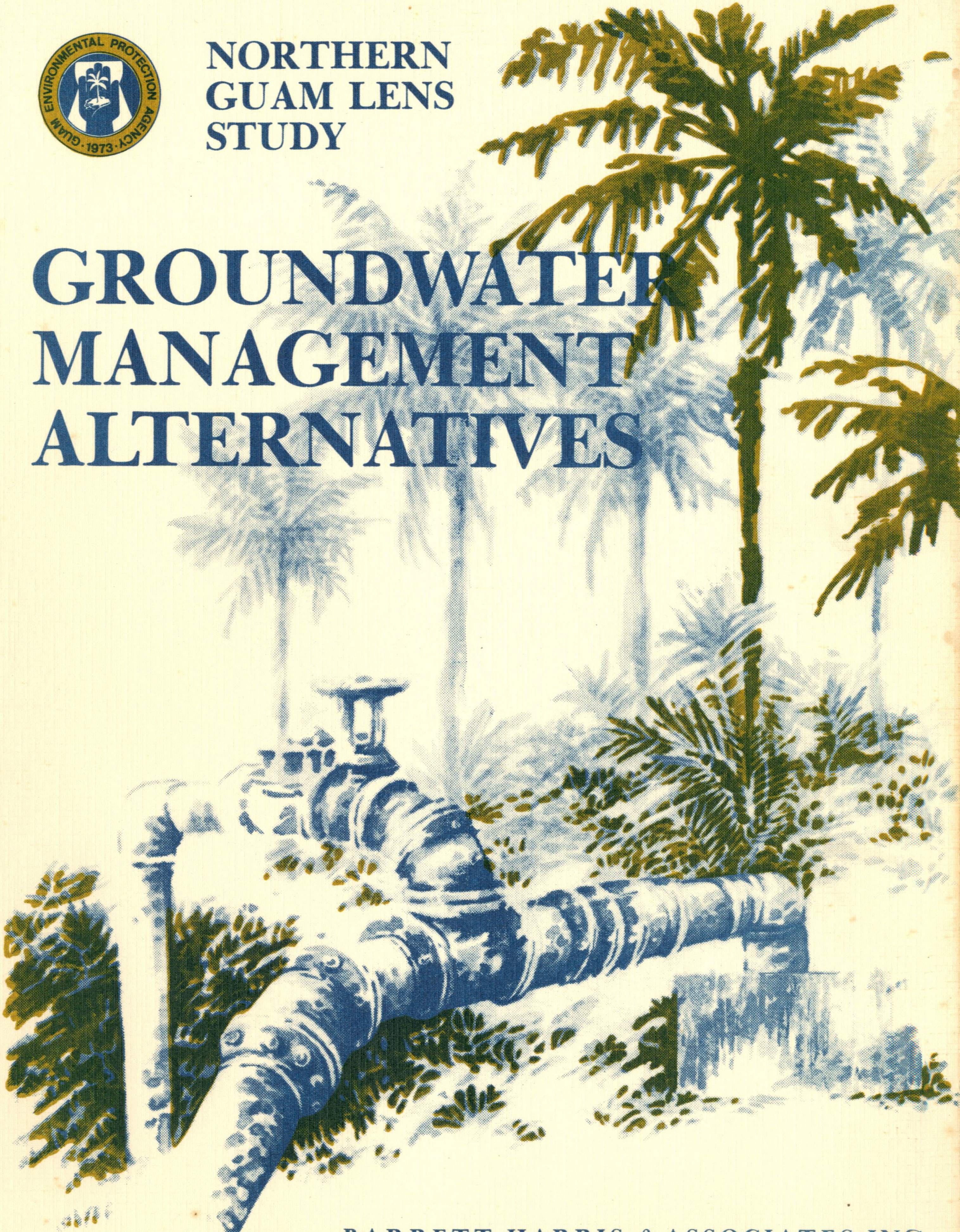
# NORTHERN GUAM LENS STUDY

# GROUNDWATER MANAGEMENT ALTERNATIVES



BARRETT, HARRIS, & ASSOCIATES, INC.
IN ASSOCIATION WITH CAMP, DRESSER & McKEE, INC.

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# GROUNDWATER MANAGEMENT ALTERNATIVES

Prepared for the

GOVERNMENT OF GUAM

GUAM ENVIRONMENTAL PROTECTION AGENCY

December 1982

Prepared by:

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in association with

Camp, Dresser & McKee, Inc.

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December 16, 1982

Guam Environmental Protection Agency
Post Office Box 2999
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Gentlemen:

We are pleased to submit herewith the Groundwater Management Alternatives Report prepared under the first phase of the Northern Guam Lens Study. This report, along with the Aquifer Yield Report, provides the background data and criteria needed to establish the framework for developing a comprehensive groundwater management program.

Our appreciation is extended to the many Government of Guam and Federal agencies who contributed to the study for without their active participation and cooperation the Northern Guam Lens Study could not have been successfully completed. A special thanks is extended to James B. Branch, who acted as the Project Manager and to John F. Mink, who served as Project Director. We look forward to discussing our findings with you at your convenience.

Very truly yours,

BARRETT, HARRIS & ASSOCIATES, INC.

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FDZ:SCK:nm

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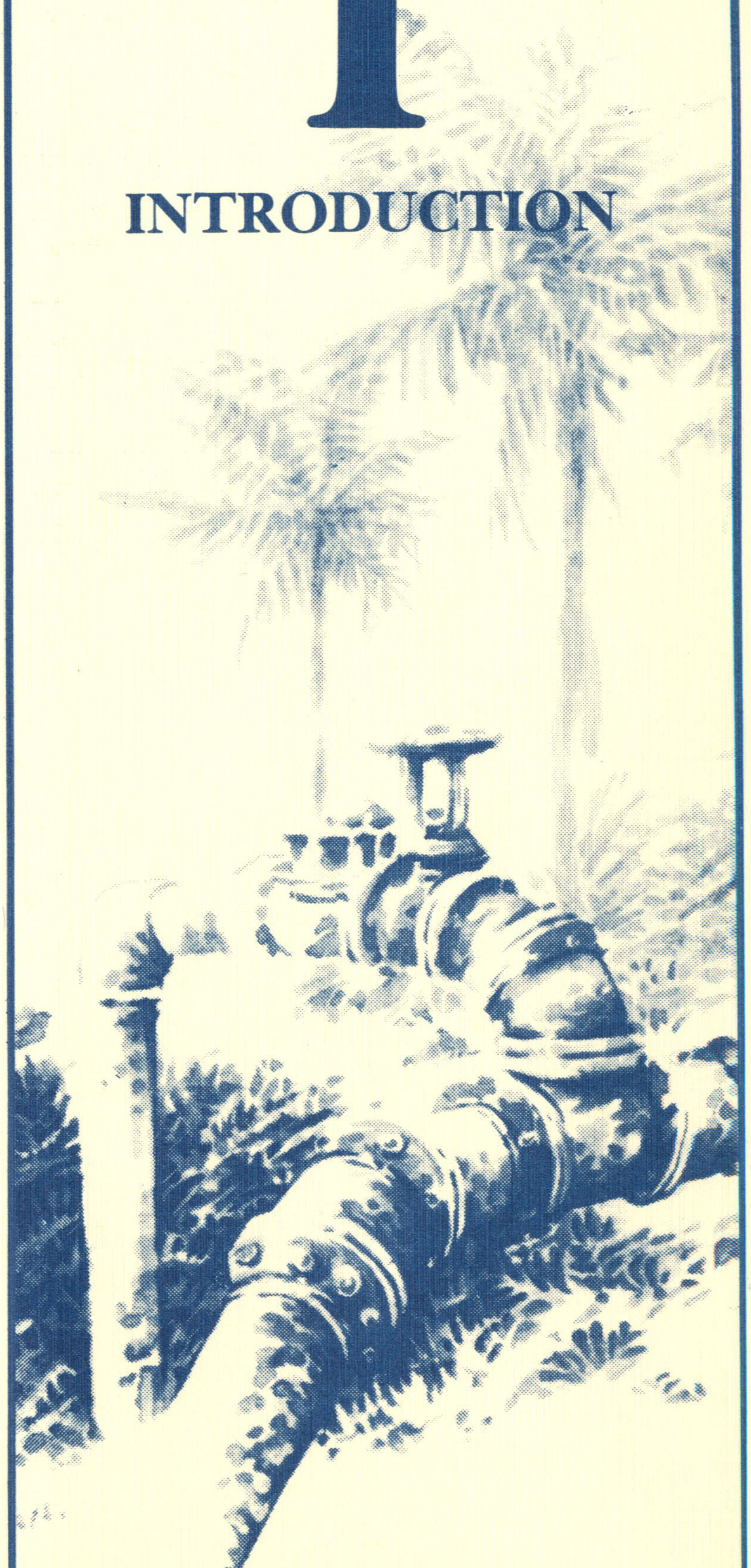
| | |
|---|---|
| APC | Areas of Particular Concern |
| BOP | Bureau of Planning |
| CPC | Central Planning Council |
| CZM | Coastal Zone Management |
| DAg | Department of Agriculture |
| DOC | Department of Commerce |
| DOI | U.S. Department of Interior |
| DLM | Department of Land Management |
| DPHSS | Department of Public Health and Social Services |
| EC | Electrical Conductivity |
| EDA | U.S. Economic Development Administration |
| EIA | Environmental Impact Assessment |
| EIS | Environmental Impact Statement |
| EPA | U.S. Environmental Protection Agency |
| FmHA | Farmers Home Administration |
| FEMA | Federal Emergency Management Authority |
| FSDWA | Federal Safe Drinking Water Act |
| gpcd | gallons per capita per day |
| gpd | gallons per day |
| GCG | Government Code of Guam |
| GovGuam | Government of Guam |
| GMS | Groundwater Management Study |
| GEDA | Guam Economic Development Authority |
| GEPA | Guam Environmental Protection Agency |
| GHURA | Guam Housing and Urban Renewal Authority |
| GPA | Guam Power Authority |
| GSDWA | Guam Safe Drinking Water Act |
| GPSDWR | Guam Safe Drinking Water Regulation |
| GSCH | Guam State Clearinghouse |
| HUD | U.S. Department of Housing and Urban Development |
| kwh | kilowatt hour |
| MLLW | mean lower low water |
| MSL | mean sea level |
| MOU | Memorandum of Understanding |
| ml | milliliters |
| mgals | milligals |
| mgd | million gallons per day |
| meq | milliequivalents |
| NAS | Naval Air Station |
| NCS | Naval Communication Station |
| NGLS | Northern Guam Lens Study |

| | |
|---|---|
| ppb | parts per billion |
| PUD | Planned Urban Development |
| PUAG | Public Utility Agency of Guam |
| RA | Regional Administrator of EPA |
| sf | square feet |
| SDRC | Subdivision Development Review Committee |
| TPC | Territorial Planning Commission |
| TSPC | Territorial Seashore Protection Committee |
| USAF | United States Air Force |
| USGS | United States Geological Survey |
| USN | United States Navy |
| UOG | University of Guam |
| WERI | Water and Energy Research Institute |
| WFMP | Water Facilities Master Plan |
| WQS | Water Quality Standards |
| WRRC | Water Resources Research Center |

# I

# INTRODUCTION



# CHAPTER I

# INTRODUCTION

## Background

The Government of Guam has long recognized the significance and importance of protecting its primary source of drinking water, the northern groundwater lens, or Northern Lens. In 1974, the legislature of the Government of Guam (GovGuam) enacted the Water Resources Conservation Act, which includes the following policy statement:

> *...(It is) the policy of the government of Guam, in recognition of its duty to conserve and control its water resources for the benefit of the inhabitants of Guam, that comprehensive planning and regulations be undertaken for the protection, conservation and development of the water resources of Guam to the end that they shall not be wasted, and shall be used to the fullest extent to meet the present and future needs for domestic, agricultural, commercial, industrial, recreational and other public beneficial purposes. It is further declared that an emergency condition exists with respect to the availability of surface and underground water on Guam and that restrictions are necessary to prevent overpumping of water from wells, the depletion of surface and underground water, the intrusion of salt water, sewage and other contaminants and the resultant permanent destruction of underground water reservoirs and sources of potable water supply.*

The Guam Environmental Protection Agency (GEPA), through powers vested by the Government, has the responsibility for implementation of the Water Resources Conservation Act. It is under this authority and with the recognition of the importance of protecting the groundwaters of northern Guam, that the Guam Environmental Protection Agency retained Barrett, Harris & Associates, Inc., in association with Camp, Dresser & McKee, Inc. to prepare a comprehensive groundwater management plan.

## Environmental Setting

Guam is the largest of the islands comprising the Mariana Islands chain, being approximately 212 square miles (550 square kilometers) in area, as shown on Figure 1-1. The island itself is approximately 30 miles in length having a width of 8-1/2 miles at

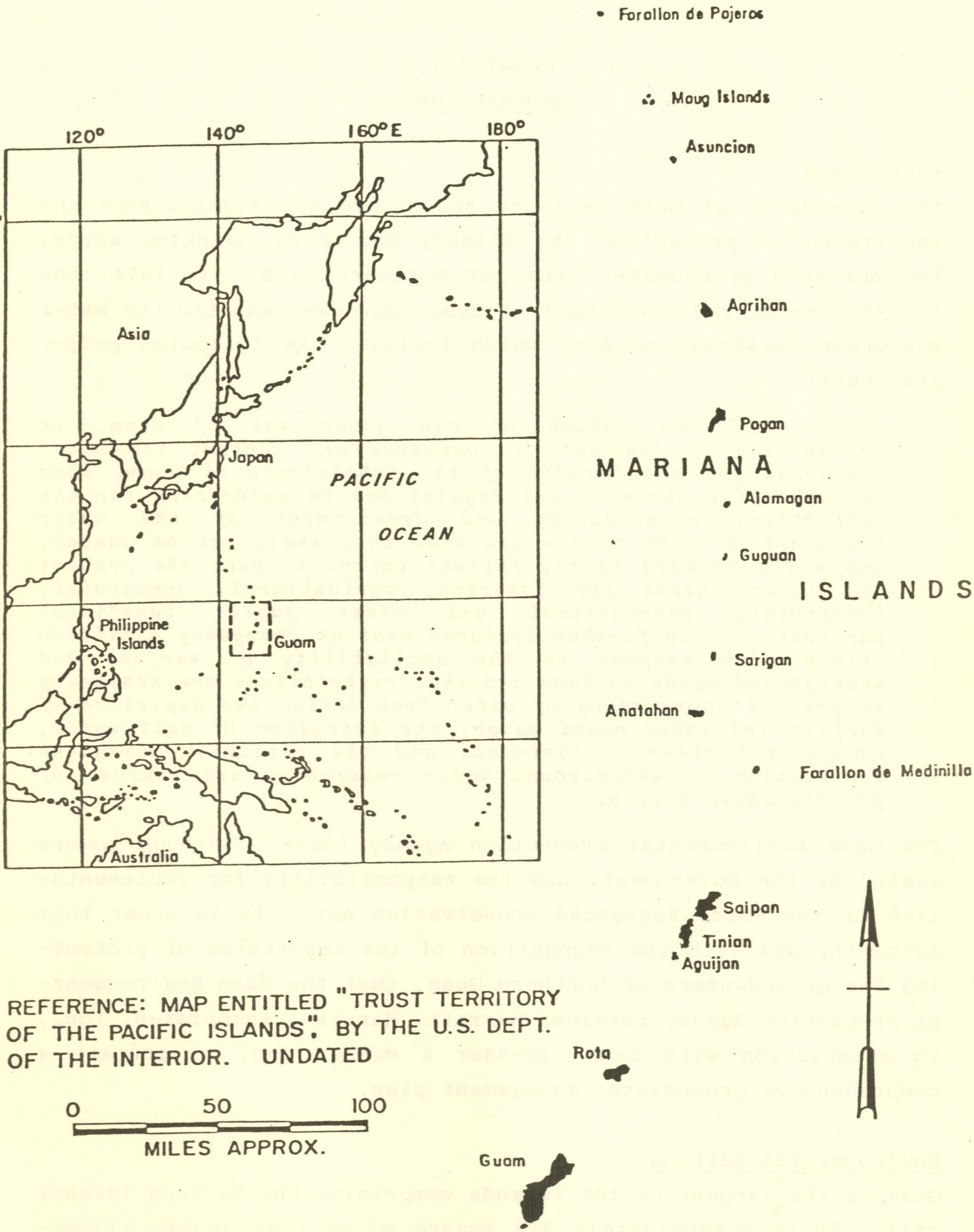



**FIGURE 1-1**
**LOCATION MAP**

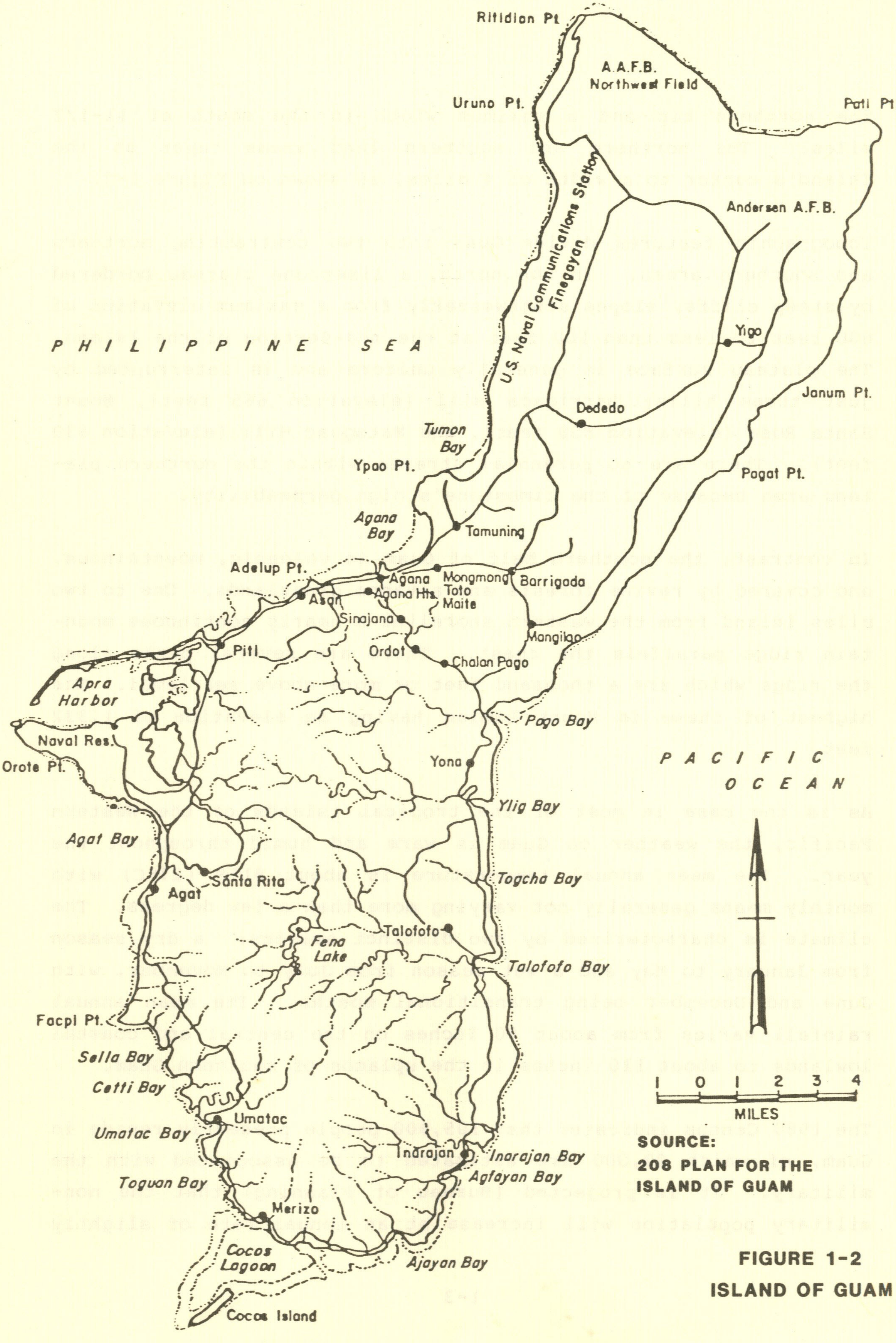
the northern tip and a maximum width in the south of 11-1/2 miles. The northern and southern land areas taper at the Island's center to a width of 4 miles, as shown on Figure 1-2.

Topographic features divide Guam into two contrasting northern and southern areas. In the north, a limestone plateau bordered by steep cliffs, slopes southwesterly from a maximum elevation of 600 feet to less than 100 feet at the mid-section of the Island. The plateau surface is generally uniform and is interrupted by just three hills: Barrigada Hill (elevation 665 feet), Mount Santa Rosa (elevation 858 feet), and Mataguac Hill (elevation 630 feet). There are no perennial streams within the northern plateau area because of the limestone's high permeability.

In contrast, the southern half of Guam is volcanic, mountainous, and covered by ravine forests and savanna grasslands. One to two miles inland from the western shoreline a nearly continuous mountain ridge parallels the coast. There are several peaks along the ridge which are a thousand feet or more above sea level. The highest of these is Mount Lamlam having an elevation of 1,332 feet.

As is the case in most of the tropical islands of the Western Pacific, the weather on Guam is warm and humid throughout the year. The mean annual temperature is about 81°F (27°C) with monthly means generally not varying more than a few degrees. The climate is characterized by two distinct seasons: a dry season from January to May and a wet season from July to November, with June and December being transitional months. The mean annual rainfall varies from about 80 inches on the central and coastal lowlands to about 110 inches in the uplands of southern Guam.

The 1980 Census indicated that 105,900 people presently reside in Guam, of which 22,000 are estimated to be associated with the military. It is projected (Bureau of Planning) that the non-military population will increase at an annual rate of slightly




**SOURCE:**
**208 PLAN FOR THE ISLAND OF GUAM**

**FIGURE 1-2**
**ISLAND OF GUAM**

less than three percent over the next twenty years, resulting in a civilian population increase from approximately 98,000 in 1980 to 167,000 by the year 2000.

In 1979, the Government of Guam, through the Guam Environmental Protection Agency and with the assistance of the Public Utility Agency of Guam (PUAG), completed an Island-wide Water Facilities Master Plan. The planning effort was completed in three phases: Phase I - Sanitary Surveys, Phase II - Water Facilities Master Plan, and Phase III - Financial and Institutional Analysis. These three documents provided the necessary framework for the safe and orderly development of water system improvements to meet projected water demands over the next twenty year period.

As detailed in the Water Facilities Master Plan, the total average production by all water purveyors on Guam (PUAG, military and private), is now approximately 30 million gallons per day (mgd). Of this total, about 20 mgd, or about 65 percent of the total production, is withdrawn from the aquifers of northern Guam. The majority of the remaining water supply is obtained from the Fena Reservoir, a surface supply in southern Guam. Although currently supplying some water to the Government of Guam, Fena Reservoir is owned and operated by the U.S. Navy.

Of the 20 mgd of groundwater produced, PUAG accounts for 16 mgd and the military uses approximately 4 mgd. By the year 2000, the total average annual demand for potable water is expected to reach 40 mgd. In addition to demands generated by population growth, other uses are expected to develop as a result of a progressive and diversifying economy. It is anticipated that a substantial water supply will be necessary to accommodate future agricultural, commercial, and industrial activities. The Government of Guam, the military, and the public at large are concerned over the adequacy of the groundwater resources to meet future needs. The need to implement measures to protect the water quality of the resources to ensure their availability for use as a

safe and reliable drinking water source for future generations to come is receiving increasing attention from Island residents.

Purpose of Study

The limestone aquifer underlying northern Guam constitutes a unique groundwater resource that has adequately responded to development as the Island's primary potable water source since 1964. Nevertheless, the physical extent of the aquifer, the dynamics of its behavior, and its sustainable yields are not known with the confidence necessary to safely plan for Guam's future development. Previous studies have estimated the sustainable yield of the Northern Lens to be about 50 mgd, closely matching the demand expected to occur in about 25 years. If the sustainable yield of the Northern Lens is significantly less than the anticipated demand, other more expensive water supply sources will have to be investigated in the near future. Determination of the adequacy of the groundwater resources of northern Guam to meet future demands is the primary objective of the investigations being conducted as a first phase of the Northern Guam Lens Study (NGLS). The findings of the first phase of the study are summarized in the "Aquifer Yield Report" and in this report, "Groundwater Management Alternatives".

The second phase of the NGLS addresses the management needs for the protection of the Northern Lens. Although some of the NGLS work has been previously submitted as separate documents, the findings of this work have been summarized herein to provide the reader with the proper foundation for understanding the rationale utilized in formulating the various groundwater management alternatives.

Scope of Work

The three reports comprising the Northern Guam Lens Study, the "Aquifer Yield Report", "Groundwater Management Alternatives", and "Groundwater Management Program", are the end-products of a comprehensive groundwater investigation program. Prior to the

initiation of these three reports, other areas of work were initiated, including:

- Topographic Surveys
- Geophysical Surveys
- Exploratory Drilling
- Mathematical Modeling
- Hydrogeologic Evaluation

The organization of the study team involved in the overall program is shown on Figure 1-3. A brief description of the scope of work for each of the program components is included in the following paragraphs.

Topographic Surveys - An accurate determination of groundwater elevations, relative to mean sea level, is critically important for estimating the capacity of the freshwater aquifers. The topographic survey identified surface elevations to the nearest hundredth of a foot at over 100 existing groundwater production and observation sites. The work was completed in July, 1980, and summarized in the report entitled "Determination of Elevations of Groundwater Sites".

Geophysical Surveys - The geophysical sector of the program consisted of seismic refraction and gravimetric surveys for delineation of the impermeable volcanic basement which underlies the limestone aquifer. Refraction survey techniques allowed the establishment of important basement features while the gravity data provided support to the seismic results. Several dominating basement features of critical importance in groundwater development were mapped as part of this work. The results of the geophysical work are included in the report entitled "Geophysical Investigations for the Northern Guam Lens Study" and are summarized in more detail in Chapter IV, "Preliminary Investigative Work".

Exploratory Drilling - Historically, data identifying subsurface geology in northern Guam has been limited. The need for additional exploratory wells as an integral part of the NGLS was clear. The objectives of the exploratory well drilling program included: 1) verification of subsurface geology obtained by geophysical work, 2) determination of aquifer characteristics by means of geophysical logs, coring and pump-testing, 3) analyses of groundwater quality, 4) use of the wells to monitor changes in the groundwater behavior and character. In total, eleven exploratory wells were completed. The exploratory wells provided essential information for evaluation of the subsurface geology and aquifer characteristics and will continue to be important as data gathering sites for as long as they remain accessible.

The exploratory wells were drilled by local contractors with the overall contract administration being performed by Barrett, Harris & Associates, Inc.

Mathematical Modeling - This phase of the program was directed toward the development of a computerized mathematical model for evaluating the dynamics of the Northern Lens. The use of such a model can be well suited for calculating sustainable yields and establishing criteria for groundwater development. The development of a mathematical model, undertaken by the Water and Energy Research Institute (WERI) of the University of Guam, proceeded in parallel with other project tasks because the success and costs associated with the development and operation of such a model were uncertain at the time of the initial undertaking. The work in developing and improving the model will continue for some time, well beyond the completion of the other program components, but the model has already exhibited its utility. The findings of this phase of the project are published in separate documents prepared by the University of Guam.

