AN ASSESSMENT OF THE WASTEWATER REUSE POTENTIAL IN PUERTO RICO

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I. INTRODUCTION

A. The Problem

There is a growing understanding in Puerto Rico of the urgent need to conserve, reuse, and recycle our limited water resources. This is a consequence of both national and local policies. The President of the United States stated the case well when presenting to Congress the First Report on Environmental Quality (1970). He said: "We can no longer afford the indiscriminate waste of our natural resources; neither should we accept as inevitable the mounting costs of waste removal. We must move increasingly towards closed systems that cycle what are now considered wastes back into useful and productive purposes".

Puerto Rico, and in particular the metropolitan area of San Juan, has seen an increase in water rationing in the last ten years. This has been caused by a variety of reasons, the most important being a significant increase in water withdrawals. Data from the USGS(1) indicates total withdrawals in the vicinity of 36.2 m^3/s in the year 1980, compared to a figure of 23.0 m^3/s in 1960, for an increase of 57% in 20 years. This increase has been biggest in the water supply sector, going from 2.6 m^3/s in 1960 to 15.4 m^3/s in 1980. In addition to this increase in withdrawals, many reservoirs have lost a significant amount of their capacities due to very high erosion rates in their mostly unprotected watersheds. The problem of quantity in reference to potable water supply is compounded by the problem of quality. The Environmental Quality Board (EQB) of Puerto Rico indicates (2) that almost all the surface water bodies of the Island have problems with high coliform counts and *Schistosoma mansoni* (bilharzia). However, these same surface water bodies are classified by EQB's Water Quality Standards (3) as potential sources of potable water.

The problem is then one of allocation of scarce resources based on two constraints: quantity and quality. Present water planning in the Island is focused on quantity, that is, providing enough for everyone. However, by ignoring the quality factor this type of allocation can have results that may be far from the most economic ones. A current example of this is the city of Ponce, in the southern part of Puerto Rico, where the Puerto Rico Aqueduct and Sewers Authority (PRASA) must transport and treat water from a reservoir which is distant from the city while excellent quality groundwater is used for sugarcane irrigation in the outskirts of the city. Meanwhile, 0.44 ^{3}/s of primary treated sewage from the city are dumped into the sea. Obviously, although quantity-wise everyone is satisfied, this is not the most economical allocation of the available resources.

This work deals with the reuse aspect in the optimal allocation of the water resource. An assesment is made of the wastewater reuse potential in the Island with emphasis on the reuse of municipal wastewaters. The report makes a brief review of the literature relevant to the reuse possibilities of the Island and discusses the previous wastewater reuse work that has been done locally. This includes both planning and three small scale projects that have been conducted in recent years. From this general background, the present water quality standards are discussed in reference to the actual and future effluent limitations in the municipal and industrial sectors. An assesment of the current situation follows, and then the future situation is described in order to develop and evaluate a number of feasible reuse alternatives. The alternatives are evaluated and recommendations are made as to possible courses of action for implementation of the selected alternatives.

II. REVIEW OF LITERATURE

A. Previous Work on the Island

Five pieces of work are discussed here: two planning efforts and three field studies. The planning efforts were directed towards small areas of the Island and the three field studies had to do with irrigation of primary and secondary treated municipal wastewater, and of rum distillery effluent. The planning efforts are discussed first.

1. Ponce Regional Water Resources Management Study (4)

The study area for this work were 14 towns in Southern Puerto Rico around the city of Ponce. The general goal underlying the wastewater analysis was to assist in the restoration and maintenance of the chemical, physical and biological integrity of waters in the study area by:

a. optimizing wastewater reuse potential
b. emphasizing the potential of the soil for wastewater treatment and disposal, and enabling reuse by ground water recharge.
c. developing water resources plans consistent with all applicable Commonwealth and Federal quality control plans.

The major emphasis of the study was on the enhancement of water supply by the use of secondary effluent from three regional wastewater treatment plants that were planned for the area. These plants were to be established at Ponce, Guayanilla and Guayama. Unfortunately, economic realities that came into being after the study was completed have caused that only the Ponce plant is now in operation at the primary level of treatment, Guayama has been designed but is doubtful that it will be built in the near future, and Guayanilla is all but forgotten. However, the planning concepts formulated by the study are still valid, and are reviewed here.

The study concentrated on the reuse of domestic wastewater flows from the regional treatment plants. Wastewater composition and water quality required for reuse options were analyzed to determine additional treatment requirements. When developing a preliminary series of plans, the wastewater management alternatives considered the water supply options recommended for the area. The possibilities of recycling municipal wastewater and of recharging ground water aquifers to increase the water supply within the study area required a detailed analysis of the physical, chemical and biological characteristics of water available for reuse and recharge. Since the exact characteristics of the effluent from the planned secondary treatment facilities was not known at the time, values were assumed based on the best available information and present state-of-the-art treatment technologies utilized by the facility planning program.

In the land application of wastewater, detailed attention was given to the ability of the soils to remove undesirable materials from the water before being collected for discharge or before reaching ground water. The study identified and classified potential land disposal areas. Soil feasibility studies, results of agricultural research on crop production and nutrient uptake, water needs for various crops and problems with heavy metals and pathogenic and viral movements were important factors in determining the feasibility of land application of wastewater. Four different plans were analyzed, based on different flow projections. Cost estimates, in 1975 dollars, ranged from $15.81 to $28.48 millions.

Reuse by industry was another possibility that the study addressed. Since any additional treatment required of the secondary treated municipal effluent would be a direct function of a particular industry, the study did not address this specific detail. However, industrial areas with the potential for use of secondary treated effluent were investigated for their possibilities.

2. Study for the Development of the Wastewater Reclamation Program for the Ponce-Juana Diaz Region (5).

This was a study sponsored by the Puerto Rico Aqueduct and Sewer Authority and the Environmental Protection Agency to evaluate the reuse of wastewater as an additional source of water for the southern section of the Island, in particular that part comprising the Ponce-Juana Diaz Wastewater Region. This area was extended to cover adjacent areas that were deemed important in terms of hydrological or water supply considerations. The study area, with its large urban area in Ponce, its vast petrochemical complex in Guayanilla-Peñuelas, and its agricultural zone in Juana Díaz, could be considered as representative of the entire Island in such a way that the recommendations presented could be extended to other parts of Puerto Rico.

The study evaluated the industrial, municipal and agricultural demands of the area and compared it to the available water sources. It was projected that a scarcit, of water would develop during the early 1980's.

The methodology used incorporated a mathematical model of the water users and suppliers of the area. This model was used to develop a large set of alternatives (500) that were then further refined and narrowed down to a workable number (11). These eleven alternatives included both the municipal and industrial sectors.

After giving weight to these alternatives, including proper consideration of cost as the most important factor, but also considering environmental impact, public opinion, and implementation capability, the following was proposed as the best combination of alternatives to develop an effective water reuse/recycle program in the Ponce-Juana Díaz Region:

> "For final disposal of the effluent from the Ponce Primary Sewage Treatment Plant, and assuming that the chlorination equipment will be properly operated and maintained to produce a fecal coliform count of less than 1000/100 ml MPN, it was recommended that said effluent be used to irrigate sugarcane in the area of Mercedita and east of this location using Bronce Lake as a storage lagoon. The possibility of future expansion of the system to use Lakes 2 and 5 should be considered depending on the results obtained at Mercedita and on the actual increase in flow at the plant.
>
> The inmediate implementation of a groundwater pricing mechanism was recommended. This is in accordance to what is specified by the Puerto Rico Water Law. A fixed charge of 5¢/m^3 was suggested, but this figure should be revised to consider other factors not relevant to the reuse/recycle considerations of this project. Once this pricing mechanism is established, it is estimated that industrial recycle will increase by means of internal process changes. This should also cause an increase in the use of sea water for cooling and the recycle of cooling water by those industries that are presently using groundwater or buying it from PRASA.

At the same time that a groundwater pricing mechanism is set in place, positive economic incentives should be provided to stimulate efficiency in the use of water. It was proposed that the concept of the recirculation factor previously described be used as a positive incentive."

The proposals made in this study also fell victim to the deteriorating economic conditions. Since the Ponce Regional is some distance away from the areas to be irrigated, the operational cost of the project was high. However, on a present value basis, it was still cheaper than building and operating a secondary facility at Ponce. The reason for not doing it was that PRASA could not afford the matching for 201 funds and decided not to build the secondary and instead apply for a 301(h) waiver. If no investment was needed for a secondary, then the investment in reuse (which was of the order of $27 million, present value in 1980) did not make much sense from PRASA's point of view.

3. Irrigation of sugarcane Fields in Southern Puerto Rico with Sewage Effluents (6).

This was a pilot study conducted in 1976-77 which used the effluent from the Ponce Regional plant (primary) and the effluent from the Fort Allen secondary plant for irrigation of sugarcane. One cycle of sugarcane growth from planting to harvesting was monitored. Fresh groundwater was been used to irrigate the other plots serving as a control. In all plots water samples from both irrigation water and percolated water were analyzed to study the pollution effects of irrigation water on groundwater quality. Soil samples were also analyzed for their physical and chemical properties in order to study the impact of irrigation water on the soil characteristics. The quality of sugarcane production was analyzed to determine the effect of irrigation water on the crop.

Ponce primary effluent was evaluated as being generally good for sugarcane irrigation. With very high salt content, the Fort Allen secondary effluent was not suitable for use as irrigation water. For plots irrigated with sewage effluents, the organic content of the soil increased somewhat during the course of the sugarcane growth. However, the amount of increase appeared to be insignificant. The COD values of the filtrates at the depths of 1.0 and 1.5 meters showed little difference among the three types of irrigation water. This indicated that most organics in sewage effluents were retained within the upper 0.5 meters of top soil.

Nitrate in sewage effluents did not seem to increase the potential of nitrogen leaching into the groundwater. At the 1.5 meter depth, the nitrate concentrations in the filtrates of all three types of irrigation water from all the plots were low and did not appear to be harmful to cane growth.

The cane production rate and the cane sugar content of the Ponce effluent irrigation were comparable to those of the groundwater irrigation. The field irrigated with Ponce effluent yielded a cane production rate of 18.4 Kg/m^2 and a cane sugar content of 9.24%.

According to the author;

> "Technically speaking, using Ponce primary effluent for sugarcane irrigation is feasible. Nevertheless, it is not easy to put the related health and psychological problems fully under control. For this specific reason, using primary effluent may not be particularly recommendable for the irrigation of sugarcane fields. With further investigation on ways of alleviating these health and psychological problems, primary sewage effluent can be a potential source of irrigation water for sugarcane fields."

However, a preliminary study by Calás and Rios (7) proved that there is a population in Puerto Rico willing to consume reused water and that a proper advertising campaign could influence the rest enough for the implementation of water reuse.

4. Actual irrigation projects.

There are two ongoing wastewater irrigation projects in Puerto Rico which have been going on since the late 70's with very little publicity or published information available. The Holiday Inn Hotel in Ponce is a small facility with a package secondary plant of about 1.5 l/s capacity. The chlorinated effluent is used to irrigate the grass of the hotel. No information is available as to any problems caused by the facility.

The second project is the irrigation of sugarcane with rum slops by Don Q distillery again in the vicinity of Ponce. These rum slops come out of the distilery at about 52°C with a BOD in the order of 30,000 mg/l. They are pumped to a holding pond where they are cooled and diluted with ground water. The dilution is about 40-60% groundwater. This mixture is then regularly applied to about 200 ha of sugarcane. Informal data available indicates that no harmful effects have been observed in the sugarcane.

B. Review of Relevant Wastewater Reuse Literature

1. Sugarcane irrigation

The single most important and comprehensive study in reuse by irrigation of sugarcane on pilot field scale began in Mililani, Oahu, Hawaii in 1971 and was completed in 1975 as Phase I by the Water Resources Research Center, University of Hawaii (8). A continuation of the study denoted as Phase II A began in 1976 with a study to examine the crop yield that might be affected by different dilutions of secondary effluent, in order to alleviate possible distribution problems (9). Another supplemental study (Phase IIB) began in 1977 on the post-treatment of secondary effluent necessary for drip irrigation (10).

The Phase I project included field and laboratory studies of changes in water quality factors, viral content in the applied and percolating water and in the soil, and sugar yields and quality when sugarcane fields are irrigated with sewage effluent. An overall evaluation together with proposed principles and guidelines for irrigation of sugarcane with sewage effluent in Hawaii was achieved.

In the Phase I study the application of sewage effluent for the first year only of a 2-yr crop cycle increased the sugar yield by about 6% compared with the control plots. However, when sewage effluent was applied for the entire 2-yr crop cycle, sugar yield was reduced by about 6% and the cane quality by about 16% even though the total cane yield increased by about 11%. This points to the need for proper management in regards to the timing of the application.

The quality of percolate from the effluent-irrigated sugarcane cultured soil was of acceptable concentration from the standpoint of groundwater quality protection: the only possible concern was for nitrate nitrogen that sporadically exceeded the 10 mg/l limit for drinking water during the first 6 to 7 months of cane growth. However, similar levels of nitrate nitrogen occurred in the ditch water-irrigated sugarcane plots receiving commercial fertilizers at normal rates and the plots irrigated with effluent during the first year and with ditch water during the second year. Furthermore, there was no major difference in the total quantity of nitrogen produced in the percolate among the three different treatments in Phase II. These results are similar to those obtained in Puerto Rico by Tang (6).

Human enteric viruses were shown to be present in the majority of effluent samples examined and, hence, can be assumed to be present in the effluent applied to the irrigated field. However, the absence of these viruses in all sugarcane percolates samples over a 2-yr period in Phase I, plus other viral studies conducted, strongly suggest that the possibility of contaminating deep underground water sources is extremely remote.

The Phase II A study was completed in 1978 with the final project report published in 1980 (9). Basically the study concluded that up to at least 25% sewage effluent, diluted in ditch water, could replace ditch water for the irrigation of sugarcane over the full 2-yr crop cycle, using the ridge and furrow method, and still maintain the same sugar yield and leachate quality as observed for the controlled tests plots. Sugar yield for the 25% dilution was equivalent to that obtained from using secondary effluent for the first half of the 2-yr sugarcane cycle and ditch water thereafter. The other environmental and cultural parameters were approximately the same as observed in Phase I.

Inasmuch as a considerable amount of attention was being given in Hawaii and other places to converting to the more water-efficient drip method for irrigation of sugarcane, the Phase IIB drip irrigation study was concerned with what additional treatment of the secondary effluent is necessary to minimize plugging of the minute holes in the plastic tubing. The project concluded that the horizontal pressure filter was inadequate. However, a modified system was able to treat a mixture consisting of 25% effluent and 75% fresh water. The treatment system consisted of vertical flow, single media sand pressure filters and in-line screens treated with high dosages of chlorine during pressure triggered backwash. A further conclusion was that the necessary high technology, skilled operators, and high O&M costs many discourage utilization of post treatment as a viable approach to wastewater use by drip irrigation.

In summary, Hawaii's results show that: (a) a municipal secondary effluent can be used for sugarcane irrigation; (b) proper application is necessary to optimize crop yield; (c) the possibility of contaminating deep underground water sources is remote.

Since the significant differences between a secondary and a primary is in organic and solids content, and since these parameters are not of major importance in an irrigation system using the ridge and furrow method, it is estimated that Hawaii's results provide a sufficient data base to justify using primary effluent for sugarcane irrigation in Puerto Rico.

2. Rice irrigation (11)

The approximately 448 ha of rice fields in the Ishidomoseki area of Kumamoto City, Japan, require about 2 m^3/s of irrigation water. This water was supplied by river flow and groundwater, but an increasing population caused that in 1975 experimental rice cultivation with municipal wastewater was initiated in order to determine the feasibility of a substitution. The initial experiments demonstrated that the rice could be grown succesfully with municipal wastewater. Therefore, after 1976 the tests were refined to establish the most suitable percentages of dilution and addition of commercial fertilizer. During the next two years, the results showed that rice cultivation was acceptable where the effluent was diluted 50% and the application of commercial fertilizer was reduced to half the usual amount.

After 1978, experiments were conducted with 50% municipal effluent and varying amounts of commercial fertilizer: 0 (control), 5.6 kg or 11.2 kg per 0.1 ha (as NH_4-N). The commercial fertilizer was applied at three intervals: 5 days before the rice was planted, approximately 53 days later, and again in 7 days. The results showed that less commercial fertilizer was needed that had previously been assumed to produce a high yield rice crop and over fertilization with nitrates had a detrimental effect on the yield.

"Wastewater Irrigation of Rice" (12) is one of a series of EPA reports to furnish information on studies and current practices on using municipal effluents for crop production. The report evaluated three areas: the potential for and extent of wastewater reuse in rice production, the resulting food chain effects, and the cost effectiveness of this reuse. It was concluded that although the costs of land treatment systems are very site specific, an overland flow or a forage irrigation system may be cost effective and should be fully evaluated. Wastewater irrigation of rice should be viewed as having the same health hazards as wastewater irrigation of wheat or other controlled agricultural food crops which are not eaten raw. EPA recommends prior to reuse: "biological treatment by lagoons or in-plant processes plus control of fecal coliform counts to less than 1000 MPN/100 ml".

3. Industrial reuse

In an industrial context, cooling towers have been the primary point of application for reclaimed municipal wastewater. According to a 1975 EPA survey (13), 6.745 m^3/s out of a total 6.832 m^3/s of industrial reuse of reclaimed municipal wastewater occurred in cooling systems. This is to be expected, since cooling represents the largest single water-using process in industry, and since relatively low quality water can serve the cooling needs. However, actual application has not been widespread. This is probably due to municipal wastewater reuse being viewed by water suppliers and users alike as a complicated subject fraught by unique problems.

In Puerto Rico the biggest potential customer for reused cooling water would be the Electric Power Authority. This is a public corporation that generates almost all the electricity used in the Island. However, its existing thermoelectric plants are all cooled by seawater and no new plants are contemplated in the near or intermediate future.

