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WATER SUPPLY AND DEMAND PROBLEMS IN RAPIDLY GROWING SMALL ISLANDS

Nobuya Miwa

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PREFACE

This report reflects the conditions in Saipan as interpreted by Dr. Nobuya Miwa from ta and information he collected in field surveys and interviews conducted in 1989. The ntents have been minimally edited to preserve as much as possible his original expressions as not to alter his intended meanings, which are at times subtle and not obvious. He has en allowed wide latitude in the presentation of his data, such as when he chooses to express loride concentration in different units of measure (ppm and mg/l).

Hiroshi Yamauchi, Ph.D.
Principal Investigator

ABSTRACT

Water resources management is one of the key issues that affect the long-term stainability of economic development and growth of small island communities. To gain rspective on this issue for Saipan, the basic water supply and demand conditions were amined with reference to comparable conditions on O'ahu and Okinawa. Water balance flow arts were designed for this purpose. Limited storage capacity and deteriorating water quality Saipan are major constraints in the potential for expanding water supplies for the future. The ng-term potential for a water-blending strategy under a unified management system to offset ese physical constraints depends on a more comprehensive institutional strategy for water sources management. In order to satisfy the necessary conditions for sustainable economic owth, a diversified strategy of direct and indirect tools of control needs to be designed and forced to secure a safe minimum standard of water conservation for Saipan.

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INTRODUCTION

Understanding the water resources of small islands provides insight into the actual nditions for economic development. An important characteristic of the water resources of a nall island is the limited supply and flow. How to manage such limited resources is a key ctor in maintaining economic activities on an island. If the water resources are exhausted, ture development on an island cannot be expected. Sustainability is an important issue of pidly growing small-island economies.

One effective solution to overcoming the problem of limited water resources is to velop a new supply augmenting engineering techniques. But this is not always sufficient. ow to manage and control water supply and demand are also key factors in making island sources sustainable. Various direct and indirect tools of water conservation are necessary ch as rules and regulations, standards, user changes, and subsidies and other fiscal devices.

To understand the characteristics of island water resources, this study compares flow arts on the water balance (i.e., the transfer of water based on supply and demand) of the ands of Okinawa, Saipan, and O'ahu. Groundwater management of Saipan is then dis-ssed to allow us to further understand water resource management on small islands.

ISLAND WATER CONDITIONS

General Features of Three Islands

Okinawa, Saipan, and O'ahu are experiencing rapid economic growth caused mainly by e expansion of tourism. As shown in Figure 1, these islands are in the tropical and btropical Pacific Ocean. Okinawa, the main island of Okinawa Prefecture, is in the middle the Ryukyu Islands, which lie between the mainland of Japan and Taiwan. Saipan is at the uthern end of the Commonwealth of the Northern Mariana Islands (CNMI), which is utheast of Japan. The Hawaiian island of O'ahu is in the middle of the Pacific, 5° south of cinawa; Saipan is 5° south of O'ahu. From Tokyo, it is about 6 200 km to O'ahu, 2 400 km Saipan, and 1 700 km to Okinawa.

Figures 2 and 3 are maps of Okinawa and Saipan, respectively. The land area of O'ahu 1 574 km^2, its highest point is Mt. Ka'ala at 1 225 m, and the population is 903,000. cinawa is elongated from north to south, and its northern area is mountainous, the highest int being Mt. Yonaha at the 498-m elevation. Its area is 1 192 km^2, which is slightly naller than O'ahu. The population is similar in size to O'ahu, about 1.1 million in 1988. ost people live in the flat, central, and southern areas. The area of Saipan is almost one-nth of the other two islands; its highest point is Mt. Takpochao at the 473-m elevation.

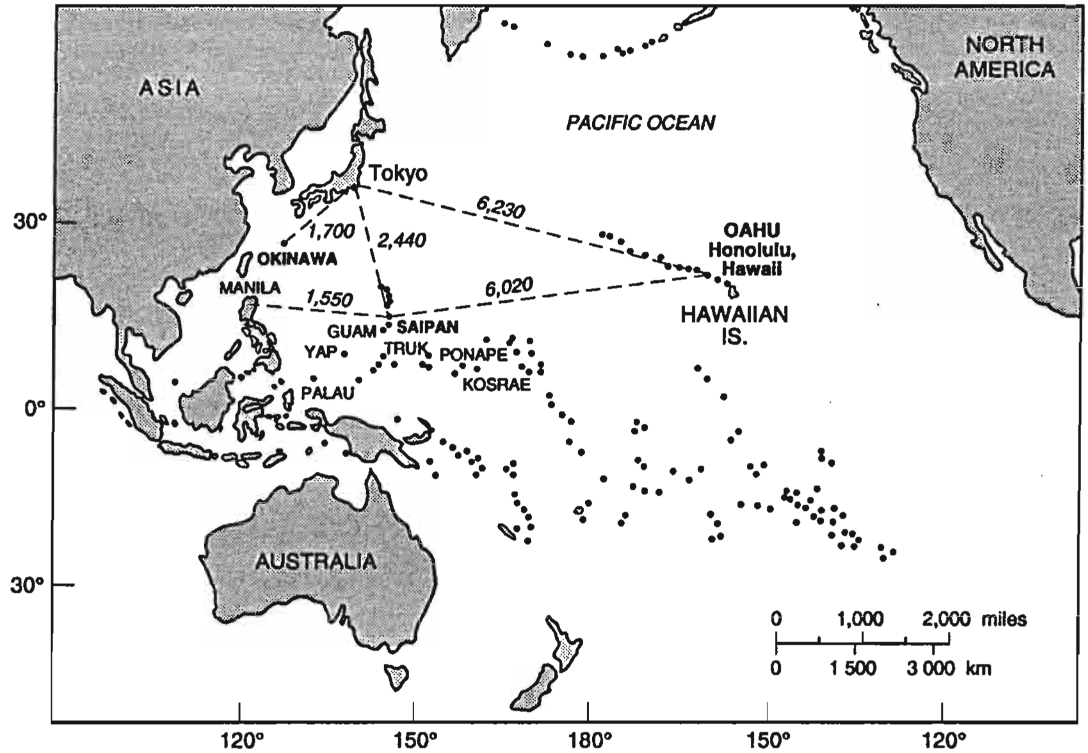


Figure 1. Location of islands of Okinawa, Saipan, and O'ahu

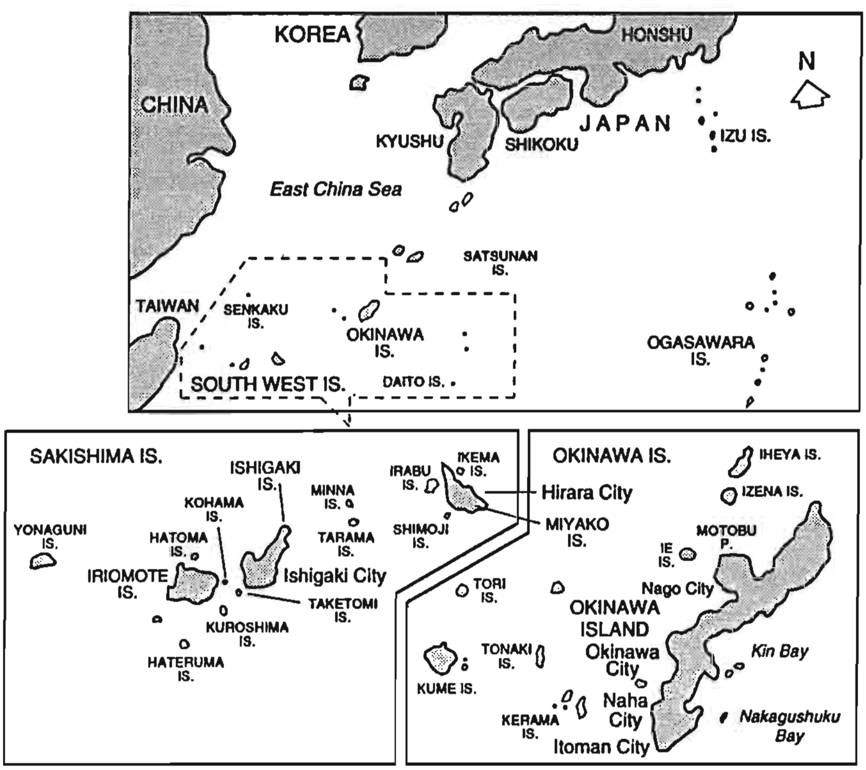


Figure 2. Okinawa island

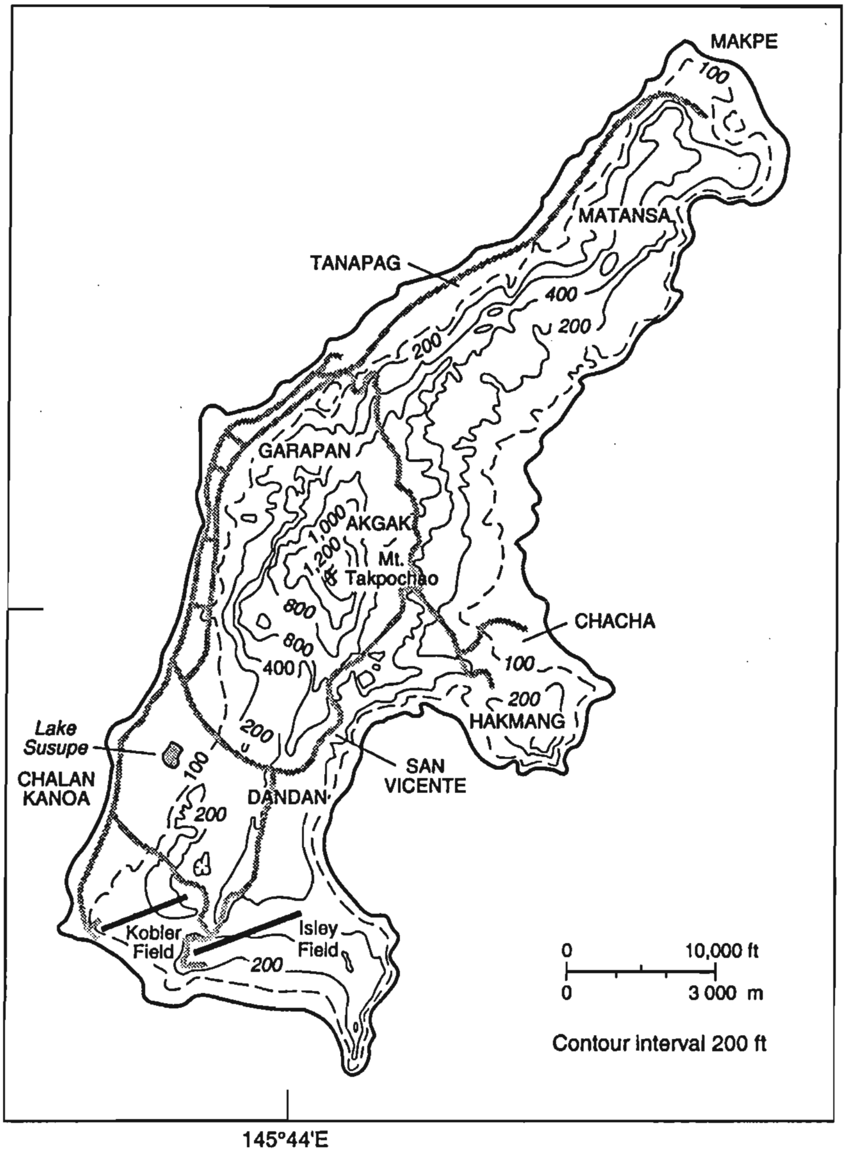


Figure 3. Saipan island, Commonwealth of the Northern Mariana Islands

›ple live mainly along the flat coastal area in the west, which is also where hotels are ated along the beach protected by offshore coral reefs.

Figure 4 shows the population growth of Okinawa, Saipan, and O'ahu. Although the ıl population for each of the three islands is not the same, their trends in population growth ːr World War II are quite similar—all show rapid growth. The trends in population growth be explained by the economic features of these islands (Table 1). The economic features Ͻkinawa are similar to those of O'ahu: tourism, sugarcane, government expenditure, and military. In Saipan, agriculture is less developed and there is no military base; tourism

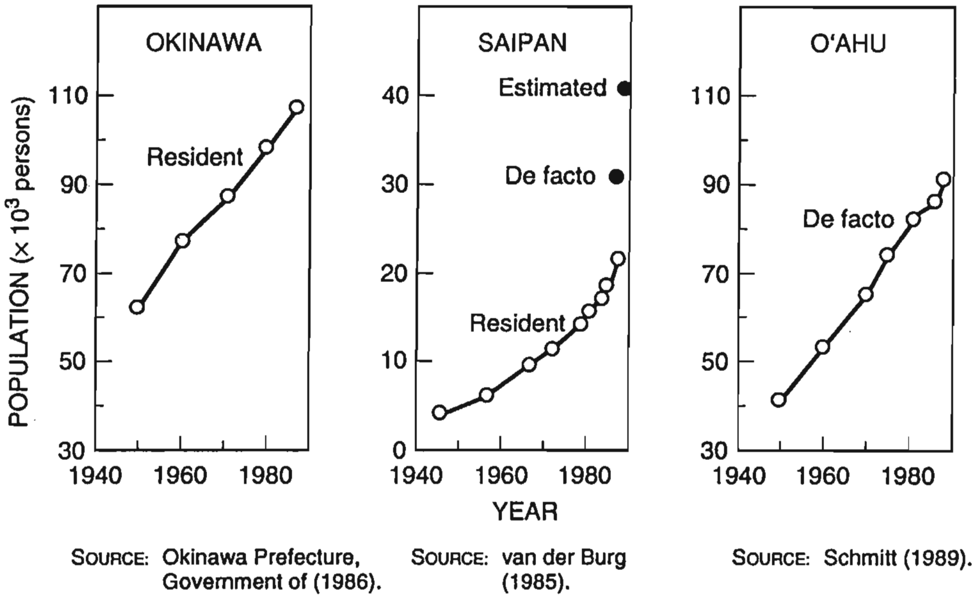


Figure 4. Population growth of Okinawa, Saipan, and O'ahu, 1945–1984

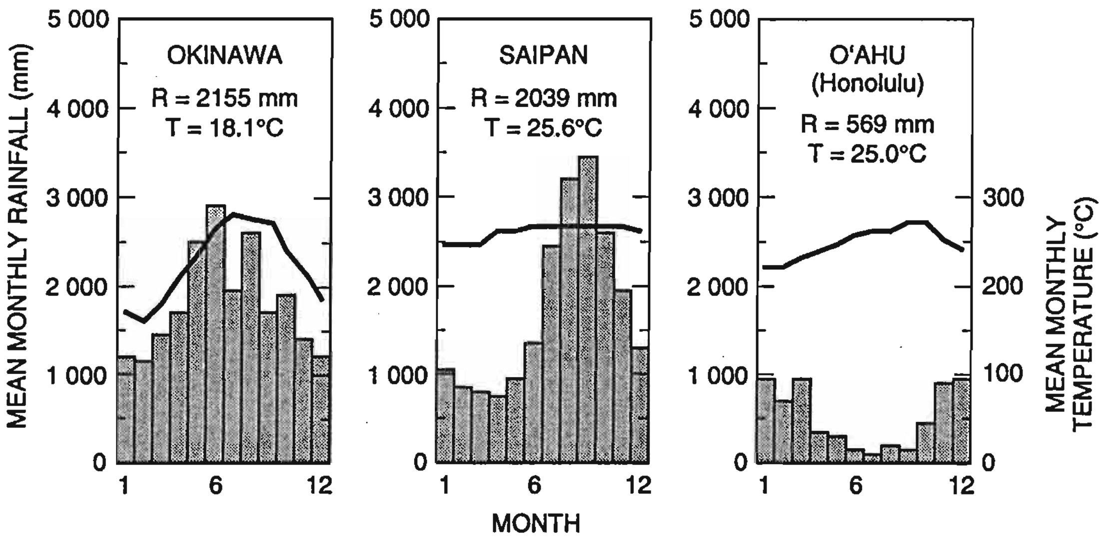
Table 1. Demographic Data for Okinawa, Saipan, and O'ahu, 1988

	Okinawa, Japan[a]	Saipan, CNMI[b]	O'ahu, Hawaii, U.S.A.[c]
Location	26°14'N, 127°41'E	15°13'N, 145°43'E	21°18N, 158°25'W
Distance from Tokyo, Japan	1 560 km SW	2 400 km S	6 400 km E
Area	1 192 km²	124 km²	1 574 km²
Population	1,069 thousand	41.7 thousand	903 thousand
Industry	Tourism Sugarcane Government expenditure Military	Tourism Garment Government expenditure	Tourism Sugarcane Government expenditure Military
Visitors/Year	2,395,000	210,000	5,800,000

[a]Okinawa Prefecture, Government of (1989).
[b]Stewart (1988).
[c]Schmitt (1989).

and garment factories are its main industries. Foreign workers constituted half of Saipan's population by the end of the 1980s.

Monthly changes in rainfall and temperature for the three islands are shown in Figure 5. Total precipitation and the monthly rainfall patterns of Okinawa and Saipan are similar. Their rainy season occurs during the summer, and both have several typhoons each year. The



SOURCE: Tokyo Astronomical Observatory (1983).
NOTE: R = mean annual rainfall; T = annual mean temperature.

SOURCE: van der Burg (1985).

SOURCE: Schmitt (1989).

Figure 5. Monthly rainfall and temperature for Okinawa, Saipan, and O'ahu

erage annual rainfall for both islands is over 2 000 mm. On O'ahu the average annual nfall is only 570 mm at the Honolulu International Airport, which is in a dry area of the and (Schmitt 1989); but the average for the whole island is 1 586 mm (Nullet and :Granaghan 1988). Its monthly rainfall pattern is the opposite of the other two islands: the ny season is in winter, because of the effects of trade winds. Table 2 shows the water ndition for the three islands.

The geological conditions of Okinawa and Saipan are similar. Both have a limestone /er on impermeable base rock, and the layer includes groundwater. Sometimes seawater :ects the chloride concentration. Because the urban area of Okinawa is mainly on such ata, the groundwater in the area is easily contaminated by urban sewage; and people use rface water in the northern mountainous area. In Saipan, only a few small streams—the ıin one being Talufofo Stream—exist, so the main water source of the island is ɔundwater. O'ahu is a volcanic island and has a large Ghyben-Herzberg lens, which is the ıin source of fresh water for the island.

