A PRELIMINARY STUDY of the TECHNICAL FEASIBILITY of AQUACULTURE

in the

ISLANDS OF
SAIPAN, TINIAN and ROTA
COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

Prepared by

COASTAL RESOURCES MANAGEMENT
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TABLE OF CONTENTS

Forward		1
Section 1	Climate and Water Data	8
Section 2	Saipan Sites	14
Section 3	Tinian Sites	34
Section 4	Rota Sites	39
Section 5	Water and Soils	43
Section 6	Aquaculture Technologies	50
Section 7	Siting Considerations	55
Section 8	Potential Species	60
Section 9	Conclusions and Recommendations	71
Section 10	References	76

LIST OF CHARTS, TABLES AND MAPS

Site Suitability Point Chart	6
Temperature and Rainfall Data for Saipan	9
Temperature and Rainfall Data for Tinian	10
Tinian Water Quality Data	10
Tinian Groundwater Data Derived from Military Wells	11
Temperature and Rainfall Data from Rota	12
Rota Water Quality Data	13
Summary of Site Characteristics by Island	Follows page 13
Saipan Water Quality Data by Site	Follows Site Description
Maps of Saipan, Tinian and Rota Sites	Follows Site Description
Known Physical and Chemical Data for Soils	49
Environmental Suitability of Aquaculture	59
Species Soil Condition Parameters	Follows page 61
Species Physical and Chemical Parameters	Follows page 61
Species Habitat, Feed and Growth Considerations	Follows page 70
Revised Numbering System Saipan Water Wells	Follows page 78

Preliminary Analysis of the Feasibility of Aquaculture Development for the Commowealth of the Northern Mariana Islands

Forward

This report addresses the suitability of nineteen sites in Saipan, Tinian and Rota, Mariana Islands for commercial scale aquaculture. Due to the nature of the project, mariculture sites and species were not investigated, therefore, all sites are based on the culture of brackish or fresh water species.

Sites within rural, agriculture and other land use districts with the potential for large and small scale commercial aquaculture facilities were researched.

Criteria presented below formed the basis for the initial site selection.

Slope: Since aquaculture facilities require essentially level surface, the selected sites have a slope of less than 10 % which has been selected to minimize expensive earthmoving requirements.

Highest Potential/Land Use: This takes in to consideration the type of present and future land-use designation. The probability of it being set aside for aquaculture development was also a factor, based on the nature and intensity of present on-site and adjacent uses.

Area: The total amount of space available for development of individual aquaculture facilities.

Water: The availability of surface, ground or piped water.

The sites were further evaluated through the collection and presentation of data available from published reports, manuscripts, maps, land use plans and government agencies. This information is summarized in the form of individual site fact sheets which provide the site description, elevation, area, soils, drainage, roads, power supply, water supply, land tenure. Additionally, where such data exists, information is presented about water quality, well characteristics and water supply data. These factors were then evaluated for the purpose of determining recommended facilities and species. Finally, the information was considered in reporting an overall suitability rating.

Each site has been mapped at 1:25,000 scale to show the general location, boundaries, topography, water supply, wells, roads, power lines and land uses.

Following is a brief explanation of each category along with an indication of how each factor was considered in evaluating suitability.

DESCRIPTION. Characteristics of the site are presented which may include land uses, adjacent land uses, size, configuration, proximity to important landmarks and vegetation.

ELEVATION. This identifies the distance in meters of the site above sea level. The primary importance of elevation relates to the cost of well development and pumping. Temperature at the higher elevations may be of concern for certain species, although this is unlikely for the Northern Marianas. Lower elevations may be subject to the damaging effects of flooding.

AREA. The size of each site is expressed in square kilometers. Each site generally exceeds the requirements of an individual aquaculture facility. It was beyond the scope of this report to determine the actual requirements for each potential facility in relation to the characteristics of each sub-unit. Additionally, the general lack of data placed great constraints on the ability to meaningfully characterize smaller units within a site. The information contained in the maps, however, such as power, water and road alignments should serve to guide the developer in the process of selecting the individual site which may be most economical and which may be further evaluated through the conduct of site specific physical, biological and chemical analyses.

SOILS. The type or types of soil found on each site is identified. Information was taken from published reports and maps. Individual soil tests were not available. Detailed descriptions of each type of soil is presented in Section 5. Site specific soil testing is considered imperative.

The type of soil generally tends to predetermine the type of aquaculture facility to be used. Earthen ponds are the most economical facility, but ponds can be built only where soils have a clay content of at least 25% and a depth of 10-12 inches. Soils with a clay content of 40 to 50 percent or more need only be 8 inches deep (Crisostomo, 1985). It is possible, but more expensive to truck-in clay soils, or to use impermeable liners in locations which have permeable soils. It is possible to use containers made of fiberglass or concrete. Soil type is also an important determinant of of site drainage and related environmental effects. A percolation test is considered mandatory for the determination of actual characteristics of a specific location.

DRAINAGE. The drainage characteristics of the soils found at each of the sites are reported. Site specific percolation tests should be conducted. This is considered necessary due to the varying composition and depths of soils found in the CNMI. The rate of percolation will assist the developer to calculate the water requirements, economics and environmental impacts of a project at a particular site. Soil permeability may also serve as an indicator of the presence of ground water beneath a site.

ROADS. The type of road which serves the site is identified as either paved, coral or four-wheel drive. It is essential to have an all-weather road to transport supplies and harvests on a year-round basis. Most of the coral roads and all the paved roads should be adequate for year-round use. The four-wheel drive roads and some of the coral roads may be impassible during the rainy season. Potential developers should consider this factor carefully, particularly for the more remote locations where road maintenance is limited.

POWER. The proximity of the power supply to the site is stated, as is the type of line and the feeder system where such information is available. The site maps show the alignment of the power lines. The availability of power to a site is considered critical as the amount required for an aquaculture facility would be too costly for on-site generation of electricity. Back-up generator capacity should be considered necessary.

WATER SUPPLY. Water is the primary requisite for aquaculture production. Fresh or brackish ground and surface waters are used to supply ponds while the public water supply provides for processing and sanitation; it is not used for aquaculture due to its expense, unreliability and presence of chlorine and other contaminants. The use of marine waters is not considered by this report.
In the Marianas, the only source of fresh water is rain. Rain water percolates through the soil cover into highly permeable limestone formations. The resulting freshwater accumulation can be characterized as either basal or parabasal ground water. Basal ground water is a lense of freshwater which is immediately underlain by saltwater. Parabasal ground water is in hydraulic continuity with the basal ground water but not in contact with sea water because it is underlain by impermeable volcanic formation. A salt water "toe" is located along the line of intersection between the fresh water-salt water interface and the contact between the limestone and volcanic basement rocks.

A mixture of sea water and fresh water is known as brackish water. Generally brackish water has a chloride content of between 500 ppm, the upper level of potable water, and 32,000 ppm, which is sea water. Brackish water probably underlies most limestone areas of Saipan, Tinian and Rota. Such water would be found at the lower elevations of the fresh water-salt water interface.

Surface water, such as lakes, streams, springs and wetlands, also originates from rain water, and may be brackish due to contact with sea water. Surface water may be perched over impermeable soils fed by watershed runoff such as lakes and wetlands. Streams occur when runoff or spring water flows over an impermeable surface and may terminate at an estuary or when permeable soils are encountered. Water may also flow from the ground as a spring. A spring results when an accumulation of percolated rainwater overflows the confines of surrounding impermeable materials.

In Saipan and Rota, surface water is a potential source of water for aquaculture. Rivers are the best source, however, they do not occur in the Northern Marianas. Springs are often existing and potential sources for potable water. Springs and streams have variable flow rates and may be less dependable than ground water. Lake Susupe is a good source of brackish water although flooding and land availability must be considered. Permanent wetland areas may be a source of brackish water, but water supply fluctuations, flooding and environmental impacts may occur.

Fresh water is a precious resource in the CNMI. Consequently, the first priority of use must be for the public water supply. Aquaculture is water intensive and, therefore, its affect on the public water supply must be seriously considered.

An aquaculture facility may impact the water supply in two ways. First, the culture of fresh water species would require a significant volume of fresh water and could reduce the supply of drinking water. This should be a primary consideration where fresh water aquifers have been developed or which could reasonably expect to be developed in the future.

The culture of brackish water species also requires a substantial volume of water. Thus a brackish water well may have damaging affects on the public water supply if the wells are located in close proximity. When basal water is withdrawn by pump, the salt water may be drawn upward if a pump is set too deep or if the volume pumped is too great. When this occurs, the water quality may not be acceptable for drinking and irrigation. The fresh water lens may be disturbed for some time after pumping has stopped. Conversely, the public water supply operation may also seriously affect the aquaculture facility's water supply in terms of quantity and quality.

Many of the aquaculture species reported herein can be successfully cultured in brackish water. The advantages related to the potential supply of brackish water and concerns over competition for fresh water would appear to favor the culture of brackish water species. The potential aquaculture sites identified by this study which are suitable for brackish water culture are numerically greater than fresh water sites.

Rainwater is not considered as a supply source because of the high cost of constructing a storage container of sufficient volume to last throughout the normal dry season with adequate reserve for periods of drought. It would be possible to supplement other sources with rainwater, however, a facility should not be designed which depended solely upon rainwater without provisions for the collection and storage of extremely large volumes of rain water.

The report contains the water data used in evaluating candidate sites. Such information should be used by the potential aquaculturist in further evaluating the site, for comparative purposes and to help identify data which are unavailable.

Known ground water data have been reported in tabular form. Such data were derived from current production wells, test holes and abandoned wells. The location of known wells were mapped if located within or adjacent to a designated aquaculture site.

Water quality data are reported for wells and reservoirs in the vicinity of a candidate site or which supply the site as an indicator of possible ground water availability and condition. Microbiological and physical and chemical conditions of the water may vary between the sampling points, usually the wells and reservoirs, and a candidate site. Differences may arise when the various well waters mix in a reservoir and if contaminants enter the distribution system.

This study attempted to report on sixteen physical water quality parameters deemed important for aquaculture planning purposes. Unfortunately, data for most of the parameters were not available. Original water quality sampling was beyond the scope of this report. On-site water quality sampling is considered absolutely necessary.

It was possible to report the capacity of the Saipan public water system to supply water to each of the sites on a consistent basis. From a study of the Saipan water system indicating average daily use and supply on an hourly basis it was possible to generalize whether water is available on a 24 hour basis.

It was not possible to report the system pressures for Tinian and Rota as the information is not available. The water system capacity is assumed to be adequate for Tinian because of the size of pump, storage and distribution capacity and the small population. Water is generally known to be available 24 hours per day. For Rota, however, the spring which supplies the irrigation line, which is the principle source for Rota sites, is known to have a minimum flow rate which barely exceeds the minimum requirement for a one acre facility.

It should be noted that the CNMI government is making many improvements to the water supply and distribution system, thus conditions described herein should improve.

LAND TENURE. In the CNMI, land is either privately owned, leased or in military retention. The report indicates whether the site ownership is private, public or military. In some cases the land is presently used for other purposes, however, it is believed that such use is either less economical or sufficiently compatible with aquaculture. Suitable arrangement may be possible. Under the terms of the military land agreements, lease-backs for aquaculture may be authorized.

RECOMMENDED FACILITY. This identifies the type of aquaculture facility which may be most cost-effective or practicable given other site characteristics such as soil and water. Generally, a facility will utilize earthen ponds, impermeably lined ponds or fabricated enclosures such as fiberglass or concrete tanks.

RECOMMENDED SPECIES. This section identifies the type of species suitable for culture, primarily on the basis of water and soil types. Either a brackish or fresh water is indicated. In a few cases, where site conditions are less suitable, a higher market type of species is suggested. For example, where the use of fabricated enclosures is warranted, a high market value species such as the Malaysian prawn may compensate for the higher production costs.

SUITABILITY RATING. This rates each site in terms of the likelihood that the site could be developed for aquaculture when the various site factors are considered. Each site is assigned a numerical value based on a formula which considers the presence and absence of necessary attributes.

Two points	Clay soils Marsh/clay soils roads Power Ground/surface water Piped water and ground/surface water Public land Elevation less than 10 meters
One Point	Marsh/sand/fill soils Four wheel drive road Piped water supply Possible ground water Private land Military retention land Public and private land Elevation of 10 - 100 meters
Zero Point	No road No Piped water No ground or surface water Limestone soils Leased lands Elevation over 100 meters
Minus One Point	No electricity No water

The highest possible number of points for one site is fourteen. Generally, the higher the score the better the candidate site, and vice versa.

The average score for Saipan was 11.2. The highest ranked site received 14 points and the lowest received 7 points. Five of 10 sites were above the island average.

The average score for Tinian was 7. The highest ranked site received 12 points and the lowest received 1 point. One of the 5 sites was above the island average.

The average score for Rota was 4.5. The highest ranked sites received 5 points and the lowest received 4 points. Two of the 4 sites were above the island average.

A summary of site characteristics and suitability by island may be found at the end of Section 1.

SECTION 1
CLIMATE AND WATER DATA

The climate of Saipan is uniformly warm and humid throughout most of the year. Afternoon temperatures are normally about 30C. Relative humidity is usually about 70 percent in the afternoon and 90 percent at night. (see Table 1 (U.S.G.S. Compilation))

Rainfall records for Saipan are available for most of the years since 1901 from German, Japanese, and U.S. sources. During the German Administration, rainfall data were collected from 1901-12 and the Japanese collected rainfall records at seven locations during 1924-42. The largest amount of rainfall recorded on Saipan occurred during typhoon Carmen, when 44-1/2 inches of rain were recorded at the Hakmang (Kagman) rain gage in 48 hours during August 10-12, 1978.

Since 1968, daily rainfall data have been collected by the Commonwealth of the Northern Mariana Islands at Hakmang Communication Center and since 1976, at the nearby Agriculture Station. The U.S. Geological Survey has collected continuous records of rainfall at the 9-Mgal (million gallon) reservoir and at Isley Field since 1977.

The dominant winds on Saipan are trade winds blowing from the east or northeast.

There is a distinct dry season from December to June, with March and April normally the driest months of the year. August and September are the wettest months of the year and usually account for one third of the annual rainfall.

Seasonal differences should be considered by the aquaculture developer. Rainfall has a number of effects on an aquaculture facility including water temperature, salinity and evaporation. It may induce algal growth in brackish water systems, cause flooding, erosion, excess runoff, introduce contaminants and make access roads impassable.

Seasonal wind direction variations should be considered. Wind turbulence of surface waters will increase the dissolved oxygen content of a pond, aid in circulation and help keep water temperature down. Winds increase evaporation, introduce contaminants and cause erosion. Typhoons can destroy the entire facility.

Cloudy periods may also affect a facility. Periods of overcast will reduce the photosynthetic production of oxygen. This is a particular problem in early mornings when the level of dissolved oxygen is normally at its lowest point in a 24 hour cycle.

Temperature and Rainfall Data for Saipan

Temperature (Centigrade)			Rainfall (inches)	
	Uplands			Uplands
Mean Annual	Maximum	Minimum		Mths. W/< 1 in.
26	32	19	Mean Annual 90.7	Apr.
			Rainiest Mths.	Least Rainy Mths.
			July - Oct.	Nov. - June
	Lowlands			Lowlands
Mean Annual	Maximum	Minimum		Mths. W/< 1 in.
29	39	20	Mean Annual 81.0	Feb. Mar.Apr.
			Rainiest Mths.	Least Rainy Mths.
			July - Nov.	Dec. - June

Saipan water data is presented for each site in Section 2.

Tinian Climate

The climate of Tinian is uniformly warm and humid. Trade winds are dominant throughout the year, although from July through October there are often winds other than northeasterly (trade) direction.

Relative humidity, in the ordinary range is from 60 to 100 percent, with values commonly between 60 and 70 percent in the warmth of the afternoon and between 85 and 100 percent during the coolest hours, just prior to dawn.

Annual rainfall averages 80 inches. (see Table 2) On the average, slightly more than half of the total annual rain falls during the rainy season (July through October), about 10 percent fall during the dry season (February through April). From year to year, rainfall is most variable during the transition seasons of November through January and May through June. Rains totalling over 4 inches per day are rare in all months and virtually never occur during the months of November through March.

There appears to be minor variations in rainfall over Tinian. This is primarily believed to be the result of the small land mass and the absence of any high mountain peaks to induce weather changes.

Temperature and Rainfall Data for Tinian

Temperature (Fahrenheit)			Rainfall (Inches)	
Mean Annual	Maximum	Minimum	Mean Annual	Months W/ <1 inch
80.4	90	75.4	79.8	Feb.-March
			Rainiest Months	Driest Months
			July-Oct.	Nov.-June

Tinian Water Data

The present water supply of Tinian is derived from two sources 400 feet apart. One site consists of a short infiltration gallery constructed by U.S. Military sources in 1944, and the other consists of two large dug wells (well 40a, 40b) constructed during the Japanese era. The sites are on the perimeter of Sisonyan Magpo, a freshwater marsh just slightly above sea level.

The infiltration gallery (well 41) is the source of Tinian's potable water which is supplied to San Jose Village, the airport and the Micronesian Development Corporation agriculture facility via 12", 8", and 6" pipes. Capacity is approximately 550 gpm.

The other source supplies irrigation water via 12" and 6" pipes. The capacity is about 1,000 gpm which is supplied for 8-10 hours a day three times a week.

Water Quality Data

	Agriculture	Potable
Total Hardness	641	600
Chlorides	299	313
Sulfates	21	14
Fluorides	0.10	0.17
Nitrates (NO3)	21.25	35

expressed in Milligrams per liter (Mg/l).
From M&E Pacific, Tinian Water Management Plan 1978.

Ground water Resource Data Derived From Military Era Wells

VICINITY	WELL #	ELEVATION (feet)	DEPTH TO WATER (feet)	CHL (ppm)	GPM	CONDITION
North Field	10	93.4		220	60	plugged
	37	100	114			
	43		8	622		
	44	9.3	8	148		
Broadway/SLH	1	255.29	254.45	85	55	
	11	290				
	12	184.43		high	60	abandoned-hi chl.
	22	220.94		150	40	
	24	247.27		70+		
	25	208.69	208.21	196+	30	
	33	233.12	232.09	50+		
Cahet/NuNu	2	261.75		20	100	
	4	225.31		35	60	
	6	239.41	237.79	100	100	capped
	17	244				capped
	19	245				plugged
	21	242.08		80+	60	plugged
	39	238		150		
Saganan Abas (Marpo)	40a	4.5		250	500	(1000 gpm*)
	40b	6.43				
	41	9.76		100	550	*
Tachungnya	13	59.96				
	46	50		650+		
	47	35				

From Burke, Military Geology of Tinian 1960.
* From M&E Pacific, Tinian Water Management Plan, 1978.

Rota Climate

The climate of Rota is humid with temperature and pressure varying only slightly throughout the year. However, rainfall and wind conditions vary markedly. These variations subdivide the year into the wet and dry seasons.

Annual rainfall on Rota averages between 97 and 121 inches with the high elevations experiencing the greater amount of rainfall. The period of heaviest rainfall occurs during July through October. The period extending from February through May marks the dry season. The rainfall ratio between the driest and wettest months of the year is roughly 1:5. Relative humidity ranges from 75 to 100 percent.

Precise temperature data are not available for Rota although, as noted, only slight variations are experienced throughout the year. However, the Sabana area experiences somewhat cooler temperatures because of its altitude.

Temperature and Rainfall Data for Rota

Temperature (Fahrenheit)			Rainfall (inches)	
Uplands			Uplands	
Mean Annual	Maximum	Minimum	Mean Annual	Mths. W/< 1 in.
*	*	*	*	*
			Rainiest Mths.	Less Rainiest Mths.
			July-Oct.	Nov.-June
Lowlands			Lowlands	
Mean Annual	Maximum	Minimum	Mean Annual	Mths. W/< 1 in.
*	*	*	*	*
			Rainiest Mths.	Less Rainiest Mths.
			July-Oct.	Nov.-June

* Data not available.

Trade winds blowing from the northeast are persistent during the period from January through May. Wind directions are far more variable during the months of July through October.

Major tropical disturbances with cyclonic winds of 33 to 65 knots are most frequent during the rainy season, although they are by no means restricted to this part of the year. The frequency of these storms is evidenced by the fact that during the 24-year period from 1945-1969, 40 typhoons (with wind speeds of 65 knots or greater) and 30 tropical storms passed within the vicinity of Rota. These storms are an integral aspect of the island's tropical climate.

Rota Water Data

Ground water Data All water is supplied from Matanhanom (eye of water) Spring and Asonan Spring. The U.S. Geological Survey estimated the mean daily flow of Matanhanom to be 1280 gpm; the absolute maximum daily flow 3,740 gpm; and the minimum daily flow less than 350 gpm. Water is distributed from this source to a 1 mg reservoir which supplies Songsong Village via 6" pipe.

Water Quality Data

	Matanhanom (1)	Reservoir intake (2)
pH		8.1
Alkalinity		145
Total Dissolved Solids	175	
Dissolved Solids		172
Total Hardness	146	140 (CaCO3)
Chlorides	11.4	11.1
Sulfates	1.5	
Fluoride	0.17	0.055

expressed in Milligrams per liter (Mg/l).

(1) From M&E Pacific, Rota Water Management Plan 1978. Data taken 1977.
(2) From Division of Environmental Quality September 10, 1982.

Asonan Spring, near Matanhanom, was measured by USGS to have an average flow of 70 gpm; a maximum daily flow of 150 gpm; and a minimum flow of 41 gpm. Measurements were taken from February to July 1971 only. This source supplies irrigation water which is distributed through an 8" pipe. No water quality data is available from Asonan.

ILLUMINATION AND INSOLATION

The longest day in the CNMI is about 13 hours (June 21) and the shortest day is about 11 hours and 10 minutes (December 22); if the period of twilight is included, the length of day is 13 hours and 50 minutes, and 12 hours respectively. (Length of day is defined as the interval between sunrise and sunset, including the twilight periods before sunrise and after sunset during which there is sufficient light for all normal outdoor activities.)

At the ground level, the radiation is a maximum of about 650 langleys (gram calories/cm2) on relatively cloudless days during November and December. Extreme cloudiness is not unusual, except for very thin high cirrus clouds, and the value at the ground nearly always exceeds 400 langleys. The radiation reaching the upper atmosphere which is reduced by cloud cover varies from 916 langleys in early May to about 685 langleys in late December (Burke). Data from the CNMI Energy Office indicates that insolation for May (1984) ranged throughout the day from 137-997 watts per square meter, while ranging from 6-791 W/SM in January (1984).

SUMMARY OF SITE CHARACTERISTICS AND SUITABILITY BY ISLAND

Saipan

SITE	ELEVATION	AREA	SOILS	ROADS	POWER	SW	PW	GW	TENURE	RATING	SUITABILITY
East Achugao	50-70	1.0	Clay	4wd	N	Y	N	N	Public	7	Fair
Kagman Transceiver	60-70	1.0	Clay	Y	Y	N	N	P	Public	10	Good
Kagman Receiver	60-65	0.78	Clay	Y	Y	N	Y	P	Public	11	Good
Naftan	60-75	1.5	Clay	Y	N	N	Y	P	Public	8	Fair
Agingan/Kobler	30-35	0.6	Clay	Y	Y	N	N	Y	Public	10	Good
Sadog Tase	1-3	0.10	sand/grvl	Y	Y	Y	Y	P	Public	13	Good
Susupe Lake	2-4	3.25	clay/mrsh	Y	Y	Y	Y	P	Public/prvt	13	Good
Chalan Laulau	5-10	0.38	clay/mrsh	Y	Y	Y	Y	P	Public	14*	Good
Tanapag	2-5	0.47	Sand/mrsh	Y	Y	Y	Y	Y	Public	13	Good
San Roque	2-5	0.23	Clay/mrsh	Y	Y	Y	Y	P	Public/prvt	13	Good

+ = 1 is the lowest possible rating while 14 is highest possible rating on the basis of this study; * = best island site.

SW = Surface Water; GW = Ground water; PW = Public water; Y = Yes; N = No; P = Possible; LS = limestone; 4wd = four wheel drive vehicle road.

Power and water availability refers to infrastructure only.

SUMMARY OF SITE CHARACTERISTICS AND SUITABILITY BY ISLAND

Tinian

SITE	ELEVATION	AREA	SOILS	ROADS	POWER	SW	PW	GW	TENURE	RATING	SUITABILITY
North Field	15-35	6.5	Fill	Y	N	N	N	Y	Military	6	Poor
Broadway	40-65	4.25	Clay	Y	Y	N	Y	Y	Military	12*	Good
Cahet Banaderon NuNu	60-85	6.6	Clay	Y	N	N	N	Y	Military	7	Fair
Sabana Abas	100-115	1.0	Clay	4wd	N	N	N	N	Leased	1	Poor
Tachungya	10-60	0.9	sand/grvl	Y	Y	N	N	Y	Private	9	Fair

+ = 1 is the lowest possible rating while 16 is highest possible rating on the basis of this study; * = best island site.

Y = Yes; N = No; P = Possible: LS = limestone; 4wd = four wheel drive vehicle road.

Power and water availability refers to infrastructure only.

Rota

SITE	ELEVATION	AREA	SOILS	ROADS	POWER	SW	PW	GW	TENURE	RATING	SUITABILITY
Sabana	430-465	5.0	LS	Y	N	N	N	P	Public	4	Poor
Gampala	160-175	2.4	LS	Y	N	N	Y	P	Public	5*	Poor
Tatgua/Igua	170-175	2.25	LS	Y	N	N	Y	P	Public	5*	Poor
As Dudu/Dugi	140-150	2.65	LS	Y	N	N	N	P	Public	4	Poor

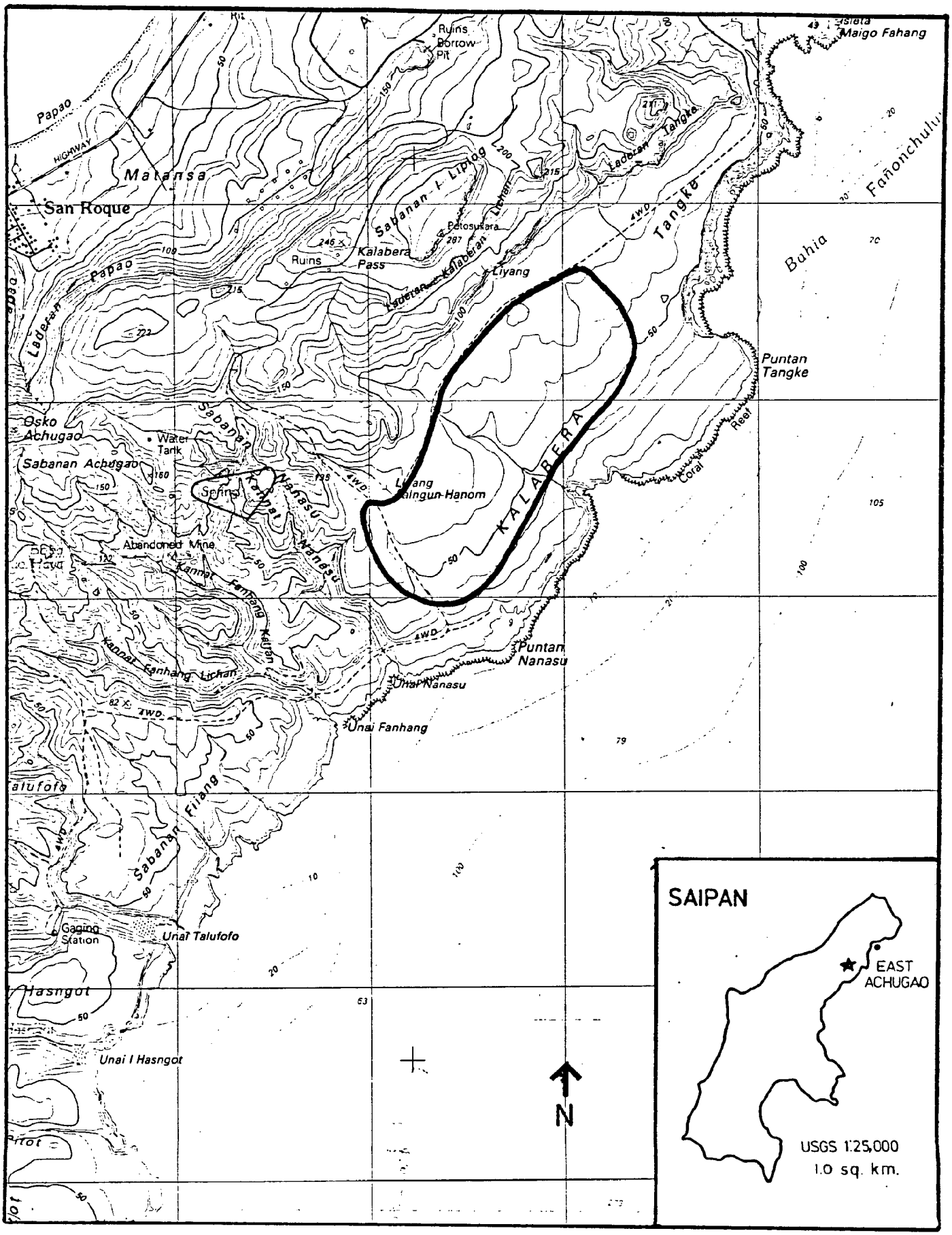
+ = 1 is the lowest possible rating while 16 is highest possible rating on the basis of this study; * = best island site.