The biggest single industry group in the Island is pharmaceutical. However, reuse/recycle literature from this group is scarce, and whatever information is available is very site-or process-specific. It is a fact that pharmaceutical products manufactured and the associated wastewater characteristics vary considerably from plant to plant, and even within plants making the same product. In addition, and because of the seasonal use of many products, production within a given pharmaceutical manufacturing plant often varies throughout the year.

The literature on other types of industrial reuse is ample. The interested reader is refered to the Industrial Recycling and Reuse sections of the Proceedings of Water Reuse Symposiums I and II (14) (15). Of particular interest in Puerto Rico is reuse in the petrochemical industry, which has been discussed by Kosarek (16) who has indicated that areas where water reuse is effective are: boiler make-up, process water, cooling water, cooling tower make-up, and product wash water. Reuse in the textile industry was examined by Tincher and Averette (17), who concluded that ozone treatment can be used to destroy most dyes and that it should be possible to destroy the color and reuse both the water and a substantial quantity of auxiliary chemicals, since ozone does not destroy the auxiliary chemicals as fast as it destroys the dyes.

EPA's Office of Research and Development (ORD) sponsored a study (18) to develop technical information on the potential for recycle and reuse of organic chemical industry wastewaters and to determine if real opportunities exist for reuse/recycle. The study was not completed because although the preliminary results identified several processes that could be reusing and recycling a larger quantity of process waters, it was determined that insufficient incentives existed at the time (1981) to promote further reuse/recycle.

Electronic components is a rapidly developing industry in Puerto Rico. A good reuse/recycle possibility is the rinse water from printed board manufacturing. Allan and Wipplinger (19) examined this recycle by using conventional pressure filters and ion exchangers. By careful consideration of the wastewater and make-up chemistries, flow characteristics, equipment design and operating parameters, better than 90% of rinse water return was achieved. A reduction in capital and operating costs over more conventional systems was also obtained.

4. Recreational reuse

Recreational reuse currently being practiced in the Mainland seems to be limited to application to parks, golf courses, and football and baseball fields (20). However, each county can cite a reservoir which is predominately filled with reclaimed wastewater and used for nonbody-contact sports. Since the peaks between supply and demand must be leveled, new storage impoundments which will support recreational use are been seeing. Bacterial/microbiological standards have been developed for recreational use; in some instances, the uses include body-contact sports. (21)

5. Domestic reuse.

Domestic reuse of reclaimed wastewater continues to be very site-specific and probably represents less than 5 percent of the number of reuse projects by the year 2000. Aquifer recharge similar to the Dan Region and Factory 21 (22) will continue to be a viable option to direct potable reuse. The Potomac Estuary Plant in Washington, D.C. (23) and the Denver Demonstration Facility (24) under construction will make significant contributions to the potable reuse alternative. Both facilities deal with the operation and demonstration of state-of-the-art technology. The Denver reuse plant is also committed to a very extensive health-effects research program. In Denver's case, projected costs of potable reuse will be competitive with new resource development by the year 1990. Since only transbasin water can be recycled, Denver must develop existing water rights and be ready to implement some form of potable reuse by the turn of the century.

III. EFFLUENT LIMITATIONS

Puerto Rico has a long history of rules and regulations to maintain the quality of the environment. This section presents the highlights of these regulations, specially as they apply to the control of water quality in the receiving waters. A discussion on the effects of this water quality standards on NPDES permits is also given.

A. Receiving waters

1. Health Department

The first regulations on receiving water quality were those promulgated by the Health Department as required by Article 8 of Law No. 142 of 1950 and Law 81 of 1912. The regulations, and their amendments, were known as Sanitary Regulations No. 127, 129 and 131. Their objective was to protect health and general welfare, to conserve or improve the quality of coastal waters, and to comply with the requirements of Public Law 80-845 as amended.

These regulations specifically prohibited the direct or indirect discharge of municipal or industrial effluents into the surface waters of Puerto Rico in such a way that the minimum water quality requirements would be exceeded. Quality requirements were set for the following parameters: coliforms, dissolved oxygen, floatables, biochemical oxygen demand, pH, radioactive substances, nutrients, color, turbidity, temperature, residue, total dissolved solids, chlorides and toxics. Additionally, the coastal waters were classified in relation to their use so that different standards applied to different areas. Classifications were as follows:

a. Class SA: for the conservation of existing natural phenomena.

b. Class SB: coastal waters dedicated to the propagation and commercial fishing of shrimps and lobsters.

c. Class SC: coastal waters to be used for swimming.

d. Class SD: coastal waters to be used for the propagation of marine life except those mentioned under Class SB.

e. Class SE: coastal water dedicated to industrial use or any other use except those mentioned previously.

With minor modifications, these classifications have survived to the present and are used in regulations from other agencies. Regulations 127, 128, 129 and 131 themselves were eliminated by article 7.3 of the Environmental Quality Board (EQB) Regulation 1, Water Quality Standards.

2. Environmental Quality Board

Water quality standards for all bodies of water in Puerto Rico were promulgated by the regulations issued by the Environmental Quality Board on January 4, 1974, which were later amended on May 1974, and August 1976. These regulations were enacted in accordance with the provisions of Law No. 9 of June 18, 1970, known as the Public Policy Environmental Act of Puerto Rico. These standards apply at all times, except for times when stream flow is less than the average minimum seven-day low flow which occurs once in any ten year period.

The water quality standards vary, depending on the designated uses for which the waters of Puerto Rico are to be maintained and protected. These uses are those specified by the Health Department, as previously discussed. Table III.1 shows the different standards applicable to the four use classifications which were designated in the regulations.

Figure III.1 shows the different water quality classifications as they apply to the water bodies of the Island.

In addition to the requirement of Table III.1, the following general and specific water quality standards were established, and apply to all bodies of water pursuant to Article 2, Section 2.1 of the above mentioned EQB Water Quality Standards Regulations of 1974, as amended:

a. The waters shall not contain neither materials atributable to discharges that will settle to form objectionable deposits, nor floating debris, scum, oil or other substances that will render them unsightly or deleterious.

b. The waters shall not contain substances in concentrations or combinations which are toxic or which produce undesirable physiological responses in humans, animals and plants. The maximum allowable concentrations of certain potentially toxic substances in receiving surface and coastal water are presented in Table III.2.

c. Organochloride pesticide residuals in surface and coastal waters shall not exceed 1/100 of the TL_m-96 of approved species. Organophosphorus and nonpersistent persticide residues shall not exceed 1/10 of the

Table III.1 Water quality standards and use classifications

	Class (*) SA	Class SB	Class SC	Class SD
1- Dissolved Oxygen	_ 5 mg/1 except for natural causes		_ 4 mg/1 except for natural causes	_ 5 mg/1. (_ 4 mg/1 a maximum of 4 hours within any 24 hour period.
2- Coliforms (**)	fecal coliform: 70 colonies per 100 ml. ——— 200 colonies per 100 ml	fecal coliform: 200 colonies per 100 ml. ——— 400 colonies per 100 ml ——— Shelfish growing areas where the numbers are: 70 col/100 ml. 230 col/100 ml.	total coliform: 10,000 colonies per 100 ml ——— fecal coliform: 2,000 colonies per 100 ml. 4,000 colonies per 100 ml.	
3- pH	7.3 to 8.5 except for natural causes			6.0 - 9.0 6.0 - 9.0 except for natural causes
4- Color	Not to be altered except by natural causes.		Not to be altered by other than natural causes except when proven harmless to biota and aesthetically acceptable.	10 units on the colorimetric Pt-C_o Standard

Table III.1 (Cont)

5- Turbidity	Not to be altered except by natural causes. Secchi disc must be visible at a minimum of 1 m	Secchi disc must be visible at a minimum depth of 1 meter.		50 JTU except due to natural causes.
6- Total Dissolved Solids	Not to be altered except for natural causes.	Not applicable		500 mg/1.
7- Chlorides	Not applicable			monthly arithmetic average not to exceed 250 mg/1.
8- Taste/Odor	None that would interfere with preservation or enjoyment.	None that would interfere with primary contact recreation or will give taste/odor to aquatic life.	None that would give taste/odor to edible aquatic life.	None that would interfere with use for potable water or give odor/taste to aquatic life.
9- Nutrients	Not to be altered except by natural causes. $P \leq 25$ ppb	To be established later		Phosphorus as Total P not to exceed 25 ppb. Board to determine minimum degree of treatment to satisfy intent of regulations on a case-by case basis.

Table III.1 (cont)

10- Other Pathogenic Organinisms	Does not apply	Free from infective forms of Schistosoma mansoni.

Source: EQB Water Quality Standards Regulations of 1974, as amended

(*) Classes:

SA - Coastal waters not intended for any activity that might be detrimental to existing natural phenomena.

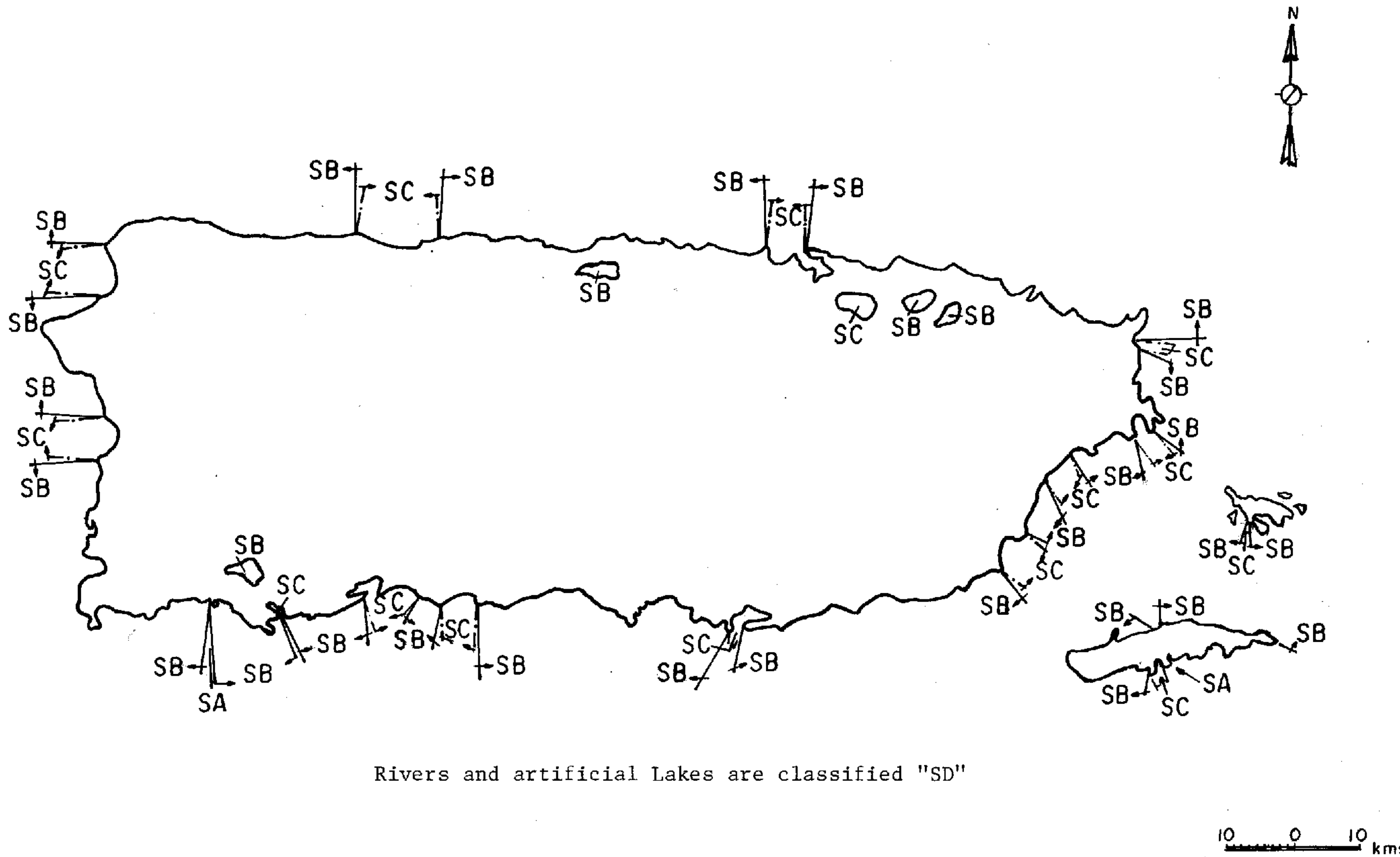
SB - Coastal waters intended for direct human-water contact and propagation of desirable species.

SC - Coastal waters intended for indirect human-water contact and propagation of desirable species.

SD - Surface waters intended as raw water sources and for propagation of desirable species.

(**) Coliforms: First figure is the maximum allowable number of colonies per 100 milliliters, as averaged for at least five samples taken over a month period. Not more than 20% of the samples should exceed the count given in the second figure.

FIGURE III.1 WATER QUALITY CLASSIFICATIONS



Rivers and artificial Lakes are classified "SD"

Table III.2 Maximum allowable concentrations of toxic or potentially toxic substances in receiving coastal and surface waters.

SUBSTANCE	COASTAL WATERS Limit (mg/T)	SURFACE WATERS Limit (mg/l)
Arsenic (AS)	0.15	0.050
Barium (B_a)	1.0	1.0
Boron (B)	4.8	1.0
Cadmium (Cd)	0.005	0.005
Carbon (Chloroform extract)	28.0	0.15
Chlorides (Cl)	---	250.0
Chromium (Cr) (hexavalent)	0.05	0.05
Chromiun (Cr) (trivalent)	0.30	0.05
Copper (C_u)	0.05	0.04
Cyanide (CN)	0.01	0.20
Detergents (Methylene blue active substances)	0.5	0.100
Fluorides (F)	1.3	---
Iron (Fe)	0.200	---
Lead (Pb)	0.015	0.05
Manganese (Mn)	0.100	---
Mercury (Hg)	0.001	0.001
Nitrogen (NO_3, NO_2, NH_3)	5.0	---
Nitrate plus nitrite (as N)	---	10.0
Phenols	0.010	0.001
Selenium (Se)	0.01	0.01
Silver (Ag)	0.001	0.001
Sulfate (SO_4)	2800.0	250.0
Uranil (UO_2)	0.500	0.500
Zinc (Zn)	0.050	0.050

Source: EQB, Amendments to the Water Quality Standards Regulations, August, 1976.

TL_m-96 of approved species. In no case shall pesticide residuals exceed the concentrations listed in Table III.3.

d. When two or more toxic materials are or may be present at the same time in a body of water, the allowable concentrations of each material shall be determined by means of biossay or any other applicable method approved by the Board. When the allowable concentration for combination of toxic materials is determined by bioassay and the presence of toxic substances is caused by only one discharge, the applicable water quality standard in the boundary of the Initial Mixing Zone for any of the toxic substances will be 1/z of the concentration of those substances multiplied by the dilution factor resulting from bioassay with the said discharge, i.e.:

$$C_c = 1/z \times C_d \times (TL_m\text{-96 or more})$$

Where:

C_c= applicable water quality standard in the body of water for any of the toxic substances present in the discharge.

C_d= concentration of toxic substances in the discharge.

z= will equal 10 for non-persistent toxicants, and will equal 100 for persistent toxicants or substances which tend to accumulate in the biological food chain.

Table III.3 Maximum allowable concentrations of pesticide residuals in surface and coastal waters

A. Organochloride Pesticides

Substance	Concentration (micrograms per liter or ppb)
Aldrin-Dieldrin	0.002
Chlordane	0.004
DDT	0.001
Endosulfan	0.001
Endrin	0.001
Heptachlor	0.001
Lindane	0.004
Methoxychlor	0.020
Mirex	0.001
Toxaphen	0.005
Perthane	0.070

B. Organophosphorus and Non-Persistant Pesticides

Substances	Concentration (micrograms per liter or ppb)
Demeton	0.100
Guthion	0.010
Malathion	0.100
Parathion	0.004
Coumaphos	0.010
Dursban	0.040
Fenthion	0.400
Naled	0.400
2, 4-D	80.00
2, 4, 5-TP(Silvex)	10.00

Source: EQB, Amendments to the Water Quality Standards Regulations, August, 1976.

When the presence of toxic substances is caused by more than one discharge, and to these discharges cannot be assigned a single Initial Mixing Zone nor separate Initial Mixing Zones without overlapping, the allowable concentration for any toxic substance in that body of water shall be determined by the Board on a case-by-case basis, in accordance with the intent expressed in (d) above, upon request of the discharge.

Article V of the EQB Water Quality Standard Regulations of 1974, as amended, establishes general provisions for mixing zones, as well as standards for granting initial (IMZ) and final (FMZ) mixing zones.

e. The maximum concentration of Ra -226 and Sr-90 shall not exceed 3 and 10 picocuries per alpha emitters, the gross beta concentrations shall not exceed 1000 picocuries per liter.

f. Hot water discharges shall not raise the monthly arithmetic mean of the maximum daily temperature of any body of water by more than 1.5°F, and shall not cause the temperature of any body to exceed 94°F. Furthermore, the rate of discharge shall not alter the temperature of the receiving body by more than 1°F per hour, and shall not exceed a raise of 5°F in any 24 hour period.

g. No thermal discharge shall be injurious to fish, shellfish or the indigenous population, nor in any way affect the desired use of the body of water. In the case of stratified lakes, the thermal discharges shall be confined to the epilimnetic layer, i.e., the region that extends from the surface to the layer of large temperature gradients.

Under the general Provisions of Article 4 of the EQB Water Quality Standards Regulations, it is established that:

a. No person shall cause or permit the discharge of any water pollutant that would prevent the receiving body of water to attain or maintain the prescribed standards.

b. No person shall cause or permit the discharge of any water pollutant in violation of the effluent limitations established pursuant to Section 402 of the Federal Water Pollution Control Act Amendments of 1972. This restriction specifically applies to point sources.

3. Puerto Rico Aqueduct and Sewer Authority

According to Chapter II of Rules and Regulations for the Supply of Water and Sewer Service and the Recreational Use of Reservoirs, Puerto Rico Aqueduct and Sewer Authority, (1967): "It is prohibited to throw into the supply sources of the water works of the Authority, such substances as sewage, industrial wastes in general, liquid substances, matter or objects that may pollute the water". It is also prohibited to throw or deposit on the banks or shores of the water sources, substances, liquids, matter or objects that may pollute the waters of the waterworks or hinder the effectiveness of the waterwork and sewer systems.

