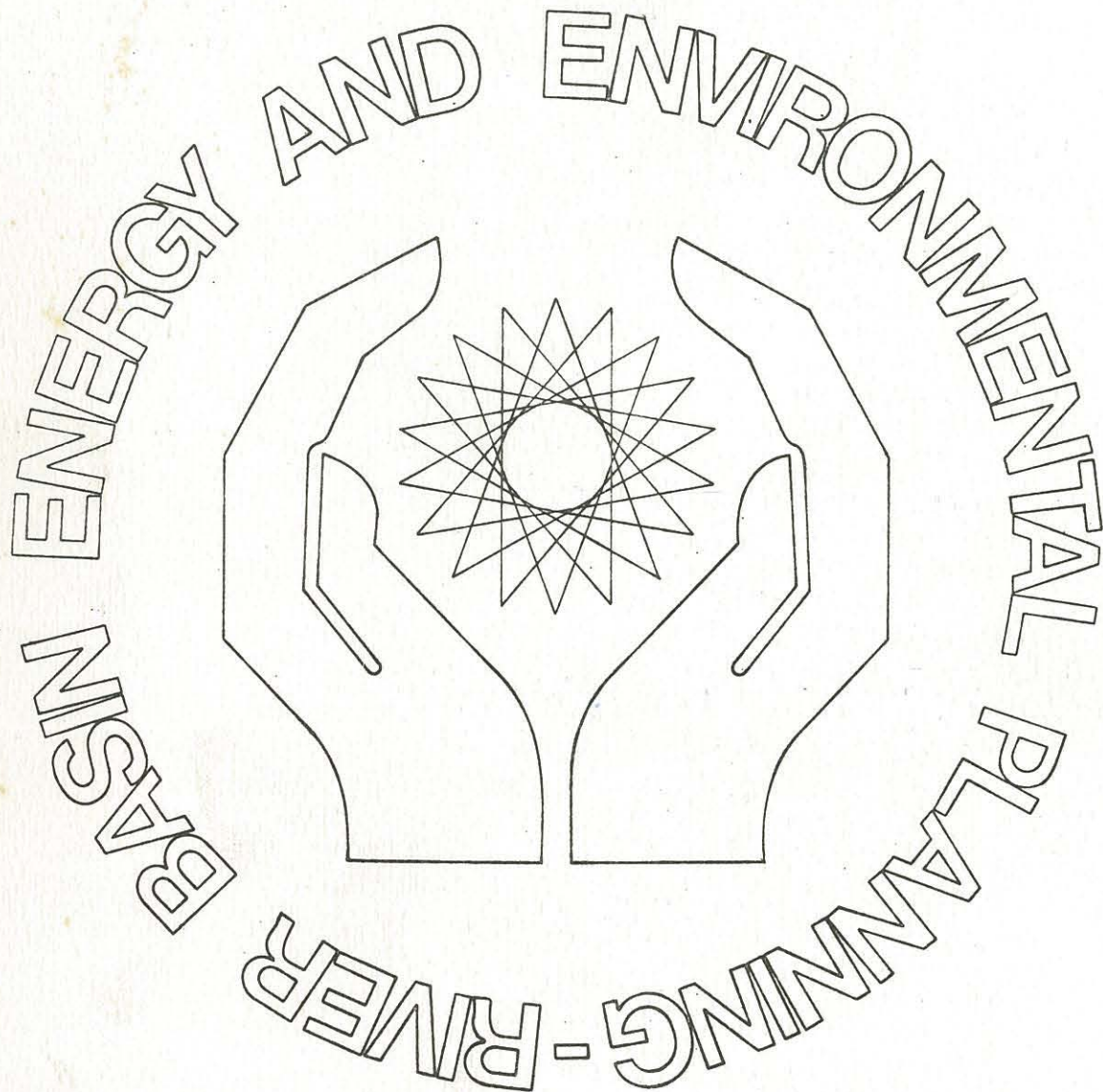


METHODOLOGIES AND INSTRUMENTS



CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO — U.S. DEPARTMENT OF ENERGY

INTRODUCTION

The Center for Energy and Environment Research of the University of Puerto Rico is pleased to publish the partial results of an intensive, ongoing research effort being carried out by a group of distinguished scientists in a variety of fields in the Espiritu Santo River Basin in Río Grande.

As a result of the rapid industrialization process and socioeconomic growth that has taken place in Puerto Rico over the last three decades, the study area has been subject to substantial ecological stress. This situation continues at an accelerated rate today, since the river basin and its surrounding area contain features that make it attractive for development purposes. It is of the utmost importance, therefore, that the wealth of data and information regarding the river basin's ecosystem already compiled and analyzed by the CEER researchers be made available to policymakers, so that future development can be carried out with a minimum of damage to this delicate ecosystem.

The CEER's Terrestrial Ecology Program has a long history. It was initiated in 1963 with a series of studies on the tropical forest ecosystem, co-sponsored by the U. S. Forest Service and the Atomic Energy Commission, on a 160-acre tract of land on the northwestern slopes of the Luquillo mountains.

In 1975, the focus of the research effort was shifted from a forest-oriented program to one centered in a drainage basin, with a view toward providing data necessary for planning and optimum resources management at the river basin level. The Espiritu Santo River Basin in Río Grande was selected as the study site.

Two years later, the Graduate School of Planning of the University of Puerto Rico was invited to join the research effort. The GSP began its analysis of the project with a series of questions: 1) what are the methodologies involved in the planning process, 2) what is the product of the research project, 3) who are its clients, 4) what timetable has been established, and 5) is river basin planning possible in Puerto Rico, and if so, what are its potentialities, levels and constraints.

The GSP determined that the principal client of the research project is the public sector, and its product the basic data and information necessary for a rational formulation and evaluation of public policy in the river basin area. It was further determined that in view of the rapid socioeconomic development taking place in the river basin, it is of vital importance to make available, on an ongoing basis, these data and information so that policy decisions affecting the river basin will be guided by the research findings. At the same time, the scientists and technicians engaged in the research project should be aware of the nature of planning—that it is a process rather than a document, and

that this process should begin immediately and be carried out concomitantly with the research effort.

In addition, the GSP produced a theoretical analysis of the possibilities and constraints on comprehensive planning at the river basin level in Puerto Rico, to provide the CEER with the guidelines necessary to achieve its goal of gearing its research effort toward a more rational management of the natural resources in the Espiritu Santo River Basin.