Y = Yes; N = No; P = Possible: LS = limestone; 4wd = four wheel drive vehicle road.

Power and water availability refers to infrastructure only.

EAST ACHUGAO

DESCRIPTION:	Bordered at the south by the Achugao Spring and the north half by "Marpi Backroad". Dense vegetation of mostly trees. The site is adjacent to the Marpi Commonwealth Forest.
SLOPE/ELEVATION:	Less than 10%. Slope. Elevation is 50-70 meters.
AREA:	1.0 square kilometers.
SOILS:	Surface soil is a mixture of various types of clay and clay-loam. (U.S.G.S. Generalized Soil Map).
DRAINAGE:	Varies with soil type. See Section 5.
ROADS:	A 4 wheel drive road is inside the Western Boundary.
POWER:	No public electricity. Main line is several miles west.
WATER:	1) Surface: East Achugao Spring is adjacent to the south. Spring discharge is 21 to 42 gpm (Stearns, 1944); 21 - 56 gpm (Glander, 1946); 13 gpm minimum, 20 gpm average, and 40 gpm maximum (as per VanderBrug 1984). The USGS map shows a stream bisecting the site, probably intermittent. 2) Public Supply: No piped water available at this site. 3) Ground water: No wells are known at this site.
LAND TENURE:	The whole of the site is located on public land. The area is designated (PDMP) for grazing agriculture.
RECOMMENDED FACILITIES:	Earthen pond.
RECOMMENDED SPECIES:	Freshwater/Brackish.
SUITABILITY:	7



Ruins
Borrow Pit
Papao
HIGHWAY
Matansa
San Roque
Sabanan I Liplog
Petosukara
Kalabera Pass
Ruins
Liyang
Laderan Kalaberan Lichan
Laderan Tangke
Tangke
Maigo Fahang
Bahia
Puntan Tangke
Coral Reef
KALABERA
Osko Achugao
Water Tank
Sabanan Achugao
Sabanan I Nanasu
Kannat Nanasu
Abandoned Mine
Kannat Fanhang Katyan
Kannat Fanhang Lichan
Puntan Nanasu
Unai Nanasu
Unai Fanhang
Sabanan Fiiang
Gaging Station
Unai Talufofo
Hasngot
Unai I Hasngot
N
SAIPAN
EAST ACHUGAO
USGS 1:25,000
1.0 sq. km.

WATER QUALITY DATA

East Achugao

Water source: East Achugao Spring (1)

pH	7.2 - 7.4	(Glander 1946)
Salinity	50	(")
Alkalinity		
Bicarbonate	332	
Hardness	312	
Ammonia		
Phosphate		
Nitrite		
Nitrate	0	
Sulfate		
Dissolved oxygen		
Temperature	25-27	(September 1965 - October 1970)
CO2		
Fecal Coliforms		
Dissolved Solids	478	
Total Bacteria		
Turbidity		

1. Data from Davis 1958 unless indicated otherwise.

NOTES APPLICABLE TO ALL WATER QUALITY DATA TABLES

a. Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

b. Sampling methods variable. Criteria is also variable, e.g. ppm (parts per million) sometimes expressed as Mg/L (which is roughly equivalent).

c. Where water source is a reservoir, data from wells which supply the reservoir are presented.

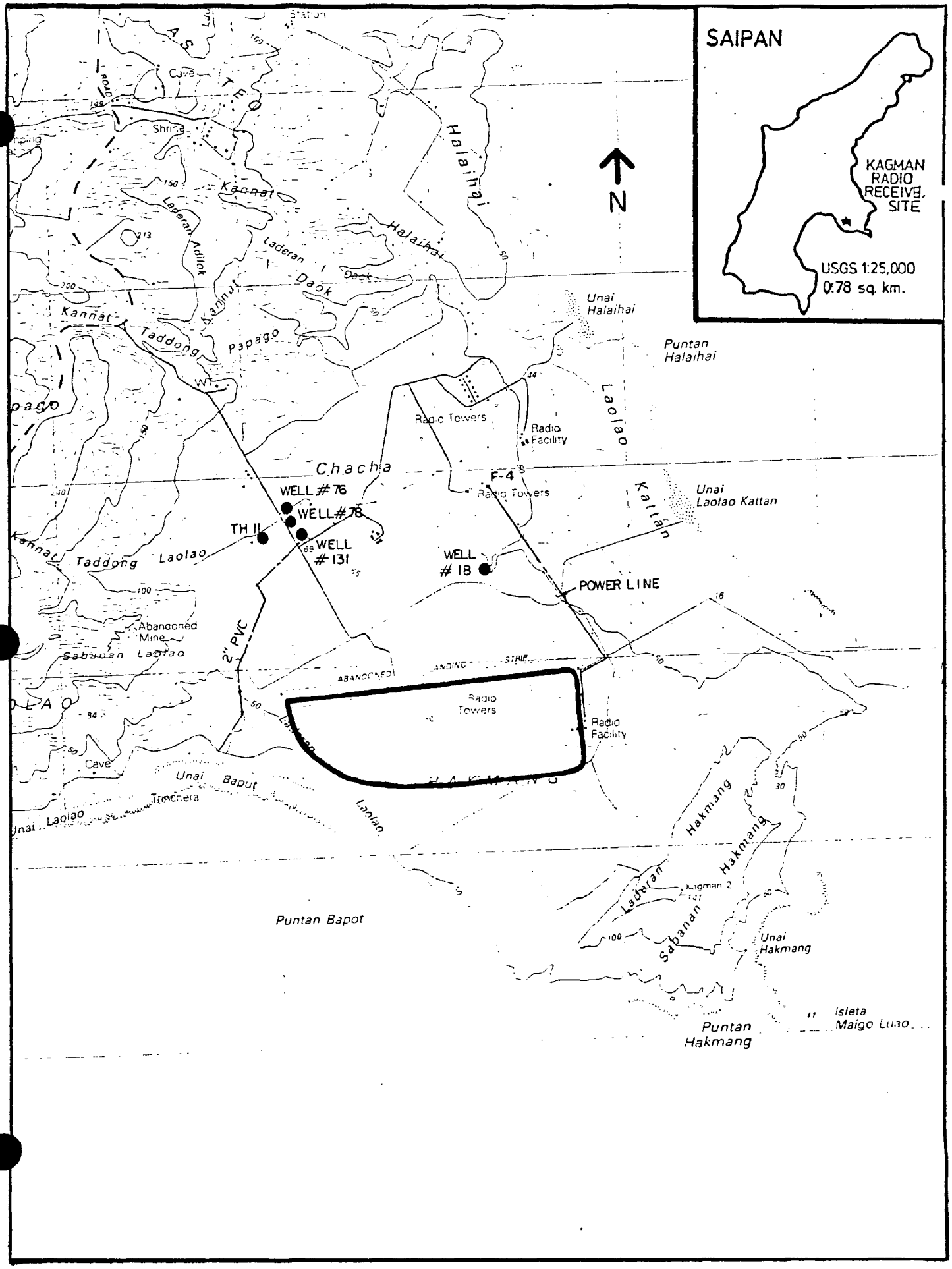
d. Blank spaces means no data available.

e. All data derived from VanderBrug and Nance.

SECTION 2
SAIPAN SITES

KAGMAN - RADIO TRANSMITTER SITE

DESCRIPTION:	This site is the present Radio Transmitter Site and Antenna field located south of the abandoned airfield in Kagman. It stretches roughly the full length of the airfield and about 800-1000 feet wide.
SLOPE/ELEVATION:	Less than 10%. Slope. Elevation is 60-70 meters
AREA:	1.0 square kilometers
SOILS:	90% or more Chacha Clay and Chinen Clay-loam. 10% or less limestone out-croppings.
DRAINAGE:	Medium (Chacha) to Well drained (Chinen).
ROADS:	There is a coral access road and asphalt runway.
POWER:	Public power available. Feeder 4.
WATER:	1) Surface: No surface water available. 2) Public Supply: Public source is not available. 0.05 MG reservoir less than 2 kilometers away. A pipeline is about 350 meters west of the westernmost boundary. 3) Ground water: No wells are located within this site, however, one military era well is located about 700 meters from the northwest corner.
LAND TENURE:	Area is designated for public facility and grazing agriculture. It is located on public land.
RECOMMENDED FACILITY:	Earthen pond.
RECOMMENDED SPECIES:	Freshwater/Brackish.
SUITABILITY:	10


SAIPAN
KAGMAN RADIO RECEIVE SITE
USGS 1:25,000
0.78 sq. km.
N
Chacha
WELL #76
WELL #78
TH 11
WELL #131
WELL #18
F-4
POWER LINE
Radio Towers
Radio Facility
Unai Halaihai
Puntan Halaihai
Unai Laolao Kattan
Kannat Taddong Laolao
Kannat Taddong Papago
Laderan Adilok
Laderan Daok
Halaihai
Laolao Kattan
Abandoned Mine
Sabanan Laolao
2" PVC
ABANDONED LANDING STRIP
Unai Baput
Trinchera
Unai Laolao
Puntan Bapot
Laderan Hakmang
Sabanan Hakmang
Kagman 2
Unai Hakmang
Puntan Hakmang
Isleta Maigo Luao
Cave
Shrine
Station

WATER QUALITY DATA

Kagman Radio Transmitter Site
Kagman - Radio Receiver Site

Water source: Hakmang Reservoir (supplied by well 76)

	well 76
pH	7.1 - 8.0
Salinity	33.9 - 85.3
Alkalinity	320 - 326
Bicarbonate	
Hardness	354 (4/21/83)
Ammonia	
Phosphate	
Nitrite	
Nitrate	
Sulfate	14 (1967)
Dissolved oxygen	
Temperature	25 C (1967)
CO2	41
Fecal Coliforms	
Dissolved Solids	406 - 552
Total Bacteria	
Turbidity	0 (1967)

Sampling analysis from 1-7-81 to 4-21-83 unless otherwise indicated.

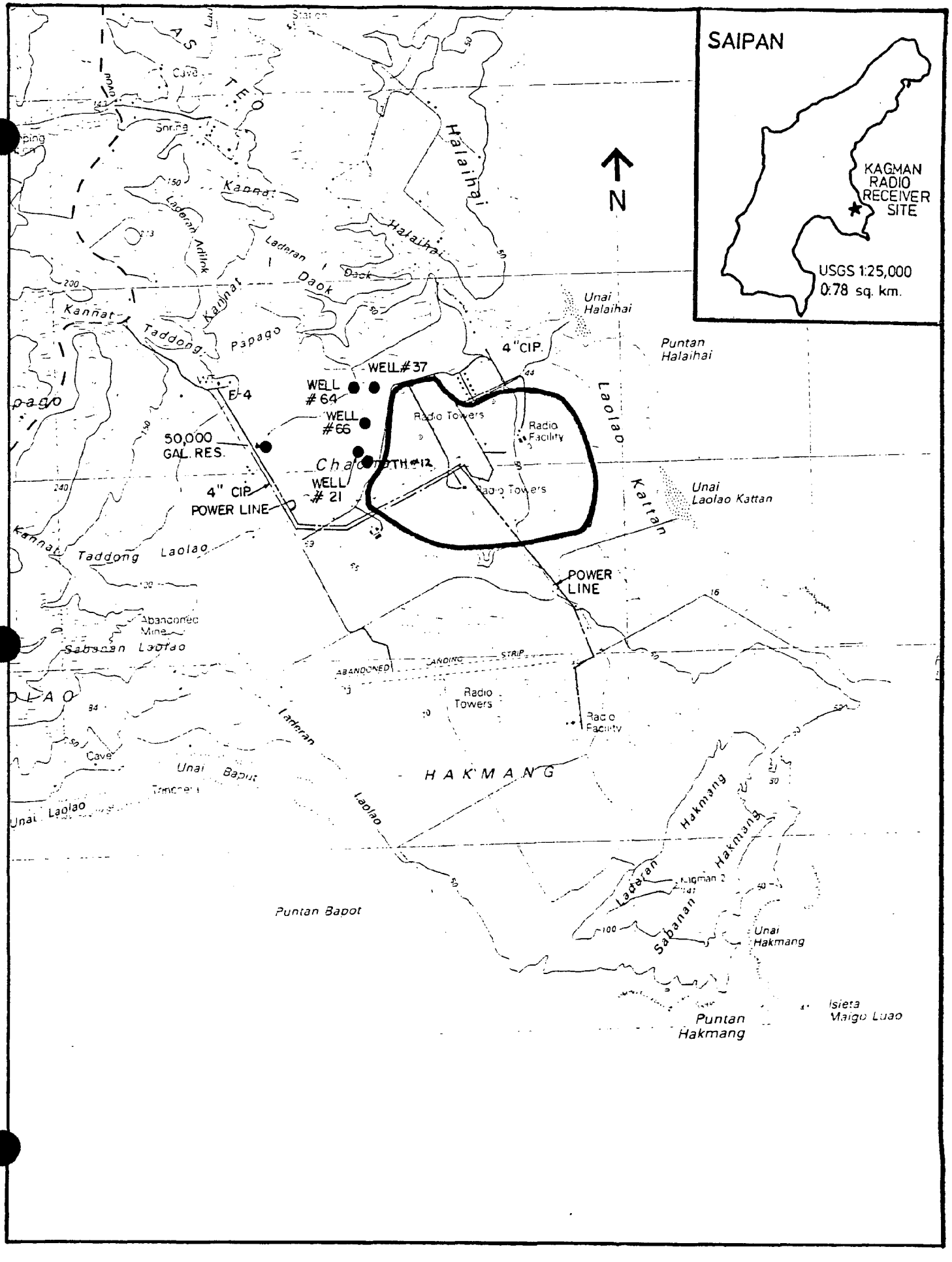
Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

WELL DATA

VICINITY	WELL	ELEVATION	DEPTH TO WATER	CHLORIDE	GPM	COMMENTS
Kagman	131	227	210			deepened to 345'
Transmitter	78	229	212			
	76		35	60-70		
	18					no well log
	TH11	245	230			abandoned 1980
Kagman	21	217	350			
Receiver	64	214	nr			
	66					used 3 months 1945
	67					"
	TH12					abandoned 1980

KAGMAN - RADIO RECEIVER SITE

DESCRIPTION:	This site occupies the Radio Receiver Site at Kagman. It is adjacent to the Samoan Housing Units and the Kagman Agriculture experimentation Site.
SLOPE/ ELEVATION:	Less than 10% slope. Elevation is 60-65 meters
AREA:	0.78 square kilometers
SOILS:	Soil is a mixture of Chacha Clay, Dandan Clay and Chinen Clay-loam.
DRAINAGE:	Medium (Chacha) to well drained (Dandan, Chinen).
ROADS:	There are coral and asphalt roads.
POWER:	Public power is available. Feeder 4.
WATER:	1) Surface: No surface water available. 2) Public Supply: Piped public water is available. Irrigation reservoir is immediately adjacent to the south boundary. The 0.05 MG Kagman reservoir is less than 2 kilometers away. Capacity: The daily use is 21.1 gpm. The supply exceeds the demand from approximately 7am to 8pm; demand exceeds supply from 8pm to 7am. System pressure ranges from 39 to 69 psi. 3) Ground water: No wells are located within the site; however, four military era wells and one recent test well are located to the west of the site.
LAND TENURE:	Present usage is radio receiving facilities. Proposed future designation is for public cropland. It is located on public land.
RECOMMENDED FACILITY:	Earthen pond.
RECOMMENDED SPECIES:	Freshwater/Brackish.
SUITABILITY:	11


SAIPAN
KAGMAN RADIO RECEIVER SITE
USGS 1:25,000
0.78 sq. km.
N
WELL #37
WELL #64
WELL #66
WELL #21
50,000 GAL. RES.
4" CIP
POWER LINE
4" CIP.
POWER LINE
Radio Towers
Radio Facility
Unai Halaihai
Puntan Halaihai
Unai Laolao Kattan
Laolao Kattan
Halaihai
Kannat Taddong
Kannat Daok
Laderan Adilok
Laderan Daok
Papago
Laolao
Sabanan Laolao
Abandoned Mine
Cave
Unai Baput
Unai Laolao
HAKMANG
Laderan Laolao
Puntan Bapot
Laderan Hakmang
Sabanan Hakmang
Unai Hakmang
Puntan Hakmang
Isieta Maigo Luao

NAFTAN PENINSULA

DESCRIPTION: This site is located less than a mile northwest from the tip of the peninsula. The west portion is surrounded by the Saipan International Airport perimeter.

SLOPE/ELEVATION: Less than 10% slope. Elevation is 65-75 meters

AREA: 1.5 square kilometers
SOILS: Mainly Chinen Clay-loam with some Dandan Clays.
DRAINAGE: Well drained.

ROADS: There are asphalt and coral roads.

POWER: Public power not available; nearest point is approximately 700 meters west. Feeder 3.

WATER: 1) Surface: Not available.

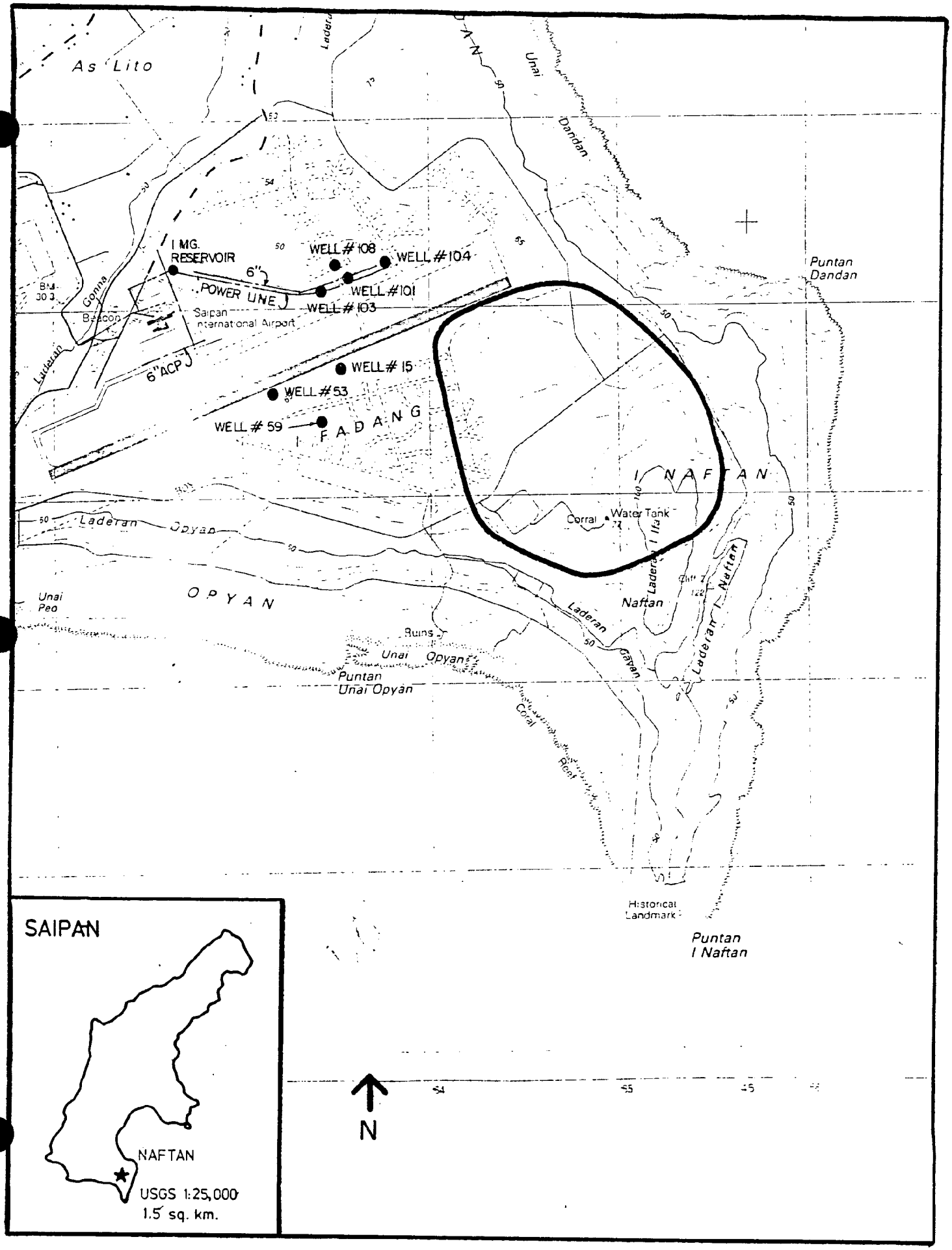
2) Public Supply: Two supply sources serve this general vicinity: the airport system and the Isley system. The nearest public source is the Isley system, located approximately 700 meters to the west. The Airport system is located about 1400 meters to the west. Line installation would require excavation of the runways or extensive routing around the runway perimeter.

Capacity: The airport system average daily usage is 20.8 gpm. The supply may slightly exceed demand from 10am to 2pm and 2am to 4am. Demand may exceed supply 7am to 10am and 6pm to 2am. System pressure is 65 psi.

The Isley system average daily usage is 245 gpm. Supply exceeds demand from approximately 6am to 9pm; demand exceeds supply from 9pm to 6am. System pressure ranges from 63-98 psi.

3) Ground water: No wells are located within the site. Three military era wells are located approximately 500 and 700 meters to the west.

LAND TENURE: Area is designated for agriculture. It is located on public land.
RECOMMENDED FACILITY: Earthen pond.
RECOMMENDED SPECIES: Brackish.
SUITABILITY: 8


As Lito
Unai Dandan
Puntan Dandan
1 MG. RESERVOIR
6"
POWER LINE
WELL # 108
WELL # 104
WELL # 101
WELL # 103
Saipan International Airport
Beacon
Gonna
Laderan
6" ACP
WELL # 15
WELL # 53
WELL # 59
I FADANG
I NAFTAN
Corral
Water Tank
Laderan Opyan
OPYAN
Unai Peo
Laderan Naftan
Naftan
Ruins
Unai Opyan
Puntan Unai Opyan
Coral Reef
Historical Landmark
Puntan I Naftan
N
SAIPAN
NAFTAN
USGS 1:25,000
1.5 sq. km.

WATER QUALITY

Water source: Isley Reservoir (supplied by Maui I, 101, 103)

	Maui I (1)	103 (2)	101 (3)	104 (4)
pH	7.0 - 8.0	7.0 - 7.7	7.1 - 7.6	7.1-7.9
Salinity	777-1730	99.8-129	122-315	277-365
Alkalinity	232-257	254-265	220-269	262-273
Bicarbonate				
Hardness	246-868 (5)	330 (11/18/82)	412 (4/21/83)	
Ammonia				
Phosphate				
Nitrite				
Nitrate				
Sulfate	250 (6/26/74)			
Dissolved oxygen				
Temperature	25.4-28.2 C (6)	28.5 C (11/18/82)		
CO2				
Fecal Coliforms				
Dissolved Solids	1850-3750	501-510	612-686	
Total Bacteria	0 per 100ml (6/74)			
Turbidity	0.14-0.80	0.16	0.10	

(1) Data from 1/7/81 to 2/25/83 unless indicated otherwise.
(2) Data from 7/9/82 to 4/21/83 " " "
(3) Data from 6/30/83 to 4/21/83 " " "
(4) Data from 8/10/82 to 4/21/83 " " "
(5) 246 (5/8/52); 670 (7/20/67); 344 (6/10/72); 868 (6/26/74).
(6) 25.4 (6/20/80); 28.0 (8/18/82); 28.2 (11/18/82).

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

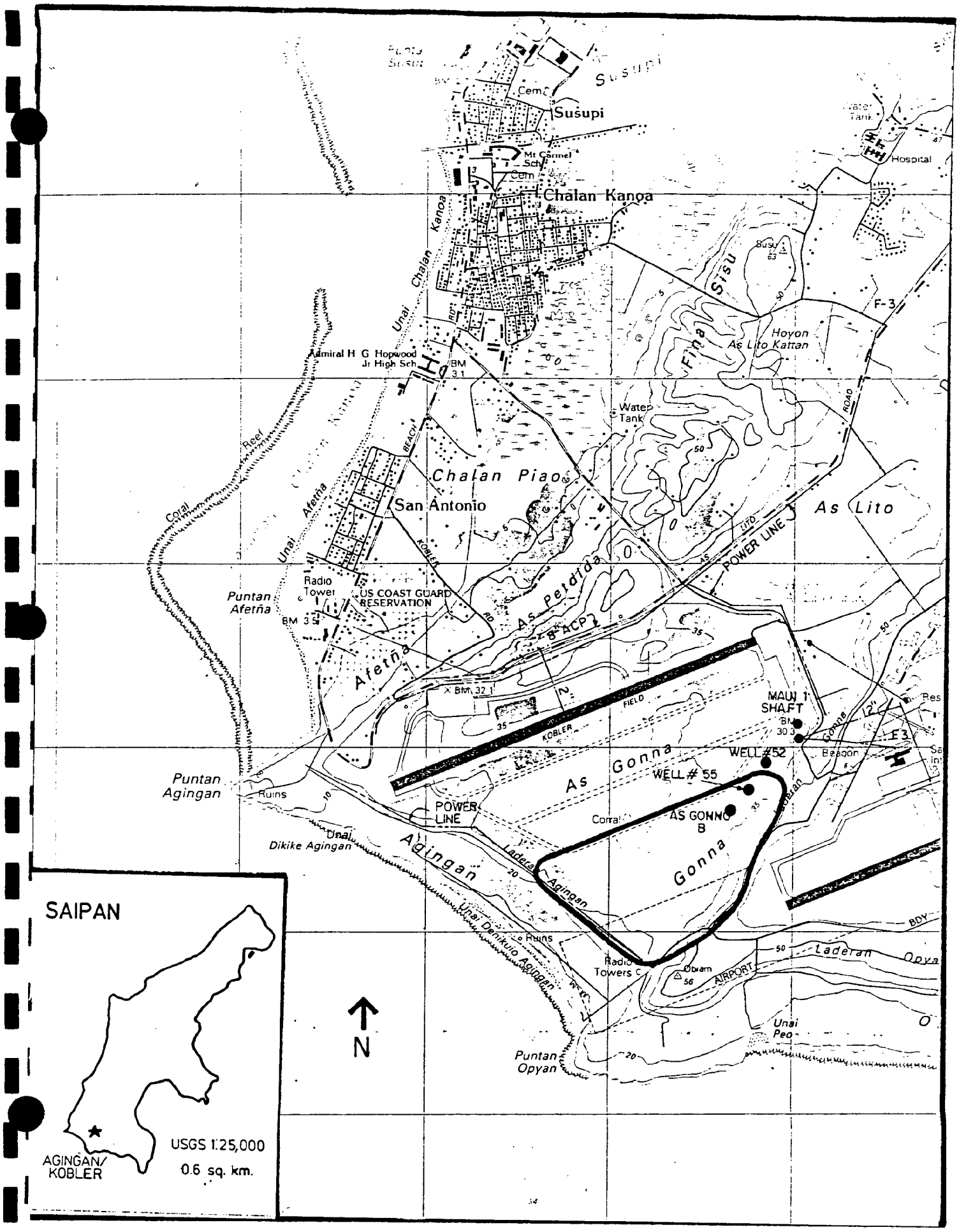
WELL DATA

VICINITY	WELL	ELEVATION	DEPTH TO WATER	CHLORIDE	GPM	COMMENTS
Naftan	15	202		50-100		used to 1948
	53	202				no permanent pump
	59	200		nr		"

Data for other mapped wells not available.