It is also prohibited to bathe, swim, wash clothes, water or bathe animals, spit, wash vehicles, or to use said waters or the water system for any purpose that might jeopardize the public health or alter the chemical or bacteriological composition of the water. Urinating, defecating, throwing or depositing on the surrounding grounds or into such waters urine, manure, molasses, rubbish, garbage, dead animals, refuse from slaughterhouses, pens or butchering establishments, are all prohibited. The Authority may order the removal or abatement of the aforementioned infectious matter, substances or objects, and if not removed within 24 hours, it may do so at the expense of the offender.

With respect to the location of septic tanks or cesspools it is stated that: "It is prohibited to locate latrines, septic tanks, or cesspools in the vicinity of the supply sources of the waterworks of the Authority, where they may pollute the water of said sources".

The enforcement power of the Authority is stated as: "It is hereby declared to constitute a public nuisance any act or thing done which may be detrimental to the water and sewer systems operated by the Authority or to the purity and conservation of the water supply sources of said water systems, the Authority being fully empowered to correct or abate such public nuisance, according to law. The Executive Director of the Authority in the name of this instrumentality may file an injunction or any other legal proceeding in court in order to enforce the provisions of the Puerto Rico Aqueduct and Sewer Authority Act and of these regulation".

B. NPDES Permits

All dischargers into the navigable waters of the Island must have an NPDES permit. These permits are given by EPA, but as the Clean Water Act requires, EQB must first provide EPA with a Water Quality Certificate. This certificate essentially specifies the quality the effluent must have such that the water quality standards will not be violated. In the case of any discharge to a river or creek, these are the SD standards. Since flow at most rivers in Puerto Rico is very low and dilution is also low, and since it is not currently possible to define a mixing zone in a river, the effluent must basically comply with the SD standards. The case is then that the requirements of EQB's certificate are usually much more stringent than secondary treatment for municipal facilities and BCT for industrial facilities. A typical water quality certificate for a municipal discharger under this stringent conditions is given in Table III.4. A quick examination of this Table indicates that advanced treatment at the level of at least carbon adsorption is required to comply with the limits. This would constitute an ideal situation from a reuse/recycle point of view, since such a good quality effluent has many uses. However, at the present none of these water quality certificates are being complied with. The reason is that all the plants with such stringent levels have interim permits that in many cases require less than secondary treatment in recognition of the obvious fact than an advanced plant can not be built overnight. It is expected that by July 1988 all municipal plants in the Island will be providing at least secondary treatment, and the need for more advanced treatment will be considered starting in late 1987.

TABLE III.4 NPDES EFFLUENT LIMITATIONS

Effluent Characteristic	Discharge Limitations			
	Kgs/day(lbs /day)		other units (specified)	
	Daily Avg	Daily Max	Daily Avg	Daily Max
Flow m^3/day (MGD)				3785.2 (1.00)
BOD_5 (mg/1)				5 mg/1
Total Suspended Solids (mg/1)				
COD (mg/1)				
Settleable Solids (ml/1)	A substantially complete removal of settleable solids shall be achieved.			
Fecal Coliforms (MPN/100 ml)			2,000	No more than 20% of the samples shall exceed 4,000.
Total Coliforms (MPN/100 ml)				10,000
Residual Chlorine (mg/1)				0.5 mg/1
Dissolved Oxygen (mg/1)	shall be at all times above			5.0 mg/1
Oil and Grease (mg/1)			10.0	15.0 mg/1
pH (SU)	shall always lies between			6.0--9.0
Turbidity (JTU)				50.0
Color (CO-Pt SU)				10.0
Chlorides (mg/1)				250.0 mg/1
Surfactants				0.1 mg/1
Carbon (Chloroform extract)				.15
Chromium ($Cr^{+}6$)(hexavalent)				0.05 mg/1
Chromium (Cr^{+3})(trivalent)				.05 mg/1
Copper (Cu)				0.05 mg/1
Cyanide (CN)				.20 mg/1
Detergents (methylene blue active substances)				.100 mg/1
Manganese (Mn)				.05 mg/1
Mercury (Hg)				0.001 mg/1
Phenols				.001 mg/1
Selenium (Se)				0.01 mg/1
Silver (Ag)				0.001 mg/1
Sulfate (SO_4)				250 mg/1
Uranil (UO_2)				0.5 mg/1
Zinc (Zn)				0.05 mg/1

IV. ASSESMENT OF CURRENT SITUATION

A. Institutional Framework

There are many agencies in Puerto Rico responsible for different aspects of water supply, as follows:

1. The Puerto Rico Planning Board is the regulatory agency at a central level for economic and social planning. As part of its functions it prepares an integrated development plan for the Island. This plan designates which area will be developed for industrial use or residential use. These designations are critical to water supply decisions.
2. The Department of Natural Resources has the responsibility for planning and managing the water resources in Puerto Rico.
3. The Environmental Quality Board (EQB) is the regulatory agency which coordinates permits for discharges and produces water quality standards, as mentioned in Chapter III.
4. The Puerto Rico Electric Power Authority owns and operates reservoirs for agricultural water supply and hydroelectric power.
5. The Department of Health monitors the drinking water supply system to insure the water quality as to prevent the spread of water-borne diseases. This agency is responsible for the implementation of the Safe Drinking Water Act.
6. The Corps of Engineers performs special comprehensive water resources studies at the request of other agencies.

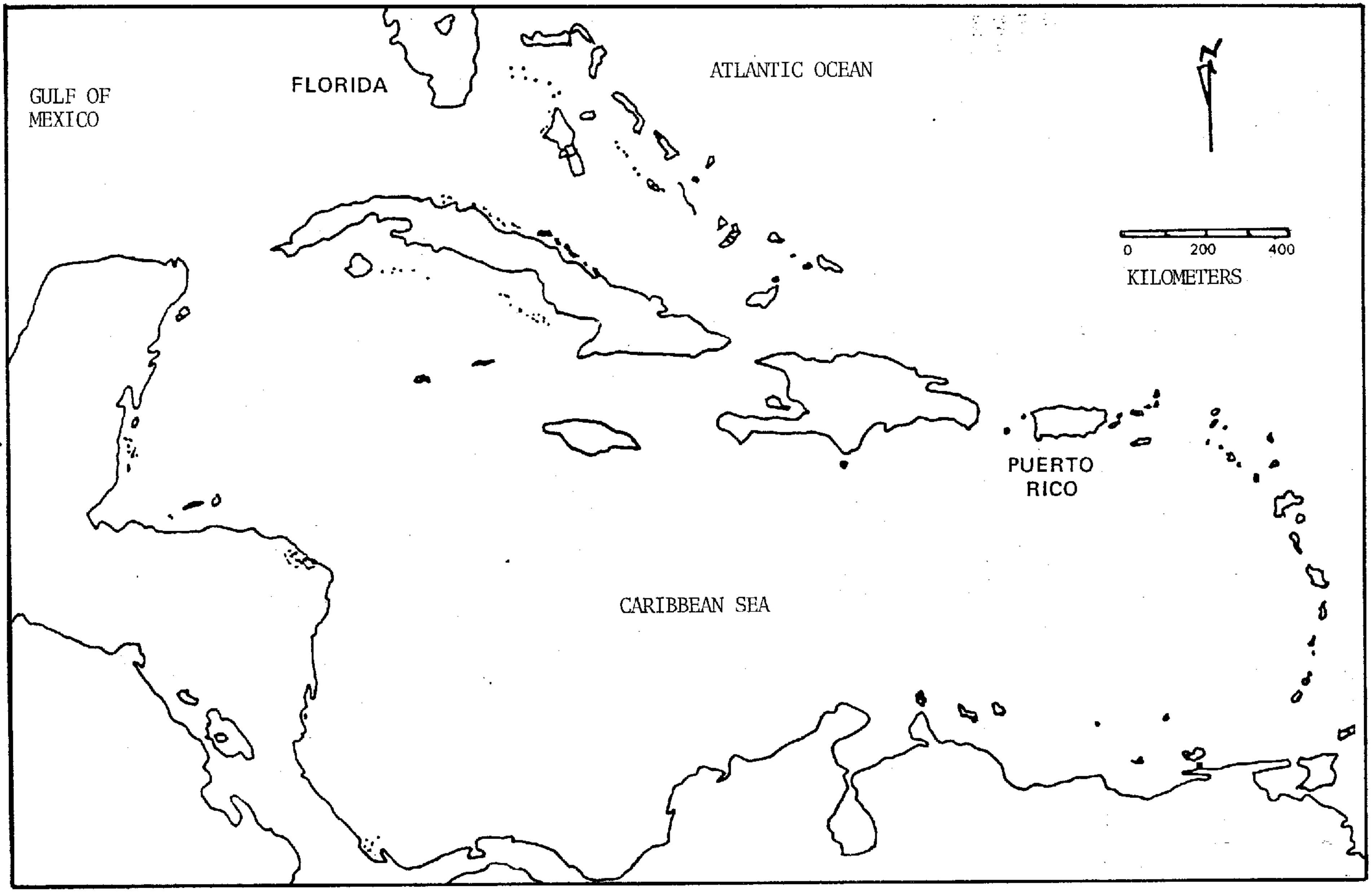
7. The Puerto Rico Aqueduct and Sewers Authority is responsible for development, construction, operation and maintenance of the aqueducts and sewers of the Island in order to provide its costumers a safe and efficient service.
8. U.S. Geological Survey is a federal agency responsible for the collection of data of interest for the water supply. They have gaging stations for the stream monitoring system and have a groundwater monitoring system in the southcoast of Puerto Rico.
9. Environmental Protection Agency is a federal agency which regulates and enforces the federal laws for the protection of the environment. Part of its responsibilities is to plan for the water supply of the nation.
10. U.S. Soil Conservation Service is a federal agency which works for the improvement of agricultural practices. This agency has proposed sites for the location of dams and constructed some.

B. Geographical Description

The Commonwealth of Puerto Rico lies midway in the Antillean Archipelago which extends from the Florida Peninsula to Venezuela. Located between the Atlantic Ocean and the Caribbean Sea, Puerto Rico is the smallest of four islands known as the Greater Antilles (See Figure IV.1)

The Island's landmass is approximately 160 Km long and 56 Km wide and its topography is characterized by a mountainous interior surrounded by coastal plains. Forty-five percent of its 2,250,000

FIGURE IV.1 PUERTO RICO AND THE CARIBBEAN BASIN



cuerdas (a Spanish unit of measurement roughly equivalent to 4000m^2) of surface area is occupied by mountains and approximately half of all lands have steep slopes with forty five or more degrees of inclination. The coastal plains account for 80% of all flat lands.

Puerto Rico's relative closeness to the equator gives rise to a tropical oceanic island climate typified by high levels of solar radiation, small variations within overall warm temperatures and fairly constant marine tradewinds. Average annual temperatures fluctate from 30°C maximum to 19.4°C minimum. Average diurnal variation, that is to say temperature change during a day, is 10.6°C compared to a mean annual temperature variation of 3.3°C.

A constant high level of solar radiation coupled with humid marine tradewinds flowing over the Island's mountainous terrain yields an average annual rainfall of 1.90m per year. This orographically influenced rainfall concentrates on the northeasterly windward slopes of mountains causing wide variations in rainfall distribution and promoting several different ecological lifezones throughout the Island. For this reason most rivers, including the largest, empty into the north coast. South of the Cordillera Central, the east-west mountain axis, rivers have shorter runs and they tend to have intermitent flows.

Rain is virtually the Island's only source of fresh water and it feeds seventeen river basins of which only seven drain areas larger than 250 Km^2. The largest river is Río Grande de Loíza draining an area of approximately 794 Km^2. Other water bodies include 25 man-made lakes or reservoirs, one natural fresh water lake named Laguna Tortuguero and 25 natural lagoons with tide influenced salt and brackish waters. Figure IV.2 shows the different water bodies of the Island.

Total runoff for Puerto Rico is estimated to be 135 m^3/s, flowing to the Island's coasts as follows: 77.4 m^3/s to the east, 14.3 m^3/s to the south and 22.7 m^3/s to the west. Average annual rainfall is shown in Figure IV.3

C. Land Use

Land use information for the Island is handled by two major government agencies: the Puerto Rico Planning Board and the Department of Natural Resources.

In general terms the Department of Natural Resources inventories existing land use patterns, while the Puerto Rico Planning Board is responsible for the assessment of future land use trends.

The Scientific Inventory of the Department of Natural Resources maintains a data bank of historic and present land use patterns. Information is organized by a computerized data storage system; aerial photographic information is analyzed and transferred to 1:20,000 quadrangle maps, concomitantly this mapped information is quantified and stored. Through a continuous data gathering process, information for the entire Island is updated and field checked every two years. Mapped and statistical information can be retrieved from the computer print-out.

In the analysis that follows active agriculture will represent agricultural lands in production. No "inactive" agriculture data was included in the calculations. Abandoned land tracts and farms were disregarded due to the lack of accurate data, although they have future development potential in agricultural production.

FIGURE IV.2 WATER BODIES

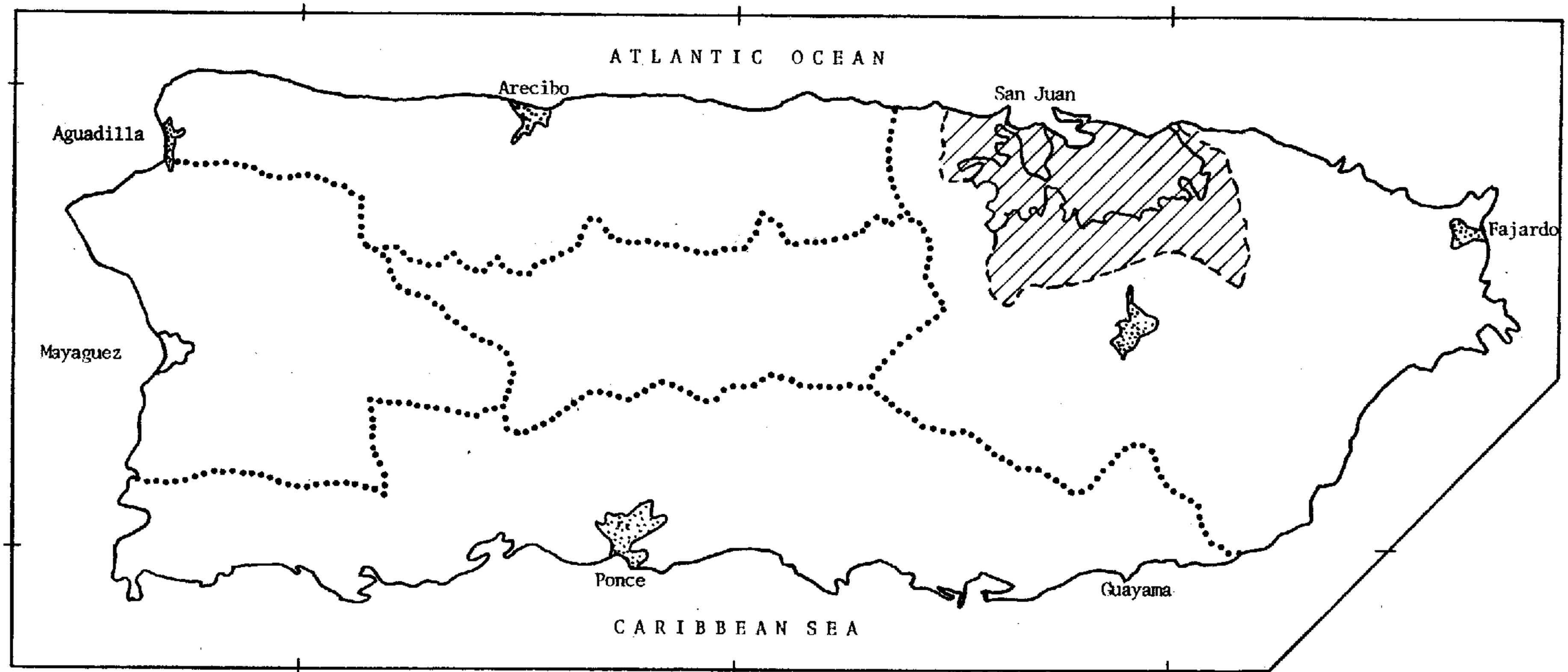
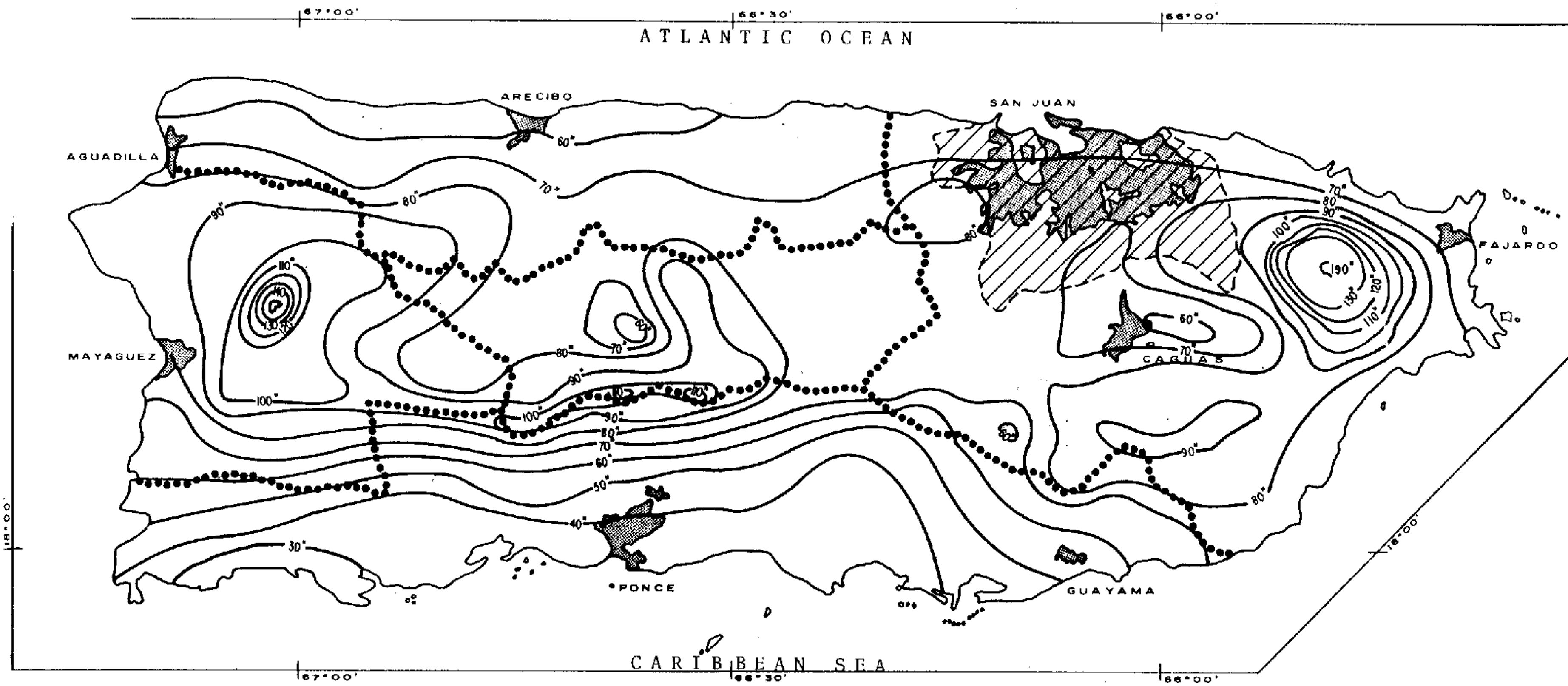


FIGURE IV.3 AVERAGE ANNUAL RAIN FALL



°°°°°Hydrologic Basins Boundary

Despite structural changes in the economy, land use in Puerto Rico has remained overwhelmingly agricultural, occupying approximately 1,209,626 cuerdas or 53.32% or the Island's surface area. Commercial-Industrial activities on the other hand occupied only 7,200 ha or .79% of the land while urban settlements occupied 28,600 ha or 3.3%.