Water Balance Flow Charts of Three Islands

The term "water balance" has many meanings from micro- to macro-situations. Water lance to soil researchers is the inflow and outflow of water in a small soil cell. But here

Table 2. Climatic, Geologic, and Hydrologic Data for Okinawa, Saipan, and O'ahu

	Okinawa, Japan[a]	Saipan, CNMI[b]	O'ahu, Hawaii, U.S.A.[c]
Mean Temperature	18.1°C	25.6°C	25.0°C[d]
Avg. Annual Rainfall	2 155 mm	2 039 mm	1 586 mm[e]
Highest Point	498 m (Mt. Yonaha)	473 m (Mt. Takpochao)	1 225 m (Mt. Ka'ala)
Geology	Rock formation of Paleozoic strata and Ryukyu limestone	Volcanic nucleus covered with coral limestone	Almost totally volcanic; sedimentary rocks around edges
Hydrology	Surface water in northern area	Groundwater	Groundwater

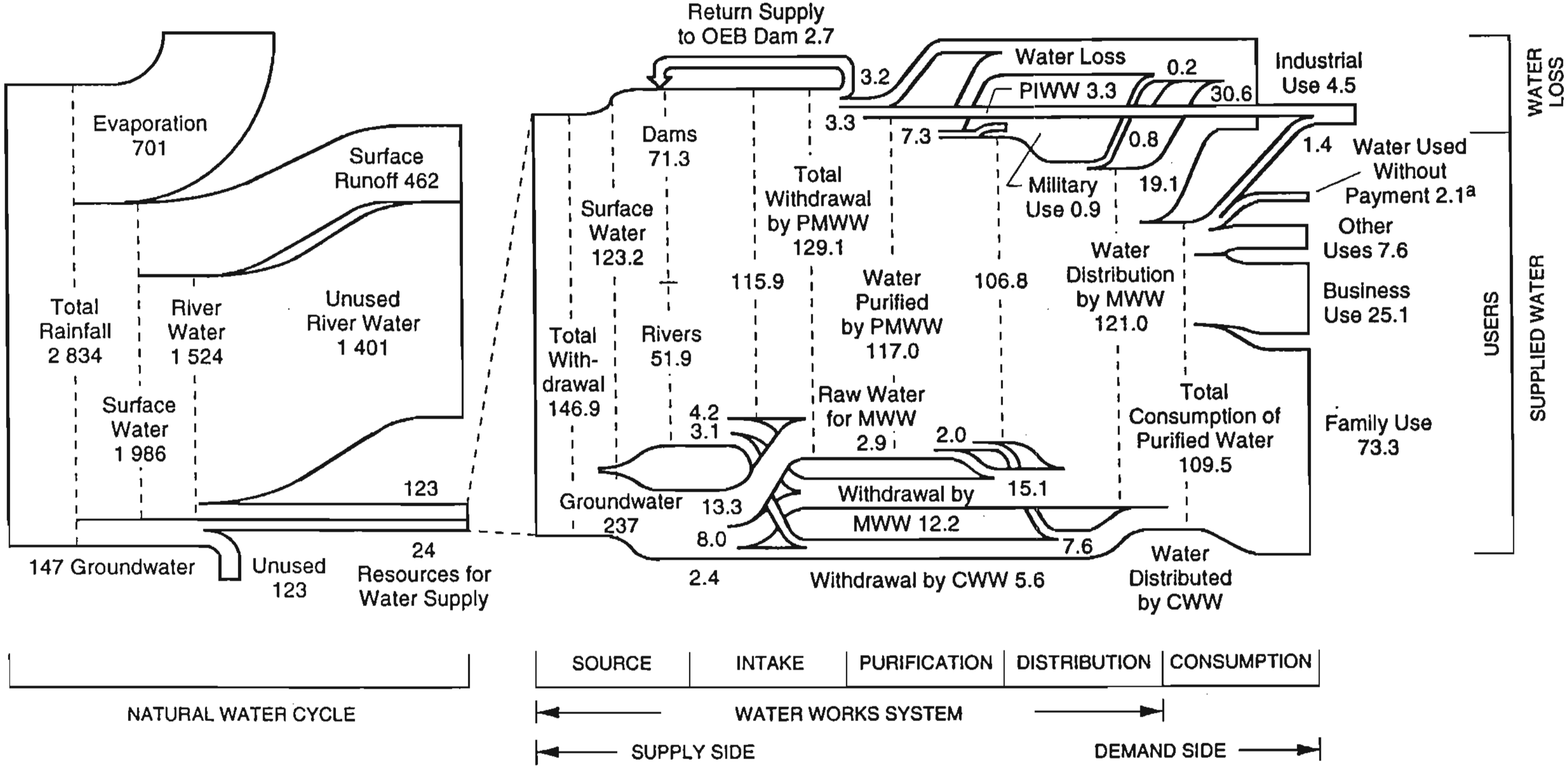
[a]Okinawa Prefecture, Government of (1989).
[b]Stewart (1988).
[c]Schmitt (1989).
[d]At Honolulu International Airport.
[e]Nullett and McGranaghan (1988).

macro-water balance includes the natural water cycle and water flow based on supply and demand.

Figure 6 shows a water balance flow chart. Total rainfall on the island becomes evapotranspiration, surface runoff, and groundwater recharge. Water is supplied through the phases of intake, transport, and purification and through the waterworks or other authorities and is consumed by several types of users. Some part of the intake water is lost as noneffective water (the total quantity of distributed water – quantity of metered water), including leakage through the system. Usually research is done on a specific phase.

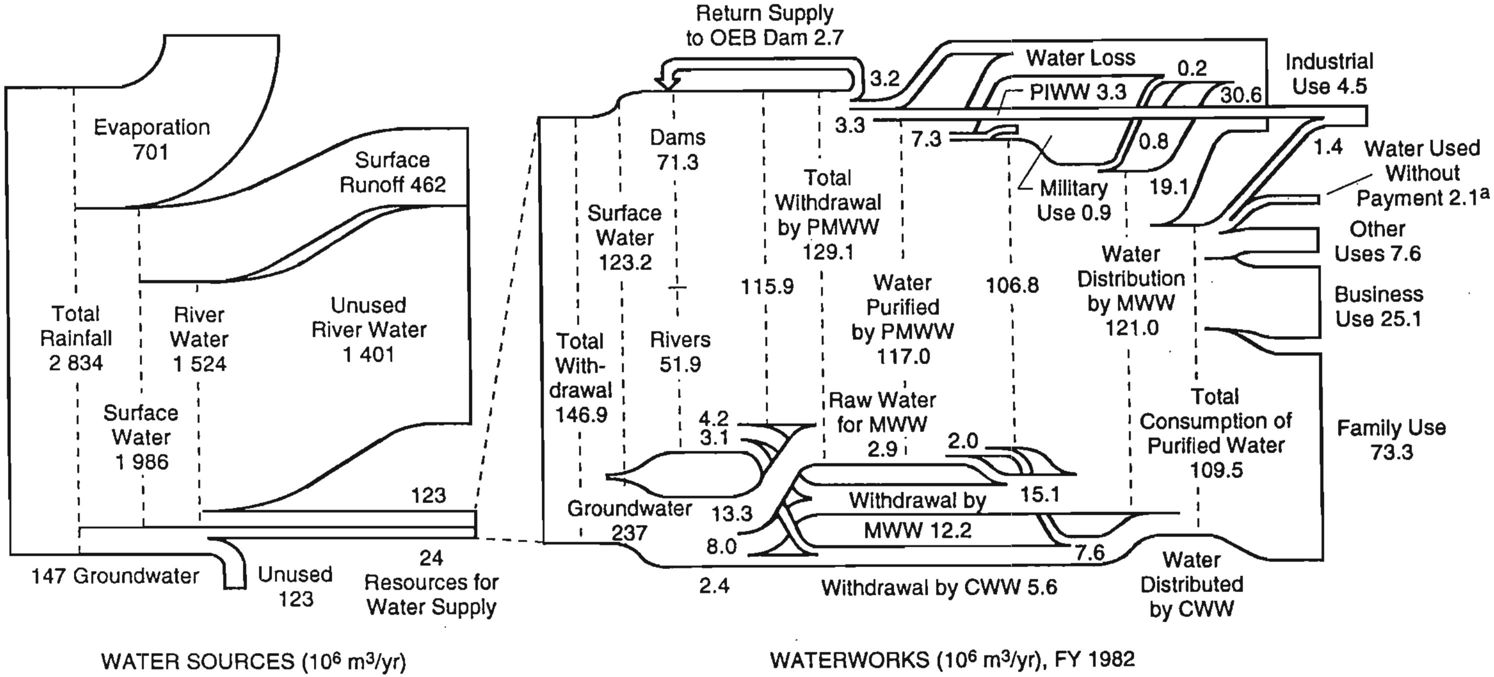
Figure 7 shows the water balance flow chart of Okinawa. In Okinawa only 4% of the total rainfall is used for water supply. Intake water is distributed through several levels and types of public waterworks, like prefectural waterworks, which include two independent systems, potable and industrial waterworks, 24 municipal waterworks, and almost 100 communal waterworks. Most of the surface and groundwater intake is purified and distributed to several types of users. The agricultural irrigation system on Okinawa is less developed.

As for the water balance of Saipan (Fig. 8), no data are available on its groundwater recharge and evaporation. The flow chart uses data from several reports and is therefore less accurate, but the water condition of the island can still be understood. Of the total rainfall, 2% is used as water intake. Similar to Okinawa, agricultural irrigation is slight. The waterworks of Saipan are managed and operated by the Commonwealth Utility Corporation (CUC). The water supply system has had many defects because of the island's long history of



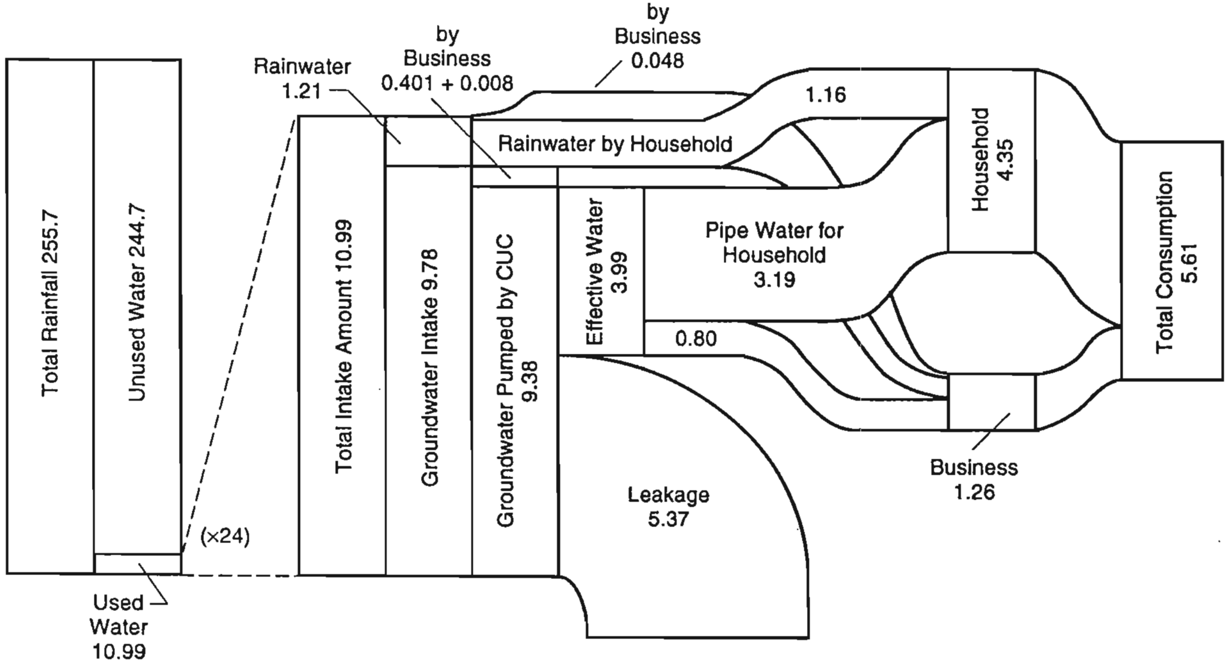
[a]Includes military, ships, and intermittent (construction, fires) uses.

Figure 6. Conceptual water balance flow chart



SOURCE: Miwa, Yamauchi, and Morita (1988).
NOTE: Total rainfall = rainfall (2 300 mm/yr) × total area; 10 yr average rainfall (1966–1975); PMWW = Prefectural Municipal Waterworks; MWW = Municipal Waterworks; CWW = Community Waterworks; PIWW = Prefectural Industrial Waterworks.
[a]Includes military, ships, and intermittent (construction, fires) uses.

Figure 7. Water balance of Okinawa, 1982



SOURCES: van der Burg (1985), Special Jt. Legislative Committee (1988), and Stewart (1988).
NOTE: Units in 10^6 m^3/yr.

Figure 8. Water balance of Saipan, 1988

economic and geopolitical disadvantages. Almost 50% of the intake water is lost to leakage; therefore, each household, business, and industry user has its own rain catchment system, and some have a reverse osmosis system. These self-supply systems cover some part of the total consumption.

Figure 9 shows the water balance of O'ahu. This flow chart shows the average water flow. From supply to demand, the flow is based on *The State of Hawaii Data Book: A Statistical Abstract*. The data are very crude, and this chart should be elaborated. The most distinguishing feature of O'ahu is the use of groundwater. Surface and groundwater intake is 22% of the total rainfall and 37% of the surface and groundwater flow. Of the total consumption, 47% is used for agricultural irrigation. Therefore leakage must equal 12%. O'ahu's institutional water supply system is much simpler than Okinawa's: the Board of Water Supply is the only public waterworks on the island.

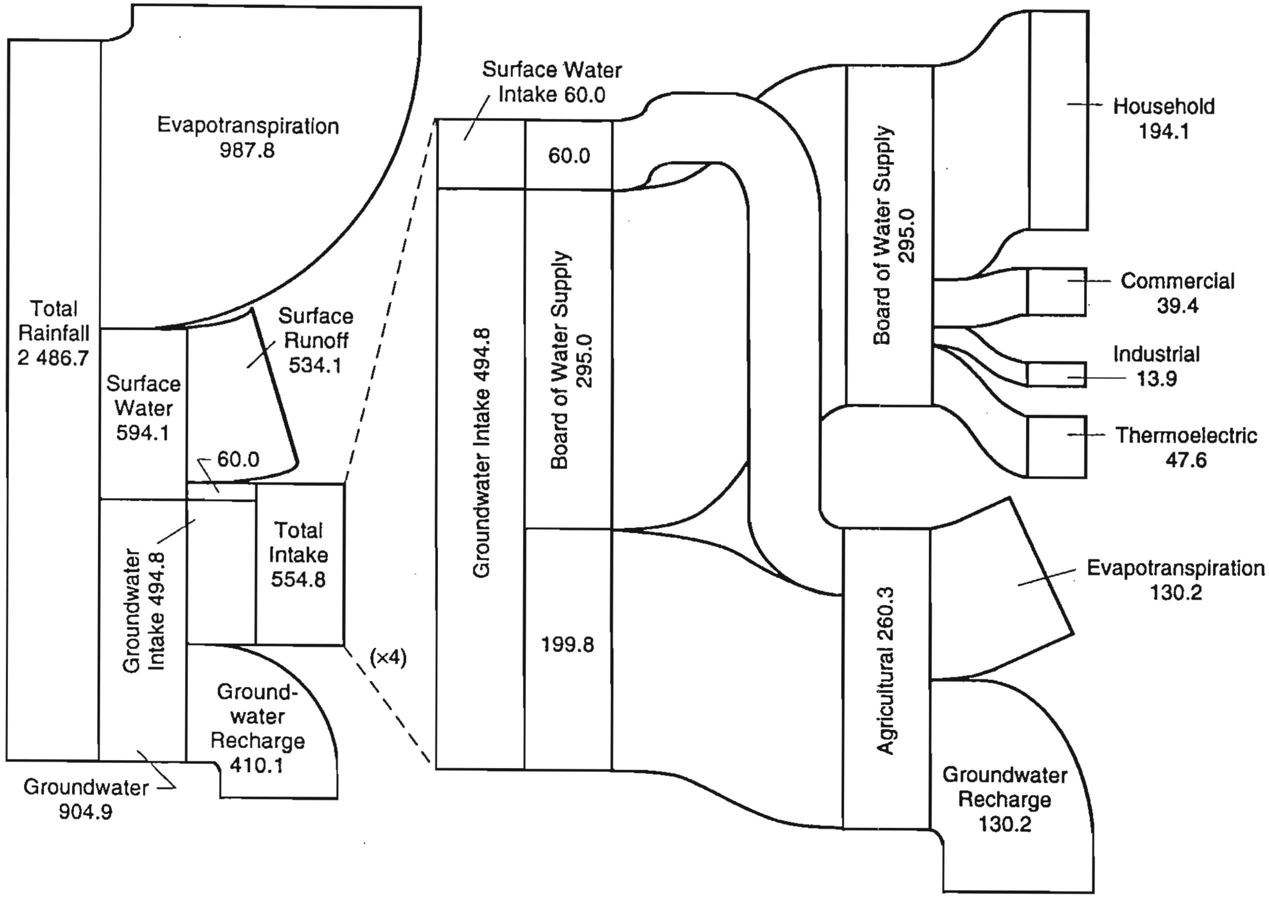
Tables 3 and 4 are summaries for the water balance flow charts of Okinawa, Saipan, and O'ahu. Population density is very high on Okinawa, 820 persons/km^2, and on O'ahu, 546 persons/km^2, and is relatively low on Saipan (336 persons/km^2) despite the rapid influx of foreign workers. Because of low density and high precipitation, Saipan's total rainfall per capita per year is more than 6 000 m^3, almost double that of O'ahu and Okinawa. Despite this, Saipan's intake water is only 2.2% of the total rainfall. Okinawa is now trying to develop many surface dams, but its intake rate is only 4%.

