revenue	mgd	Revenue	mgd	Revenue	mgd	Av mgd
		10/99-9/00	10/99-9/00	10/00-9/01		10/01-9/02		10/02-9/03		10/03-9/04		5 yrs.
365												
2.7	Residential	16241837	16.4808087265348	1.4E+07	14.426	1.4E+07	14.22496	1.3E+07	13.48357	1.4E+07	14.49318	14.6217
3.56	Commercial 1	2891147	2.22498614745267	2772245	2.133481	2785880	2.143974	3028122	2.3304	2969250	2.285093	2.223587
3.56	Commercial 2	543519	0.41828459288903	532844	0.410069	571413	0.439751	584069	0.449491	776222	0.59737	0.462993
3.56	Commercial 3	621077	0.47797214098815	612123	0.471081	658838	0.507032	522041	0.401755	724786	0.557785	0.483125
1.19	Agriculture	163462	0.37633705537009	196727	0.452923	196826	0.453151	203822	0.469258	224660	0.517233	0.45378
1.19	Irrigation	119892	0.27602624611488	148944	0.342912	115443	0.265783	101670	0.234074	91491	0.210639	0.265887
3.56	Government	1749164	1.34613206095121	1921809	1.478997	2011675	1.548157	2085098	1.604662	2037635	1.568135	1.509217
3.56	Federal	16082	0.01237648145298	35926	0.027648	17361	0.013361	18462	0.014208	27090	0.020848	0.017688
3.56	Golf Course	75409	0.05803370786517	81704	0.062878	45714	0.035181	15860	0.012206	27480	0.021148	0.037889
3.56	Hotel	3022918	2.32639525935047	3390070	2.60895	3280505	2.524631	3061859	2.356364	4111818	3.164397	2.596147
	Total	25444507	23.9973524189694	2.4E+07	22.41494	2.4E+07	22.15598	2.3E+07	21.35599	2.5E+07	23.43583	22.67202



TARIFF SHEET
FOR
WATER/SEWER RATES
EFFECTIVE JUNE 1, 2000

The Guam Waterworks Authority (GWA) Rate Schedule provided herewith went into effect June 1, 2000 pursuant to the Public Utilities Commission's Decision and Order dated June 2, 2000. The water and sewer rates promulgated by the Governor of Guam pursuant to PL 23-45 that were effective December 6, 1996, still remain in effect except as amended by the water and sewer rates set forth herein.

WATER

RESIDENTIAL WATER

METER SIZE	BASIC WATER CHG	LIFELINE WATER CONSUMPTION PER K/GAL FOR LT 5000 gallons	WATER CONSUMPTION PER K/GAL FOR GT 5000 gallons
3/4"	$ 6.00	$ 2.40	$ 2.85
1"	$ 7.00	$ 2.40	$ 2.85
1 1/2"	$ 11.00	$ 2.40	$ 2.85
2"	$ 14.00	$ 2.40	$ 2.85
3"	$ 25.00	$ 2.40	$ 2.85
4"	$ 35.00	$ 2.40	$ 2.85
6"	$ 65.00	$ 2.40	$ 2.85
8"	$ 95.00	$ 2.40	$ 2.85
10"	$ 130.00	$ 2.40	$ 2.85
12"	$ 155.00	$ 2.40	$ 2.85

COMMERCIAL & GOVERNMENT WATER

METER SIZE	BASIC WATER CHG	WATER CONSUMPTION PER K/GAL
3/4"	$ 6.00	$ 3.56
1"	$ 7.00	$ 3.56
1 1/2"	$ 11.00	$ 3.56
2"	$ 14.00	$ 3.56
3"	$ 25.00	$ 3.56
4"	$ 35.00	$ 3.56
6"	$ 65.00	$ 3.56
8"	$ 95.00	$ 3.56
10"	$ 130.00	$ 3.56
12"	$ 155.00	$ 3.56