The most important sugar cane producing areas in Puerto Rico are located in the coastal plains. This crop occupies 101,500 ha or 12% of the total surface area of the Island and 53% of the active agricultural lands.

Pineapple growing areas are concentrated in Barceloneta and the Lajas Valley. Surface area used for pineapple production amounts to 2,900 ha. Of the total land area, 0.3% is used for pineapple or 1% of the active agricultural lands.

The coffee producing lands are located in the Island's interior mountain areas. Total land area used for coffee amounts to 72,400 ha. This represents 8% of the Island's total surface area and 37% of all active agricultural lands.

Tobacco production is concentrated in the central municipalities and it occupies 1300 ha or 0.2% of the total land surface area. This crop accounts for 1% of the active agricultural land.

Citrus fruits occupy a total of 1000 ha of land which represents 0.1% of the total land area and 0.5% of all active agricultural lands.

Intensive agriculture covers 4,200 ha or 2.2% of the active agricultural lands and 0.5 of the total surface area. Small farms comprise 0.08% of the total surface area and 0.3% of the active agricultural land with 6,500 ha. Active agriculture represents 0.2% of the surface area of the Island and 0.8% of the agricultural land. This activity uses 1,600 ha acres for active production. The smallest category is that of specially farms with 123 ha of land which represents 0.06% of active agricultural lands and scarcely 0.01% of total land surface area.

Urban expansion in Puerto Rico during the last 25 years has been significant. Today it accounts for most of the built up land in the Island. In general terms, lands classified as urban settlements occupy 28,600 ha or 3.3% of the total surface area of the Island and 45% of the built up land.

Rural population still encompasses the majority of Puerto Rico's population, although its percent of the total population has been steadily decreasing during the last few decades. In terms of built up areas it accounts for 3.2% of the total surface of the Island and for 44% of the built up land with 28,000 ha.

Industrial activities in Puerto Rico have increased dramatically taking over large tracts of land, in many instances good agricultural land. Industries occupy a total of 3,600 ha or 5.6 of all built up areas and 0.4% of the Island's total surface area.

Commercial activities have experienced a considerable expansion during the last 25 years. Today commercial activities cover 5.5% of the built up land and 0.4% of the total surface area with 3,500 ha. Table IV.1 summarizes land use activities in Puerto Rico.

D. Hydrological Conditions

1. Estimated water budget

Rainfall is virtually the only source of fresh water, averaging 1.90 meters annually, which is equivalent to 526 m^3/s.

Table IV.1

LAND USE DISTRIBUTION BY MAIN CATEGORIES:

Use	Hectares (ha)
Agriculture	
Sugar Cane	101,500
Pineapple	2,900
Tobacco	1,300
Coffee	72,400
Intensive Agriculture	4,200
Small Farms	6,500
Citrus Fruits	1,000
Bananas	1,400
Special Agriculture	123
Active Agriculture	1,600
Urban	28,600
Rural	28,000
Industrial	3,600
Commercial	3,500
Total Surface Area of Puerto Rico	894,000
Total Agricultural Land	489,000
Total Active Agricultural Land	193,000
Total Built Up Land	63,300

Of the total rainfall, 0.74 meters are estimated to be runoff, 0.58 meter superficially and 0.16 meters by infiltration. The remaining water returns to the atmosphere as total evapotranspiration.

2. Surface water characteristics

The surface waters of Puerto Rico flow from the Cordillera Central to the sea in more than 100 rivers and creeks characterized by the small size of their watersheds and the short length of the rivers. Puerto Rico is divided into 33 principal watersheds, the largest of these being 794 Km^2 drainage basin of the Río Grande de Loíza. Only seven rivers have drainage areas in excess of 250 Km^2.

Streamflow varies widely as a result of heavy and often short showers. Low base flow in streams in the Luquillo mountains is between 11 to 22 l/s per Km^2 and in the interior uplands area generally is 3 to 11 l/s per Km^2. Low base flow in streams on the south slope of the central divide is between 0 and 4 l/s per Km^2. There are no perennial streams in the island's drier southern exposure.

Impoundment is generally necessary to develop a significant quantity of water for beneficial use. A total of 25 reservoirs have been constructed island-wide with a safe yield estimated as $29.2m^3/s$. A large portion of this supply was originally developed for hydroelectric power and are not located near water supply demand centers.

3. Groundwater characteristics

Three types of groundwater systems occur on the Island: (1) Unconfined alluvial aquifers; (2) both confined and unconfined limestone aquifers; (3) waterbearing fault system in igneus parent material on the Island's interior. The shallow unconfined alluvial aquifer occurs along most coastal areas and in river valleys and are the most important source of water on the south coast.

Both confined and unconfined aquifers have been developed for supply on the north coast west of San Juan, principally for municipal and industrial uses. Most interior locations rely on surface water diversions and impoundments for water supply.

The yield of individual wells in both the alluvium and the limestone may exceed 63 l/s. The current withdrawal of groundwater islandwide is estimated at 11.4 m^3/s of which approximately 70% is for irrigation.

E. Existing Water Usage

Water usage in Puerto Rico can be divided in three categories: municipal, which includes all water withdrawn by the Puerto Rico Aqueduct and Sewer Authority (PRASA) and distributed for residential, commercial and light industrial usage; agricultural, which basically includes irrigation water and livestock usage; and self supplied industry, which involves the private groundwater extractions of the three water using groups. The municipal sector uses the most water, withdrawing an estimate 16.4 m^3/s in FY 1981-82. (25) This represents an increase of 39% over the previous year and 7.4% over the production in FY 1979-80. PRASA operates 51 water treatment plants, 9 compact plants, and 175 wells that receive chlorination in urban areas; and 23 compact plants, 74 surface diversions, 9 partial plants and 170 wells in the rural areas.

Agriculture is the second largest water user in Puerto Rico and the largest user of groundwater. Agriculture accounts for appriximately 9.7 m^3/s where water for livestock drinking amounts to only 0.4 m^3/s.

It is estimated that 28,000 ha are irrigated at least once a year, including over 20,000 ha on the southcoast alluvium and in the Lajas Valley, which are irrigated regularly. Approximately 95% of this irrigated land is sugarcane.

Despite the scarcity of water for agriculture, no adequate water management techniques are used. For instance, irrigation is not based on measured soil moisture, and the quantity of irrigation water going to fields is not measured.

Furrows used both and off the farm are large, yet no program has been implemented to increase the efficiency of water distribution. As a result of these and other problems the sugar industry has sustained heavy loses. The Department of Agriculture has formulated a plan for agricultural development and diversification which greatly reduces the emphasis on sugarcane and encourages the production of rice for the local market. To support the implementation of this plan, it will be necessary to bring large areas of the north coast under irrigation practices and investigate the potential for developing additional irrigation supplies.

Information on industrial use on the island is poor. It is estimated (26) that approximately 4.4 m^3/s are used by industries of which 75% or more is groundwater.

The water demands in Puerto Rico have been projected by the Department of Natural Resources (27) by using a scenario technique, in which possible conditions which might lead to high levels or low levels of water demand are described. Based on this, a "high" and "low" water use is expected to lie somewhere between these two projections. Projections are presented on Table IV.2.

TABLE IV.2
ESTIMATES OF CURRENT AND PROJECTED
WATER WITHDRAWAL IN PUERTO RICO

User Category		Withdrawal (m^3/s) 1975	1985	2000
Municipal -	Total	14.8	19.7	26.4
	Urban	13.3	18.8	25.5
	Rural	0.9	0.9	0.9
Industrial -	(high)	4.4	6.4	11.0
	(low)	4.4	5.1	6.4
Agricultural -	(high)	10.5	20.1	31.2
	(low)	10.5	10.5	10.5
Total -	(high)	29.3	46.1	68.6
	(low)	29.3	35.3	43.2

The historic and projected production and consumption of municipal water in Puerto Rico is shown in Figure IV.4

F. <u>Water Quality Assesment</u>

The Islandwide 208 Project performed a water quality assesment of Puerto Rico in 1979 (26). The major highlights of their assesment are as follows:

"1. Streams: The general water quality condition of streams on the Island indicates that meeting the 1983 National Water Quality Goals does not appear promising. Analysis of existing water quality data show that a significant number of monitoring and sampling stations have frequent water quality standards violations. In particular, the coliform content of the majority of water bodies sampled is unacceptable.

2. Coastal areas: As with streams, a large number of ocean water quality monitoring and sampling stations have frequent standards violations. Coliform levels appear to be worsening at several monitorings stations. The significant problems appear to be caused by point source discharge of wastewaters into the coastal areas along with the discharge of polluted stream flow. Sand bar formations, sediment buildup on reefs, and salt water intrusion are also recognized as problems to be concerned with in coastal areas.

3. Lakes and ponds: Several studies have been performed for lakes to determine the extent of eutrophication

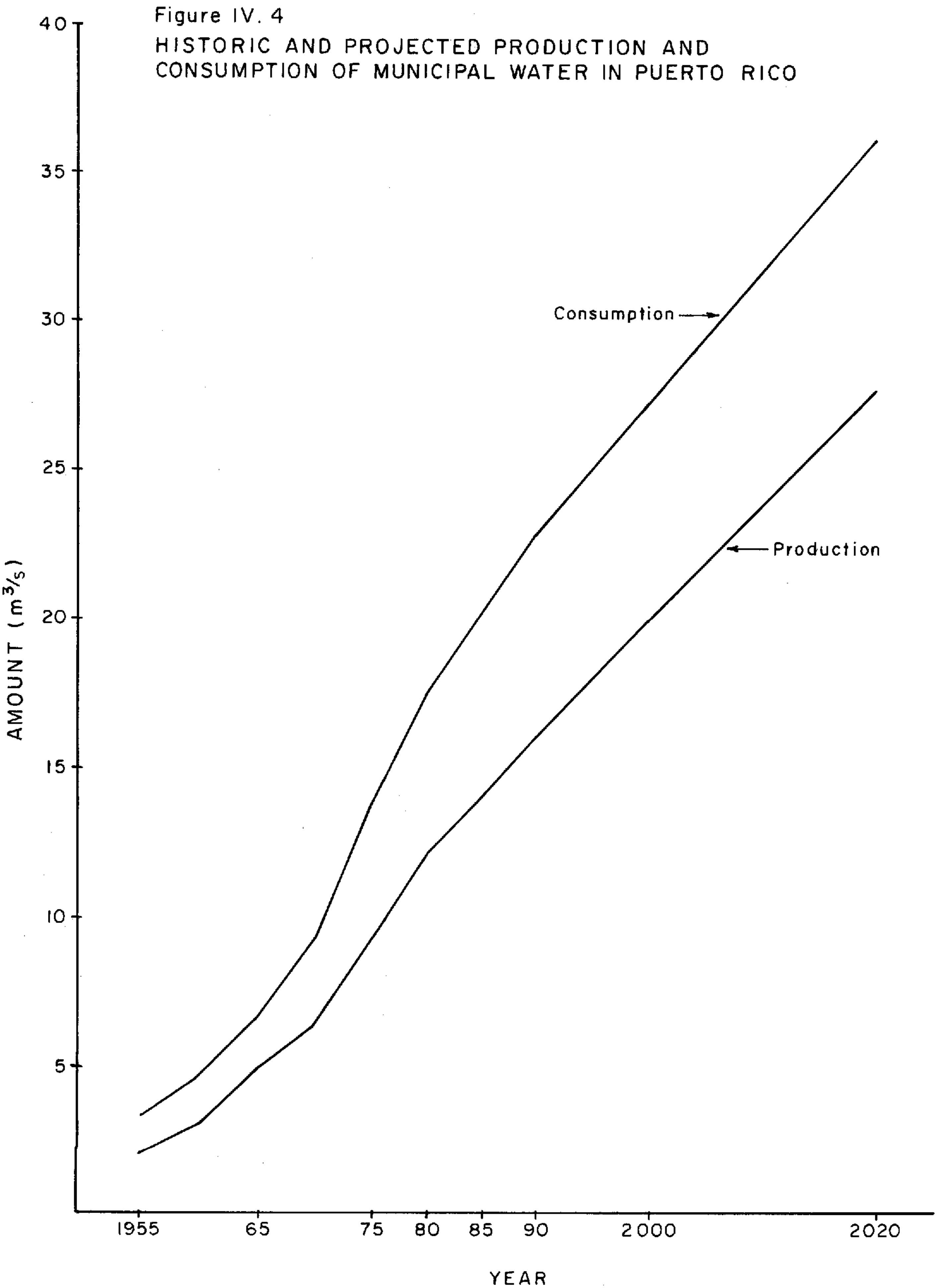


Figure IV. 4
HISTORIC AND PROJECTED PRODUCTION AND
CONSUMPTION OF MUNICIPAL WATER IN PUERTO RICO
40
35
30
25
20
15
10
5
AMOUNT (m^3/s)
Consumption
Production
1955
65
75
80
85
90
2000
2020
YEAR

and sediment buildup in these water bodies. The conclusions of these studies indicate that several lakes on the Island have potentially significant eutrophication and sedimentation problems.

4. Groundwater aquifers: Very little data exists on the extent of groundwater contamination. Due to this significant lack of available information, no definitive assessment can be made of the quality characteristics of this very important source of water supply."

In mid 1982 and based on water quality data from water years 1981 and 1982. (28)(29), the situation had not changed appreciably. The USGS assesment was as follows:

" The chemical and bacteriological quality of surface waters in Puerto Rico did not change significantly during water years 1981-1982. Untreated or partially treated sewage disposal continues to be the Island's most detrimental water resource problem. Coliform bacteria, an indicator of human and animal wastes, is found in concentrations above 10,000 colonies per 100 ml at many of the sampling sites.

Rivers that are associated with population centers show higher bacteria concentrations that streams in rural areas. Quebrada Blasina near Carolina and Río Caguitas at Highway 30 at Caguas show the highest concentrations of fecal coliform bacteria. Other sites that show high fecal coliform concentrations are Río Hondo below Río Hondo at Bayamón and Río Guayanilla at Central Rufina. All four sites have recorded coliform concentrations higher than one (1) million colonies per 100 ml.

Industrial pollution often reveals itself as exotic inorganic or organic contamination. The inorganics which are normally absent or nearly so in the natural environment are arsenic, cadmium, chromium, lead, mercury, selenium and silver. This is not an exhaustive list of inorganic contaminants but are those inorganics that have been designated as having a detrimental effect on human health.

Water samples for analyses of these elements were collected once each water year at most of the monitoring sites. Analyses of both the dissolved and solid phase is referred to as a total recoverable sample. At the NASQUAN stations, a federal funded water quality program, both total recoverable and dissolved inorganics were analyzed three times a year. Total recoverable and dissolved concentration sampled at these sites are listed in Table IV.3.

Other organic contaminants of interest in water quality appraisals include organic pesticides which are used in large quantities by agriculture. Samples for the most common pesticides were collected once at most sites. DDT, DDD, DDE, aldrin, dieldrin, endrin, chlordane and diazinon were found in over 20 percent of the sites sampled, but the concentrations were near the detection limits of the analytical techniques."

TABLE IV.3

CONCENTRATIONS ON INORGANICS AT SELECTED STREAMS

	Cromium		Lead		Mercury	
	total	dissolved	total	dissolved	total	dissolved
	* * *		Micrograms per liter		* * *	
Río Grande de Manatí	80	10	21	1	3.9	2.2
Río de la Plata	30	10	46	1	2.0	1.4
Río Fajardo	40	10	65	1	.8	.8
Río Grande de Patillas	10	10	5	1	4.0	1.5
Río Grande de Añasco	40	10	14	1	.8	.2

G. Wastewater

1. Industrial

The Islandwide 208 project (26) developed a waste load inventory of industrial dicharges in 1979. This inventory included 422 industries which were discharging to surface waters. However, a major problem that this survey had was that 70% (1113) of the Industrial Water Use Questionnaires sent to industries not regulated by an NPDES permit and not included in PRASA files as connected to municipal treatment facilities were not returned. In addition, the information given in the report includes only the industry name and location, and no information is provided as to amount of flow and/or quality of the effluent.