The rainfall of O'ahu is rather low, about 70% of the other two islands. Although the total flow of water per capita of O'ahu is almost the same as that of Okinawa, the use rate of O'ahu is extremely high because its natural storage capacity is very large; and storage capacity is a significant factor for the use rate of water resources. In Okinawa, dams are developed in mountainous areas, and storage capacity increases gradually, even though it is not as effective as O'ahu's.

Differences in distribution systems also exist for the three islands. As mentioned earlier, Okinawa has several types of waterworks. Differences in water management are apparent as well but are not discussed here.

General Water Resource Conditions of Saipan

This section presents the more practical aspect of water management on a small island, with reference to Saipan. The problem of water condition on Saipan is leakage, which is due to the use of asbestos cement pipes after the war; the pipes have been easily destroyed by heavy trucks used during the construction of hotels. Water quality is low, pressure is not uniform, and supply is not predictable.



SOURCES: Schmitt (1989), Department of Geography (1983), Board of Water Supply (1986), Takasaki (1978).

NOTE: Units in 10^6 m^3/yr.

Figure 9. Water balance of O'ahu, 1985

Table 3. Summary of Water Balance Flow Charts for Okinawa, Saipan, and O'ahu

	Okinawa, Japan	Saipan, CNMI	O'ahu, Hawai'i, U.S.A.
Area (km^2)	1 192	124	1 574
Population ($\times 10^3$)[a]	977	41.7	860
Precipitation (mm/yr)[a]	2 300	2 057	1 586
Natural Water Cycle (10^6 m^3/yr)			
Evapotranspiration	701 (25)	—	988 (40)
Surface Water	1 986 (70)	—	594 (24)
Groundwater	147 (5)	—	905 (36)
Total Precipitation	2 834 (100)	256 (100)	2 487 (100)
Amount of Intake (10^6 m^3/yr)			
Surface Water	123.2 (84)	0 (0)	60.00 (11)
Groundwater	23.7 (16)	9.78 (89)	494.8 (89)
Rainwater Catchment	b	1.21 (11)	b
Total Intake	146.9 (100)	10.99 (100)	554.8 (100)
Amount of Consumption (10^6 m^3/yr)			
Household	73.3 (65)	4.35 (78)	194.1 (35)
Industrial	4.5 (4)	1.26 (22)	13.9 (3)
Commercial	25.1 (22)	b	39.4 (7)
Other	9.7 (9)	0 (0)	47.6 (9)
Agricultural	c	c	260.3 (47)
Total Consumption	112.6 (100)	5.61 (100)	555.3 (100)

SOURCES: Same as Figures 7, 8, and 9.
NOTE: Percentages shown within parentheses.
[a]Numbers are not the same as those in Table 1 because of difference of year.
[b]Included in Industrial figure.
[c]Data too small to be calculated.

Table 4. Summary of Water Balance Flow Data for Okinawa, Saipan, and O'ahu

	Okinawa 1981	Saipan 1988	O'ahu 1985
opulation density (persons/km^2)	820	336	546
otal flow of water per capita per year (m^3/person/yr)	2 901	6 132	2 890
se rate of surface water (%)	6.2	—	10.1
se rate of groundwater (%)	16.1	—	54.7
otal use rate of water resources (%)	3.9	2.2	22.3
ousehold water consumption per capita per day (liters/person/day)	307	286	618
eakage (%)	21	49	12

But the reason for the imperfections in the water system is not so simple. We should ɔnsider the historic, economic, and political backgrounds of the island after World War II. ecause of the serious imperfections in the system, after the war, each household had its own ιin catchment cistern for drinking water use. Today, the use of bottled drinking water is ιirly widespread in Saipan. Public water is used for nonpotable purposes, such as washing ıd bathing, because it contains high concentration of chloride. Most of the 28 existing hotels ̧tewart 1988) have their own reverse osmosis system and purified brackish water from rivate wells on site. Self-supply systems constitute 29% of the total consumption. Such self-ıfficiency has significant meaning, as will be discussed later.

The CNMI Government has called this situation "the water war" and is trying hard to nprove conditions with assistance from engineers of the U.S. Department of Interior, eological Survey. The leakage situation has rapidly improved, and the CNMI government is ɔnvinced that the water goals should be shifted from improvement of quantity to nprovement of quality. Its main interest is in determining a means to distribute a plentiful ıpply of drinking water.

Although fulfilling immediate needs is very important, long-term needs must also be ɔnsidered, because the groundwater of Saipan is easily affected by seawater. If a large nount of the intake water is affected, available water could be scarce in the future.

The main water resource of Saipan is groundwater. Only Talufofo Stream on the east de of the island is considered a future source of surface water. Many wells are used for ater supply. Hotels on the west shoreline withdraw brackish water from the porous mestone layer of on-site wells. CUC is now pumping water from about 60 wells that are ıainly in the central and southern areas of the island. High-production well fields are in ıerto Rico, Kagman, Isley, and Kobler.

Figure 10 shows the chloride concentration of wells in each well field in Saipan. Although varying widely, well chloride concentrations along the coastline are generally very high—some over 6 000 mg/l. Several public water wells also have high concentrations, over 3 000 mg/l. High-quality water with a chloride concentration of less than 30 ppm occurs in a high basin in the central area, which is independent from seawater. The quality of wells in the same field differs from each other. This shows the complexity of the island's groundwater system.

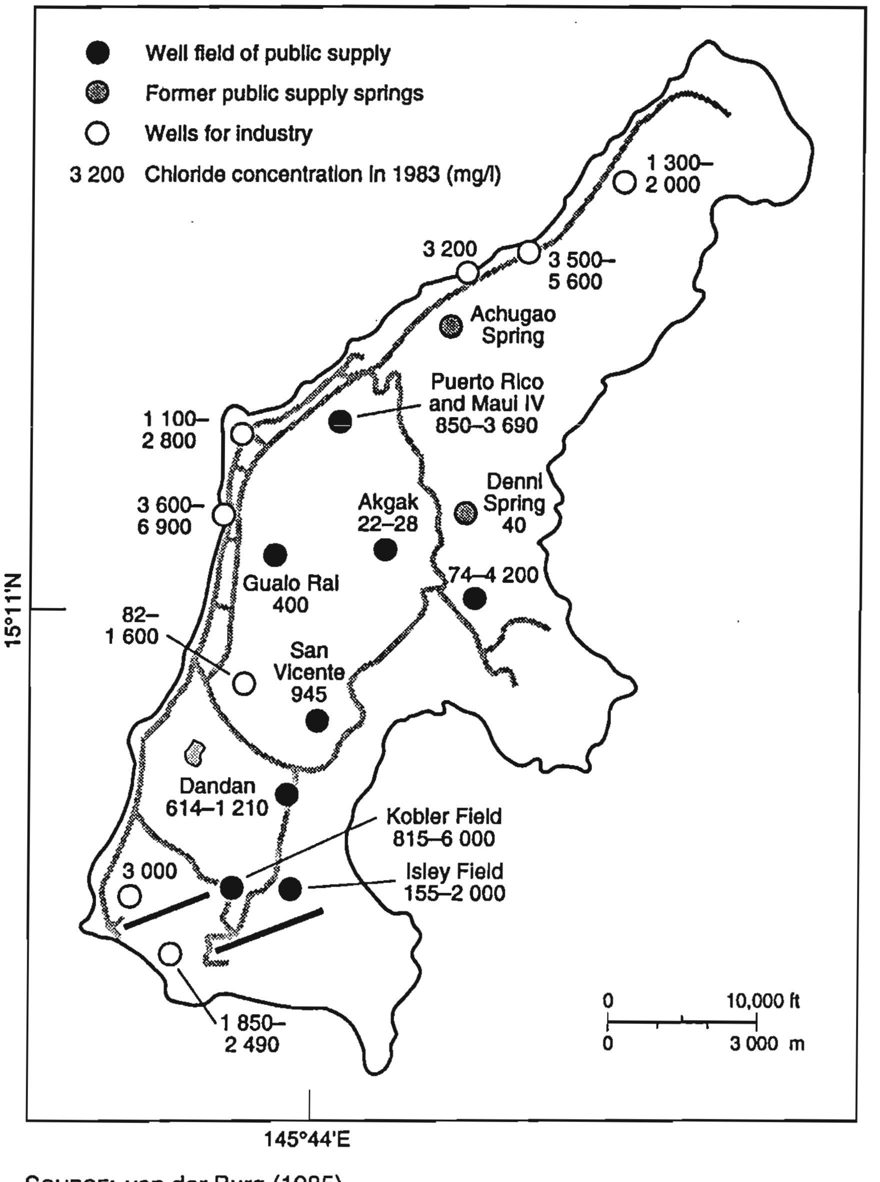
When considering long-term management of water resources, we can point out the following three features of groundwater. First, the average groundwater quality for public water is very high (Tables 5 and 6). In September 1983, nearly half of the total intake was from wells with chloride concentrations of more than 1,000 ppm. The average concentration increased from 700 ppm in 1980 to about 900 mg/l in 1983. Second, groundwater quality is easily affected by recharge and intake rates (Fig. 11). In Figure 11, concentration peaked in March 1982, just after a pumping test. The quality of groundwater in Kobler Field, which is in the southern area of Saipan, changes with rainfall. Third, there has been a large number of developed and abandoned wells (Table 7). From 1944 to 1983, 205 wells were developed, but only 32 of them were in use in 1983. Most of the drilled wells were abandoned, mainly because of high pumping rate, intrusion of seawater, and water quality deterioration. After World War II, U.S. troops dug many unplanned wells, and uncontrolled intake increased the chloride concentration. Water production after World War II caught up with the increase in population (Fig. 12), but the life of wells was short.

Now the question is whether it is possible for the public water supply to catch up with the growing demand. Some CUC engineers think the total groundwater intake is reaching the upper limit of the natural sustainable yield. Another question is whether the per capita supply can be increased. In 1988, consumption per capita per day of CUC water divided by total population (residents and nonresidents) was 286 liters. If the leakage rate decreases from 50% to 20%, daily per capita consumption will be 489 liters. This value is rather low compared with 618 liters for Hawaii. In addition, the population will grow rapidly.

TWO SCENARIOS OF FUTURE GROUNDWATER MANAGEMENT IN SAIPAN

Management of Groundwater Quality and Quantity

How can groundwater be managed in the future? The Saipan government is now planning to develop additional high-quality groundwater or surface water by mixing it with existing groundwater intake and to supply potable pipeline water (Fig. 13), that is, A million m^3/day with Q_i mg/l existing low-quality groundwater intake is mixed with X million m^3/day



SOURCE: van der Burg (1985).

Figure 10. Chloride concentration of well fields in Saipan

Table 5. Quality of Production Wells, Saipan, September 1983

Chloride Concentration (mg/l)	No. of Wells	Sum of Pumping Rate	
		(m^3/day)	(%)
0–499	10	7 233	47
500–999	44	1 106	7
1 000–1 499	11	4 131	27
1 500–1 999	3	867	6
2 000–2 999	3	1 733	11
≥3 000	1	354	2
Total	72	15 424	100

SOURCE: van der Burg (1985).

Table 6. Average Chloride Concentration of Production Wells, 1980–1983

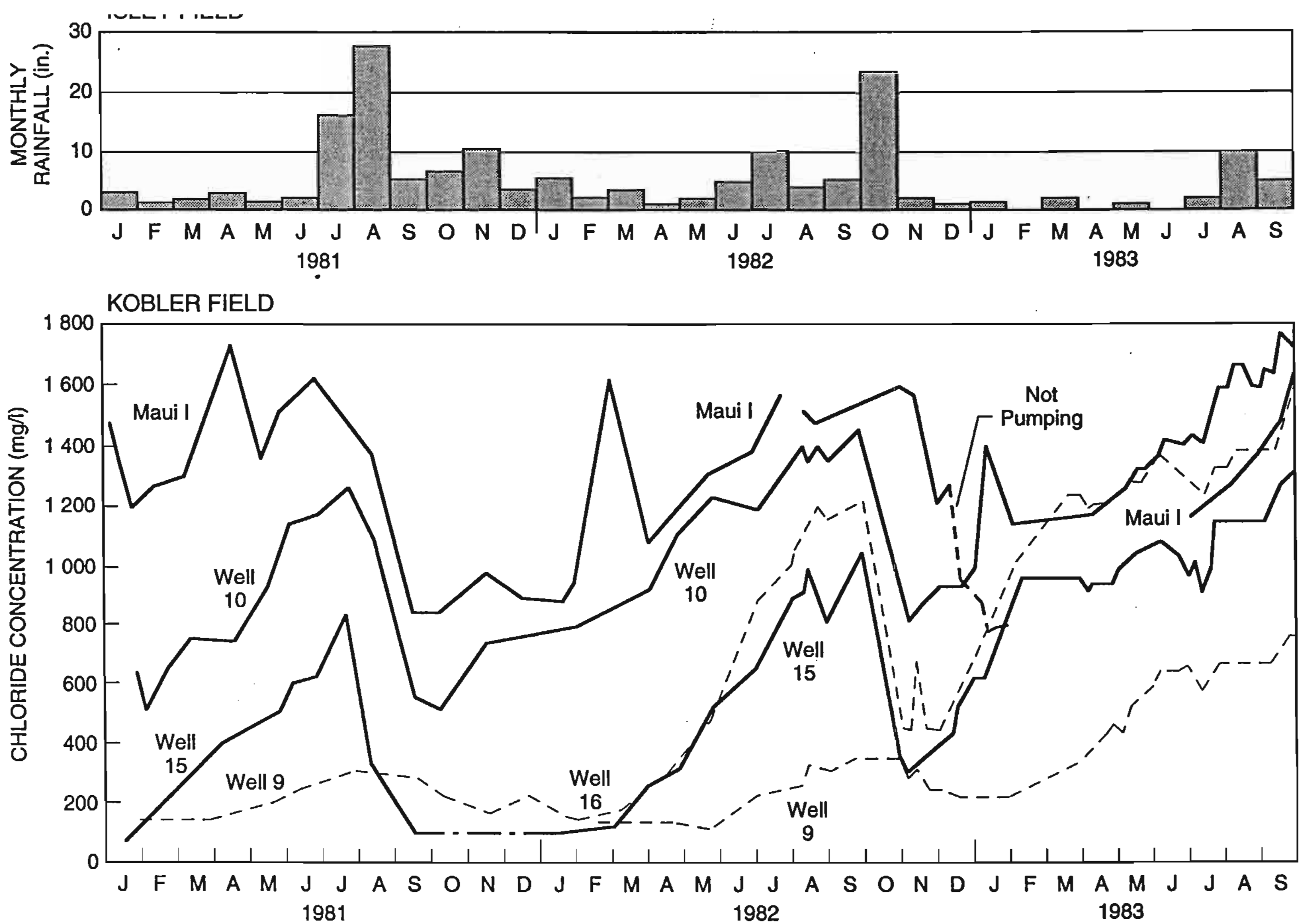
Date	Chloride Concentration (mg/l)
06/17/80	689
08/18/82	686
09/07–09/83	878

SOURCE: van der Burg (1985).

Table 7. Number of Developed Wells, Saipan

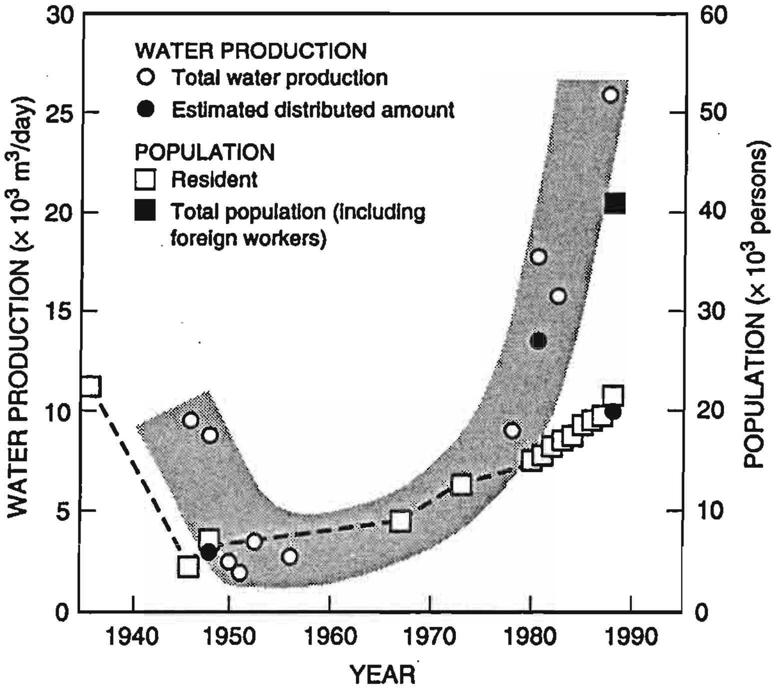
Year	No. of Wells
1944–1945	83
1956–1962	4
1969–1971	20
1977	30
1979–1980	27
1981–1983	41

SOURCE: van der Burg (1985).
NOTE: Only 4 out of 87 wells drilled from 1946 to 1969 still used today. Thirty-two production wells in 1983, 60 in 1988.



SOURCE: van der Burg (1985, p. 70).

Figure 11. Chloride concentration of wells at Kobler Field and rainfall at Isley Field



SOURCE: van der Burg (1985).

Figure 12. Population growth and water production in Saipan

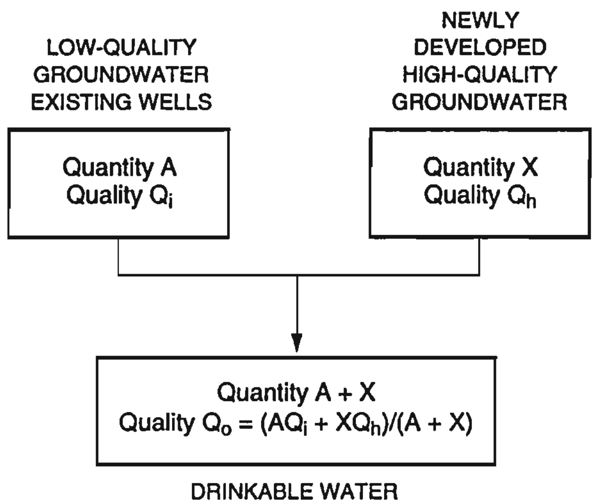


Figure 13. Mixing low- and high-quality groundwater

th Q_h mg/l newly developed high-quality water. This becomes Q_o mg/l moderately potable ater:

$$Q_o = \frac{(A * Q_i + X * Q_h)}{(A + X)}.$$

though the quality of groundwater varies throughout the island, it is assumed here that all oundwater can be mixed perfectly and used for human consumption.