Hydrogeologic Evaluation - Before definitive conclusions could be reached regarding the extent and characteristics of the limestone

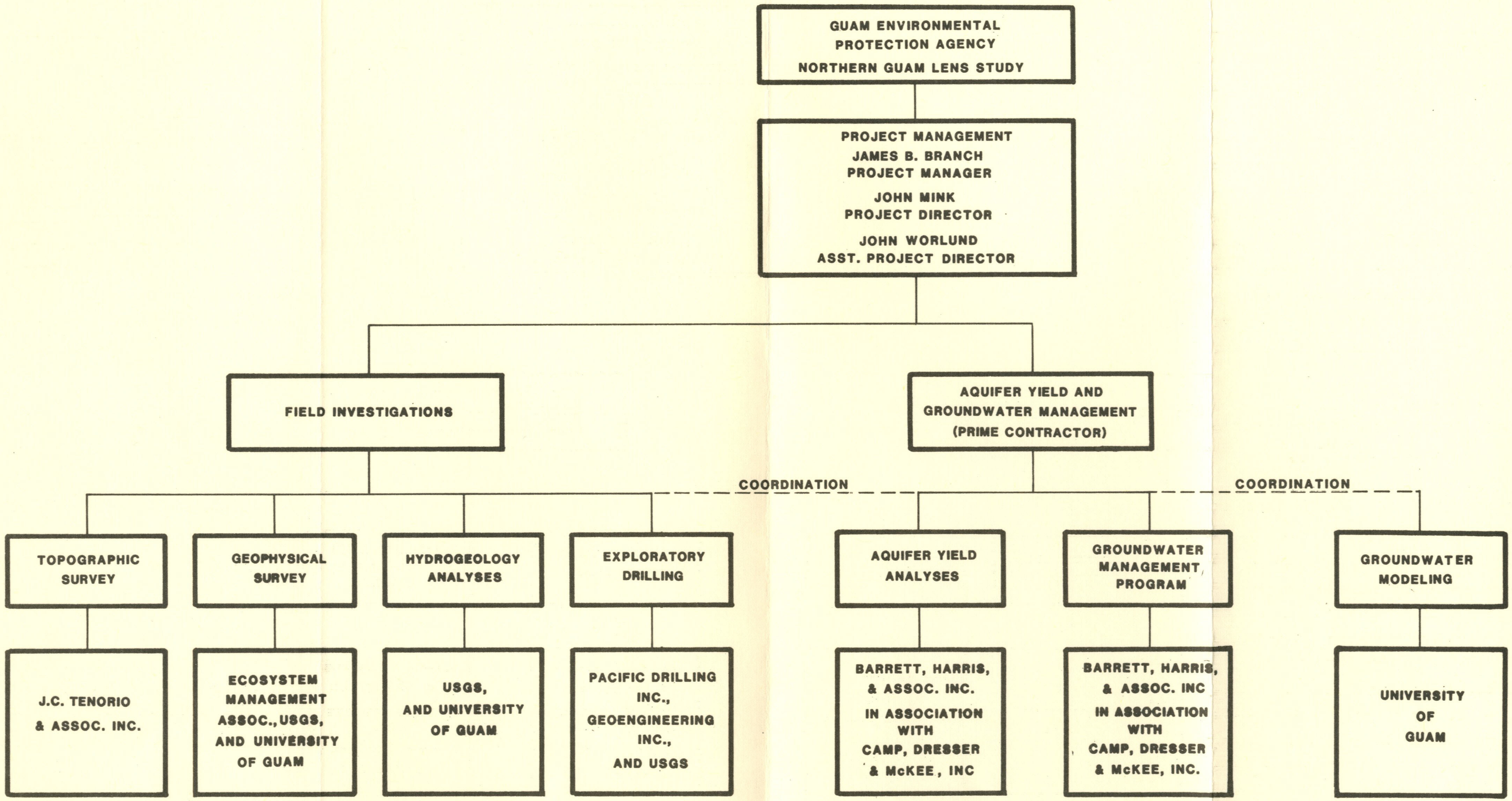



FIGURE 1-3

ORGANIZATION OF STUDY TEAM

aquifer, data collected as part of the geophysical survey and exploratory drilling program required analyses and interpretation of results. Much of these analyses and interpretations were comleted by the U.S. Geological Survey and the University of Guam. Other evaluations were performed by the Project Director, John Mink, and the prime contractor.

The primary goals of the first phase Northern Guam Lens Study were to: 1) identify the extent and dynamics of the northern aquifer and 2) to determine sustainable yields at various levels of development. The findings of this work are included in the companion document to this report entitled the "Aquifer Yield Report". The scope of work for this first phase initially included tasks associated with the development of a groundwater management plan. However, due to funding limitations, the scope of work for the groundwater management element was reduced to identification of management needs and alternative management plans in order to complete the technical elements of the work. It is the intent of this document, "Groundwater Management Alternatives", to provide the necessary documentation and framework for developing a comprehensive groundwater management plan.

As additional funding became available, the NGLS scope of work was expanded to address groundwater management needs. The primary objectives of the second phase were to 1) develop a schedule for future groundwater development, 2) establish rules for managing the Northern Lens, and 3) recommend institutional arrangements for protecting and conserving the resource. These three objectives are addressed in the Groundwater Management Program documents.

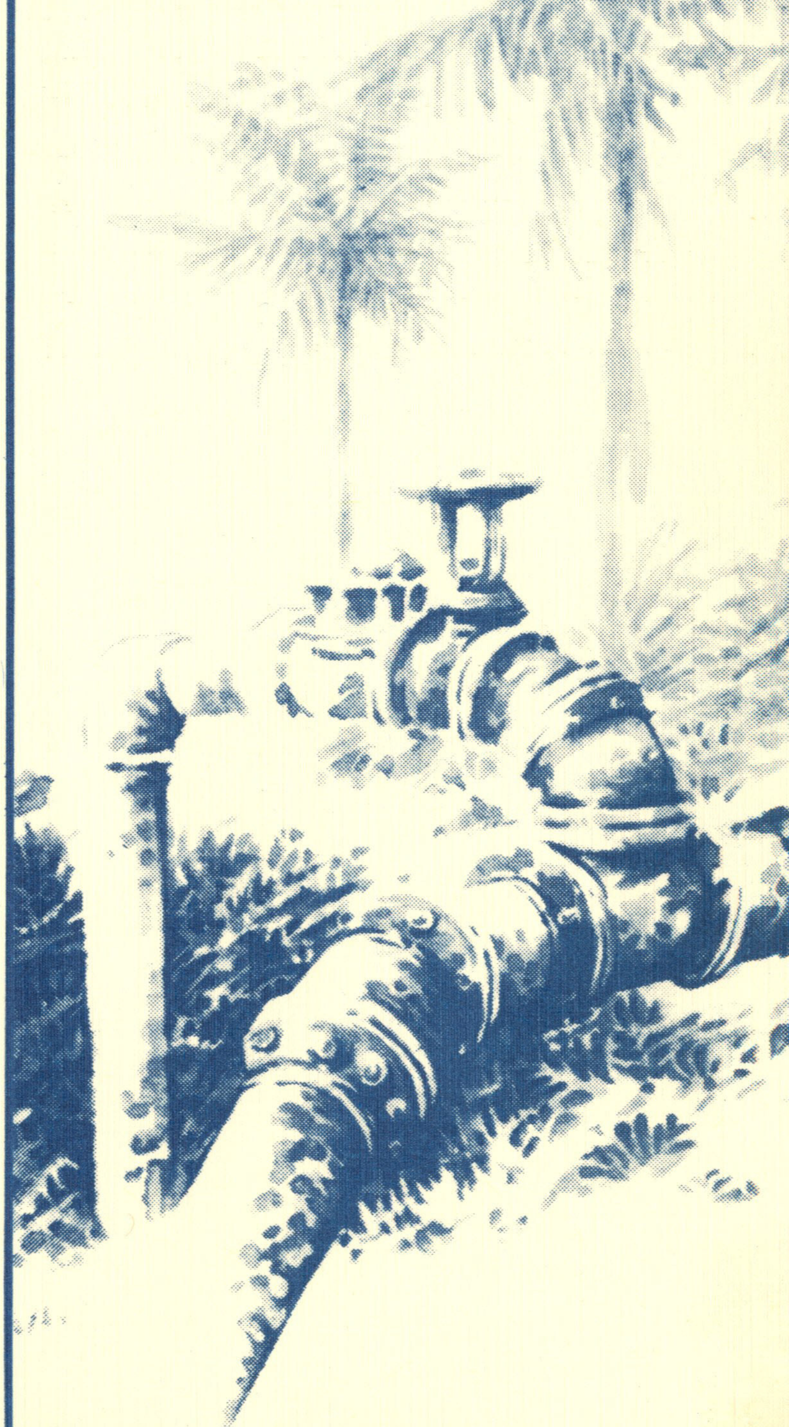
<u>Organization of the Report</u>

The report consists of ten chapters plus an appendix. Chapter I, the Introduction, describes the purpose of the study and the project team. Chapter II summarizes pertinent conclusions reached during the study and makes recommendations. Chapter III outlines

key management issues and needs that were formulated at the early stages of the work effort. Chapter IV provides a summary of the preliminary investigative work including the topographic surveys, geophysical surveys, and exploratory well program. A summary of the anticipated water demands projected to occur over the next twenty year period is included in Chapter V. Many of the environmental features of the Island influencing groundwater development and protection are described in Chapter VI. The physical and operational characteristics of existing wells are detailed in Chapter VII. Chapter VIII provides background on GovGuam agencies responsibilities and existing laws, regulations, and interagency agreements that influence groundwater management activities. Chapter IX discusses various alternatives for satisfying groundwater management needs. From the alternatives outlined in the previous chapter, Chapter X recommends those alternatives to be developed into a comprehensive groundwater management plan.

# II

# CONCLUSIONS AND RECOMMENDATIONS



# CHAPTER II

## CONCLUSIONS AND RECOMMENDATIONS

The Groundwater Management Alternatives report presents the preliminary studies and background information for development of the Groundwater Management Program. In this chapter, text discussions have been summarized, conclusions are presented, and the alternatives that have been selected to comprise the management program are outlined.

To provide input for development of the management issues and needs to be addressed in the study, local agencies were approached and invited to submit their ideas and concerns. The agencies approached included the U.S. Navy, U.S. Geological survey, U.S. Air Force, Public Utility Agency of Guam, Bureau of Planning, Water and Energy Research Institute of the University of Guam, Department of Commerce and the Guam Environmental Protection Agency.

As a result of the input received from these agencies management issued were categorized into technical and institutional issues. The needs to be addressed by the management plan were found to relate to physical solutions, a monitoring program, regulations, revenue sources, water allocation, and enabling legislation.

The specific technical issues were:

- What is the shape of the Northern Lens and how does it vary?
- How does the thickness of the Northern Lens fluctuate with respect to recharge?
- How do rates and direction of flow vary within the Northern Lens?
- What is the thickness of the transition zone and how does salinity vary with depth within the Northern Lens?

- How does water quality vary within sections of the Northern Lens at different depths?

- What will be the effects of prolonged dry seasons upon yield from the Northern Lens?

- What are the effects on the Northern Lens of various well configurations and pumpage rates?

- What are the mechanics of natural recharge of the Northern Lens and how do they vary with different geological conditions?

Institutional issues that were identified include:

- What organization or procedural modifications within existing individual agencies are required for effective management of the Northern Lens?

- Would the most effective and acceptable framework for overall management of the Northern Lens be an existing agency, a group of agencies, or a separate new agency?

- Who has legal authority over the groundwater? Should legislation be enacted defining water rights in the Northern Lens?

- How much will the management plan cost to implement and operate and how will it be financed?

- What are the consequences of the lack of a well coordinated groundwater management plan?

Specific needs to be addressed in the management plan include:

- Physical solutions

    a) Delineation of optimum well development areas

    b) Establishment of development priorities

    c) Assessment of need for development of alternative water supplies, i.e., surface sources

    d) Recommendations to improve well performance, to maximize efficiencies, and improve maintenance

    e) Well construction standards to guide future construction of wells

- Monitoring Program

    a) Identification of key indicators required to adequately monitor the Northern Lens

    b) Establishment of adequate monitoring and data collection programs

    c) Designation of a central data collection agency

    d) Development of a monitoring program that can provide an "early warning" system for identification of potential contamination

- Regulations

    a) Establishment of pumping regulations

    b) Modifications to existing regulations and/or establishment of new regulations regarding well location, design, construction, operation and abandonment

    c) Modification of existing regulations or establishment of new regulations to control growth in order to protect the Northern Lens

    d) Establishment of regulations regarding recharge locations, methods, and water quality standards

    e) Regulations regarding storm drains

- Revenue Sources

    a) The management plan will need to address the anticipated costs for the program and identify revenue sources

- Water Allocation

    a) The plan will need to establish statutory authority over Guam's groundwater resources which will likely involve execution of a Memorandum of Understanding (MOU) between GovGuam and the military

- Legislative Authority

    a) Implementation will require an administrative framework to assume overall responsibility for management

b) Legislation for implementing the program must be enacted by the Guam Legislature

Preliminary Investigative Work

Preliminary investigations included topographic and geophysical surveys, exploratory well drilling, and hydrogeologic analyses. Summary findings of these investigations are as follows.

Topographic Survey - In the Northern Lens, the height of the water table above sea level (called the head) is an important parameter in defining the size and shape of the groundwater aquifer. Accurate ground surface elevations are needed so that both water depths and water table elevations may be accurately established. For many of Guam's older well sites, recorded elevations were not taken to the degree of accuracy required by the studies.

Mean Sea Level (MSL) was established as a standard datum and ground elevations to the nearest hundredth of a foot were taken during the topographic survey of 106 water production and observation sites. The July 1980 report, "Determination of Elevations of Groundwater Production Sites", presents the details of the survey approach and a complete tabulation of the results. Table 4-1 summarizes the final survey elevations.

Geophysical Surveys - The objective of the geophysical surveys was to obtain an understanding of the extent and complexity of the subsurface volcanic formations. Knowledge of the depths to the volcanic formations were considered important for defining the groundwater flow system in the limestone aquifer.

A total of 56 seismic refraction profiles were run in April, 1980. Seismic waves were generated with one to three pound explosives placed in holes seven to twelve feet deep. The gravity survey was conducted during the same period with measurements being made at 321 stations, including stations in southern Guam

to determine the continuity of structural features exhibited in the north.

The refraction survey enabled the identification of important subsurface regional structures and provided better definition of the relationship among them. These structures include:

> The Mataguac Rise - a rise in the basement above sea level in a roughly elliptical area of about ten square miles between Dededo and Andersen Air Force Base. The area serves as a critical source of recharge for aquifers on its flanks.
>
> The Santa Rosa-Barrigada Rise - a linear subsurface ridge extending from the vicinity of Mt. Santa Rosa to Barrigada. The ridge plunges steeply on its flanks into the Yigo Trough on the west forcing groundwater to drain in this direction. The probability of successfully obtaining substantial supplies of potable groundwater from east of the ridge is thus diminished.
>
> The Yigo Trough - a subsurface low between the Mataguac Rise and the Santa Rosa - Barrigada Rise extending from Tumon Bay along a gentle arc to the vicinity of the south boundary of Andersen Air Force Base over a length of about eight miles. It receives recharge from both rises and channels a large volume of fresh groundwater toward Tumon Bay.

Exploratory Wells - An exploratory well program was initiated in October, 1980 with the following principal objectives:

- Verification of the basement configuration;
- Determination of the lithologic characteristics of the aquifer;
- Establishment of the hydraulic characteristics of the aquifer;

- To describe groundwater dynamics on local and regional scales;
- To describe water quality distribution, vertically and laterally; and
- To employ wells for observation and long term monitoring of aquifer behavior.

Eleven wells were contracted for; twelve were drilled.

An analysis of the geophysical investigations and exploratory well drilling program produced the subsurface volcanic basement map shown on Figure 4-2. Aquifer types, i.e., basal and para-basal aquifers, are shown on Figure 4-3. The Aquifer Yield Report contains a complete description and analysis of the underlying basement structures and the estimated aquifer yields.

Water Demands

The scope of work for the NGLS did not include determining water demands but considerable studies have already been conducted through the Water Facilities Master Plan (WFMP) completed in late 1979. The data contained in this report are taken from the WFMP.

The four groups of water users are the U.S. Air Force, U.S. Navy, GovGuam (PUAG) and private users. Sources include wells, springs, and surface supplies. Except for the Navy's Fena Reservoir, the bulk of water production is from groundwater sources.

Per capita use by service area varies throughout the Island, with the variation being largely a function of degree and type of supportive services provided within the community. For water demand projections, per capita use in each service area is estimated at:

| | |
|---|---|
| Service Area "A" | 80 gpcd |
| Service Area "B" | 145 gpcd |
| Service Area "C" | 100 gpcd |
| Service Area "D" | 105 gpcd |

Future average daily water demands were estimated by applying anticipated per capita demands to population projections. Demand variations were determined by the following ratios (to average day demands):

| | |
|---|---|
| Average Day in Maximum Month | 1.20 |
| Maximum Day | 1.50 |
| Peak Hour | 3.00 |

Figure 5-4 illustrates the level of increased water demands to the year 2000 for varying percentages of unaccounted-for water. In terms of relating the projected water demands to the sustainable yield of the Northern Lens, the pertinent water demand is the "average day in the maximum month" demand, or 120 percent of the average day demand.

Projected water demands for the Commercial Port/Industrial Park complex and for agricultural purposes are presented in Tables 5-3 and 5-4, respectively. Total public water requirements are shown on Figure 5-6. These projections in Figure 5-6 can vary depending upon the extent to which the unaccounted for water component varies.

Military water demands are projected and shown in Table 5-5. Private water production is estimated to remain at the one million gallon a day level to the year 2000.

Islandwide future water requirements are shown on Figure 5-7, which were estimated by totalling the projected average annual demands of PUAG, the military, and private users.

Environmental Situation

The Northern Lens can be easily disrupted and water quality affected through over pumpage, inadequate well design, changes to natural drainage patterns and through the introduction of waste materials.

The quality of the groundwaters is equally as important as its quantity. Measures of chemical, physical, biological and radiological constituents must be specified. Several Federal and local laws and regulations have been enacted to specify water quality standards. In particular these are:

Water Quality Standards - recently revised and formally approved by the Board of Directors of GEPA in September, 1981. These standards must still receive approval of the Legislature and Governor of Guam.

U.S. Public Law 95-217 - Federal law that sets national goals for discharge of pollutants and attaining interim goals of water qality.

Federal Safe Drinking Water Act - Federal law specifying requirements and authority for enforcing safe drinking water standards.

Guam Safe Drinking Water Act - which establishes along with its companion document, the Guam Primary Safe Drinking Water Regulations, requirements and authorities at the local government level relative to enforcement of safe drinking water standards. Guam's primary drinking water standards are listed in Table 6-1.

Recommended limits for constituents in industrial process waters are listed in Table 6-3. Also, classes of irrigation waters based on concentrations of certain constituents are shown in Table 6-4.

In light of today's ever-increasing water demands and Guam's limited water resources, an effective groundwater management plan must consider the potential effects of reuse of available water supplies. One method is to reclaim treated domestic wastewater. Not all wastewater can be reclaimed. Quality of the wastewater; costs of treatment, conveyance and distribution; and the price users are willing to pay, limit the amount that may be reclaimed.

Existing Water Quality Program - Guam has suffered from a lack of a systematic program for sampling and analysis of both its surface and groundwater supplies.

Locations of historical sampling sites are shown in Figure 6-2. A representative summary of groundwater quality is presented in Table 6-6. Based on available data it is concluded that the groundwater quality on Guam is generally suitable for most domestic, industrial, and irrigation needs projected through the year 2000.

The most significant constituents related to origin and movement of groundwaters are: calcium, chloride, silicate, nitrate, magnesium, and total hardness. The two most important are chloride, which reflects salt water intrusion, and nitrogen, which may be an indicator of pollution.

Coliform bacteria is also of significance as it can be used as an indicator organism for pathogenic bacteria, viruses, or protozoa. Table 6-8 shows the PUAG wells which have had positive results from coliform tests at least once between May 1979 and November 1981.

Priority Pollutants - Although historical data analyses provide a fair indication of the inorganic compounds that can be expected in the Northern Lens, the need for a comprehensive water quality monitoring program clearly exists. The primary objectives of priority pollutant analyses are 1) to determine the existence of pollutants, 2) to identify the sources, and, if sources are found, 3) to develop an effective source control plan. The U.S. EPA has compiled a list of priority pollutants comprised of over 130 inorganic and organic compounds and pesticides. The compounds analyzed as part of the NGLS are presented in Table 6-9.

Stormwater Runoff and Recharge - In most of northern Guam, rainfall does not runoff but percolates through the limestone to the groundwater. Any pollutants picked up and transported by stormwaters could be discharged into the Northern Lens. The more developed areas produce a large volume of runoff which recharges the aquifer via ponding basins or dry wells. In other areas, the

stormwaters are discharged to the coast, reducing the recharge to groundwaters.

There are 36 ponding basins distributed among 10 subdivisions in northern Guam as identified in Table 6-10. Figure 6-3 indicates areas where ponding basins are used for stormwater disposal. Many of these basins have been neglected and not properly maintained.

Urban development which increases the extent of impervious surfaces, does not necessarily reduce the recharge to the groundwaters unless the stormwaters are collected and discharged to the ocean. The use of ponding basins could actually increase recharge. The more serious potential problem, however, is the quality of recharge waters rather than quantity.

Dry Wells - In northern Guam, dry wells are used mainly for draining runoff in military development areas. There are at least 104 dry wells at Andersen Air Force Base. Reportedly there are at least four dry wells located on NAS and at least two on NCS.

In 1969, a joint study by the Air Force and USGS found that contaminants were entering the Andersen dry wells in several areas. No contamination related to dry well drainage was found in any samples collected south and west of the base. In light of the new knowledge about the basement volcanics, additional consideration should be given to the location and continued use of dry wells.

A University of Guam investigation of urban runoff quality concluded that runoff entering ponding basins were generally of high quality. Table 6-11 summarizes the water quality characteristics of urban runoff in Guam.

Groundwater Monitoring - The prediction of aquifer yields and assessment of groundwater quality variations require a comprehensive monitoring program. Major gaps still exist in the data base which restrict the accuracy of the sustainable yield analyses. The two most important data gaps are accurate, long-term groundwater level measurements and evapotranspiration information which is used to determine recharge for each hydrologic subbasin.

Additional monitoring efforts are also needed to detect groundwater pollution.

Land Use - On Guam, the Bureau of Planning establishes long-range plans for land use and development while the Territorial Planning Commission through its staff agency, the Department of Land Management, regulates and administers land uses and developments.

In 1977, the Bureau of Planning prepared the Land Use Plan Guam, 1977-2000. In the Plan, Guam's major land areas were identified and evaluated for development potential, existing characteristics, environmental restrictions, or ecological complexities. Four civilian land use districts were defined: urban, rural, agricultural and conservation. A map indicating the boundaries of each is presented on Figure 6-6.

## Well Production Facilities

Description of Facilities - In all, 87 deep wells and an infiltration gallery presently withdraw water from the Northern Lens. PUAG owns 71 of the deep wells, the U.S. Air Force owns eight, the U.S. Navy owns three and private companies own five. The Air Force also owns the infiltration gallery known as the Tumon Maui Well.

Thirteen wells are located in the south. PUAG operates two of these and the rest are privately controlled.

Figure 7-1 shows all the well locations in northern Guam. Table 7-1 is a summary of PUAG wells currently in operation and a complete inventory of all PUAG wells is presented in Appendix A.

Most of PUAG's wells were originally developed and operated by private companies wholesaling the water to PUAG for distribution. Since 1976 PUAG has owned the wells but operation and maintenance are still contracted out to a private company. The basic services provided by Pacific Drilling, Inc. under the current contract are summarized in Table 7-2. The current operations and maintenance contract has a duration of four years dating from February 1, 1980 with costs for services being renegotiable every year.

The design and construction of PUAG's wells have been standardized. Discharge piping and controls are essentially identical except for differences in configuration to adapt each well to a particular site. Pumps and motors are standardized with replacement units maintained in stock. Appurtenances include a meter, a slow-closing check valve and a pump control valve. Chlorination equipment has been installed at thirty-two well stations. The typical well station facility is shown on Figure 7-2.

Evaluation of Facilities - A comprehensive study of well stations was made based on field inspections conducted in June of 1982, interviews with PUAG and Pacific Drilling, Inc. staff and existing records, drawings and plans. The findings of the study include:

Design - Well capacities have been limited to 200 gpm based on recommendations made in the 1976 report "Groundwater Resources of Guam: Occurrence and Development" by John Mink.

The same size and type of pump is used for all well stations with only the number of pump stages varying. The performance curve for the pumps indicates that over a 70 percent

efficiency can be achieved by these pumps over a wide range of flows.

Detailed hydraulic analyses are typically neglected in design of not only well facilities but also in transmission or distribution system improvements. The pump selection process has been based on as little information as a single pressure reading taken along the distribution main near the proposed point of connection for the proposed well.

Because the majority of wells are not housed, chlorination equipment is located outside and subject to the effects of direct sunlight and vandalism.

For those wells being chlorinated, a substantial savings could be realized by applying the chlorine solution through a pipe directly into the well rather than by injecting the solution into the distribution system line using a booster pump. In-well chlorination would eliminate the need for the booster pump and could reduce operational costs by $2,000 per well per year.

Less than half of PUAG's wells have been provided with adequate air lines or sounding tubes for determination of water level.

Various sizes of production meters, from 3 to 6 inches, are used. There is no need for such a range, inasmuch as all wells produce approximately 200 gpm.

Pump control valves have been provided although not all wells require them. Regardless, the valves are non-functional. Surge protection for certain wells is therefore not available.

Operation - All of the wells are presently operated manually upon instructions to Pacific Drilling from PUAG. Visual inspections of reservoir levels are the basis for determining which wells are to be operated. Presently, most of the wells are operated on a continuous basis.

Automatic pump control and reservoir level monitoring equipment are important to prevent water wastage from overflowing reservoirs and to effectively monitor the operation of the system as a whole.

Chlorination equipment is also operated based on feed rates determined by PUAG. However at the time of the inspection of facilities in June, 1982, thirteen of the thirty-two wells had empty chlorine tanks.

Maintenance - The field inspection also revealed numerous deficiencies with the well stations which are graphically summarized on Figure 7-5. The more serious problems noted about the condition of facilities include:

a) Pump control valves - Electrical connections for these valves have been disconnected. The valves are no longer operational.

b) Production meters - nearly 20 percent of the meters are not functioning.

c) Well Screens - Severe "in-casing" drawdowns are evidently occurring reportedly due to "failed" well screens. Chemical treatment of the older wells has thus been discontinued although it is required by the operation and maintenance contract.

d) Pump Efficiency - Approximately one-third of the wells operate at 150 gpm or less. Flow rates have changed from a low of 70 to a high of 245 gpm. Thus many wells are operating outside the optimum efficiency range as shown on Figure 7-4.

Reporting Procedures - Pacific Drilling submits monthly reports to PUAG summarizing well production and O&M activities. The

report includes 1) a summary of production by wells, 2) volts, amperes, and resistance readings for each well, 3) a listing of all work performed, and 4) an invoice for production and for preventive maintenance and repairs made that month. The data is not assembled in an organized manner so that a history of each well station can be easily developed.

Well Operation Contract - Problems with the current contract include 1) lack of specificity of the work to be done, 2) failure to provide a mechanism for certifying compliance with the requirements, 3) lack of requirements for operating and maintaining chlorination equipment, and 4) no mechanism or system of accounting for verifying maintenance expenses or accounting for flow of materials.