In 1981-82 PRASA, under the requirements of the Clean Water Act, conducted a pretreatment study. A major part of the study was the Industrial Waste Survey, which produced a master list of 3114 industries. Based on questionnaire returns and phone calls, 67% of these firms were classified. Of the remaining 1017 firms, 676 industries did not respond at all and 341 were classified as out of business. The preliminary review of the questionnaires resulted in the deletion from further investigation of 1261 firms which were either out of business or not applicable. A total of 836 firms cooperated with the survey and were given detailed review. From this analysis it was concluded that 37 municipal plants had significant industrial usage. In terms of percentage of plant flow, the figures were in the order of 8-10%, but with high values of 80% in Manatí, 62.2% in Barceloneta and 43.4% in Guanajibo Homes. The total industrial flow going into municipal facilities was estimated as 0.33 m^3/s.

Information about industries which have their own discharges is scarce. Although the majority of the industries with significant discharges have NPDES permits, about 5% still are waiting for the issuance of the permit and an unknown number of others have never filed for a permit. In addition, some of the permits exclude flow measurement of things like cooling water and storm water discharges.

2. Municipal

Puerto Rico's municipal wastewater system has changed drastically in the last 15 years. In 1972 the existing system was comprised of 99 individual subsystems, of which 6 did not include any treatment facilities. In 8 towns the treatment was provided by a community septic tank of unknown capacity. Table IV.4 shows the flow and design capacity of the systems existing in 1972.

In order to improve the situation a Comprehensive Water Quality Management Plan for P.R.: 1970-2020 (30) was developed. The main concept proposed by the plan was the use of regional treatment facilities for municipal wastewater and some industrial wastewaters. The recommended system is shown in Figure IV.5 and includes 16 regional facilities serving 50 towns. Twenty-eight towns were supposed to retain their treatment systems, which were to be upgraded as needed.

The economic realities of the late 1970's reduced the scale of the planning. The 1982 domestic wastewater system of Puerto Rico consists of 110 operating facilities, of which three can be considered as regionals (Puerto Nuevo, Barceloneta and Ponce). In addition, there are six other regional plants almost completed (Mayaguez, Arecibo,

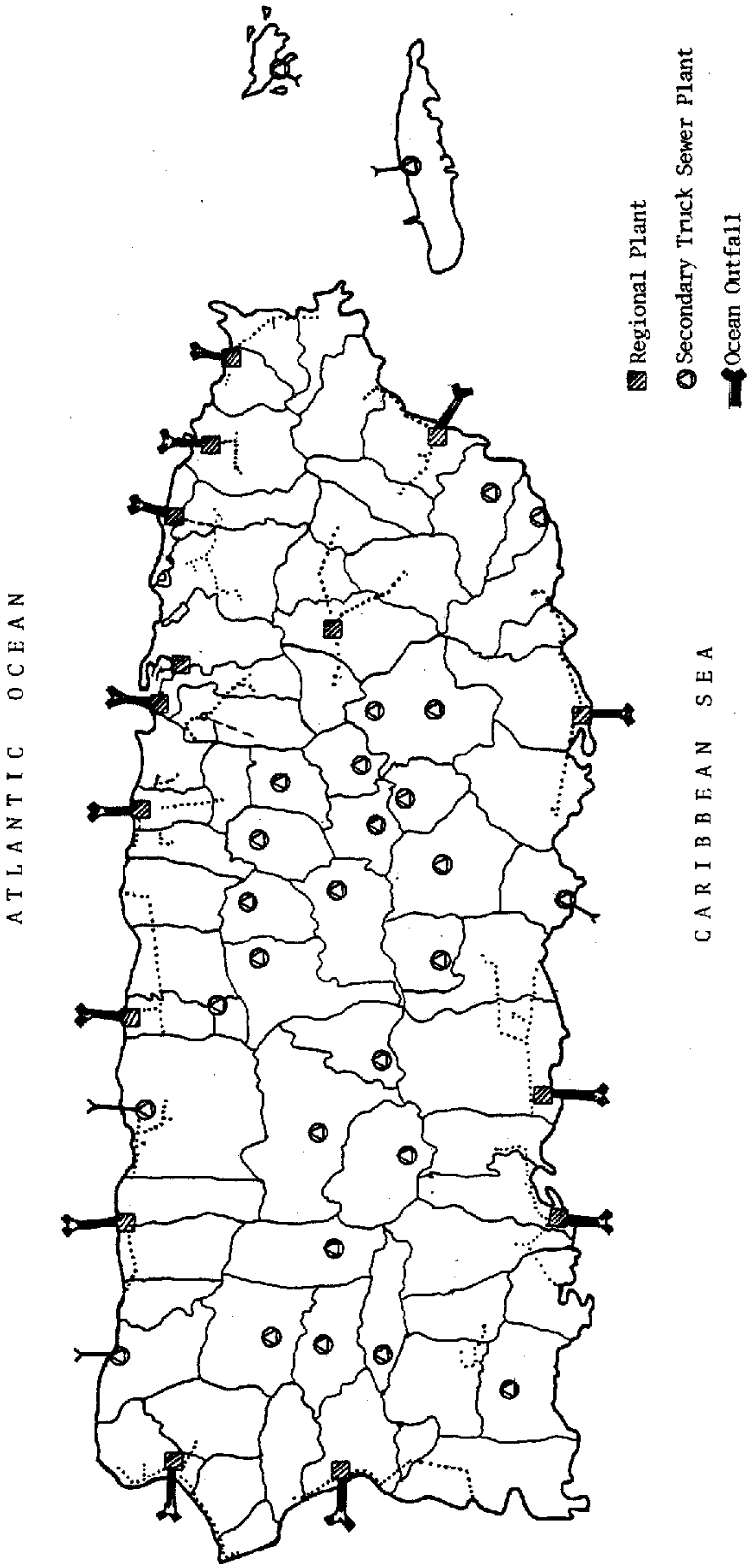
TABLE IV.4

EXISTING TREATMENT SYSTEMS: 1972

Type of plant	Number of plants	Design capacity	Average flow 1/s
1. Activated sludge	8	79.7	55.2
2. Continuous aeration	2	12.2	9.6
3. Trickling filters	49	1,488.5	1,055.5
4. Compact filters	3	9.8	9.6
Total secondary systems	62	1,590.2	1,129.9
1. Settling and separate digestion	6	1,555.8	2,029.7
2. Imhoff tanks	17	90.8	120.2
Total primary systems	23	1,646.6	2,149,9
1. Community septic tanks	8	——	——
Totals	93	3,236.8	3,279.8

FIGURE IV.5

PLANNED WASTEWATER SYSTEM FOR PUERTO RICO



Hatillo, Bayamón, Carolina and Aguadilla). Table IV.5 gives a summary of the design capacities and the actual flow of the existing facilities, and Figure IV.6 shows their geographical location. There are four remaining sewer systems which are discharging raw wastewater to the sea, but three of them will tie to one of the regionals mentioned above. Only Guayama will not be receiving treatment in the intermediate future.

A comparison of Table IV.5 with IV.4 shows that in ten years the system capacity has increased from 3.237 m^3/s to 7.363 m^3/s and the average flow has increased from 3.28 m^3/s to 5.831 m^3/s. In 1972 the flow exceeded the design capacity, but this situation was reversed by 1982. However, a significant part of the increase in the total design capacity was due to the Puerto Nuevo plant (2.1 m^3/s) and a large number of smaller facilities outside the San Juan area are operating under significant overloads. The comparison of both tables also shows a significant increase in the number of activated sludge plants, from 8 to 44. This has been due to a preference by small project developers for package activated sludge units, generally of the contact stabilization mode. The number of trickling filter plants has remained about constant and eight Imhoff tanks and six community septic tanks have been eliminated.

The operational status of the domestic wastewater treatment plants is another matter. In 1977 EPA filed suit in the U.S. District Court for P.R. alleging multiple permit violations and general noncompliance with the Clean Water Act at 91 of PRASA's facilities. PRASA and EPA entered into a consent agreement shortly thereafter, in which a long list of improvements were agreed upon. By 1980 EPA went back to Court because PRASA was slow in its compliance,

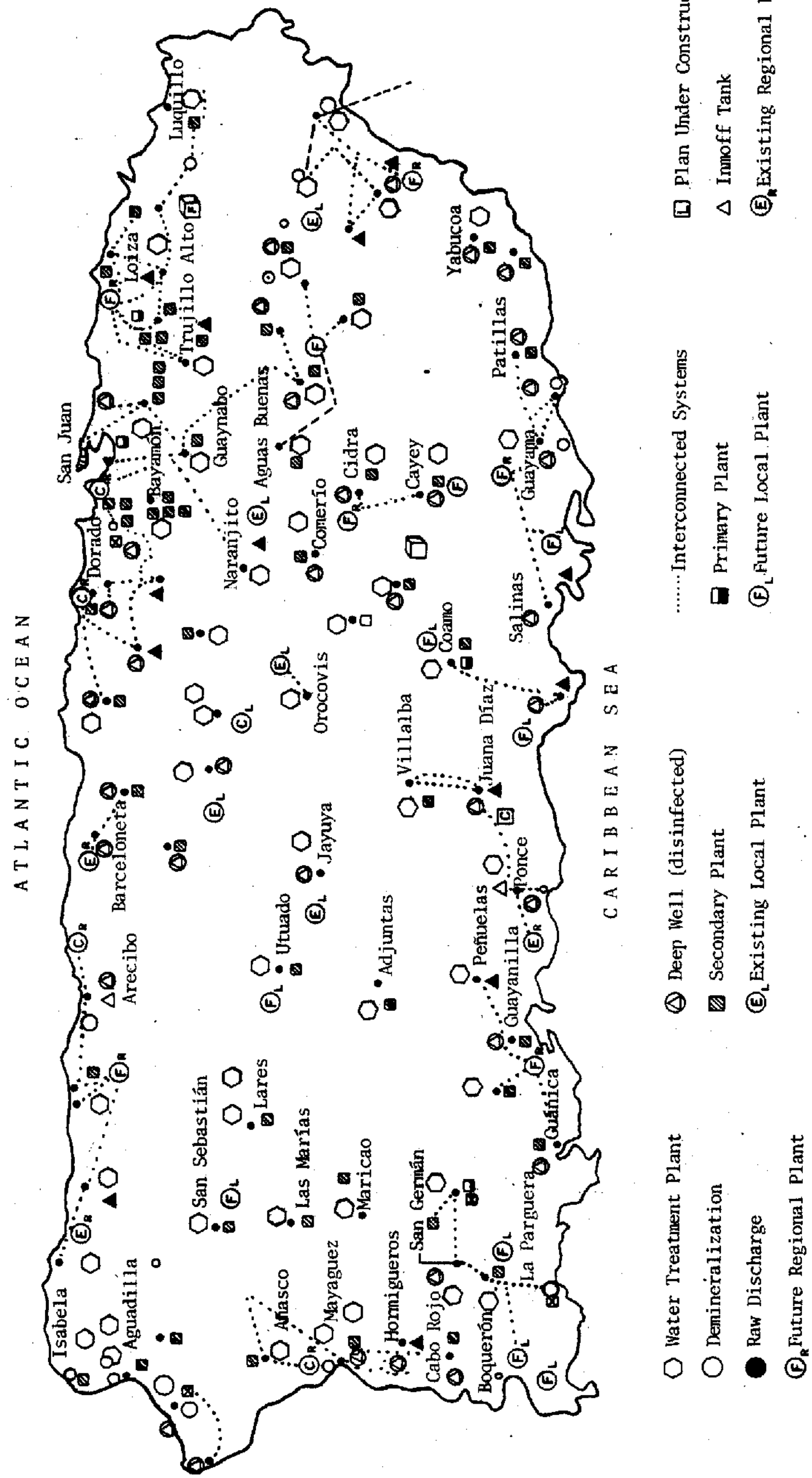
TABLE IV.5

EXISTING TREATMENT SYSTEMS: 1982

Type of Plant	Number of Plants	Design Capacity (1/s)	Average Flow (1/s)
1. Activated sludge	44	1,390	766
2. Continuous aeration	1	13	15
3. Trickling filters	48	2,141	2,031
Total secondary systems	93	3,544	2,812
1. Settling and separate digestion	6	3,750	2,880
2. Imhoff tanks	9	60	117
Total primary systems	15	3,810	2,997
1. Community septic tanks	2	9	22
Totals	110	7,363	5,831

FIGURE IV.6

TREATMENT SYSTEMS: 1982



and entered into another consent agreement which along with another list of system-wide improvements to be made, created an Office of the Monitor to oversee overall compliance. This Monitor has been on the job since August 1980 and submits quarterly reports to the Court summarizing the status of compliance of PRASA's plants. The November 1982 report (31) rated nine plants as satisfactory, 16 as marginally satisfactory, and 61 as unsatisfactory, out of a total of 86 under the consent agreement. In addition, in late 1982 EPA filed another civil action against PRASA, again alleging multiple permit violations at 16 additional facilities. This case is still under litigation.

The above points to a very poor operational condition at the municipal facilities in the Island. Under present conditions, this makes reuse a viable alternative for disposal in only a few facilities.

V. ASSESMENT OF FUTURE SITUATION

A. Introduction

Projections of any kind in Puerto Rico tend to be highly uncertain. Future levels of activity are dependent on a variety of factors, including the political and economic climate of the Island and the United States, export-import market, labor market, cost of raw materials, etc. The objective here is to outline general development trends and then to translate these into levels of future water demands. Conflicts are identified so that a better assesment of reuse possibilities can be made in the next chapter.

B. Population

The Puerto Rico Planning Board (PRPB) has developed two relatively recent long-range population projections using 1970 population as the base.

1. 8CX7: The 8CX7 population projection to the year 2020 for each municipality was developed by the PRPB using the 1970 census data as the base year. The cohort survival projection method was utilized. This projection was published in May of 1975, and was used to develop the water demand projections in the Corps of Engineer's Island-Wide Water Supply Study for Puerto Rico, September 1980.

   The 8CX7 projection accurately forecasted Puerto Rico's overall population for 1980 (less than 1 percent over projection). It did, however, underestimate the 1980 population in 64 municipalities, which was compensated by a significant over-projection for the municipality of San Juan.

2. 75-35: In February of 1978 the PRPB released new cohort survival population projections to the year 2000, known as the 75-35 projection. This population projection was developed because it was determined that the 8CX7 projection was underestimating the population growth in many municipalities from 1970-75. The 75-35 projections were based on estimated 1975 municipality populations and 1970 age and sex cohorts updated to 1975. This model overestimated total 1980 population by approximately 11 percent including values for 55 municipalities. This population projection was utilized by the Environmental Quality Board's Island-wide 208 Project.

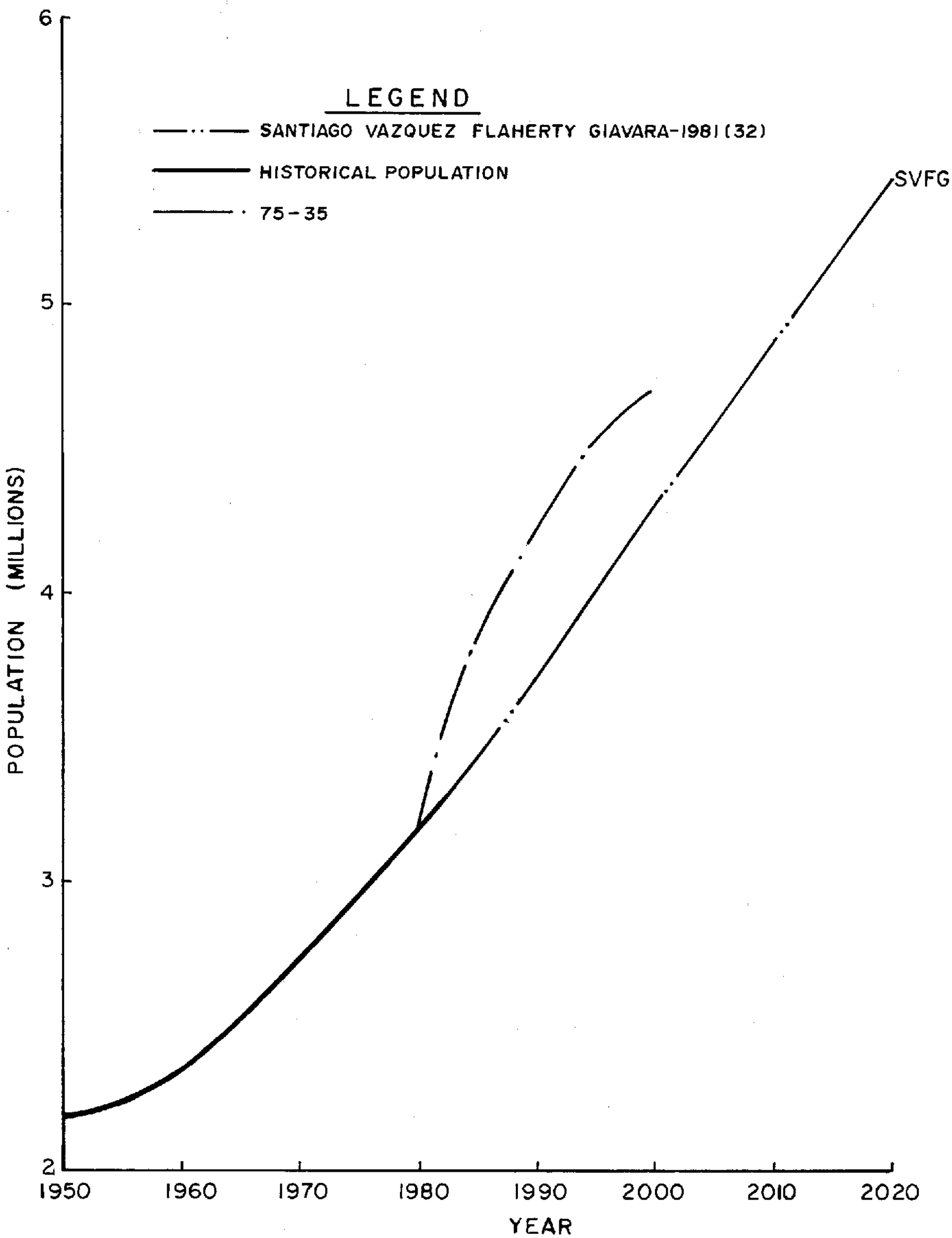
A third set of projections were made by Santiago Vazquez et al (32) in the Islandwide Water Supply Implementation Plan. These projections were made by PRASA region and are shown in Table V.1. Figure V.1 compares the Santiago Vazquez projections with the PRPB's 75-35. Based on the results given in this figure, more than 40 percent of the Island's population will be concentrated in the San Juan and Bayamón Regions by the year 2020. The high projected growth of population in the Bayamon Region combined with the already highly populated San Juan Region will contribute to the large water demand within the San Juan metropolitan area. In addition, although the total Arecibo Region growth rate lags behind Bayamón, Humacao, Mayaguez, and San Juan, the coastal area within the region has a significant growth rate.