Now we can discuss two scenarios of future water resource management in Saipan. In se 1 (Fig. 14), after mixing existing low-quality groundwater of quantity A with newly veloped high-quality water of quantity X, potable water of quantity (A + X) will be pplied and will meet the population's water demands. In case 2 (Fig. 14), the supplied antity is not changed after mixing low- and high-quality water where the quantity of isting low-quality well water should be decreased to the quantity of (A – Y). In this case, ake quantity of existing wells can be diminished, so that their quality will improve. Water ortages should be covered by certain conservation practices.

The question is how much high-quality water of quantity X or Y should be developed mix with Q_i mg/l low-quality water to distribute planned quality of Q_o mg/l water. Here, quantity of water that should be developed can be calculated as follows:

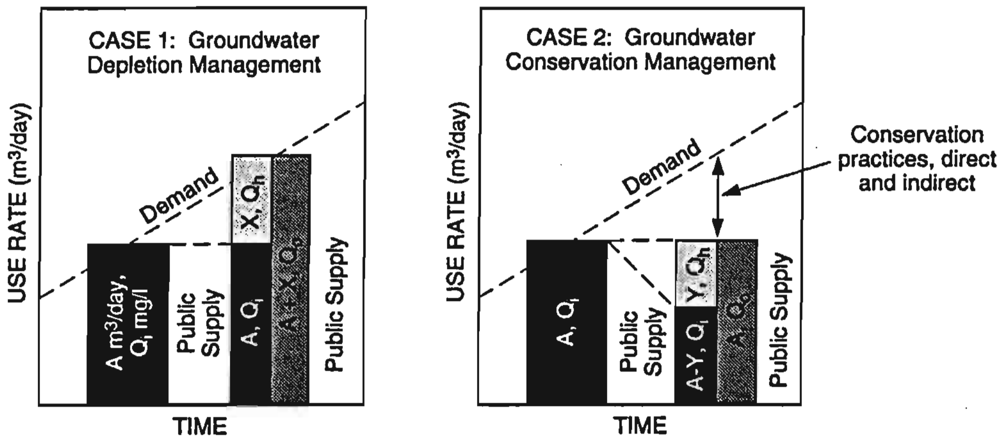
$$\text{for scenario case 1}, X = \frac{A * (Q_i - Q_o)}{(Q_o - Q_h)} = k_1 * A \text{ ; and}$$

$$\text{for scenario case 2}, Y = \frac{A * (Q_i - Q_o)}{(Q_i - Q_h)} = k_2 * A .$$

These relationships are shown in Figure 15, where the horizontal axis shows the quality existing groundwater (Q_i) and the vertical axis shows the planned quality of distributed inking water. The k is a coefficient which should be multiplied by existing groundwater antity A. The quantity of high-quality water that should be developed is X, which is equal $k_1 * A$. In this calculation, the quality of newly developed water Q_h is supposed to be 0 mg/l.

In scenario 1, for example, to decrease the existing quality of 800 mg/l to the extent of planned quality of 600 mg/l, the value of k_1 becomes 0.4. If the existing groundwater antity is 10 million m^3/yr, 4 million m^3/yr is the quantity of newly developed high-quality oundwater. If the planned water quality of the public supply system is 200 ppm, that is, nkable, k_1 becomes 6.0. This means six times the existing water or 60 million m^3/yr of gh-quality water would have to be developed. This is obviously impossible.

In scenario 2, to distribute 600 and 200 mg/l of drinking water, 0.29- and 0.86-fold, spectively, of the existing water would have to be developed.



NOTE: X, Y = production of newly developed, high-quality water for which chloride concentration is assumed to be Q_h mg/l

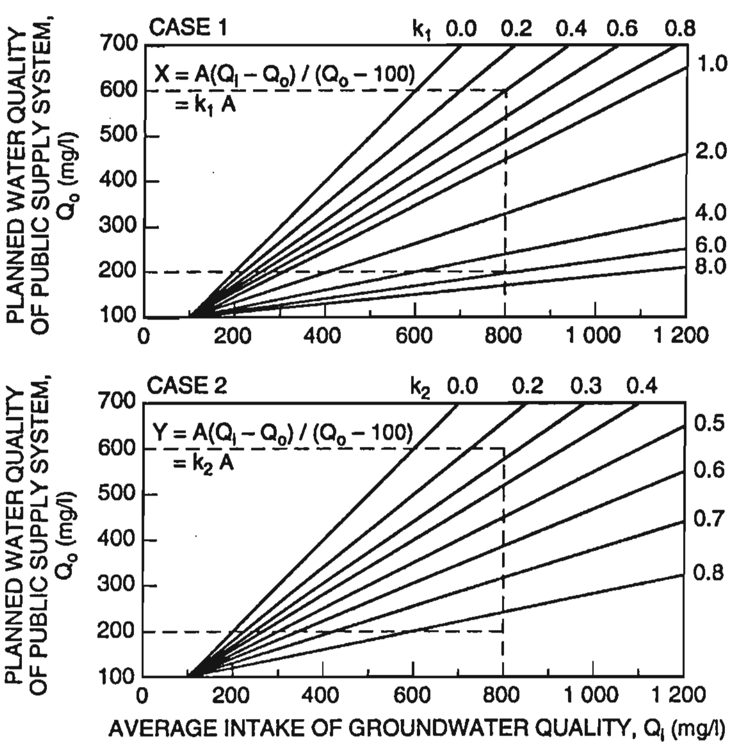
A = existing well production

Q_i = average quality of existing pumped groundwater

Q_o = planned water quality of public supply system

Q_h = chloride concentration of high-quality water.

Figure 14. Two cases of groundwater management for a small island



NOTE: X, Y = production of newly developed, high-quality water for which chloride concentration is assumed to be 100 mg/l

A = existing well production

Q_i = average quality of existing pumped groundwater

Q_o = planned water quality of public supply system

k_1, k_2 = ratio of additional high-quality water production over existing well production.

Figure 15. Improvement of supplied water quality

Standards of chloride concentration of potable water are presented in Table 8. Quality f less than 250 ppm is desirable for drinking and under 350 ppm is desirable for irrigation.

Some Calculations for Future Water Quality Management

A more understandable example of water quality management is presented in Figure 16. t present, approximate intake quantity is 6 mgd (million gallons per day) (0.26 m^3/s), opulation is 40,000, leakage rate is 50%, and average water quality is 800 ppm. The ollowing assumptions are made for the example in Figure 16: the increment ratio of opulation is 100%, the increment ratio of consumption per capita is 25%, and the chloride oncentration of additionally developed high-quality groundwater is 40 ppm. The problem is hat the water quality (Q_o) of piped water will be when what amount (X) of high-quality roundwater is mixed with low-quality groundwater that is used for piped water. Here, the otal intake of groundwater in the future is B. We also assume that all groundwater in the land can be mixed completely.

The method of calculation is shown in Table 9. Since half of 6 mgd is lost as leakage nd piped water is distributed for 40,000 people, water consumption per capita per day is 5 gal (0.284 m^3). Future consumption is assumed to increase by 25%, so future water onsumption per capita per day would be 93.75 gal (0.355 m^3). Since 80,000 people use 3.75 gal each, the total amount of piped water that should be supplied is 7.5 mgd .33 m^3/s). Future leakage rate is assumed to be 25%, so 10 mgd (0.44 m^3/s) intake of oundwater is necessary, and the additional amount of high-quality groundwater that must e developed is 4 mgd (0.18 m^3/s). And average water quality after mixing becomes 96 ppm, which is not drinkable.

If the population does not increase, total intake water becomes 5 mgd (0.21 m^3/s), hich is less than the present 6 mgd (0.26 m^3/s). If 4 mgd of 40 ppm of groundwater can be eveloped, intake of 1 mgd (0.04 m^3/s) of 800 ppm groundwater would be enough to mix ith high-quality groundwater. The quality of piped water would be 192 ppm chloride.

To distribute drinkable water, development of high-quality water is necessary while aintaining the present level of population and water consumption.

Two Types of Water Management

In case 1, extremely large amounts of high-quality groundwater are necessary for nproving the quality of drinking water. In case 2, the need for additional high-quality water less and the emphasis is instead on the conservation of existing water.

Table 8. Standard of Chloride Concentration for Water Use

	(mg/l)
Natural Conditions	
Seawater[a]	19 000
Groundwater[a]	6
Standard for Water Use	
Potable quality for all purposes	150
Unusable for drinking	250
Unusable for irrigation or industry	350
Taste unpalatable	500
Unsafe drinking water quality for cattle	3 000–4 000

SOURCE: Driscoll (1986, p. 101).
[a]Avg. Cl^- concentration.

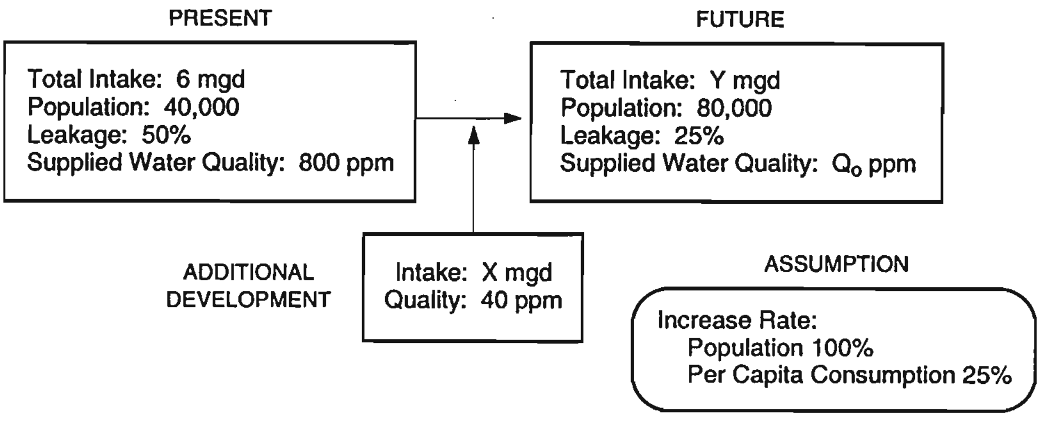


Figure 16. Future water quality

Table 9. Example of Future Water Quality and Supply, Saipan

Consumption per capita per day		
Present	(6 mgd × 0.5)/40,000	= 75 gal per capita per day
Future I	75 gal/day × (1 + 0.25)	= 93.75 gal per capita per day
Future II	75 gal/day × (1 + 0.25)	= 93.75 gal per capita per day
Total consumption of Commonwealth Utility Corporation water		
Present	6 mgd × 0.5	= 3 mgd
Future I	93.75 × (40,000 × 2)	= 7.5 mgd
Future II	93.75 × 40,000	= 3.75 mgd
Water quality after mixing		
Future I	(6 mgd × 800 ppm + 4 mgd × 40 ppm)/(6 mgd + 4 mgd)	= 496 ppm
Future II	(1 mgd × 800 ppm + 4 mgd × 40 ppm)/(1 mgd + 4 mgd)	= 192 ppm

What does this mean from a socioeconomic standpoint? In case 1, the quantity of stributed water increases while the need to conserve water decreases. Demand, in turn, will crease as the government tries to develop additional groundwater to meet the increasing ater demands. People depend on the public water system, and the responsibility of the vernment becomes very high. The average quality of groundwater will need to be higher; is will require the government to spend a lot of money to improve the quality of groundater. This plan emphasizes the present rather than the future.

In case 2, the total supply by the government is not changed, so various efforts will be eded. These include self-supplying systems, such as rain catchments for households and verse osmosis systems for hotels; and water-conserving planting called xeriscaping. rough these efforts, people will become more conscious of the need to conserve water, so mand itself might decrease. Conservation practices in various areas should be promoted rough public education and economic incentives provided by government. Case 2 improves oundwater quality and emphasizes the future rather than the present. This type of control is onservation type of groundwater management.

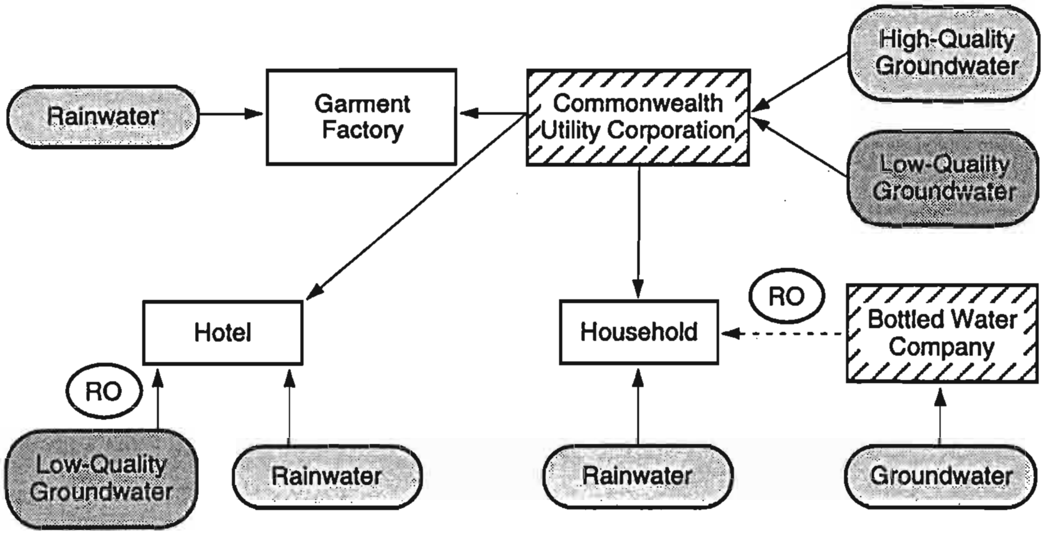
Water resource problems in urban areas of Japan, such as Tokyo, Osaka, and Fukuoka, e occurring because the existing policies that govern water resource management courage depletion. Recently more conservative water resource management policies have en adopted in several areas in Japan.

COMPARISON OF ALTERNATIVES

The present condition of the water supply system is shown in Figure 17. At present, the ain supplier, CUC, intakes low- or high-quality groundwater to supply households, hotels, d garment factories. One company, using its own reverse osmosis system, sells mainly ttled water for households and the service industry. This company uses groundwater and nwater to decrease the chloride concentration in untreated water. Hotels and garment tories use piped water, rainwater, and reverse osmosis systems. Agricultural use of water not discussed here.

To supply water through only one system is not advantageous in long-term groundwater anagement. Using the depletion and conservation types of management discussed earlier, can compare four alternatives for future water supply systems in Saipan.

ALTERNATIVE 0. Alternative 0 (Fig. 18) is a modern municipal water supply system that ovides potable water through one system. This system functions only when high-level hnology for construction and management is available and when users follow the rules



NOTE: RO = reverse osmosis system.

Figure 17. Schematic of present Saipan water supply system

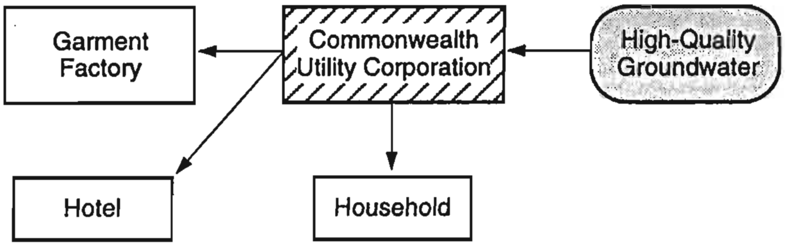


Figure 18. Water supply system for Saipan: Alternative 0

lequately. This system does not provide any feedback to control the growth of water :mand, so it requires that groundwater increase in quantity and decrease in quality. If high-iality groundwater is plentiful compared to water demands, problems will not occur. The iality of piped water is unstable under drought conditions. In this alternative, identifying the pper limit of available high-quality groundwater is very important from a hydrological point ' view. The present water supply system of Saipan is based on a concept of this type of ternative.

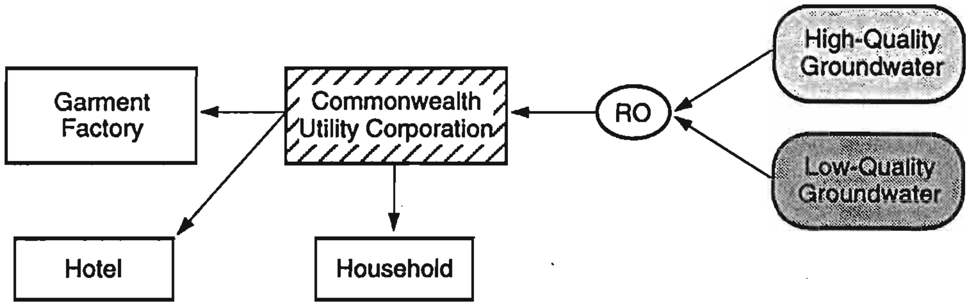
ALTERNATIVE 1. Alternative 1 (Fig. 19) is almost the same as alternative 0, but uses w-quality groundwater to make up water shortages. To make supplied water drinkable, a verse osmosis system is necessary for desalination. Earlier we discussed mixing low- and gh-quality groundwater, but in practice, a system in which one facility mixes groundwater om various wells throughout the island and then distributes water for all the people living ι the island is very difficult, technically and economically. Several small reverse osmosis stems would be necessary in various locations, and construction and maintenance costs ight be very high compared to that for just one large reverse osmosis system. Also, this :ernative cannot curtail the growth in water demand and seems very expensive.

ALTERNATIVE 2. In alternative 2 (Fig. 20), high- and low-quality groundwater are used parately. High-quality groundwater is purified through a reverse osmosis system for drink-g water, and low- or other-quality water is used through the present system. Uses other than r drinking might increase, so groundwater quality might further deteriorate.