Laws, Regulations and Agreements

The Government of Guam derives its powers entirely from the Organic Act enacted by the U.S. Congress. Pursuant to the authority granted by the Act, the Guam Legislature has, since 1960, adopted numerous laws providing for the protection of the land, water and air resources of Guam in order to maintain a high quality environment for the enjoyment of the people of Guam.

A review of the laws, rules and regulations was conducted and the following specific items may require modification in order to implement an effective groundwater management program:

Water Resources Conservation Act (Title LXI, Chapter II) Government Code of Guam (GCG)

1. Law pertains to well drilling, permits and licensing. It may not reflect findings of the NGLS and may not meet the needs of the Groundwater Management Program.

2. Act is applicable only to wells constructed after December 30, 1974.

3. Act does not specifically address right to inspect military well facilities.

4. Fees for permits, penalties, etc. are to be deposited in PUAG Fund.

5. Schedule of fees and charges is outdated.

6. Well production meters are to be installed by GEPA, not the well owner.

Toilet Facilities and Sewage Disposal Act (Title LXI, Chapter IV, GCG)

1. Requires GEPA approval for all sewage facilities, except for single-family dwellings, before building permit or Certificate of Occupancy is issued. Specific right of approval of individual on-site wastewater disposal facilities (e.g., septic tanks with leach fields) is not provided.

2. Empowers PUAG (rather than GEPA) to operate under, administer and enforce this legislation.

Zoning Law (Title XVIII, GCG)

1. Establishes procedures for enforcement, appeals and reviewing of zoning map. Rezoning of lands within aquifer recharge areas does not specifically require an evaluation of potential adverse impacts to the groundwater quality.

2. Minimum lot size for rural areas is 20,000 sf with minimum area of 10,000 sf per dwelling. This size of lot may be in conflict with recommended minimum size lots using on-site wastewater disposal facilities for lands overlying aquifer protection zone.

3. Agricultural subdivisions can have lots as small as 20,000 sf and do not require connection to a public sewer. This may be in conflict with recommended minimum size lots having on-site wastewater disposal facilities for land overlying groundwater protection zone.

4. Zoning changes are not required to have to undergo the SDRC/TPC review process. The legislature can directly make zoning changes without review by TPC.

Principal Source Aquifer Designation - In compliance with regulations implementing the Safe Drinking Water Act, GEPA has taken the necessary steps to have the northern groundwater resource designated as a principal source aquifer. The designation of the Northern Lens as a principal source aquifer was made in a notice

published in the Federal Register on April 26, 1978. This action means that "no commitment for Federal financial assistance may be entered into for any project which the administer determines may contaminate" the Northern Lens.

The U.S. Environmental Protection Agency (U.S. EPA) has promulgated procedural guidelines for project reviews for any project which could possibly contaminate the principal source aquifer. U.S. EPA has final project review authority, but this authority only applies to projects for which application for Federal financial assistance has been submitted.

Memorandums of Understandings - As a result of the principal source aquifer designation, a number of memorandums of understanding (MOU) between local and Federal agencies were signed and issued between the following agencies:

- U.S. Environmental Protection Agency (U.S. EPA) and Guam Environmental Protection Agency (GEPA)
- U.S. Department of Housing and Urban Development (HUD), EPA, GEPA, Guam Housing and Urban Renewal Authority (GHURA), and Guam State Clearinghouse
- United States Economic Development Administration (EDA), EPA, GEPA, Guam Department of Commerce, and Guam State Clearinghouse
- Federal Highway Administration, EPA, GEPA, DPW, and Guam State Clearinghouse
- Farmers Home Administration (FmHA), EPA, GEPA, DPWQ, Guam State Clearinghouse (draft form only)

The MOU between EPA and GEPA was executed in May, 1978, and provides for cooperative project review activities to ensure protection of the principal source aquifer. The general contents of the other MOU's are indicated in Table 8-1.

Military Agreement - A Basic Agreement between the U.S. Navy and GovGuam has been in existence since 1950. This agreement provid-

ed for the transfer of facilities from the Navy to GovGuam which included water systems. The agreement, as revised in 1955, also addresses permissable civilian use of Navy water and the terms for such uses.

Recommended Alternatives For Groundwater Management Plan

In all, 47 alternative measures were developed for consideration as part of the Groundwater Management Program. These alternatives addressed needs related to physical solutions, a monitoring program, laws and regulations, water appropriations, and revenue sources. Detailed descriptions of the 47 alternatives can be found in Chapter IX. Of the 47 alternatives, 31 were selected to comprise the recommended management program.

The following represent the selected physical solution alternatives:

| | |
|---|---|
| Alt. 1 | Prepare Groundwater Development Map |
| Alt. 2 | Designate Well Production Levels and Construction Standards for Specific Groundwater Conditions |
| Alt. 3 | Identify Available Yields for Each Groundwater Subbasins |
| Alt. 6 | Utilize Subbasin Characteristics to Schedule Future Well Development |
| Alt. 7 | Identify Costs as a Function of Well Capacities |
| Alt. 8 | Modify PUAG Well Design Standards |
| Alt. 9 | Require Detailed Hydraulic Calculations for All Well and Water Transmission Main Designs |
| Alt. 12 | Utilize Video Equipment for Inspection of Wells |
| Alt. 14 | Conduct Semi-Annual Well Facility Inspections |
| Alt. 15 | Amend Existing Operations Contract Between PUAG and Pacific Driling, Inc. |
| Alt. 17 | Develop Well History Records |
| Alt. 18 | Install Telemetry Equipment and Automatic Controls for Selected Wells |

Alt. 20 Conduct a Seminar for Well Development Practices

Alt. 21 Conduct a Data Processing Training Program for PUAG

The following represent the selected monitoring program alternatives:

Alt. 24 Undertake Evapotranspiration Studies

Alt. 25 Initiate Comprehensive Groundwater Level Measurement Program

Alt. 27 Monitor All Production Wells for Chlorides and Nitrates

Alt. 28 Selectively Monitor Key Priority Pollutants on a Limited Basis

Alt. 29 Require That All Wells Be Metered and Maintained in Satisfactory Operating Conditions

Alt. 30 Record Water ProductionRates at Weekly Interval for Wells Serving Public Water Systems

Alt. 32 Compile Groundwater Data Report

Alt. 33 Update Aquifer Yield Report

The following represent the selected laws and regulation alternatives:

Alt. 34 Designate GEPA as the Groundwater Management Authority

Alt. 35 Revise the Existing Water Resources Conservation Act

Alt. 36 Revise the Water Pollution Control Act

Alt. 38 Define a New Groundwater Protection Zone

Alt. 40 Establish a Minimum Size of Lots Within Ground-Water Protection Zone

Alt. 44 Execute a Memorandum of Understanding Between GEPA Department of Interior, U.S. Navy, and U.S. Air Force

Alt. 45 Formulate a Groundwater Technical Advisory Committee

The following represent the selected Groundwater Allocation alternatives:

Alt. 46 Recognize Historical Water Use

Alt. 47 Develop Well Construction and Well Operating Permits

# III

# MANAGEMENT ISSUES AND NEEDS

# CHAPTER III

## MANAGEMENT ISSUES AND NEEDS

### General

The goal of the Northern Guam Lens Study (NGLS) is to develop a comprehensive groundwater management plan that can be effectively implemented and will result in safe withdrawals from and protection of Guam's principal source aquifer, the Northern Lens. Before such a plan can be formulated, key issues and needs relating to the development and protection of this water source must first be recognized. The key issues and needs can then be used to formulate various alternative groundwater management plans including water development programs and institutional arrangements.

### Local Agency Input

Because of the importance of local input, an effort was made during the early stages of the study to ensure that local agencies clearly understood the objectives of the study and had adequate opportunity for input into the identification of key issues which were to be addressed. The approach taken involved first contacting all agencies which would be ultimately affected by the study and then discussing a preliminary list of issues with each and obtaining their initial comments. At a later date, the agencies were again contacted for the purpose of expanding upon and finalizing the list of issues. Finally, the key issues were presented and discussed in a public workshop held on November 7, 1980. This procedure allowed each agency adequate time to consider the issues and ample opportunity to provide comments. Interviews were held with representatives of the following agencies:

- U.S. Navy (USN)
- U.S. Geological Survey (USGS)
- U.S. Air Force (USAF)
- Public Utility Agency of Guam (PUAG)
- Bureau of Planning (BOP)

- Water and Energy Research Institute (formerly Water Resources Research Center), University of Guam (WERI)
- Guam Environmental Protection Agency (GEPA)
- Department of Commerce (DOC)

During the interviews, a letter was given to each agency representative describing the purpose of the preliminary contact that included a list of issues previously identified. Mention was made that the preliminary issues, along with comments received from the agencies, would be incorporated into a final list of issues which would be discussed with each agency.

The following paragraphs summarize the content of each agency's comments and concerns regarding the issues that should be addressed during the course of the study.

U.S. Navy - The Navy believed that for the money available for the study, it would be difficult to accurately verify a mathematical model. They stated that a model must be verified and calibrated to accurately predict groundwater dynamics. Their overall impression was that complicated numerical models may not provide the most reliable analysis of the Northern Lens. Thus, the Navy believed an important issue was definition of the model type for use in the NGLS.

The Navy also stated that the study must first resolve difficult technical questions before a management plan can be developed. Therefore, the Navy emphasized that the study should be geared toward technical output as opposed to management issues.

With regard to overall management of the water resources, the Navy is opposed to combining the military and civilian water systems or sharing of water production facilities. The primary reason given for this position was national defense. The Navy is responsible for providing water for normal demands and for unusual demand conditions such as a sudden influx of refugees or

providing water for a large number of ships arriving concurrently in Apra Harbor. The Navy believes that with over 20 million gallons of gravity storage, they have a very reliable water system. In general, their water is obtained from surface supplies and is softer than the groundwaters of Guam. The Navy supply is being effectively treated at the Navy's Fena Water Treatment Plant.

On the other hand, they stated the GovGuam (i.e. PUAG) systems have historically experienced frequent operating problems, including numerous leaks, power outages, and poor maintenance. The Navy, in short, is opposed both to the selling of water and to turning over their system to the civilian sector. The Navy believes an important issue is the role that each of the various water producing entities on Guam will play in the overall management of the Northern Lens.

Another issue the Navy believes important is the practice of diverting recharge through storm drains to coastal waters. In general, the Navy has stated that any physical facility or operational policy or practice which has the potential for damaging the Northern Lens should be thoroughly investigated.

The Navy was opposed to the siting of non-military wells on military owned land for the purpose of producing water for civilian or private needs. They indicated that the Navy would have to be convinced that no other supply alternative is feasible before they would entertain this type of proposal. They did not have any strong objections to the siting of groundwater monitoring wells on military land but did indicate that formal approval would be required.

Finally, the Navy voiced their concern over the increasing high costs of on-island power production. They indicated that the cost of power should be considered in formulating a plan for future water supply development.

U.S. Geological Survey - The Guam Sub-District of the USGS also has strong beliefs regarding the conduct of the study and resolution of issues. The USGS believed that many of the technical issues could be resolved without a model using data alone. It is their opinion that if less money were spent on modeling, more money could be used for the data collection tasks which would provide needed information for the analysis of the Northern Lens. The USGS thus believes an important issue is the reevaluation of the emphasis between the data collection, modeling, and management aspects of the program.

U.S. Air Force - The USAF initially voiced two concerns. The first was directed towards the best location for additional monitoring wells. The concern was raised regarding the intended locations of monitoring wells on military property and the need for coordinating the construction of these wells with the Air Force.

The second concern the USAF voiced was management-oriented and dealt with allocation of water from the Northern Lens. Once the maximum sustainable yield has been established, the USAF believes it is important to allocate a certain percentage of the total yield to each of the water purveyors on Guam, namely PUAG, the Navy, and the Air Force. They believe this is important as future demands will likely exceed the Northern Lens' "sustainable yield". The USAF indicated that their current production levels have reached about 3 mgd; however, flow records from their Santa Rosa Reservoir indicated that only 2 mgd was being conveyed to Andersen Air Force Base. Thus, the Air Force could have an unaccounted-for water rate of up to 1 mgd.

Bureau of Planning - The first of BOP's concerns dealt with the proliferation of unsewered subdivisions overlying the aquifer. In the past, it has been common for most unsewered subdivisions on Guam to use septic tanks with leach fields as the means for wastewater disposal. Such a system can have varying impacts on

the groundwater aquifer. On one hand, it could tend to contaminate the resource as a result of nitrate in the wastewater moving through the limestone layers and eventually reaching the saturated zone. On the other hand, it serves as a source of groundwater recharge to the saturated zone. The BOP feels these questions are very critical and should be addressed.

A second area of concern was the suitability of aquifer recharge through dry wells and ponding basins. Surface runoff recharges the aquifer itself but also represents a potential for polluting the aquifer. The BOP believes the question as to whether or not storm drains discharging to coastal waters should be allowed must be resolved as storm drains remove an input to the Northern Lens hydrologic system and thus could have a damaging effect on the resource.

The Land Use Plan completed by BOP in 1977-78 never received legislative approval. Subsequent to this plan a new plan was completed by the BOP. The BOP has no legal authority to enforce the proposed land uses on Guam as designated through their planning efforts to date. Currently, the Land Use Plan only serves as a guide for the Territorial Planning Commission (TPC) in their decisions on where and what type of development will and will not be allowed. It is up to the TPC to enforce the recommendations of the BOP as they relate to future development on Guam.

Water and Energy Research Institute - During the initial interview, WERI stated that one issue needing consideration is the level of sophistication required for the modeling effort. It was pointed out that for relatively simple questions such as "How does the thickness of the Lens vary with respect to recharge?", a simple computer analysis could be conducted. However, for more complex questions involving more than one dimension, such as questions concerning the rates and directions of flow within the Northern Lens, a more complex model will be required to accurately analyze the Northern Lens.

Public Utility Agency of Guam - PUAG had several comments regarding the issue of future location of wells. They believe it is extremely important that before drilling a well there should be reasonable assurance that it will be productive. They have recently drilled a number of unproductive wells. They have also drilled some wells recently which yielded saline water. PUAG believes that management guidelines should stipulate where wells should be drilled, and provide an estimate of the quantity and quality of water that may be expected. They suggested researching the driller's logs of the unproductive wells for data which may be useful during the study.

Under the management aspects of the study, PUAG believes that an important issue to be addressed is land ownership. PUAG indicated their concern that a number of prime drilling sites are privately owned or belong to the military. The Bureau of Planning often arranges for a land transfer but this does not always progress smoothly. PUAG also questioned the drilling of military wells on non-military lands; for example, the Tumon Maui Well, which belongs to the USAF, is not entirely within military land.

Another issue raised by PUAG was also mentioned by the USAF. This issue involves ownership of the groundwaters of Guam. PUAG believes this is an important issue to address in the management study. It is PUAG's point of view that the people of Guam own all of the groundwaters and the military should purchase groundwater from PUAG.

There also are management issues that need resolution within Gov-Guam itself. PUAG mentioned instances in which other agencies such as the Department of Public Works have requested that PUAG relocate wells based on land use. PUAG feels stringent land use controls should be developed to give priority to proper well location.

Department of Commerce - The DOC's concerns fall within the area of agricultural development. Agricultural development on Guam is minimal (probably less than 600 acres) and the DOC does not foresee a substantial increase in development in the near future. The DOC does not believe that BOP's land use map accurately delineates agricultural areas.

Development of Issues

Based on the preceding information and contacts with local agencies, a list of technical, management, and institutional issues was developed. In the following paragraphs, the primary issues are segregated by type and identified separately.

Technical Issues - There are a number of technical questions regarding Guam's northern groundwater aquifer. These questions must be answered if full use and efficient exploitation of the aquifer is to be achieved. Prior investigations have concluded that the northern Guam groundwater aquifer is a fresh-water lens floating on saltwater and conforms to a Ghyben-Herzberg formation. The ultimate question which must be answered is "What is the acceptable sustainable yield of the aquifer?" Extensive field investigations have been conducted in an attempt to define the physical subsurface conditions of northern Guam and thus permit an improved estimate of sustainable yield. In addition, data have been collected and analytical methods used to show the response of the Lens to various imposed groundwater production levels and patterns.

A number of issues have been identified which raise questions concerning the actual shape of the Northern Lens, the quality of water within the Northern Lens, and the response of the Northern Lens to various well patterns and production levels. Among these are:

- What is the shape of the Northern Lens and how does it vary?

° How does the thickness of the Northern Lens fluctuate with respect to recharge?

° How do rates and direction of flow vary within the Northern Lens?

° What is the thickness of the transition zone and how does salinity vary with depth within the Northern Lens?

° How does water quality vary within sections of the Northern Lens at different depths?

° What will be the effects of prolonged dry seasons upon yield from the Northern Lens?

° What are the effects on the Northern Lens of various well configurations and pumpage rates?

° What are the mechanics of natural recharge of the Northern Lens and how do they vary with different geological conditions?

Institutional Issues - The Guam Environmental Protection Agency (GEPA) has primary responsibility for protection and enhancement of the environment. With regard to water, this responsibility includes ensuring that drinking waters are safe and protected. In carrying out this responsibility, GEPA must interface with numerous other agencies whose primary functions are different than those of GEPA. In attempting to carry out their functions in an efficient manner the other agencies may experience a direct confrontation with some of GEPA's policies. To avoid overlapping functions, nebulous areas of responsibility, and conflicting policies, certain institutional issues must be considered.

Legislative requirements as well as a funding mechanism for implementing any management plan certainly must be evaluated. Institutional issues identified included:

° What organization or procedural modifications within existing individual agencies are required for effective management of the Northern Lens?

° Would the most effective and acceptable framework for overall management of the Northern Lens be an existing agency, a group of agencies, or a separate new agency?

- Who has legal authority over the groundwater? Should legislation be enacted defining water rights in the Northern Lens?

- How much will the management plan cost to implement and operate and how will it be financed?

- What are the consequences of the lack of a well coordinated groundwater managment plan?

Development of Management Needs

Once the technical data have been collected and analyzed and the Northern Lens defined to the accuracy possible within the constraints of the available data and various modeling capabilities, a set of recommendations for management of the Northern Lens to achieve the stated objectives will be developed. Implementation of the management plan for the Northern Lens requires action in the following areas:

- Physical Solutions
- Monitoring Program
- Regulations
- Revenue Sources
- Water Allocation
- Legislation Authorizing Management Program

A brief description of specific needs within these areas is included in the following paragraphs.

Physical Solutions - The Aquifer Yield Report, prepared as part of the overall NGLS, provides the most accurate picture of Guam's groundwater characteristics to date. The report details areas of prime groundwater development, type of groundwater system (i.e., basal or para-basal lens), estimated sustainable yields for individual groundwater basins, and recommended well design criteria (i.e., production rates, well depths, and related data). This information can be used to optimize scheduling and physical procedures for well development. Needs in the area of well development scheduling include delineation of optimum development areas,

establishment of development priorities, and assessment of the need for development of alternative water supplies, i.e., surface sources.

In order to properly manage existing well facilities and to ensure that future facilities will be properly constructed and maintained, a facilities and operations evaluation should be undertaken. First, a review of the current well station facilities and their operations should be completed. Recommendations should be made to improve well performance, maximize well efficiencies, and improve maintenance procedures that may extend the service life of the facilities. Well construction standards should be adopted that are consistent with the findings of the Aquifer Yield Report and should be used for all future well construction on Guam.

Finally, the overall mode of well operations should be evaluated to determine the need for automatic well control systems. Automatic control of selected facilities would help reduce water losses, provide more efficient well operation, and result in economic savings to Government of Guam. Without an effective well operations program, water losses can be expected to continue through the overflowing of water storage tanks.

<u>Monitoring Program</u> - With the conclusion of the NGLS, substantial data will have been collected and preliminary models developed and calibrated to predict the physical workings of the Northern Lens. However, the task of analyzing the Northern Lens must be an on-going process. Therefore, it is essential to continue the monitoring and data collection programs to gather more information on the Northern Lens to allow refinement of existing models or development of new models that will more accurately define the Northern Lens dynamics.

Certain management needs have been identified in conjunction with on-going data collection and monitoring programs. These needs are summarized as follows:

- Costs will certainly play an important role in the implementation of any program and thus there is the need to identify those key indicators that are essential to adequately monitor the Northern Lens.

- Once the key data needs have been identified it is essential that adequate monitoring and data collection programs are actually established and carried out.

- One agency should be designated to act as the central compiler of all data collected.

- A monitoring program should be developed for providing an "early warning" system to identify potential contamination to the aquifer.

Regulations - The successful prevention of damage to the Northern Lens caused by future activities dictates the need for development and implementation of regulations to protect the overall resource. As a first step, a complete review of regulations presently impacting the Northern Lens must be made including those regulations regarding pumpage, land use, and recharge.

All areas of man's influence on the Northern Lens fall under one of two categories, namely, withdrawals from the Northern Lens or recharge to the Northern Lens. With respect to withdrawals of water from the Northern Lens, the following needs must be satisfied:

- Establishment of pumping regulations so that damage to the Northern Lens will not occur.

- Modifications to existing regulations and/or establishment of new regulations regarding well location, design, construction, operation, and abandonment.

With respect to recharge to the Northern Lens, the following needs have been identified:

- Modification of existing regulations or establishment of new regulations which will control growth in order to protect the Northern Lens.

- Establishment of regulations regarding recharge to the Northern Lens to include recharge locations, methods of recharge, and modification, if necessary, of water quality standards for recharge.

- Regulation of the removal of water from the hydrologic system via storm drains.

Revenue Sources - The implementation, administration, and enforcement activities of the groundwater management plan will undoubtedly require a substantial operating budget. The management plan will need to address the anticipated costs for this program as well as outline revenue sources for covering these program costs. Revenue sources could include governmental appropriations, permit fees, pumpage taxes, penalties, fines, and forms of taxation.

Water Appropriation - There is no consensus as to who has the legal authority over Guam's groundwater resources. As the Island's water demands increase and approach the safe yield of the Northern Lens, the competition for the remaining groundwater will increase. To ensure that the Northern Lens is not contaminated from over pumpage, an orderly system for monitoring existing and future water withdrawals must be established. It is clear that the system, however developed, must be equitable to all parties (i.e., GovGuam, USN, USAF, and private users) and receive the approval of the Guam Legislature. In addition to the development of statutory law, it is likely that a memorandum of understanding (MOU) between Gov uam and the military would be beneficial in defining management needs and respective agency roles in groundwater management activities.

Legislation Authorizing Management Plan - Through the efforts completed as part of the NGLS, a comprehensive groundwater management plan will be developed. To implement the proposed plan, an administrative framework must be structured to assume overall responsibility for management of the Northern Lens and the authority for implementing the program must be established by the Guam Legislature.

If the successful management of the groundwater resource is to be assured, it is likely that one agency must assume overall responsibility for implementing, administering and enforcing the various program features. The framework for this role could be structured as one activity of an existing agency, such as GEPA, or incorporated into a totally new GovGuam agency. The agency's responsibilities should include the administration of the data collection program, updating of regulations and program activities, and the administration and enforcement of regulations. The formulation of this administrative body will require a spirit of cooperation and compromise from a diverse group of GovGuam agencies and the military; each having different functions and priorities, but all having a vested interest in Guam's groundwater resources.

Once the groundwater management activities are defined and the responsible administering agency is selected, the Government Code of Guam will need to be amended to provide the necessary statutory law for implementing the management and regulatory program.

# IV

## PRELIMINARY INVESTIGATIVE WORK

# CHAPTER IV

## PRELIMINARY INVESTIGATIVE WORK

### General

The Northern Guam Lens Study (NGLS) formally began in September, 1979, when the project director was first selected. Shortly thereafter the first contract, topographic survey, was awarded. The geophysical contract was executed in February, 1980, and the University of Guam's Water and Energy Research Institute and the U.S. Geological Survey began hydrogeologic work in March, 1980. Exploratory well drilling contracts were let on a sequential basis beginning in October, 1980. The following paragraphs summarize the findings of these preliminary project activities.

### Topographic Survey

In groundwater systems conforming to a Ghyben-Herzberg fresh water lens configuration, the height of the water table above sea level (called the head) is a critical parameter because, for every one foot of head, 40 feet of fresh water theoretically extends below sea level. In fresh water lenses, variations in head are quite small and, therefore, accurate water table data are required to establish the size of the lens formation and groundwater flow gradients, i.e., the direction of groundwater movement. Thus, accurate ground surface elevations for wells are required to accurately measure the water level elevations.

Recorded elevations for many of Guam's older well sites were not taken to the degree of accuracy required by the Northern Guam Lens Study, and in numerous instances the datum on which they were based was uncertain. A common datum historically used by the Navy is mean lower low water (MLLW), which is 1.35 feet lower than mean sea level (MSL) on Guam. A very significant error in elevation can occur if the incorrect datum is utilized. The standard datum employed in the NGLS study is MSL.

To establish MSL as the standard datum and to provide accurate ground surface elevations to the nearest hundredth of a foot, a field survey of 106 water production and observation sites on northern Guam was undertaken. Details of the survey approach and complete tabulation of results are available in the July, 1980, report entitled, "Determination of Elevations of Groundwater Production Sites". A summary of the final survey elevations is presented in Table 4-1.

The survey assigned accurate elevations to all PUAG wells, many of which differed significantly from earlier assumed elevations. For instance, the approximate elevation of Well A-11 was thought to be 178 feet, but field surveys indicated the true elevation to be 170.63 feet. Many well sites either had no listed elevations or were assigned elevations from USGS maps. It is understandable that when wells were first drilled in Guam, obtaining accurate elevations was less important than developing an operational water supply.

While accurate elevation data produced by the survey are critical to meaningful groundwater analysis, they will also serve as the baseline for future monitoring of the fresh water lens.