TABLE V.1

SUMMARY OF POPULATION BY PRASA REGION

REGION	POPULATION (Thousands) 1980	1990	2000	2010	2020
SAN JUAN	810	918	1044	1177	1312
ARECIBO	420	475	533	587	640
MAYAGUEZ	417	482	552	623	694
PONCE	437	496	556	610	661
GUAYAMA	244	272	301	330	361
HUMACAO	446	538	643	750	862
BAYAMON	412	543	668	794	914
TOTAL	3186	3724	4297	4871	5440

Figure V. I
POPULATION PROJECTIONS



C. Industrial Growth and Water Needs

Projections of economic activity tend to be highly uncertain. This observation is particularly accurate for Puerto Rico which has experienced rapid growth over the past forty years and is affected by mainland and international activities.

Future levels of economic activity are dependent on a variety of factors including the socio-political and economic climate on the Island and the mainland, export-import and labor markets, cost of raw materials, and other economic factors. Reliable economic forecasts are difficult over the short and long term.

Santiago Vazquez et all (33) projected heavy industry growth in order to estimate its future water requirements. Projections were based on industry data and historic trends. Light industry water demands were developed separately based on a percentage of projected PRASA domestic water demand. Total industrial demand in 1980 was estimated at about 4.6 m^3/s, projected to increase to 5.4 m^3/s by 1990 and 7.7 m^3/s in 2020.

D. Agricultural Growth and Water Needs

Agricultural production in Puerto Rico, in terms of gross product and employment, has significantly declined since the 1950's. Due to the steady decline of sugarcane production, irrigation water use has also declined.

The Commonwealth is currently developing programs to promote and expand agriculture production on the Island. A major new rice program is planned by the Commonwealth and is partially implemented. Rice production is planned principally for the north coast and to a lesser degree in the Lajas Valley. Due to the large water irrigation requirements for rice, water use conflicts with domestic water supply may occur in the future on the north coast.

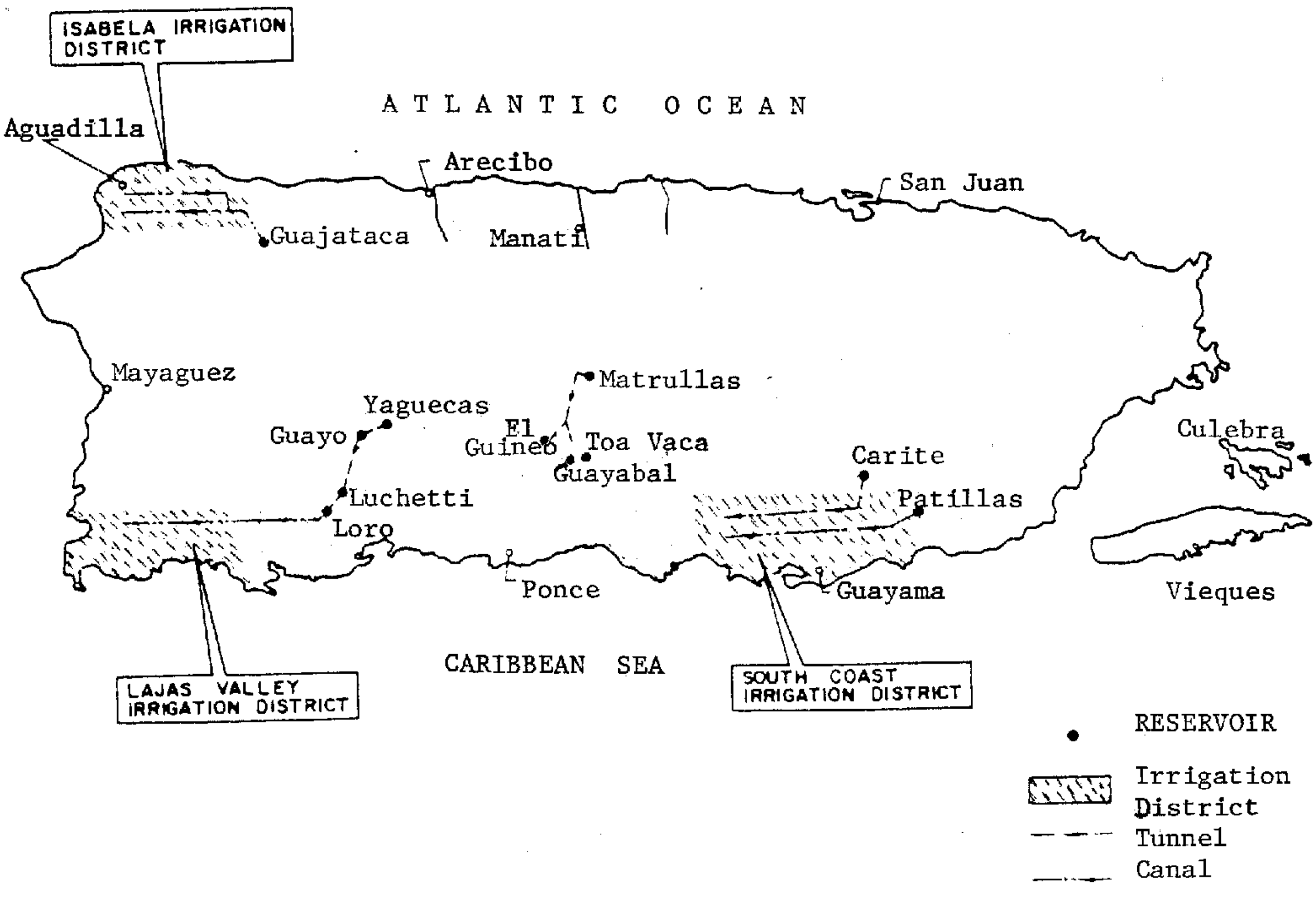
Other crops requiring irrigation and planned for the future, according to information from the Department of Agriculture, are vegetables (south coast), sugarcane (east, south, and west coast), sugarcane (east, south, and west coast), and cotton (Lajas Valley). The following summarizes the current water usage in the irrigation districts, according to Santiago Vazquez (33):

1. Water use by agriculture in the Isabela Irrigation District is currently approximately 88 l/s.
2. Water use by agriculture in the Lajas Valle Irrigation District is currently approximately 0.79 m^3/s.
3. On the south coast, the irrigation rate in the mid-1970's was approximately 10.5 m^3/s (5.7 m^3/s groundwater and 4.8 m^3/s surface water). Due to the reduction in sugarcane production, irrigation water usage has declined. However, data describing current levels does not exist.

These irrigation districts are shown in Figure V.2. Future agriculture water demands have been estimated by the Department of Agriculture. They report the 1980 island-wide agricultural water demand to be 19.3 m^3/s, and project it to grow at an annual rate of 4-5%. This growth rate (4%) would result in a 1990 water demand of

FIGURE V.2

EXISTING IRRIGATION SYSTEMS



28.5 m^3/s and 92.7 m^3/s by 2020. However, due to the unknowns in the data, Santiago Vazquez (33) recommends that 28.5 m^3/s be used as the 2020 figure. Agriculture programs which are in the development stage by the Department of Agriculture, according to their 12 year development program, are summarized as follows:

1.	Rice-Arecibo, Manatí and Cibuco Valleys	4.8 m^3/s
2.	Rice - Guanajibo Valley	1.8 m^3/s
3.	Vegetables - South Coast	1.2 m^3/s
4.	Sugar - East, South and West Coast	2.8 m^3/s
5.	Cotton - Lajas Valley	0.7 m^3/s
	TOTAL	11.3 m^3/s

Based on the available data from the Department of Agriculture, future water allocation and water use conflicts among the sectors can not be accurately evaluated and identified. Santiago Vazquez (33) recommends that a broad and detailed agriculture study be conducted.

E. Domestic Water Needs

Water need projections are used to determine future water system capacity requirements. PRASA water need includes water the Authority must produce in order to satisfy all domestic, light industry and Fomento industrial park consumption, while accomodating acceptable water loss. Factors used in domestic water demand projections include projected population and per capita water consumption. Ligh industry demand is based on a percentage of domestic demand; industrial park demand was provided by Fomento.

As indicated in Table V.2, PRASA currently produces 15.9 m^3/s of water at a cost of approximately $65 million excluding debt. In six of the seven PRASA regions, as well as island-wide, water need exceeded production in 1980 (current PRASA production deficit), reflecting the inadequacy of existing facilities.

As summarized in Figure V.3, PRASA water need is projected to increase from 16.7 m^3/s 1980, to 22.0 m^3/s in 1990 and 35.7 m^3/s in 2020. This amounts to an additional 19.1 m^3/s during these 40 years. This increase includes Fomento industrial parks, which account for 1.1 m^3/s in 1990 and 2.5 m^3/s in 2020.

F. Island-wide Requirements and Availability

A summary of Island-wide water requirements is given in Table V.3. Santiago Vazquez et al (33) has calculated the available water supply for PRASA from surface sources as 13.2 m^3/s. This figure was computed using the safe yield of the raw water supply or the design capacity of the water treatment plant, whichever was smaller. Table V.3 shows that PRASA is currently producing 16.7 m^3/s. This excess can be explained by the fact that 50% of the water plants are overloaded (33). The best example is probably PRASA's largest plant, Sergio Cuevas, which is producing 3.5 m^3/s, was designed for 2.6 m^3/s and feeds from a reservoir with a safe yield of 2.4 m^3/s.

PRASA currently produces approximately 3.5 m^3/s of potable water supply from wells. Other significant groundwater users are self-supplied industry (3.1 m^3/s) and agriculture (5.7 m^3/s). Therefore, total existing groundwater withdrawal is estimated at about 12.3 m^3/s. However, as Santiago Vazquez et al state, the estimates of groundwater

TABLE V.2

SUMMARY OF CURRENT PRASA PRODUCTION, WATER NEED AND WATER LOSS (1980)

Region	Production(m^3/s)	Water need(m^3/s)	Water loss (%)
San Juan	4.7	5.7	39
Arecibo	2.0	2.1	37
Mayaguez	1.9	2.0	36
Ponce	2.1	2.2	33
Guayama	1.0	1.1	38
Humacao	1.5	1.8	34
Bayamon	2.5	1.8	34
TOTAL	15.7	16.7	36

Figure V.3
DOMESTIC (PRASA) WATER NEEDS PROJECTIONS (33)

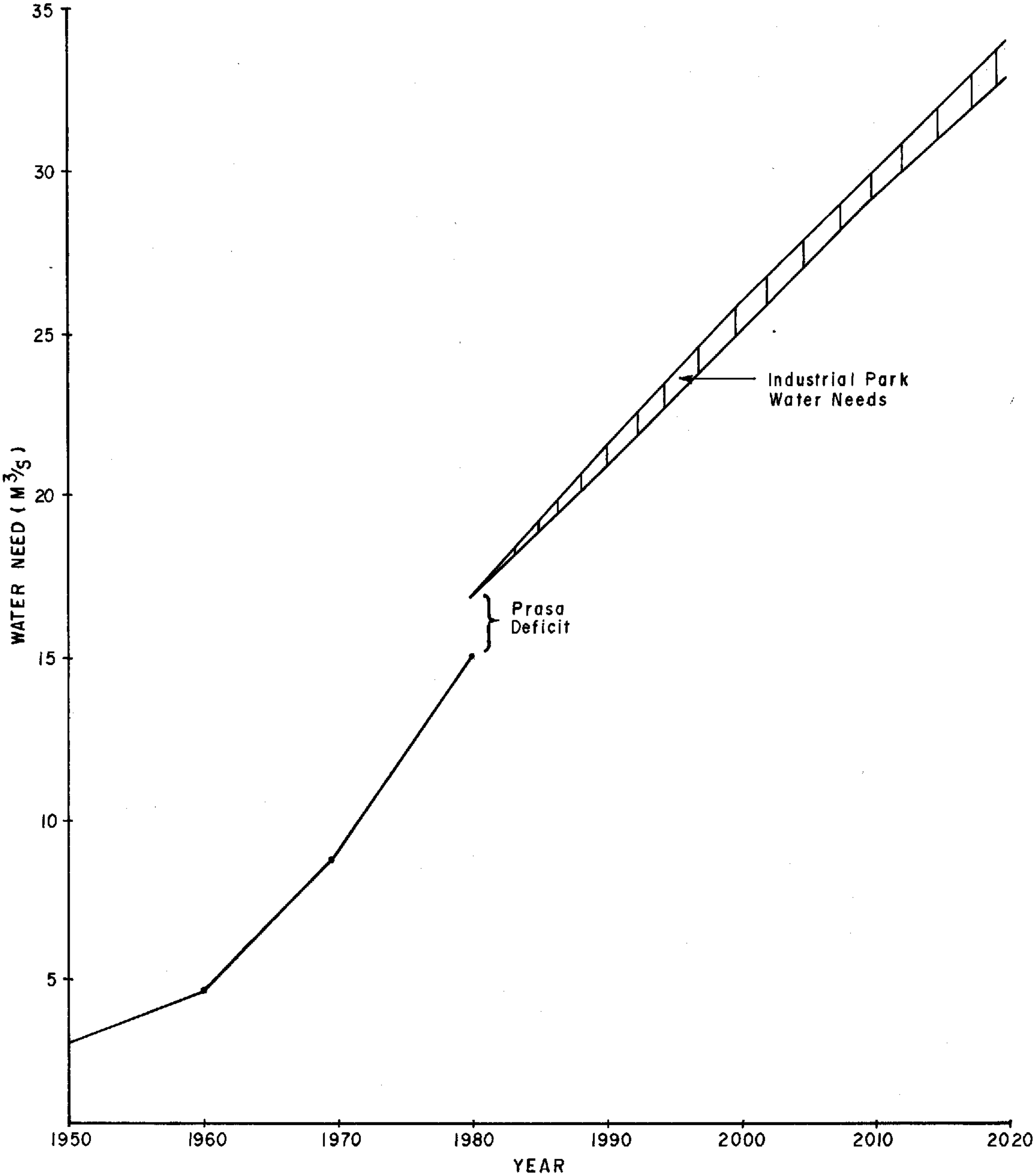


TABLE V.3

SUMMARY OF ISLAND WIDE WATER REQUIREMENTS

	1980 (m^3/s)	1990 (m^3/s)	2020 (m^3/s)
Domestic (PRASA)	16.7	20.8	33.2
Industrial parks	0	1.1	2.5
Industrial self-supplied	4.6	5.4	7.7
Agriculture	19.3	28.5	28.5
	40.6	55.8	71.9

Data from Santiago Vazquez et al (33).

use by industry and agriculture are based on limited and outdated data.

A study by the U.S. Army Corps of Engineers (34) estimated the following amounts of available water in 1975:

1. wells: 11.7 m^3/s
2. surface diversions: 5.0 m^3/s
3. reservoirs: 9.8 m^3/s.

This gives a total of 26.5 m^3/s as the available water with a total demand then of 30.1 m^3/s.

In summary, the above indicates that there is an urgent need to develop new sources of water. Both the studies by Santiago Vazquez et al (33) and by the Corps of Engineers proposed the construction of a series of reservoirs around the Island and other management measures such as an increase in water conservation. The Corps includes water reuse in two of their four plans, up to a point of reuse accounting for 12.6% of the total water demand by 2035. This proposed water reuse is to be mainly irrigation with municipal wastewater and diversion of treated wastewater toward aquifer recharge areas supplying irrigation wells. Santiago Vazquez does not make any recommendations for water reuse, and bases his plans on mostly structural solutions.

VI. DEVELOPMENT AND EVALUATION OF ALTERNATIVES

A. Introduction

There are five basic wastewater reuse alternatives applicable to Puerto Rico: recreational, domestic, industrial, irrigation and aquifer recharge. This chapter details what each of this alternatives would mean on the Island and evaluates their effectiveness. The approach used is to update the information available in the reports that have been previously reviewed and to develop new possibilities. A discussion of each alternative is given in terms of the evaluation criteria mentioned below.

B. Description of Alternatives

1. No action

The no action alternative means that no reuse projects will be implemented and that the plans formulated by Santiago Vazquez et al will be combined to produce a comprehensive management program to supply Puerto Rico's water needs.

2. Recreational reuse

This alternative would reuse water for irrigation of recreational facilities, in particular golf courses and public parks. The water used here would be municipal wastewater that has received secondary treatment and has been disinfected to a fecal coliform level of 2000/100 ml. Possible areas are the four golf courses in Dorado, the two at Rio Grande (Berwind and Rio Mar), and the ones at Humacao (Palmas del Mar), Fajardo (El Conquistador), Mayaguez (Club Deportivo) and Ponce. The only park would be Luis Muñoz Marin park in San Juan. Of the golf courses, only the ones at Dorado have a secondary wastewater plant at a reasonable distance. The park has the Puerto Nuevo regional plant nearby, but it only offers primary treatment.

Based on an approximate water use of 5000 m^3/ha/yr (35) it is estimated that the four Dorado courses could use about 32 l/s of the effluent of the Dorado plant, which is currently about 55 l/s. This effluent would have to be piped for distances of 3-5 Km to the four golf courses, going through the town of Dorado.