ALTERNATIVE 3. Alternative 3 (Fig. 21) is a diversified system that is recommended as e future water system for Saipan. Rainwater might be used in households and companies as currently done, and conservation and recycling practices in daily life should be couraged. Bottled water would be for drinking use. Drinking water should be inexpensive cause it is fundamental for daily life. For this purpose, high-quality groundwater should be ed as untreated water for the reverse osmosis system. This alternative (1) minimizes the ality and quantity of groundwater needed and (2) makes users conscious of conserving iter. Naturally people desire to move from the present condition to that of alternative 2 to iprove the water supply system, because conservation and recycling practices are a burden people. Institutional support is highly recommended to promote such practices.

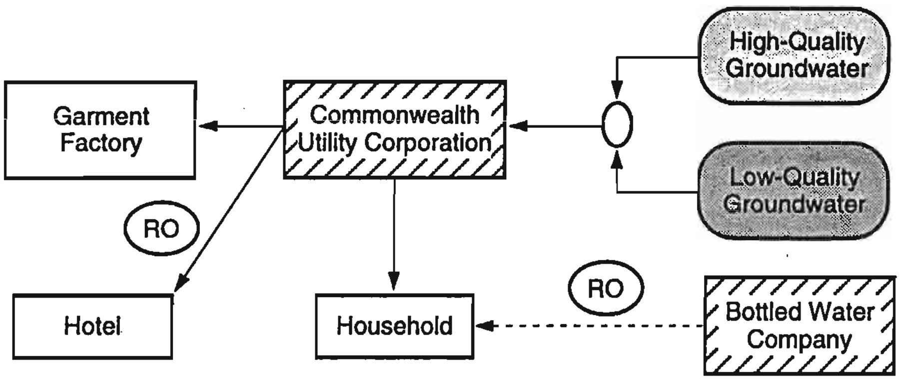
CONCLUSION AND PROPOSALS FOR SAIPAN'S WATER MANAGEMENT

It is important that we consider and compare two types of water resource management. ıe is called "groundwater depletion type" or "unification type;" the other is the



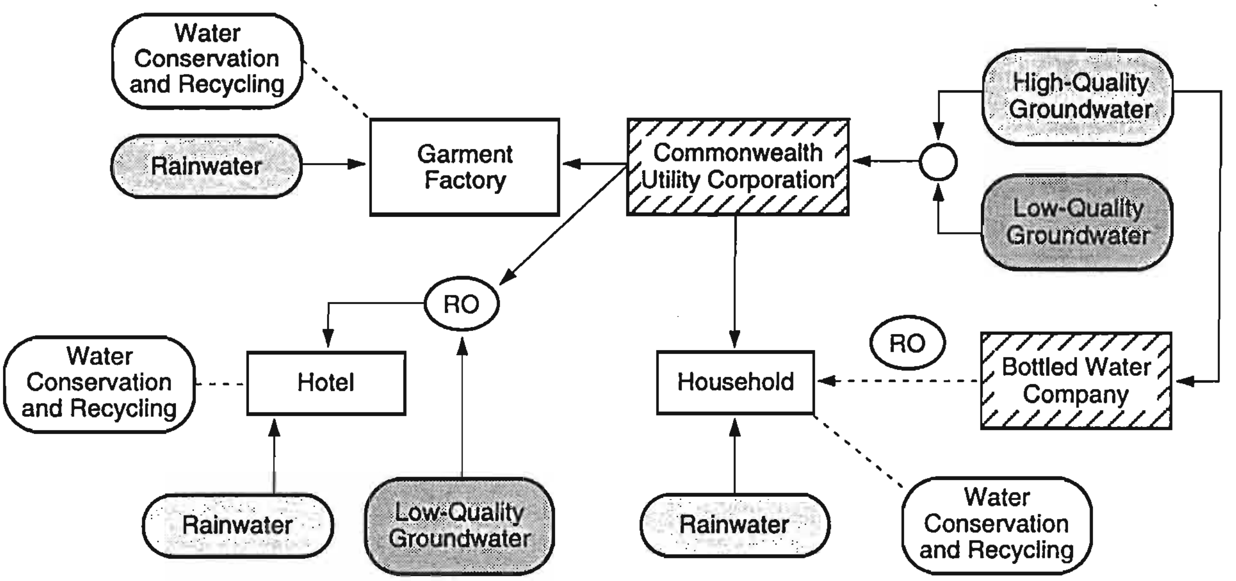
NOTE: RO = reverse osmosis system.

Figure 19. Water supply system for Saipan: Alternative 1



NOTE: RO = reverse osmosis system.

Figure 20. Water supply system for Saipan: Alternative 2



NOTE: RO = reverse osmosis system.

Figure 21. Water supply system for Saipan: Alternative 3

;roundwater conservation type" or "diversification type" management. "Unification" means at demand should be covered by a single public waterworks, and "diversification" means at various sectors should construct and maintain their own. Safe minimum standards are :cessary to avoid future economically irreversible conditions incurred by the present 'actice of intensive and exhaustive water usage. Groundwater conservation type management is one example of this standard.

In the discussion on water balance, the importance of the stock of natural water sources was mentioned. Not only natural but also artificial stocks of water might enhance e possibility of a conservation type management. Diversified water supply systems, such as ose in Okinawa, might also contribute to the conservation of water resources.

The following are proposals for future water management in Saipan:

1. Drinking water should be inexpensive and clean; it should be supplied by a bottled water system.
2. Bottled water should be affordable by the average household. To make bottled water cheaper, the chloride concentration of intake water of bottling companies should be improved. If the quality of untreated water for reverse osmosis systems could be improved, maintenance costs of the systems could be reduced and the bottled water would be cheaper.
3. If the CUC or private sector used high-quality groundwater as the source of bottled drinking water, it would not be necessary to use reverse osmosis systems to treat bottled drinking water, and the price of bottled water could be easily reduced.
4. To eliminate the cost of delivering bottled water to each household, stores should sell bottled water. (Such stores could be community centers for residents to learn about the water conditions of Saipan.)
5. The government recommends that hotels use reverse osmosis systems even if the CUC can provide a plentiful supply of piped water. If hotels can get piped water, they can reduce the maintenance costs of their reverse osmosis systems. (Problems due to drought can be minimized.)
6. Households should have rainwater catchments to reduce the cost of water bills and the load on the municipal system.
7. Low income families prefer rainwater to bottled water for drinking because of the minimal cost. Such an option should be kept. Consequently, rain cisterns should be inspected regularly to maintain standard water quality conditions.

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APPENDIXES

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Figures

Tables

APPENDIX A. WATER SUPPLY IN SAIPAN

Water Supply

WATER SUPPLY BY WATERWORKS. To overcome Saipan's serious water problems, the ommonwealth Utility Corporation (CUC) is trying to improve the water supply system. CUC now mixing low- and high-quality groundwater and supplying private companies, such as ›tels and garment factories, public facilities, and households. Hotels and garment factories are ırtially self-supplying. When conditions require water rationing, households have first pri-·ity. Garment factories do not seem to use water for processing clothes; instead, their daily ater use is mainly for the workers. Hotels have their own purifying system—a reverse ımosis system—because of their proximity to the seashore and to the intrusion of saltwater.

Leakage from pipes is a serious problem, and CUC is improving the pipeline system. The ımber of households supplied for 24 hours is not large.

Under continual rationing, the water supply is controlled by valves on main pipes, and ere is an order of user priorities. Given first priority, households are supplied from 6:00 to 00 A.M. Schools are supplied from 8:00 A.M. until 2:00 P.M. Hotels are supplied from 3:00 6:00 P.M. The maximum amount of water supplied to a hotel is 80,000 gal (303 m^3)/day, hich is similar for garment factories. According to CUC, the planned increment of water .pplied to one hotel guest is 145 gal (0.55 m^3)/day.

Interviews with residents showed that there are various means for managing the water .pply. Because the water rationing schedule is not dependable, people store as much piped ater as possible when CUC turns on the water. Taps to household tanks are always open, eatly reducing the water-pressure in branch pipes at high elevations. In some households, ater is wasted as it spills over the tanks; in other households, only air comes out of the pipes, people cannot shower and must borrow water from their neighbors. This imbalance in the ater supply is a major issue of concern.

Family J, for example, has six family members, two of them infants. Family J does not e rainwater; they use bottled water for drinking and cooking and CUC water for other ırposes. Each week they buy four 5-gal bottles of water that comes from Saipan and sells for :/bottle. Family J has a 1,000-gal (3.8-m^3) concrete tank to catch CUC water.

The CNMI Seven-Year Strategic Development Plan (A.D. Little International, Inc. 1988) ntains many development and improvement plans (App. Tables A.1. and A.2.). These plans n be categorized as (1) repairing/replacing water pipes to lessen the leakage rates, (2) ıproving water wells to maintain productivity, (3) developing high-quality water, (4) arranging the water pipe network, (5) installing water meters, and (6) developing surface ater sources.

Appendix Table A.1. Water Projects, Phase 2, Saipan

Project Name	Project Description	Cost	Construction Timing	Funding
Groundwater production enhancement	Define and quantify water-producing aquifers	$2,500,000 ($72,000)[a]	1992	DOI (covenant) USGS
Well pump panel improvements	Replace ~55 panels; standardize panel board components	$300,000	1988	OTIA (PHS designer)
Well quality control meters	Monitor water quality of existing 59 productive water wells	$60,000	1988	OTIA
Navy Hill water distribution system	Distribute water to various subdivisions on Navy Hill	$704,000 ($76,970)	1987	DOI
Maui IV/Tasa Res. waterline	Replace existing waterline from Maui IV Treatment Plant to Tasa Reservoir with new waterline	$1,400,000 ($104,387)	1987	DOI
Tasa Reservoir/ Marpi waterline	Connect with Maui IV/Tasa Reservoir Waterline Project to deliver water to Marpi and Lower Base areas	$2,000,000 ($255,893)	1988	DOI
Agag/Capitol Hill Res. waterline	Upgrade Agag Booster Pump Station facilities; enlarge size of water transmission line	$700,000 ($64,930)	1986	DOI
Garapan waterlines	Replace several deteriorated mains	$500,000 ($50,000)	1991	DOI
Saipan water system project	Convey water from Kagman to San Vicente, then to other southern villages; replace/ upgrade distribution system in Chalan Kanoa and Susupe	$4,133,600 ($263,082)	1987	Farmers Home Administration ($3,100,200 grant, $1,033,400 loan)

SOURCE: A.D. Little International, Inc. (1988, Apps. B.1, B.2, B.3).
NOTE: Phase 2 projects to be funded from bond money or by ongoing Federal assistance program.
[a]Design cost.

Since January 1990, CUC has been steadily improving the water system. CUC responds to the daily requests of residents, while it works to improve the system day and night. It seems that the water system will be improved in the near future.

BOTTLED WATER. Several bottling companies process salty groundwater to sell as bottled water. One company we interviewed has an 80 to 90% share of the market. The company uses a reverse osmosis system to treat groundwater from a nearby well and rainwater from the company's roof. It produces 12,000 to 15,000 gal (45.4–56.8 m^3)/day; 70% of

Appendix Table A.2. Additional Water Projects, Saipan

Project Name	Project Description	Cost (× $1,000)	Construction Period	Private-Funding Opportunities
ak detection ɔgram	Locate and repair leaks throughout water system	100	1989	Impact fees
hugao Springs ɛll and reservoir	Rehabilitate existing reservoir; drill a well	500	1989	Impact fees
ıalan Kiya well d reservoir	Construct new well/res.	600	1989	Impact fees
ɔnni Springs CDS and ıterline	Upgrade water collection facility; replace old waterline	1,200	1989–1990	Impact fees
lufofo wells	Drill new wells	300	1989	Impact fees
arpi waterline tension and servoir	Extend waterline; construct new reservoir	600	1989–1990	Impact fees
n Vicente strict system d reservoir	Upgrade distribution systems; construct new storage	750	1990	Impact fees
Lito Reservoir d chlorinator	Construct new storage and treatment facilities	700	1990–1991	Impact fees

URCE: A.D. Little International, Inc. (1988; Apps. B.1, B.2, B.3).
ɪTE: Additional projects could be implemented with funds from sources other than bond money or Federal funds ntified for phase 2 projects.

hich is sold as bottled water and the rest as ice. The wholesale price of bottled water is .35/gal and the retail price is $1.50/gal; bottled water imported from California is $2.95/gal.

Several stores sell bottled water. People wait in line to buy bottled water in the morning :00–9:30 A.M.) and evening (3:00–5:00 P.M.). Bottled water is not delivered.

According to the interview, three family members consume 5 gal (19 liters)/wk; that is, ıe person consumes 0.238 gal (0.9 liters)/day. From this, we can calculate the number of ople who use bottled water each day:

$$15{,}000 \text{ gal/day} \times \frac{70\%}{0.238 \text{ gal/person/day}} \times \frac{1}{90\%} = 49{,}000 \text{ persons}$$

ıis means that most of the island's population use bottled water.

RAINWATER. We interviewed a company that produces and sells rain catchment tanks. ɔsts of several capacities of rain tanks are provided in Appendix Table A.3. More than 90%

Appendix Table A.3. Water Tanks Costs, Saipan

Capacity		Water Tank Cost ($)		
(gal)	(m^3)	Concrete	FRP[a]	Basement
600[b]	2.3	570	700	175
1,000[c]	3.8	880	950	—
1,500	5.7	1,155	1,350	250
2,000	7.6	1,400	1,900	300
3,000	11.4	1,890	2,800	300

SOURCE: Rain tank company file.
[a]Fiber reinforced plastic.
[b]Recommended tank capacity for low-quality water needs.
[c]Recommended tank capacity for high-quality water needs.

of the households have rainwater catchment tanks. Of all the tanks, 60 to 70% are made of fiber reinforced plastic, according to the interview results, although this estimate seems high.

The capacity of rain catchment tanks recommended by the company is 1,000 gal (3.8 m^3) for low-quality needs (bathing, washing clothes, and purposes other than drinking), and 500 gal (1.9 m^3) for high-quality needs (drinking and cooking). In Saipan, people store rainwater and CUC-piped water in one tank—a practice recommended by CUC.

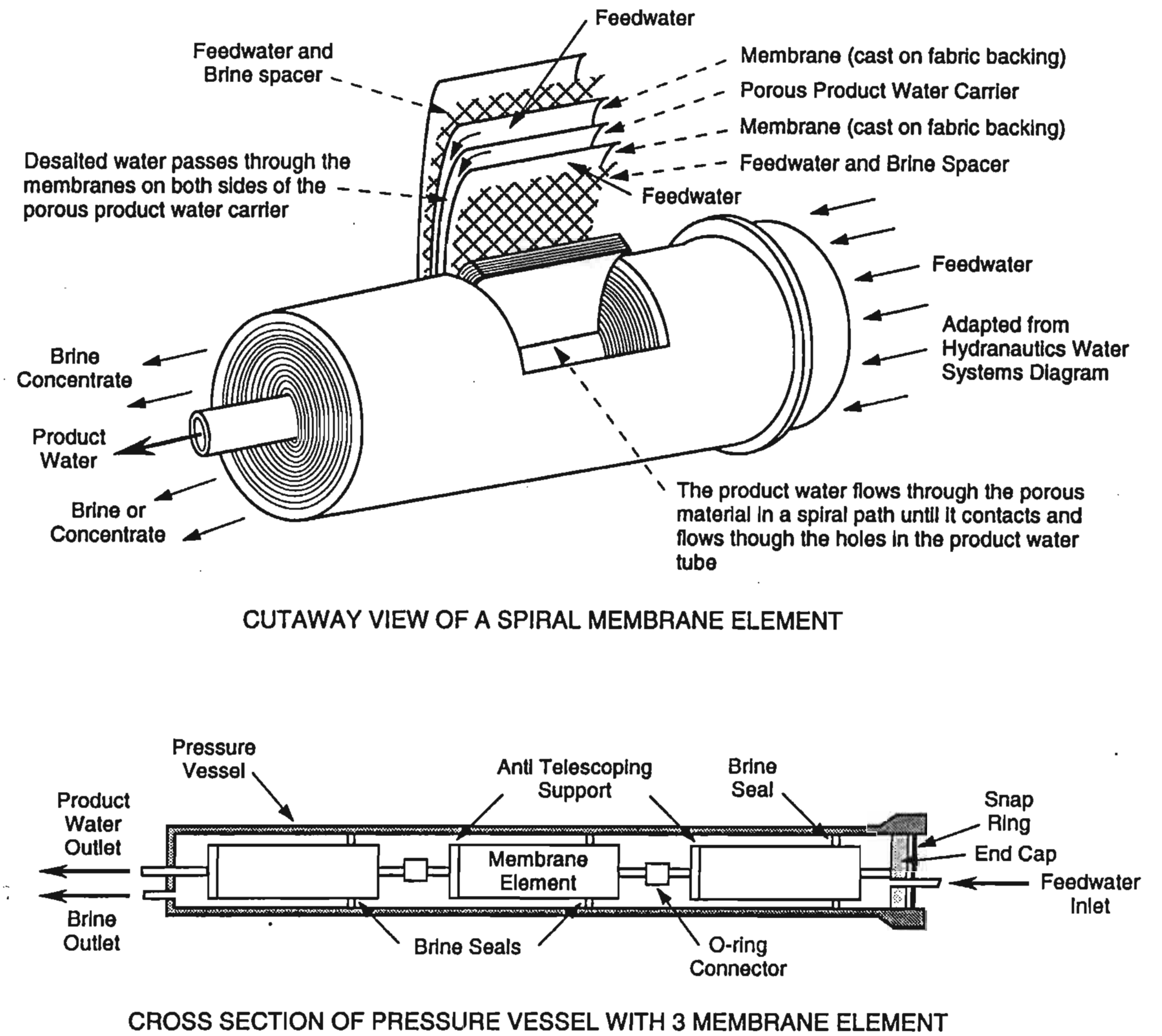
Concern exists that the quality of water in catchment tanks should be checked and improved. However, there is no regulation (or education of users) controlling water quality in catchment tanks, such as by cleaning out several centimeters of sediment, mud, reef particles, and organisms settled in the bottom of the tank.

REVERSE OSMOSIS SYSTEM. Most of the large hotels in Saipan have their own reverse osmosis system to meet their water needs. Usually they drill wells on their land and pump salty groundwater from them. As shown in Appendix Figure A.1, a reverse osmosis system consists of modules which include layers that filter particles.