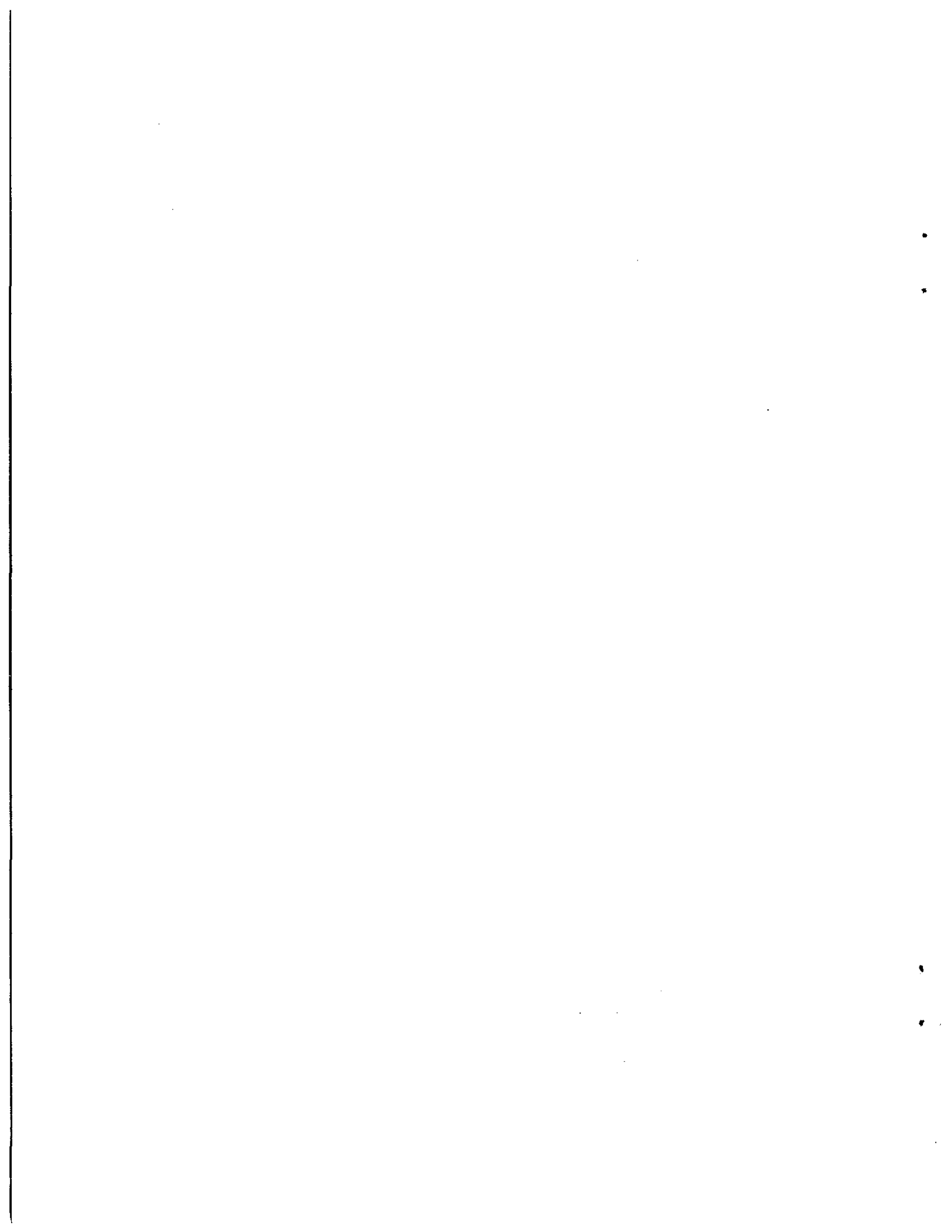
This interdisciplinary effort provided the framework for a more meaningful exchange between the natural scientists conducting the research project and the clients of that research effort, culminating in the Seminar on River Basin Planning: Methodologies and Instrument, held by the CEER and the GSP in September, 1978. At this seminar, a group of policymakers from both the public and private sectors was invited to participate in an interchange of information and ideas with the scientists of the CEER and the planners of the GSP.

The initial results of this effort were extremely positive. On the one hand, the policymakers were introduced to a wealth of information valuable for the management, development and conservation of the natural resources in the Espiritu Santo River Basin. They were provided as well with a detailed theoretical framework on river basin planning, to enable them to incorporate the data and information provided by the CEER researchers into the formulation of policy decisions affecting the river basin. Perhaps even more important, the beginning of a continuing dialogue was established between the policymakers and the CEER that should facilitate achieving the goal of incorporating into future policy decisions the results of the CEER research effort.

This publication consists of the papers presented at that seminar by members of the Center for Energy and Environment Research and the Graduate School of Planning.

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**A BRIEF HISTORY OF THE
TERRESTRIAL ECOLOGY PROGRAM**

BY

RICHARD G. CLEMENTS, Ph.D.

CENTER FOR ENERGY & ENVIRONMENT RESEARCH

The Terrestrial Ecology Program was initiated in 1963 with a series of studies on the tropical forest ecosystem. Through a cooperative agreement between the U. S. Forest Service and the Atomic Energy Commission, a 160-acre tract of land on the northwestern slopes of the Luquillo mountains in eastern Puerto Rico was set aside as a research area. The mission of the program was threefold: 1) to study the effects of gamma radiation on the tropical forest ecosystem, 2) to study the cycling of stable and radioactive isotopes through and within the ecosystem, and 3) to study the basic biological functions of this system such as respiration, transpiration and photosynthesis.

Approximately 18 months of pre-irradiation measurements were carried out to characterize the forest prior to imposing the irradiation treatment. In January, 1965, a section of the forest was subjected to gamma radiation from a 10,000 Curie Cesium source for a period of 90 days, followed by removal of the source. Intensive post-irradiation studies and measurements were conducted through 1966. The results of this phase of the Program were published by Dr. H. T. Odum (1970). The study of succession in the irradiated area is still under observation today.

Beginning in 1966, studies were initiated on the cycling of both stable and radioactive isotopes in the rain forest system. Since 1969, increased emphasis has been placed on the hydrological cycle from a quantitative and chemical standpoint.

In 1972, Odum organized a meeting in Gainesville, Florida, for the purpose of preparing a proposal for a Tropical Biome Study to be submitted to the National Science Foundation. This study would have become part of the United States effort in the International Biological Program. The Staff of the Terrestrial Program prepared a sub-unit of the main proposal, entitled "An Integrated Watershed Study." The main proposal did not prosper due to a lack of funds.