3. Groundwater recharge

Groundwater recharge requires wastewater of excellent quality. At the present time the best treatment provided in the Island is secondary. Any attempts at recharge would require the construction and operation of tertiary facilities and would be located in the aquifers of the South Coast, where the water supply problem is worst and where salt water intrusion is also a problem. Given the current economic conditions on the Island, where the current objective is to have secondary treatment by 1988, it is almost impossible that a tertiary facility of any significant size will be built in the intermediate future. Therefore, although groundwater recharge will remain a viable alternative for the long range, it is not a short term solution.

4. Domestic reuse

Domestic reuse, as used here, means using the effluent of a wastewater treatment plant as influent of a water treatment plant. As with groundwater reuse, it requires a high degree of treatment. Based on the same arguments, domestic reuse is only considered on a long term basis and not as a short term viable solution.

5. Industrial reuse

Industrial reuse can be thought of as self recycle of industrial effluents or the use of treated municipal wastewaters for industrial purposes, mainly cooling. A third possibility is the reuse of an industrial effluent for uses such as irrigation. In their study, the Corps of Engineers (34) identified 15 significant industrial wastewater sources. However, 6 of those are now out of business, leaving 4 sugar mills, one tuna packing, one rum distillery, two petroleum refiners, and one organic chemicals industries for a total flow of 0.89 m^3/s. The four sugar mills produce an effluent which is very high in suspended solids and BOD, and the treatment given is minimal, at best. The effluent from the rum distillery is also untreated and its BOD is of the order of 30,000 mg/l. This leaves a total of about 0.40 m^3/s as available for irrigation of sugarcane.

As to reclying, PRASA's pretreatment study (36) identified eighty six industries with a potential for recycling. The examples given as having the highest potential are the cement plants and refineries. As part of the Ponce-Juana Diaz reuse project (5), some industries were contacted to pulse their attitude towards reused water. It was concluded that in general, industry is most agreable to reuse water. However, some technological difficulties had been encountered by at least one major industry in its attempt to reuse its own treated wastewaters.

The Ponce-Juana Diaz project determined that a substantial part of the water used by industry in the area came from private wells, including a significant amount used for cooling purposes. This is an obvious sector where substantial savings could be made with good reuse practices. It was estimated at the time that 0.35 m^3/s

of groundwater were used for cooling, and that it was technically possible to reduce that figure by 90%.

6. Irrigation

The irrigation alternative in Puerto Rico means sugarcane irrigation. Rice irrigation is a possibility once the cultivation of rice is moved from the current area in Manatí. In this area there is no secondary treated effluent without significant industrial discharges.

The Corps of Engineers identified the sites for potential wastewater reuse by agriculture. These sites are given in Table VI.1. Flows are as projected for the year 1995. Of the regional plants mentioned in the table the following will not be built in the near or intermediate future: Boquerón, Dorado, Fajardo and Humacao. The following plants will not be upgraded to secondary, again in the near or intermediate future: Aguadilla, Arecibo, Bayamón, Puerto Nuevo and Carolina. The remaining possibilities are as follows:

1. Lajas: the plant is in extremely poor operation. An upgrading is expected to take place by 1988. The plant is near the Lajas Irrigation System. It is a distinct possibility once upgraded.
2. San German: plant operation ranges from poor to mediocre. Improvements are possible. However, there is no nearby irrigation system. Possibilities are poor.
3. Sabana Grande: plant will be upgraded to secondary by 1988. Situation is similar to San German and possibilities of reuse are also poor.
4. Tuna companies: existing secondary plant discharges to the sea. Use for irrigation would require pumping. Institutional arrangements would be complex. Possibility

TABLE VI.1

POTENTIAL WASTEWATER FOR REUSE BY AGRICULTURE

Regional Wastewater Facility or Industrial Source	Available Flow m^3/s	Agricultural Center Location
Lajas	0.048	Lajas
Boquerón	0.043	Cabo Rojo
San Germán	0.096	San Germán
Sabana Grande	0.043	San Germán
San Germán/ (Sabana Grande)	0.140	San Germán
Tuna Companies (Mayaguez)	0.149	
Mayaguez w/ Tuna Companies added	0.934	Añasco
Aguadilla	0.565	Aguada
Central Coloso	0.109	Aguada
Aguadilla	0.565	Aguadilla
Camuy	0.140	Arecibo
Puerto Rico Distillers (Arecibo)	0.052	
Arecibo	0.714	Arecibo
Central (Cambalache)	0.109	Arecibo
Barceloneta	0.504	Manatí
Dorado	0.701	Vega Baja
Dorado	0.701	Dorado
Bayamón	1.32	Dorado

TABLE VI.1 (cont)

Regional Wastewater Facility or Industrial Source	Available Flow m^3/s	Agricultural Center Location
Puerto Nuevo	3.63	Dorado
Carolina	1.54	Río Grande
Puerto Nuevo	3.63	Río Grande
Fajardo	0.276	Fajardo
Humacao	0.394	Humacao
Humacao	0.394	Naguabo
Sun Oil Company (Yabucoa)	0.096	Yabucoa
Roig Sugar Mill (Yabucoa)	0.109	Yabucoa

of reuse is poor.

5. Central Coloso: untreated effluent very high in BOD and SS. Poor possibility of reuse.
6. Camuy: excellent secondary facility currently not in operation. Sugarcane fields adjacent. Good possibility by 1988 or so.
7. P.R. Distillers: untreated rum slops very high in BOD and SS. Complex institutional arrangements required. Poor possibility for reuse.
8. Central Cambalache: has ceased operation.
9. Barceloneta: highly controversial secondary plant receiving wastes from many pharmaceutical plants. Toxics are probably present in the effluent. Sugarcane fields adjacent. Complex institutional arrangements required. Extremely poor reuse possibilities.
10. Sun Oil: secondary effluent from a refinery. Sugarcane field adjacent to plant. Complex institutional arrangements required. Probably the best industrial alternative, but still poor overall.

The Ponce-Juana Diaz study proposed the use of the effluent from the Ponce regional plant for irrigation of the sugarcane area east of Ponce. Changes in the Island's economic conditions since 1978 have made the cost of pumping this effluent prohibitive and the project has been all but discarded.

A final possibility proposed here is the use of the effluent from El Coquí plant in Salinas for irrigating the nearby sugarcane fields. This is one of the best secondary treatment plants in the Island, producing about 5 l/s of crystal water with a BOD usually around 10-15. This amount of water would be enough for about 8 ha.

This facility would be excellent as a pilot/demostration project.

C. Evaluation Criteria

1. Contribution to solving the problem

The previous chapters indicate that Puerto Rico will be facing a water shortage if the available water supply is not increased in the intermediate future. There are essentially two plans to solve the problem, one by the Corps of Engineers (34) and another one by Santiago Vazquez et al (33). Both of these plans propose enough structural measures to solve the problem well into the 21st century. The question of how much a particular alternative contributes to solving the problem must then be seen in the short term first and then for longer periods of time. Therefore, this criteria will be evaluated in terms of three ratings: significant, minor, and no effect.

2. Technological criteria

The case of implementation of any alternative depends on many factors. One of the most important is the availability of appropriate technology for accomplishing the proposed alternative. In the case of the five reuse alternatives mentioned above, the technology is available for all of them. The question then becomes whether the technology has been tested at the scale which the alternative requires and whether the technology is implementable in Puerto Rico. The second part address posible problems such as the availability of trained personnel, availability of spare parts, and the possible need for complex supporting elements such as laboratories and instruments for process control. Each alternative will be evaluated as complex, moderate or simple under this criteria.

3. Cost/benefit ratio

The cost of any alternative can be divided into capital expenditures and operation and maintenance (O&M). O&M costs must be paid by the agency or organization which is sponsoring the project, while under certain circumstances the capital costs might be partially paid by federal assistance under the construction grants program of the Clean Water Act. These costs must then be weighted against the expected benefits of the alternative. These benefits might be tangible such as a reduction in the cost of wastewater disposal or intangible such as an improvement in environmental quality. This criteria will be evaluated as high, intermediate and low.

4. Institutional/administrative

Previous chapters have described the functions of the different agencies dealing with water issues in Puerto Rico. In this criteria consideration is given to the laws, regulations and policies of the different agencies which would be involved in the implementation of each alternative and possible problems and conflicts which might develop such as the need to change any regulations or the possible contradictions in the public policy as interpreted by each agency. This criteria also addresses the administration of the proposed alternatives and considers questions such as: Who is going to be responsible if anything goes wrong?; How will any income generated by the alternative be divided? Who will have responsibility for what? This criteria will be rated as complex, moderate, or simple.

5. Environmental impact

The reuse alternatives mentioned above can have an environmental impact ranging from minimal to large, depending on the size of the project developed under the alternative. Extreme examples would be the construction of a dam versus a local recreational reuse project such as a small recreational lake. Considerations under this criteria are: probable environmental impact of the proposed action; unavoidable adverse impact of the action; relationship between short range use of the environment by man and long term productivity; and irreversible commitments of the environment caused by the action. Joining together these considerations, the environmental impact is evaluated as significant, moderate, or slight.

6. Public acceptance

The implementation of any reuse alternative is largely dependent on the willingness of those affected to accept it. It would, for example, be impossible to implement domestic reuse if the inhabitants of an area were not willing to use potable water that was previously wastewater. This criteria will be rated as high, medium or low.

D. Evaluation of Alternatives

Table VI.2 presents in tabular form the evaluation of the alternatives previously discussed. The reasons behind each rating areas follows:

1. No action

Doing nothing obviously does not contribute to solving the problem of water needs. However, it is a simple solution both in terms of technological and institutional/administrative criteria. Since it does not do anything, its only environmental impact is caused by what it does not do: solve the problem. Although it does not provide any benefit, it does not have a cost, either. Therefore, its cost/benefit ratio is considered as intermediate. Public acceptance

TABLE VI.2

EVALUATION OF ALTERNATIVES

Criteria	Alternative 1	2	3	4	5	6
1. Solution to problem	no effect	no effect	minor	minor	minor	minor
2. Technological	simple	simple	complex	complex	moderate	simple
3. Cost/benefit	inter-mediate	inter-mediate	high	high	inter-mediate	low
4. Institutional/Administrative	simple	moderate	mode-rate	complex	simple	simple
5. Environmental impact	slight	slight	mode-rate	signi-ficant	slight	slight
6. Public acceptance	high	medium	medium	low	low	medium

Alternatives:
1. No action
2. Recreational
3. Groundwater recharge
4. Domestic
5. Industrial
6. Irrigation

has been rated as high because this alternative does not interfere with the publicly announced plans of the government, and this plans will eventually bring a solution to the problem. Another reason for this rating is that any reuse alternative will require a public education campaign, and since this alternative does not, it must be rated above those who do.

2. Recreational

Recreational reuse would involve only about 32 l/s. This is an insignificant amount and will have no effect on the overall water problem. Since the secondary effluent is already available, the only technological requirement would be pumps to connect with the also existing irrigation system. This would require an expenditure of funds for electricity, and there would be a need to determine who would pay for it. Since the golf courses are private property, contracts would have to be drawn specifying costs and responsibilities. This would also involve the regulatory agencies since a new permit for the Dorado plant would be needed. Due to the small area under irrigation, and the absence of major aquifers in the area, the environmental impact would be slight. Public acceptance would have to be obtained, but is not considered to be a major problem due to the high educational level of the affected persons (mostly golf players, which in Puerto Rico are at least upper middle class).

3. Groundwater recharge

Due to the absence of tertiary plants in the Island, this is a high cost alternative which would require complex technology. It is doubtful that the required technical expertise is currently available in the Island. Since the effect of this alternative in solving the problem depends on the building of tertiary plants, its current contribution to a solution is minor. To further complicate things, the institutional/administrative arrangements would be very complex, involving all the regulatory agencies both at the Commonwealth and Federal level. Public acceptance, in particular if the aquifer is used for potable water supply, would be difficult, although not impossible. Depending on the aquifer, the environmental impact could be either moderate or significant. A rating of moderate is given here assuming that the aquifer to be used would be one in the South Coast, and that recharge would be used to counteract salt water intrusion.

4. Domestic

This alternative is very similar to the previous one. It has a very high technological complexity and the institutional/administrative problems would be enormous. This is compounded by at best a low level of public acceptance and a high cost in relation to benefits. The environmental impact would also be significant.

5. Industrial

Industrial reuse is considered in terms of irrigation of sugarcane and recycle. Since the possibilities for irrigational use are small, this discussion is based on reuse as recycle.

In terms of the solution to the problem, industrial recycle can only have a minor effect because the biggest use, cooling, usually uses seawater. Technological problems vary, and depend on the quality of the current effluent and the required quality for raw water. Current policies of the Commonwealth allow industry to withdraw almost all the groundwater they need free of charge. Industrial recycle would almost require the imposition of a cost for this water (as is required by the Water Law) and the Ponce-Juana Diaz study recommended 5¢/m^3 as the figure which would trigger reuse at most industries. However, and due to the current economic realities of P.R., anything that can be conceived as even remotely influencing industry to leave is unthinkable. Therefore, public acceptance would be very low and this by itself almost eliminates the alternative. Since the reuse would not involve outside entities, institutional/administrative problems would be minimal. Environmental impact would be positive, since there would be a reduction in the amount of contaminants discharged to the environment. In terms of cost, it could be high for the industry because of the added treatment capabilities required in some cases, and the cost/benefit ratio would be moderate.

6. Irrigation

As previously shown, the number of wastewater plants whose effluents can be used for irrigation is severely limited, therefore limiting the available flow. The main reason for this is that the regional system which was proposed for Puerto Rico in the early 1970's did not materialize and the few regionals that were built were only primary. Therefore, even if all the possibilities were implemented inmediately, the overall flow contribution would be small. Technologically, there are very few difficulties in implementing a sugarcane irrigation program once the secondary effluent is available. Possible problems involve the irrigation system, in particular if the traditional ridge-and-furrow method is changed to modern drip irrigation, and the safety precautions that must be taken to protect the health of the workers. The cost/benefit ratio is low because the only cost involved is, in some cases, the pumping cost, and even though the benefits are not that large, they exist in a smaller scale. Institutionally, the problems would be simple because the government, through the Sugar Corporation, owns the lands which are candidates for irrigation. This would also simplify the administrative problems associated with needed permits from different agencies and other regulatory matters. Since the amount of land to be irrigated will be small, environmental impact will be minimized. This slight environmental impact has been verified by work done in Puerto Rico, and previously discussed here. Finally, public acceptance is estimated to be moderate, since again previous work indicates that the local public, given the appropriate educational campaign, is willing to accept this reuse.

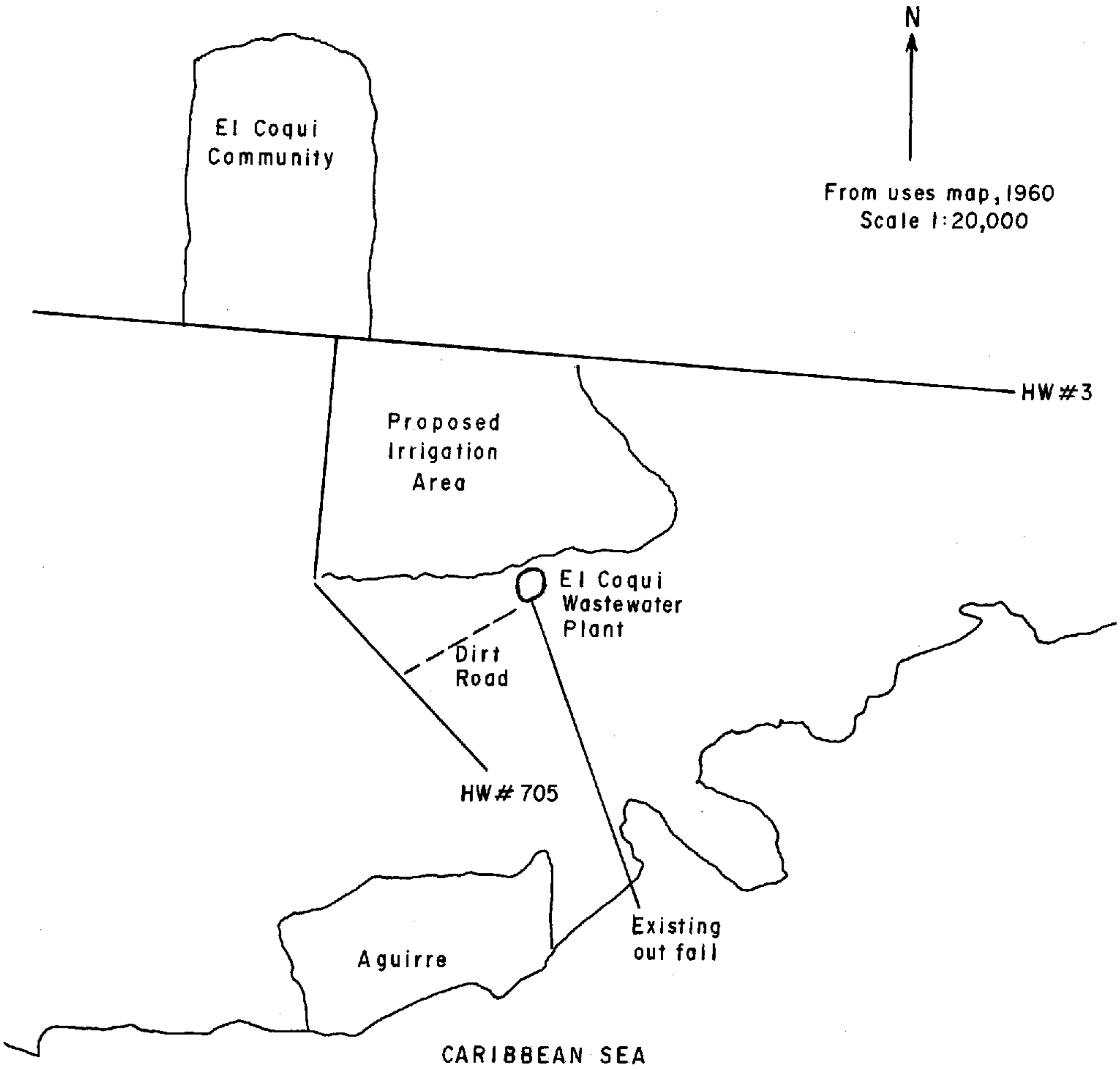
E. Selected Alternative and Implementation

The above analysis indicates that the best wastewater reuse alternative for Puerto Rico is the use of secondary treated municipal effluent for sugarcane irrigation. This is an alternative that has been tested extensively in Hawaii and locally at a pilot scale. In terms of satisfying the current overall water needs of the Island, reuse will have a small impact, but should be started because in the long-term future it might have a significant impact.