Hotels hire companies to construct reverse osmosis systems and/or maintain them or buy water from companies using reverse osmosis systems. In general, reverse osmosis systems are expensive and require a high level of technology, so only hotels with much capital can use these systems. In Saipan the only technique used to purify low-quality groundwater is the reverse osmosis system.

Water Demand

PIPED (POTABLE) WATER USE. There are two types of billing for piped water. If water is supplied for 24 hours, the metered rate is used, but if water is supplied for only a few hours in



›URCE: Division of Water and Land Development (1985).

Appendix Figure A.1. Spiral-wound reverse osmosis unit

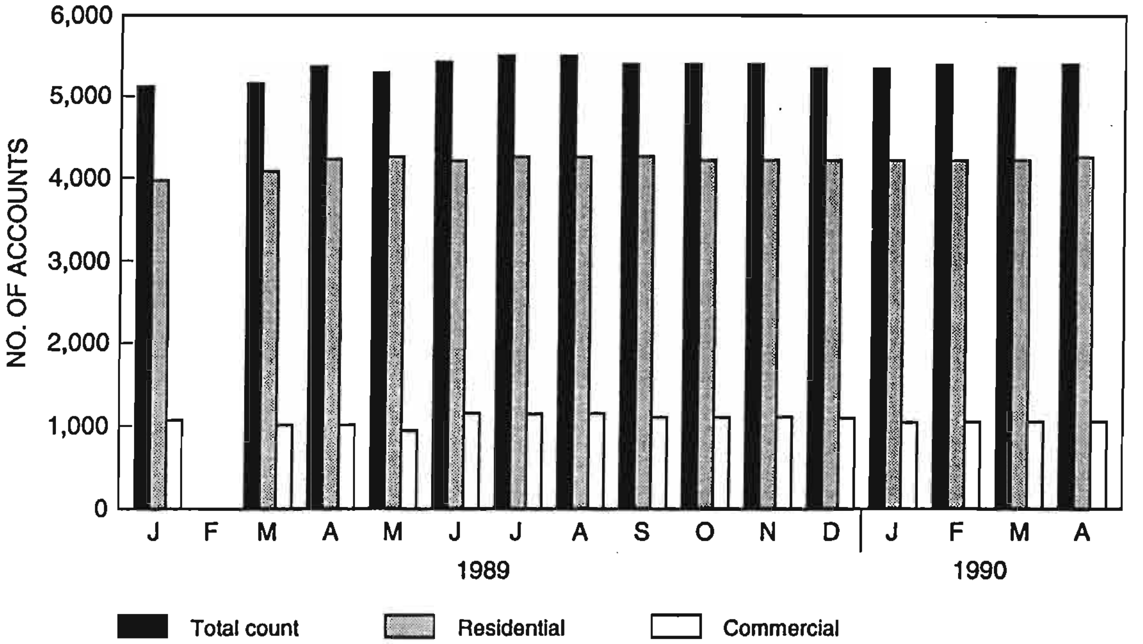
lay, then the meter is activated by air in the pipe and cannot accurately show the amount of ıter used. In such cases, a flat rate is used. The metered rate should be paid with base nsumption of 6,000 gal (22.7 m^3)/mo. From this, the relationship of a flat rate to a metered e shows the ratio of water supply for several hours to 24 hours. In April 1990, 68% of all useholds supplied with water were billed a flat rate, whereas 32% were billed a metered rate.

Appendix Figure A.2 shows a 5.6% increase in the number of water meters in use from ıuary 1989 to April 1990: from 5,117 to 5,405 meters. In this period, the number of meters ıdually increased. As shown in Appendix Table A.4, in April 1990, the metered count was ŀ75, 27% of the total number of accounts. Equipping each household with a meter is highly omoted.

Appendix Table A.4. Commonwealth Utility Corporation Water Use

	Meter	Flat	Total
No. of Accounts	1,475	3,930	5,405
% Residential	92.0	74.6	79.4
% Commercial	7.9	24.9	20.2
% Public	0.1	0.5	0.4
Amt. Used (mil gal/mo)	149.9	38.0	188.0
% Residential	91.3	46.6	82.3
% Commercial	8.7	42.5	15.5
% Public	0.0	10.9	2.2
Amt. Billed ($/mo)	—	—	370,783
% Residential	—	—	81.2
% Commercial	—	—	16.6
% Public	—	—	2.2

SOURCE: Commonwealth Utility Corporation file, April 1990.



SOURCE: Summary of billing records of the Commonwealth Utility Corporation file (1990).

Appendix Figure A.2. Commonwealth Utility Corporation water meter use

The number of meters for residential, public, and commercial use did not change much ıring that same period. In April 1990, of the total number of meters (5,405), 79.4% was for sidential, 20.2% for commercial, and 0.4% for public use. The monthly change in water ;age is shown in Appendix Figure A.3. Of the total usage per month, 60 to 70% was for ›useholds and the rest for businesses. Water consumption by residents increased from 80 mil ıl/mo (mgm) (302.8×10^3 m^3/mo) to 155 mgm (586.7×10^3 m^3/mo). Improvement of the peline system is one of the reason for this, but these figures include meters with flat and etered billings, so we cannot say precisely.

Residential water use is discussed now with using numbers in Appendix Table A.4. The 'erage number of family member is assumed to be five, because the total number of residents Saipan in 1986 was 21,777 (Stewart 1988) and the total number of residential meters in ›90 was 4,292, so we can assume the number of residents has not increased.

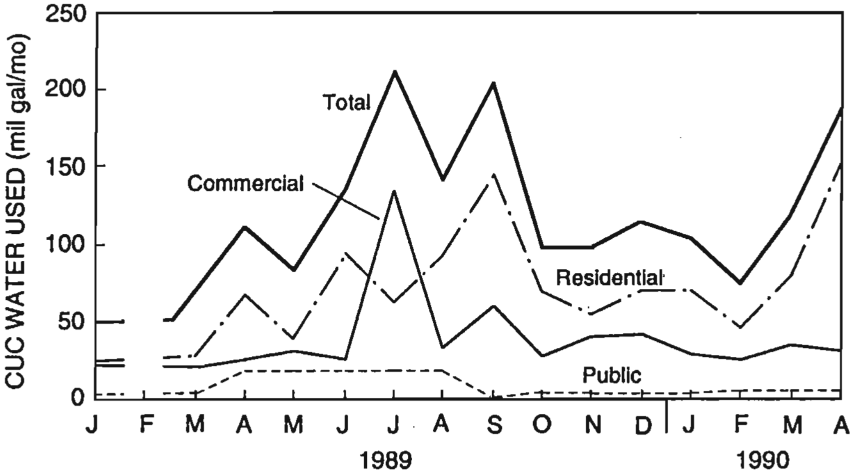
If the number of family members is five and the total amount from meters is divided by e sum of the number of metered and fixed billings then consumption per capita per day ;comes 67 gal (367 liters). This value seems more reasonable. This value is only for sidents.

Water revenue for April 1990 is given in Appendix Table A.4. Of the total revenue, 81% as for residential use and 17% for commercial use. This proportion is almost equal to the oportion of the meters and the proportion of served amount of metered.

HOUSEHOLD EXPENDITURE FOR WATER USE. A case study of household water use in ıipan is discussed here. Appendix Table A.5 shows the typical household water usage. enerally, most households buy drinking water in bottles from a bottling company, using rain- ater from their cisterns for other purposes that require relatively high-quality water and using ped water from their catchments for low-quality water needs. Every household does not use ese three types of water but are assumed here to do so. Also, many households do not have wage lines, but are assumed here to have them.

Using results of the survey, we assume one family uses 0.476 gal (1.8 liters)/day of ›ttled water for drinking, 20 gal (76 liters)/day of rainwater for cooking, and 85 gal 22 liters)/day of piped water for other uses. It pays $0.40 for 1 gal of bottled water and ..85 for 1,000 gal of piped water. In addition, the family possesses a cistern that costs $700 ıd a water catchment that costs $950. These might last 20 years. For the sewage line, the mily pays $7.93 a month. Based on these assumptions, a family of five pays $66.96 a onth; that is, $59.03 for drinking and other purposes and $7.93 for the sewage line.

WATER USE BY HOTELS. On the Philippine Sea side of Saipan is a large coral reef that esents excellent possibilities for tourism. Also, Saipan is the nearest foreign tropical island to pan. There are many large modern hotels along the western seashore.



SOURCE: Commonwealth Utility Corporation file, April 1990.

Appendix Figure A.3. CUC water used per month, January 1989–April 1990

Appendix Table A.5. Total Expenditure for Water Use By Five-Person Household

A. Water Cost
1. Pipeline water
   85 gal/person/day[a] × 5 persons × 30 days × \$1.85/1,000 gal[b] = \$23.59/mo
2. Rainwater
   20 gal/person/day[c] × 5 persons × 30 days × \$0.00/1,000 gal = \$0.00/mo
3. Bottled water
   0.476 gal/person/day[d] × 5 persons × 30 days × \$0.40/gal[e] = \$28.56/mo

B. Rain Catchment Tank
1. For drinking (500-gal capacity)
   \$700[f]/20 yr/12 mo[g] = \$2.92/mo
2. For other use (1,000-gal capacity)
   \$950[h]/20 yr/12 mo = \$3.96/mo

C. Sewage Line
   \$7.93/mo (for one metered account)[i]

Total	Piped and rainwater	\$59.03/mo
	Sewage	\$7.93/mo
	Total	\$66.96/mo

NOTE: All facilities not always installed in every household.
[a]Use average amount from category 01 of CUC billing summary file from Nov. 1989.
[b]According to flat rate, one county pays \$11.10/6,000 gal/mo (i.e., \$1.85/1000 gal). For the metered account, total counts of category 01 (residential) used 136.7 mil gal/mo in April 1990; in same month, total billing amount of 01 was \$268,033. Water rate of metered account was \$1.96/1,000 gal.
[c]According to CNMI report (1988), one household uses 55 gal/person/day of piped water and 20 gal/person/day of rainwater.
[d]Based on the interview of family J, 5 gal × 4 bottles/6 persons/wk.
[e]\$2 for one 5-gal bottle (interview of family J).
[f]Based on data from rain catchment company.
[g]Interest rate not considered.
[h]Based on data from rain catchment company.
[i]Average sewage billing amount of one count of category 01 from Nov. 1989 to Mar. 1990, based on CUC billing summary file.

As shown in Appendix Table A.6, in March 1988, there were 22 hotels (total number of oms, 1,650) in operation, 6 under construction (583 rooms), and 9 planned (1,892 rooms). the future, there will be 37 hotels (4,125 rooms).

In order to understand the water use conditions of hotels, we compiled a questionnaire App. D). Five hotels completed a questionnaire in a survey conducted with the cooperation of e Saipan Hotel Association. The participating hotels each had 200 to 300 rooms.

As shown in Appendix Figures A.4 and A.5, the number of tourists fluctuates. There are ree peaks: March, July, and December. Appendix Figure A.6 shows the monthly change in ater consumption of hotels D. Monthly consumption fluctuates with the number of monthly sitors, but the fluctuation in the per capita water consumption by tourists (App. Figs. A.7 and .8) is in opposition to the number of tourists. This indicates the existence of self-supplying ater systems in the hotels—since hotels cannot increase the daily consumption easily even if e number of tourists increases. In Appendix Figure A.9, consumption per capita of three otels (A, D, and N) is in proportion to the number of tourists, but not at a fourth hotel (H).

Of the five hotels, four have reverse osmosis systems and rain cisterns. Their water ources are diverse: well, rain cistern, and piped water. Hotels that have reverse osmosis ystems use mainly well water; additionally, they use rainwater and piped water. As shown in ppendix Figure A.10, hotels A, N, and H use groundwater as the reverse osmosis source; otel D uses piped water. Rainwater and piped water are used for diluting low-quality ground-ater and prolonging the life of the reverse osmosis modules. Using piped water for diluting eans it cannot be used as drinking water. Only hotel H uses some piped water directly. sually hotels must double their consumption capacity to clean reverse osmosis system odules.

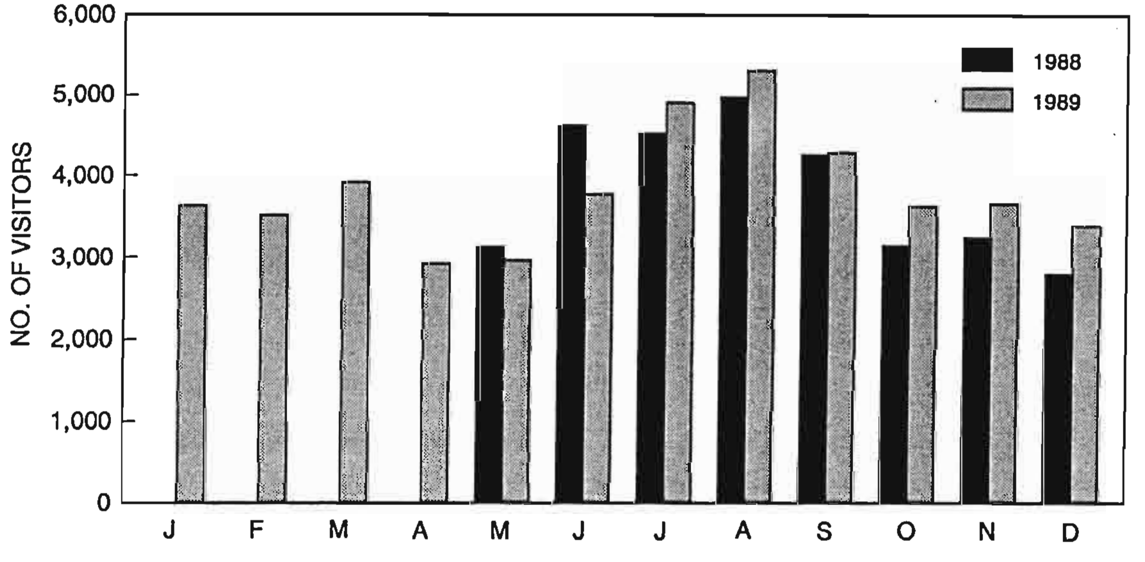
As shown in Appendix Figure A.11, the construction cost of a reverse osmosis system is proportion to the capacity of the system. The cost is \$750 to \$1,000/m^3 (\$2,839 to 3,785/1,000 gal). Maintenance costs \$0.11 to \$0.76/m^3 (\$0.42 to \$2.88/1,000 gal); the range due to the concentration of the source water and the life of the modules. Reverse osmosis ater is used for all purposes. Total dissolved solids concentration of untreated water is tween 3,500 and 5,000 ppm, and the concentration of purified water is between 50 and 00 ppm.

Since the ratio of catchment area to capacity of rain cistern is diverse (App. Fig. A.12), inwater systems must be planned for effective use. The construction cost of a rain cistern is 500/m^3 (\$2,271/1,000 gal), which is almost the same as for a reverse osmosis system. Of ourse, the maintenance cost of a rain cistern is negligible. Rainwater is used for all purposes cept drinking. It is used for washing dishes, watering lawns, and washing cars—all of hich require high-quality water.

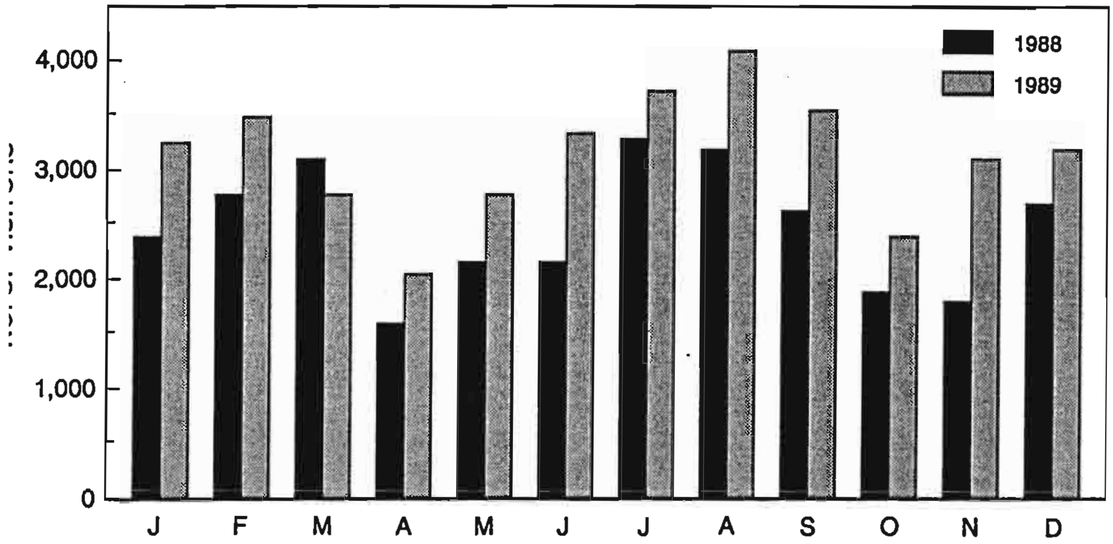
Appendix Table A.6. Number of Hotels, Saipan, 1987

No. of Rooms	Operating	Under Construction	Planning Stage	Total
<10	5	0	1	6
11–50	11	1	1	13
51–150	0	4	2	6
151–200	3	0	1	4
201–300	2	1	1	4
301–400	1	0	1	2
>401	0	0	1	1
Unknown	0	0	1	1
Total				
No. of Hotels	22	6	9	37
No. of Rooms	1,650	583	1,892	4,125

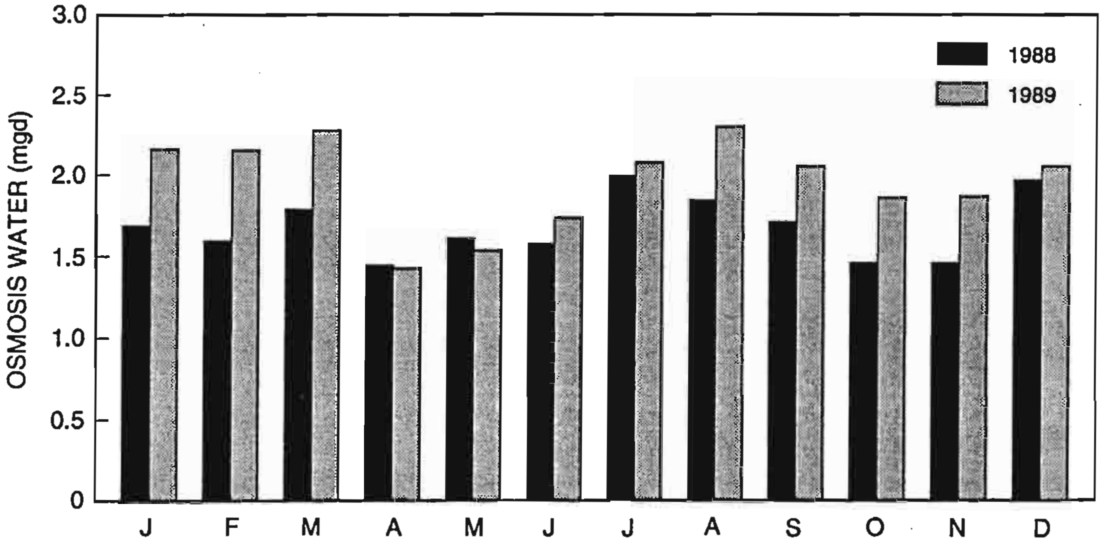
SOURCE: Stewart (1988).