## Geophysical Surveys

Since the earliest hydrogeological investigations were conducted in northern Guam, it was realized that an understanding of the elevation of the "basement" volcanics, i.e., the subsurface volcanic formations with respect to mean sea level, was important in order to define the groundwater flow system in the limestone aquifer. The existence of basement volcanics had been confirmed prior to the Northern Guam Lens Study as several existing wells penetrated the limestone formations and underlying volcanic formations. Also, the volcanics are exposed in a few locations such as at Mataguac Hill and Mt. Santa Rosa. Although known to exist, an understanding of the extent and complexity of the basement volcanics was far from complete. Clearly, additional

TABLE 4-1
ELEVATION OF GROUNDWATER PRODUCTION SITES

| Well Designation | Elevation of Marker (MSL) | Location of Marker |
|---|---|---|
| **A-Series Wells** | | |
| A-1 | 68.31 | Top of building floor |
| A-2 | 119.41 | Top of building floor |
| A-3 | 103.85 | Top of building floor |
| A-4 | 141.00 | Top of conc. slab |
| A-5 | 146.14 | Top of building floor |
| A-6 | 153.38 | Top of conc. slab |
| A-7 | 138.86 | Side of adj. power pole |
| A-8 | 128.17 | Side of adj. power pole |
| A-9 | 186.73 | Top of conc. slab |
| A-10 | 190.25 | Top of conc. slab |
| A-11 | 170.63 | Top of conc. slab |
| A-12 | 138.45 | Top of conc. slab |
| A-13 | 130.98 | Top of conc. slab |
| A-14 | 210.06 | Top of conc. well collar |
| A-15 | 199.03 | Top of conc. well collar |
| A-16 | 208.74 | Top of conc. well collar |
| A-17 | 193.77 | Top of chlorine tank pad |
| A-18 | 194.97 | Top of chlorine tank pad |
| A-19 | 135.98 | Side of conc. well collar |
| A-20 | 141.18 | Side of conc. well collar |
| A-21 | 183.10 | Top of conc. well collar |
| A-22 | 239.94 | Top of conc. well collar |
| **AG-Series Wells** | | M-8 |
| AG-1 | 469.93 | Top of conc. slab |
| AG-2 | 505.97 | Top of conc. well collar |
| **D-Series Wells** | | |
| D-1 | 381.98 | Top of conc. slab |
| D-2 | 381.61 | Top of conc. slab |
| D-3 | 383.52 | Top of conc. slab |
| D-4 | 383.59 | Top of conc. slab |
| D-5 | 377.75 | Top of conc. slab |
| D-6 | 396.66 | Top of conc. slab |
| D-7 | 387.96 | Top of conc. slab |
| D-8 | 414.24 | Top of conc. slab |
| D-9 | 388.03 | Top of conc. slab |
| D-10 | 390.63 | Top of conc. slab |
| D-11 | 392.96 | Top of conc. slab |
| D-12 | 421.44 | Top of conc. slab |
| D-13 | 400.22 | Top of conc. slab |
| D-14 | 318.90 | Top of conc. well collar |
| D-15 | 363.22 | Top of conc. well collar |
| D-16 | 329.26 | Top of conc. slab |
| D-17 | 301.14 | Top of conc. slab |
| D-18 | No data available | |

| Well Designation | Elevation of Marker (MSL) | Location of Marker |
|---|---|---|
| **F-Series Wells** | | |
| F-1 | 424.73 | Top of conc. slab |
| F-2 | 450.41 | Top of conc. slab |
| F-3 | 455.32 | On pipe support footing |
| F-4 | 456.97 | On fence post footing |
| F-5 | 390.33 | Top of conc. slab |
| F-6 | 346.99 | Top of pad for well outlet |
| F-7 | 365.92 | Side of adj. power pole |
| F-8 | 439.45 | Top of conc. well collar |
| F-9 | 393.73 | Top of conc. slab |
| F-10 | 436.87 | Top of conc. slab |
| F-11 | 440.85 | Top of conc. slab |
| **H-Series Wells** | | |
| H-1 | 291.95 | Top of chlorine tank pad |
| **M-Series Wells** | | |
| M-1 | 395.27 | Top of conc. slab |
| M-2 | 402.70 | Top of conc. slab |
| M-3 | 422.48 | Top of conc. slab |
| M-4 | 422.37 | Top of conc. slab |
| M-5 | 273.45 | Top of conc. slab |
| M-6 | 326.29 | Top of conc. slab |
| M-7 | 289.41 | Top of conc. slab |
| 436.47 | | Top of conc. slab |
| M-9 | 448.62 | Top of conc. slab |
| M-10 | 228.81 | Top of conc. well collar |
| M-11 | 295.29 | Side of conc. well collar |
| M-12 | 272.05 | Top of conc. well collar |
| M-13 | 308.45 | Top of conc. slab |
| M-14 | 474.41 | Top of chlorine tank pad |
| **Y-Series Wells** | | |
| Y-1 | 415.16 | Top of conc. slab |
| Y-2 | 414.72 | Top of conc. slab |
| Y-3 | 415.82 | Top of conc. slab |
| Y-4 | 397.85 | Top of pipe support footing |
| Y-5 | 433.35 | Top of conc. slab |
| Y-6 | 428.43 | Top of conc. slab |
| **GHURA Wells** | | |
| GH-1 | 414.45 | Top of conc. slab |

| Well Designation | Elevation of Marker (MSL) | Location of Marker |
|---|---|---|
| **U.S. Air Force Wells** | | |
| MW-1 | 346.61 | Top of conc. floor in front of door |
| MW-2 | 350.55 | Top of conc. stoop at bldg. center |
| MW-3 | 409.17 | Top of conc. casing for well pipes |
| MW-5 | 418.18 | Top of conc. curb for open pit |
| MW-6 | 394.87 | Top of conc. curb for open pit |
| MW-7 | 367.84 | Top of conc. curb for open pit |
| MW-8 | 357.62 | Top of conc. curb for open pit |
| MW-9 | 356.26 | Top of sidewalk at corner of bldg. |
| TMT | 192.74 | Top of conc. block for pipe |
| BPM-1 | 495.97 | Top of conc. stoop in front of door |
| TW-4 | 8.10 | Top of conc. floor |
| NW | 491.59 | Top of conc. slab |
| AFMW | 483.45 | Top of conc. casing for well pipes |
| RW | 242.76 | Top of conc. casing for well pipes |
| **U.S. Navy Wells** | | |
| NCS-1A | 428.90 | Top of conc. slab |
| NCS-1B | 411.42 | Top of conc. curb near door |
| NCS-2 | 363.55 | Side of adjacent power pole |
| NCS-3 | 355.06 | Top conc. footing of steel post |
| **Private Wells** | | |
| Black Const. | 204.07 | Top of conc. slab |
| San Miguel | 212.23 | Top of AC pav't. |
| Foremost | 138.29 | Top of AC pav't. |
| HRP-1 | 326.97 | Top of conc. block |
| HRP-2 | 337.27 | Top of conc. casing |
| Island Equip. | 79.52 | Top of AC pav't. |

Abbreviations

| | |
|---|---|
| AC | asphaltic cement |
| adj. | adjacent |
| bldg. | building |
| conc. | concrete |
| pav't | pavement |

Source: Determination of Elevations of Groundwater Production Sites, 1980.

investigative work was required to better map the location and depths of the limestone-volcanic interface.

Geophysical techniques had long been proposed as a means of mapping the basement on a regional scale but, prior to the NGLS, had never been employed. As part of the NGLS program, seismic refraction and gravity surveys were successfully completed in April, 1980. Magnetic and seismic reflection techniques were tested but discontinued as inappropriate for the program. Interpretations have continued throughout the study as other data were generated.

A total of 56 refraction profiles were made in the 100 square miles of northern Guam. Length of the profiles averaged 2,500 feet but varied from 2,000 to 3,500 feet. Seismic waves were generated by detonating one to three pound explosives placed in holes seven to twelve feet deep. In simplified terms, the seismic refraction technique differentiates subsurface formations by measuring the velocity of the seismic waves produced by the detonated explosives.

The gravity survey was carried out during the same period as the seismic work. Measurements were made at 321 stations, some of which were in southern Guam even though this area is not included in the NGLS. The southern readings were taken to determine the continuity of structural features exhibited in the north. Details and complete data for both the seismic and gravity work can be found in the report entitled, "Geophysical Investigations for the Northern Guam Lens Study".

<u>Seismic Refraction Survey</u> - The results of the refraction survey were generally satisfactory and in some instances quite definitive. Although the program funding did not permit sufficient profiles to be run to yield unequivocal resolution of the basement volcanic configuration in all of northern Guam, important subsurface regional structures were identified and the relation-

ships among them better defined. The knowledge obtained proved consistent with point sources of information, including wells and volcanic outcroppings and with the results of the gravity survey.

In the majority of all profiles, three distinct seismic velocities were encountered indicating a top layer of limestone, an intermediate limestone layer, and the basement volcanic rock. The first limestone layer exhibited an unusually low velocity, clearly differentiating it from the second limestone layer. In most profiles the volcanic basement was also differentiable from the intermediate limestone, but in several instances the higher range of velocity in the limestone overlapped the lower velocity range of the volcanics so that a judgement based on other factors had to be made in selecting depth to basement. The three layer model consisting of two limestone layers overlying the volcanic basement is applicable throughout most of northern Guam.

Based on the geophysical survey data, in conjunction with groundwater chloride concentrations and exploratory well data, elevation contours of the basement volcanics were estimated. In general, where the basement volcanics are more than about 150 feet below sea level, fresh water is underlain by salt water and a Ghyben-Herzberg "basal" lens formation is likely to exist. In the interval between about 150 feet below sea level and sea level, the Ghyben-Herzberg lens is influenced by impermeable basement volcanic formations and "parabasal" conditions occur. Parabasal conditions occur when the fresh water lens rests on the impermeable volcanic basement rather than salt water.

The results of this seismic refraction survey identified several basement features of significant hydrologic importance, including:

<u>The Mataguac Rise</u> - A rise in the basement above sea level in a roughly elliptical area of about 10 square miles between Dededo and Andersen Air Force Base was outlined. Several

hundred feet of limestone overlie the basement except at small volcanic outcrops near Mataguac. As a general rule, groundwater cannot be developed where the basement is above sea level but, nevertheless, this area serves as a critical source of recharge for aquifers on its flanks.

The Santa Rosa-Barrigada Rise - This feature is a linear subsurface ridge extending from the vicinity of Mt. Santa Rosa to Barrigada. The basement rises above sea level over a 10 mile distance as a narrow ridge varying from a few tenths of a mile to more than a mile wide. The seismic data is consistent with the occurence along the ridge of residual positive gravity anomalies. The ridge plunges steeply on its flanks, and at its southwest nose, drops below sea level before reaching the Agana Swamp. On the west, the ridge plunges into the Yigo Trough, while on the east, the sea level contour apparently coincides with Janum Springs. All of the ridge is covered by limestone. This formation is profoundly important in regional hydrology because it acts as a barrier to groundwater flow. Most groundwater is forced to drain toward the west, which diminishes the probability of successfully obtaining substantial supplies of potable groundwater east of the ridge.

The Yigo Trough - A subsurface low was defined between the Mataguac Rise and the Santa Rosa-Barrigada Rise extending from Tumon Bay along a gentle arc to the vicinity of the south boundary of Andersen Air Force Base over a length of about eight miles. In the well defined portion of the trough, width varies from 1.5 miles at Dededo-Yigo to about half a mile at Andersen Air Force Base. The trough is an extremely important hydrologic feature because it receives recharge from both the Mataguac and Santa Rosa-Barrigada Rises and channels a large volume of fresh groundwater toward Tumon Bay. This explains why the Marbo Air Force wells, many of the PUAG D-Series and M-Series wells, and the Air Force Tumon infiltration gallery are such excellent water sources.

Gravity Survey - A gravity survey was included in the geophysical sector as a means to supplement data yielded by seismic refraction, but a subsidiary purpose was to provide a reconnaissance view of gravity distribution on the island because no such survey had been done before. The normal goal of a gravity survey, which is the determination of regional gravity anomalies, was successfully accomplished.

Over northern Guam regional gravity varies from about 200 milligals (mgals) on the east coast to 220 mgals at the positive anomaly near Potts Junction on Marine Drive. Although not a large gradient, it is significant. A closure of 4 to 5 mgals encircles this high in the northwest quadrant of the Island. The high is not coincident with the volcanic outcrop at Mataguac or the larger exposure at Mr. Santa Rosa. This gravity high has been interpreted as reflecting a deep plutonic core having a radius on the order of 12,000 feet and its center of mass at a depth of 22,000 feet. The regional gravity anomalies did not prove to be a clear guide to basement elevations, but they were indicative of primary subsurface structures.

Exploratory Wells

To reinforce and supplement the results of the seismic and gravity surveys an exploratory well program was initiated in October, 1980. As used in this study, exploratory wells are drilled holes that penetrate into fresh waters and salt water portions of the aquifers and occasionally are drilled to the volcanic basement for the purpose of gathering information on the geology of the aquifer and underlying volcanics as well as the groundwater systems. At each exploratory well a vertical line in the groundwater domain can be precisely measured. If enough wells are strategically located, a large part of the domain may be accurately defined. From this information, in conjunction with other data, fundamental characteristics of the entire groundwater domain was established in terms acceptable for hydrologic and mathematical modeling.

Principal objectives of the exploratory well program were as follows:

- Verify the basement configuration
- Determine lithologic characteristics of the aquifers
- Establish hydraulic characteristics of the aquifers
- Describe groundwater dynamics on local and regional scales
- Describe water quality distribution, vertically and laterally
- Employ wells for observation and long term monitoring of aquifier behavior

In total, eleven exploratory wells were contracted for and twelve were drilled as part of the overall exploratory well program. The locations of the exploratory wells and a summary of the well logs are presented on Figure 4-1.

Summary of Findings

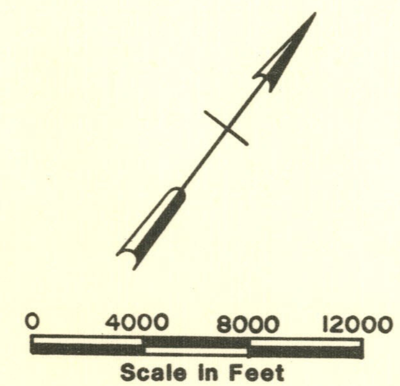
An analysis of the geophysical investigations and exploratory well drilling program produced a very important product, an elevation contour map of the subsurface volcanic basement. An understanding of the structures that underlie the aquifers, as depicted on Figure 4-2, is necessary to establish the foundation for estimating aquifer yields and identifying groundwater basins.

Using the principles of a Ghyben-Herzberg lens formation in combination with an understanding of the basement volcanics, delineation of basal, parabasal and groundwater recharge areas can be made as shown on Figure 4-3. Figure 4-4 illustrates the cross-sectional views of basal and parabasal groundwater conditions. For a complete description and analysis of the underlying basement structures and the estimated aquifer yields, the reader is referred to the Aquifer Yield Report.

## EXPLORATORY WELL DRILLING SUMMARY

| WELL NO. | WELL LOCATION | DRILLED DEPTH (FEET) | CASING DEPTH (FEET) | DEPTH TO VOLCANICS (FEET) | WATER LEVEL (FEET) | LAND SURFACE ELEVATION (FEET) | DATE COMPLETED |
|---|---|---|---|---|---|---|---|
| EX-1 | MONGMONG | 597 | 300 | - | 8.0 | 97.27 | 12/16/80 |
| EX-2 | ANDERSEN BOUNDARY YIGO | 300 | - | 273 | - | 563.9 | 03/05/81 |
| EX-3 | ADACAO | 535 | - | 365 | - | 447.3 | 04/10/81 |
| EX-4 | FATHER DUENAS SCHOOL | 400 | 400 | - | 6.3 | 153.71 | 03/16/81 |
| EX-5(1) | DEDEDO | 570 | - | - | 3.94 | 387.24 | 11/13/81 |
| EX-5a | DEDEDO | 600 | - | - | - | 385.16 | 01/01/82 |
| EX-6 | MACHECHE | 462.8 | - | - | 3.61 | 309.41 | 08/07/81 |
| EX-7 | WETTENGEL JUNCTION | 698 | - | - | 3.76 | 283.31 | 10/08/81 |
| EX-8 | NORTHWEST FIELD | 657.6 | - | - | 2.58 | 462.49 | 09/28/81 |
| EX-9 | BARRIGADA | 513 | - | - | 3.22 | 239.41 | 08/21/81 |
| EX-10 | FINEGAYAN NCS | 704.5 | - | - | 2.99 | 348.54 | 09/05/81 |
| EX-11 | LATTE HEIGHTS | 513 | - | 440 | 5.17 | 389.86 | 01/06/82 |

(1) Obstruction during drilling restricted completion of well
(2) Elevations refer to mean sea level (MSL) datum



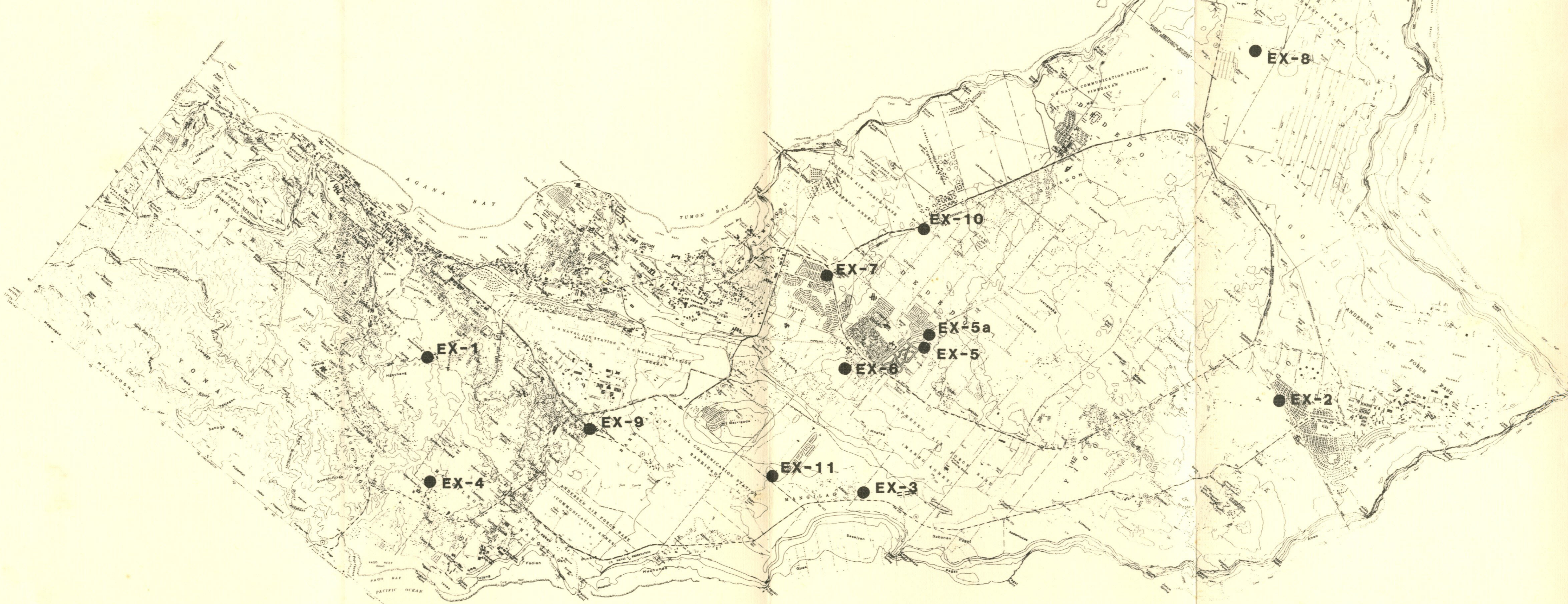




FIGURE 4-1

EXPLORATORY WELLS

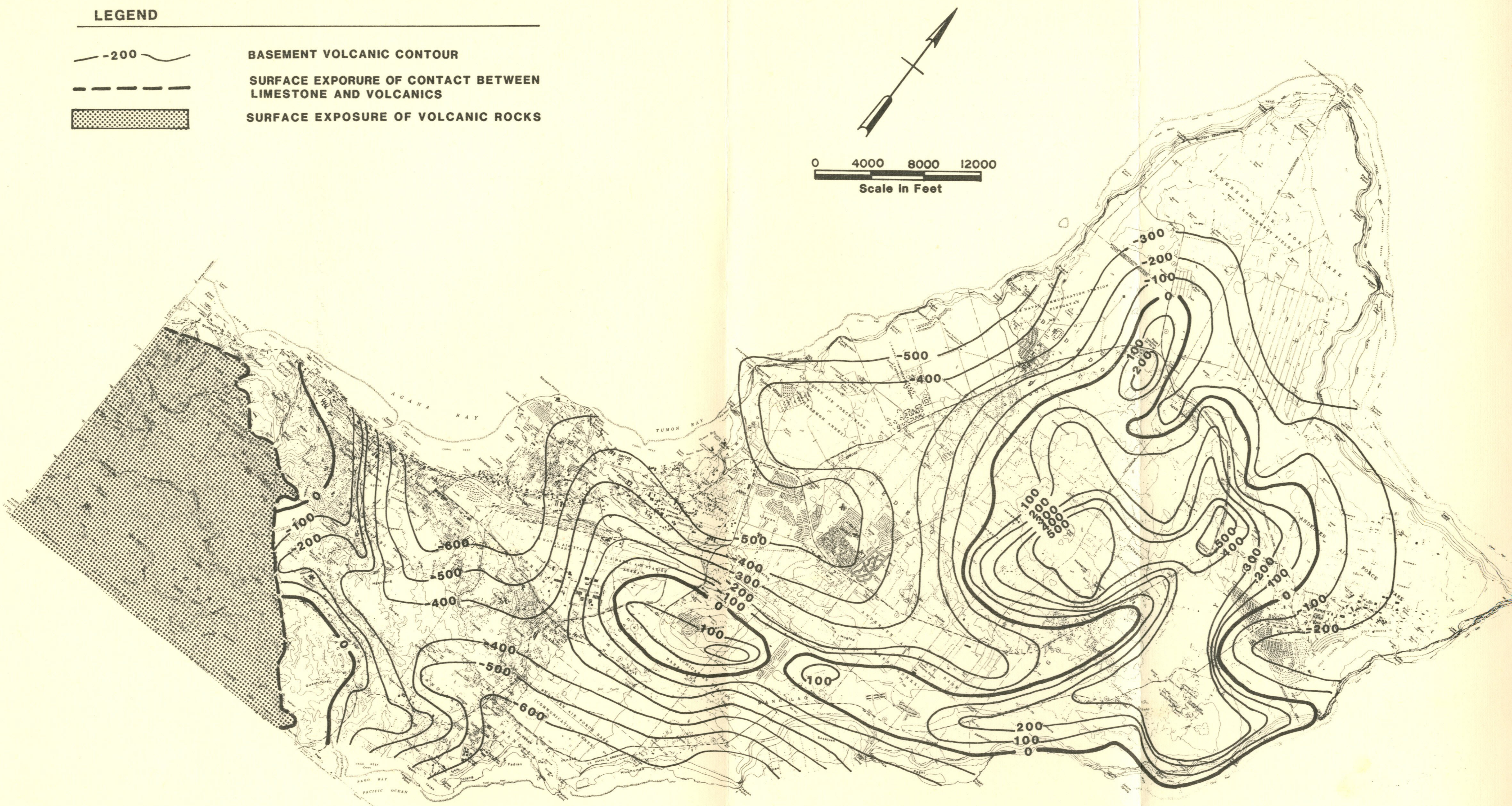
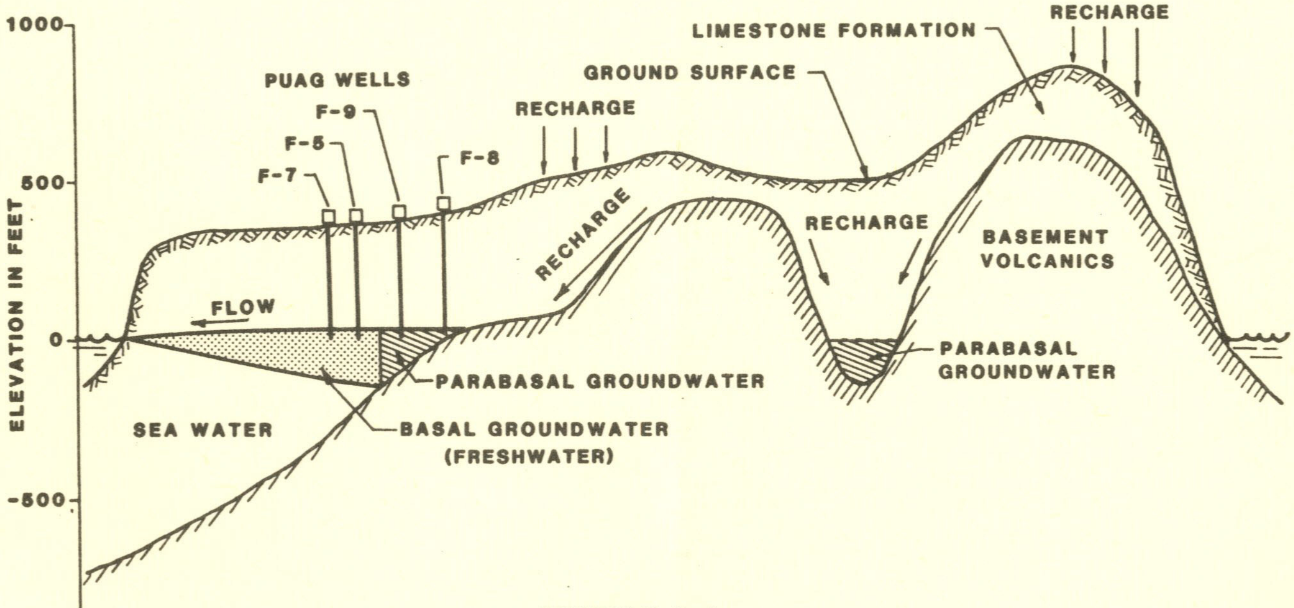
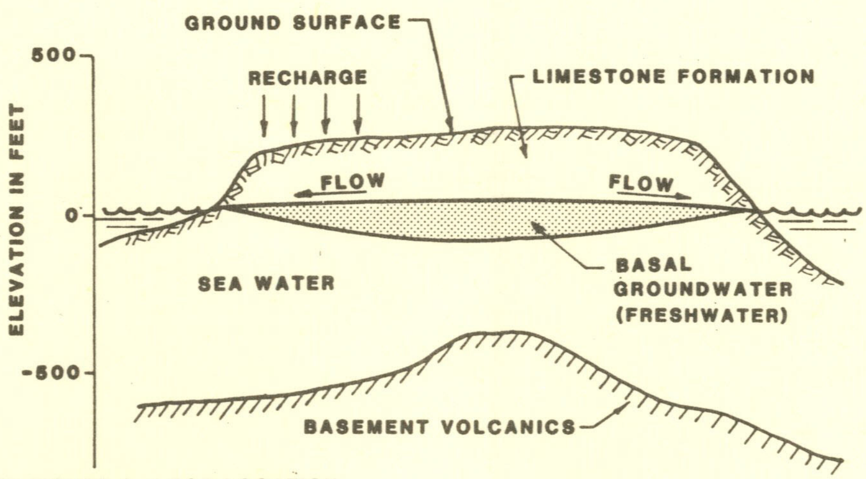