AGINGAN/KOBLER

DESCRIPTION:	These are southwest of Koblerville and north of Ladder Beach. These sites are roughly about 1/2 mile long and a little less wide.
SLOPE/ELEVATION:	Less than 10% slope. Elevation 30-35 meters
AREA:	0.6 square kilometers
SOILS:	Mainly Dandan Clay and Chinen Clay-loam, with a limestone belt lining the south boundary
DRAINAGE:	Well drained.
ROADS:	There are coral roads.
POWER:	Public power is available. Feeder 3.
WATER:	1) Surface: No surface water available. 2) Public Supply: The nearest piped water sources are approximately 350 meters to the north and 775 meters to the west. Capacity: The average daily usage is 45.25 gpm; supply is exceeded from approximately 3-6 pm and 5am to 7am. Supply may slightly exceed demand from 8pm to 3am. System pressure ranges from 38-86 psi. 3) Ground water: Two military era wells are located within the site. Other military era and present day wells are found to the north.
LAND TENURE:	These areas are designated for agricultural usage. It is located on public land.
RECOMMENDED FACILITY:	Earthen pond.
RECOMMENDED SPECIES:	Brackish.
SUITABILITY:	10



Susupi
Susupi
Cem
Mt Carmel Sch
Cem
Chalan Kanoa
Unai Chalan Kanoa
Hospital
Fina Sisu
F-3
Hoyon As Lito Kattan
Admiral H G Hopwood Jr High Sch
BM 31
Water Tank
Reef
Coral
Unai Afetña
BEACH
Chalan Piao
San Antonio
As Lito
POWER LINE
KOBLER
Radio Tower
US COAST GUARD RESERVATION
Puntan Afetña
BM 35
As Petdida
8" ACP
Afetña
BM 32 1
KOBLER
FIELD
MAUI 1 SHAFT
BM 30 3
Beacon
F3
WELL #52
WELL # 55
As Gonna
Puntan Agingan
Ruins
POWER LINE
Corral
AS GONNO B
Gonna
Unai Dikike Agingan
Agingan
Laderan Agingan
Unai Denikuio Agingan
Ruins
Radio Towers
Obiam
AIRPORT
Laderan Opya
BDY
Unai Peo
Puntan Opyan
N
SAIPAN
AGINGAN/ KOBLER
USGS 1:25,000
0.6 sq. km.

WATER QUALITY DATA

Agingan/Kobler

Water source: Wells 9, 10, 11, 15, 16, 17

	9(1)	10(2)	11(3)	15(4)	16(5)	17(6)
pH	7.2-7.8	7-8.2	7.1-7.8	7.0-7.9	7.1-7.9	7.2-7.9
Salinity	84.1-375	84.1-1440	648-1300	77-988	140-1220	105-1070
Alkalinity	221-238	205-213	200-232	220-235	223-244	241-249
Bicarbonate						
Hardness	400(4/83)	354(4/83)	732(8/83)	568(4/83)	672(4/83)	680(4/83)
Ammonia						
Phosphate						
Nitrite						
Nitrate						
Sulfate						
Dissolved oxygen						
Temperature	28(6/83)	28.2(11/82)	26.5(3/83)	28(6/83)	28(6/83)	
CO2						
Fecal Coliforms						
Dissolved Solids	342-854	1220-2840	1700-2270	332-1740	562-2360	520-1720
Total Bacteria						
Turbidity	.09-.50	.08-80	.10-.26	.08-1.10	.14-.25	.16-.37

(1)-(4) Data from 1/7/81 to 4/21/83 unless indicated otherwise.
(5) Data from 6/6/80 to 4/21/83 " " "
(6) Data from 2/4/82 to 4/21/83 " " "

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

WATER QUALITY DATA

Agingan/Kobler (continued)

Water source: Wells 111 and 113

	111 (7)	113 (8)
pH	7.1 (11/18/82)	
Salinity	147-1200	
Alkalinity	222-240	
Bicarbonate		
Hardness		
Ammonia		
Phosphate		
Nitrite #2	3.6 (11/18/82)	
Nitrate #3	3.6 (11/18/82	
Sulfate	30 (11/18/82)	
Dissolved oxygen		
Temperature	28.5 (11/18/82)	
CO2		
Fecal Coliforms		
Dissolved Solids	1530 (9/7/82)	
Total Bacteria		
Turbidity	.17 (9/7/82)	

(7) Data from 3/25/82 to 4/21/83 unless indicated otherwise.
(8) No data available

WELL DATA

VICINITY	WELL	ELEVATION	DEPTH TO WATER	CHLORIDE	GPM	COMMENTS
Kobler	52	97		40		abandoned late 1940's
	55	100		nr		no eqpt to operate
	As Gonno B	97		40-1000		collapsed 1956
	Maui I	96			313 gpm	

SADOG TASE

DESCRIPTION: This site oriented in a north to southwest direction, is located at the north end of the Commercial Port area where a small stream empties into Tanapag Harbor. This is a very significant basal spring on Saipan with regard to volume of discharge. The spring water also supports a unique stand of mangroves trees and an estuarine area.

SLOPE/ELEVATION: Less than 10% slope. Elevation is 1-3 meters

AREA: 0.10 square kilometers

SOILS: Mainly Shioya loamy sand with some marsh.

DRAINAGE: Very rapid (Shioya) to very poor (marsh).

ROADS: There are asphalt roads.

POWER: Public power available. Feeders 2 and 3.

WATER: 1) Surface: Surface water available. Starch Factory spring has a rate of discharge of 1-2 mgd (694-1388 gpm). (Stearns, 1944); 100,000 - 130,000 gpd (69-90 gpm) (Cloud); 2 mgd (Nance).

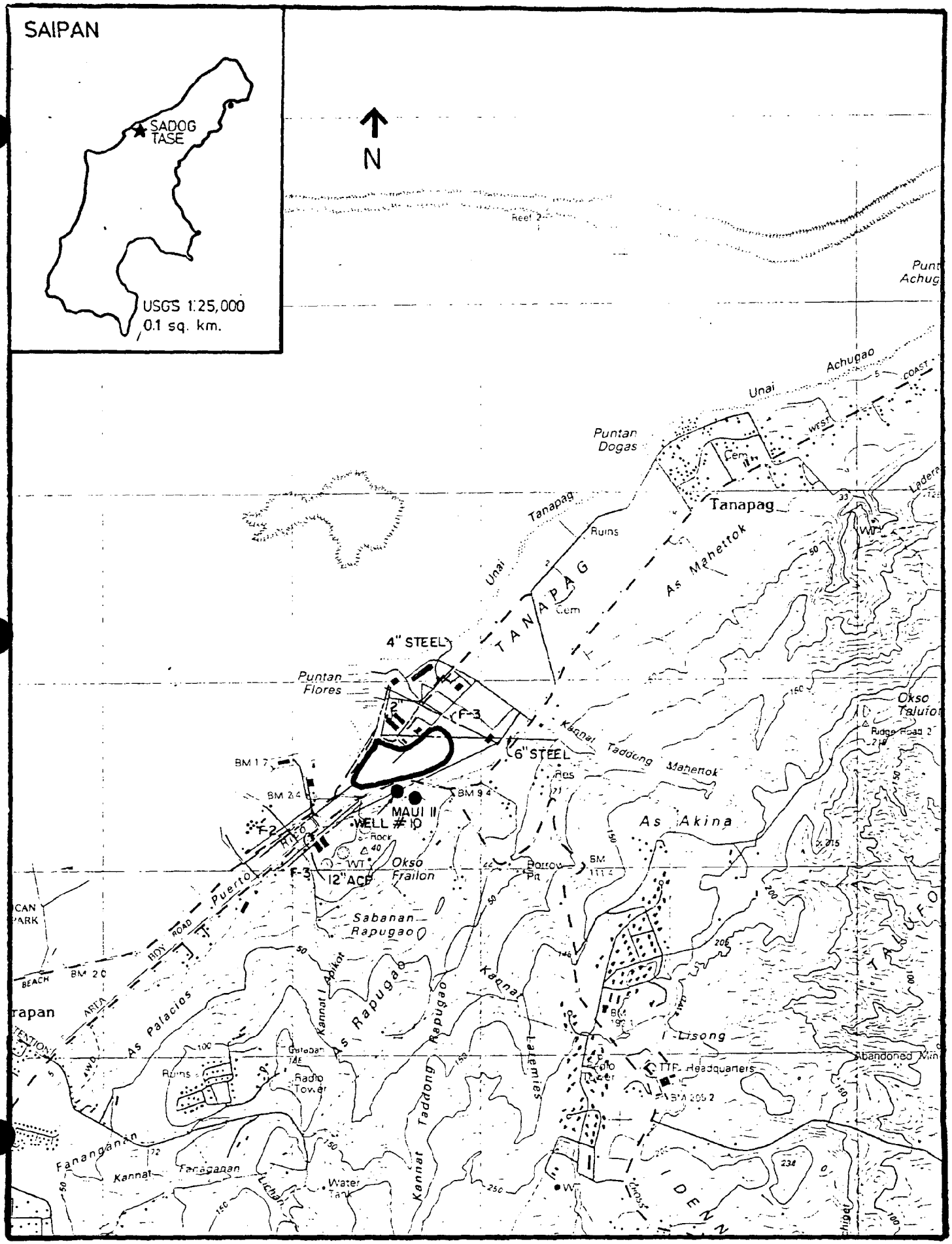
2) Public Supply: Piped water is available to parts of the site.

Capacity: The average usage for the water system is 315 gpm. Supply is exceeded from approximately 5pm to 11pm. Supply exceeds demand from approximately 11pm to 8am. System pressure ranges from 14-65 psi.

3) Ground water: No wells are located within the site. Two military era wells are located within 175 meters of the south boundary.

LAND TENURE: Area is designated as wetland and conservation (U.S. Army Corps of Engineers and CRMP Rules and regulations.). It is located on public land.

RECOMMENDED FACILITY: Lined pond; earthen pond.
RECOMMENDED SPECIES: Brackish.
SUITABILITY: 13


SAIPAN
SADOG TASE
USGS 1:25,000
0.1 sq. km.
N
Reef 2
Punt
Achug
Unai
Achugao
COAST
WEST
Puntan Dogas
Cem
Tanapag
Ruins
Unai
Tanapag
TANAPAG
As Mahettok
Cem
4" STEEL
Puntan Flores
F-3
6" STEEL
Kannat Taddong Mahettok
Res
BM 1 7
BM 2 4
BM 9 4
MAUI II
WELL # 10
F-2
F-3
12" ACP
Okso Frailon
Rock
Borrow Pit
As Akina
Okso Taluio
Ridge Road 2
Puerto
Sabanan Rapugao
BEACH
BM 2 0
As Palacios
Kannat I Apikot
As Rapugao
Rapugao
Kannat
Latemies
I Lisong
Abandoned Min
Radio Tower
Ruins
Gatapan
TTP Headquarters
Fananganan
Kannat
Fanaganan
Lichan
Water Tank
Kannat Taddong
IDENN
TALUFO

WATER QUALITY DATA

Sadog Tase

Water source: Starch Factory Spring (SFS) (1), Tanapag Spring 1 (2), Tanapag Spring 2 (3), Maui IV (4)

	SFS	TS1	TS2	MIV
pH				
Salinity	(1206 (Stearns 1944) 680 (Davis 1958) 900 (Glander 1946) 480-1200 (Piper 1946-47) 2420 (Cox 1956) 1200 (Ronimus 1981); preceding refers only to Starch Factory Spring)			
				147-1712
Alkalinity			250-262 249 (4/83)	
Bicarbonate	252	232	256	176 (3/23/50) 293 (7/20/67)
Hardness	465	45	4	615 (4/21/83)
Ammonia				
Phosphate				
Nitrite				
Nitrate	7.6			0.4 (3/23/50)
Sulfate		16	8.2	49 (3/23/50) 48 (5/8/52)
Dissolved oxygen				
Temperature	32 (5/8/52; 1515 hours)			28.2 (11/18/82)
CO2				
Fecal Coliforms				
Dissolved Solids	1560	310	325	259-2760
Total Bacteria				
Turbidity				0.18-1.3

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

WATER QUALITY DATA

Sadog Tase (Continued)

Water source: Wells 142 (5), 143 (6), 144 (7), 145 (8)

	142	143	144	145
pH	7.2 (4/21/83) 6.9 (6/26/74)	7.1-8.1	7.0-7.8	7.3-7.6
Salinity	1600 (6/26/74) 855 (4/21/83)	114-1510	121-1360	368-2410
Alkalinity	249 (4/21/83)	255-272		237-272
Bicarbonate				
Hardness	545 (4/21/83)			
Ammonia				
Phosphate				
Nitrite				
Nitrate				
Sulfate		92 (6/26/74)		
Dissolved oxygen				
Temperature			28.2 (11/18/82 at 1350 hour)	28.0 (7/1/83 at 1200 hour)
CO2				
Fecal Coliforms		0/100ml (6/74)	0/100ml (6/74)	
Dissolved Solids		498-3050	996-1800	1610-4120
Total Bacteria				
Turbidity		0.11-0.59	0.13-3.0	0.09-0.18

(1) Data taken September 1945 (Davis 1958) unless otherwise indicated. Water considered too salty to be potable.
(2) Data taken 12/1/44 (Davis 1958).
(3) Data taken 12/5/44 (Davis 1958).
(4) Data taken from 2/17/82 to 4/21/83 unless otherwise indicated.
(5) Data from dates indicated.
(6) Data from 1/7/81 to 4/21/83 " " "
(7) Data from 1/27/81 to 4/21/83 " " "
(8) Data from 6/16/82 to 4/21/83 " " "

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

WELL DATA

VICINITY	WELL	ELEVATION	DEPTH TO WATER	CHLORIDE	GPM	COMMENTS
Sadog Tase	10	45		360-460		discontinued 1944
	Maui II	11		400-1000		caved in

SUSUPE LAKE/CHALAN KANOA

DESCRIPTION: This site includes Lake (Hagoi) Susupe and its marshes, which extend from Afetna to Chalan Kiya (north-south axis), and Chalan Kanoa and the rise to the southern limestone plateau (west-east axis). The entire site is probably the unfilled portion of an uplifted lagoon (Bowers, 1950). The lake is located in the north-central portion of the site, and its width is approximately 1000 m. The marshes north and south vary in width between 500 and 800 m. These data, however, reflect the extremely atypical high rainfall conditions of 1976, and the dimensions given are on the high side. Lake Susupe now supports tilapia, mosquito fish (Gambusia affinis), anguillid eels and shrimp (palaemon debilis). Formerly, 'long silver fish' probably flagfish (kuliidae), mullet or milkfish were known to inhabit the lake.

SLOPE/ELEVATION: Less than 10% slope. Elevation is 2-4 meters.

AREA: 3.25 square kilometers

SOILS: Primarily marsh. (Silts and clay). The soil material is dark, plastic and highly molted. In some places it contains nearly enough organic matter to be classed as muck. The adjacent areas are of clay compositions.

DRAINAGE: Poor to very poor.

ROADS: There are coral and asphalt roads.

POWER: Public power available. Feeders 2 and 3.

WATER: 1) Surface: Surface water available (Lake Susupe). Salinity is 1900 ppm average. It varies with rainfall and tide.

2) Public Supply: Public piped water is available along the north, midwestern, and southern third of the project area.

Capacity: refer to Naftan site, Isley system.

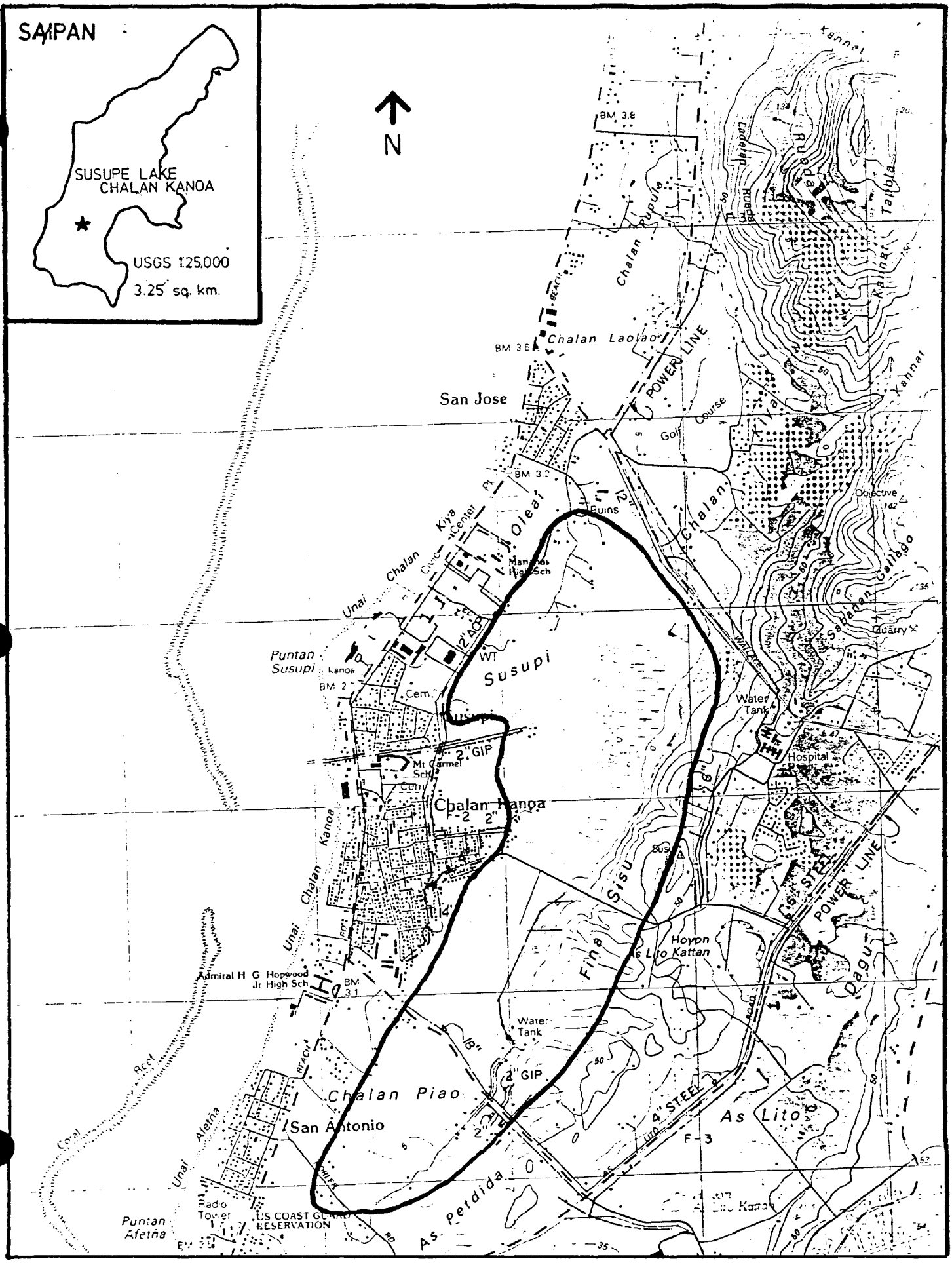
3) Ground water: Dug wells are reported in the area.

LAND TENURE: Classified as wetland. (U.S. Army Corps of Engineers and CRMP Rules and Regulations.). It is located on public and private land.

RECOMMENDED FACILITY: Earthen pond; cage or basket.

RECOMMENDED SPECIES: Brackish.

SUITABILITY: 13


SAIPAN
SUSUPE LAKE
CHALAN KANOA
USGS 1:25,000
3.25 sq. km.
N
San Jose
Chalan Laolao
POWER LINE
Golf Course
Chalan Kiya
Kannat Tabla
Objective
Sabanan Gallego
Quarry
Water Tank
Hospital
Susupi
Puntan Susupi
Chalan Kanoa
Mt Carmel Sch
Admiral H G Hopwood Jr High Sch
Chalan Piao
San Antonio
Puntan Afetna
Radio Tower
US COAST GUARD RESERVATION
As Petdida
As Lito
Hoyon As Lito Kattan
Fina Sisu
Dagu
4" STEEL
2" GIP
F-2
F-3
Unai Chalan Kanoa
Unai Afetna
Coral Reef
Chalan Pupula
Ladelan Rueda
Kannat
Ruins
Marianas High Sch
Civic Center Pk
Oleai
WT
Cem
Susupi
Water Tank
Hoyon As Lito Kattan
Lito Kattan

WATER QUALITY DATA

Lake Susupe/Chalan Kanoa

Water source: Surface: Lake Susupe
Public : See Naftan Site

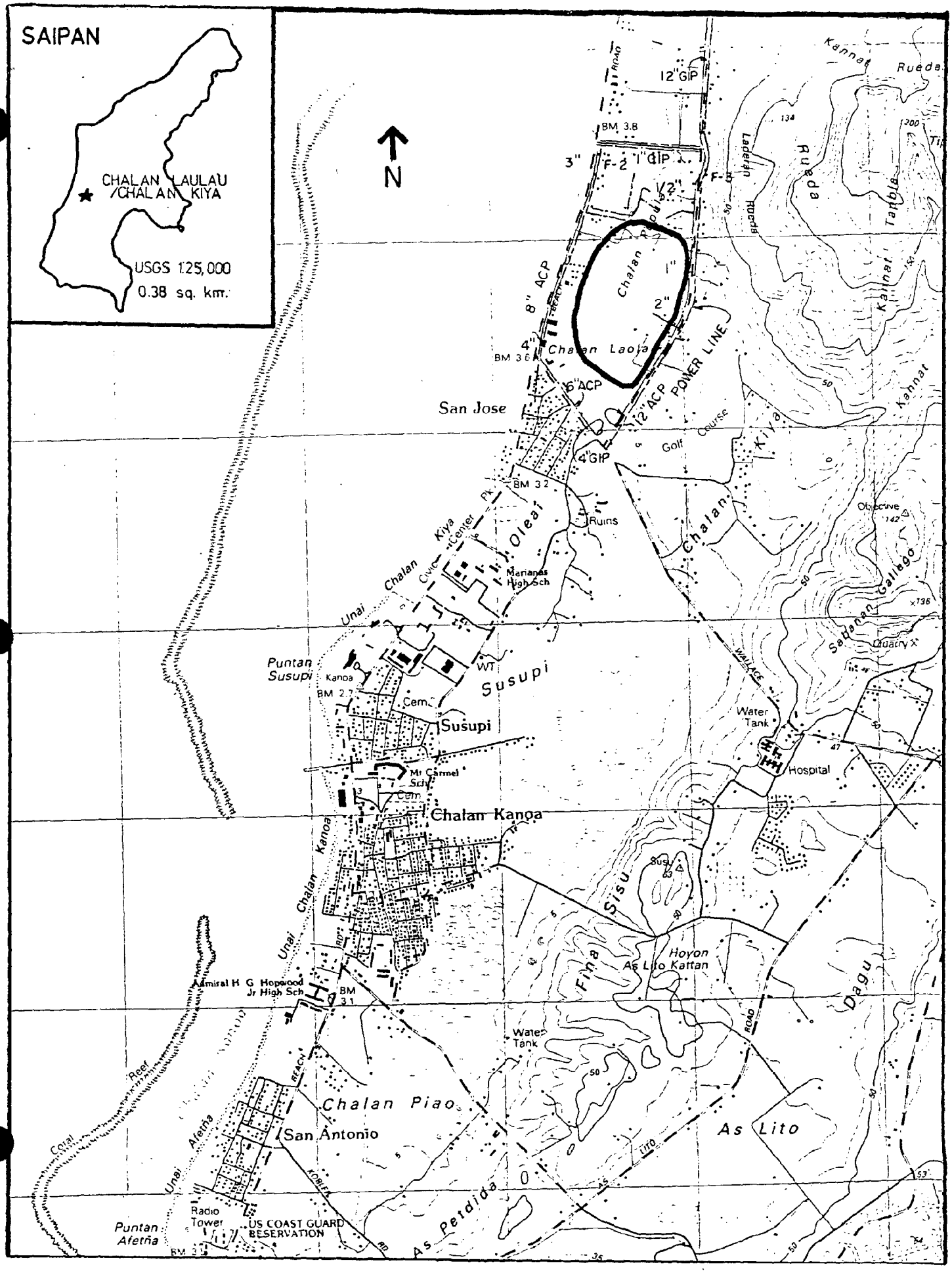
	1967	12/78*	12/79*	8/28/81	11/19/82
pH	8.6	7.6	7.2	7.8	7.8
Salinity	1715	<1000	2500	1200	760
Alkalinity	180			100	116
Bicarbonate					
Hardness	728			480	35
Ammonia					
Phosphate					
Nitrite					
Nitrate				0.01	< 0.1
Sulfate				70	85
Dissolved oxygen		5.6	7.0		
Temperature	25	30	30.25	28	28
CO2					
Fecal Coliforms					
Dissolved Solids	3745			2140	1450
Total Bacteria					
Turbidity	20			1.8	

* taken at a depth of 1 meter. Army Corps of Engineers, US Fish and Wildlife Service.

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

CHALAN LAULAU/KIYA

DESCRIPTION:	This site lies north of Susupe on the west coastal lowlands near the Whispering Palms Golf Club. The area includes a 500 m by 250 m marsh.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 5-10 meters
AREA:	0.38 square kilometers
SOILS:	Marsh with Alluvial and Chacha Clays.
DRAINAGE:	Well drained (alluvial) to medium (Chacha) to poor (marsh).
ROADS:	There are coral and asphalt roads.
POWER:	Public power is available. Feeders 2 and 3.
WATER:	1) Surface: Part of the area is a wetland. 2) Public Supply: Public supply is available along the western and northern boundaries. Capacity: The average daily usage is 607.5 gpm. The supply may exceed the demand from approximately 8am to 12pm and 1pm to3pm; the demand exceeds the supply from 3pm to 6am. System pressure ranges from 2-60 psi. 3) Ground water: No wells are located in the area.
LAND TENURE:	Classified as wetland. (U.S. Army Corps of Engineers and CRMP Rules and Regulations.). It is located on public land.
RECOMMENDED FACILITY:	Earthen pond; lined pond.
RECOMMENDED SPECIES:	Brackish.
SUITABILITY:	14


SAIPAN
CHALAN LAULAU /CHALAN KIYA
USGS 1:25,000
0.38 sq. km.
N
12"GIP
BM 3.8
3"
F-2
1"GIP
1/2"
F-3
Chalan Laola
1"
2"
8" ACP
4"
BM 3.6
6"ACP
12"ACP
POWER LINE
San Jose
4"GIP
BM 3.2
Golf Course
Kiya
Chalan
Ruins
Oleai
Civic Center Pk
Marianas High Sch
Unai Chalan Kiya
Puntan Susupi
Kanoa
BM 2.7
WT
Susupi
Cem
Susupi
Mt Carmel Sch
Cem
Chalan Kanoa
Unai Chalan Kanoa
Admiral H G Hopwood Jr High Sch
BM 3.1
Water Tank
Hospital
Fina Sisu
Hoyon As Lito Kattan
Dagu
Water Tank
Chalan Piao
San Antonio
Unai Afetna
Coral Reef
Radio Tower
US COAST GUARD RESERVATION
Puntan Afetna
As Petdida
As Lito
Kannat Rueda
Ladeian Rueda
Rueda
Kannat Tanbla
Kannat
Objective
Sadanan Gallego
Quarry
WALLACE
ROAD
BEACH
KOBLER RD
AS LITO

WATER QUALITY DATA

Water source: Wells 162, 163 (no data) and 164

No information is available about the surface water.