The proposal was rewritten and submitted to the Atomic Energy Commission in Washington, D.C. with a request that the Terrestrial Program be permitted to change its mission from forest-oriented research to that of a drainage basin. This plan was approved in February, 1975 and we proceeded to develop a five year research plan.

The rationale for the basin study was based upon the Island's rapid development which was accentuating, and continues to do so, the conflict between man and environment. In view of the rapidly changing socioeconomic conditions and the natural resources limitations, the decision making process requires input data from three areas; the physical, biological and cultural. While many isolated, ecologically oriented studies have been conducted in tropical environments, few if any, provided the data base for optimum environmental management.

Thus, with approximately 12 years of research in the Luquillo Forest area, the drainage basin was selected as the unifying concept to provide baseline ecological data for environmental assessment at the local and regional levels.

Each drainage basin can be considered a separate entity with its own ratio of land devoted to forests, agriculture, industry and housing. Major shifts in the land use apportioned to each of these sectors will affect the quantity and quality of water available. These in turn will determine the potential expansion of agriculture, industry and housing in the drainage basin.

In the planning of the Program we recognized the following general research areas:

1. Climatology
2. Hydrology
3. Soils
4. Plant Ecology
5. Limnology
6. Animal Ecology
7. Land Use
8. Socio-Economic Analysis
9. Planning
10. Modelling

Review papers were prepared on the first seven areas in which two questions were asked: 1) what background data or information was available and 2) based upon the information available, what additional studies need to be done.

We found that in many cases the data bases were insufficient or non-existent. Thus it was necessary to begin with some very basic surveys and characterization studies. The general and specific objectives of our initial effort, which we are in the process of completing now, is shown in Figure 1.

Figure 1: Goals and Objectives of the Drainage Basin Project

General Objectives

- TO PROVIDE BASELINE ECOLOGICAL DATA FOR FUTURE ENVIRONMENT ASSESSMENT STUDIES AT THE LOCAL AND REGIONAL LEVELS!
- TO DETERMINE THROUGH AN ECOSYSTEM APPROACH MANAGEMENT ALTERNATIVES FOR THE WISE UTILIZATION OF ENERGY, WATER AND LAND RESOURCES.

Specific Objectives

- TO DETERMINE AND DESCRIBE THE PRECIPITATION, TEMPERATURE AND SOLAR RADIATION REGIMES OF THE ESPIRITU SANTO DRAINAGE BASIN.
 - TO SURVEY, IDENTIFY AND DESCRIBE THE FLORAL AND FAUNAL DISTRIBUTIONS IN THE FRESHWATER STREAMS.
 - TO SURVEY, IDENTIFY AND DESCRIBE THE FLORAL AND FAUNAL DISTRIBUTIONS IN THE ESPIRITU SANTO ESTUARY.
 - TO ASSEMBLE, COLLATE AND EVALUATE AVAILABLE HYDROLOGICAL DATA AND IDENTIFY DATA GAPS.
 - TO COLLATE EXISTING SOILS DATA AND IDENTIFY RESEARCH NEEDS.
-

I would like to set the stage with two examples to think about. The first is taken from the Forward of the Club of Rome report on the "Limits to Growth". "The intent of the project is to examine the complex of problems troubling men of all nations; poverty in the midst of plenty; degradation of the environment; loss of faith in institutions; uncontrolled urban spread; rejection of traditional values and inflation and other monetary and economic disruptions. These seemingly divergent parts of the "world problem" have three characteristics in common:

1. They occur to some degree in all societies .
2. They contain technical, social, economic and political elements.
3. They interact.

It is the predicament of mankind that man can perceive the problem yet, despite his considerable knowledge and skills, he does not understand the origins, significance, and interrelationships of its many components and thus is unable to devise effective responses. The failure occurs in large part because we continue to examine single items in the "problem" without understanding that the whole is more than the sum of its parts, that change in one element means change in the others."

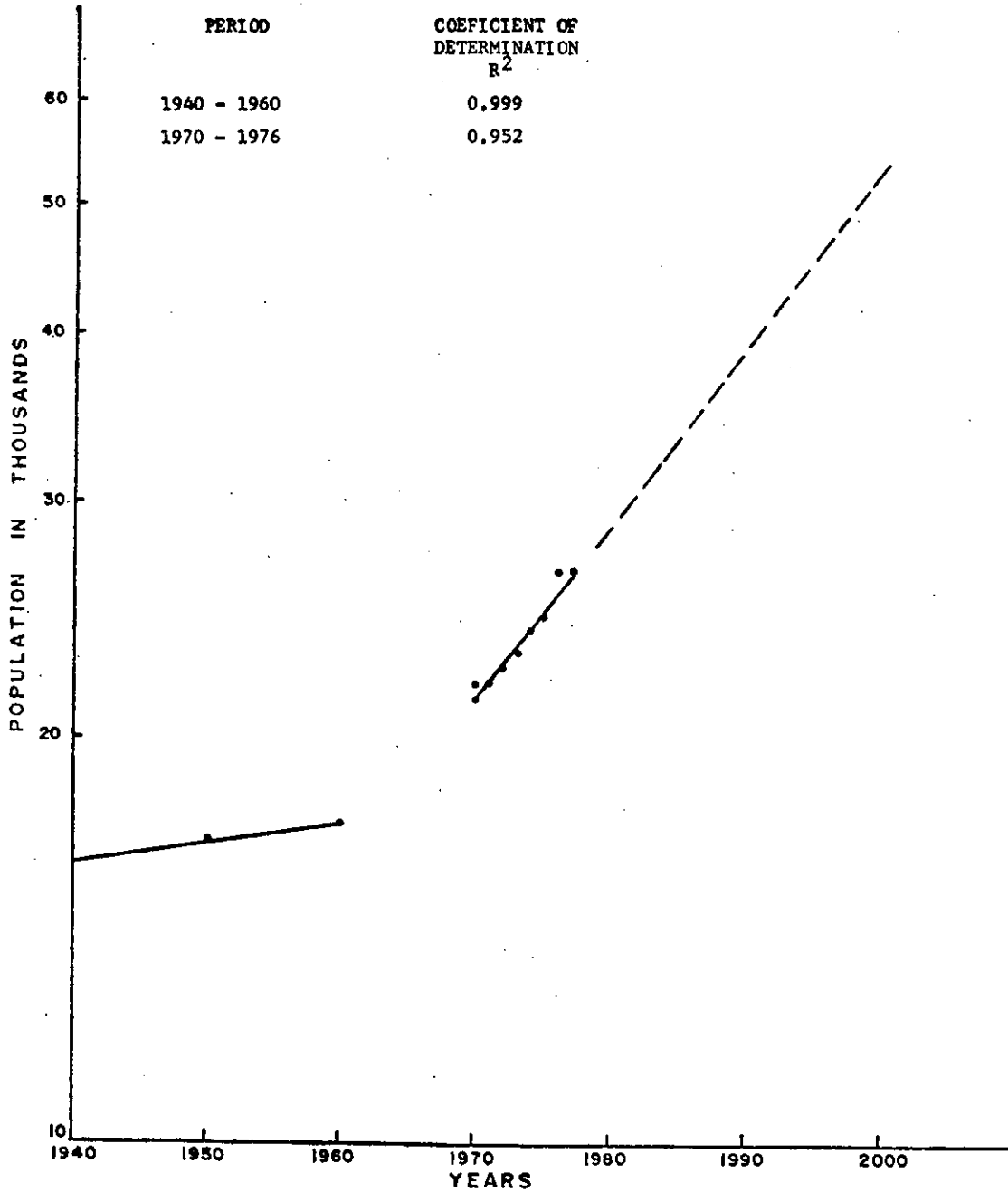
The second example deals with the problem of exponential growth. Of course, we understand the problems involved in systems that exhibit exponential increases, but there appears to exist a paradox. While we recognize its impact, our reaction time in real life is too slow. To illustrate, I want to use two examples, one from the Club of Rome Report and one from real life.