FIGURE 4-2
BASEMENT VOLCANIC CONTOUR MAP




SECTION A-A




NOTE: SEE FIGURE 4-4 FOR LOCATION
OF CROSS-SECTIONS

SECTION B-B

FIGURE 4-3

GROUNDWATER CROSS-SECTIONS

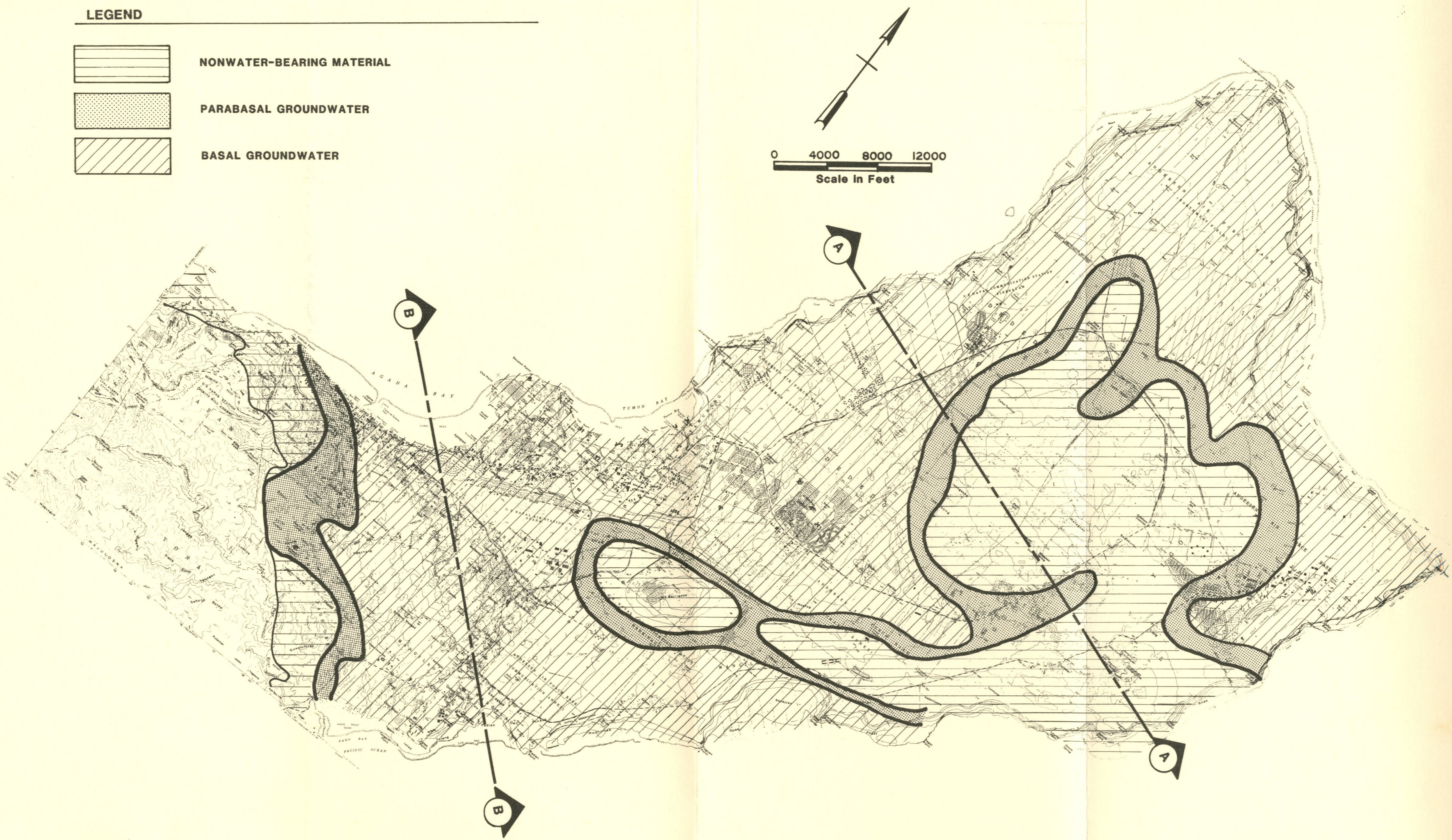
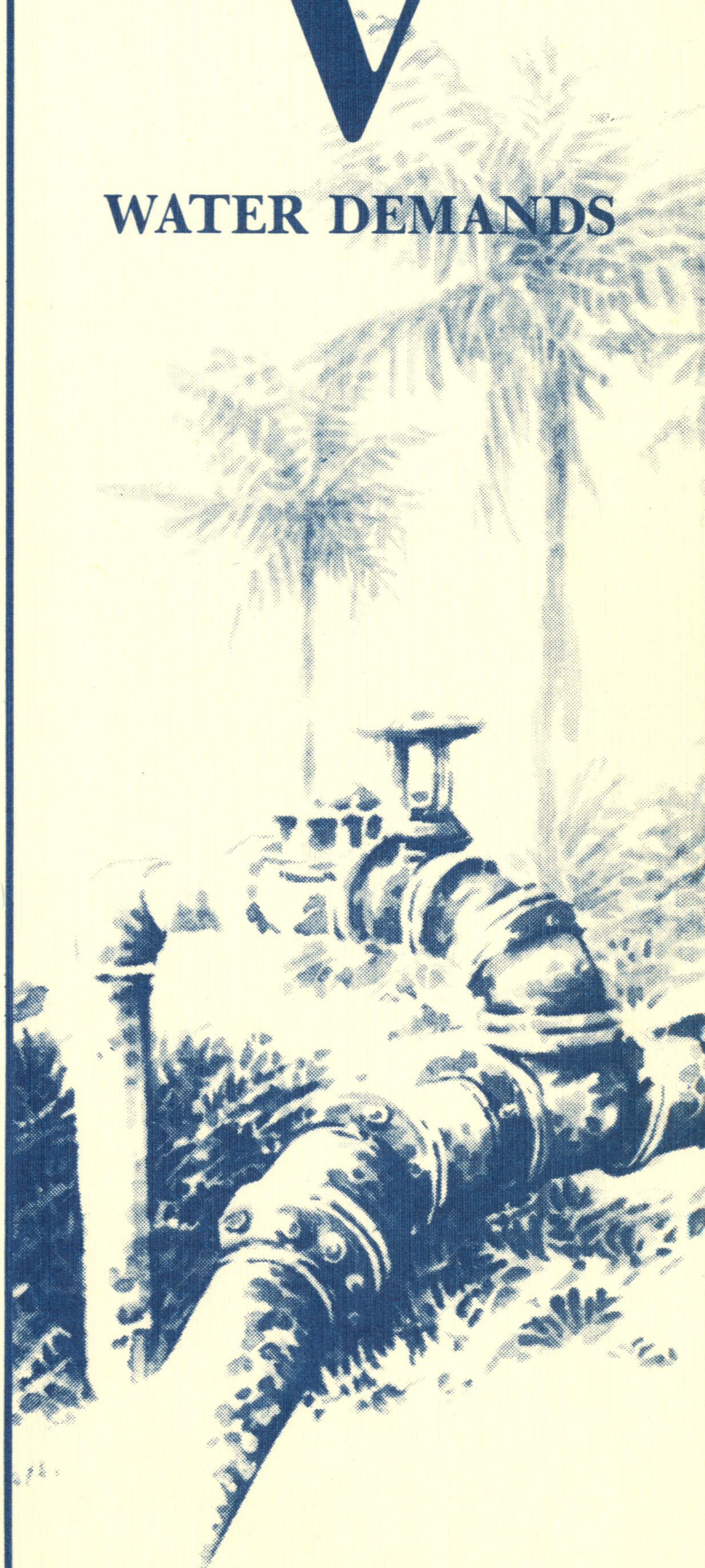



FIGURE 4-4
DISTRIBUTION OF AQUIFER TYPES

# V

# WATER DEMANDS



# CHAPTER V

## WATER DEMANDS

### Background

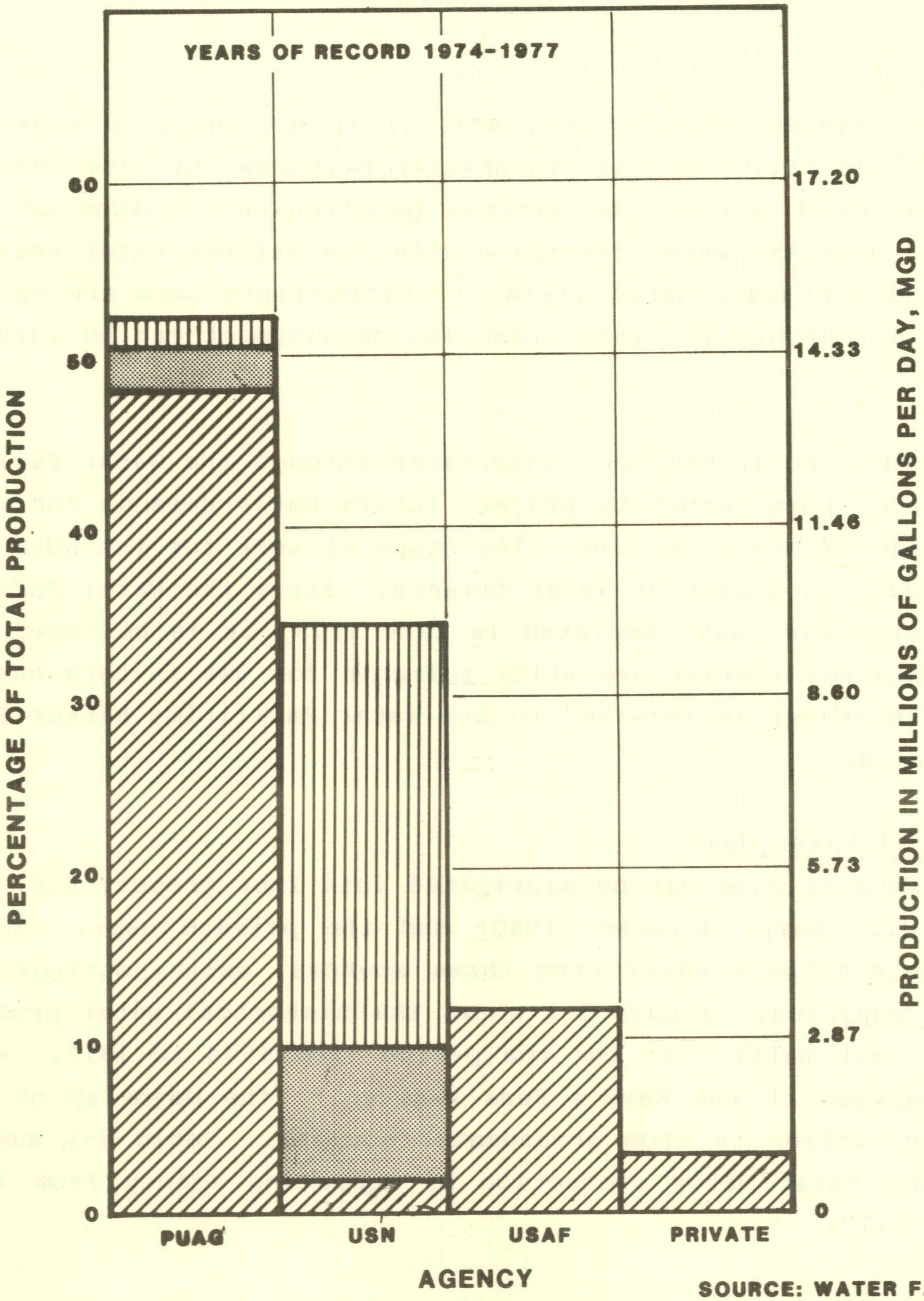
For water system planning purposes, it is necessary to know not only the capability of the groundwater resource but also the demand for water within the various geographical regions of the Island. Once the water demands within the various water service areas and the sustainable yield of the Northern Lens are established, a schedule for water resource development can be identified.

Considerable study has been undertaken through the Water Facilities Master Plan (WFMP) to project future water demands for various planning areas on Guam. The scope of work for the NGLS did not include an update of water demands. Since the Water Facilities Master Plan was completed in late 1979, it is believed the data contained therein are still suitable for use in this analysis. The reader is referred to the Water Facilities Master Plan for details.

### Historical Water Use

Water users on Guam can be segregated into four groups; U.S. Air Force, U.S. Navy, GovGuam (PUAG) and the private user. These users obtain their water from three sources; wells, springs and surface supplies. Figure 5-1 shows the historical water production by each water user for the period from 1974 to 1977. With the exception of the Navy's Fena Reservoir, the majority of the water production is from groundwater sources. Table 5-1 summarizes the total water production by operating agency from 1974 through 1977.

To better analyze the characteristics of PUAG's water system, the service areas have been divided into four regional water systems as shown on Figure 5-2.




SOURCE: WATER FACILITIES MASTER PLAN, 1979

LEGEND

WELLS

SPRINGS

SURFACE

FIGURE 5-1

HISTORICAL WATER PRODUCTION BY OPERATING AGENCY

TABLE 5-1

HISTORICAL WATER PRODUCTION BY OPERATING AGENCY

| Agency | Production in mgd 1974 | 1975 | 1976 | 1977 | Average | Percent |
|---|---|---|---|---|---|---|
| Government of Guam | 13.79 | 15.30 | 15.13 | 15.23 | 14.85 | 51.9 |
| U.S. Air Force | 2.93 | 3.48 | 3.37 | 3.45 | 3.31 | 11.6 |
| U.S. Navy | 9.67 | 9.68 | 9.47 | 9.58 | 9.60 | 33.6 |
| Private | 1.12 | 1.02 | 0.67 | 0.53 | 0.83 | 2.9 |
| TOTAL | 27.51 | 29.48 | 28.64 | 28.79 | 28.59 | 100.00 |

Source: Water Facilities Master Plan, 1979.

Water Demands - The Public Utility Agency of Guam categorizes its customers into five groups; residential, commercial, governmental, agricultural, and irrigation. Figure 5-3 shows the percent of annual demand by month for each use category.

Unaccounted For Water - Unaccounted-for water on Guam (water loss due to leaks, meter malfunction, illegal connections, pipeline flushing, etc.) account for a high percentage of total water production. The relationship between water demand and water production was evaluated by comparing PUAG's total water production (including water purchased from the military) to PUAG's water meter records. The results indicated that unaccounted-for water is approximately 30 percent of the total water produced by PUAG.

Per Capita Use - On Guam the per capita use varies throughout the Island, with the variation being largely a function of degree and type of supportive services provided within the community. For example, in Regional Service Area B, where the majority of the Island's business activities are located, there exists a much higher per capita demand than in the northern or southern areas.

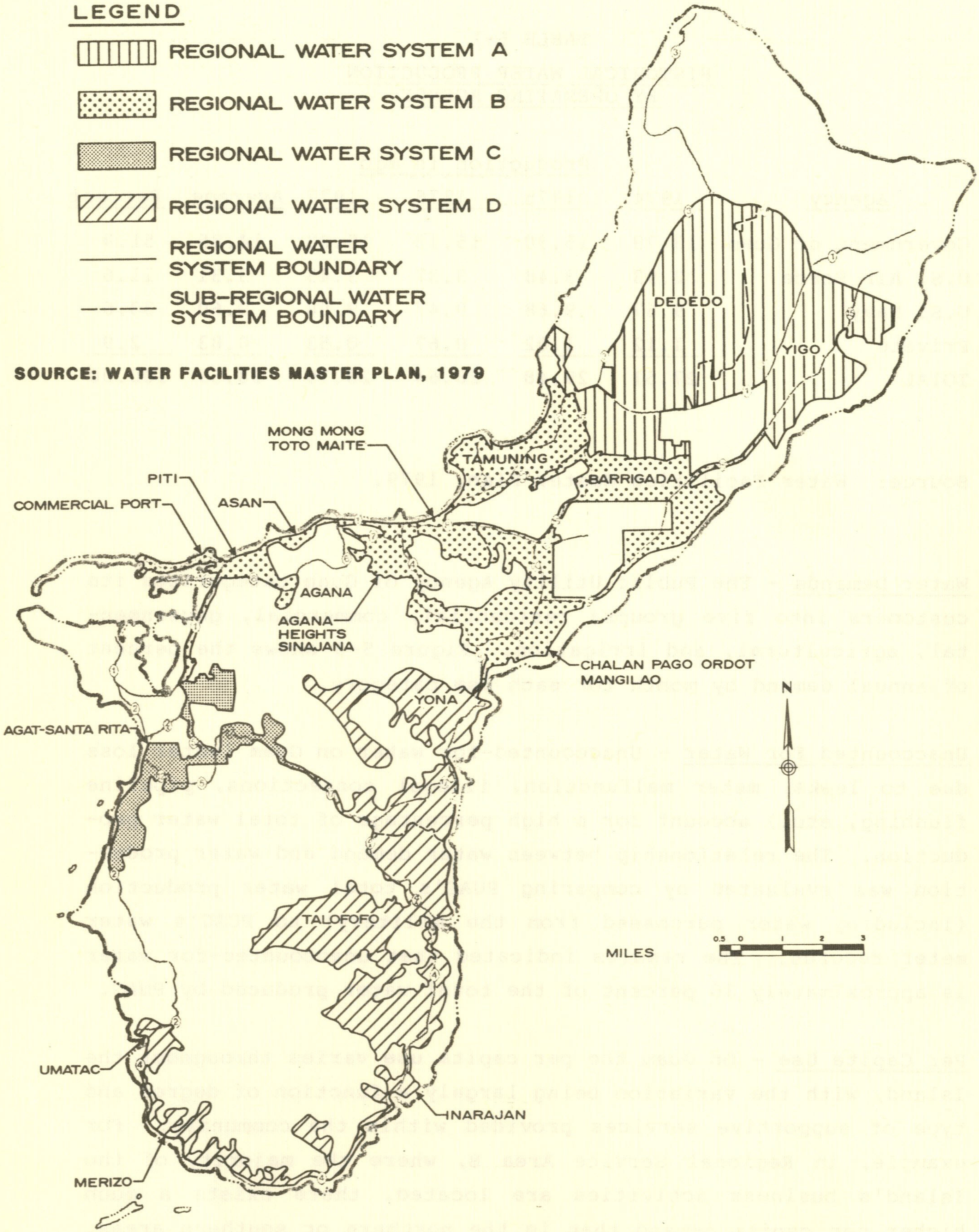



FIGURE 5-2
REGIONAL WATER SYSTEM
BOUNDARIES

Table 5-2 shows existing PUAG per capita use calculated from water use and population data. In light of Guam's limited water supply plus practice of conservation, it is expected that future per capita use will not increase greatly if at all. Instead, the water uses are expected to remain approximately the same as the 1978 values. For projection purposes, it has been assumed that the per capita use for the various service areas will be as follows:

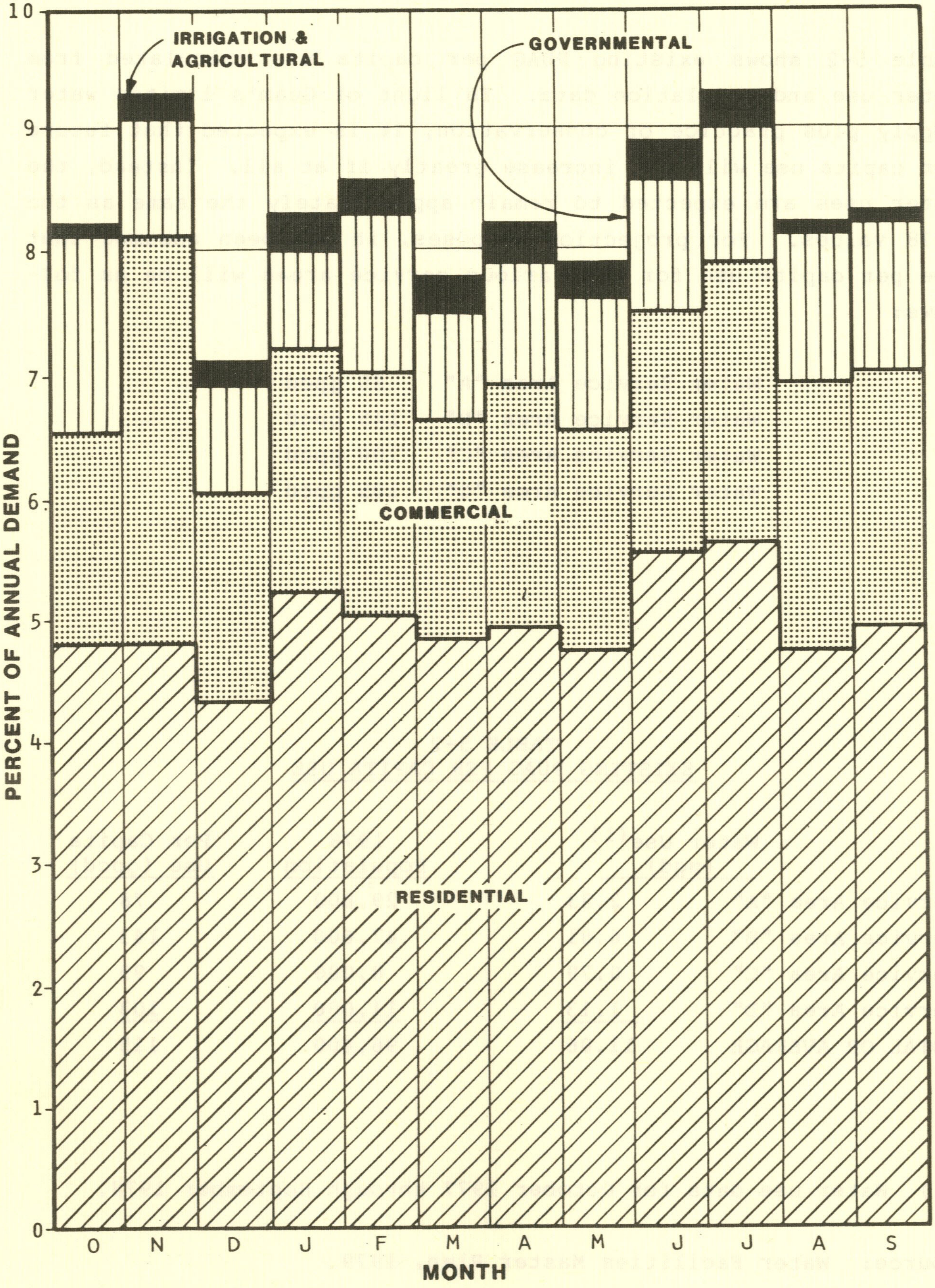
| | |
|---|---|
| Water Service Area "A" | 80 gpcd |
| Water Service Area "B" | 145 gpcd |
| Water Service Area "C" | 100 gpcd |
| Water Service Area "D" | 105 gpcd |

TABLE 5-2
EXISTING PUAG PER CAPITA USE

| | Water Use[1] (mgd) | 1978 Population | Per Capita Use (gpcd) |
|---|---|---|---|
| Service Area "A" | 2.33 | 29,800 | 78 |
| Service Area "B" | 6.81 | 47,600 | 143 |
| Service Area "C" | 0.79 | 8,000 | 99 |
| Service Area "D" | 1.13 | 11,000 | 103 |
| TOTAL OR AVERAGE | 11.06 | 96,400 | 115 |

(1) Water use data for October 1977 through September 1978.

Source: Water Facilities Master Plan, 1979.




SOURCE: PUAG WATER RECORDS
FROM OCTOBER 1977
THROUGH SEPTEMBER 1978

FIGURE 5-3

WATER DEMANDS BY MONTH

Projected Domestic Water Demands

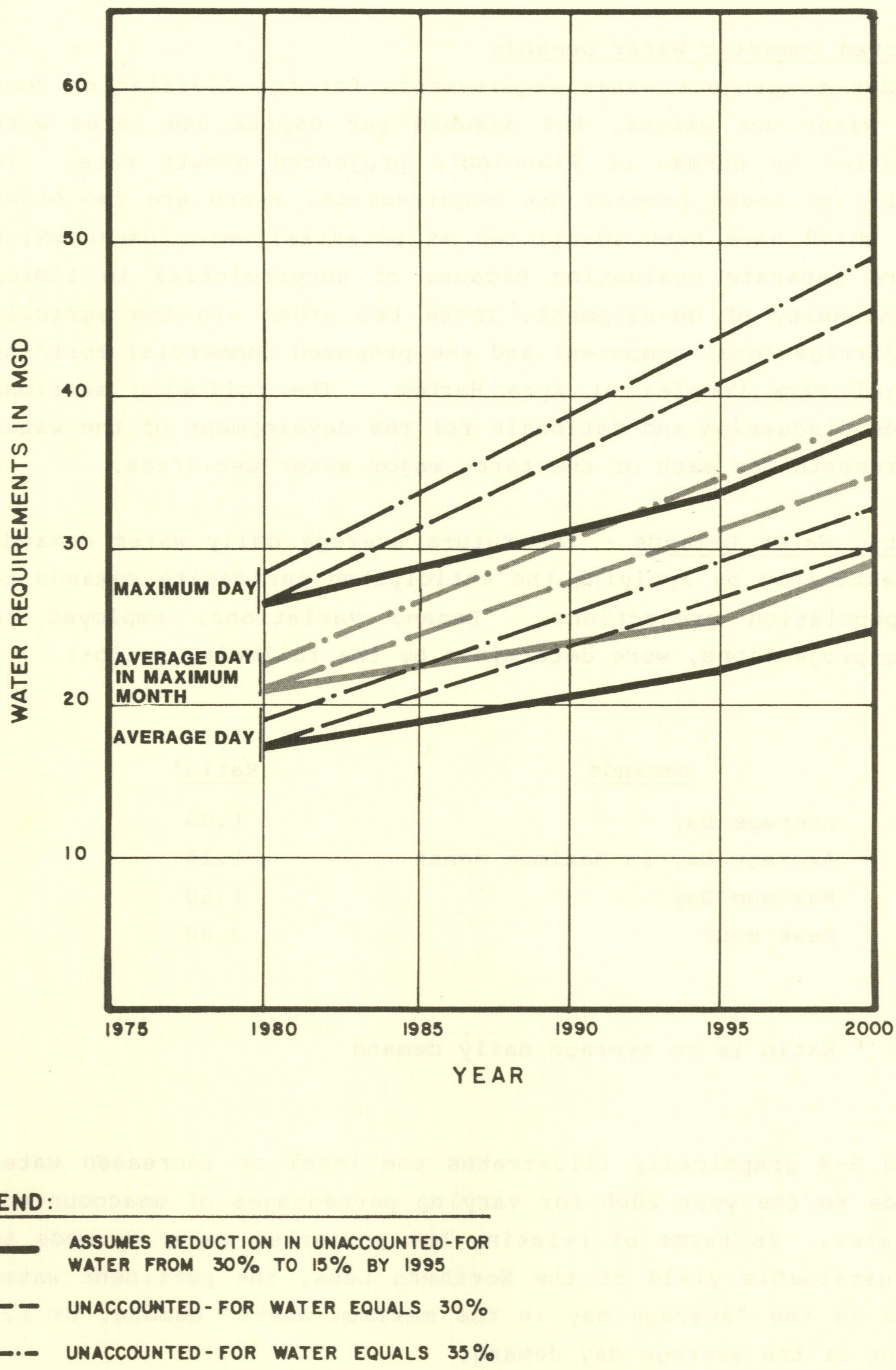
In order to project water requirements for the civilian or domestic water use sector, the assumed per capita use rates were multiplied by Bureau of Planning's projected growth rate. In addition to these general use requirements, there are two other areas which have been identified as potential water users which require separate evaluation because of uncertainties in timing and intensity of development. These two areas are the agricultural/irrigational component and the proposed Commercial Port/Industrial Park Complex at Apra Harbor. The following sections provide discussion and rationale for the development of the water requirements for each of the three major water use areas.

Domestic Water Demands - The future average daily water demands were estimated by applying the anticipated per capita demands to the population projections. Demand variations, employed in making projections, were determined by the following ratios:

| Demands | Ratio* |
|---|---|
| Average Day | 1.00 |
| Average Day in Maximum Month | 1.20 |
| Maximum Day | 1.50 |
| Peak Hour | 3.00 |

* Ratio is to average daily demand

Figure 5-4 graphically illustrates the level of increased water demands to the year 2000 for varying percentages of unaccounted-for water. In terms of relating the projected water demands to the sustainable yield of the Northern Lens, the pertinent water demand is the "average day in the maximum month" demand, or 120 percent of the average day demand.




SOURCE: WATER FACILITIES MASTER PLAN, 1979

**FIGURE 5-4**

**DOMESTIC WATER DEMANDS**

The sustainable yield of the Northern Lens is defined as the rate at which water can be withdrawn from the aquifer continuously without affecting the quality of the water withdrawn or the integrity of the fresh water lens. For short periods of time, water withdrawals can exceed the sustainable yield without detrimental effects. For the purpose of this study, it has been assumed that the sustainable yield can be exceeded on a daily or weekly basis but that the "average day in the maximum month" demand must not exceed the sustainable yield.