	162	163 (1)	164
pH	7.4-7.7	7.080	7.3-7.7
Salinity	400-1600	1320-2050	242-2950
Alkalinity	242-285	295	257-289
Bicarbonate			
Hardness	684 (1)	984	
Ammonia			
Phosphate			
Nitrite			
Nitrate			
Sulfate			
Dissolved oxygen			
Temperature			
CO2			
Fecal Coliforms			
Dissolved Solids	2620 (ts)*	2890 (ts)	
Total Bacteria			
Turbidity			

(1) Data from Division of Environmental Quality FY1985 First Quarter Report (10/22/84 sample date).

* ts means total solids.

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

TANAPAG

DESCRIPTION: This site is bisected by a major road and a few tertiary roads. The major road (Chalan Pale Arnold) divides the east and west portions with the smaller roads running perpendicular. The area is about 600 m wide and about 1000 m long. Vegetation is mostly "karisso" (Phragmites K) with cultivated Morning Glory (Kangkung). The immediate surrounding areas are newly established homestead village rural residences, and industrial facilities. A private aquaculture facility is planned for the area.

SLOPE/ELEVATION: Less than 10% slope. Elevation 2-5 meters

AREA: 0.47 square kilometers

SOILS: Shioya loamy sand and marsh.

DRAINAGE: Rapid (Shioya) to poor (marsh).

ROADS: There are asphalt roads.

POWER: Public power is available. Feeder 4.

WATER: 1) Surface: Tanapag Spring #1 and #2 is located within the area boundary. Two wetlands lie within the area boundary.

2) Public Supply: the Site is dissected by a 6" pipeline.

Capacity: The average daily usage is 315 gpm. The supply exceeds the demand from approximately 4pm to 11pm; the demand exceeds the supply from 11pm to 5am. System pressure ranges from 14-65 psi.

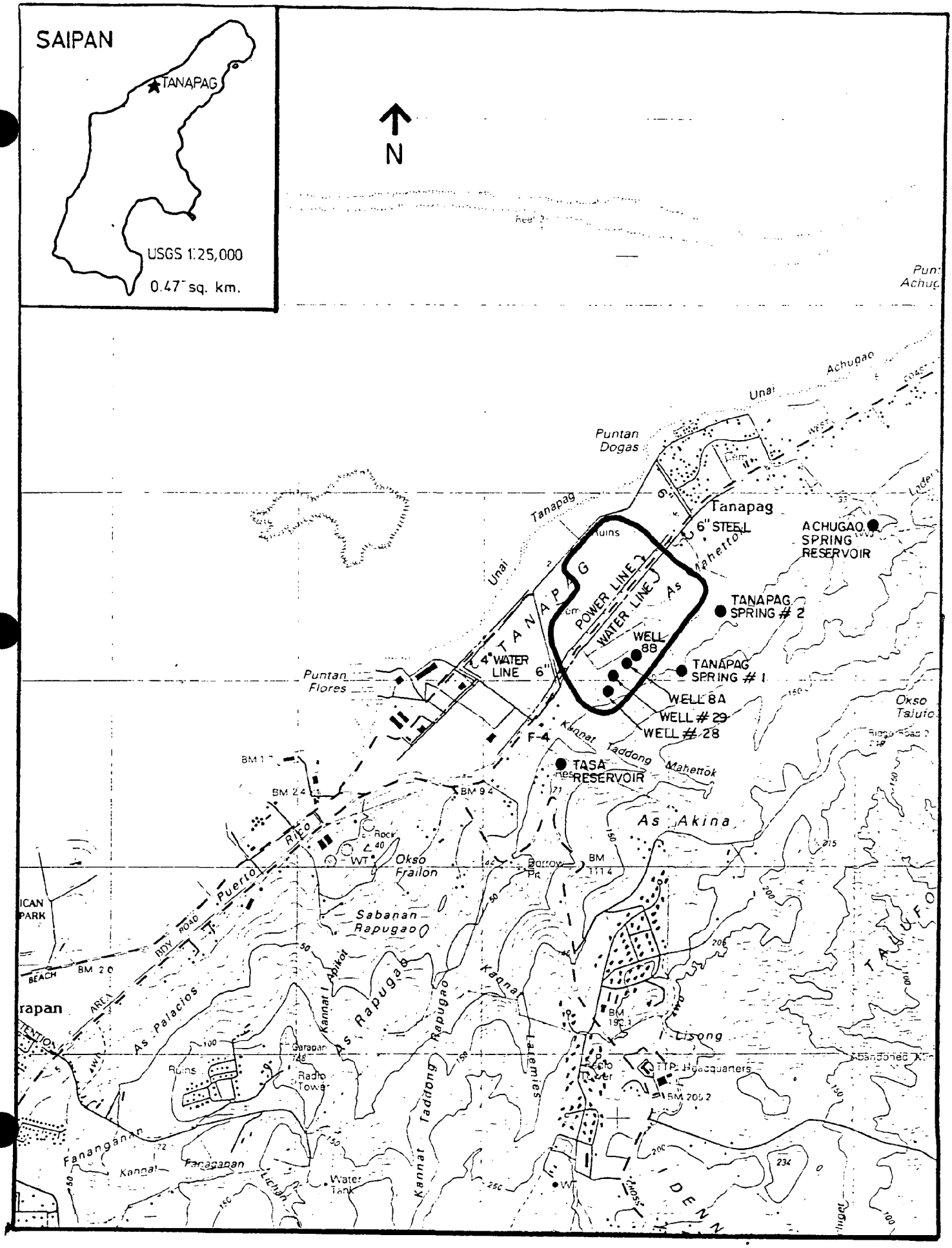
3) Ground water: Four military era wells are located within the project area.

LAND TENURE: Part of the area is classified as wetland. (U.S. Army Corps of Engineers and CRMP Rules and Regulations.). It is located on public land.

RECOMMENDED FACILITY: Earthen pond; lined pond.

RECOMMENDED SPECIES: Brackish.

SUITABILITY: 13


SAIPAN
TANAPAG
USGS 1:25,000
0.47 sq. km.
N
Puntan Dogas
Unai Achugao
Tanapag
6" STEEL
ACHUGAO SPRING RESERVOIR
TANAPAG SPRING # 2
TANAPAG SPRING # 1
WELL 8B
WELL 8A
WELL # 29
WELL # 28
POWER LINE
WATER LINE
4" WATER LINE
Puntan Flores
F-4
TASA RESERVOIR
Kannat Taddong Mahettok
As Akina
Okso Frailon
Sabanan Rapugao
As Rapugao
As Palacios
Puerto Rico
Kannat Apikot
Kannat Taddong Rapugao
Kannat Latemies
Lisong
TTP Headquarters
Radio Tower
Ruins
Water Tank
Fananganan
Kannat Fanaganan
Okso Talufo
Abandoned
Borrow Pit
Rock
WT
BM 2.4
BM 9.4
BM 111.4
BM 20
BM 205.2
BEACH
AREA
BDY ROAD
Garapan
Lichan
Ridge Road 2

WATER QUALITY DATA

Tanapag

Water source: Surface
Public

Surface: Same as Starch Factory Springs (see Sadog Tase site).

Public: Tanapag Reservoir partially supplied by Maui IV wells (see Sadog Tase site). Achugao Reservoir is supplied by Achugao spring.

	Achugao Spring (No. 1) (1)	Achugao Reservoir (2)
pH	7.2-7.4 (Glander, 1946)	7.39 (10/22/84)
Salinity	70 (Glander, 1946)	220 (11/5/84)
Alkalinity		260 (10/22/84)
Bicarbonate	325	
Hardness	269	352 "
Ammonia		
Phosphate		
Nitrite		
Nitrate	0	
Sulfate	13	
Dissolved oxygen		
Temperature	25.5-28.0 (Dec. 68-Oct.71)	
CO2		
Fecal Coliforms		
Dissolved Solids	380	672 "
Total Bacteria		
Turbidity		

(1) Data from 12-1-44 (Davis 1958) unless otherwise indicated.
(2) Data from Division of Environmental Quality FY1985 First Quarter Report.

Figures expressed in Mg/L (milligrams per liter) except pH, Temperature and Turbidity. Temperature in degrees Centigrade; Turbidity in NTU.

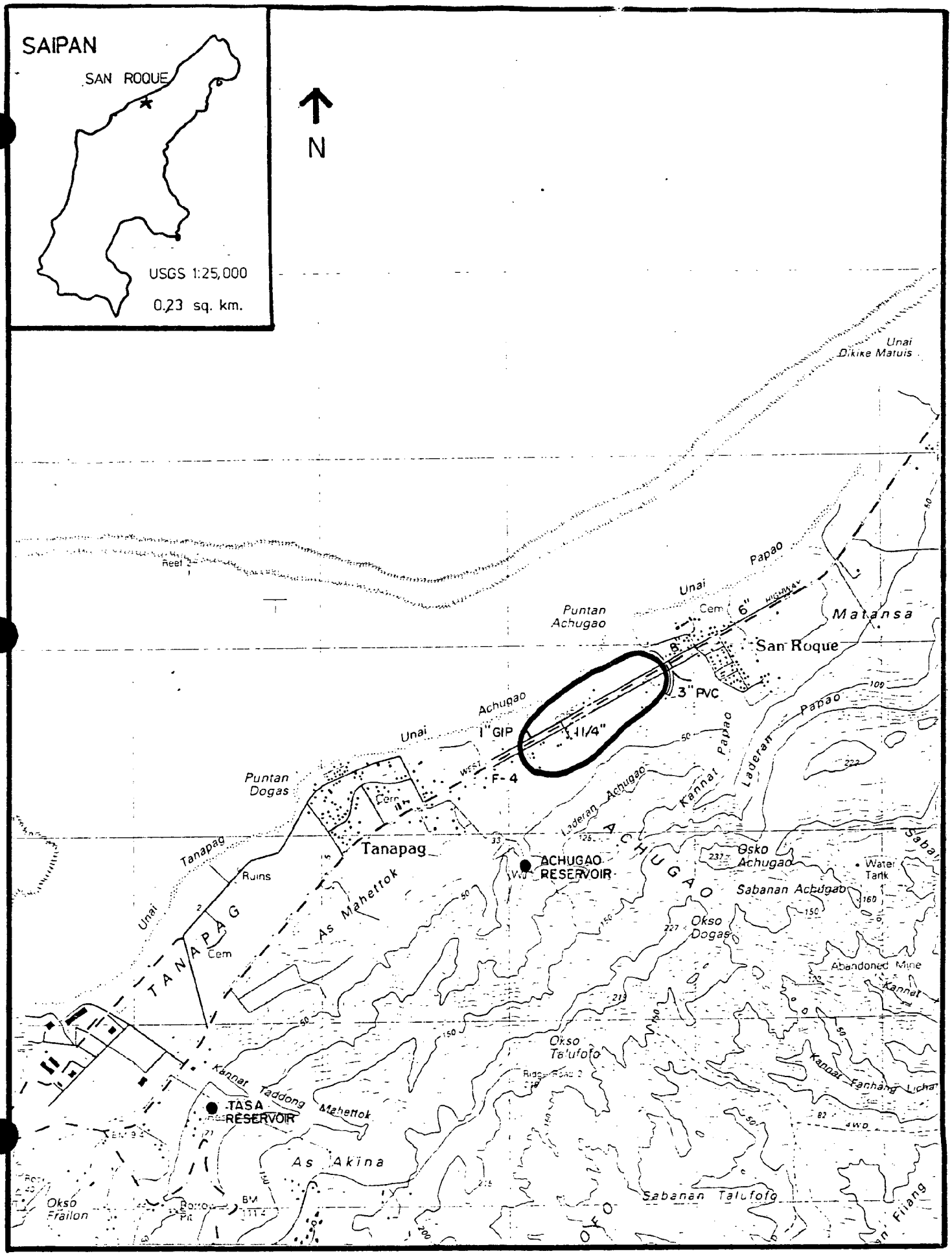
WELL DATA

VICINITY	WELL	ELEVATION	COMMENT *
Tanapag	8a	115	at Tanapag Springs
	8b	120	"
	28	23	pumped dry quickly
	29	27	"

* Original reference did not explain comment.

SAN ROQUE

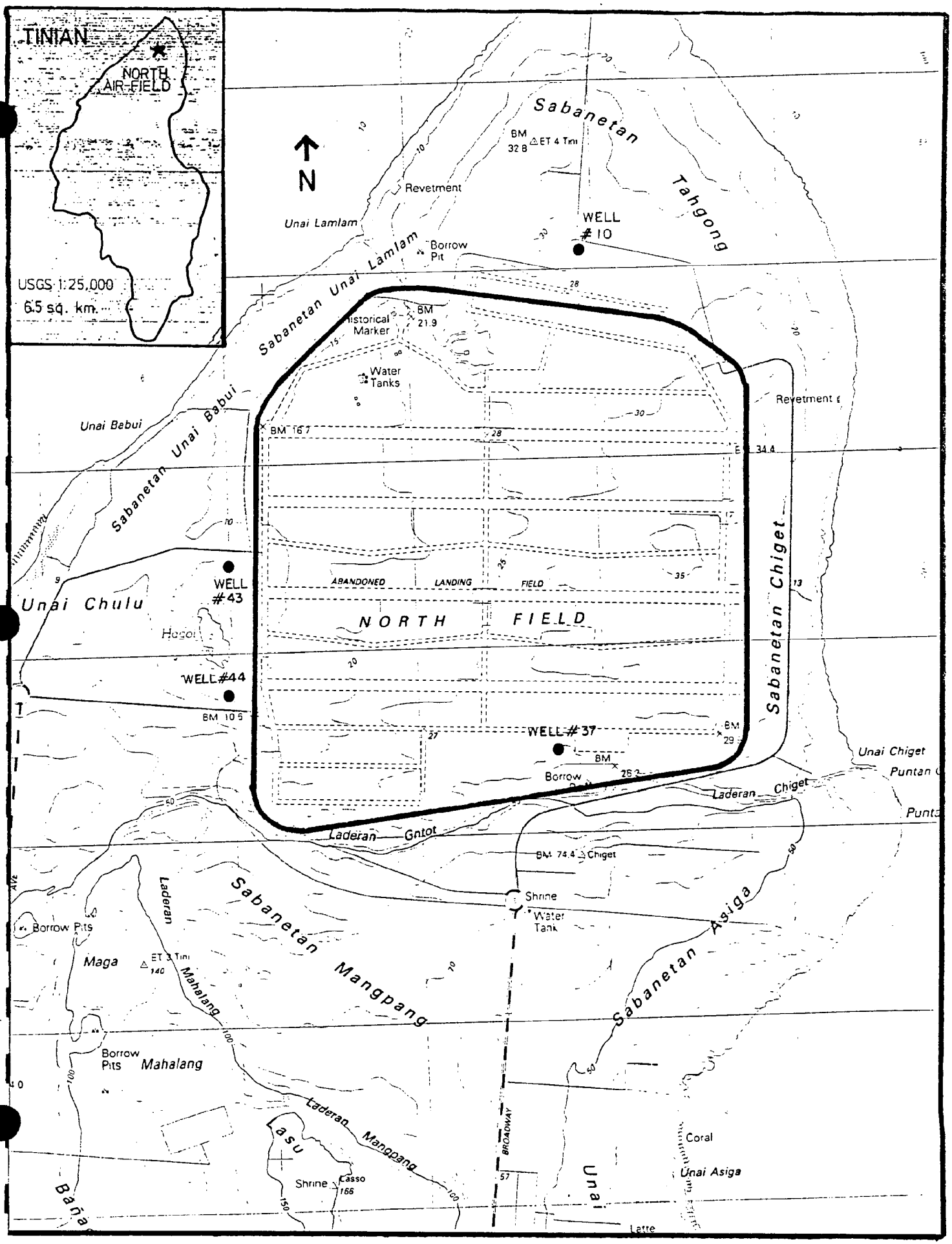
DESCRIPTION:	The area is located just south of the main San Roque village and divided by Chalan Pale Arnold. It is a low-lying area dominated by Phragmites K . It periodically floods with heavy rainfall. Part of the area is developed through rural use by the surrounding residents. It retains water from the rainfall run-off from the watershed to the east.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 2-5 meters
AREA:	0.23 square kilometers
SOILS:	Mainly marsh with Chacha and Alluvial Clays.
DRAINAGE:	Well drained (alluvial) to medium (Chacha) to poor (marsh).
ROADS:	There is an asphalt road.
POWER:	Public power available. Feeder 4.
WATER:	1) Surface: Surface water available.
	2) Public Supply: Public supply available. A 6" pipe running parallel to Chalan Pale Arnold, bisecting the site.
	Capacity: refer to Tanapag site.
	3) Ground water: No wells are located within the area.
LAND TENURE:	Part of the area is classified as wetland. (U.S. Army Corps of Engineers and CRMP Rules and Regulations.). It is located on public and private land.
WATER QUALITY DATA:	No information on surface water is available. Public: refer to Tanapag site for Achugao Spring and Tanapag Reservoir.
RECOMMENDED FACILITY:	Earthen pond; lined pond.
RECOMMENDED SPECIES:	Brackish.
SUITABILITY:	13


SAIPAN
SAN ROQUE
USGS 1:25,000
0.23 sq. km.
N
Unai Dikike Matuis
Reef
Unai Papao
Puntan Achugao
Cem
6"
HIGHWAY
Matansa
San Roque
8"
3" PVC
Unai Achugao
1" GIP
1 1/4"
F-4
Puntan Dogas
Cem
Tanapag
Ruins
Unai Tanapag
TANAPAG
Cem
As Mahettok
ACHUGAO RESERVOIR
Laderan Achugao
Kannat Papao
Laderan Papao
ACHUGAO
Osko Achugao
Water Tank
Sabanan Achugao
Okso Dogas
Abandoned Mine
Kannat
Okso Talufofo
Kannat Fanhang Lichat
Kannat Taddong Mahettok
TASA RESERVOIR
As Akina
Okso Frailon
Sabanan Talufofo
Filiang

SECTION 3
TINIAN SITES

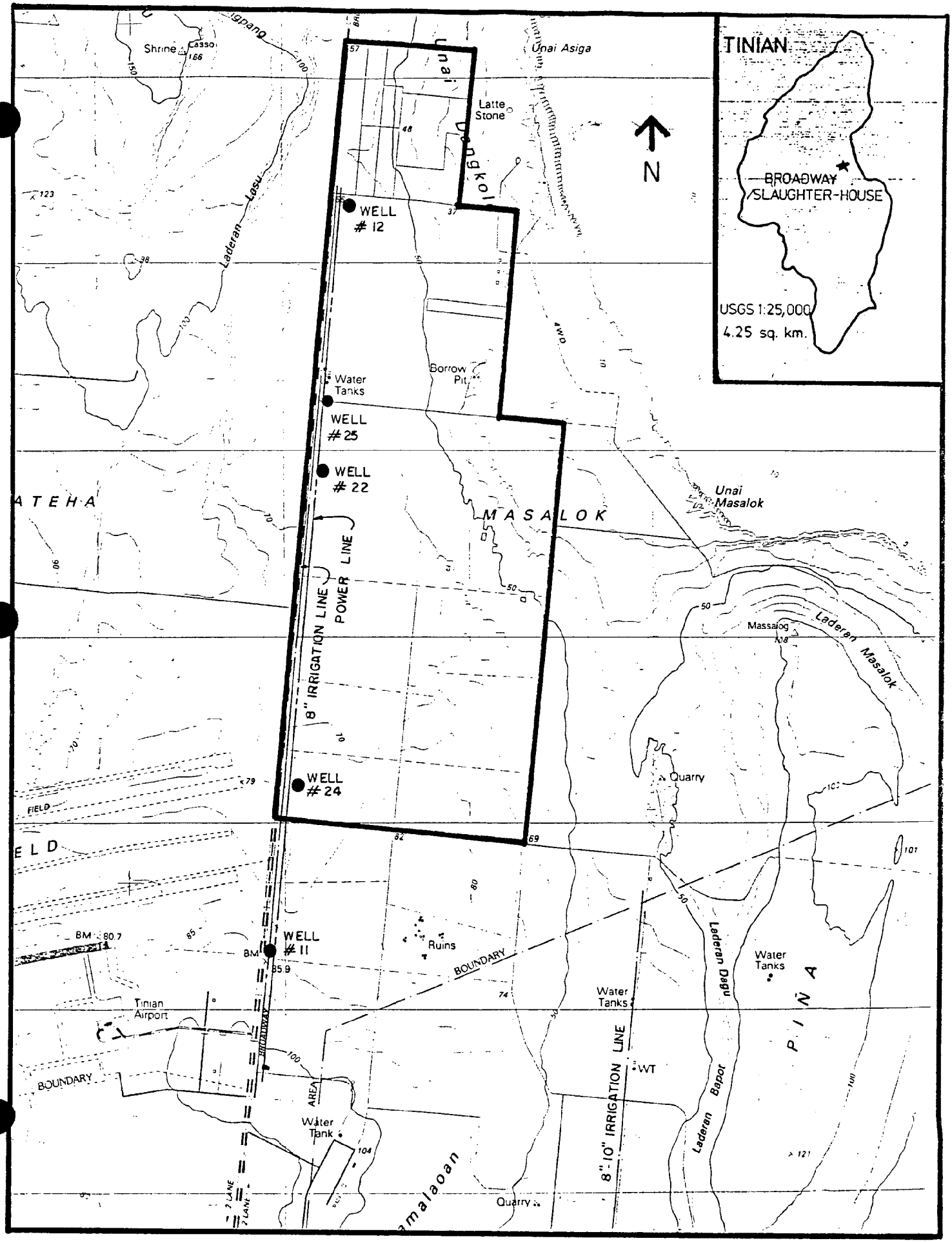
NORTH AIR FIELD

DESCRIPTION:	This the abandoned North Air Field on Sabanetan Gatut and Sabanetan Chiget. To the west is a marsh land commonly referred to as "Hagoi". The whole area is bisected by paved and hardened surface.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 15-35 meters.
AREA:	6.5 square kilometers.
SOILS:	Deeply filled with limestone rubble and crushed rock during construction operations for the air strip. Generally non-reclaimable.
DRAINAGE:	Rapid (limestone) to poor (asphalt/fill).
ROADS:	There are numerous asphalt roads.
POWER:	No public electricity available. The main line is two miles south.
WATER:	1) Surface: Wetland is located to the west, however, the wetland is considered critical habitat for the Marianas Mallard. 2) Public Supply: No public water is available. The nearest public supply line (8-10") is roughly 2.5 miles south. 3) Ground water: most of this area is presumed to be well developed basal lens at sea level with salinity less than 600 ppm. (Burke). One abandoned well is located within the site and three additional military era wells are located adjacent to the site boundaries.
LAND TENURE:	Military lease area. Atomic Bomb Pit is located within the area.
RECOMMENDED FACILITY:	Lined pond; fabricated enclosure.
RECOMMENDED SPECIES:	Fresh/brackish.
SUITABILITY:	6


TINIAN
NORTH AIR-FIELD
USGS 1:25,000
6.5 sq. km.
N
Sabanetan Tahgong
BM 32.8
ET 4 Tini
Revetment
Unai Lamlam
Sabanetan Unai Lamlam
Borrow Pit
WELL #10
Historical Marker
BM 21.9
Water Tanks
Revetment
Unai Babui
Sabanetan Unai Babui
BM 16.7
E 34.4
Sabanetan Chiget
ABANDONED LANDING FIELD
NORTH FIELD
WELL #43
Unai Chulu
WELL #44
BM 10.5
WELL #37
BM 29
BM 26.2
Borrow
Unai Chiget
Puntan
Laderan Chiget
Laderan Gntot
BM 74.4
Chiget
Shrine
Water Tank
Sabanetan Asiga
Sabanetan Mangpang
Laderan
Borrow Pits
Maga
ET 3 Tini
140
Mahalang
Borrow Pits
Mahalang
Laderan Mangpang
Asu
Shrine
Casso
166
BROADWAY
Coral
Unai Asiga
Unai
Latte

BROADWAY/SLAUGHTERHOUSE

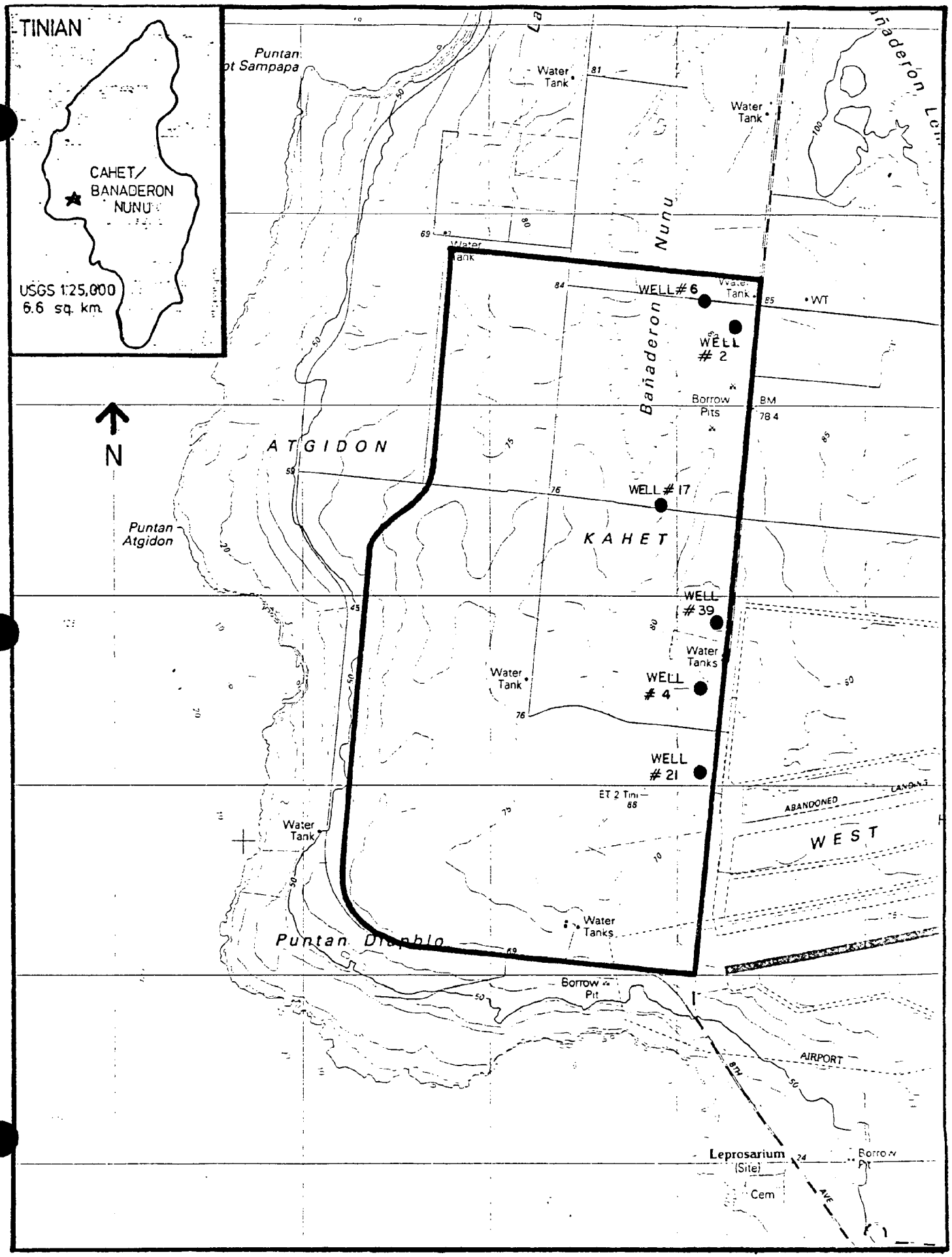
DESCRIPTION:	This includes the MDC slaughterhouse, 1/2 mile east and about 3 miles south, west to the Broadway, and all the way north and back to the slaughterhouse. This area has been developed for extensive cattle grazing by MDC.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 40-65 meters
AREA:	4.25 square kilometers.
SOILS:	Mainly the Dandan shallow rocky clay and moderately deep to rocky clay and limestone patches.
DRAINAGE:	Well drained.
ROADS:	There are asphalt and coral roads.
POWER:	Public power is available along the western boundary.
WATER:	1) Surface: No surface water available. 2) Public Supply: Public supply is available (8-10" line). 3) Ground water: This area is presumed to be well developed basal lens at sea level with salinity less than 600 ppm. (Burke). At least four military era wells are located along the western boundary.
LAND TENURE:	MDC lease land is in military lease area.
RECOMMENDED FACILITY:	Earthen pond.
RECOMMENDED SPECIES:	Fresh/brackish.
SUITABILITY:	12