The first involves the French riddle of the lily plant cited in the report. "Suppose you own a pond on which a water lily is growing. The lily plant doubles in size each day. If it were allowed to grow unchecked, it would completely cover the pond in 30 days, choking off the other forms of life in the water. For a long time the lily plant seems small and so you decide not to worry about cutting it back until it covers half the pond. On what day will that be? On the 29th day, of course. You have one day left to save the pond".

In real life, the growth of the Municipality of Rio Grande is following the classical example of exponential increase, and then some as shown in Figure 2. In populations exhibiting exponential growth, many related factors tend to exhibit the same growth pattern; i.e. sewage production, solid waste production, land required for disposal of solid wastes, pollution, water consumption, demands on natural resources, etc.; Coincidental with this conference, a new project that eventually will result in 2,500 additional homes was announced in today's papers. There is currently under construction in the area an urbanization with a projected total of 2,500 units. If we figure an average of four people per unit, the estimated increase in population would be on the order of 20,000 persons. The current population of the Municipality of Rio Grande is approximately 27,000, which

means that we can anticipate an almost doubling of the present population with the completion of these two projects. The question in view of such a situation is: Do we wait until the "29th day", or do we begin now?

Figure 2: Growth of the Municipality of Río Grande



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PHYSICAL AND ECOLOGICAL ASPECTS

OF THE ESPIRITU SANTO

DRAINAGE BASIN

BY

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Terrestrial Ecology Division

The drainage basin presents a diversity of ecosystems for its small size. The upper ridges of the basin from 200 M elevation upward are occupied by relatively undisturbed forest. Within the forested area four distinct types are recognized: the Dwarf or Mossy forest, the Palm forest, the Colorado forest and the Tabonuco forest. Between the forest boundary and the coastal plain is a zone which includes rural settlements, pasture and cultivated lands, and might be called a transitional forest belt between 100 M and 200 M elevation. The coastal plain area embraces pasture land, sugar cane fields, plaintain and banana farms, and a coconut plantation. Included in this region is the estuary, which is bounded by excellent stands of mangrove communities of *Rhizophora mangle*, *Laguncularia racemosa*, and *Avicennia nitida* Jacq. The immediate offshore area includes a fringing of coral reefs and beds of turtle grass (*Thalassia testudinum*).

The Espiritu Santo River originates in the Dwarf Forest at an elevation of approximately 1,000 M and falls to sea level over a distance of about 20 Km. Its drainage area is approximately 21 square kilometers. The three main tributaries of concern are the quebradas Sonadora, Grande, and Jiménez. Some of the characteristics of the system are shown in Table 1.

Table 1: Characteristics of the Espiritu Santo Basin

Main Stream	Length Km.	Ave. Grade M/100 M	Drainage Area Km ²
Espiritu Santo	19.5	5.1	20.6
1000 M to 50 M elevation	8.9	10.6	
50 M to Sea level	10.6	0.47	
Tributaries			
Quebrada Sonadora	3.8	21.0	1.5
Quebrada Grande	6.4	13.6	1.9
Quebrada Jiménez	7.5	12.6	3.9

BIOLOGICAL PHASES OF THE BASIN

The drainage basin may be subdivided into three major divisions based upon major vegetation and slope: upper, middle and lower divisions. Each division has its terrestrial, aquatic and terrestrial-aquatic interface systems along with a recognizable flora and fauna.

UPPER BASIN

In the Espiritu Santo River, a sharp faunal break occurs at approximately 200 M elevation due to a series of high waterfalls. This marks the upper limit of distribution for several species of fish, all species of aquatic molluscs and possibly many other aquatic organisms. The break in the terrestrial system is less sharp, but is associated with the boundary of the national forest at approximately 100 M elevation. Although relatively undisturbed, the forest zone between 100 M and 200 M may be considered transitional and as the upper limit of the middle division.

The terrestrial system of the upper watershed has been extensively studied as part of the ongoing Terrestrial Ecology Program of the Puerto Rico Nuclear Center during the 1960's. These studies resulted in descriptions of the flora and fauna with keys and check lists, measurements of isotopes cycles and food webs, and evaluation of stress effects on the tropical forest by gamma irradiation and mechanical defoliation (Odum, 1970).

The interface systems encompass the network of feeder brooks within the forest, most of which have alternating stretches of surface and subterranean water flow. They are characterized principally by their lack of solar input, due to shading by the forest, and also by highly specialized saprovores and detritovore biotas. These biotas include bacteria, aquatic fungi, numerous insects (mostly larvae), species of filter feeding shrimp and the crab *Epilobocera sinmatifrons* as the apparent top carnivore. Algae and fishes are absent or rare in these streams.

The aquatic system is the main river channel and the channels of the three major tributaries that flow through the forest. It is characterized by continuously flowing water with a well developed autotrophic flora. The effect of man's actions on the lower reaches of this system is visible in the form of increased siltation, introduction of detergents and sewage, and the harvest of edible wild animals.

The biota and food web relationships of the aquatic system has received little attention in past studies and is poorly understood.

Current research in this area has focused on the cycling of chemical elements within and through the compartments of the forest ecosystem.