Commercial Port/Industrial Park Water Demands - In recent years the Government of Guam has given strong consideration to the expansion of the existing Commercial Port. If the expansion materializes a substantial increase in water usage could result. It is difficult to accurately predict the future Commercial Port/Industrial Park water requirements without knowing the type and extent of industrial and commercial activities that will be located in the expanded complex. For estimating purposes the existing Commercial Port water requirements were examined to provide an indication of future water requirements. There are four major water users projected for the expanded complex, including the power plant, cannery, industrial park, and the actual commercial port complex itself. Table 5-3 shows the projected water demands for the Commercial Port/Industrial Park complex in five year increments from 1980 to the year 2000.

Agricultural Water Demands - Prior to World War II, Guam was largely an agrarian society. However, with the destruction of the agricultural economy during the war and the influx of the military, the Island was transformed from an agricultural to a military-based economy. There has, however, been a renewed interest in redeveloping the agricultural industry with the hope that Guam can once again return to self-sufficiency. In pursuing this goal the Bureau of Planning (BOP) identified prime agricultural areas on Guam in their Land Use Plan (1979). Criteria for selecting these areas was based on topography, soil data, and

TABLE 5-3

PROJECTED WATER DEMANDS FOR COMMERCIAL PORT/INDUSTRIAL PARK COMPLEX

| | Water Demand in mgd | | | | |
|---|---|---|---|---|---|
| | 1980 | 1985 | 1990 | 1995 | 2000 |
| Guam Power Authority | 0.21 | 0.27 | 0.31 | 0.35 | 0.39 |
| Commercial Port Complex | 0.06 | 0.19 | 0.31 | 0.44 | 0.56 |
| Fish Cannery | - | 0.05 | 0.10 | 0.15 | 0.15 |
| Industrial Park | - | - | 0.38 | 0.77 | 1.15 |
| TOTAL | 0.27 | 0.51 | 1.10 | 1.71 | 2.25 |

Source: Guam Water Facilities Master Plan, 1979

climate. As a result of their efforts agricultural districts were developed as shown on Figure 5-5. Land in the north has generally not been designated for agriculture in an effort to protect the groundwater aquifer. This policy could change in light of the findings of NGLS. In order to estimate agricultural water demands, the type and quantities of fruit and vegetables likely to be produced on Guam were projected along with the land requirements for these major crops. A critical question that must be answered before projecting demands for irrigation water is whether agriculture on Guam will be geared towards self-sufficiency or towards a larger commercial activity which could be engaged in exporting agricultural products. Since there are many unknowns regarding the available water supply the Water Facility Master Plan proposed that, for the time being, projection of agricultural water demands be based on reaching self-sufficiency. Once dependable yields are established perhaps a more ambitious agricultural program could be undertaken. Table 5-4 shows the projected agricultural demands on Guam assuming that development will occur within BOP's designated agricultural lands.

**NOTE**

ACREAGE FIGURES INDICATE GROSS LAND AREAS AND MAY NOT INDICATE THE ACTUAL USABLE AGRICULTURAL AREA

SOURCE: LAND USE PLAN-GUAM, 1977-2000
BUREAU OF PLANNING,
GOVERNMENT OF GUAM

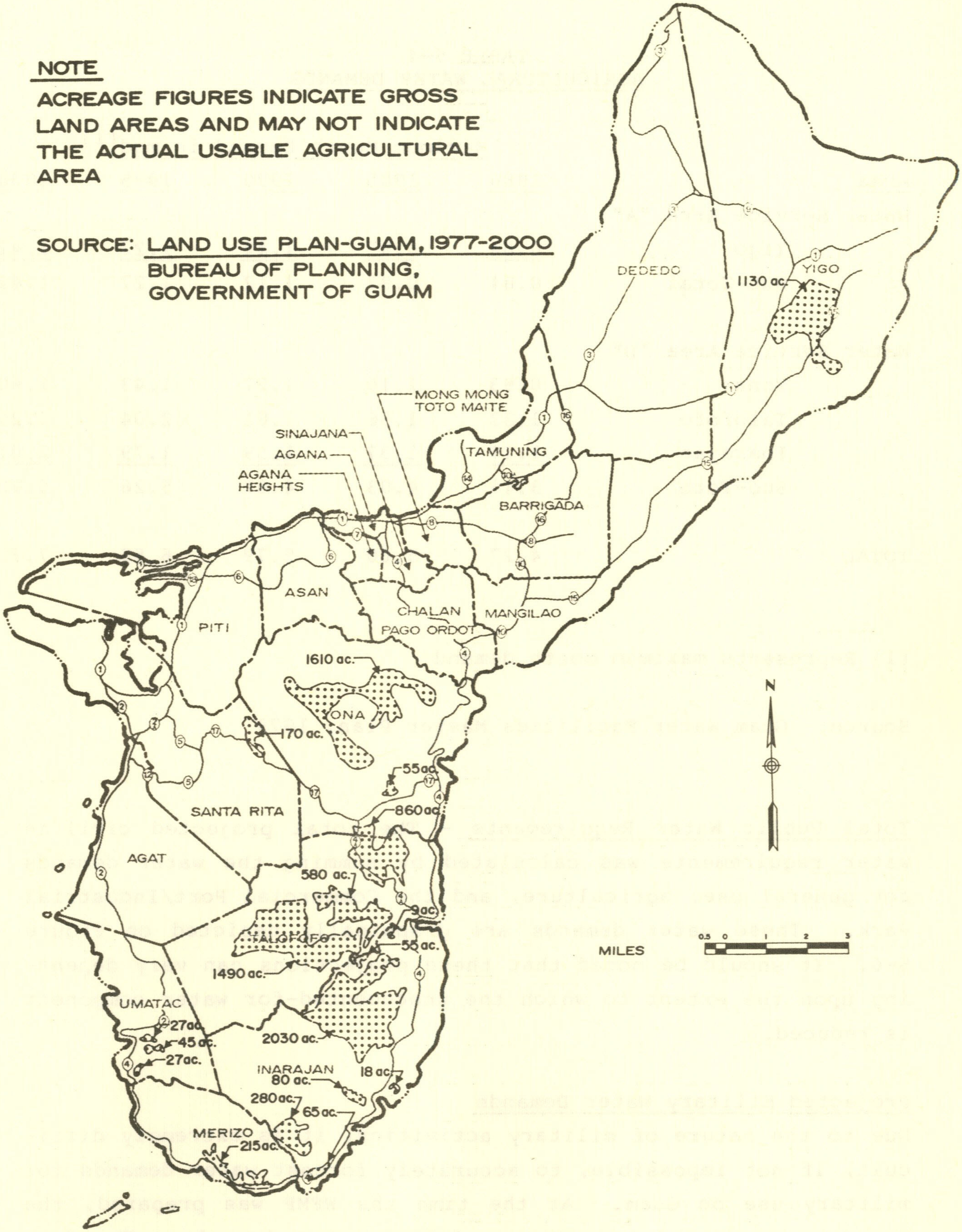



**FIGURE 5-5**

**AGRICULTURAL LAND USE DISTRICTS**

TABLE 5-4
AGRICULTURAL WATER DEMANDS

| Area | Maximum Month Demand in mgd[1] 1980 | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|
| Water Service Area "A" | | | | | |
| Yigo | 0.84 | 0.97 | 1.12 | 1.27 | 1.42 |
| Sub-Total | 0.84 | 0.97 | 1.12 | 1.27 | 1.42 |
| Water Service Area "D" | | | | | |
| Yona | 0.93 | 1.10 | 1.27 | 1.43 | 1.60 |
| Talofofo | 1.33 | 1.56 | 1.81 | 2.04 | 2.29 |
| Inarajan | 1.17 | 1.37 | 1.59 | 1.79 | 2.01 |
| Sub-Total | 3.43 | 4.03 | 4.67 | 5.26 | 5.90 |
| TOTAL | 4.27 | 5.00 | 5.79 | 6.53 | 7.32 |

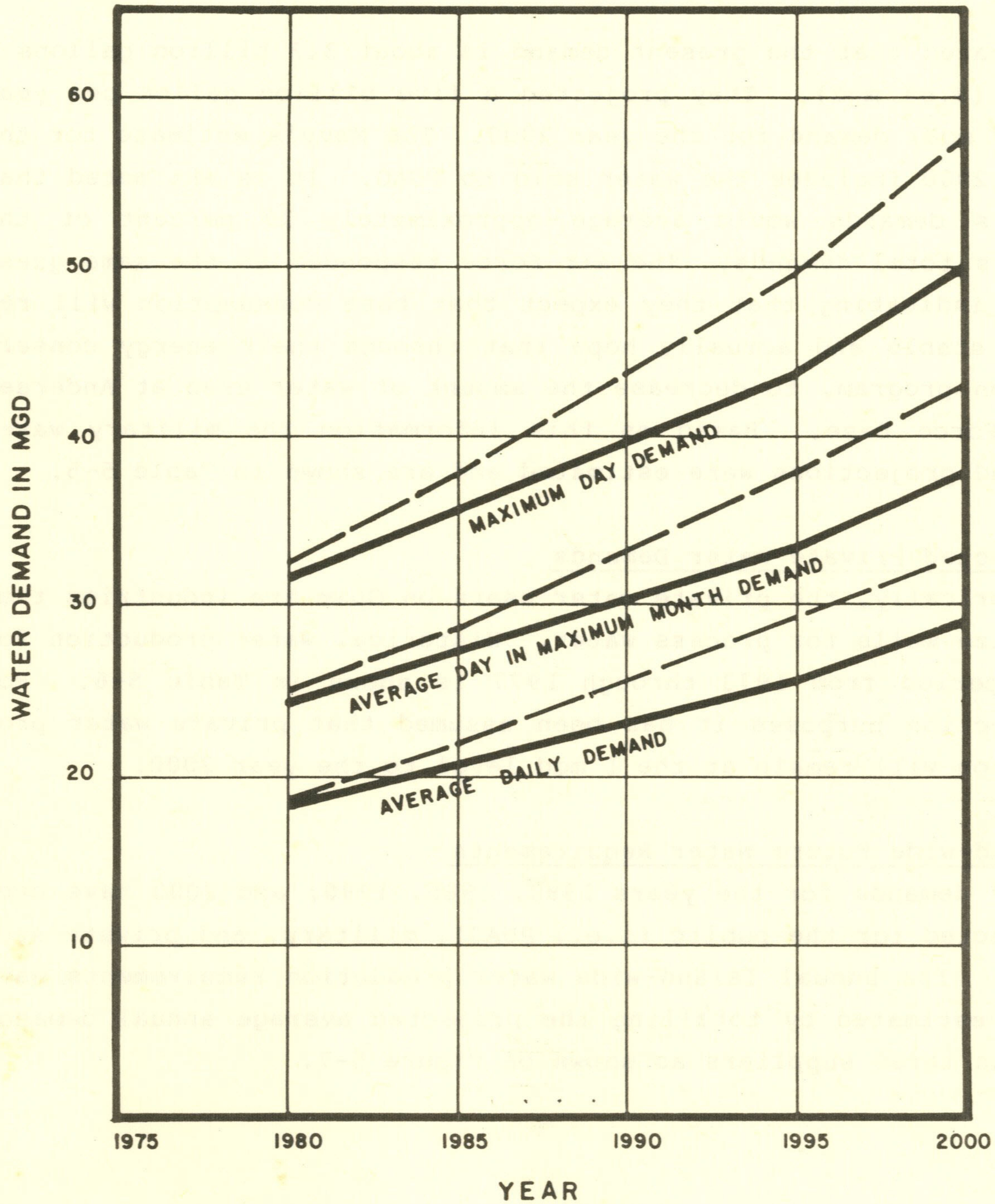
(1) Represents maximum month demand

Source: Guam Water Facilities Master Plan, 1979

Total Public Water Requirements - The total projected civilian water requirements was calculated by summing the water demands for general use, agriculture, and the Commercial Port/Industrial Park. These water demands are graphically depicted on Figure 5-6. It should be noted that these projections can vary depending upon the extent to which the unaccounted-for water component is reduced.

Projected Military Water Demands

Due to the nature of military activities, it is extremely difficult, if not impossible, to accurately forcast water demands for military use on Guam. At the time the WFMP was prepared, the Navy was requested to estimate future water demands. The Navy




LEGEND:

(solid line) WATER DEMANDS INDICATING EXISTING "UNACCOUNTED-FOR" WATER DEMANDS REDUCING TO 15 PERCENT IN 1995

(dashed line) WATER DEMANDS INDICATING "UNACCOUNTED-FOR" WATER DEMANDS EQUAL TO 30 PERCENT

SOURCE: WATER FACILITIES MASTER PLAN, 1979

**FIGURE 5-6**
**PROJECTED PUBLIC WATER DEMANDS**

indicated that the present demand is about 3.3 billion gallons a year (9.04 mgd). They projected a five billion gallon per year (13.7 mgd) demand for the year 2000. The Navy's estimate for the year 2000 includes the water sold to PUAG. It is estimated that PUAG's demands would average approximately 30 percent of the Navy's total demands. The Air Force responded to the same question indicating that they expect that base consumption will remain stable and actually hope that through their energy conservation program, to decrease the amount of water used at Andersen Air Force Base. Based on this information the military water demand projections were estimated and are shown in Table 5-5.

Projected Private Water Demands

Historically, the private water users on Guam are industries that utilize wells for process water. Historical water production for the period from 1973 through 1977 is shown in Table 5-6. For projection purposes it has been assumed that private water production will remain at the 1 mgd level to the year 2000.

Island-wide Future Water Requirements

Water demands for the years 1980, 1985, 1990, and 2000 have been projected for the public (i.e., PUAG), military, and private sectors. The annual Island-wide water production requirements have been estimated by totalling the projected average annual demands of the three suppliers as shown on Figure 5-7.

TABLE 5-5
PROJECTED MILITARY WATER DEMANDS

| Year | Water Demand in mgd U.S. Navy(1) | U.S. Air Force | Total |
|---|---|---|---|
| 1980 | 6.8 | 3.5 | 10.3 |
| 1985 | 7.4 | 3.5 | 10.9 |
| 1990 | 8.3 | 3.5 | 11.8 |
| 1995 | 9.0 | 3.5 | 12.5 |
| 2000 | 9.6 | 3.5 | 13.1 |

(1) Excludes water production from Navy facilities for PUAG demands. Assumes Navy production will increase linearly from 1977 to 2000.

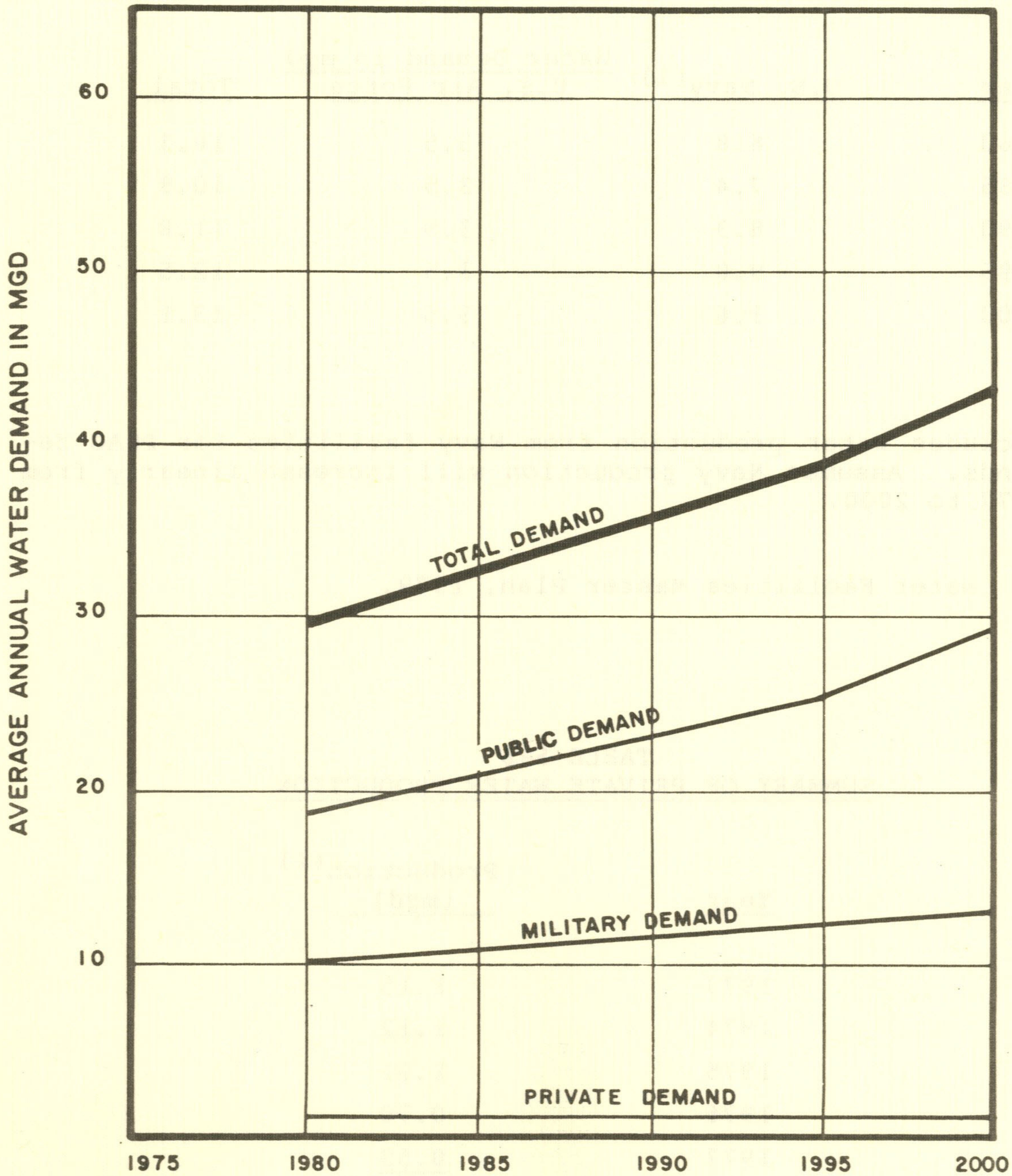
Source: Water Facilities Master Plan, 1979.

TABLE 5-6
SUMMARY OF PRIVATE WATER PRODUCTION

| Year | Production(1) (mgd) |
|---|---|
| 1973 | 1.15 |
| 1974 | 1.12 |
| 1975 | 1.01 |
| 1976 | 0.70 |
| 1977 | 0.53 |
| AVERAGE | 0.90 |

(1) Production is based on estimates only.

Source: Water Facilities Master Plan,1979.



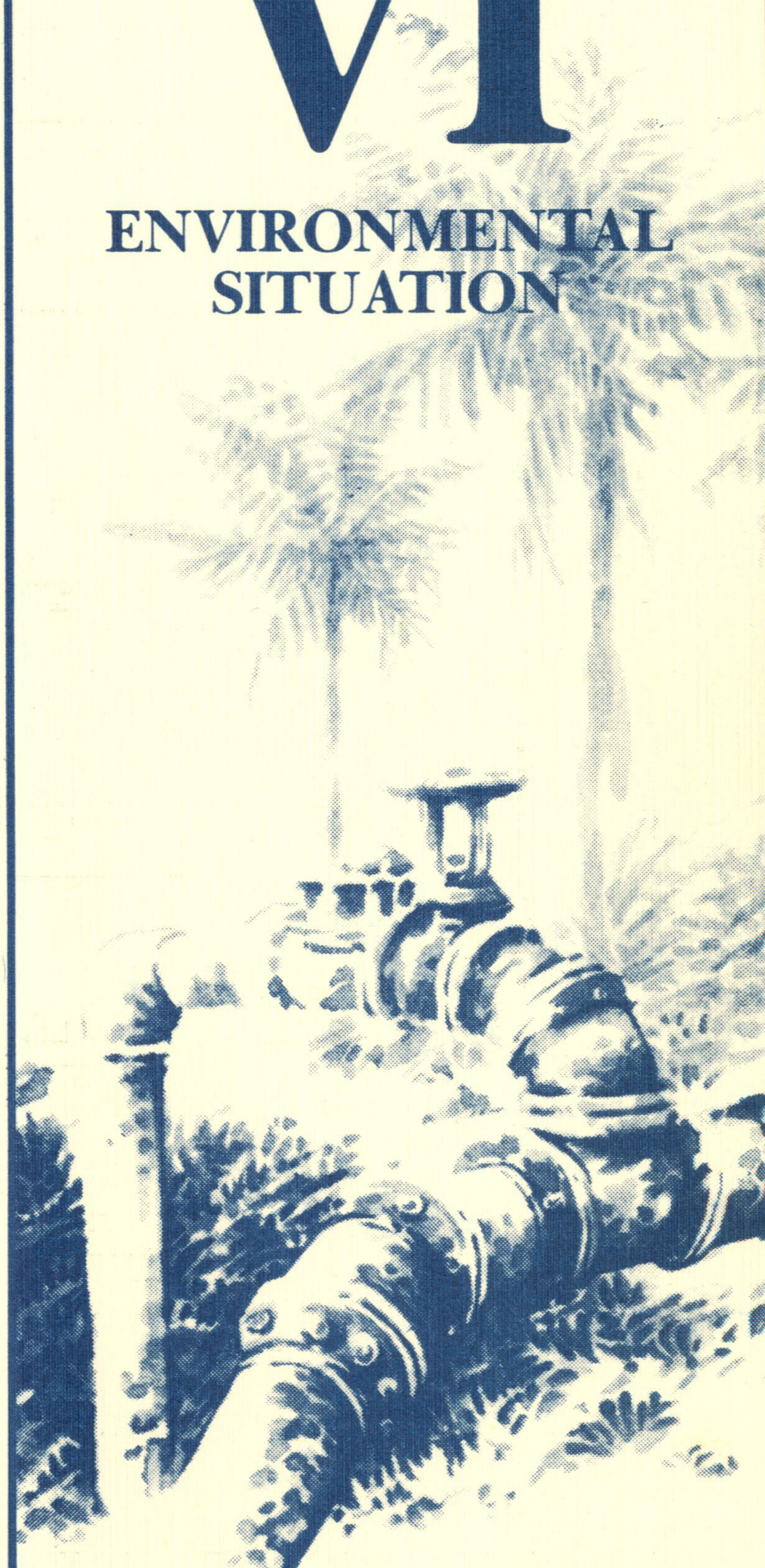

NOTE: ASSUMES REDUCTION IN PUAG UNACCOUNTED-FOR WATER FROM 30 PERCENT IN 1980 TO 15 PERCENT BY 1995.

**SOURCE: WATER FACILITIES MASTER PLAN, 1979**

**FIGURE 5-7**
**ISLAND-WIDE WATER PRODUCTION REQUIREMENTS**

# VI

## ENVIRONMENTAL SITUATION



# CHAPTER VI

## ENVIRONMENTAL SITUATION

### Background

Over 80 years ago, two investigators working independently along the European coast observed that salt water occurred underground, not at sea level, but at a depth below sea level of about 40 times the height of the fresh water above sea level. This phenomenon can be attributed to a hydrostatic equilibrium existing between two fluids of different densities. The equation derived to explain the phenomenon is generally referred to as the Ghyben-Herzberg relation and can be described as:

$$z = 40h$$

where z and h are as shown on Figure 6-1. It is this type of groundwater condition that is found throughout much of northern Guam.

Because Guam is a small island, isolated from other land masses, and is relatively undeveloped, there are few pollution problems. On the other hand, island environments can be easily disrupted. Alternative groundwater management programs must consider such factors as water quality, land uses, aquifer recharge, and other parameters. In particular, the Ghyben-Herzberg formation can be easily disrupted and water quality affected through over pumpage, inadequate well design, changes to natural drainage patterns, and through the introduction of waste materials.

### Water Quality Objectives

In September, 1981, the GEPA Board of Directors formally approved the recently revised Water Quality Standards (WQS) for Guam. These standards were also approved by the Legislative Branch of the Government of Guam and by the U.S. Environmental Protection Agency.

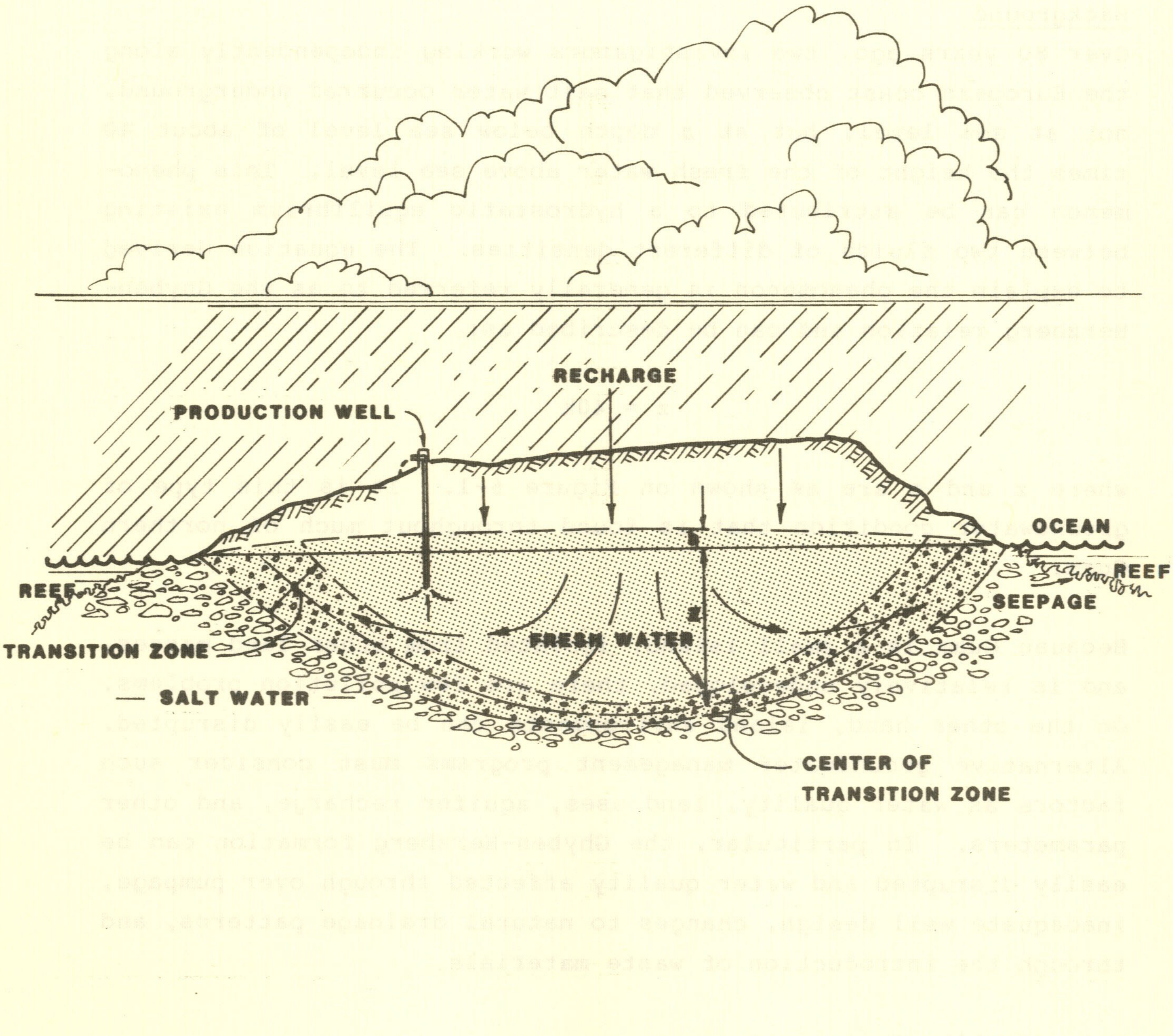



**FIGURE 6-1**

**GHYBEN-HERZBERG LENS FORMATION**

The stated policy of the Water Quality Standards is as follows:

*It shall be the public policy of Guam to:*

1. *conserve, protect, maintain, and improve the quality of the waters for drinking water supply and food processing, for the growth and propagation of aquatic life, for marine research and for the conservation of coral reefs and wilderness areas, and for domestic, agricultural, commercial, industrial, recreational, and other legitimate uses;*

2. *provide that no pollutant discharge into any water be allowed, unless (a) the discharge first receives processing which will assure the pollutant removal or provide the control technology necessary to protect the designated beneficial uses of the waters, and (b) the discharge meets the effluent limitations established for that discharge; and*

3. *provide for the prevention, abatement and control of new and existing water pollution.*

Further, under the terms of U.S. Public Law 95-217:

1. *It is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985;*

2. *It is the national goal that wherever attainable, an interim goal of water quality, which provides for the protection and propagation of fish, shellfish and wildlife, and provide for recreation in and on the water, be achieved by July 1, 1983; and*

3. *It is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited.*

The WQS go on to indicate the basis upon which the standards were developed:

*Waters whose existing quality was better than the established standards as of April, 1968, will be maintained at the same high quality existing at that time.*

*Water whose existing quality is less than the established standards for their use due to the presence of substances, conditions, or combinations thereof attributable to domestic, commercial and industrial discharges or agricultrual,*

*construction and other land use practices, shall be improved to comply with the established standards. However, in such cases where the natural conditions are of lower quality than criteria assigned, the natural conditions shall constitute the water quality criteria. Water quality criteria in boundary areas shall be established so that the most stringent standard applies.*

*Waters will not be lowered in quality unless and until it has been affirmatively demonstrated to the Administrator of the Guam Environmental Protection Agency that such a change is justifiable as a result of necessary social, environmental, or economic development, and that such development will not interfere with or become injurious to any uses made of, or potentially possible in, such waters. Any industrial, public or private project or development will require, as part of the initial project design, provision for the pollutant removal or control technology necessary to protect the designated use of receiving waters or maintain the existing high quality of the receiving waters.*

*The purpose of these Water Quality Standards is to prevent degradation of water resources resulting from pollution sources. It is not the intent of these standards to restrict activities which may cause pollution but rather to regulate such activities or practices that may cause a water resource to be degraded.*

Water Quality Standards

The quality of groundwater is equally as important as its quantity. Water must be of suitable quality for the intended beneficial use whether it be for drinking water, industrial use, or for irrigation of agricultural lands. To establish quality criteria, measures of chemical, physical, biological and radiological constituents must be specified.