TINIAN
BROADWAY
SLAUGHTER-HOUSE
USGS 1:25,000
4.25 sq. km.
N
Unai Asiga
Unai Dangkol
Latte Stone
Shrine
Lasso
Laderan Lasu
WELL # 12
Water Tanks
Borrow Pit
WELL # 25
WELL # 22
ATEHA
MASALOK
Unai Masalok
POWER LINE
8" IRRIGATION LINE
Massalog
Laderan Masalok
Quarry
WELL # 24
FIELD
ELD
BM 80.7
WELL # 11
BM 85.9
Ruins
BOUNDARY
Tinian Airport
BROADWAY
AREA
Water Tank
Water Tanks
Laderan Dagu
Water Tanks
PIÑA
8"-10" IRRIGATION LINE
WT
Laderan Bapot
Quarry
amalaoan

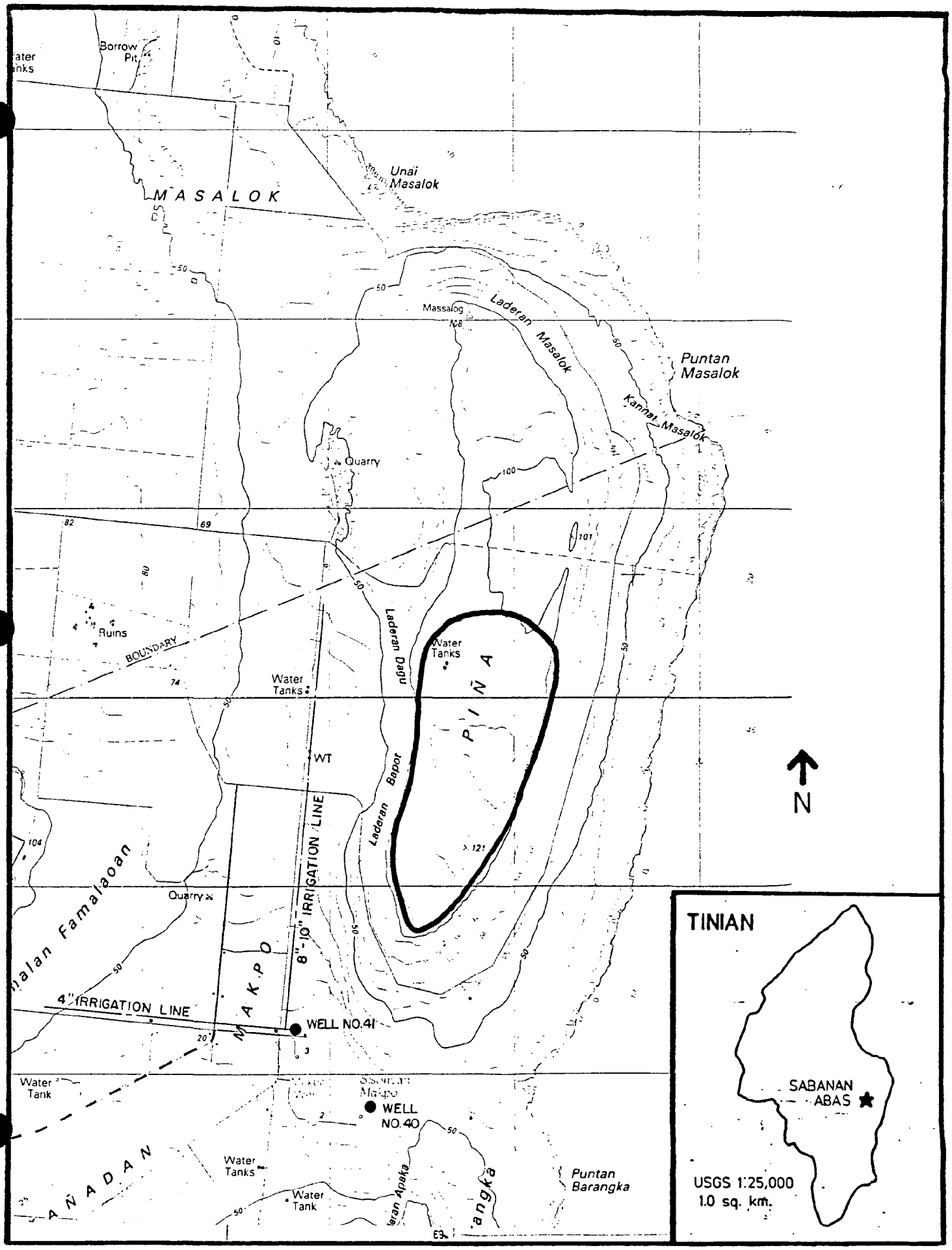
CAHET/BANADERON NUNU

DESCRIPTION:	This area is located on the southwest end of what is called the Central Plateau. It is probably as large as the North Air Field but a little less flat. It is criss-crossed by narrow roads, and is also served by a secondary road.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 60-85 meters
AREA:	6.6 square kilometers.
SOILS:	Dandan shallow rocky clay and moderately deep to deep clay. The clay have protruding pinnacles and fragments of limestone.
DRAINAGE:	Well drained.
ROADS:	There are coral roads.
POWER:	Public electricity is a mile east.
WATER:	1) Surface: No surface water. 2) Public Supply: Public supply is available at the airport one mile east. 3) Ground water: This area is presumed to be well developed basal lens at sea level with salinity less than 600 ppm. (Burke). At least seven military era wells are located in this area.
LAND TENURE:	Military lease area. Present usage is grazing agriculture.
RECOMMENDED FACILITY:	Earthen pond.
RECOMMENDED SPECIES:	Fresh/brackish.
SUITABILITY:	7


TINIAN
CAHET/
BANADERON
NUNU
USGS 1:25,000
6.6 sq. km.
N
Puntan
Sampapa
Water
Tank
Water
Tank
Water
Tank
Banaderon
Nunu
WELL # 6
WELL
2
WT
Borrow
Pits
BM
78.4
ATGIDON
WELL # 17
KAHET
Puntan
Atgidon
WELL
39
Water
Tanks
Water
Tank
WELL
4
WELL
21
ET 2 Tini
ABANDONED
WEST
Water
Tank
Water
Tanks
Puntan Diablo
Borrow
Pit
AIRPORT
Leprosarium
(Site)
Cem
Borrow
Pit

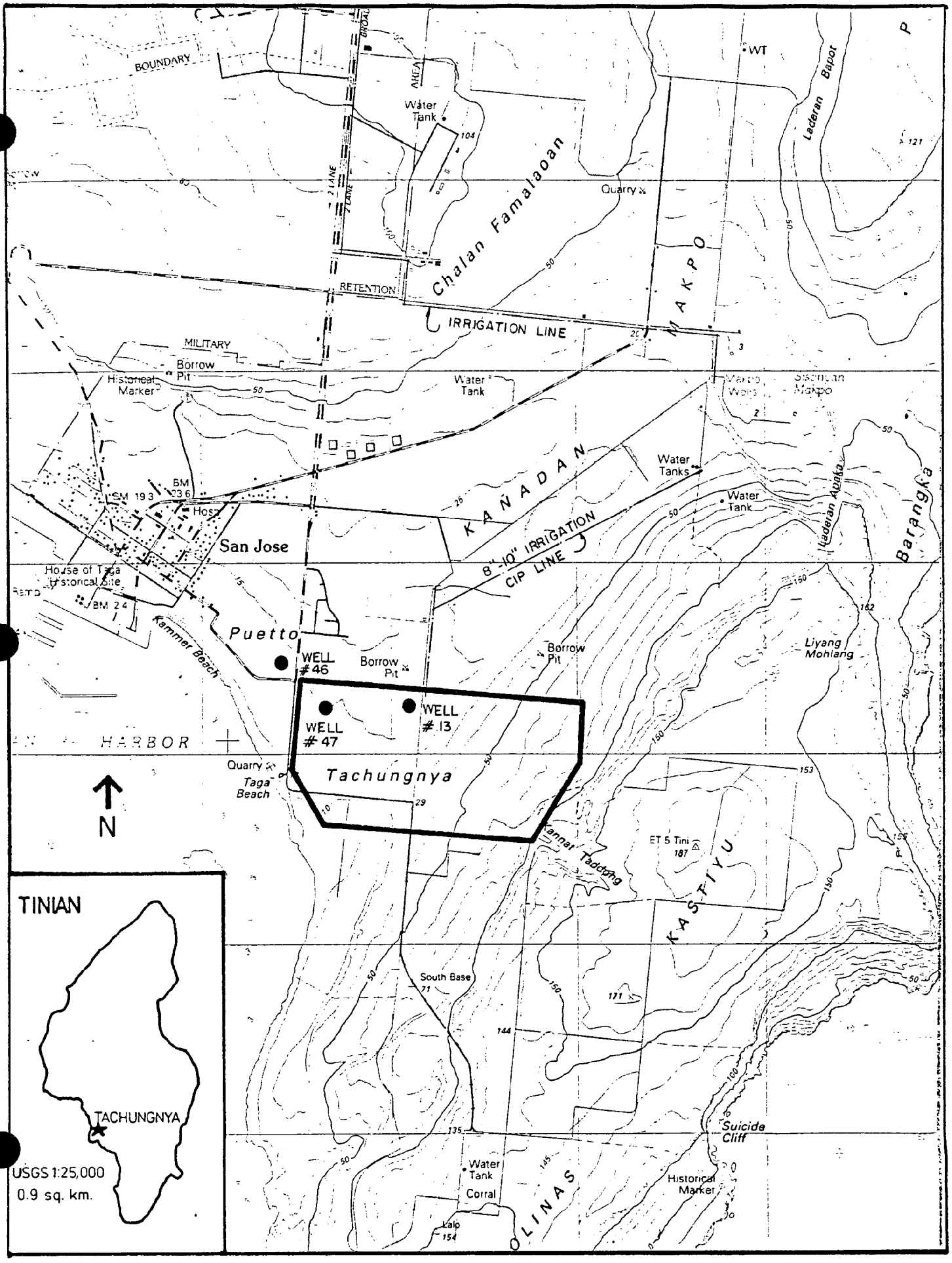
SABANAN ABAS (PINA)

DESCRIPTION:	This is located on top of Sabanan Abas on the north of the South Eastern Ridge. It is approximately 1/2 mile from the coast.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 100-115 meters.
AREA:	1.0 square kilometers.
SOILS:	Mainly Masalog clay surrounded by a scarped limestone belt.
DRAINAGE:	Medium to moderately rapid.
ROADS:	The area is accessible by 4 wheel drive trail.
POWER:	No power is available. The nearest line is about two miles west.
WATER:	1) Surface: Magpo lake is roughly 1/3 of a mile to the south. 2) Public Supply: Reservoir located around Magpo vicinity. The irrigation line is 1/3 of a mile away. An 8-10" potable water transmission is located about 1.5 miles west. The line is at an elevation of about 1-3 meters. 3) Ground water: Probably no lens exists because of either volcanic soils or faults at sea level (Burke).
LAND TENURE:	Agriculture - Micronesian Development Corporation land usage. It is located on public land.
RECOMMENDED FACILITY:	Earthen pond.
RECOMMENDED SPECIES:	Brackish; high market.
SUITABILITY:	1


Borrow Pit
Unai Masalok
MASALOK
Massalog
Laderan Masalok
Puntan Masalok
Kannat Masalok
Quarry
Ruins
BOUNDARY
Water Tanks
Laderan Dagu
Laderan Bapot
PIÑA
WT
8"-10" IRRIGATION LINE
Quarry
4" IRRIGATION LINE
WELL NO.41
NAKPO
WELL NO.40
Water Tank
Puntan Barangka
N
TINIAN
SABANAN ABAS
USGS 1:25,000
1.0 sq. km.

TACHUNGNYA

DESCRIPTION:	This site is located immediately east of Taga Beach, about a mile distant from San Jose Village, and a few hundred feet from the coast. Historic properties are found in the Tachungnya vicinity.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 10-60 meters.
AREA:	0.9 square kilometers.
SOILS:	The last 20% to the west end is mostly Shioya type soils. The majority is Alluvial clay with relatively small amount of Dandan shallow rocky clay.
DRAINAGE:	Very rapid (Shioya) to well drained (alluvial, Dandan).
ROADS:	There are coral roads.
POWER:	Public electricity is available.
WATER:	1) Surface: No surface water available. 2) Public Supply: A 6" supply pipe is located about 65 meters north. 3) Ground water: No freshwater lens at southwest corner; remainder probably greater than 600 ppm chlorides (Burke). Two military era wells are located within this site and one well is adjacent to the northwest corner.
LAND TENURE:	Designated agricultural zone. It is located on both public and private land.
RECOMMENDED FACILITY:	Lined pond; fabricated enclosure.
RECOMMENDED SPECIES:	Brackish.
SUITABILITY:	9

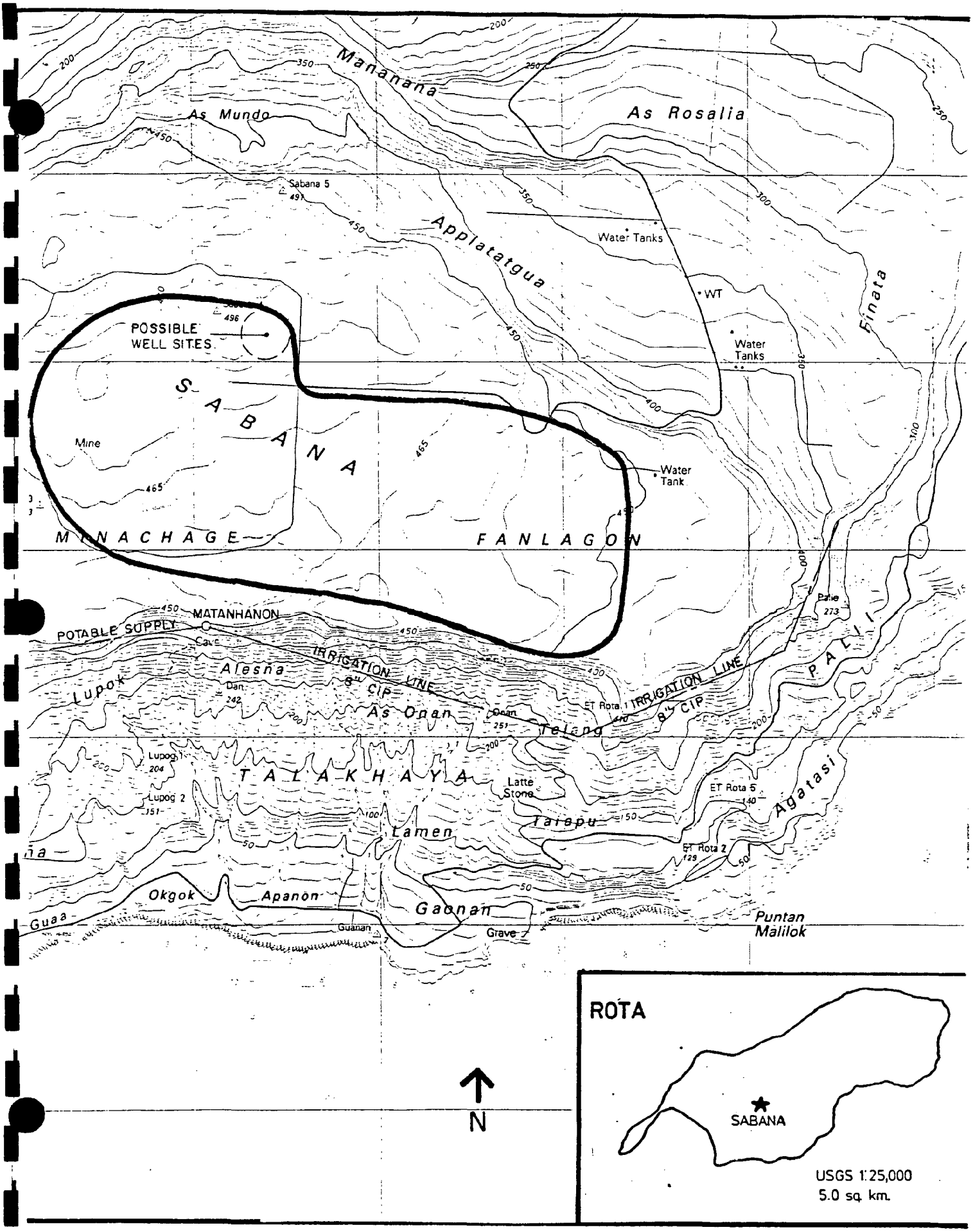


BOUNDARY
Water Tank
Chalan Famalaoan
Quarry
RETENTION
IRRIGATION LINE
MILITARY
Borrow Pit
Historical Marker
Water Tank
MAKPO
Laderan Bapot
Sisonyan Makpo
KAÑADAN
Water Tanks
Water Tank
Laderan Apaka
Barangka
8"-10" IRRIGATION CIP LINE
San Jose
House of Taga Historical Site
BM 24
Kammer Beach
Puetto
WELL #46
Borrow Pit
Borrow Pit
Liyang Mohlang
WELL #47
WELL #13
HARBOR
Quarry
Taga Beach
Tachungnya
N
Kannat Taddong
ET 5 Tini
KASTIYU
South Base
Suicide Cliff
Water Tank
Corral
Lalo
Historical Marker
OLINAS
TINIAN
TACHUNGNYA
USGS 1:25,000
0.9 sq. km.

SECTION 4
ROTA SITES

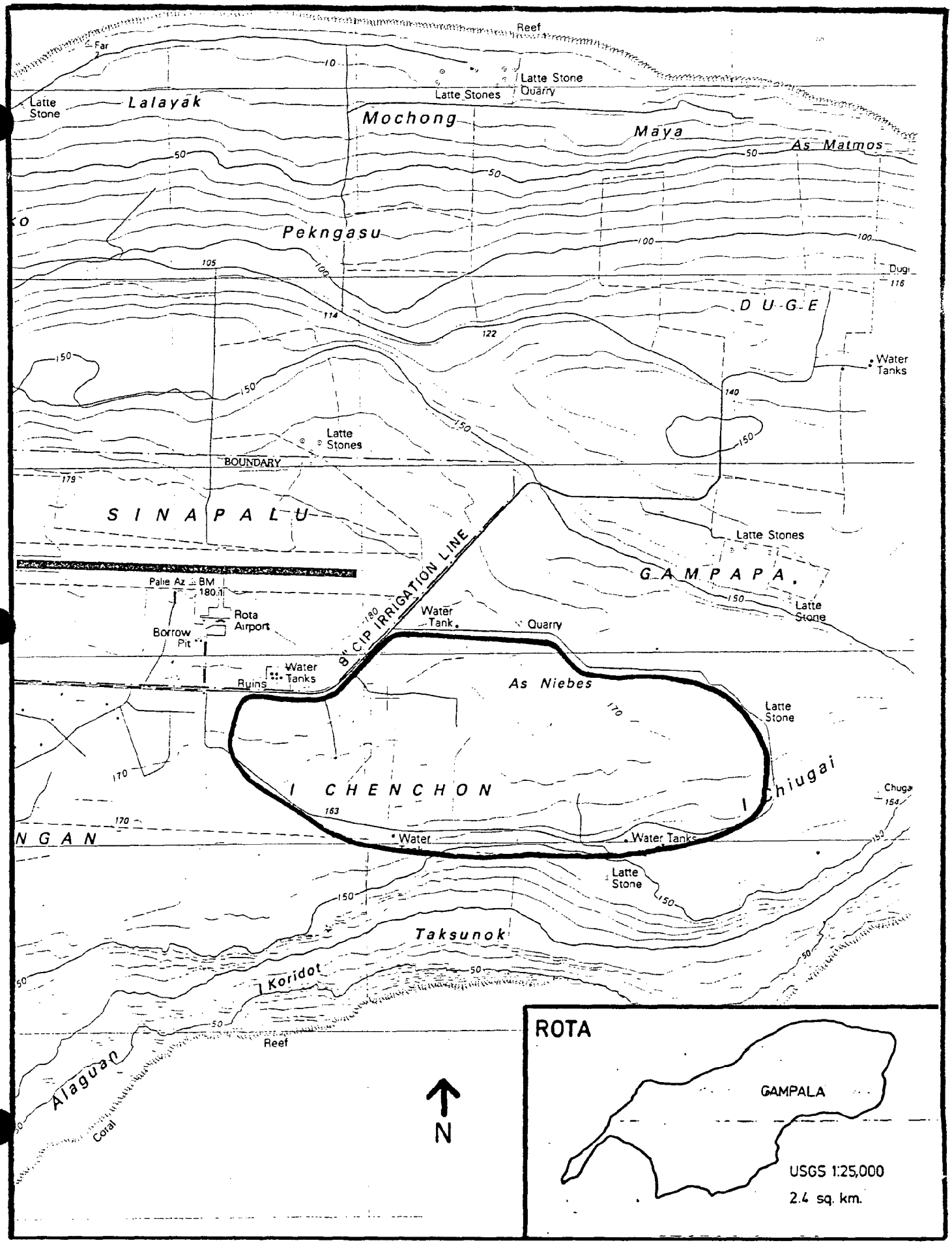
SABANA

DESCRIPTION:	This area covers Sabana and part of Fandango. It is located on the top of the Southern Plateau (Mt. Marina) and occupies about 20% of the plateau. Various access roads serve this area.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 430-465 meters.
AREA:	5.0 square kilometers.
SOILS:	Soils developed on limestone. Bedrock is at or near the surface in most places and loose rocks occur on the surface. Soil depth is 1-4 inches.
DRAINAGE:	Unspecified, presumed rapid to well drained.
ROADS:	There is a coral road.
POWER:	None
WATER:	1) Surface: The nearest surface water available is from the water cave (Matanhanom) located at the cliff base adjacent to the south boundary of the Sabana. 2) Public Supply: Public supply transmission line is located at the base of a 100 meter cliff near Matanhanom. 3) Ground water: probable in excess of 500 ppm salinity.
LAND TENURE:	Designated for grazing and cultivating type of Agricultural uses. It is located on public land. This site is within the proposed boundaries of the Luta Forest.
RECOMMENDED FACILITY:	Lined pond; fabricated enclosure.
RECOMMENDED SPECIES:	Brackish; high market.
SUITABILITY:	4


Mananana
As Mundo
As Rosalia
Sabana 5
Applatatgua
Water Tanks
WT
Finata
POSSIBLE WELL SITES
SABANA
Mine
Water Tank
MANACHAGE
FANLAGON
MATANHANON
POTABLE SUPPLY
Cave
IRRIGATION LINE 8" CIP
Alesna
Lupok
Dan
As Onan
Onan
Telang
ET Rota 1
IRRIGATION LINE 8" CIP
PALI
Pale
TALAKHAYA
Lupog 1
Lupog 2
Latte Stone
ET Rota 5
Agatasi
Tarapu
Lamen
ET Rota 2
Okgok
Apanon
Gaonan
Guaa
Guanan
Grave
Puntan Malilok
N
ROTA
SABANA
USGS 1:25,000
5.0 sq. km.

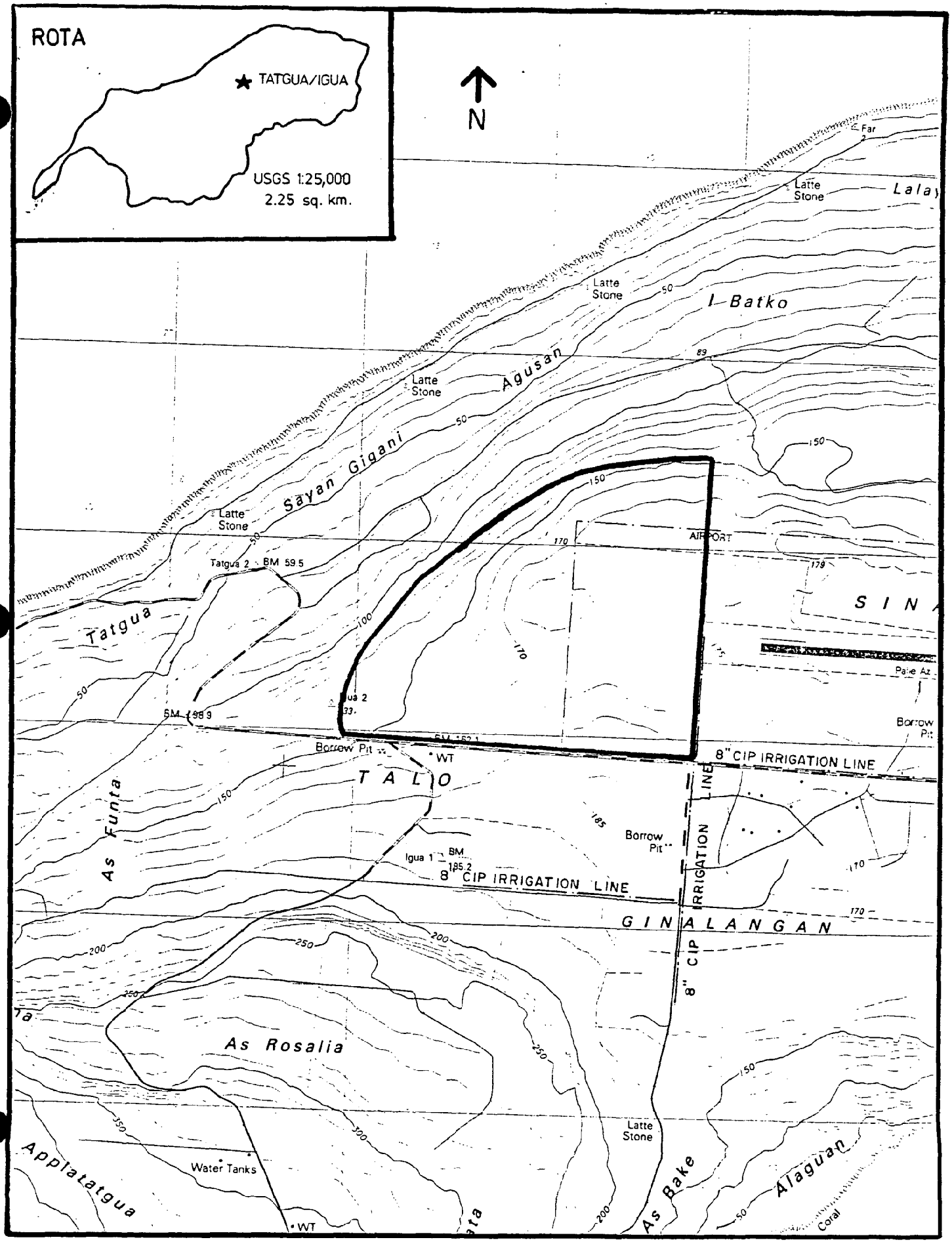
GAMPALA

DESCRIPTION:	Located on the east of Sinapalo subdivision and Rota Airport. It lies about 1/2 mile inland. It starts at the Latte Stone Quarry, 1/2 mile south and about 1 mile West to East.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 160-175 meters.
AREA:	2.4 square kilometers.
SOILS:	Soils developed on limestone. Bedrock is at or near the surface in most places and loose rocks occur on the surface. Soil depth is 1-4 inches.
DRAINAGE:	Unspecified, presumed to be rapid to well drained.
ROADS:	There are coral roads.
POWER:	None
WATER:	1) Surface: No surface water available. 2) Public Supply: The Irrigation line borders the northwest corner of the Gampala site. 3) Ground water: Probable in excess of 500 ppm salinity.
LAND TENURE:	Designated for agricultural uses. It is mostly located within public lands. A small portion, however, is private.
RECOMMENDED FACILITY:	Lined pond; fabricated enclosure.
RECOMMENDED SPECIES:	Brackish; high market.
SUITABILITY:	5


Reef
Far
Latte Stone
Latte Stone Quarry
Latte Stones
Lalayak
Mochong
Maya
As Matmos
Pekngasu
DUGE
Dugi
Water Tanks
Latte Stones
BOUNDARY
SINAPALU
8" CIP IRRIGATION LINE
Latte Stones
GAMPAPA
Latte Stone
Palie Az BM 180.11
Rota Airport
Borrow Pit
Water Tank
Quarry
Water Tanks
Ruins
As Niebes
Latte Stone
ICHENCHON
Chiugai
Chugai
NGAN
Water Tank
Water Tanks
Latte Stone
Taksunok
Koridot
Reef
Alaguan
Coral
N
ROTA
GAMPALA
USGS 1:25,000
2.4 sq. km.