MIDDLE DIVISION

Human use of this zone consists mostly of residence, agriculture and recreation. Agricultural land use is mainly for pasture, and fruit trees. Residential homes are widely scattered and only recently has a small urbanization-type project been introduced. Few industrial sources of pollution are present since light industry is the only type present or anticipated in the area.

Unlike the upper watershed, little is known of the flora and of the terrestrial system. Part of the work effort in this area has been to describe the flora and fauna of the forested areas, pastures and croplands. In the future, inputs-outputs in terms of hydrology and chemistry will be compared to the upper and lower watersheds.

The interface system consists mainly of intermittent streams that drain the pasture lands. Again little is known on the hydrology and chemistry of these streams and their output to the aquatic system. Most of the aquatic biota are native to Puerto Rico. However, the african snail *Biomphalaria*, an introduced species, has had a profound effect since it is the vector for Schistosomiasis.

LOWER WATERSHED

The flat lowlands of the coastal plain extend landward for approximately 5 Kms. Río Grande, the major town, is located on the coastal plain about 0.5 Kms. west of the Espíritu Santo River.

The terrestrial system was dominated at one time by sugarcane but today is almost equally occupied by sugarcane, pasture and coconuts. *Rhizophora mangle* flanks both sides of the river from the coastline inland for approximately 2 Kms. Well established stands of *Lagunculara racemosa* are found, behind the red mangrove. To the east of the river, extensive areas of mangrove include the red, white and black mangroves. Due to the low elevation of the coastal plain, drainage is necessary for crop production.

The interface system is comprised of both natural and manmade drainage ways about which little is known. Flora and fauna have not been described.

Little is known of the aquatic system of this estuary. Residents of the area state that the river is rich in fish life including red snapper, tarpon, barracuda and snook. Water hyacinths have invaded the estuarine waters but appear to be controlled by periodic flooding. Salt water intrusion 3 to 4 Kms. inland has been confirmed by chemical analysis. Pollutants are evident but studies have not been conducted to establish the degree of pollution and its effect on the flora and fauna.

The mouth of the river and fresh water-salt water mixing zone is protected from the easterly currents by a promontory that extends seaward approximately 2 Kms. The promontory and river mouth are further protected by a fringing coral reef that lies parallel to the coastline (100-200 M offshore).

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**PHYSICAL, HISTORICAL, AND
SOCIOECONOMICAL CHARACTERISTICS
OF THE MUNICIPALITY OF RIO GRANDE**

BY

JOSE A. FERNANDEZ

(Mr. Fernandez was a student at the Graduate School of Planning of the University of Puerto Rico at the time the seminar on river basin planning was held. He conducted research under the direction of Dr. Héctor López Pumarejo and presented the following paper at the seminar.)

The municipality of Río Grande lies in the northeast part of the Island, bounded on the west by Canóvanas, on the south by Las Piedras and Naguabo, on the east by Luquillo and Fajardo, and on the north by the Atlantic Ocean. It has a total land area of 60.8 square miles, or about 40,000 acres. The urban center of Río Grande is only 20 miles from the center of San Juan.

The municipality is made up of the town of Río Grande and eight barrios: Ciénaga Arriba, Ciénaga Baja, Guzmán Arriba, Herrera, Jiménez, Mameyes II and Zarzal. It is largely rural, with the town itself made up of only .20 square miles. Barrio Jiménez, covering 12.03 square miles, is the largest barrio and Herrera, 3.25 square miles, is the smallest.

PHYSICAL CHARACTERISTICS

The coastal plain is made up of low-lying land with marshy areas, especially in the central, western and northwestern parts of the municipality. The south-east part of the coastal plain is characterized by semiflat to rolling land, with elevations ranging from 80 to 410 feet above sea level. Topography in the hill region varies from rolling to moderately steep, with elevations averaging about 250 feet above sea level throughout the entire municipality.

The most rugged terrain lies in the east-central sector, the site of El Yunque, one of the Island's highest mountains with an elevation of 3,496 above sea level. A total of 56 per cent of the Sierra de Luquillo range lies within Río Grande's municipal limits.

Agricultural land within the municipality includes some 26 different types of soil. The deep soils at the summit, with gradients of 26 to 40 per cent and characterized by moderate to very severe erosion, are found throughout nearly the entire Sierra Luquillo range, as well as in small areas in the hill region. These soils cover nearly 20,000 acres and are made up of the Guineos, Múcara and Catalina varieties. In the hill area, the predominant soils are medium deep, humid at the summit, with gradients ranging from 16 to 35 per cent and moderate to severe erosion, characteristics of the Múcara variety. These lands make up a considerable area of the south-eastern part of the coastal plain.

Among other soil types of some importance in the municipality is the Coloso variety, a humid, alluvial soil found in some 2,000 acres in the south-central part of the coastal plain as well as in small areas in the southwestern and eastern parts of the municipality. Another 2,000 acres is made up of the Salador type, acid or alkaline soils with some areas affected by salt but highly productive when reclaimed.

The Cataño and Corcega type, calcareous coastal soils, cover most of 1,400 acres, while the Martín Peña type, a humid, slightly acid organic soil that requires drainage, makes up a little more than 2,000 acres.

Year-round temperatures vary from an average of 74°F in the inland mountainous area to 76° F on the coast. The mountainous region in the southern part of the municipality lies within the area of highest precipitation on the Island. In general, temperatures begin rising in March, reaching a maximum of 80°F during July and August, and drop again in September, falling below 74° F during January and February.

Four large rivers run through the municipality, the Herrera, the Río Grande, the Espíritu Santo and the Mameyes, or Tabonuco. There is also a smaller river in barrio Mameyes known as the Tabonuco. The municipality also has some 12 streams, several springs and other small bodies of running water.

In addition, there are some 1,671 acres of mangrove forests in Río Grande. The Espíritu Santo River mangrove, which borders the river basin at its mouth, has been declared an area of public interest by the Planning Board.

According to the Scientific Inventory of Land Use published in 1972 by the Natural Resources Department, the municipality of Río Grande is made up of a total of 40,021.26 acres, of which 35.37 per cent is dedicated to agriculture. (See Table 1 for a breakdown of land use in the municipality.)

Table 1: General Land Use in the Municipality of Río Grande

Use	Acres	Percentage
Agriculture	14,153.73	35.37
Forests	20,637.60	51.57
Water	103.67	.26
Reservoirs	218.18	.54
Marshes	2,130.92	5.32
Urban	1,013.30	2.53
Rural	1,143.06	2.86
Public	112.58	.28
Industrial	75.68	.19
Recreation	227.71	.57
Commercial	87.13	.22
Land Cover	—	—
Non-Productive	107.50	.27
Communications	10.17	.02
Transportation	—	—
Water Transportation	—	—

Source: Natural Resources Department of Puerto Rico. Scientific Inventory of Land Use, 1972.