It is recommended that the first wastewater reuse project be established at El Coquí, in Salinas. This area is shown in Figure VI.1. An area of about 8 ha can be irrigated by just connecting a pipe from the existing effluent to the nearby irrigation system. The plant should retain its current ocean outfall to be used at times when irrigation is not needed and in case of emergencies.

The agencies responsible for the implementation of this alternative would be the P.R. Aqueduct and Sewers Authority and the Department of Agriculture. The Environmental Protection Agency, the

Figure VI. I
EL COQUI WASTEWATER PLANT



Environmental Quality Board and the Health Department would be involved from the regulatory standpoint.

In order to overcome any public objections, a citizen information program should be implemented. This would include newspaper articles, radio and television programs, and some presentations to the public in the Salinas area. Additionally, a training program for users of the system should be implemented. This program would be geared to informing users of new techniques and technical assistance available in the use of wastewater for irrigation.

This being a pilot project, the monitoring requirements must receive special consideration because of the wide variety and complexity of parameters and effects that should be monitored. The following general subjects should be incorporated into a detailed monitoring program:

1. Parameters to be monitored
2. Monitoring procedures
3. Interpretation of results and actions to be taken

During the initial years of operation, monitoring results should be analyzed and reviewed with various specialists. For example, interpretation of groundwater data by a reohydrologist may be necessary. Results that should be referred to personnel outside the normal operating staff should be identified.

VII. CONCLUSIONS AND RECOMMENDATIONS

1. The role of wastewater reuse in supplying Puerto Rico's water needs will be small in the near and intermediate future. On a long range basis, reuse can have a significant effect.
2. The current technological status of the Island's wastewater treatment plants precludes the use of their effluents for groundwater recharge or domestic reuse. This situation is not expected to change in the near or intermediate future.
3. The best current alternative for wastewater reuse is the irrigation of sugarcane fields with domestic effluents treated to a secondary level.
4. It is recommended that a wastewater reuse program by irrigation of sugarcane fields be started at the El Coquí community in Salinas.

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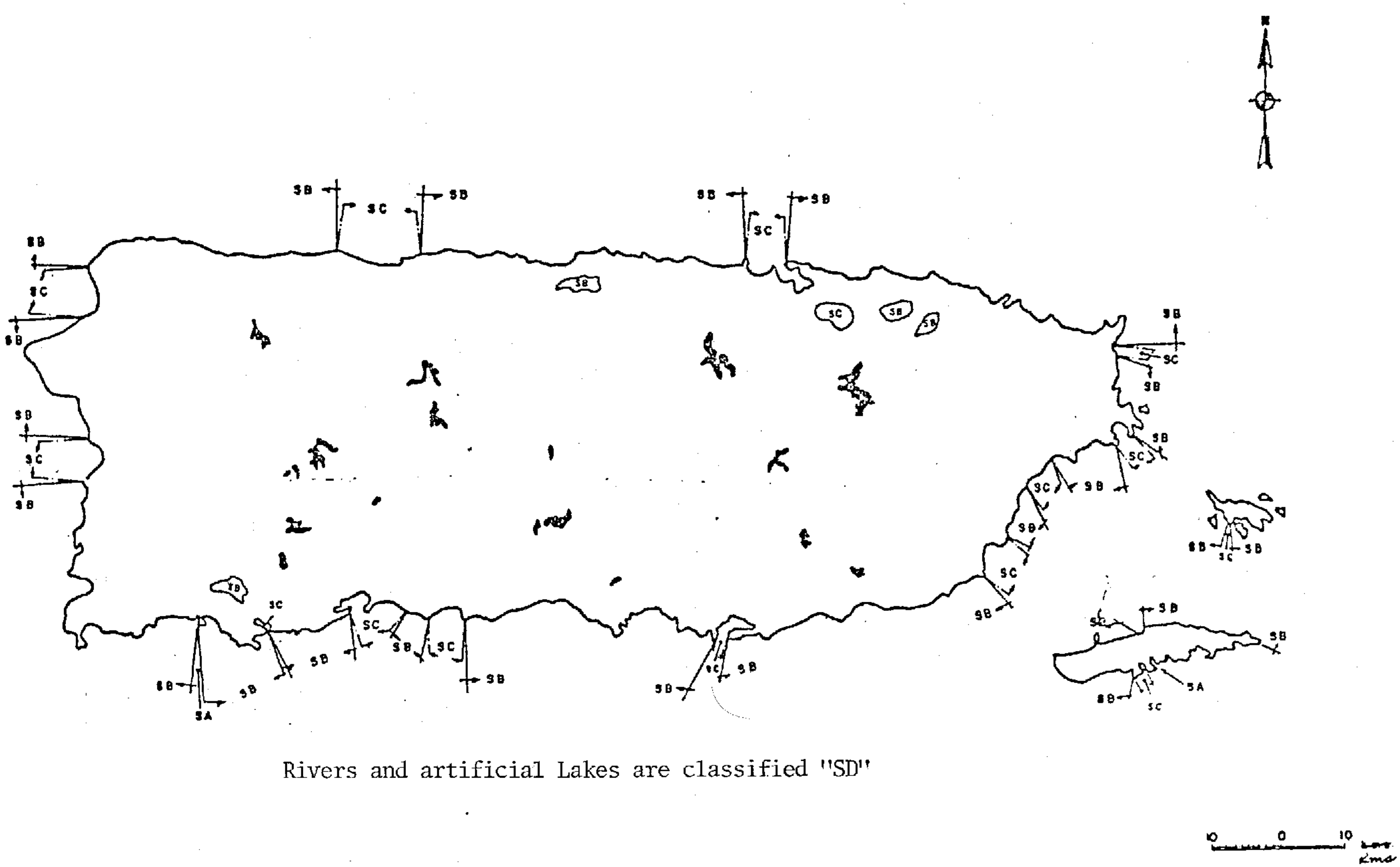
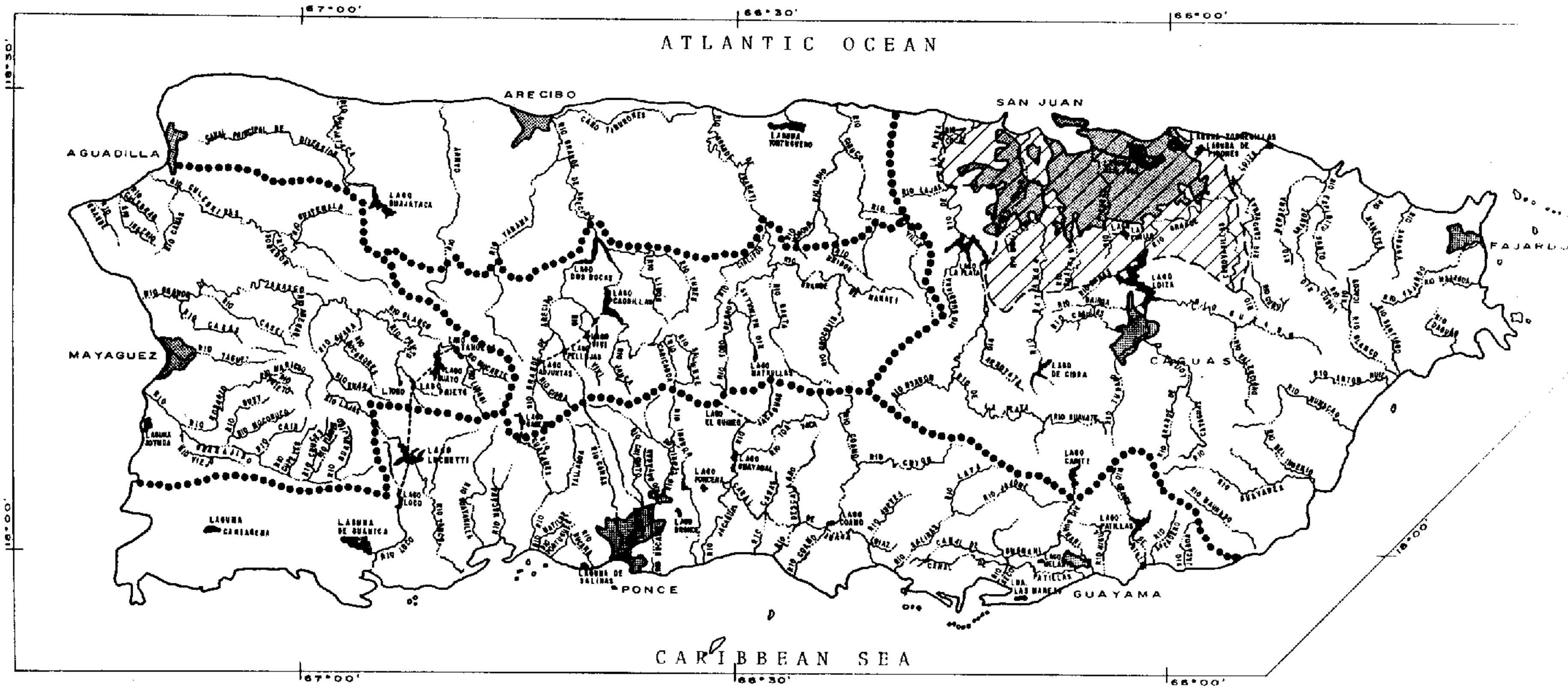
FIGURE III.1 WATER QUALITY CLASSIFICATIONS



Rivers and artificial Lakes are classified "SD"

FIGURE IV.2 WATER BODIES



ooooo Hydrologic Basin Boundary

FIGURE IV.5

PLANNED WASTEWATER SYSTEM FOR PUERTO RICO

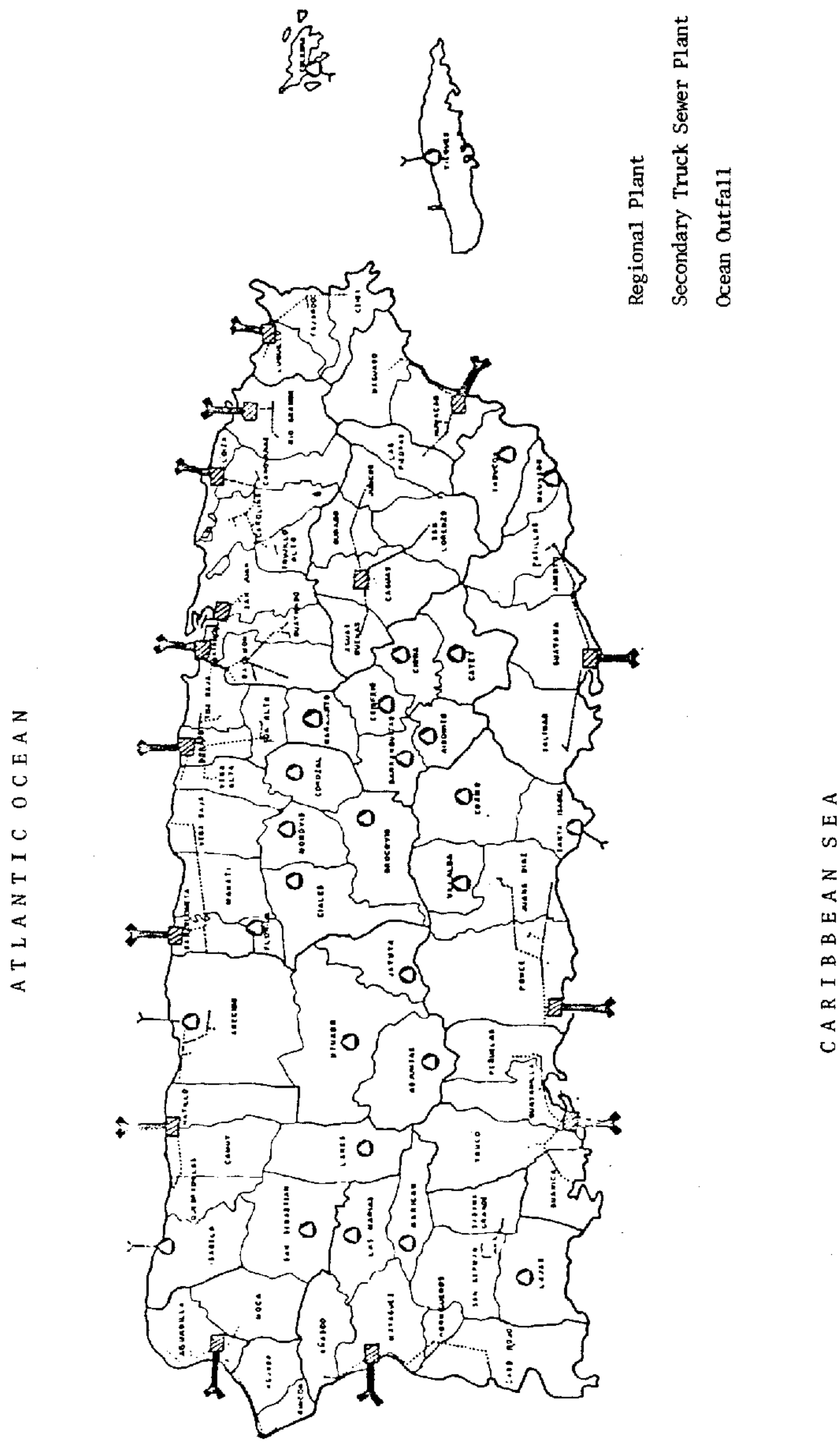


FIGURE IV.6

TREATMENT SYSTEM: 1982

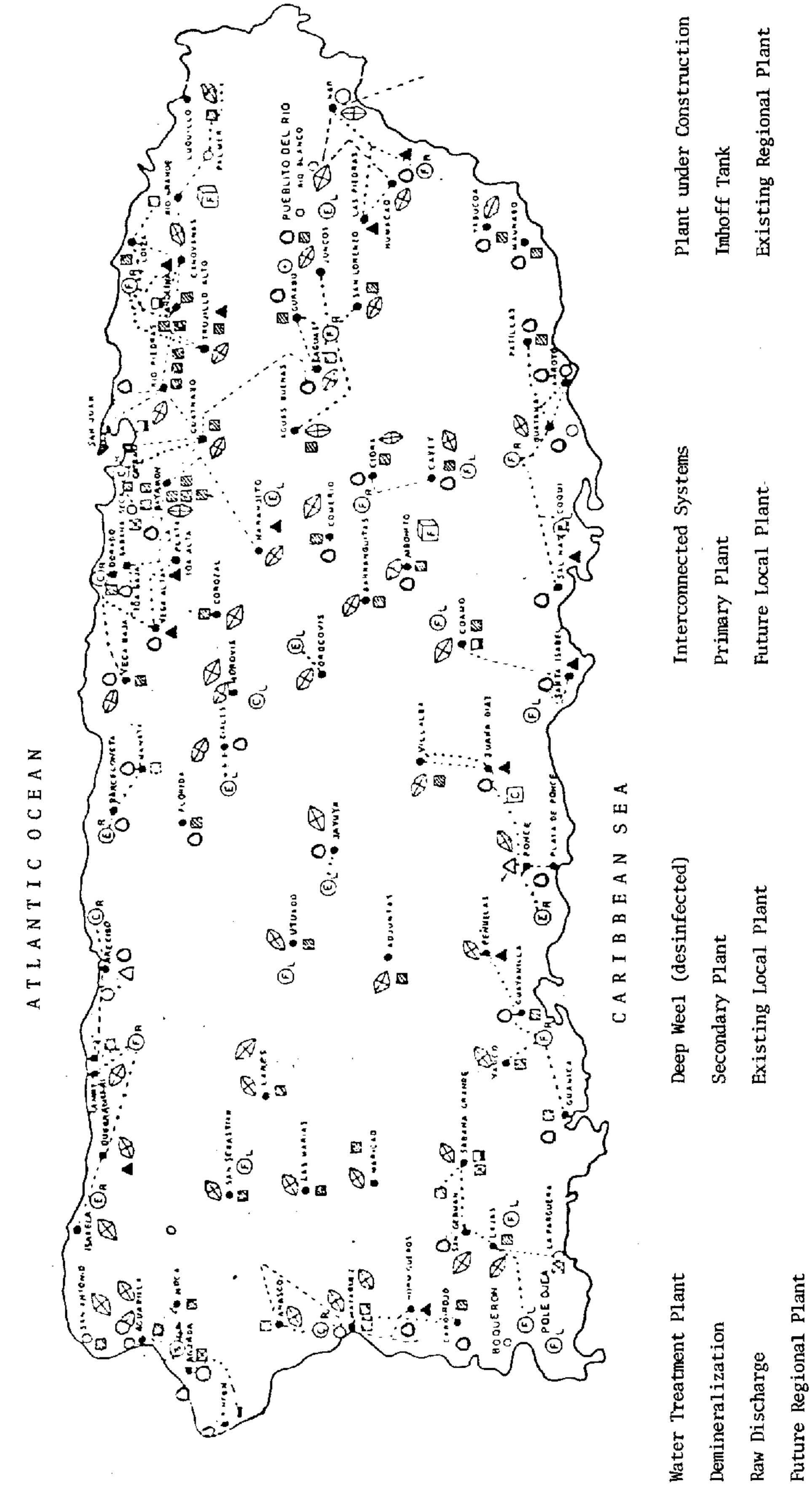


FIGURE V.2

EXISTING IRRIGATION SYSTEMS