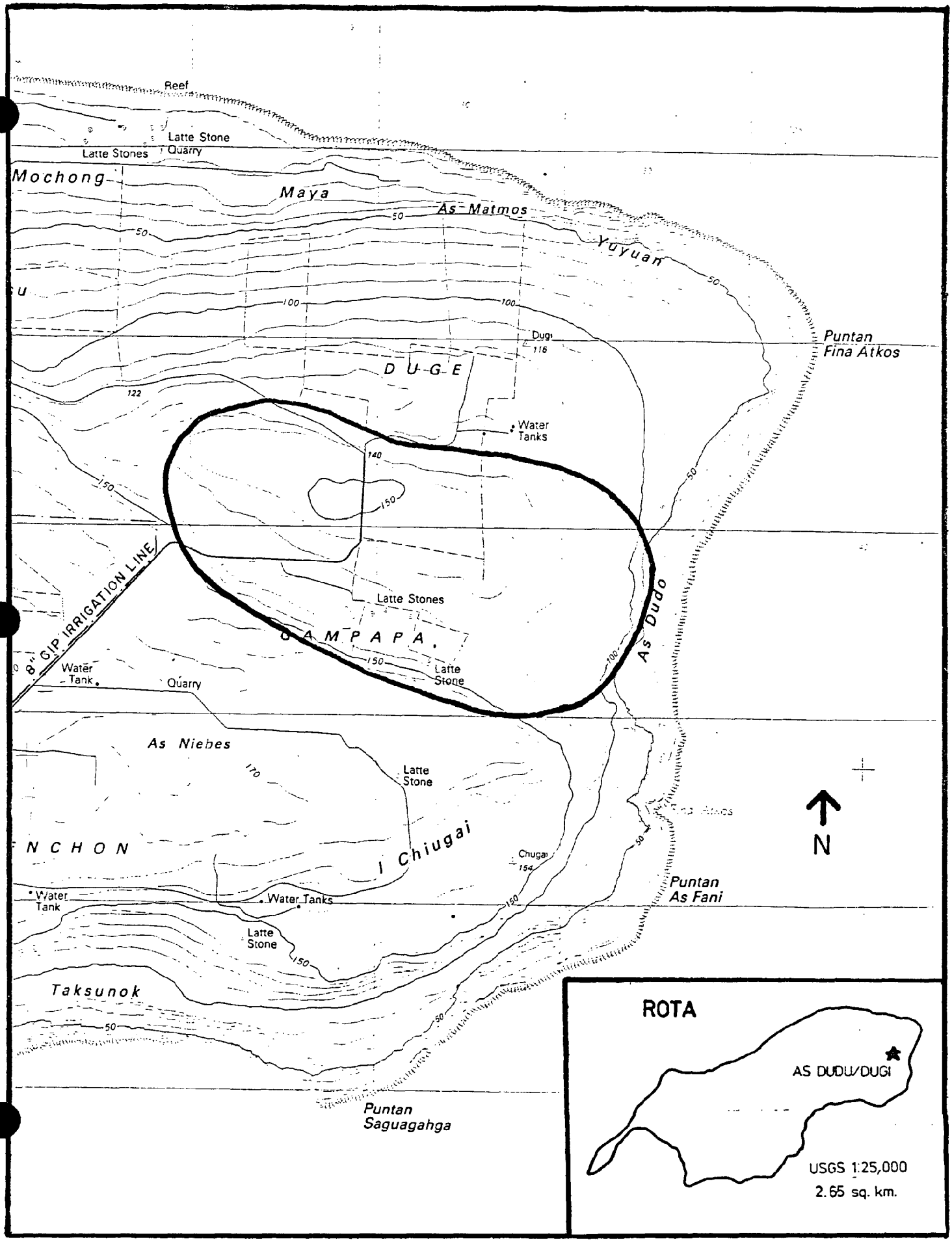
TATGUA/IGUA

DESCRIPTION:	This area is located directly at the west end of the airport runway. It is a triangular shape, stretching from the Sinapalo intersection a mile north and a mile west.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 170-175 meters.
AREA:	2.25 square kilometers.
SOILS:	Soils developed on limestone. Bedrock is at or near the surface in most places and loose rocks occur on the surface. Soil depth is 1-4 inches.
DRAINAGE:	Unspecified, presumed to be rapid to well drained.
ROADS:	There are coral roads.
POWER:	None. Rota airport immediately to the east has its own generation facility.
WATER:	1) Surface: No surface water available. 2) Public Supply: The Irrigation line borders about one-half of the east boundary. 3) Ground water: Probable in excess of 500 ppm salinity.
LAND TENURE:	Designated for agricultural uses and public facility type zone. It is located on public land.
RECOMMENDED FACILITY:	Lined pond; fabricated enclosure.
RECOMMENDED SPECIES:	Brackish; high market.
SUITABILITY:	5


ROTA
TATGUA/IGUA
USGS 1:25,000
2.25 sq. km.
N
Far
Latte Stone
Lalay
Latte Stone
I Batko
Agusan
Latte Stone
Sayan Gigani
Latte Stone
Tatgua 2 BM 59.5
Tatgua
AIRPORT
S I N A
Palle Az
Borrow Pit
Borrow Pit
WT
T A L O
8" CIP IRRIGATION LINE
As Funta
Borrow Pit
Igua 1 BM 185.2
8" CIP IRRIGATION LINE
8" CIP IRRIGATION LINE
G I N A L A N G A N
As Rosalia
Latte Stone
Applatatgua
Water Tanks
WT
As Bake
Alaguan
Coral

AS DUDU/DUGI

DESCRIPTION:	This is located at the far northeast of the island. It is about a quarter mile from the coast, separated by cliffs and steep ravines.
SLOPE/ELEVATION:	Less than 10% slope. Elevation is 140-150 meters.
AREA:	2.65 square kilometers.
SOILS:	Soils developed on limestone. Bedrock is at or near the surface in most places and loose rocks occur on the surface. Soil depth is 1-4 inches.
DRAINAGE:	Unspecified, presumed to be rapid to well drained.
ROADS:	There are coral roads.
POWER:	None.
WATER:	1) Surface: No surface water available.
	2) Public Supply: The irrigation line terminates about 350 meters from the western boundary.
	3) Ground water: Probable in excess of 500 ppm salinity.
LAND TENURE:	Designated for agricultural uses. It is located on public land.
RECOMMENDED FACILITY:	Lined pond; fabricated enclosure.
RECOMMENDED SPECIES:	Brackish; high market.
SUITABILITY:	4


Reef
Latte Stone Quarry
Latte Stones
Mochong
Maya
As Matmos
Yuyuan
Puntan Fina Atkos
Dugi
DUGE
Water Tanks
Latte Stones
CAMPAPA
Latte Stone
As Dudo
8" GIP IRRIGATION LINE
Water Tank
Quarry
As Niebes
Latte Stone
NCHON
I Chiugai
Chugai
Water Tank
Water Tanks
Latte Stone
Puntan As Fani
Taksunok
Puntan Saguagahga
N
ROTA
AS DUDU/DUGI
USGS 1:25,000
2.65 sq. km.

SECTION 5
WATER AND SOILS

Water Quality

In determining the feasibility of any aquaculture enterprise, it is necessary to evaluate the various chemical, biological and physical parameters that influence the success of the endeavor. As with terrestrial agriculture, an aquaculture facility must provide minimum natural amenities if it is to be economically viable; the prime requisite being an ample supply of water possessing certain basic chemical characteristics. Among the most important and easily measured are dissolved oxygen content, pH, alkalinity and salinity (Bardach). Generally, as long as basic salinity requirements are met, most untreated water sources will support a given species. It is the maintenance of the original water quality that is the challenge. The following water quality parameters may apply.

DISSOLVED OXYGEN. The level of dissolved oxygen (DO) is one of the most critical parameters of water quality (Stickney, 1979). Insufficent DO levels can result in stress, disease, parasite outbreaks, and even death. Most aquaculture species quickly succumb to certain minimum DO levels. At the very least they will refuse to eat, thus causing growth rate and food conversion efficiency to suffer. Many factors affect the DO level in water, including the activities of animals. The level at which DO begins to induce stress varies with species (3 ppm for tropical species, Crisostomo, 1985), but a reasonable general lower limit could be set at 5.0 ml/l (ppm) (Dr. Steven Nelson, pers. comm.). Thus DO must be measured routinely; and if levels fall below acceptable levels, well-aerated new water must be introduced or the existing water aerated by one of several methods.

AMMONIA. Once adequate DO levels are maintained, the toxicity of excreted nitrogen compounds becomes the most limiting parameter (Colt and Armstrong, 1979). There are three sources of ammonia in aquaculture systems: (1) naturally occuring in the water supply, (2) metabolites of fish (3) bacterial decomposition (Liao, 1974). It is the un-ionized form of ammonia that has been shown to be toxic to fish and should not exceed 0.1 ppm (FitzGerald). Whether ammonia will occur in its ionized (NH+) or un-ionized state is a function of other water parameters such as pH, temperature, and carbon dioxide concentration. Since ammonia is inhibitory to growth at any concentration, these levels must be kept as low as possible, a conservative limit for ionized ammonia being 2 ppm at pH8 (Dr. Steven Nelson, pers. comm.). However, even at levels as low as 0.12 ppm, reduced growth and histologic effects have been noted (Boyd, 1979).

NITRITE. Ammonia, in any system, undergoes nitrification to nitrate through a nitrite (NO_2^-) intermediate by aerobic bacteria. These reactions, whether naturally occuring or part of a biofilter system, are responsible for maintaining ammonia concentration at acceptable levels. The end product, nitrate, is not toxic in moderate concentrations, however nitrite is second only to ammonia in undesirabity in aquaculture systems. Rare, in open systems or ponds, nitrite can accumulate in closed, recirculating systems that have not been properly stabilized. Concentrations not in excess of 0.2 ppm are considered acceptable.

PHOSPHATES. Phosphorus in the form of phosphate is a required nutrient for plant growth and, thus, influencial in maintaining algal blooms that are generally desirable in pond culture. Phosphate is usually present in minute concentrations, because of its high mobility in biological systems. Elevated concentrations do not usually produce obvious effects in the cultured species, but indirectly in increased primary productivity.

TEMPERATURE. As long as warmwater species (having temperature optima above 25 C) are selected for cultivation in the tropics, water temperature will not generally be a problem. It is important, however that drastic changes in temperature are avoided.

CHLORIDES/SALINITY. Since most mariculture is practiced in oligohaline (highly saline) and mesohaline (medium saline) waters, diurnal, seasonal, and random fluctuations in salinity are likely to occur from rainfall, runoff, evaporation, tides, and wave action. The organisms, thus suggested for culture are euryhaline (varying salinity). These species can tolerate a wide range of salinity although optimum rates of growth and efficiency for each species do exist within a narrower range. However, under most aquaculture strategies, no attempt is made to maintain a constant salinity within such limits.

ALKALINITY. Alkalinity is defined as the capacity of water to resist changes in pH and is measured in terms of bicarbonate and carbonate ions. If alkalinity is extremly high, carbonates may precipitate on surfaces of the culture system.

HARDNESS. Hardness is the concentration of divalent cations (primarily calcium and magnesium). Low hardness can adversly affect some freshwater aquaculture species.

pH. Again, the natural buffering capacity of seawater, resulting from the presence of high concentrations of calcium carbonate ions, pH levels generally are greater than 8.0. It is critical that the pH of a closed system not be allowed to become too alkaline, since under those conditions, ammonia is more likely to be found in its un-ionized (ie. toxic) state.

CHLORINE. Chlorine is introduced into the public water supply to kill bacteria. It is considered extremely toxic to aquaculture organisms. Tolerance levels may be as low as 0.5 ppm. Chlorine may be removed from water by agitation, activated charcoal filtering, ultra-violet sterilization and use of sodium thiosulphate (Crisostomo, 1985).

FECAL AND TOTAL COLIFORMS. Coliform bacteria pose no problem to the health of organisms in an aquaculture system. The presence of coliforms, however, may indicate the presence of other harmful bacteria in the water. The presence of fecal and total coliforms does not necessarily indicate the presence of harmful bacteria in the organism itself which would affect marketability from a public health point of view.

TOTAL BACTERIA. Other than pathogenic bacteria which may affect the species being cultured or present a public health problem, the most important bacteria in any aquaculture system are those responsible for the nitrification of ammonia to nitrite and nitrates discussed above. These are naturally occuring bacteria and will be present in any stabilized system.

DISSOLVED SOLIDS. Dissolved solids are generally not a consideration unless they interfere with light penetration such that primary productivity is reduced to unacceptable levels (> 20,000 mg/l) (ppm). An inordinate amount of suspended matter, resulting from runoff from heavy rains for example, can lead to clogging of the gills or irritation of gill filaments and other membranes. Most species can tolerate up to 100,000 mg/l (ppm) for a week or more. Most aquacultural waters have dissolved solids on the order of 100mg/l (ppm).

Soil Conditions

The soils found at each site will determine the type of facility and give a good indication of the development and operations costs. Clay soils are more suitable for earthen pond facilities since sufficient quantities of such a soil type will retain water. The presence of clay soils at a given location will mean that an earthen facility can be constructed rather than having to utilize impermeable materials or fabricated enclosures. Conversely, sandy, alluvial and limestone soils generally will not retain water, thus necessitating the use of impermeable materials or fabricated enclosures. Earthen ponds, depending upon the fertility of the soil and other factors, will tend to produce natural feedstocks which through careful selection of the species to be cultured, can greatly reduce costs which otherwise would be incurred for artificial feedstocks.

This segment identifies the various soil properties and the significance of each property to aquaculture.

TYPE. The soil at any prosepective site should have good water retention capacity. Should this be a problem, however, it is possible to seal ponds against leakage. At least a 25% clay content is desirable to ensure water retention (Bardach). A depth of 10-12 inches should be adequate to retain pond water for soils with a clay content of 25%, while 8" of 40-50% clay content soil should be adequate (Crisostomo, 1985). Clay material also enhances the formation of soft colloidal bottom, essential for promoting the desirable biochemical balance and hiding places for some species during portions of their life cycle.

pH. A soil pH of 6.5 to 7.5 is generally desirable to encourage algal growth, especially in ponds in which herbivores will be cultured (Huet). pH should be greater than 5.5. The addition of lime (550 kg/ha) will increase the pH if too low, or reduced through the application of sulfate of ammonia fertilizer. It is not possible to reduce the pH if too high. Soils with a pH below 7.0 are considered acidic while soils with a pH greater than 7.0 are considered alkaline.

AMMONIA NITROGEN. As indicated above, ammonia nitrogen in its un-ionized state is extremely toxic and should be minimal. If soils carry their normal complement of nitrifying bacteria, however, ammonia levels will remain below tolerable limits.

NITRATE NITROGEN. High nitrate concentrations are characteristic of the soils of Saipan. However, there is little concern for nitrate accumulation in open ponds. Nitrate itself is not toxic and is removed from the water by primary producers in the system (Stickney, 1979). In a closed, recirculating system, high nitrate levels may be indicative of a general deterioration in water quality.

PERCENT ORGANICS. Generally, 25-50% organics is recommended in substrate soils in order to support the growth of algae and benthic biomass necessary to promote a healthy system.

CALCIUM, POTASSIUM, PHOSPHORUS. These elements are required to support substrate biomass accumulation. They are present in sufficient quantities in most soils. They are not considered to be a factor in siting aquaculture facilities on Guam, whose soils are similar to those of the Northern Marianas.

Soil Units, Drainage and Alkalinity/Acidity

This segment details the characteristics and known properties of soils found at the various aquaculture sites of Saipan, Tinian and Rota.

ALLUVIAL CLAY. Yellowish-brown clayey sediments in alluvial fans from chacha soil. Depth is usually over 20 inches. Underlying rock is Mariana limestone 1 to 8 feet thick, generally 2 to 5 feet.

The soil is well drained. Surface runoff is medium to rapid and internal drainage is medium. Moisture retention is moderate.

Mildly alkaline to slightly acid.

CHACHA CLAY. Strong-brown to yellowish-brown, firm, plastic clay with dark grayish- brown upper layer; generally quite acid. Soil depth is usually over 30 inches. Underlying rock is Tagpochau limestone 1 to 5 or more feet, generally 2 to 4 feet.

The natural drainage is about medium externally, and medium or slightly less internally. Chacha clay remains moist for considerably more of the time than Saipan Clay.

Neutral to slightly acid.

SAIPAN CLAY. Reddish or yellowish-red, firm, plastic clay with dark-brown to reddish-brown granular clay upper layer; acid; generally stony. Soil depth is usually less than 30 inches. Underlying rock is Tagpochau limestone 1 to 5 or more feet, generally 2 to 4 feet.

Drainage is medium to rapid externally, medium internally. Surface runoff occurs on the gently sloping and sloping areas only during infrequent torrential rainfalls. Moisture retention is medium.

Slightly acid.

MASALOG CLAY. Reddish, friable to moderately firm clay; very shalllow and rocky to moderately deep. Underlying rock is Mariana limestone 0 to 4 or more feet thick, generally 0.5 to 2.5 feet.

Surface or external drainage is slow; there is no defined stream drainage. There may be moderate runoff during extremely heavy rains, but most of the water settles or percolates through the soil and underlying limestone. Internal drainage is medium to moderately rapid. Moisture retention is low.

Mildly alkaline to slightly acid.

DANDAN SHALLOW ROCKY CLAY. Dark brown granular clay over brown, friable, permeable clay, with protruding pinnacle and fragments of Mariana limestone. Soil depth is usually more than 20 inches. Underlying limestone is 0 to 2 or more feet thick, generally 0.5 to 1.5 feet.

The soil is well drained; surface runoff is generally slow. Most of the drainage is by medium to rapid percolation. Moisture retention is low.

Mildly alkaline.

DANDAN MODERATELY DEEP TO DEEP CLAY. Same as above, but the deeper soil has less limestone pinnacles and fragments at surface; both phases trend to reddish-brown locally. Soil depth is usually more than 20 inches. Underlying rock is Mariana limestone 1.5 to 5 or more feet thick, generally 2 to 4 feet.

These soils are well drained. Because of medium to rapid internal drainage, surface runoff is slow. Moisture retention is low to moderate.

Neutral to mildly alkaline.

LIMESTONE ROCK LAND. Limestone cliffs and gently to steeply sloping rocky scarps with thin mantle of dark-brown, or reddish-brown granular clay interspersed among limestone ledges, pinnacles, and fragments. Underlying rocks are Mariana and Tagpochau limestones generally less than 0.5 feet thick.

The rock land is well drained. surface runoff is slow on gentle slopes. Moisture retention is low.

SHIOYA SOILS. Calcarious sand and gravel coastal terrace; weakly developed dark grayish-brown to pale-brown upper layer over light yellowish-brown to white shelly sand and coral debris. Soil depth is usually more than 30 inches. Underlying rock is mainly Mariana limestone 1 to 8 feet thick, generally 2 to 5 or more feet thick.

Surface drainage is very slow to nonexistent, as water drains rapidly to very rapidly downward through the soil. Lack of colloidal clay and silt in the soil material makes moisture retention very low.

CHINEN CLAY LOAM. Clay loam, dark-brown; moderately developed medium to coarse granular structure; friable and non-plastic. The soil depth is usually more than 20 inches and may be as much as several feet in crevices and fissures in the limestone. The contact of the soil and limestone is abrupt with many small pockets of deep soil and many small pinnacles of limestone exposed at the surface.

Chinen soils are generally stony and shallow. They are classified as well-drained.

Alkaline.

MARSH AND SWAMPLAND. Depressional areas near sea level, in limestone, with organic soils and some clay; trees in the swamp and tall reeds in marshes; high water table, some open water in marshes. Soil depth is usually more than 30 inches. Underlying rock is Mariana limestone 2 to 5 or more feet thick.

The areas are permanently imponded and very poorly drained.

Neutral to slightly alkaline.

SOIL DEVELOPED ON CORAL LIMESTONE. (Rota only) These soils are relatively shallow. They average about 7 inches in depth and are dark brown to dark-reddish brown in color. Texture range from sticky plastic clay to friable to granular loam. It is underlain by a similar soil type which may extend to depths of about 8 inches to a rare 20 inches (Bowers 1950).

Drainage is probably rapid.

Acidity/Alkalinity not known, estimated to be alkaline.

Information about physical and chemical characteristics of CNMI soils is very limited. Of the eight soils for which data exists, three are found at various aquaculture sites. Of the specific characteristics available, the following are applicable to aquaculture:

Soil type	Horizon	Depth (in.)	Ca	K	Na	% clay	pH
Chacha Clay	A1	0-7	14.9	0.4	0.7	66.3	6.1
	B2	7-24	7.4	<.1	.7	79.4	5.7
	B3	24-72	6.4	.1	.6	78.4	5.3
Saipan Clay	A1	0-4	18.9	0.3	0.6	85.4	6.7
	A3-B1	4-15	9.6	.2	.3	91.8	6.9
	B2	15-36	8.2	.2	.3	91.3	7.0
	B3	36-80	3.8	.2	.1	95.1	6.6
Dandan Clay	A1	0-6	29.1	0.4	0.7	67.4	6.7
	B2	6-21	8.0	.2	.9	88.3	5.8
	B3	21-36	3.5	.2	.6	83.1	6.0

(Adapted from McCracken)

SECTION 6
AQUACULTURE TECHNOLOGIES

Most aquaculture in the world makes use of one of five management systems, which in order of increasing levels of intensity of culture are: ranch management, static pond or pool aquafarming, cage or basket culture, raceway culture and closed high-density systems (Crisostomo, 1985).

RANCH MANAGEMENT. In this system, species under culture forage or browse for natural foods in large natural water embayments or sheltered coves. Minimum use is made of confinement by fences, etc. An extreme example of this technique is salmon culture in Washington State. Briefly, salmon young are released in the streams which flow to the sea. the young salmon feed, grow and mature in the open ocean, then migrate back up their 'parent stream' to spawn. At this time fishery biologists remove a quantity of fish for spawning stock for the next cycle. During the migration, commercial fishing interests harvest a large quantity of the salmon. The CNMI has virtually no riverine or other inland areas where this system of management could be applied. Its application to mariculture may be favorable.

STATIC/SEMI-STATIC POND AQUAFARMING. In this system, the stock is confined in earthen, concrete, rubber/plastic-lined or otherwise-structured ponds. Static systems receive no water except from natural occurrences while semi-static system operators manage water supply and conditions. Natural foods present in the pond are generally stimulated by fertilizers, and/or supplemented by foods provided by the farmer. This basic system with its various modifications is probably the system most prevalent in the world today. Guam, Hawaii and other parts of the region have numerous examples of this farming technique. This system is the preferred system for the CNMI during the early stages of aquaculture development.

RACEWAY CULTURE. In this system high stock densities in minimal areas are permitted because a large volume of water either by gravity feed or by pump is continuously passed through the enclosure. The total food requirement for the stock must be provided by the farmer. In general the higher capital costs and water and technology requirements tend to rule out this system for the CNMI. The system's small land requirements would be appropriate to the situation here if the other problems could be overcome which may be possible for high market value stock such as shrimps and prawns.

CAGE OR BASKET CULTURE. In this system the stock is confined in wire mesh or net cages, suspended or supported (on rafts) in large bodies of water, static or flowing. All feed is again furnished by the farmer. This technique has limited application potential in the CNMI except for Susupe Lake. Its application to mariculture may be favorable.

CLOSED HIGH-DENSITY CULTURE SYSTEM. In this system the stock is confined in a container, through which a continuously recycled flow of water is passed. The water is treated to purify it for reuse. Feed again must be entirely furnished by the farmer. This system may be applicable in the CNMI due to the small land and water requirement of the system. However, in comparison with other systems, large capital investment is demanded to support the sophisticated technology of closed-cycle systems.

Preferred System for CNMI

Due to the total lack of an aquaculture industry of any size in the CNMI, the concomitant lack of experience and supporting technologies, and the lower capital cost, the Static Pond System (earthen pond) is considered most appropriate for the CNMI. In addition, the high cost of feed which must be imported has been the chief barrier to profitable operation of other agricultural ventures in the CNMI, and the same barrier is certain to exist for aquaculture along with problems associated with water supply, infrastructure and probable distribution and marketing obstacles. The pond system produces much of its own food which, if properly matched with the target species, should result in lower production costs and fewer inputs. Finally, soil and water conditions of selected areas of the CNMI are more suitable for this method.

There are two general types of pond which may be constructed, the dugout pond and the levee pond. The former type is excavated such that the bottom lies below the surrounding grade. In levee ponds, the water is retained above ground level by a dam and levees or their natural topographic contours. Levee ponds are preferable for all forms of aquaculture, since, unlike dugout ponds, they may be drained completely dry without pumping.

Ponds should be completely drained of water at a minimum of every two years to dry and recompact the soil and to oxidize accumulated organic matter (Crisostomo, 1985). A standard method to facilitate drainage of the pond, is to slope the bottom toward the outlet at about 0.2-5%. All obstructions should be removed, and irregularities smoothed out. If soil used in levee construction is taken from the pond site, the borrow sites should be outside the pond to minimize the removal of non-permeable soils. Irregular bottoms may prevent full drainage, thus resulting in less than complete stock capture during harvest.