Of the land dedicated to agriculture, pastureland accounts for the major portion with 12,041.99 acres. An additional 1,076.91 acres are planted in coconut groves. Sugar cane, which played a major role in the municipality's economy until the mid 1960s, was no longer being cultivated by 1974, according to the Agricultural Census of that year. The reasons for the disappearance of this agricultural sector will be explored below.

ECONOMIC ACTIVITY

Agriculture. This sector has continued to be Río Grande's major economic activity since the municipality was founded in 1840. By 1897, Río Grande had a total of 28,551 acres dedicated to agriculture, chiefly sugar cane and pastureland.

Agriculture's share in the municipality's economy has been on the decline, however, following the period 1940-64, when sugar cane was its mainstay. (See Table 2). As early as the 1960's, the Agricultural Extension Service expressed concern, in its *Long Range Work Program*, that many canefields were becoming pastureland for cattle. This shift is reflected in the statistics for the years 1950-64 and after that period all agricultural activity, including the raising of beef and dairy cattle, showed declines in production. By 1975-76, only three dairy farms were still operating in the municipality according to the Agriculture Department's *Agricultural Statistics Annual*.

The agricultural activity in Río Grande can be divided into three distinct periods:

1. Prior to 1898: Coffee
2. 1898-1964: Sugarcane, coconuts, milk
3. 1964-Present: Poultry and eggs.

Aviculture, an activity characterized by small investment requirements in both capital and manpower, has been the only agricultural activity that has remained constant in the municipality. The Agriculture Department has assigned a total of \$45,800 for the development of aviculture in Río Grande.

Government. The impact of the Industrial Development Program established in Puerto Rico in the 1940s can be seen in the creation of agencies for infrastructure development, such as the Water Resources Authority, the Aqueducts and Sewers Authority and the Government Development Bank. These agencies, together with other government dependencies, invested a total of \$53,826,965 in the municipality of Río Grande during the period 1942-77, or 1 per cent of the total spent islandwide on permanent public works. Table 3 presents a cost breakdown of the permanent improvements programs, with educational projects accounting for the largest share.

Table 2: Agricultural Participation and Distribution in the Rio Grande Municipality

	1897	1910	1920	1930	1940	1950	1959	1964	1969	1974
No. of Farms	462	920	500	521	465	564	646	415	173	168
Amount of Land*	28,551	36,549	28,025	18,675	23,100	23,900	22,167	18,438	8,574	8,718
Total Planted*	1,261	24,937	21,702	8,291	20,100	7,756	6,734	4,094	1,885	1,455
Sugar Cane*	245	2,492	2,971	612	4,020	4,933	3,573	2,563	312	0
Coffee*	424	813	835	665	180	344	390	144	39	7
Coconut*	n.d.	n.d.	n.d.	n.d.	1,123	1,272	1,201	911	850	371
Vegetables*	92	1,082	n.d.	36	140	46	79	26	184	126
Pasture*	16,088	n.d.	2,000	n.d.	12,736	11,862	12,381	10,546	3,964	5,183
Mountains & Weeds*	11,202	11,612	6,323	10,384	3,000	4,282	3,052	3,796	2,725	1,770
No. of Cows	7,258	4,155	6,733	2,490	4,917	4,414	6,898	7,614	3,569	752
No. of Chickens	n.d.	4,832	4,434	4,674	6,220	6,146	8,983	12,986	17,000	25,086

* (PR) Land measure (Cuerdas) 4,810 sq.yds.

Source: For First Year 1897: Coll y Toste, Cayetano, *Reseña del estado social, económico e industrial de la Isla de Puerto Rico al tomar posesión de ella los Estados Unidos.*

Todos los demás años: U.S. Bureau of the Census, *Census of agriculture, Puerto Rico. 1910, 1930, 1950, 1959, 1964, 1969 y 1974.*

**Table 3: Total Cost of Permanent Improvement Programs
Municipality of Rio Grande (1942-1977).**

PROGRAM	TOTAL COST
1. Rural and urban sewers and aqueducts	\$ 3,145,649
2. Rural communities and housing	777,839
3. Fomento projects	3,061,651
4. Energy projects	1,780,325
5. Educational projects	15,770,563
6. Public works projects	10,059,461
7. Land Authority projects	8,468,557
8. Public buildings projects	1,878,387
9. Recreational projects	222,439
10. Urban communities and housing	8,623,574
Total Cost	\$53,826,965
Cost of permanent improvements in Puerto Rico, 1942-1977	\$5,837,281,000
Rio Grande's percentage of total	.9 per cent

Source: Planning Board, Area of Economic and Social Planning,
Government Programming Bureau.

At least partially as a result of these investments, the municipality's adjusted internal income has increased steadily: from \$4.2 million in 1950, to \$8 million in 1960, to \$16.9 million in 1970 and \$25.9 million in 1973. The manufacturing sector's share increased from \$3.9 million in 1960 to \$8.8 million in 1970. The municipal government's share was \$.6 million in 1950, \$.9 million in 1960 and \$2.4 million in 1970.

As part of the public policy to develop the economic infrastructure of the northeastern part of the Island, the Governor of Puerto Rico stated in his 1978 Message to the Legislature that about \$24 million would be invested in the area during fiscal 1978-79 for the construction and expansion of urban aqueducts systems to increase potable water supplies. This investment includes completion of the Río Blanco filtration plant in Naguabo and construction of a filtration plant in El Yunque with a capacity of 10 million gallons a day, which will use water from the Espíritu Santo and Río Grande rivers. The first stage consists of a retention wall and pumping system to take water from the Espíritu Santo River, while the second will consist of a series of reservoirs. The Aqueducts and Sewers Authority has studied various alternatives for establishing reservoirs in the Espíritu Santo and Mameyes rivers.

Manufacturing. The adjusted internal income figures cited above show that manufacturing is the sector that has had the greatest economic impact on the municipality of Río Grande since 1950.

Although manufacturing has been able to absorb part of the labor force left idle by the decline of agriculture, a Planning Board study of the geographical movement of Río Grande's workers made in 1963 indicates that about 21 per cent of the persons employed in the municipality reside elsewhere. The majority of these non-residents, or about 37 per cent, are residents of Loíza. The Planning Board cites as the principal reason for this situation the fact that recent improvements to Highway 3 have reduced considerably the economic distance between Río Grande and surrounding municipalities. The Planning Board estimates that by 1980, the demand for trained workers in the manufacturing sector in Río Grande will increase by 6,500 jobs. This increase in demand could also provoke an increase in the importation of workers from other municipalities.