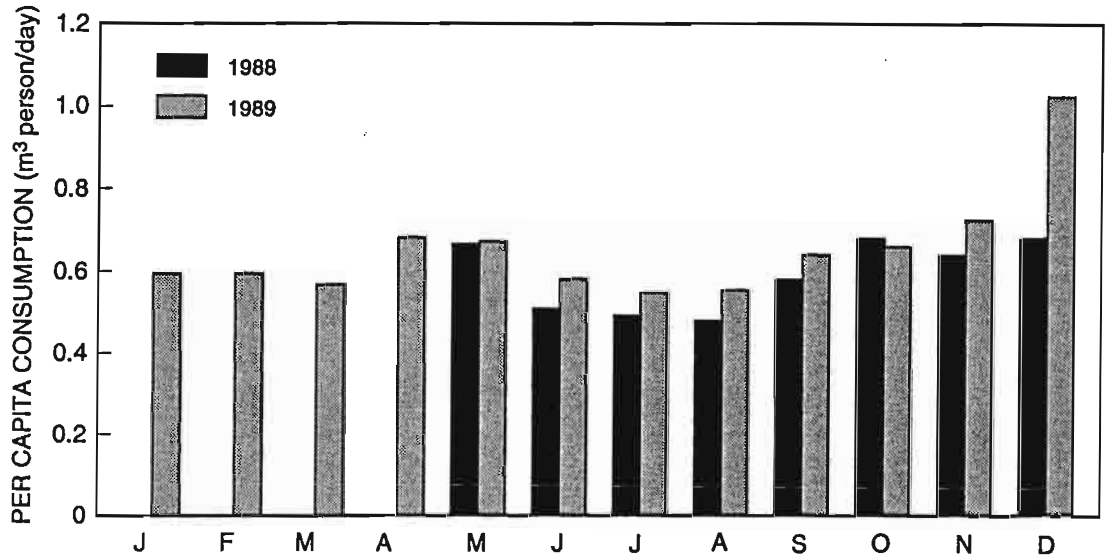
Appendix Figure A.4. Number of monthly visitors, Hotel N



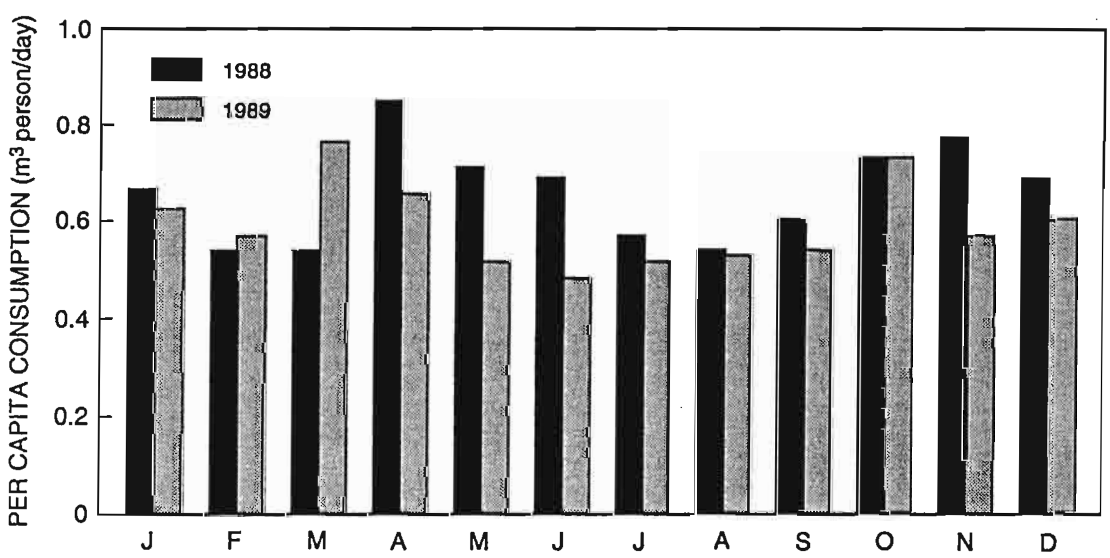
Appendix Figure A.5. Number of monthly visitors, Hotel S



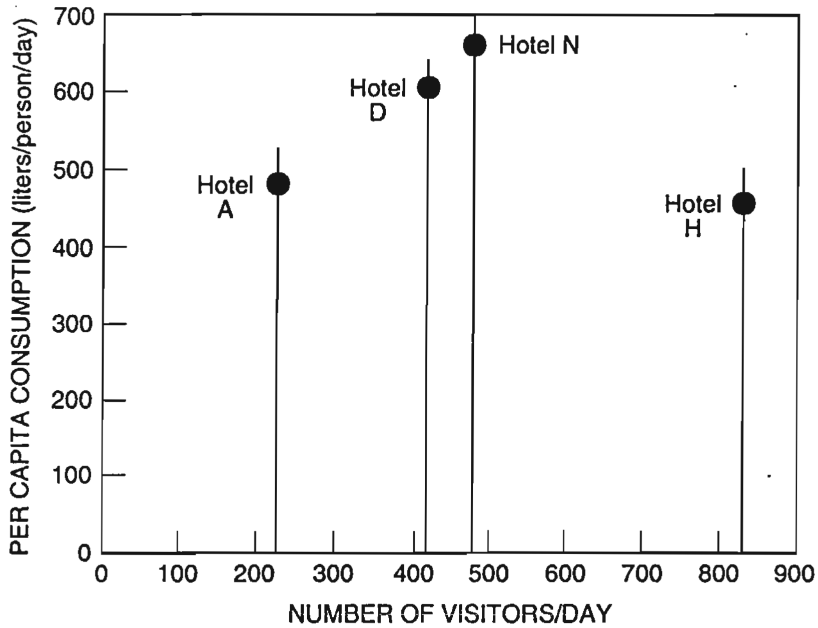
Appendix Figure A.6. Monthly consumption of reverse osmosis water, Hotel D



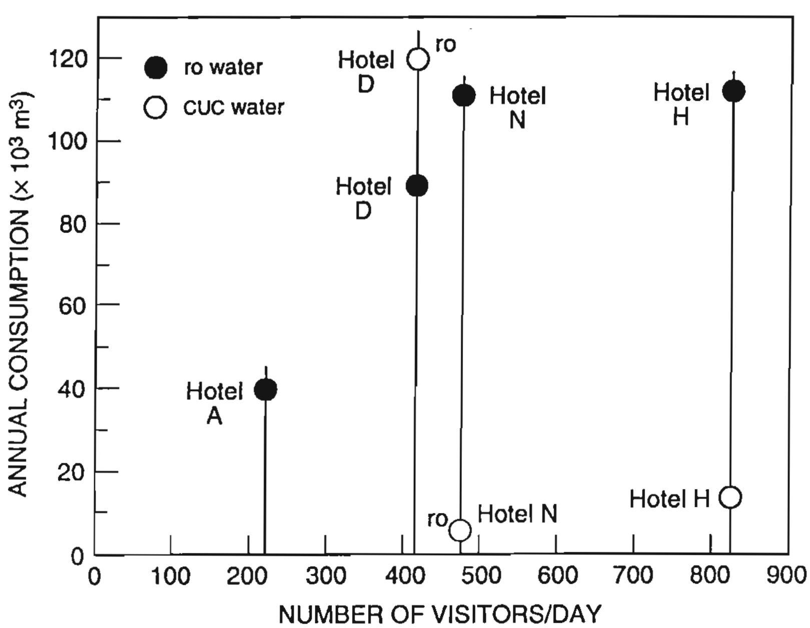
Appendix Figure A.7. Daily per capita water consumption of visitors, Hotel N



Appendix Figure A.8. Daily per capita water consumption of visitors, Hotel D



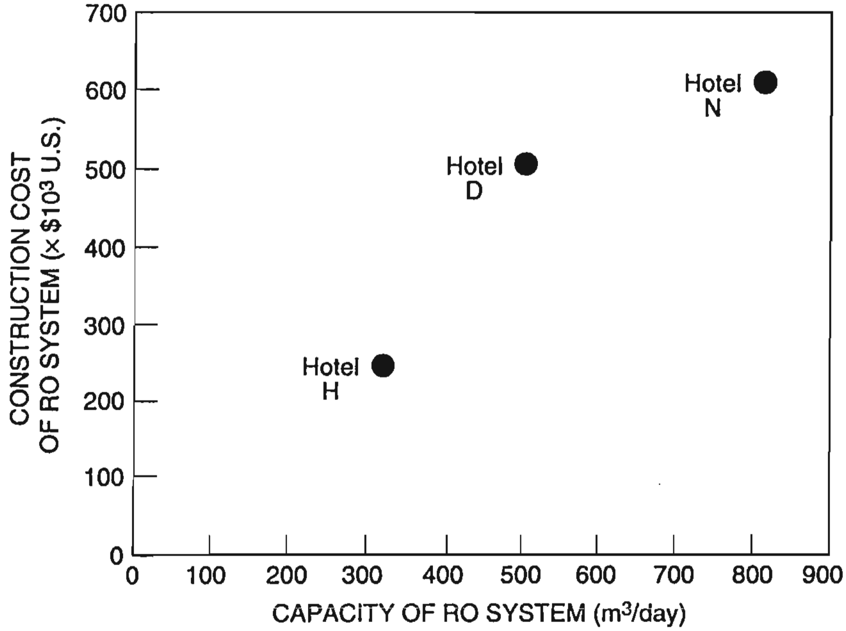
Appendix Figure A.9. Daily number of visitors vs. water consumption for four hotels, 1989



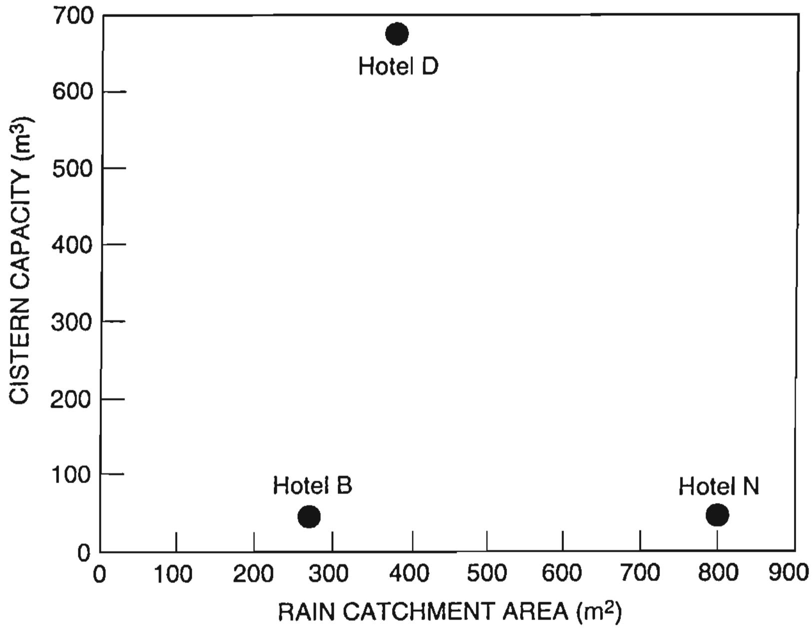
NOTE: ro = source for reverse osmosis system.

NOTE: Hotel A records start from July 1989; value shown in this graph is calculated from half year data.

Appendix Figure A.10. Daily number of visitors vs. annual water consumption of hotels, 1989



Appendix Figure A.11. Capacity vs. construction cost of reverse osmosis system



Appendix Figure A.12. Catchment area vs. capacity of rain cistern

Piped water is used for reverse osmosis untreated raw water or for several uses. Piped ater is used for washing cars, which rust easily. But some hotels use piped water for all ırposes. There may be a difference in the quality of the piped water supplied to different eas.

The cost of piped water is \$0.13 to \$3.00/m^3. The \$3.00 figure seems too high; the ːtual amount supplied may be less than the minimum supplied because of the rationing hedule.

Per capita water consumption in 1988 and 1989 was 600 to 660 liters/day for two hotels ıd 460 to 480 liters/day for two other hotels. These values exclude consumption of rainwater. is not known why the values differ. Usually one visitor consumes 1000 liters (264 gal)/day water in Okinawa; Saipan's estimate seems conservative.

The future water demands of hotels are discussed below using data collected from Hotel ikko (cf., App. B). As mentioned before, in March 1988, the total number of rooms in ›eration or under construction was 1,892, and in the planning stage, 2,233. In the future, the tal number of rooms will be 4,125.

Hotel Nikko has 313 rooms, and water consumption per room is 1 m^3 (264 gal)/day. ıey use 100 to 150 m^3/day for sprinkling their lawns during the dry season. If they sprinkle eir lawns during the entire year, daily consumption per room becomes about 0.32 to 48 m^3. If the total number of rooms in Saipan is 2,233, then daily consumption by hotels is 233 m^3 (0.03 m^3/s) for building use and 715 to 1,072 m^3 for sprinkler irrigation. The total is 948 to 3,305 m^3/day. In the future, total daily consumption by 4,125 rooms will be 4,125 ^{3} for building use and 1,320 to 1,980 m^3 for sprinkling, for a combined daily total of 5,445–105 m^3. The areas sprinkled differ widely among hotels. The calculation above is too crude predict future water use by hotels, yet we can say that water is a very vital element for high-ıality resorts, and that water demands will inevitably grow.

Because the pipeline system is now being improved, hotels should develop self-pplying systems which use on-site, low-quality groundwater that is prone to infiltration by awater. The cost of a reverse osmosis system is very high; thus hotels would like to use the eaper piped water (App. Table A.7).

If piped water will be inexpensive in the future, hotels will use it rather than some other ıter source. In the long term, this will deteriorate the quality of groundwater, which is the urce of piped water. More specifically, groundwater quality might deteriorate severely during ɜ drought season. Who pays the cost of groundwater quality conservation? How should ꟷlustries and the government share the cost of groundwater quality conservation? These might big issues in the future, especially for the hotel industry and the people of Saipan who nefit from this industry. A centralized, uniform water supply system might have some

Appendix Table A.7. Water Quality and Water Rate, Saipan

Purveyor	Chloride Concentration (ppm)	Unit Water Rate ($/gal)	Note
Imported bottled water	<10	2.95	—
Domestic bottle company	<10	0.90	$4.50/5 gal
Reverse osmosis company	300	0.016	$16.00/1,000 gal
Commonwealth Utility Corporation	1,000	0.0016	$111.50/70,000 gal
Okinawa Enterprise Bureau	<30	0.30	—

difficulties, which will be discussed later. How to share the cost in time and space is a big issue.

WATER DEMANDS OF OTHER INDUSTRIES. Other demands that should be discussed are those of garment factories, service industry such as restaurants, and agriculture. Garment factories import cheap materials and labor from the Philippines, Taiwan, and Korea to export products to the U.S. mainland. Based on interviews, at least one factory has used huge amounts of water for dying and washing products and has polluted streams and ponds. But we could not determine whether the factory is continuing such practices. Almost all of the factories might use less water under severe environmental and water resource conditions.

One garment factory that we visited started in 1986 and has 620 workers; it uses CUC water only for toilets and cooling. This factory has constructed rain cisterns of 423.1 m^3 at a cost of $55,000 and uses 4.23 mil gal (19 gal/day/person or 17 liters/day/person) of rainwater a year. Another factory uses piped water, rainwater, and on-site groundwater. Water demand for cooling of factories and other uses should be considered, but most of the water used by factories is for the domestic use of workers.

For agriculture, only one well in Kagman Field is known to be used for irrigation. Other agricultural areas seem to be irrigated by rainwater. Irrigation is a big issue in Saipan, where most of the vegetables are imported.

No data are available on the water demands of a service sector such as restaurants. Most restaurants apparently use rainwater for cooking. How to mange the quality of rainwater in cisterns is a big issue.

APPENDIX B. HOTEL WATER USE IN SAIPAN

Almost all of the large hotels on Saipan are situated along the beach road on the western oastline. Water rationing is an economic hardship for the hotel industry and an inconvenience) hotel guests; thus, every effort must be made to overcome this problem. Descriptions of fforts already made and a plan for the future as a result of interviews with personnel of Hotel [, one of the largest hotels on Saipan, are discussed in this section of the report.

Hotel N, which is located in the San Roque area, has 313 rooms (App. Table B.1). The verage visitor's stay is 3.7 days and the number of guests per room is two. On a yearly basis, ıe room occupancy rate is approximately 80 to 85%, and the average number of monthly isitors is 4,500. Of the total visitors, 95% are Japanese. Hotel occupancy is highest mainly om January to March and from June to September. On Saipan, winter is the dry season; thus, ınuary to March is a critical period from the standpoint of water supply for visitors.