The outlet design should permit the pond, exclusive of the harvest basin, to be drained in 48 hours or less. Two L shaped stand-pipe outlets are used which can be swivelled in an up or down motion. The lower end protrudes through the levee wall. The upper end which is outside of the pond is set at the desired elevation of the pond water. When upright the pipe serves to prevent pond drainage while at the same time allowing excess water to drain out. When the pipe is reclined to a horizontal position, the water drains out.

A simple facility, described herein has its advantages in that should a larger scale facility evolve, the earthen ponds initially constructed, will be needed to hold broodstock for any hatchery facilities. However, it is not recommended that hatchery facilities be a primary goal. Instead, initial attempts should depend on imported or locally captured fry.

Pilot Demonstration Facility

Due to the infant stage of aquaculture in the Northern Marianas, with its economic feasibility yet to be established, it will be wise to limit the capital outlay to a basic low technology facility that can be elaborated upon as commercial sales increase and better technology become available.

Polyculture is the production of a combination of species which will feed off natural waste products and plant growth. These species will in turn fertilize a pond with their waste product. The per species yield of polyculture is lower than through monoculture, but total yield is greater (Nelson 1983).

Polyculture is recommended until such time that one species proves superior in production and/or economics to make monoculture a consideration. A polyculture production of milkfish, tilapia, Gracilaria , and penaeid shrimp may be viable in terms of species compatibility, brackish water tolerance, simpler technical requirements, lower feed cost, and greater likelihood of success of one or more species. It should be noted that Gracilaria may not tolerate low salinities, while milkfish, tilapia and penaeid shrimp should survive a range of salinities.

A polyculture facility would be managed as follows: After ponds are built, they are cleaned, leveled and dried for 2-6 weeks after which agricultural lime is applied at 400 kg/ha in order to absorb excess C02 and provide calcium for ecdysis (moulting) in the shrimp.

The pond is then fertilized with an organic fertilizer such as chicken manure at a rate of 1-3 tons/ha to induce growth of zooplankton. Water is added to a depth of 5-10 cm, then 2-3 days later a commercial inorganic fertilizer (16/20/0) is added at a rate of 50-250 kg/ha (or use 18/46/0 fertilizer at a rate of 50-100 kg/ha) to induce the growth of the microbenthos complex (lablab) and green filamentous algae (lumut); two weeks should be sufficient (Crisostomo, 1985).

Ponds are then filled to 20-30 cm and Gracilaria is stocked to form a 15 cm deep carpet. After the Gracilaria is established (2-3 months), the water level is raised to 0.70-1.0 m and milkfish and tilapia fry are stocked. When milkfish fry have attained a size such that they are immune to predation (2-4 weeks), the penaeids can be stocked. The growing milkfish will feed on the epiphytic algae on the Gracilaria until they are big enough to eat the algae itself at which time they and the Gracilaria are harvested. Tilapia eat the zooplankton, while shrimp graze on the lablab. To accelerate growth, a commercial pellet food should be used after about 30 days at a rate of 5% of body weight per day.

Harvest time and weight for each species is:

milkfish	6-10 months	1 pound
tilapia	6-8 months	0.75 - 1 pound
shrimp	6-8 months	5-20 pieces/pound
gracilaria	4-8 months	na

The harvest of the milkfish and tilapia is accomplished at the same time by net with a mesh size which will permit the shrimp to pass through. Shrimp are caught with a smaller mesh net. If timing is carefully practiced, all three species may be harvested at the same time. Gracilaria is harvested by hand.

A standard method of net harvest is for two people to drag the net through the water, or by securing one end of the net while one person circles the pond. If the pond is large, it would be necessary to use a truck or tractor.

Dams and Levees

Dams and Levees literally hold a levee pond system together and thus their structural integrity is of paramount importance in construction. These materials must be made of nonporous materials and be of sufficient size to withstand the pressure of the water in the pond. Where mechanized equipment is to be used, the levees must be made considerably wider than what is structurally necessary in order to accommodate vehicle access. About 0.6 m of the levee should be above the maximum water level. Water level refers to the level of pond water and flood waters which may inundate a particular site. The inside bank should be very steep to discourage plant growth which may provide habitat for unwanted species, interfere with management or reduce structural integrity. Outside banks should be immediately planted with grass to impede erosion.

A soil which has at least 25% clay content is required to provide adequate safeguard against seepage. Seepage rates of clay is about 0.005-0.008 inches/hour. Ponds built on lower quality soils may be improved by the addition of 30 to 45 cm of good clay content soil before compaction. The clay content is known for three CNMI clays, Chacha, Dandan and Saipan, which is respectively 66.3-78.4%, 67.4-83.1% and 85.4-95.1% all of which well exceed 25% minimum clay content standard. Analyses of other CNMI soils should be undertaken to determine clay percentage.

In the absence of suitable clay content soils, other impermeable materials may be used, however, the cost is high. One such material is neoprene. The main advantages of neoprene over other plastics are its inertness in water (lack of chemical toxicity) and its durability. Liquid application to bare pond bottoms have a water loss rate of about 0.014 inches/hour. Other materials include polyethylene, vinyl, or butyl rubber. These materials are structurally weak and must be handled very carefully, but when properly installed they are easily kept intact and watertight. Minimum thickness for pond liners used over materials no coarser than sand is 2mm for polyethylene and vinyl

and 4mm for butyl rubber. Where the bottom contains gravel or poorly sorted coralline materials, these thicknesses should be doubled. Concrete may also be used.

Size of Ponds

Ponds of all sizes have been successfully used in aquaculture, however, most ponds have a surface area of approximately 1 acre (Saruwatari). To be commercially successful at least 5 acres may be necessary for the extensive method while as little as 0.5 acres may be feasible for an intensive facility (Crisostomo, 1985). Even after the choice of size has been narrowed down by consideration of biological, topographical an economic factors, the culturist usually must weigh the relative advantages of small and large ponds.

Advantages of small ponds include: 1) ease and quickness of harvest; 2) quicker drainage and refill; 3) ease of disease and parasite treatment; 4) If all or part of stock is lost, the loss of one small pond is less; and 5) less subject to dam and levee erosion by wind.

Advantages of large ponds include: 1) less construction cost per acre of water; 2) less space requirement per acre of water; 3) more subject to wind action and therefore less subject to oxygen depletion; and 4) more conducive to rotation with terrestrial crops.

Pond depth depends partly on the type of species but primarily on climate. If fish alone are to be cultured, a depth of 1.5 to 2.0 meters is desirable. If prawns are to be included, the water level should not exceed 1.2 meters (Crisostomo). In warmer areas such as the CNMI deep water is unnecessary as it is low in productivity and often devoid of dissolved oxygen. Sufficient depth is warranted to prevent the establishment of rooted aquatic plants which may occur at depths less than 0.75 m, and to protect against thermal stress. Often the optimum temperature for growth is very close to the upper tolerance limit.

SECTION 7
SITING CONSIDERATIONS

Water Supply

A constant supply of appropriate quality water must be available throughout the year to replace losses due to evaporation, seepage, and drainage during management operations. The prospective pond builder should base his considerations on conditions prevailing during the hottest and or the driest part of the year, when evaporation is greatest and oxygen depletion in the pond is most likely.

The CNMI is estimated to have a mean annual evaporation rate of 76.6 inches (1 inch per acre/day (Saruwatari)) based on CNMI rainfall data and evaporation data collected on Guam (Army Corps of Engineers). The general guideline pertaining to an adequate water supply is that 25 gpm/acre (93.75 l/ha) is needed on a year-round basis (Crisostomo). An average pond of one surface acre and having a depth of 1.5 meters would require 1.6 mg initially, and following each harvest cycle which requires full drainage.

The public water system is inadequate to provide this quantity for most areas or Saipan; the Tinian supply may be adequate; however, for Rota. the minimum supply flows for the irrigation system which supply some of the aquaculture sites was measured to be 41 gpm. Thus a one acre pond which requires 25 gpm would probably have to compete with other users as the minimum flows occur during the dry season when farmers also need the water.

The economics of using public water, however, is questionable. At the present cost of $0.50 per 1,000 gallons, the cost of water per acre would be $800 to fill the pond, plus $18 per day or $6,570 per year to maintain the supply. Additionally, chlorine which is added to the supply, may adversely affect algal growth needed to sustain certain species and may also directly affect cultured species.

By far the best source of water for a pond is a well, although spring water or even surface runoff may be successfully used (Bardach) if the volume is sufficient. Well water is preferred because it assures more dependable flow and is usually free of disease organisms, parasites, predators, trash fish, pesticides, silt and other contaminants and pollutants.

The temperature of ground water in the CNMI appears to range from 24 to 28 degrees C, while surface waters of Lake Susupe ranged from 25-30.5 C and spring waters ranged from 25-32 C. These temperatures should be suitable for most preferred species, especially when the ground water is used to replenish pond water which has reached ambient temperature due to solar gain. Other than the expense of drilling a well, the only physical problem normally encountered in using well water is that it is often low in dissolved oxygen and high in carbon dioxide and nitrogen. This situation can be reversed by spraying it into the pond, splashing it in off a flat surface, or passing it over a series of baffles so that harmful gases may be exchanged for atmospheric oxygen.

All CNMI candidate sites except two (East Achugao, Sabana Abas) are believed to have ground water, but in most cases, the chloride content is high. None of these sites are located sufficiently close to present well fields to have an affect on the public water supply. Nevertheless, extensive over pumping of a brackish aquifer may cause salt water intrusion of nearby well fields and may preclude future ground water development for the public water system. Test holes and pump tests are recommended to ensure an adequate and sustainable water supply for an aquaculture facility. In addition to brackish water wells, springs such as Starch Factory Spring are brackish. The use of brackish water for aquaculture would restrict the choice of culture to brackish water species.

The cost of well water development varies with the altitude and the acreage of the facility. A well serving a facility located at a higher elevation will have much greater development cost than one located at sea level where the water table may be as little as 4 feet below grade. The average facility size of one acre requires a pump with a minimum capacity of 25 gpm which requires a 3 hp motor; a two acre pond would require a 7.5 hp motor; a 3 acre pond would require a 10 hp motor; a 6 acre pond would require a 25 hp pump, etc. The larger the pump capacity and motor, the greater the initial capital and operating cost. Small facilities at lower elevations may be able to utilize windpumps or photovoltaics if electricity is not available on site.

Several of the selected sites include wetlands within their boundaries. It is possible to utilize these areas for pond culture through excavation and levee construction to form enclosed areas of standing water. This method is not recommended due to the inability to drain the pond. Also, there is little if any data about the supply of water and recharge rates, thus it would be difficult to determine the year-round supply of water. Another problem is the potential for damage caused by flooding. Finally, projects which affect wetlands are subject to lengthy CNMI and Federal environmental reviews and permits. Such permits serve to protect natural conditions of the wetlands which involve rare and endangered wildlife, flood protection and fisheries while minimizing adverse impacts of permitted activities.

Rainwater is not considered a suitable source of water. This is because of the high construction cost associated with a storage facility and a large tributary area needed to catch the rainwater from. A catchment would have to be fairly large to supply a little over 13 million gallons a year which is required to supply 25 gpm per acre on a year round basis and two harvests per year exclusive of reserves for periods of drought. The tributary area would probably require more impermeable surface than the entire facility.

Marine water supplies may also be feasible for facilities located close to the coast. Such a water supply would either be used to support marine species or would be mixed with lesser saline waters. The use of marine waters would entail substantial pumping costs, engineering and construction considerations and environmental review.

Power Supply

Electrical supply is critical. Electricity is required to operate wells, circulation pumps, lighting, etc. Most sites on Saipan are served by 13.8 KVA aerial circuits capable of providing single and three phase service. Tinian has 720 kva aerial circuits. Fewer of the Tinian sites are served and none of the Rota sites have electricity. The initial cost of extending electrical service must generally be borne by the developer, however, the CNMI permits the cost to be credited against utility charges. The cost of electricity in the CNMI is pro-rated and ranges from $0.05 kwh for up to 800 kwh to $0.08 in excess of 25,000 kwh per month. A demand charge is added for three phase use.

Alternate energy devices may be appropriate for smaller scaled projects in the absence of public supply. Such devices could included wind driven water pumps, gasifiers to produce electricity, methane digestors to produce gas which is then used to fuel electrical generators, photovoltaics to run low volume pumps and for lighting, and diesel generators.

Roads

The existence of year-round, all-weather roads is an important infrastructural requirement. It is absolutely necessary that overland access to a facility be maintained at all times, both to ensure logistic support for operations and to allow for the ready transport of fry or harvested products either to retail and wholesale outlets or for export. Such roads must extend to within a distance of 0.25 miles of the proposed pond site. Fortunately, most of the selected sites for the CNMI are served by adequate roads.

Drainage

The type of soil and the extent of impermeable surface of a facility influence the drainage characteristics of a site. The clay soils which are best for pond systems because of their water retention capability often present drainage problems for the same reason. Generally, there are two concerns. First, it is desirable to prevent runoff from entering a pond. This is because runoff can carry contaminants such as oil, grease, pesticides and silts which can kill the stock, or significantly reduce productivity. This problem can be managed through the use of levee style ponds, or through channelization to divert the runoff away from a facility. Another problem is flooding, which in addition to introducing contaminants, can result in loss of stock, the introduction of unwanted species, and structural damage. Flood damage generally can be avoided by the selection of sites outside of known floodplains or through project designs which accomodate potential flooding such as construction of levee heights in excess of the historical maximum flood level, and stronger levee walls.

Environmental Impacts

The construction and operation of an aquaculture facility will result in environmental impacts. The impacts may range from minor to severe, depending upon the location of the facility and management practices.

In general, the types of impacts may be physical, biological, social and economic. Physical effects include land alteration, removal of vegetation, construction, emplacement of impermeable surfaces and discharge of wastewater. Biological effects include surface and ground water quality degradation, introduction of exotic species, and destruction of natural habitat. Social effects include use conflicts, competition for sites between aquaculturists and farmers or other users of rural lands, competition for water, market competition between fishermen and aquaculturists, drinking water contamination and possible nuisances, such as odors and increased traffic. Economic effects include the potential for losses due to project failure, or logistical problems in receiving inputs or transporting harvests and the lack of a labor force with experience and skills in aquaculture technology.

CNMI and Federal Government agencies will require Environmental permits for aquaculture projects. Permits which may be required include:

CNMI	Coastal Resources Management Permit Earthmoving Permit Underground Injection Control Permit Historic Site Permit
FEDERAL	National Pollutant Discharge Elimination System Permit Army Corps of Engineers (Dredge and Fill) Permit

Additionally, Applications for public land leases and Earthmoving Permits must be accompanied by an environmental assessment.

Government agencies, in arriving at permit decisions, attempt to identify and examine impacts of a project and determine the means to avoid or mitigate adverse affects.

The following Aquaculture Suitability Model will assist the aquaculturist in evaluating the effects of an aquaculture facility on the environment and its relationship with other human and natural uses.

ENVIRONMENTAL SUITABILITY OF AQUACULTURE

EXISTING LAND AND WATER USES	
Rural	2
Commercial	2
Light	2
Heavy	2
Resort	2
Historic	2
Scenic	2
Wilderness	1
Recreation	2
Institutional	2
Forestry	2
Tree Crops	2
Taro	2
Livestock	2
Fishing	2
Quarry/Dredge	1
VEGETATION	
Seagrass	2
Beach strand	2
Marsh	2
Secondary forest	2
Grassland	2
Primary forest	1
endangered/unique	1
ANIMAL	
Terrestrial	1
Marine	1
Endangered/unique	1
CLIMATE	
Storm waves	2
Prevailing wind	3
Salt spray	2

HYDROLOGY	
Spring/stream	3
Flood plain	2
Recharge	1
Watershed	1
Intertidal	3
Subtidal	3
Reservoir	1
SERVICES	
Water	5
Solid waste	5
Waste water	5
Seawall/brkwter	5
Road/channel	5
Airports	4
Harbor/dock	4
Walks/paths	5
Power	5
Fire	5
Police	5
Health	4
CONSEQUENCES	
Erosion	7
Flood	5
Drought	5
Sedimentation	5
Air pollution	5
Water pollution	7
Noise	8
Habitat loss	7
Resource loss	5
Alteration of unique quality	7

1: Probable Conflict
2: Possible Conflict
3. No Conflict
4. Mandatory
5: Site Determined
6: Unnecessary
7: Critical
8: Beneficial or No Effect

Excerpted from Suitability Model Matrix Prepared by Office of Planning and Statistics, Trust Territory of the Pacific Islands, circa 1979 (with modification).

SECTION 8
POTENTIAL SPECIES

In this section several species are discussed that have been cultured under conditions that exist in the Northern Marianas. The species reported herein are classified as fresh water and brackish water species, however, the discussion of freshwater species has been limited only to species which can tolerate higher salinities or broad fluctuations in salinity. Therefore, all reported species should be suitable for culture in waters of the CNMI, providing other conditions are acceptable.

The experiences of other Pacific islands, particularly Guam, with each of the species is also highlighted for the purposes of information transfer. For more detailed information, refer to A Review of Aquaculture Programs in the Pacific Islands Region prepared by the Pacific Islands Development Program of the East-West Center, 1984. This and other references were used in preparing this section.

Table 1 relates known water and soil parameters to the various fresh and brackish water species. Table II identifies habitat, growth and basic marketing considerations of selected species. Other considerations are discussed below.

Fresh Water Species

TILAPIA (SP.). The National Aquaculture Development Plan (1983) identifies tilapia as one of the most promising groups of cultured fishes in tropical countries. This species has a variety of feeding habits, but in general is an aggressive opportunistic feeder. They are currently being cultured on Guam, exhibiting rapid growth and reproductive rates, and good quality flesh. Tilapia are known to exist in Susupe Lake, thus concern over the introduction of this species should be minimal. Also, the Philippine, Taiwanese and Korean community and Japanese tourists may represent a good market due to their familiarity and acceptance of the species. *Orcohromis mossambicus* is found in Lake Susupe, Saipan.

Tilapia was introduced to Guam in 1954 and test cultured. This initial effort was unsuccessful. In 1974, the reddish-orange hybrid was introduced and experimentally cultured. It was initially considered to be of secondary importance, but by 1979, hybrid commercial culture was ongoing. The hybrid was marketed as 'cherry snapper' since tilapia had a poor market image. Experimental culture of monosex populations of tilapia was ongoing.

The introduction of tilapia into earthen ponds can be detrimental since they dig holes. Tilapia can also cause problems in polyculture operations because they are aggressive feeders and can out-compete more desirable species. It is reported that at the aquaculture center in Western Samoa, where they were raising milkfish and *Macrobrachium* in brackish water earthen race ways and ponds, inadvertently introduced tilapia destroyed the levees and gateway systems (CRM letter 2/14/85).

MACROBRACHIUM ROSENBERGII . The giant freshwater prawn or Malaysian prawn is endemic to the southeast Asia an Indo-Pacific area, with its furthest northeastward extent being to the Palau Islands. They grow best in warm tropical climates with temperatures between 15 and 25 degrees C and have a tolerance for 12-14% salinity (1200-1400 ppm). This species has been grown successfully in Guam, Honolulu and other parts of the region for several years. They are relatively free of disease, suitable for polyculture, have omnivorous feeding habits and their applicability to intensive or extensive culture make them desirable species. Proper shelter must be provided to avoid cannibalization during moulting. The lack of locally available post-larvae is the main constraint to the introduction of this species to the CNMI. As a luxury food, M. rosenbergii has a high market value. Another species, M. lar, is found in freshwater streams in Rota and Saipan.

In 1973, M. Rosenbergii, was identified as a primary species for culture consideration in Guam and was introduced by the Guam Government in 1974 from Hawaii. Production capability was 4,637 kg/ha/yr with a two-crop system. Production was achieved in a stagnant pond with turkey starter (28%) as feed.

In 1976, nearly 750,000 post-larvae prawns were stocked for culture. In 1977, the first harvest produced about 757 kg of prawns which were sold locally. In 1977, pond culture was emphasized. Expansion was limited because seed stock was obtained only when Hawaii had a surplus production of post-larvae. The construction of a hatchery was recommended.

The Guam Division of Aquatic and Wildlife Resources provided post-larvae to Guam prawn farmers at no cost except air freight charges. Hawaii placed a one million post-larvae quota on Guam, which was sufficient to stock about 5 hectares.

Palau and Taiwan were identified as alternative post-larval sources. Prawn post-larvae could be obtained from the Micronesian Mariculture Demonstration Center at Palau for about $20 per 1000 including freight (no longer available; (Crisostomo, 1985). Post-larvae from Taiwan would cost $32 per 1000 plus freight charges. The construction of a hatchery was again recommended.

The primary objective of the proposed hatchery was to establish a multi-species hatchery to produce commercial quantities of post-larval stages of M. rosenbergii to satisfy expected demand by commercial producers and to provide facilities for the development of aquaculture in Guam.

SPECIES SOIL CONDITION PARAMETERS

SPECIES	SOIL pH	AMMONIA	% ORGANICS	CALCIUM	IRON
Tilapia	6.6-7.5	Negligible	25-50%	n/a	n/a
Mullet	6.6-7.5	Negligible	25-50%	n/a	n/a
Penaeid Shrimp	6.6-7.5	Negligible	25-50%	n/a	n/a
Gracilaria	6.6-7.5	Negligible	25-50%	n/a	n/a
Mangrove Crab	6.6-7.5	Negligible	25-50%	n/a	n/a
Rabbitfish	6.6-7.5	Negligible	25-50%	n/a	n/a
Milkfish	6.6-7.5	Negligible	25-50%	n/a	n/a
Macrobrachium	6.6-7.5	Negligible	25-50%	n/a	n/a

SPECIES PHYSICAL AND CHEMICAL WATER PARAMETERS

SPECIES	DIS. OXYGEN	AMMONIA	NITRITE	TEMPERATURE	SALINITY	pH
Tilapia	>5.0 ppm	<2.0 ppm	<0.2 ppm	27 - 33.5	0 - 9 ppt	3.4 - 11
Mullet	>5.0 ppm	<2.0 ppm	<0.2 ppm	3 - 35	15 - 25 ppt	
Penaeid Shrimp	>5.0 ppm	<5.0 ppm	<100 ppm	12 - 34	5-25 ppt (P.mon) 16-34 ppt (P.jap)	7.0 - 8.6
Gracilaria	>5.0 ppm			20 - 25	8 - 25 ppt	6.0 - 9.0
Mangrove Crab				25 - 30	10 - 40 ppt	
Rabbitfish	>2.0 ppm	<2.0 ppm	<0.2 ppm	23 - 34	4 - 50 ppt	
Milkfish	>5.0 ppm	<2.0 ppm	<0.2 ppm	> 12	10 - 25 ppt	7.8 - 9.5
Macrobrachium	>5.0 ppm	<5.0 ppm	<100 ppm	25 - 30	0 - 4 ppt	7.0 - 8.0

In 1980 the Guam Legislature allocated $25,000 for the construction of a hatchery. The operation was a joint effort of the Marine Laboratory, the College of Agriculture and Life Sciences, and the Sea Grant Marine Advisory Program. The facility was constructed, but a number of technical and logistical problems prevented the operation from fulfilling projected productions. Problems included an inadequate fresh water supply due to rusty lines, rusty water and regular power failures which disrupted aeration. Also, farmers did not pay for fry, thus reducing operating capital (Crisostomo, 1985).

A private prawn hatchery was established in 1982. It was designed to provide seed for a planned 40.5 ha grow-out facility. The University of Guam and the Guam Department of Commerce provided technical assistance. The production was minimal and consequently forced its closure after six months due to economic infeasibility (Crisostomo, 1985).

By 1982, of the 17.8 ha of commercial ponds in operation in Guam, 10.9 were used in prawn culture. (PIDP)

ANGUILLA JAPONICA . The freshwater eel *A. japonica* is catadromous with the migration of mature eels to the sea for spawning and the return of the elvers to rivers. It is at this point that the elvers are captured and held before stocking in grow out ponds. All pond culture is dependent on the capture of wild stock. The source of juveniles include China, Korea, Taiwan and Japan, although these countries experience shortfalls for their own requirements. Other species may be substituted, including *A. australis* , *A. anguilla* and *A.rostrata* however, their demand is less due to their smaller size and tougher skin. The main market is Japan. *Anguilla sp* is reported in Rota's Babao Stream.

In 1973, the freshwater eel, *Angulla japonica,* was identified as a secondary species to be considered for culture on Guam. The eel was introduced by the Government of Guam from Taiwan. Based on early work in Guam the eel was most promising. Growth was rapid under warm water conditions, with harvestable sizes obtained in four months.

In 1973, the Government operated a freshwater experimental fish farm, with one of two ponds devoted to raising eels, milkfish, and tilapia. Freshwater eel, *A. japonica,* had the potential of contributing significantly to the export of total aquaculture products. About 80 mt of eel were exported to Japan annually.
By 1977, results of trial culture of *A. japonica* indicated good growth rates, however, the project was discontinued because of the difficulty in obtaining elvers.

In 1977, freshwater eels were commercially raised on Guam. A private venture received its first stocking of baby eels in April 1977. Also that year, the eel, *A. rostrata,* was introduced to Guam from South Carolina by the same firm.

The facilities for commercial culture included four concrete walled ponds. the total area was 2 ha, with an additional 12 ponds planned. The facility was eventually to produce 90.1 mt/year with seed imported from Taiwan. In 1978, the first 1.8 mt of eels was shipped to Japan.

In 1978, A. japonica elver supply from Hong Kong was inadequate. A. rostrata was imported from South Carolina to fill the supply. However, production was poor and its market acceptability in Japan was poor in comparison with A. japonica. The poor growth rate was attributed to its lower temperature tolerance and to its higher susceptibility to disease.

In 1979, eel culture was conducted on a small scale. There were two private operations culturing eels with about 5 ha of ponds. The local market was small so most were shipped live to Japan. Elvers of A. japonica originated in mainland China and were shipped to Guam via Hong Kong. Some were grown for one month on Guam then shipped to Taiwan as a product of Guam. The others were grown to market size in Guam.

Major existing aquaculture activities in Guam included eel culture at the pilot/commercial level for local and export food.

By 1982, one private operator had a 5.0 ha facility in operation on the Agfayan River. Their primary crop was eel imported as elvers from mainland China. The production in 1981 was about 60,000 kg (12.3 mt), 98 percent of which was shipped to Japan. By 1982, production of eels was terminated because of scarcity of elvers and competition by Asian countries (Crisostomo, 1985).

PANGASIUS SUTCHI . The southeast Asian catfish P. sutchi is generally grown as a monoculture, but polyculture can be used with suitable species. They live in rivers, and lakes, and can be raised in ponds or cages. They will not reproduce in ponds since they require moving water for reproduction to occur. This fish has good potential because of its high production per unit area (75,000-95,000 kg/year/ha) (FitzGerald). However, they require a 20% or more protein feedstock and have a high feeding rate per day. Juveniles must be obtained from the wild.

In 1975, the Government of Guam introduced the Southeast Asian catfish, Pangasius sutchi, to Guam from Thailand as brood stock. Initial culture experiments by the Division of Aquatic and Wildlife Resources had unfavorable results that were attributed to improper diet and competition for food with tilapia in polyculture.

In 1979, when the government was considering the multi-species hatchery, one of the secondary species targeted was P. sutchi, which was considered superior to the channel catfish Ictalurus punctatus for culture in tropical areas.

CLARIAS . C.batrachus, C. macrocephalus , and C. fucus are other southeast Asian catfish with high productivity per unit area (80,000-90,000 kg/year/ha). They are easily bred in captivity, of hardy nature, and feed on a wide variety of vegetable and animal matter. The species has an accessory organ for breathing air which permits it to exist in oxygen poor ponds and to leave in search of food which requires precautions in the pond design. It burrows into the mud to survive extensive dry periods which limits the alterability of species to those which will not become prey of the catfish (e.g. prawns).