There were nine factories operating in Río Grande in 1950, and this number increased to 14 in 1960, 32 in 1970, declining slightly to 29 in 1977. Of the 29 factories currently operating in the municipality, 22 were promoted by the Economic Development Administration. Nineteen are located on Highway 3 from Km. 21.0 to 32.3; only one, Systematic Industries, is located in the urban center.

The majority of Río Grande's factories, 11, manufacture clothing and related goods. Another five produce stone, clay or glass products, five machinery and electrical equipment, two metal products and another two chemical products. There are individual plants producing wood, paper and related products, and three produce non-electric machinery.

According to a memo submitted by the Executive Director to the Industrial Development Co. to then-La Fortaleza Interagency Coordinator Antonio Santiago Vázquez, on June 13, 1978, the company is negotiating with Stanric Electrical Equipment for the establishment of an additional plant in Río Grande. The Executive Director also reported that additional factory facilities are currently under construction as part of the agency's Industrial Urbanization Program. The project is made up of 36 acres and included in a federal appropriation of \$5,080,200.

In addition, the Economic Development Administration is negotiating for the establishment in Río Grande of two new manufacturing enterprises. One of them, a U.S. based company, would provide employment for 30 persons in the manufacture of metal loops and have an initial capital investment of \$200,000. The second, involving a \$118,200 investment of local capital, would manufacture steel structures and create 100 jobs. The agency currently has no long-range promotion projects planned for the municipality.

Expansion of the manufacturing sector in Río Grande has led to urban growth in the municipality, as can be seen in the following section.

Construction. Construction activity has been concentrated in the development of the municipality's urban periphery. In less than 10 years, such projects as Villas de Río Grande, Jardines de Río Grande, Río Grande Hills, Alturas de Río Grande and others have gone up.

The Planning Board estimated the value of construction in Río Grande at \$1.02 million in 1955, increasing to \$5.78 million in 1960 and \$39.22 million in 1970. In other words, construction value quadrupled between 1955-60, and increased five times during the period 1960-1970.

As of December 1977, thirteen new development projects for the municipality had been submitted to the Planning Board. Five of these projects are residential, another five are residential-tourism complexes, one is commercial and industrial expansion. Table 4 provides a breakdown of these projects, the largest of which is the 663-acre Costa Serena development and the smallest a sports center to be built by the Parks and Public Recreation Administration on a 5,530 square-meter lot.

Table 4: Relation of Approved Projects for the Rio Grande Municipality up to December 31, 1977.

Proposer	Number	Project	Date	Class.	Localization	Cuerdas*
Río Grande Dev. Corp.	68-065 Urb ²	Jardines de Río Grande	11/16/76	Res.	B. Pueblo	92.74
Urbanizadora 3T	70-044 Urb. ³	Colinas de las 3T Urb.	9/23/75	"	B. Jiménez y Zarzal	51.66
Urbanizadora Río Vista Inc.	70-109 ²	Alturas de Río Grande	8/15/77	"	B. Guzmán Abajo	227.17
Hyatt-Río Mar	71-049 ²	Tourist-Residential Proj.	2/22/77	"	B. Mameyes	320 u
CRUV	72-056CVD ²	Alturas de Rio Grande	5/13/77	"	B. Guzmán Abajo	! 81
Costa Serena Dev.	72-130 Urb. ²	Residential-Hotel Urb.	3/28/77	"	Boca Herreras	663.0
Neftalí Adorno	73-022 Urb. ²	Reperto Montesereno	7/14/76	"	B. Guzmán Arriba	29.0
Las Coles Estates	73-095d ³	Tourist-Residential Urb.	10/13/76	"	B. Zarzal	5.5
Autoridad de Tierras	75-5-1610PG ³	Enlarge Factory	8/25/76	Ind.	B. Ciénaga Baja	
El Faro Dev. Corp.	75-5-0052-SPD ⁴	Tourist-Residential Urb.	11/29/76	Res.	B. Zarzal	13.74
Caribbean Home Const. Corp.	76-22-A-471 ² CPD	Tourist-Residential Urb.	12/ 8/76	"	B. Mameyes	33.75
Centro Plaza 65 Inc.	76-22-A-575 ² CPD	Commercial building	5/24/76	Com.	B. Ciénaga Baja	16,023 m ²
APRP	76-22-A-748 CGA	Sports Center	7/ 7/77	Rec.	Urb. Villa	5,530 m ²

* (PR) Land measure (Cuerdas) 4,810 sq.yds.

Source: Junta de Planificación, Negociado de Presupuesto de Terrenos.

¹ Last date of project revision

² Under transaction for construction

³ Under construction

⁴ Prorogation request for construction

Housing. According to the Planning Board's Housing Information System, Río Grande had a housing inventory of 3,614 units in 1960, of which 93 per cent were occupied. By 1970, the inventory consisted of 5,997 units of which 84 per cent were occupied and by 1977, there were 9,194 units with 92 per cent of them occupied. A total of 3,197 units were built from 1970 to 1977, or an increase of 53 per cent. The Planning Board estimates that there will be a demand for an additional 949 units by 1980, and 4,575 units by 1985.

Of the 8,474 units which made up Río Grande's housing stock in 1977, 48.5 per cent were valued at \$10,000 or more; 86 per cent of these units were owner-occupied and the remaining 14 per cent rented.

Only 21 per cent of Río Grande's rural housing is classified as substandard, and 17 per cent of its rural housing stock. It ranks seventh islandwide in terms of the condition of its rural housing stock, and tenth regarding urban housing.

Commerce. A commercial planning study conducted by the Commerce Department in Río Grande concluded that local consumers were more attracted to the shopping areas of Río Piedras and Fajardo than to the municipality's commercial district. On the other hand, Río Grande's commercial center attracts consumers from the neighboring towns of Loíza, Luquillo and Canóvanas.

On the basis of projected development, the Commerce Department estimates, however, that the commercial sector will be a major source of employment, goods and services for Río Grande residents in the future. If the projected growth rate in employment is achieved, the department estimates that the municipality's income will be about \$53.2 million by 1985. It also estimates an increase in the demand for retail goods of \$9.1 million by 1980, to be absorbed by the shopping centers of Villas de Río Grande and Alturas de Río Grande.