Drinking Water - The Guam Safe Drinking Water Act (GSDWA) was adopted by the Government of Guam on December 27, 1977, as the territorial response to the Federal Safe Drinking Water Act (FSDWA). Section 57288 of the GSDWA authorizes GEPA to prescribe such rules and regulations as may be necessary to implement its provisions. Pursuant thereto, GEPA adopted the Guam Primary Safe Drinking Water Regulations (GPSDWR) on March 27, 1978.

The U.S. Environmental Protection Agency (EPA) concluded that the GSDWA and its companion document, the GPSDWR, were equivalent to or comparable with the requirements of the FSDWA. On that basis, GovGuam, acting through GEPA, was granted primacy on September 10, 1978, for the purpose of administering the federal law on Guam.

The GSDWA and the GPSDWR are subject to regulations promulgated pursuant to the federal law, including the Interim Primary Drinking Water Regulations, which became effective June 24, 1977, and the Organic Drinking Water Regulations, which became effective February 9, 1978.

Consistent with the Federal Primary Drinking Water Regulations, the GPSDWR specify maximum contaminant levels for inorganic chemicals, organic chemicals, turbidity, micro-biological contaminants and radionuclides. These primary drinking water standards are reproduced in Table 6-1.

Federal Secondary Drinking Water Regulations were first published in the July 19, 1979, edition of the Federal Register and are reproduced in Table 6-2. To date, GEPA has not adopted secondary drinking water standards but is in the process of adopting standards for trihalomethanes (THM), sodium, and corrosivity.

Industrial Water - While the total volume of industrial water demands on Guam in the near future is not anticipated to be substantial, some industrial processes are particularly sensitive to certain constituents found in typical water supplies. As an example, makeup water for high pressure boilers must meet extremely exacting criteria whereas water of as low a quality as sea water can be satisfactorily used for cooling of condensors. Salinity, hardness and silica are three parameters that usually are of major importance for industrial water. Recommended limiting concentrations for process waters of selected industries are presented in Table 6-3.

TABLE 6-1
PRIMARY DRINKING WATER STANDARDS IN GUAM

| | |
|---|---|
| **Physical Characteristics** | |
| Turbidity, units | 1.0 |
| **Inorganic Chemicals, mg/l** | |
| Arsenic | 0.05 |
| Barium | 1.0 |
| Cadmium | 0.01 |
| Chromium | 0.05 |
| Fluoride | 1.4-2.4 (1) |
| Lead | 0.05 |
| Mercury | 0.002 |
| Nitrate (as N) | 10.0 |
| Selenium | 0.01 |
| Silver | 0.05 |
| **Organic Chemicals, mg/l** | |
| Chlorinated hydrocarbons | |
| Endrin | 0.0002 |
| Lindane | 0.004 |
| Methoxychlor | 0.1 |
| Toxaphene | 0.005 |
| Chlorophenoxys | |
| 2,4-D | 0.1 |
| 2,4,5-TP Silvex | 0.01 |

Biological

a. One coliform bacteria per 100 ml as arithmetic mean of samples.

b. Four coliform bacteria per 100 ml in more than one sample when less than 20 samples are examined.

c. Four coliform bacteria per 100 ml in more than five percent of the samples when 20 or more samples are examined.

| | |
|---|---|
| **Radioactivity** | |
| Radium 226, Radium 228 | 5 pCi/l |
| Gross Alpha activity | 15 pCi/l |
| Gross Beta activity | 4 mrem/year |

(1) Maximum contaminant level based on temperature.

TABLE 6-2
NATIONAL SECONDARY DRINKING
WATER STANDARDS

| Constituent | Level |
|---|---|
| Chloride | 250 mg/l |
| Color | 15 color units |
| Copper | 1 mg/l |
| Corrocivity | Noncorrosive |
| Foaming agents | 0.5 mg/l |
| Iron | 0.3 mg/l |
| Manganese | 0.05 mg/l |
| Odor | 3 threshold odor number |
| pH | 6.5-8.5 |
| Sulfate | 250 mg/l |
| Total Dissolved Solids(TDS) | 500 mg/l |
| Zinc | 5 mg/l |

Irrigation Water - Five parameters are primarily used for the classification of water supplies as related to their suitability for irrigation purposes. These include: 1) percent sodium, 2) dissolved mineral solids, 3) boron concentration, 4) chloride concentration and 5) sulfate concentration.

The sensitivity of plants to the various constituents in the water supply can vary widely under actual field conditions depending upon the climate, soils and the particular plant varieties. In many cases an inferior water supply may be used for irrigation purposes as long as the user accepts the consequent penalties in lowered crop quality and yields. Hence, criteria for the classification of irrigation water supplies are usually expressed as a range of limiting concentrations with lower limits reflecting the threshold values above which the impact of a particular constituent can be detected. A suggested list of criteria for the classification of surface and groundwaters on Guam for irrigation purposes is presented in Table 6-4.

## Water Reclamation

In light of today's ever-increasing water demands and Guam's limited water resources, an effective groundwater management plan must consider the potential effects of reuse of available water supplies. One method of water conservation that has gained considerable popularity in recent years is the reuse of treated domestic wastewater, commonly referred to as wastewater reclamation. Wastewater reclamation can serve many purposes and benefits, including:

- Increased pollution control and thus greater protection for the environment.
- Augmentation of natural water supplies, thus reducing the need for development of new sources and imports of water, and permitting rivers and oceans to remain in their natural state.
- A more economical alternative source of water for some uses.

Not all of the wastewater produced can be reclaimed and reused. In general, the amount that may be reclaimed for reuse is limited by the quality of the wastewater, cost of treatment, the cost of conveyance and distribution to the area where it will be used, and the price that users are willing to pay.

The concept of wastewater reclamation is gaining wider public acceptance. Results of recent public opinion surveys on the use of reclaimed water indicated that those questioned generally favored its use for 1) industrial cooling and other operations, 2) irrigation of crops, highway landscaping, and golf courses, and 3) supplies for recreational lakes. As might be expected, the same surveys indicated opposition to the use of reclaimed water increased significantly with the likelihood of personal use, for example: drinking, cooking, and bathing.

Before wastewater can be used for benficial purposes it must first be treated. The basic objective of waste treatment is to

TABLE 6-3

RECOMMENDED LIMITING CONCENTRATIONS FOR INDUSTRIAL PROCESS WATERS
(Units in mg/l, Except as Noted)

| Use | Turbidity Units | Color Units | Taste & Odor | Dissolved Solids | Hardness as $CaCO_3$ | Alkalinity as $CaCO_3$ | pH Units | Chlorides | Sulfates | Iron | Manganese | Iron Plus Manganese | Hydrogen Sulfide | Flouride | Other Requirements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Air-Conditioning | - | - | Low | - | - | - | - | - | - | 0.5 | 0.5 | 0.5 | - | - | Not corrosive or slime-promoting. |
| Baking | 10 | 10 | None-Low | - | (a) | - | - | - | - | 0.2 | 0.2 | 0.2 | 0.2 | - | Potable. |
| Boiler Feed | 10 | 40 | - | 500-2,500 | 40 | - | 8.4 | - | - | - | - | - | 3 | - | Potable if steam is used for food preparation. For pressures up to 750 psi. |
| Brewing | 0-10 | 0-10 | None-Low | 500-1,500[b] | (c) | 75-80[d] | 6.5-7.0[e] | 60-100 | - | 0.1 | 0.1 | 0.1 | 0.2 | 1.0 | Potable, numerous other requirements. |
| Carbonated Beverages | 1-2 | 5-10 | None-Low | 850 | 200-250 | 50-130 | - | 250 | 250 | 0.1-0.2 | 0.2 | 0.1-0.4 | 0-0.2 | 0.2-1.0 | Potable; COD, 1.5; organic matter, infinitestimal; algae and protozoa, none. |
| Confectionery | - | - | Low | 50-100 | Soft | - | 7.0 | - | - | 0.2 | 0.2 | 0.2 | 0.2 | - | Potable. |
| Dairy | - | None | None | 500[f] | 180 | - | - | 30 | 60 | 0.1-0.3 | 0.03-0.1 | - | - | - | Potable; $NO_3$-N, 5.5; $NO_2$-N, 0; $NH_3$N, trace only, COD as $KMnO_4$, 12. |
| Food Canning & Freezing | 1-10 | - | None-Low | 850 | (g) | 30-250 | 7.5 | - | - | 0.2 | 0.2 | 0.2-0.3 | 1.0 | 1.0 | Potable; free from saptrophylic organisms; NaCl 1,000-1,500; $NO_3$-N, 2.8; $NH_3$-N, 0.4. |
| Food Equipment, Washing | 1 | 5-20 | None | 850 | 10 | - | - | 250 | - | - | - | 0.1 | - | 1.0 | Potable, organic matter, infinitestimal. |
| Food Processing, General | 1-10 | 5-10 | Low | 850 | 10-250 | 30-250 | - | - | - | 0.2 | 0.2 | 0.2-0.3 | - | 1.0 | Potable |
| Ice Manufacture | 5 | 5 | Low | 170-1,300 | - | - | - | - | - | 0.2 | 0.2 | 0.2 | - | (h) | Potable; $SiO_2$, 10. |
| Laundering | - | - | - | - | 0-05 | 60 | 6.0-6.8[c] | - | - | 0.2-1.0 | 0.2 | 0.2-1.0 | - | - | |
| Textile | 0.3-25 | 0-70 | - | - | 0-50 | - | - | 100 | 100 | 0.1-1.0 | 0.05-1.0 | 0.2-1.0 | - | - | |

NOTES:
(a) Some calcium is necessary for yeast action. Too much hardness retards fermentation, but too little softens the gluten to produce soggy bread.
(b) Not more than 300 mg/l of any one substance.
(c) $CaSO_4$ less than 100 to 500 mg/l; $MgSO_4$ less than 50 to 200 mg/l.
(d) For dark beer alkalinity as $CaCO_3$ may be 80 to 150 mg/l.
(e) Range, lower to upper limits.
(f) Total solids.
(g) For legumes, 25 to 75, for fruits and vegetables; 100 to 200; for peas, 200 to 400.
(h) 1.5 mg/l of flouride has been reported to cause embrittlement and cracking of ice.

SOURCE: Water Quality and Treatment, American Water Works Association (1969).

## TABLE 6-4
## SUMMARY OF CLASSIFICATIONS OF IRRIGATION WATERS

| | Irrigation Water Classifications | | |
|---|---|---|---|
| | CLASS I | CLASS II | CLASS III |
| Parameters | Excellent to good, or suitable for most plants under most conditions | Good to injurious, harmful to some under certain conditions of soil, climate practices | Injurious to unsatisfactory, unsuitable under most conditions |
| Percent Sodium (Na) $\frac{Na \times 100}{Na+Ca+Mg+K}$ meq/l | Less than 30-60% (Most recent work favors a 60% limit) | 30-75% | More than 70-75% |
| Boron, mg/l | Boron recommendation for water of this class is generally accepted as less than 0.5 mg/l; however tolerant plants will not be injured by 1-1.5 mg/l | 0.5-2.0 mg/l although for tolerant plants water with boron up to 3.35 mg/l may be satisfactory | More than 2 mg/l although water with more than 1.0 may be highly unsuitable for sensitive plants |
| Chlorides meq/l | Less than 2-5.5 | 2-16 | More than 6-16 |
| Sulfates meq/l | Less than 4-10 | 4-20 | More than 12-20 |
| Specific Conductivity (Concentration of ions) EC X $10^6$ at 25°C | Earlier studies suggested limit of about 500, but more recently 1000 has been accepted. | 500-3000 | More than 2500-3000 |
| Total salts, mg/l | Up to about 700 | 350-2100 | More than 1250-2100 |

EC: electrical conductivity
meq: milliequivalents

Source: McKee & Wolf (1963)

remove or neutralize pollutants that have been added during its use so that it can be safely discharged to the environment or reclaimed for reuse. The degree of treatment required for reuse is dependent upon its intended use. For example, reclaimed water may require a higher degree of treatment for use in irrigation of food crops than for irrigation of a golf course.

GEPA has not adopted regulations specifically establishing acceptable levels of constituents in reclaimed water. The present WQS state that:

> *...these standards cannot be applied to water/wastewater to be reused to produce products which may end up in the human food chain, such as crops, animal feed or animal products. The Agency (GEPA) will consider such reuse on a case-by-case basis using available guidelines.*

For landscape irrigation purposes, GEPA would be concerned only if the reclaimed water would eventually reach surface waters or groundwaters wherein the WQS effluent limitations would come into effect. However, it can be expected that any reuse of wastewater that may come into contact directly or indirectly with the general public may first require approval by GEPA based on minimal health risk criteria.

One state that is actively encouraging wastewater reclamation is California. To regulate the use of reclaimed water, California has adopted regulations pertaining to both water quality and appropriate surveillance measures that must be satisfied in order to avoid health hazards.

For purposes of illustrating what might be expected in Guam, a condensed version of California's regulations governing the degree of treatment required for different intended uses is shown in Table 6-5.

TABLE 6-5
STATE OF CALIFORNIA
WASTEWATER RECLAMATION CRITERIA

| Type of Use | Method of Irrigation | Degree of Treatment: Primary | Secondary(1) | Tertiary(2) | Minimum Degree of Disinfection(3) |
|---|---|---|---|---|---|
| Food Crop Irrigation | Spray/Surface | | X | X | 2.2 |
| Fodder, Fiber and Seed Crop Irrigation | Spray/Surface | X | | | |
| Pasture Irrigation for Milking Animals | Surface/Spray | | X | | 23 |
| Landscape Irrigation | | | X | | 23 |
| Nonrestricted Recreational Impoundment | | | X | X | 2.2 |
| Restricted Recreational Impoundment | | | X | X | 2.2 |
| Landscape Impoundment | | | X | | |

(1) Secondary treatment includes oxidation.
(2) Tertiary treatment includes coagulation, clarification and filtration.
(3) Degree of disinfection measured by the median number of coliform organisms per 100 milliliter samples.

Source: Wastewater Reclamation Criteria, California Administrative Code, Title 22, Division 4.

## Existing Water Quality Monitoring Programs

Guam has suffered from a lack of a systematic program for sampling and analysis of both its surface and groundwater supplies. The available data has been generally limited and usually reflected the results of sampling and analyses conducted for specific projects, reports, or for conformance with drinking water standards.

most of the water quality data presented herein were obtained from published and unpublished records of the USGS or from the 1976 report by John Mink entitled "Groundwater Resources of Guam: Occurrence and Development".

Historical Groundwater Quality

Locations of historical sampling sites are shown on Figure 6-2. A representative summary of groundwater quality on Guam is presented in Table 6-6. Based on the available data it is concluded that the groundwater quality on Guam is generally suitable for most domestic, industrial, and irrigation needs on the Island projected through the year 2000. As with surface supplies, there are no known analyses of boron in any of the available reports of groundwater quality. However, there is also no evidence that boron concentrations are high enough to cause any problem even for the more sensitive plants.

The principal dissolved constituents of the groundwaters of northern Guam, in terms of significance related to origin and movement of the groundwaters, are: calcium (Ca), chloride (Cl), silicate ($SiO_2$), nitrate ($NO_3$), magnesium (Mg) and total hardness, with the relative concentrations of each reflecting the origin of the water. Perhaps the two most important constituents are chloride, which reflects salt water intrusion, and nitrogen which may be an indicator of pollution.

Chlorides - On Guam, the chloride content can be used to indicate the origin of the water. Any water with less than 30 mg/l of chloride may be assumed to have been derived from rainwater. Rainwater is found to have up to approximately 30 mg/l of chloride because of the close proximity to coast line and the associated sea spray that is carried across much of the Island. Higher concentrations of chlorides in the groundwater may be attributed to the hydrodynamic mixing associated with tidal fluctuations and other pertubations. Mink, in his report entitled, Groundwater Resources of Guam: Occurrence and Development (1976) suggests that as a general rule, immediately adjacent to the

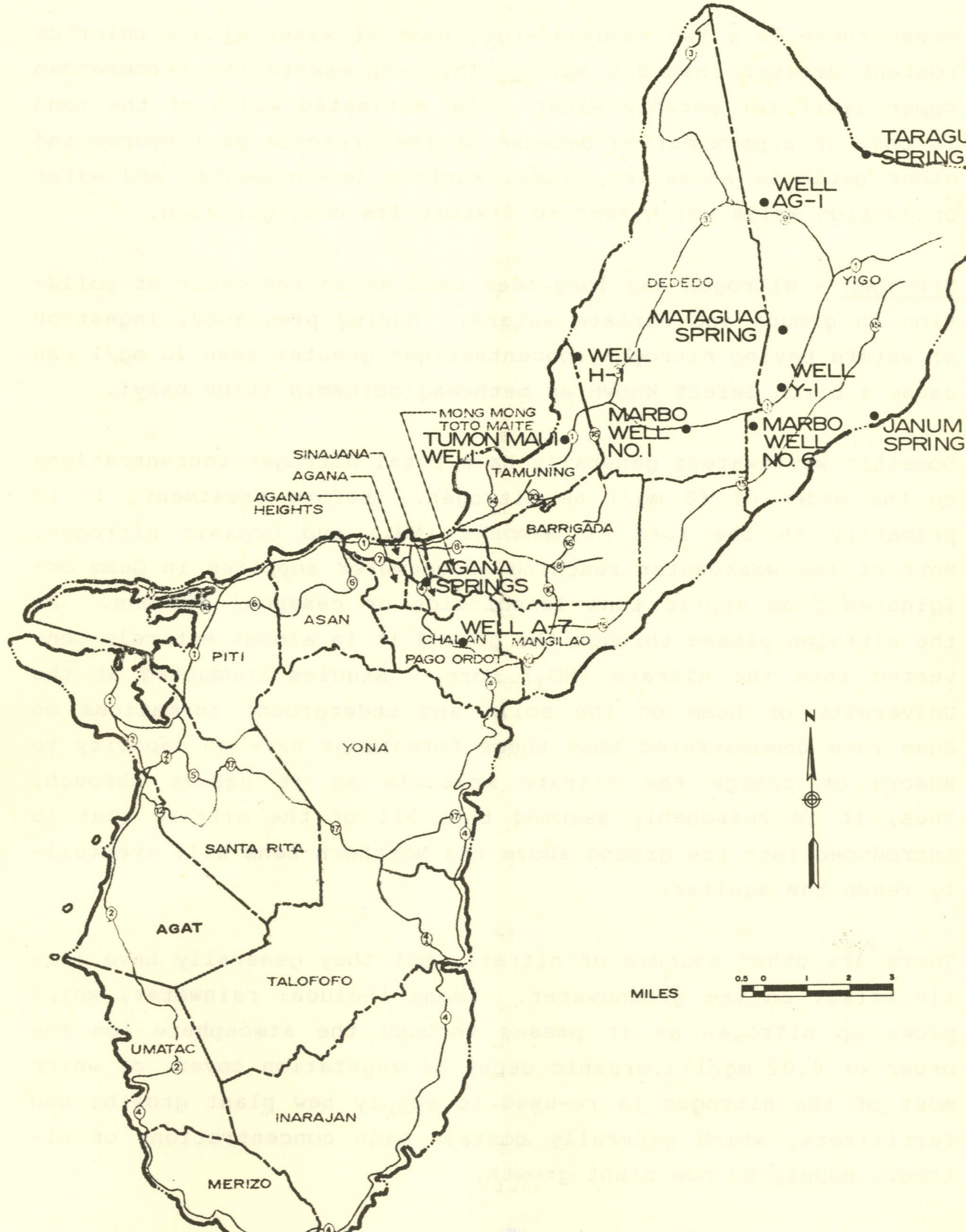



**FIGURE 6-2**

**WATER QUALITY SAMPLE LOCATIONS**

ocean there is a two thousand-foot band of water with a chloride content greater than 250 mg/l. This represents the recommended upper limit for potable water. The estimated width of the band is only an approximation because of the presence of fissures and other geologic anomalies, local surface impoundments, and water production wells which tend to distort its configuration.

Nitrogen - Nitrogen has long been used as an indicator of pollution in ground and surface waters. During pregnancy, ingestion of waters having nitrogen concentrations greater than 10 mg/l can cause a birth defect known as methemaglobinemia (blue baby).

Domestic wastewaters generally have total nitrogen concentrations on the order of 60 mg/l as nitrogen. Before treatment, it is primarily in the form of ammonia ($NH_4$) and organic nitrogen. Most of the wastewater reaching groundwater supplies in Guam originates from septic tank leachfields or cesspool systems. As the nitrogen passes through the ground it is almost entirely converted into the nitrate ($NO_3$) form. Studies conducted at the University of Guam on the soils and underground formations on Guam have demonstrated that these formations have no capacity to adsorb or change the nitrate molecule as it passes through. Thus, it is reasonably assumed that all of the nitrate that is introduced into the ground above the Northern Lens will eventually reach the aquifer.

There are other sources of nitrate, but they generally have little effect on the groundwater. These include: rainwater, which picks up nitrogen as it passes through the atmosphere (on the order of 0.02 mg/l); organic decay of vegetation cover, of which most of the nitrogen is re-used to supply new plant growth; and fertilizers, which generally contain high concentrations of nitrogen supplying new plant growth.

As shown in Table 6-6, the background nitrate concentrations found in the Northern Lens is in the neighborhood of 2.0 mg/l as

TABLE 6-6

GROUNDWATER QUALITY ANALYSES

| Constituents | Units | Tumon Maui Well | Marbo Well No.6 | Marbo Well No.1 | Well AG-1 | Well Y-1 | Well A-7 | Well H-1 | Agana Springs | Tarague Spring | Mataguac Spring | Janum Spring |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arsenic | mg/l | < 0.010 | < 0.010 | < 0.010 | — | — | — | — | — | — | — | — |
| Chromium | mg/l | < 0.050 | < 0.050 | < 0.050 | — | — | — | — | — | — | — | — |
| Copper | mg/l | < 0.020 | < 0.020 | < 0.020 | — | — | — | — | — | — | — | — |
| Fluoride | mg/l | < 6.1 | < 0.1 | < 0.1 | — | — | — | — | — | 0.1 | — | 0.1 |
| Lead | mg/l | < 0.050 | < 0.050 | < 0.050 | — | — | — | — | — | — | — | — |
| Zinc | mg/l | < 0.050 | < 0.050 | < 0.050 | — | — | — | — | — | — | — | — |
| Barium | mg/l | < 1.0 | < 1.0 | < 1.0 | — | — | — | — | — | — | — | — |
| Cadmium | mg/l | < 0.010 | < 0.010 | < 0.010 | — | — | — | — | — | — | — | — |
| Calcium | mg/l | 10.0 | 7.2 | 9.2 | 87 | 86 | 117 | 90 | 101 | 74 | 36 | 4.2 |
| Iron | mg/l | < 0.100 | 0.160 | 0.240 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | — | 0.05 | — |
| Magnesium | mg/l | 10.0 | 14.3 | 10.0 | 3.2 | 6.1 | 2.4 | 10.2 | 6.6 | 14 | 5 | 8.7 |
| Manganese | mg/l | < 0.050 | < 0.050 | < 0.050 | — | — | — | — | — | — | — | — |
| Mercury | mg/l | < 0.002 | < 0.002 | < 0.002 | — | — | — | — | — | — | — | — |
| Nitrate (as N) | mg/l | 1.7 | 2.2 | 1.3 | 1.2 | 1.0 | 1.0 | 2.0 | — | 1.53 | — | 3.5 |
| Selenium | mg/l | < 0.010 | < 0.010 | < 0.010 | — | — | — | — | — | — | — | — |
| Silver | mg/l | < 0.010 | < 0.010 | < 0.010 | — | — | — | — | — | — | — | — |
| Chloride | mg/l | 84 | 56 | 60 | 23 | 18 | 16 | 97 | 36 | 155 | 19 | 9.9 |
| Sulfate | mg/l | 9 | 4 | 7 | 3.4 | 3.0 | 0.3 | 23 | 11 | 25 | 3.4 | 3.0 |
| Alkalinity | mg/l | 264 | 180 | 232 | — | — | — | — | — | — | — | — |
| Conductivity | umhos | 728 | 540 | 580 | 455 | 450 | 535 | 705 | — | 932 | — | 299 |
| pH | units | — | — | — | 7.3 | 7.3 | 7.0 | 7.3 | 7.4 | 8.2 | 7.5 | 8.0 |
| Total Organic Carbon | mg/l | < 1 | < 1 | 2 | — | — | — | — | — | — | — | — |
| Total Dissolved Solids | mg/l | — | — | — | 282 | 271 | 342 | 450 | 389 | 542 | 226 | 179 |
| Silicate | mg/l | — | — | — | 1.0 | 1.4 | 4.6 | 0.7 | — | — | — | — |
| Endrin | ug/l | < 0.02 | < 0.02 | < 0.02 | — | — | — | — | — | — | — | — |
| Lindane | ug/l | < 0.01 | < 0.01 | < 0.01 | — | — | — | — | — | — | — | — |
| Metnoxychlor | ug/l | < 0.04 | < 0.04 | < 0.04 | — | — | — | — | — | — | — | — |
| Toxaphene | ug/l | < 2.0 | < 2.0 | < 2.0 | — | — | — | — | — | — | — | — |
| 2,4-D | ug/l | < 3.0 | < 3.0 | < 3.0 | — | — | — | — | — | — | — | — |
| 2,4,5-TP Silvex | ug/l | < 3.0 | < 3.0 | < 3.0 | — | — | — | — | — | — | — | — |

Notes:
1. Analyses for Tumon Maui well and Marbo Wells No. 1 and 6 taken from U.S. Air Force sampling performed March 1, 1978.
2. Analyses for Agana Spring, Mataguac Spring analyzed during period of 1951-1957, taken from Groundwater Resources of Guam: Occurrence and Development (1976).
3. Analyses for Tarague Spring and Janum Spring analyzed in 1969, taken from Groundwater Resources of Guam: Occurrence and Development (1976).
4. Analyses for PUAG and Gorco Wells taken from Groundwater Resources of Guam: Occurrence and Development (1976) during period of 1967-1969.
5. See Figure 6-2 for water quality sample locations.

nitrogen, which is greater than the 1.0 mg/l, or less, normally found in groundwaters. Table 6-7 shows nitrogen concentrations found in water production wells in Guam. If the amount of nitrate being introduced into the ground via septic tank leachfields and cesspools can be predicted and the amount of rainfall contributing to the aquifer is known, the impact of these wastewater systems on the groundwater nitrate concentrations can be established.