CHINESE CARP. These fish are mainly recommended as a secondary species to increase overall productivity by more fully utilizing the three dimensional space of the pond, and help maintain a balanced pond environment. Grass carp are herbivores which help to control grasses and aquatic vegetation; silver carp feed on phytoplankton; bighead carp are carnivores feeding on zooplankton; common carp feed on detritus and snail carp feed on live molluscs.

In 1973, the grass carp Ctenopharyngodon idellus, and other carp were selected as having culture potential in Guam. In 1974, the Government of Guam introduced from Taiwan bighead carp, grass carp, silver carp and common carp. Stocks were obtained from Taiwan, but could be artificially bred in Guam once breeding stocks were established. Artificial stocks were, however, never artificially bred (Crisostomo, 1985).

Carp was also a secondary species of the proposed multi-species hatchery. In 1979, the majority of the prawn ponds were managed as polyculture systems with several species of chinese carp cultured as secondary species.

Marketing of alternative species such as carp would be limited to a local market because of its low price. Export markets could not be accessed economically. The Guam Department of Agriculture planned to propogate Chinese carp for local aquaculturists wanting to culture them. In 1982 the Deparment of Agriculture was constructing an experimental hatchery for carp, catfish, and tilapia. The hatchery is complete except for an activated charcoal filter which when installed will permit operation to commence (Crisostomo, 1985).

By 1982, the major aquaculture activities for Guam included tilapia and Chinese carp cultured as a demonstration project to provide local food. (PIDP)

SOFT SHELL TURTLE. The soft shell turtle (Trionyxz sinensis) is a high priced item that is considered a delicacy in Taiwan and Japan. Its culture is carried out in ponds with concrete or stone walls with an overhang to prevent escape. It feeds mainly on trash fish and animal products. Growth of the turtle normally takes approximately two years before it reaches a harvestable size (600 g); however, this growth period could be reduced to about one year due to favorable climatic conditions of the Marianas (FitzGerald). This is a rather limited culture for a special market.

In 1977, a T. sinensis culture project was initiated by a private entrepreneur. The project failed because the enclosure did not prevent escape. A second individual later attempted turtle culture with facilities which included three concrete tanks, an egg incubation house, and a well. Carp and tilapia were also cultured as secondary species. Marketing was aimed at Taiwan.

In 1978 another pond operator was engaged in turtle culture for export to Hawaii and the west coast United States. Small scale local farmers also cultured the species. Size segregation was used to prevent cannibalism. Brood stock was developed and achieved on a diet of trash fish.

Turtles were marketed in Hawaii, and potential markets on the U.S. west coast and in Japan and Taiwan were being examined. The Taiwan market preferred 500 to 600 g turtles, while the Japanese preferred 600 to 700 g turtles.

BAIT FISH. A key factor in the development of skipjack tuna fisheries in this area of the Pacific would be a suitable supply of bait fish. A number of species have been considered and used as bait fish including Orcochromis mossambica, Dorosoma petenense, Poecilia vittata, P.mexicana, Sardinell melanura, Engraulus japonicus, Chanos chanos, Kuhlia sandviciensis, mullet, and cyprinids (FitzGerald).

Important factors influencing the selection of suitable bait fish species are: to be prolific, continuous breeding, gregarious, of good growth rate, hardy (both in culture and during holding in bait wells), show suitable behavior, size, color and shape to attract tuna, and be attractive to fishermen. Poecilia mexicana is widely reported as the best species for culture and bait applications (CRM letter 2/14/85).

Fishing trials in 1977 resulted in catch rates of 0.89 fish/hook minute, compared with 0.58 fish/hook minute obtained in American Samoa. Mollies were superior bait when rough weather caused high mortality with natural bait, when tuna concentrations were found more than 80 km from shore, or when natural bait was limited (Bryan).

In 1983, an economic feasibility study was done on culturing molly for skipjack tuna bait in Hawaii, American Samoa, Guam, and the Northern Marianas. Molly culture was considered economically feasible (Schug and Shang 1984).

In Palau, two baitfish hatchery tanks were constructed with Sea Grant funds at the Micronesian Mariculture Demonstration Center (MMDC) to supply P. vittata for the pole and line fishery as the natural supply could support only 15 Okinawa-style fishing boats. Three additional grow-out ponds and a baitfish hatchery tank were provided by the Trust Territory government.

Hatchery production was 2,000 to 4,000 fry/day. Fish were transferred to grow-out ponds fertilized with chicken manure. Bait size was reached in three to four months. Growth on natural foods (mosquito larvae and chironomid larvae) was equivalent to growth rates obtained using pelleted foods.

The culture of the topminnow, Poecilia sp. was discontinued at the MMDC in Palau. Although the technical feasibility of culturing topminnows was demonstrated, natural baitfish were abundant in the lagoon and local tuna boats were not receptive to the idea of an unfamiliar species of baitfish. In addition, the pole and line tuna fishery in Palau was defunct.

AQUATIC ALGAE. Aquatic algae are among the most diverse members of the plant kingdom. They occur in a wide range of shapes and sizes, from microscopic single-celled species, such as Spirulina , to the giant kelp, Macrocystis which can attain a length of 140 feet. Algae are classified into four groups on the basis of pigmentation: greens (chlorophyceae), blue-greens (cyanophyceae), reds (Rhodophyceae) and browns (Phaeophyceae). Green and blue-green algae, while present in saltwater, are more commonly associated with freshwater. Red and brown algae, which are the most economically important, are found almost exclusively in marine environments. Browns are particularly abundant in cold northern waters, although a few species are found in the tropics. Red are numerous at all latitudes. Spirulina (blue-green) which is produced by a CNMI Energy Office demonstration project, and Gracilaria (red) may be of particular application in the CNMI.

Algae culture can contribute to low cost feed production for livestock; the recovery of waste nutrients from human and animal wastes through conversion into salable product; the recovery of waste water from industrial, agricultural or aquacultural operations while producing a salable product; and the production of less expensive forms of energy through anaerobic digestion and distillation. A local market for animal feed may exist in the CNMI and a high value export market for human food grade Spirulina exists in the United States.

The intensive commercial culture of single-celled freshwater algae, particularly Chlorella spp. and Sprirulina spp. is practiced in similar fashion in macroalgae cultivation in various places around the world with productivity averaging 160 mt/ha/yr. The Commonwealth Energy Office is culturing Spirulina on a small-scale basis, however production records and forecasts are not available. A pilot plant in Mexico reportedly produces .91 mt wet weight of fresh algae per day. The State of Hawaii is supporting a small-scale preliminary feasibility study to investigate the potential for Spirulina culture which indicated that by using livestock waste as a fertilizer, production could be between 11-16 mt/ha/yr. Under suitable conditions, these algae may be comprised of as much as 50 to 60 percent protein. Although Chlorella has possibilities as a food supplement, there remain the questions of poor digestibility and palatability. Chlorella is cultured extensively in Japan and Taiwan.

The culture of seaweed as a food product has been limited primarily to the Orient (Bardach, 1972), however they have other uses in western industry. One such group of algae is the red alga Gracilaria , an important source of agar. It is interesting to note also that Gracilaria is often used in polyculture ventures in Taiwan in conjunction with milkfish and penaeids (Chen,1976). One species, Gracilaria lichenoides , found only on Saipan, was found to be of the highest quality with respect to gel strengths of agar extracts when compared to species from Guam and Taiwan (Nelson et al., 1982; Nelson et al., 1983). In polyculture with milkfish, Gracilaria provides a substrate for epiphytic, blue-green and green algae that provide food in their early growth stages, however, the fish must be harvested before they become big enough to actually eat the algae itself.

In American Samoa, it was suggested that water hyacinths, or the algae Spirulina sp. be cultured in the wastewater reclamation program. Water hyacinths could produce methane gas or be used as hog or cattle feed. Spirulina could also be used as feed. The main benefit of this system would be clean freshwater that would be available for irrigation or for further treatment to the potable stage (Shleser and May).

Gracilaria from the CNMI could serve a gourmet market in Japan and Hawaii, and perhaps a limited market in Guam. The species thrives in oceanic waters better than brackish waters. (personal communication R. Lujan)

Brackish Water Species

MULLET. The mullet (Mugil cephalus) is another promising species for tropical aquaculture development. They have high-quality flesh, exhibit extreme tolerance to salinity and temperature and feed at a low trophic level. Some species of mullet are locally available; these being Chelon engeli , Crenimugil crenilabis, Liza vagiensis and Neomyxus leuciscus (Amesbury and Myers, 1982). However these species are smaller and slower growing than Mugil cephalus . Unless a reliable source of Mugil cephalus fry is located, local species would have to be utilized. This could prove feasible, however, in a polyculture system by virtue of their low position on the food chain, feeding on plankton, benthic algae and decaying higher plants and low density requirements.

For Guam, mullet culture was recommended as a secondary species to fill the niche not occupied by the primary cultured species (Fitzgerald 1977).

In Palau, three species (milkfish, grey mullet, and tilapia) were recommended for culture in brackish water ponds. Wild mullet stocks appeared to be inadequate as a source of stock for commercial fishponds. Despite this finding, the development of mullet culture was recommended. There is presently no active research program at the MMDC.

In the Cook Islands, a minimum of 12 months was required to demonstrate production growth rates for mullet, starting with 12.7 to 15.2 cm fingerlings. Experiments suffered from (unspecified) logistical and support problems.

In Fiji, mullets were found to grow well in brackish water ponds.

MILKFISH. The milkfish (Chanos chanos) is one of the fishes best suited for culture in brackish water ponds. This species is very euryhaline, disease resistant, a high quality food fish with a rapid growth rate. It feeds near the bottom of the food chain, mostly on algae such that fairly dense populations can be maintained in restricted areas (Bardach, 1972). They are remarkably free of disease and parasites, none of which are considered pathogenic. This species has been successfully raised in polyculture with mullet, penaeid shrimp and Gracilaria (Bardach, 1972).

At the present, the majority of stock must be caught from the wild although some are available from hatcheries. The closest possible supply of fry at present is Palau or Yap; however, their runs are too unpredictable in quantity and time to be a dependable source and there is no organized commercial harvest. Milkfish are the single most important species imported to Guam (including as fry) and perhaps the CNMI from the Philippines (62.7 mt in 1981) and retail for $4.60 to $6.14 per kg (Meyers et al., 1983). The Guam market would be a possible outlet for cultured milkfish from the Northern Marianas in addition to the local market.

In 1973, milkfish, Chanos chanos, was identified as having culture potential in Guam. In 1974, the milkfish was introduced to Guam from the Philippines by the government of Guam. Freshwater culture was done on a small scale by the Division of Aquatic and Wildlife Resources.

The closest sources of milkfish fry were Palau and Yap. As in Guam, fry runs in Palau and Yap were to unpredictable in quantity and time to be a dependable fry source. The Philippines, the major area of milkfish fry runs, enforced a moratorium on milkfish fry export.

In 1978, pond operators faced a scarcity of milkfish fry. That year it was reported that the Philippines, the only source of milkfish fry, banned their export. This was done in order to corner the market on this highly developable species.

In 1980, the Government of Guam operated a freshwater experimental fish farm with one of two ponds devoted to raising eels, milkfish, and tilapia.

PENAEID SHRIMP. Penaeid shrimp are perhaps the most readily marketable of all species. A number of penaeid species are suitable for culture, however, Penaeus monodon and P. japonica would probably be the most desired (FitzGerald). The species are generally hardy and can tolerate a wide range of temperature and salinity conditions provided that changes occur gradually (Yap et al., 1979). Penaeid culture is usually carried out in tidal ponds for maximum water circulation. Utilization of pumps would be necessary to ensure proper

circulation in non-tidal ponds. As a luxury food, penaeids have a high market value. The expense involved in obtaining gravid females and the subsequent rearing through larval and post larval stages may make them difficult to market in the Northern Marianas. The local market should be able to utilize the product, and Guam may be able to absorb any commercially produced penaeids. One shrimp species, Palaemon debilis, is found in Lake Susupe, Saipan.

In 1973, the "sugpo" shrimp, P. monodon was identified as having culture potential in Guam due to its fast growth rate and large size. P.japonica is desired because of its growth rate and the preference of the Japanese market for this species (Crisostomo, 1985).

A feasibility study conducted in 1979 found that the marine shrimp appeared to have potential on Guam, but development was limited by lack of local brood stock sources and limited land suitable for marine shrimp farming. Pilot-scale hatchery and grow-out testing of this group using imported brood stock was recommended. Small scale local farmers cultured P. monodon at one time. P. merguiensis was also cultured on Guam at one time as a demonstration. There is currently no penaeid culture on Guam, due to lack of stocking material (Crisostomo, 1985).

Another species, which has been experimented with by a private research group on Guam is P. vannamel. It is recommended for its good growth rate and tolerance to salinity and water quality (Crisostomo, 1985).

In Palau, the MMDC was planning to develop the culture of P. monodon which occúrred in Palauan waters. The MMDC was concentrating its efforts on culture of P. monodon and other key species. The MMDC successfully spawned and raised key species to include saltwater shrimp to supplement the production of inshore species utilized by local people and to promote culture of species of high commercial value for export. Sporadic efforts to raise P. monodon were not successful and were terminated in 1975. By 1983 there was no active P. monodon program at the MMDC.

In American Samoa, shrimp culture was considered possible (Shleser and May 1977). Factors including artificial spawning problems, land, expensive feeds, and a small local market may limit this possibility. Shrimp culture was considered a very marginal activity at best. Penaeid shrimp were cultured in conjunction with rabbit fish and topminnow. This was done as a side activity of the baitfish culture project.

RABBITFISH. Rabbitfish (Siganidae) are important foodfish throughout the Western Pacific. The juveniles are especially sought after as a delicacy, with whole villages participating in harvests of annual runs. The adult rabbitfish is also a desired food item, however, it is felt by some local fishermen that it is not as common as it once was. Tsuda et al. (1976) analyzed the possibility of culturing the species Siganus argenteus . It also withstands large fluctuations in temperature and salinity. It was shown to be able to exist on the green alga Enteromorpha clathrata , although growth rates were better

when supplemented with commercial feed. Despite the apparent advantages, it is not recommended that rabbitfish culture be actively pursued at this time, because of the yearly fluctuation in juveniles appearing on the reef. If induced spawning and larval rearing techniques become routine, it may be possible to rear Siganids to the juvenile stage (the preferred food fish stage) and obtain several crops per year; at the same time alleviating the current fishing pressure on the species in the wild.

In 1973, Guam identified the rabbitfish, Siganus spp., as having culture potential in Guam. Investigations on the feasibility of rearing Siganus in Guam waters indicated that of the two species with schooling behavior on Guam, S. argenteus had a better growth rate than S. spinus. By supplementing the diets of these herbivorous fishes, higher growth rates could be realized. However, trout chow was too expensive to be used as a food supplement. Until an inexpensive supplement was found, the culture of Siganus would not be economically feasible.

The culture potential of S. argenteus on Guam was encouraging (Tobias 1976) (apparently on the basis of the tolerance of this fish to environmental parameters and its faster rate of growth). Major disadvantages had to be overcome prior to successful culture of this fish. One disadvantage was fluctuation in the wild stock, which necessitated development of routine spawning and rearing techniques. Experimental spawning had been successful in Tahiti. Another area was the identification of a low-cost, high-protein feed supplement.

Juvenile siganids had a higher market value than adults and thus should be considered the final market product. In addition, juveniles could be used as a baitfish.

MANGROVE CRAB. The mangrove crab (Scylla serrata) has long been an incidental product of brackish water pond culture in southeast Asia, flourishing with no management whatsoever (Bardach, 1972). Though no longer common in the Northern Marianas, fry can still be obtained from the Philippines. Its desirability as a cultured species in the Northern Marianas is further enhanced by its being already established as a favorite food item. The biological aspects of the species are, however, not well known and cultivation techniques are as yet poor and undeveloped (Lavina,1980). The economic production of mangrove crabs is very difficult because of their tendency to walk away from ponds, aggressiveness and low production capability per unit area. Scylla serrata is, therefore not highly recommended as a potential aquaculture species.

In 1975, the government of Guam introduced the mangrove crab from Taiwan. The Division of Aquatic and Wildlife Resources and a commercial pond operator attempted an unsuccessful small-scale mangrove crab culture trial. The crab had a high market value but low production per unit area, thus its commercial culture was unlikely in Guam.

Scylla serrata was identified by the American Samoan government as a possible aquaculture species. This crab was aggressive, cannibalistic, and carnivorous; thus successful culture was doubtful.

SPECIES HABITAT, FEED AND GROWTH CONSIDERATIONS

SPECIES	FEED HABIT	HARVEST WEIGHT	KG/HA/YR (1)	GROW-OUT TIME (2)	GROWTH
Milkfish	Herbivore	1+ lb.	5000-10000	6-10 vs 4-6	Uniform
Macrobrachium	Omnivore	10-20/lb.	2000-4000	7-10 vs 4-8	Variable
Mullet	Herbivore	1 lb.	100-300	6-10 vs 5-7	Uniform
Penaeid Shrimp	Omnivore	5-20/lb.	600-5000	6-8 vs 3-6	Uniform
Tilapia	Omnivore	.75 lb.	1000-8000	6-8 vs 3-6	Uniform
Gracilaria				4-8	Uniform

1. Kilograms per hectare per year. Range represents production for low trophic and for commercial feed.
2. Range represents months of growout time for low trophic feed and for commercial feed.

SECTION 9
CONCLUSIONS AND RECOMMENDATIONS

This report is oriented toward the low technology, low cost type of commercial facility rather than the more capital intensive facilities. This type of operation is believed to be a more practical application which is in reach of potential CNMI aquaculturists given the CNMI water, soil and infrastructure resources and possible labor and market conditions (which have not been studied). Thus the low technology facility is the one most likely to be developed by the local private sector and receive the support of the government.

As a result of this bias, the sites which were ranked below average were not dropped from consideration and hence from this report because the lesser ranked sites may be suitable for the more advanced facilities using intensive methods of culture. Such facilities utilize fabricated enclosures and concentrate on high market value export species. Thus they may be sufficiently capitalized and profitable to make a higher investment in order to make use of sites which are less suitable for low technology operations. Intensive facilities can, of course, take advantage of the better locations which are unused and would be wise to do so.

There are also portions of each site which may be less desirable or more desirable than other portions within the same general site. The selection of the actual location for a development cannot be made by a preliminary feasibility study such as this one, and the actual site parameters must be identified by the developer who must then conduct full site investigations to ensure that actual conditions are suitable for a profitable operation.

Of all lands and inland aquatic waters considered, nineteen specific locations were identified which were judged to have some degree of aquaculture potential ranging from above average to poor. The total area of potentially suitable land in the Northern Mariana Islands of Saipan, Tinian and Rota was 14.06 square kilometers. An additional 27.4 square kilometers has marginal to poor aquaculture potential.

On the basis of this study, it has been determined that commercial scale aquaculture in the Commonwealth of the Northern Mariana Islands is technically feasible at a limited number of locations, particularly on Saipan and to a lesser extent on Tinian. Rota does not have suitable characteristics for aquaculture at the present time.

CNMI Conditions

Saipan offers the best group of locations for extensive aquaculture facilities. This is primarily due to its relatively larger size, favorable topography, lower elevations, better distribution of infrastructure, presence of clay soils, and more surface waters. Five sites were rated highly and comprised an area of 4.43 square kilometers. Three sites were considered marginal and had an area of 2.38 square kilometers. Opportunities for aquaculture development are considered fair to good.

Tinian sites as a group are ranked second, primarily because of infrastructure limitations and military land tenure. Ground water resources are considered favorable. One site ranked highly and comprised an area of 4.25 square kilometers. One other site with an area of 0.9 square kilometers was considered marginal. The opportunity for commercial aquaculture development is considered marginal. However, the apparent availability of developable ground water, low elevations and clay soils may balance out the problems, particularly if permission can be obtained for leasebacks of military land.

Rota is hampered by limestone soils, higher elevation of flat lands, rugged topography and poor distribution of infrastructure. All four Rota sites, comprising a total area of 12.3 square kilometers, were ranked low. Opportunities for commercial aquaculture are considered poor. One mitigating factor would be the potential ease and inexpense of reaching Guam markets by sea from nearby Rota. Larger, higher market facilities whose revenues can justify higher development costs necessary to overcome the constraints may be possible.

Constraints to Aquaculture Development

The development of an aquaculture industry in the CNMI is faced with many constraints. The major constraint identified by this study is the uncertainty of a sufficient and reliable water supply. The lack of significant rivers, streams and other surface waters requires aquaculture to depend upon ground water sources.

The apparent solution to this problem would be to tap brackish ground water which is relatively plentiful in many locations or to redevelop potable supplies such as those developed by the United States military forces to supply their troops and which were subsequently abandoned for various reasons. Thus the aquaculturists will find it necessary to drill new wells or, depending upon the location and condition, to renovate the military era sources. This will be costly, however, at the lower elevations development costs should be reasonable and cost-efficient.

The quality of water, particularly with respect to salinity, effectively limits the range of species which can be cultured to brackish water species. In a few locations, it may be possible to newly tap a high quality aquifer, however, it would be advisable to reserve the use of high quality waters for human consumption. Similarly, where military era wells tapped aquifers which are now sources for the present potable supply, the potential developer should carefully consider the impact of the facility upon the potable supply and the subsequent community impact. The impact of the public water supply operation on the aquaculture facility must also be considered.

Another constraint is the scarcity of organized baseline chemical, physical and biological data. This is attributable to the early stage of development of the CNMI and the lack of emphasis placed on scientific and statistical data. This situation makes the task of data collection and evaluation difficult which in turn limits the practicability of making an accurate assessment of the technical feasibility of aquaculture. The lack of information also makes it more difficult for the potential aquaculturist to make informed choices as to site and species suitability. The added expense of original data collection which must then be borne by the developer affect the profitability of a project.

This report has endeavored to correlate the available data to the various sites, not only to evidence the technical rationale for the selection of individual sites, but to serve as a data base for potential aquaculturists. This will inform them of the extent of the data which are available, and the data which is not available and which must be obtained. The sites were identified by this report on the basis of the best available information. Obviously, it will be wise for the potential aquaculturists to conduct one's own site specific investigations before making actual development decisions.

The lack of knowledgeable and experienced individuals, businesses and government policy in the area of aquaculture also impedes the introduction and growth of aquaculture in the Northern Marianas. At the time of this study a government aquaculture policy had not been formulated, and there were no aquaculture facilities in operation. One project ,however, was known to be in an advanced stage of planning. For the present, the potential aquaculturist will find it necessary to rely on the expertise and experience of other countries, states and territories, universities and institutes, and private consultants. The resource center nearest to the Northern Marianas is Guam whose government and university has an active aquaculture development program and which along with private facilities have over a decade of experience in private and government operations. The University of Guam Aquaculture Extension Agent is particularly knowledgeable and experienced. Such extension services are available to the private and government sectors of the CNMI and should be utilized.

Another problem is the uncertainty over the sources, availability, quantity and reliability of supplies of stock. This is not unique to the CNMI, however, it is in part a function of the lack of a government program and the lack of private aquaculture operations. Even in locations where aquaculture is well advanced, individual ventures and in fact entire industries have failed because of supply shortfalls in the source country or intense competition and resultant higher costs among the industries supplied. This makes the CNMI situation more precarious as it (if it) embarks toward aquaculture development without the benefit of a support system. The relatively remote location of the CNMI may make the problem more difficult. With careful research and planning, and firm assurances of a reliable supply, it should be possible to overcome the lack of support programs.

Existing air cargo service should be adequate, particularly for Saipan, to ensure regular supply shipments (and as necessary, regular product export). Depending upon the hardiness of the species and the proximity of the source location, it may also be possible to receive supplies by ocean cargo at considerably less expense than air cargo. For the most part, brood stock must be obtained from Taiwan, the Philippines, Japan and the United States. It may also be possible to obtain some stock from Guam. For some species such as Tilapia, mullet and rabbitfish, it may even be possible to obtain wild stocks locally.

Uncertainties over economic and market conditions in the CNMI and the potential to serve export markets also constrain the introduction of aquaculture. There has been little or no research conducted to gauge local and foreign markets, if any, which may exist for various species which can be cultured under conditions found in the CNMI. This will not prevent well-financed developers from determining such information, but it will certainly discourage less well-financed operations as may be more likely to originate from the CNMI.

Recommendations

After review of the literature, and conditions in the CNMI it would appear warranted to establish an aquaculture development program in the CNMI. In general, such a program should be designed to encourage the local private sector to implement appropriate aquaculture operations. The government should also consider the advantages and disadvantages of the introduction of higher technology operations. Such an operation, if participating in the local market, may out compete smaller operations and discourage the initiation of new local ventures. Conversely, in some locations, such higher technology facilities may be the only feasible aquaculture venture.

An aquaculture program should collect and disseminate technical information; provide extension services; conduct market studies and market development programs (e.g. publicize recipes, local produce, etc.); maintain brood stock, feed and other inputs which are not locally available; establish demonstration facilities in a joint venture with a private business or through a turnkey arrangement whereby the government develops one or more facilities then hands it over to a private operator in return for some form of renumeration such as lease payment or an agreement to collect and report data; prepare standard facility designs for various species; and develop package loan programs in cooperation with private and governmental financial institutions for rapid spin-off of demonstration facilities into private commercial facilities.

Short of a comprehensive program, an effort should be made to conduct complete soil and water analyses for each site with apparent potential. For water, the most urgent data needed includes the determination of the levels of ammonia, phosphate, nitrite, alkalinity and dissolved oxygen. For soils, the most urgent data needs include the levels of pH, ammonia nitrogen, nitrate nitrogen, percent organics and soil composition.

Additional Studies Recommended

Two additional research projects are recommended. A study should be conducted to determine if the species and conditions which were found to be technically feasible in this study are economically feasible. The study should examine development and operation costs for various types of facilities and species, revenues, local and export markets, alternate land uses, capitalization requirements, funding sources, institutional requirements and related matters.

Second, the technical and economic feasibility of mariculture should be determined. Such a report would identify suitable coastal locations, mariculture facilities and marine species for culture and serve as a companion volume to this report.

SECTION 10

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REVISED NUMBERING SYSTEM

SAIPAN WATER WELLS

Effective Date: 3/1/85

WELL FIELD	OLD NO.	NEW NO.	CHANGE TO
Isley Field	101	10-01	
	102	10-02	
	103	10-03	
	104	10-04	
	105	10-05	
	106	10-06	
	107	10-07	
	108	10-08	
	109	10-09	
	201	10-10	
	202	10-11	
Kobler Field	9	11-09	
	10	11-10	
	11	11-11	
	15	11-15	
	16	11-16	
	17	11-17	
	111	11-21	11-01
	116	11-26	11-06
	Maui I	11-99	
Agag Field	TH10	12-01	12-10
	50	12-02	12-50
	70	12-03	12-70
	73	12-04	12-73
	74	12-05	12-74
	75	12-06	12-75
	121	12-07	12-01
Kagman	76	13-01	13-76
	131	13-02	13-01
	Agri.	13-03	
Maui IV Field	141	14-01	
	142	14-02	
	143	14-03	
	144	14-04	
	145	14-05	
	146	14-06	
	147	14-07	
	Maui IV	14-99	
Gualo Rai	151	15-01	
	154	15-04	

WELL FIELD	OLD NO.	NEW NO.	CHANGE TO
Puerto Rico	162	16-02	
	163	16-03	
	164	16-04	
Marpi	171	17-01	
	172	17-02	
Sablan Quarry	148	18-01	18-48
	149	18-02	18-49
	150	18-03	18-50
	4X	18-04	
	5X	18-05	
	6X	18-06	
	7X	18-07	
	8X	18-08	
	9X	18-09	
Calhoun	1X	19-01	
	2X	19002	
DanDan/	6	20-01	20-06
San Vicente	7	20-02	20-07
	3	20-03	
	S.V. Well	20-04	

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