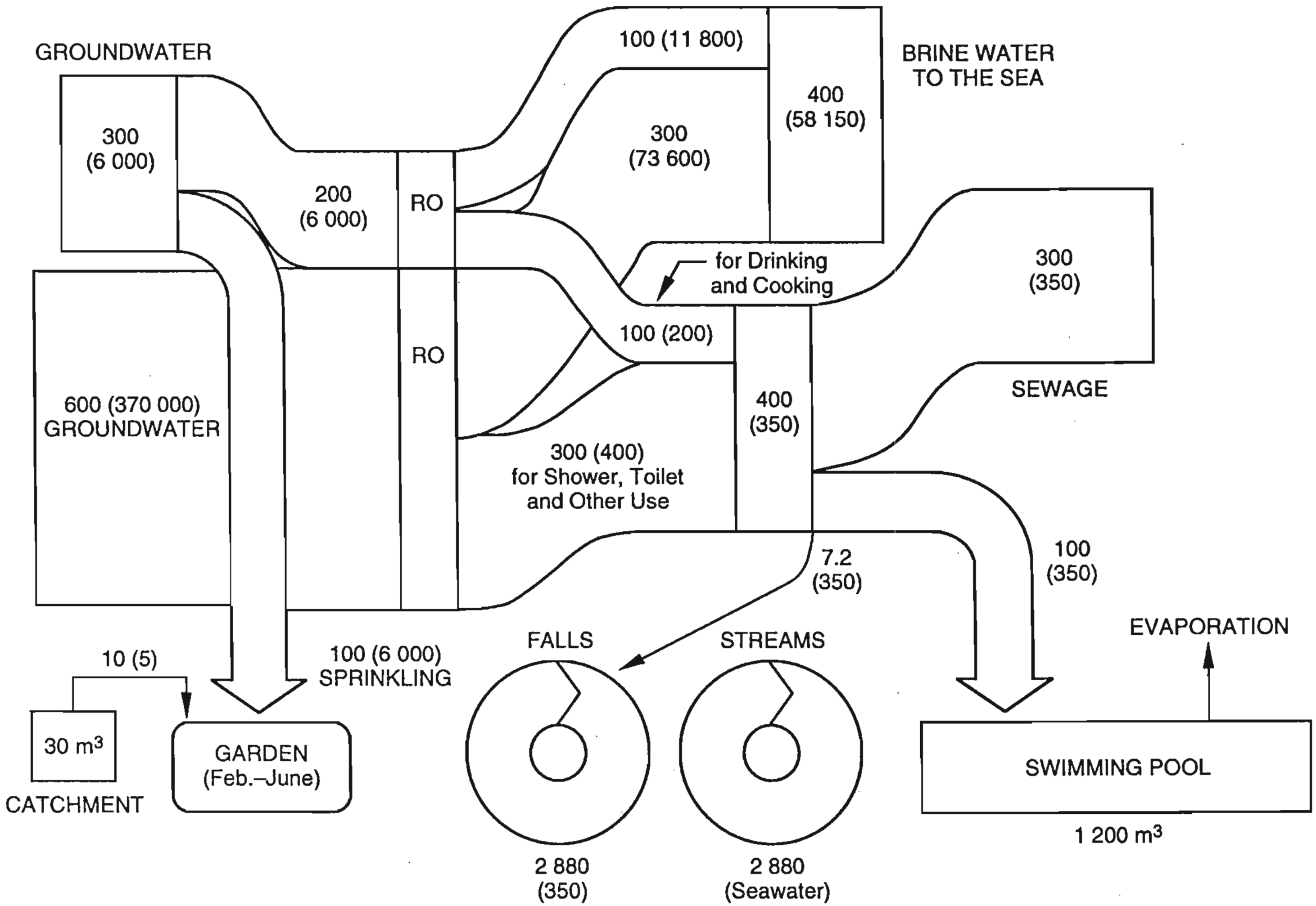
Hotel N is self-sufficient where water is concerned. The approximate daily consumption er room is 1 m^3 (254 gal)/day. Consumption for resort use (swimming pool, water falls, and vers) and watering of grounds is 100 to 150 m^3/day. Total consumption by the hotel is 400 to 50 m^3/day. Actual consumption in June 1990 was 379 m^3/day. Divided by the number of aily guests, 547.4 persons, the daily consumption per capita becomes 92 liters/day.

This hotel has several water sources. One is CUC piped water, which CUC does not ıpply because of rationing. The main sources of water are on-site wells. The four wells on the ountainside are 25 m deep and have been in use since the hotel opened for business. The 5 m deep well on the seaside has been in use since September 1989.

The total dissolved solids (TDS) concentration of the wells on the mountainside is 5,000 6,000 ppm, and of the well on the seaside, 37,000 ppm. The concentration of water filtered / reverse osmosis (RO) of the former is 200 ppm and of the latter, 400 ppm. Daily capacity of e reverse osmosis system is 750 m^3. Another water source is a 30 m^3 capacity rain catchment stern used for watering during the dry season (February–June).

The water balance of this hotel is shown in Appendix Figure B.1. Of the daily high-ıality mountainside groundwater withdrawn of 300 m^3, 100 m^3 is purified by the reverse smosis system, 100 m^3 is for hotel use, and the residual 100 m^3 becomes brine water. The take amount of 600 m^3 from seaside wells is purified; 300 m^3 of it is for hotel use. Of the)0 m^3 of purified water, 100 m^3 is for the swimming pool, 7 m^3 for waterfalls, and 300 m^3 r all hotel users.

The brine water (400 m^3) seems clear, but its TDS concentration is 60,000 ppm. It is scharged to the sea via a small stream, in which there are some algae. This high concentration



NOTE: 200-flow (use) rate (m^3/day); (6 000)–TDS concentration (ppm).
NOTE: Number of rooms: 313; guests: 4,500/day; length of stay 3.7 days/guest; per capita water consumption 690 liters/day (183 gal/day).

Appendix Figure B.1. Water balance flow chart for Hotel N, 1989

Appendix Table B.1. Hotel N Guests, 1989

Guests/Year	4,500 guests/mo × 12 mo = 54,000 guests/yr
Guests • Day/Year	54,000 guests/yr × 3.7 days/guest = 199,800 guests • day/yr
Guests/Day	199,800 guests • day/yr by 365 days/yr = 547.4 guests/day
Room Occupancy/Year	313 rooms/day × 85% occupancy × 365 days/yr = 97,108.25 rooms/yr
Guests/Room	199,800 guests • day/yr by 97,108.25 rooms/yr = 2.06 guests/room

brine water is of great concern to the people of Saipan. Brine water does not seem to affect e survival of aquatic life. For example, some fishes from the Hotel N's stream have been en in the drainage canal, and tilapia fish are common in the RO brine water in the Garapan ea.

Methods of brine disposal include underground injection wells, a sewage treatment plant, d a shallow, coastal lagoon. The first method is impossible because it increases the TDS ncentration in the groundwater, which many hotels use. As for the second method, high-ncentration brine water has a negative effect on the activated sludge in a treatment plant and ssens its treatment capability. The third method is inexpensive but requires an assessment of e diffusion and potential impact on the aquatic lagoon environment. Several alternatives must assessed to determine the most suitable method of disposal.

When the hotel was being planned, the issue of water supply was a serious nsideration. The hotel site was selected because of a nearby marsh and the possibility of taining groundwater. Water quality and quantity are important issues for hotel management.

For a hotel to have its own RO system to enable a self-sufficient source of water is a stly burden. Thus, some hotels are contemplating abandonment of their self-supply systems d reliance on the CUC.

At present, Hotel N maintains the mountainside RO facility, but the seaside facility (App. ble B.2) is maintained by a water treatment company that sells purified water to the hotel for 6.00/1,000 gal ($4.23/m^3). This company plan to recoup construction and maintenance sts within five years.

The cost of the mountainside RO facility (350-m^3/day capacity) is shown in Appendix ble B.3. Because this method uses high pressure to filter dissolved solids in untreated water, concentration of untreated water increases, and the life of the modules decreases. The odules must be changed every two years instead of the usual five years. There are four units, ch of which has 12 modules. In Saipan, $20,000 is needed to change one unit; $80,000 was id to change modules in two years.

Appendix Table B.2. Water Purification Costs Using Reverse Osmosis System at Seaside Well, Hotel N, Saipan

Groundwater Intake	600 m^3/day
Production	300 m^3/day
Total Production, 5 yr	300 m^3/day × 365 days/yr × 5 yr = 547,500 m^3
Total Expenditure	547,500 m^3/5 yr × \$4.23/m^3 = \$2.32 million/5 yr = \$0.46 million/yr

Appendix Table B.3. Construction and Maintenance Costs of Reverse Osmosis System at Mountainside Wells, Hotel N, Saipan (Interest Rate and Power Cost Excluded)

	Cost (\$)
Machine (four units)	275,164
Piping Work	51,461
Electrical Work	178,637
Construction	37,540
Total	542,802
Module Change Cost	40,000
Avg. 5-yr Cost	\$542,802/5 yr + \$40,000/yr = \$1,485,604/yr

NOTE: Capacity of RO system with 4 modules = 350 m^3/day.

Based on interviews, the hotel pays about \$700,000/yr for water. Roughly calculated, water costs \$4.80/day, when daily reverse osmosis production is about 400 m^3 (App. Table B.4.).

For example, the fixed water rate for residents is \$11.10/6,000 gal (22.7 m^3) (for 0.75-in. pipeline); that is, \$1.85/1,000 gal. If a company used 70,000 gal (265 m^3) of CUC water, its water rate would be \$1.60/1,000 gal (App. Table B.5).

What we can understand from the crude calculation above is, if the CUC pipeline is improved and hotels can be supplied plentifully, the water cost for hotels will be one-tenth the cost under the present water rate system. It is natural that hotels eagerly expect to reduce their water cost under the present, severe competition between hotels. Ten percent of a hotel's total expenditure is for water in Saipan, compared to 4 to 5% in Japan.

Under such severe water conditions, Hotel N makes a great effort to improve its water usage.

1. During a drought, the hotel distributes water-conservation promotion letters to its rooms and to all relevant travel agents.

Appendix Table B.4. Water Cost, Hotel N, Saipan

Total Expenditure for Water Use	\$700,000/yr
Reverse Osmosis Production	400 m^3/day
Unit Cost	\$700,000/yr/400 m^3/day/365 days = \$4.80/m^3 = \$18.20/1,000 gal

Appendix Table B.5. Piped Water Cost

Gallons	Unit Cost (\$/1,000 gal)	Billing Amount (\$)		
0–3,000	0.50	3,000 × 0.50/1,000	=	1.50
3,001–15,000	1.25	12,000 × 1.25/1,000	=	15.00
15,001–30,000	1.50	15,000 × 1.50/1,000	=	22.50
30,001–60,000	1.75	30,000 × 1.75/1,000	=	52.50
60,001–	2.00	10,000 × 2.00/1,000	=	20.00
Total				111.50
Unit Cost		\$111.50/70,000 gal	=	\$1.59/1,000 gal

2. The hotel uses various recycling methods to conserve water while using it to enhance the hotel environment and provide water-related recreational attractions. Waterfalls use recirculated water, and only a small portion of RO water is used for the swimming pool. Streams in the hotel garden are seawater.
3. The hotel uses rainwater for emergencies and for watering during the drought season.
4. As for watering the gardens, various qualities of water are used according to the needs of plants and trees. Well water with a 6,000-ppm TDS concentration is used to water grass during the drought season from February to June, after which grass revives in the rainy season.
5. The hotel has removed plugs from the bath tubs because almost all of the visitors are Japanese, whose custom it is to fill up the bath. This practice is wasteful, so the plugs were removed. As a result, water consumption decreased by two-thirds to one-half. Other hotels also follow this practice.

The above practices are good examples of the conservation type of water management scussed earlier.

APPENDIX C. IMPACT FEE

The CNMI government is planning to introduce an impact fee to strengthen weaknesses in the infrastructure. The impact fee did not become an ordinance until July 1990, but is has been applied when new hotels with outside capital were planned. For example, when Hotel Nikko Saipan was planned, no water main could supply the hotel, so the hotel constructed water lines for several kilometers from the CUC water main. At that time, conditions presented by the CNMI government were (1) that the construction cost of water lines extended from the CUC water main to the hotel should be paid for by the hotel and (2) that residents along the line could connect to the line and use the water.

Concerning "present" and "future" water resource management, the impact fee was developed to provide the CNMI government with an additional source of capital for its infrastructure and minimize expenditures for constructing and improving facilities. In every city, continuous expansion of the infrastructure, such as extending water mains to accommodate urban growth, means increasing fiscal demands. New businesses and residents who would like to use the infrastructure should pay their cost.

The impact fee is a big issue for the CNMI government because the big users of water are not residents but, rather, visitors from Japan. It might be reasonable for the government to request a fee for nonresidents who would like to engage in business on the island. Foreign businesses would like to connect their pipes to the CUC water main to have plentiful and inexpensive water, and they would be willing to pay an expensive fee to establish their business on the island. A negotiation of fees can be established.

Next, the impact fee is discussed from the standpoint of long-term resource and environmental conservation. Big water users, such as hotels, suffer during the drought season. Tourists usually consume four times more water than does the average household; hotels use water for maintenance of grounds, waterfalls, and streams. At present CUC cannot meet the demands of hotels because of rationing practices controlling the quantity and time of the supply; thus, hotels should maintain their own water supply systems. The reverse osmosis system needed to filter high chloride concentration groundwater is a considerable economic burden on hotels.

If the CUC pipe system can be improved and hotels can connect their pipes to the CUC main, CUC can save additional construction costs for the hotels and hotels can obtain as much water as they want. Hotels depend on CUC water lines, and CUC depends on groundwater. Because of the limitation of and high demand on groundwater sources, excessive pumping results in high concentrations of chloride in the groundwater and high costs of piped water.

Groundwater depletion cannot be reflected in the impact fee or water rate. "Depletion" ıeans water quality depletion. If water conservation is not practiced today, the result will be ıture groundwater depletion in quality and quantity.

How much of the cost hotels and CUC should pay is another political and economic issue. uch economic decisions are very difficult to make. One simple proposal is that the fee nposed should reflect the effort a hotel makes to be self-sufficient. This type of incentive :omotes conservation and recycling of water and conservation of groundwater resources. If a ıal system such as alternative 3 mentioned earlier is constructed and some extent of groundater quality depletion is admitted, hotels can use low-quality piped water as the untreated ater for their reverse osmosis systems and save on maintenance costs of their water systems.

APPENDIX D. WATER USE SURVEY IN SAIPAN

The questionnaire you are asked to complete is designed to develop a better understanding of the changing water use patterns in Saipan. Although water conditions are improving through the efforts of many in both the private and public sectors, the water resources of Saipan are not unlimited. It is important to plan sensibly in order to secure a balanced and sustainable growth for the long-term future.

The results of the survey will be tabulated and reported in a form that will ensure that your answers will be held in strict confidence. After completing the questionnaire, please return it in the self-addressed envelope provided. If you have any questions and need help in completing the form, please call the following telephone number ________.

This survey is made possible through a grant from the U.S. Department of the Interior, Geological Survey, to the Water Resources Research Center of the University of Hawaii. It is being conducted in close cooperation with the Commonwealth Utility Corporation and the Government of the Commonwealth of the Northern Mariana Islands.

Your full cooperation in this effort will be greatly appreciated.

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Questionnaire on Water Use in Saipan (Hotels and Garment Factories)

What is your company? Please choose one.

1. Hotel 2. Garment factory 3. Other ( )

When did your company start?

In 19( )

If your company is a hotel, please let us know the number of visitors in 1988 and 1989. If otherwise, please skip this question.

In 1988 ( ) visitors.

In 1989 ( ) visitors.

Average visitor duration of stay is ( ) days.

Please let us know the number of your employees.

The number of employees is ( ).

What kind of water supply system does your company have?

Please choose everything you use.

a. Reverse osmosis system

b. Rain catchment cistern

c. Piped water catchment system

d. Wells

e. Other source ( )

Please answer following items related to the systems your company uses.

a. Reverse osmosis system

(1) When did your company install this system?

The year was 19( ).

(2) What is the source of this system?

(a) Seawater (b) Well water (c) CUC water (d) Recycled water

(3) Please let us know the total consumption of water from this source in 1989.

Total consumption was ( ) gal/yr or ( ) m^3/yr

(4) For what purposes do you use this water? Please choose every purpose you use.

(a) Drinking (d) Laundry (g) Washing cars

(b) Cooking (e) Lawn irrigating (h) Others ( )

(c) Dishwashing (f) Toilet flushing

b. Rain catchment system

(1) When did your company install this system?
The year was 19(   ).

(2) What is the catchment area and capacity of rain catchment cistern of your company?
Rain catchment area is (   ) ft^2 or (   ) m^2.
The capacity is (   ) m^3 or (   ) m^3/yr.

(3) What is the total consumption of water from this source in 1989?
Total consumption was (   ) gal/yr or (   ) m^3/yr.

(4) For what kind of purposes do you use this water? Please choose every purpose you use.

(a) Drinking	(d) Laundry	(g) Washing cars
(b) Cooking	(e) Lawn irrigating	(h) Others ( )
(c) Dishwashing	(f) Toilet flushing	

c. CUC piped water

(1) When did your company install this system?
The year was 19(   ).

(2) If you have a piped water catchment tank connected to the CUC pipeline, please let us know the capacity of the tank.
The capacity is (   ) m^3 or (   ) m^3/yr.

(3) What is the total consumption of water from this source in 1989.
Total consumption was (   ) gal/yr or (   ) m^3/yr.

(4) For what kind of purposes do you use this water? Please choose every purpose you use.

(a) Drinking	(d) Laundry	(g) Washing cars
(b) Cooking	(e) Lawn irrigating	(h) Others ( )
(c) Dishwashing	(f) Toilet flushing	

d. Other water system

(1) What kind of system is this?
The system is (   ).

(2) When did your company install this system?
The year was 19(   ).

(3) Please let us know the total consumption of water from this source in 1989.
Total consumption was (   ) gal/yr or (   ) m^3/yr.

(4) For what kind of purposes do you use this water? Please choose every purpose you use.

(a) Drinking	(d) Laundry	(g) Washing cars
(b) Cooking	(e) Lawn irrigating	(h) Others ( )
(c) Dishwashing	(f) Toilet flushing	

: you have any opinion about the water use and water resources of Saipan Island, please let us now your opinion.

lease write your name and your company's name, address, and phone number. We would ke to send you the results of this questionnaire.

'our name
'ompany's name
.ddress of company
hone

hank you for your kind cooperation.