Coliform Bacteria - Coliform bacteria is of significance as it can be used as an indicator organism signaling the possible presence of pathogenic bacteria, viruses or protozoa. The diseases caused by waterborne bacteria are usually intestinal and include typhoid fever, dysentery, cholera and gastroenteritis. Infectious hepatitis is a disease that is caused by waterborne viruses.

The coliform group consists of organisms of both fecal and nonfecal origin. The total coliform count is the standard laboratory test used to indicate contamination of drinking water. When the total coliform count is large, fecal coliforms are usually counted to determine the possible sources of contamination. Fecal coliform to total coliform ratios of 0.20 or greater may indicate pollution by raw sewage or domestic wastewater.

Determination of coliform organisms in Guam's groundwater is completed by the membrane-filter technique. Samples are collected at the well sites on a monthly basis. Analysis consists of passing 100 ml of the water sample through a membrane filter which retains the bacteria. The bacteria are then contacted with a nutrient-rich agar and incubated. After incubation the colonies are counted and the bacteria concentration in the original water sample determined. The water source is considered as potentially contaminated if the total coliform count is greater than 4/100 ml.

## TABLE 6-7

## NITRATE-NITROGEN CONCENTRATION IN WELL WATERS ON GUAM

in mg/l

| Well | Mean | Standard Deviation | Well | Mean | Standard Deviation |
|---|---|---|---|---|---|
| A-1 | 1.306 | - | F-1 | 0.914 | 0.190 |
| A-2 | 2.118 | - | F-2 | 0.910 | 0.178 |
| A-3 | 1.035 | - | F-3 | 0.888 | 0.186 |
| A-4 | 1.729 | - | F-4 | 0.496 | 0.994 |
| A-5 | 1.035 | - | F-5 | 1.132 | 0.190 |
| A-6 | 1.729 | - | F-6 | 1.212 | 0.128 |
| A-7 | 2.294 | - | F-7 | 1.869 | 0.254 |
| A-8 | 1.800 | 0.033 | F-8 | 1.203 | 0.216 |
| A-9 | 1.888 | 1.212 | F-9 | 1.590 | 0.754 |
| A-10 | 1.639 | 1.596 | F-10 | 0.836 | 0.058 |
| A-11 | 0.753 | - | F-11 | 0.858 | 0.179 |
| A-12 | 0.753 | - | | | |
| A-13 | 1.798 | 0.149 | H-1 | 1.961 | 0.039 |
| A-14 | 2.231 | 0.061 | | | |
| A-15 | 4.158 | 0.135 | M-1 | 1.200 | 0.268 |
| A-17 | 2.630 | 0.291 | M-2 | 1.231 | 0.108 |
| A-18 | 2.196 | 0.110 | M-3 | 0.854 | 0.546 |
| A-19 | 4.030 | 0.384 | M-4 | 1.054 | 0.214 |
| A-21 | 1.294 | 0.001 | M-5 | 1.664 | 0.757 |
| | | | M-6 | 1.465 | 0.669 |
| AG-1 | 1.139 | 0.366 | M-7 | 1.748 | 0.537 |
| AG-2 | 1.740 | 0.541 | M-8 | 1.486 | 0.310 |
| | | | M-9 | 1.416 | 0.438 |
| D-1 | 1.764 | 0.713 | M-12 | 2.323 | 0.501 |
| D-2 | 1.679 | 0.410 | M-14 | 2.006 | 0.445 |
| D-3 | 1.511 | 0.746 | | | |
| D-4 | 1.687 | 0.668 | MW-1 | 2.458 | 0.865 |
| D-5 | 2.204 | 0.492 | MW-2 | 2.478 | 0.572 |
| D-6 | 1.300 | 0.629 | MW-3 | 2.397 | 0.634 |
| D-7 | 1.205 | 0.697 | MW-5 | 1.593 | 0.587 |
| D-8 | 1.262 | 0.443 | MW-6 | 2.272 | 0.615 |
| D-9 | 1.032 | 0.269 | MW-7 | 1.950 | 0.686 |
| D-10 | 1.401 | 0.790 | MW-8 | 2.382 | 0.382 |
| D-11 | 1.383 | 0.550 | MW-9 | 1.859 | - |
| D-12 | 1.526 | 0.699 | | | |
| D-13 | 0.936 | 0.516 | Y-1 | 2.539 | 0.464 |
| D-14 | 3.958 | 0.965 | Y-2 | 2.482 | 0.346 |
| D-15 | 2.375 | 0.579 | Y-3 | 3.112 | 0.766 |
| D-16 | 2.944 | 0.047 | Y-4 | 2.457 | 0.646 |
| D-17 | 1.009 | 0.431 | Y-5 | 1.906 | 0.446 |
| D-18 | 3.070 | - | Y-6 | 2.070 | - |

Notes: Calculated from data received from GEPA lab for the years 1979, 1980,1981. When only one data point was available, no standard deviation is shown.

Table 6-8 shows the PUAG wells which have had positive results from the coliform test at least once during the period of May 1979 through November 1981. Most of these wells have had so few positive results and at such low concentrations that they are not of concern as health hazards. However, Wells A-6, A-13, and Y-3 do show a significant number of positive results and are of concern.

Wells A-6 and A-13 occur in the argillaceous limestone formation in central Guam. Well A-6 is located near Afami Road and Well A-13 is south of the Guam Penitentiary. Contamination of these water sources could be a result of subsurface discharge from nearby septic tanks and cesspools, improper well construction, or other circumstances.

Well Y-3 has a history of contamination predating the current data. Well Y-3 is located in Yigo near the Commissioner's office, which once used a cesspool for wastewater disposal. Other houses also discharged wastewater into this cesspool, which was suspected as a source of contamination of Well Y-3. Tests were conducted in 1974 to determine if such was indeed the case. Dye and saltwater dumped into this cesspool appeared in well samples within 24 hours. The Commissioner's office has since been connected to a newly constructed public sewer.

<u>Miscellaneous Constituents</u> - The concentrations of silica vary from about one mg/l in the limestones to in excess of 90 mg/l for the waters draining the volcanic area. Silica concentrations indicate the lithology of the aquifer in which the water moves. These concentrations do not normally cause any significant problems.

The groundwaters have variable concentrations of total hardness (calcium and magnesium carbonate). The concentration is associated with the carbon dioxide content of the incident water and its action upon the limestone. The carbon dioxide is derived

from both the atmosphere and from biological activity in the overlying soil. Also, additional hardness is derived from sea water interaction. Hardness levels of up to 400 mg/l are found in some groundwaters, particularly in the A-Series well region.

Water hardness is an important water characteristic as hard waters require considerable amounts of soap to produce a foam or lather and also produce scale in metal water pipes, hot water heaters, and boilers. The hardness of water varies considerably from place to place although, in general, surface waters are softer than groundwaters. Waters are commonly classified in terms of the degree of hardness as follows:

| | |
|---|---|
| 0 - 75 mg/l | Soft |
| 75 - 150 mg/l | Moderately Hard |
| 150 - 300 mg/l | Hard |
| 300 - up mg/l | Very Hard |

The optimum water hardness is usually considered to be in the range of 80 to 100 mg/l as $CaCO_3$. The limestone formations in northern Guam cause the water to be high in hardness. As an example, for water from wells in the Yigo area, the average hardness is about 270 mg/l as $CaCO_3$.

Priority Pollutants

Although historical data analyses provide a fair indication of most inorganic compounds to be expected in the groundwater of Guam's Northern Lens, but the need for a comprehensive water quality monitoring program clearly exists. The first task to be undertaken as part of the Northern Guam Lens Study was a priority pollutant survey. The U.S. Environmental Protection Agency has developed a list of priority pollutants, comprised of over 130 inorganic and organic chemical constituents and pesticides. A list of the compounds is presented in Table 6-9.

TABLE 6-8

WATER WELLS WITH POSITIVE RESULTS OF BACTERIA CONTAMINATION

| Well | Number of Test Runs | Number of Samples | Total Coliform per 100 ml May 1979 through November 1981 High | Low | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| A-1 | 37 | 2 | 12 | 8 | 1.0 | 2.8 |
| A-2 | 37 | 2 | 10 | 1 | 5.5 | 6.4 |
| A-3 | 37 | 1 | 9 | 9 | 9.0 | 0 |
| A-4 | 37 | 1 | 10 | 10 | 10.0 | 0 |
| A-5 | 37 | 3 | 16 | 2 | 8.7 | 7.0 |
| A-6 | 37 | 18 | 85 | 3 | 23.8 | 29.2 |
| A-7 | 37 | 1 | 11 | 11 | 11.0 | 0 |
| A-8 | 37 | 1 | 13 | 13 | 13.0 | 0 |
| A-9 | 37 | 2 | 6 | 1 | 3.5 | 3.5 |
| A-10 | 37 | 4 | 10 | 3 | 5.8 | 3.4 |
| A-11 | 37 | 4 | 53 | 2 | 22.3 | 22.1 |
| A-12 | 37 | 2 | 42 | 2 | 22.0 | 28.3 |
| A-13 | 37 | 10 | 8 | 1 | 4.0 | 2.5 |
| A-14 | 37 | 3 | 20 | 1 | 8.0 | 10.4 |
| A-15 | 37 | 2 | 137 | 2 | 69.5 | 95.5 |
| A-17 | 37 | 4 | 38 | 1 | 19.5 | 20.8 |
| A-18 | 37 | 5 | 22 | 1 | 6.6 | 8.7 |
| A-19 | 37 | 6 | 22 | 1 | 5.2 | 8.3 |
| A-21 | 37 | 2 | 17 | 1 | 9.0 | 11.3 |
| AG-1 | 37 | 3 | 3 | 1 | 1.7 | 1.2 |
| AG-2 | 37 | 1 | 1 | 1 | 1.0 | 0 |
| D-2 | 37 | 1 | 6 | 6 | 6.0 | 0 |
| D-3 | 37 | 5 | 16 | 1 | 6.0 | 5.8 |
| D-4 | 37 | 2 | 5 | 1 | 3.0 | 2.8 |
| D-5 | 37 | 5 | 347 | 1 | 92.8 | 149.6 |
| D-7 | 37 | 2 | 3 | 1 | 2.0 | 1.4 |
| D-8 | 37 | 2 | 15 | 2 | 8.5 | 9.2 |
| D-9 | 37 | 3 | 42 | 1 | 16.3 | 22.4 |
| D-10 | 37 | 1 | 1 | 1 | 1.0 | 0 |
| D-11 | 37 | 1 | 2 | 2 | 2.0 | 0 |

| Well | Number of Test Runs | Number of Samples | Total Coliform per 100 ml May 1979 through November 1981 High | Low | Mean | Standard Deviation |
|---|---|---|---|---|---|---|
| D-12 | 37 | 3 | 4 | 2 | 3.3 | 1.2 |
| D-14 | 37 | 3 | 6 | 1 | 3.0 | 2.6 |
| D-16 | 37 | 1 | 2 | 2 | 2.0 | 0 |
| D-17 | 37 | 1 | 4 | 4 | 4.0 | 0 |
| D-18 | 37 | 1 | 5 | 5 | 5.0 | 0 |
| F-1 | 37 | 1 | 1 | 1 | 1.0 | 0 |
| F-3 | 37 | 3 | 27 | 1 | 10.0 | 14.7 |
| F-4 | 37 | 3 | 18 | 3 | 9.7 | 7.6 |
| F-6 | 37 | 3 | 2 | 1 | 1.3 | .58 |
| F-7 | 37 | 3 | 26 | 2 | 13.3 | 12.0 |
| F-8 | 37 | 7 | 43 | 1 | 8.6 | 15.6 |
| F-11 | 37 | 1 | 1 | 1 | 1.0 | 0 |
| H-1 | 37 | 2 | 9 | 1 | 5.0 | 5.7 |
| M-1 | 37 | 2 | 3 | 1 | 2.0 | 1.4 |
| M-2 | 37 | 1 | 1 | 1 | 1.0 | 0 |
| M-3 | 37 | 4 | * | 1 | N/A | N/A |
| M-5 | 37 | 7 | 80 | 1 | 17.9 | 28.8 |
| M-6 | 37 | 5 | 18 | 1 | 6.2 | 7.0 |
| M-7 | 37 | 6 | 20 | 1 | 8.7 | 6.2 |
| M-8 | 37 | 2 | * | 3 | N/A | N/A |
| M-9 | 37 | 1 | 5 | 5 | 5.0 | 0 |
| M-12 | 37 | 3 | 2 | 1 | 1.3 | 0.58 |
| M-14 | 37 | 2 | 21 | 1 | 11.0 | 14.1 |
| Y-1 | 37 | 3 | 8 | 1 | 3.3 | 4.0 |
| Y-2 | 37 | 3 | 12 | 1 | 5.0 | 6.1 |
| Y-3 | 37 | 16 | 400 | 1 | 42.3 | 96.8 |
| Y-4 | 37 | 3 | 19 | 1 | 12.0 | 9.6 |
| Y-5 | 37 | 2 | 25 | 2 | 13.5 | 16.3 |

Note: Too numerous to count

Source: PUAG laboratory results

## TABLE 6-9
## LIST OF PRIORITY POLLUTANTS

**Volatile Organic Compounds**

Acrolein
Acrylonitrile
Benzene
Bromomethane
Bromodichloromethane
Bromoform
Carbon Tetrachloride
Chlorobenzene
Chloromethane
2-Chloroethylvinyl ether
Chloroform
Chloromethane
Dibromochloromethane
Dichloroethylene
1.1-Dichloroethane
1.2-Dichloroethane
1.1-Dichloroethene
trans-1.2-Dichloroethane
1.2-Dichloropropane
cis-1.3-Dichloropropene
trans-1.3-Dichloropropene
Ethylbenzene
Methylene chloride
1.1.2.2-Tetrachloroethane
Tetrachlorethene
1.1.1-Trichloroethane
1.1.2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
Toluene
Total Tricholomethane
Vinyl chloride

**Base/Neutral Organic Compounds**

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Benzo(g,h,i)perylene
Chrysene
Dibenzo(a,h)anthracene
Fluoranthane
Fluorene
Indeno(1,2,3-cd)pyrene
Naphthalene
Phenanthrene
Pyrene

**Acid Organic Compounds**

4-Chloro-3-methylphenol
2-Chlorophenol
2.4-Dichlorophenol
2.4-Dimethylphenol
2.4-Dinitrophenol
2-Methyl-4.6-dinitrophenol
2-Nitrophenol
4-Nitrophenol
Pentachlorophenol
Phenol
2.4.6-Triclorophenol

**Ethers and Esters**

Bis(2-chloroethyl)ether
Bis(2-chloroethoxy)methane
Bis(2-ethylhexyl)phthalate
Bis(chloroisopropyl)ether
4-Bromophenyl phenyl ether
Butyl benzyl Phthalate
4-Chlorophenyl phenyl ether
Diethylphthalate
Dimethylphthalate
Dioctylphthalate
Di-n-butylphthalate
Isophorone

**Pesticide Compounds**

Aldrin
a-BHC
B-BHC
d-BHC
Y-BHC
Chlordane
2.4.5-TP Silvex
4.4-DDD
4.4-DDT
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan Sulfate
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
Lindane
Methoxychlor
Toxaphene
PCB-1015
PCB-1221
PCB-1232
PCB-1242
PCB-1248
PCB-1254
PCB-1260

**Nitrogen Containing Compounds**

Benzidine
2.4-Dinitrotoluene
2.6-Dinitrotoluene
1.2-Dephenylhydrazine
Nitrobenzene
N-Nitrosodimethylamine
N-Nitrosodi-n-propylamine
N-Nitrosodiphenylamine

**Chlorinated Hydrocarbons**

2-Chloronaphthalene
1.3-Dichlorobenzine
1.4-Dichlorobenzene
1.2-Dichlorobenzene
3.3-Dichlorobenzidine
Hexachlorobenzene
Hexachlorobutadiene
Hexachloroethane
Hexachlorocyclopentadiene
2.3.7.8-Tetrachlorodibenzo-p-dioxin
1.2.4-Trichlorobenzene

**Elements**

Antimony
Arsenic
Barium
Beryllium
Cadmium
Chloride
Chromium
Copper
Fluoride
Iron
Lead
Manganese
Mercury
Nickel
Nitrogen ($NO_2$)
Selenium
Silver
Thallium
Zinc

**Miscellaneous**

Asbestos
Cyanides
Phenols
Sulfate
Foaming agents
Oil and grease

The primary objectives of the priority pollutant analysis are to 1) determine the existence of pollutants in the groundwater aquifer, 2) to identify the sources of pollutants, and, if sources are found, 3) to develop an effective source control plan. The results of this analysis is discussed in detail in the Groundwater Management Program report.

Stormwater Runoff and Recharge

In most of northern Guam, rainfall does not run off overland as stream or river flow, but percolates through the limestone to the groundwater. Any pollutants picked up and transported by stormwater could be discharged into the fresh water lens. The more developed areas of northern and central Guam produce a large volume of runoff which is discharged via storm drains to ponding basins or dry wells, thereby recharging the aquifer. In other cases, the storm waters are discharged to coastal waters, thus reducing the amount of recharge to the groundwater, but avoiding the potential for groundwater contamination.

Ponding Basins - Ponding basins are the most widely used means of stormwater disposal for the civilian urbanized subdivisions of northern Guam. Currently, there are a total of 36 ponding basins distributed among 10 subdivisions in northern Guam as identified in Table 6-10. Figure 6-3 indicates areas where ponding basins are used for stormwater disposal.

The use of ponding basins for stormwater disposal in northern Guam is possible because of the high permeability of the limestone. The primary purpose of ponding basins is temporary storage and disposal of stormwater runoff. They also serve a secondary role as a source of groundwater recharge. The Department of Public Works now requires ponding basins where the natural seepage into the ground would otherwise be decreased by development.

Maintenance of ponding basins is under the jurisdiction of the Division of Maintenance and Operations of the Department of

TABLE 6-10
PONDING BASINS IN NORTHERN GUAM

| Location | Number of Basins |
|---|---|
| Harmon Loop-Dededo | 1 |
| Ypaopao-Dededo | 2 |
| Old Kaiser | 14 |
| Liguan Terrace | 3 |
| NCS GHURA 502 | 1 |
| NCS GHURA 503 | 2 |
| Latte Heights | 4 |
| Barrigada Heights | 2 |
| Radio Barrigada Station | 1 |
| Marianas Terrace | 1 |
| Perez Acres - Yigo | 1 |
| GHURA Low Cost | 2 |
| Vocational Technical High School | 1 |
| Hospital Road - Tamuning | 1 |
| TOTAL | 36 |

Source: Division of Operations and Maintenance, Department of Public Works, Guam.

Public Works. The Division is responsible for vegetation control and silt and debris removal. Historically, ponding basins have been neglected and not properly maintained because of inadequate funding. Previous studies conducted by Dames and Moore (1978) through the Water Resources and Research Center recommended that silt and vegetation should be removed on an annual basis in order to prevent reduction in the recharge rate.

In the past there has been considerable controversy as to the relationship between groundwater recharge and the urban development of northern Guam. It has been frequently stated that impervious surfaces in the recharge area (e.g., streets, buildings, etc.) will result in a net decrease in recharge. Although this

may be the case if stormwater is collected and discharged to coastal waters, the argument does not hold true if ponding basins are properly constructed and maintained. Dames and Moore (1978) showed that a ten percent increase in recharge could result from the use of ponding basins in a development which created 40 percent impervious cover. On this basis, recharge from a quantity standpoint does not appear to be a factor for controlling development. However, serious attention should be given to the quality of runoff water and its potential for contamination of the aquifer.

Dry Wells - In northern Guam, dry wells are used mainly for draining runoff in military development areas. There are at least 104 dry wells draining airfields and residential areas at Andersen Air Force Base. There are an additional unknown number of dry wells located in Northwest Field as well as on Navy land. Most of the Andersen wells are approximately 200 feet deep, but vary in depth from 35 to 500 feet. None of the wells reportedly open below the water table and most are actually 20 to 60 feet less than the reported depths. This discrepancy in depth could be due to a number of factors including, sloughing of materials, sediment accumulation or inaccurate depth measurements.

As shown on Figure 6-3, the northern limestone formation in the Andersen Air Force Base area rises to nearly 600 feet above sea level. Thus, it can be assumed that most dry wells have approximately 300 to 400 feet of filtering material between the well bottom and the groundwater lens formation.

Little is known regarding the physical features of the Navy's dry wells. Reportedly, there are at least four wells located on NAS and at least two on NCS. The dry wells at NAS are in the vicinity of the fuel pumping station on the perimeter road. The NCS wells are located in the golf course area.

Stormwater Runoff into Coastal Waters - Storm drains are found mainly in coastal urbanized areas such as Tumon Bay, Tamuning and Agana. The construction of storm drains which discharge to coastal waters reduces the available recharge to the aquifer. The continued use of this practice could lead to a degradation of water quality due to saltwater intrusion. Figure 6-3 indicates the major urban areas with discharge to coastal waters.

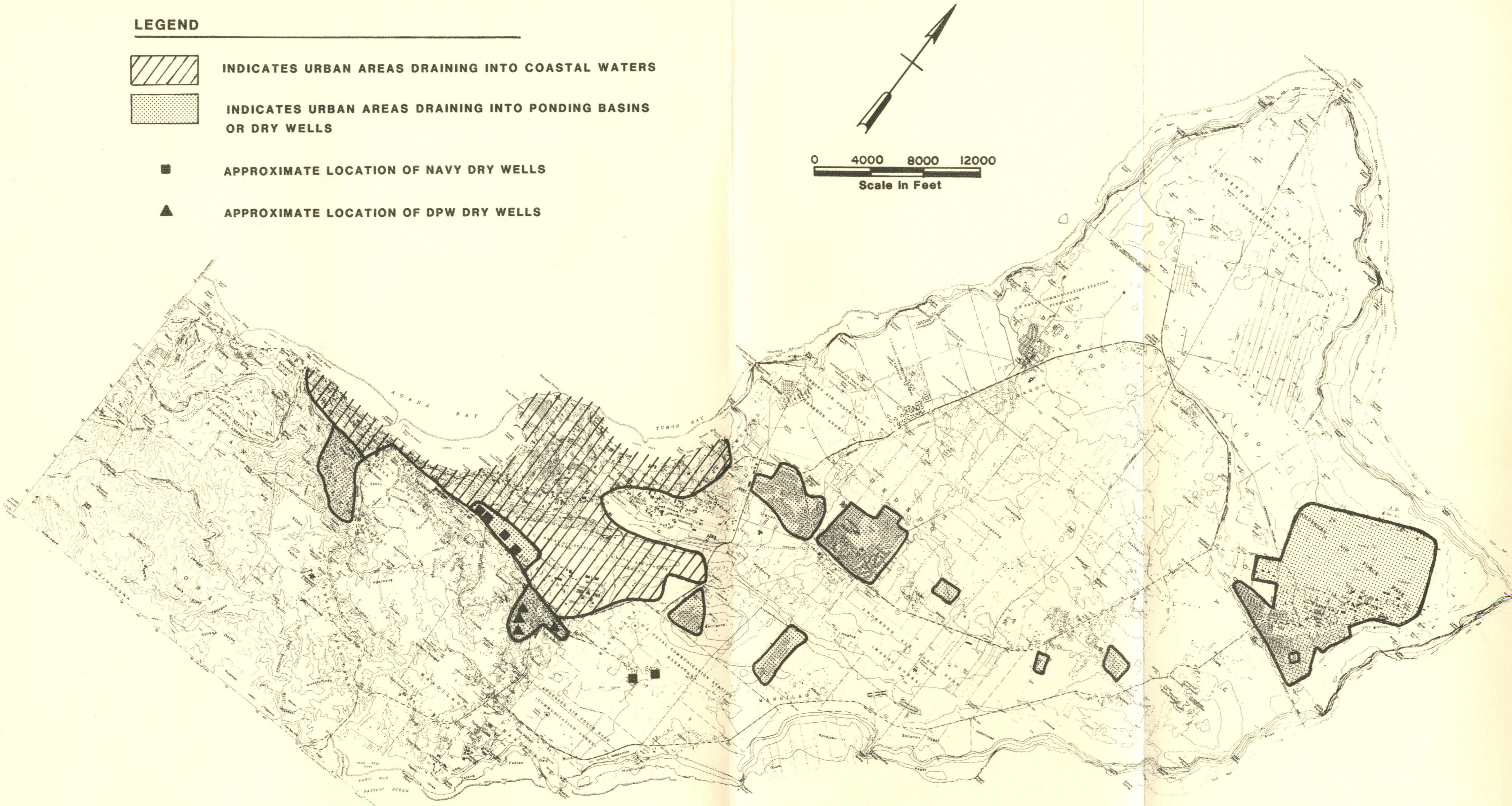
Stormwater Run off Quality - In 1969, a joint study of potential contamination from runoff entering the Andersen dry wells was conducted by the Air Force and USGS. Contaminants were found to be entering the dry wells in several areas, including:

- The sump below the jet engine overhaul areas containing two dry wells between Sk-4 and Bldg. No. 18006.
- The drainage pool behind jet engine test block off the perimeter road at the west end of the north taxiway.
- The drainage ditch and sump at the perimeter road and Third Street below the Aerospace Ground Support Branch.
- The Capehart Housing area sump.

In the first three areas, the potential contaminants were carbon wastes from aircraft maintenance areas. The water entering the sump in the Capehart Housing area was found to be contaminated by the following pesticides:

| | |
|---|---|
| DDD | 0.03 ppb |
| DDE | 0.06 ppb |
| DDT | 0.16 ppb |
| Diazinon | 0.28 ppb |
| Malathion | 0.28 ppb |

No contamination related to dry well drainage was found in any of the samples collected from sources to the south and west of the base.




NOTE: OVER 100 DRY WELLS ARE LOCATED ON ANDERSEN AIR FORCE BASE AND ARE TO NUMEROUS TO LOCATE ON THIS SCALE OF MAP.

FIGURE 6-3

STORMWATER DRAINAGE PATTERNS