Tourism. Potential tourist attraction of both an historic and scenic nature can be found in Río Grande. Among these are the Indian hieroglyphics in the Espíritu Santo riverbed in the the Jiménez Arriba sector, the El Verde recreational area and a number of Spanish colonial houses. The Elisa Colberg Girl Scout Camp is also located in the municipality.

A recently built hotel, Río Mar, is now operating and the Hyatt International Corporation plans construction of a \$160 million residential-tourism complex in the area, which is expected to give an additional boost to the economy.

Other such projects are planned, including the Costa Serena development, Las Coles Estates, and projects of the El Faro Development Company and Caribbean Homes Construction Corporation.

The area also offers typical foods and entertainment, particularly during the Feast of the Virgin of Carmel in July and during the Christmas season.

The municipality has a Double A baseball team, a cockfighting pit and a basketball team.

In addition, there is a modestly priced boating excursion offered daily down the Espiritu Santo River.

SOCIAL CHARACTERISTICS

The population of Río Grande is relatively young. In 1970, 76 per cent of the population was under 40 years of age, younger than the islandwide pattern by 2 per cent. In terms of annual average family income, however, the municipality is below the islandwide average. Annual average family income in Río Grande is \$2,793, or \$270 less than the islandwide figure of \$3,063. Only 47 per cent of Río Grande's families have an income above the average figure, while that percentage is 49 per cent islandwide.

The social variable with greatest impact on the municipality's integral growth is population growth. Table 5 shows population growth changes in Río Grande and in Puerto Rico as a whole. It can be seen that the growth rate in the municipality projected for 1980 and 1985 is nearly three times greater than the islandwide figure.

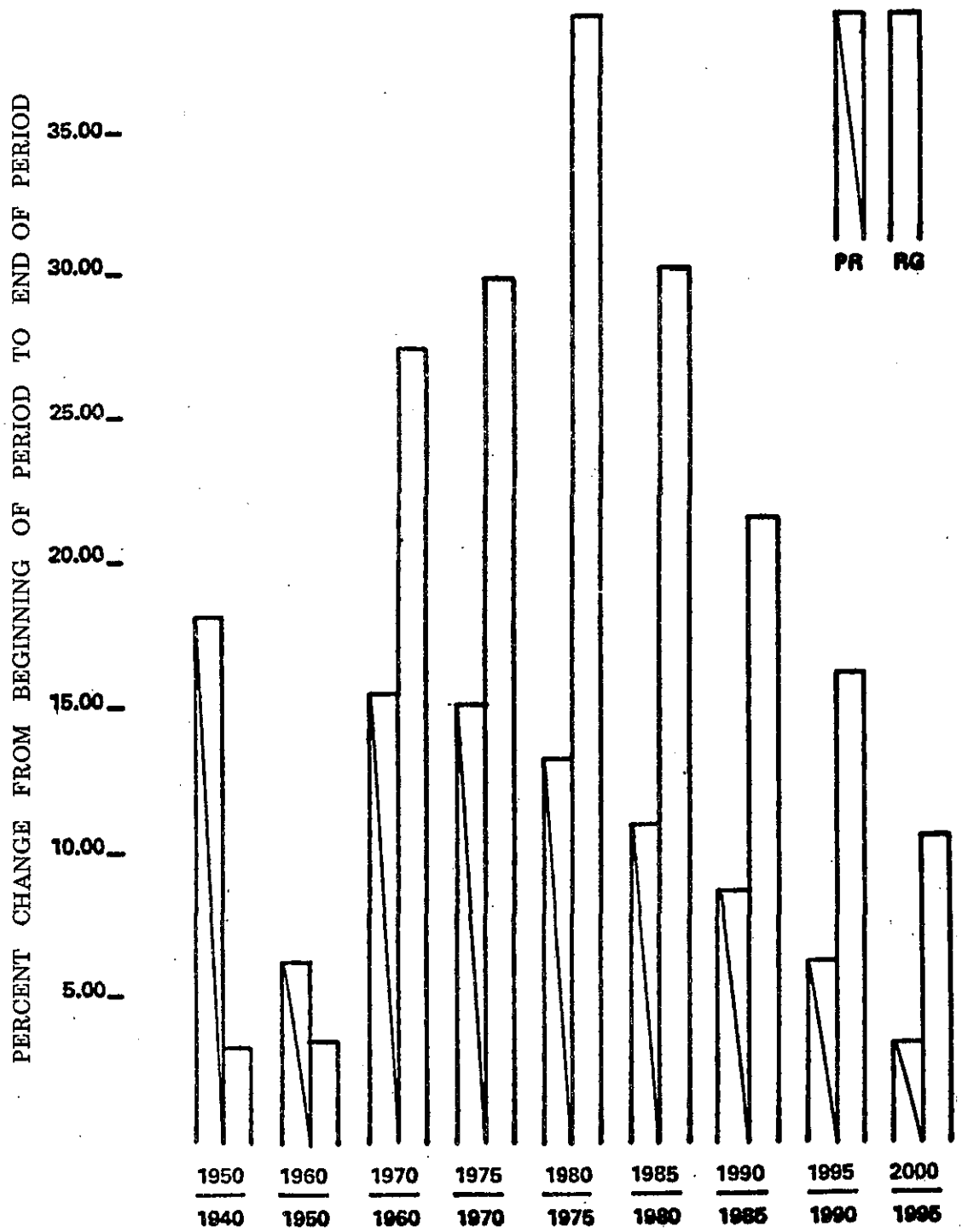
Table 5: Total Population

Year	Puerto Rico	$\Delta\%$	Río Grande	$\Delta\%$
1940	1,869,255		16,116	
1950	2,210,703	18.30	16,651	3.32
1960	2,349,544	6.29	17,233	3.50
1970	2,712,033	15.40	22,032	27.85
1975	3,120,900	15.08	28,600	29.81
1980	3,531,100	13.17	39,700	38.81
1985	3,916,100	10.90	51,800	30.48
1990	4,263,000	8.86	63,000	21.62
1995	4,523,700	6.12	73,100	16.03
2000	4,673,400	3.32	81,600	11.63

Source: Junta de Planificación de Puerto Rico

Figure 1 shows this relationship as a histogram.

Figure 1: Population Growth — Island of Puerto Rico VS Municipality of Rio Grande



Fuente: Junta de Planificación de Puerto Rico.

Official Planning Board population estimates indicate that Río Grande will reach its greatest rate of population increase by 1980, and that increase is expected to exceed the islandwide figure by 25 per cent. The increase is expected to continue through the year 2,000, although at a slower rate. The growth rate will still be 8 per cent greater than that of the Island as a whole, however. Also by the year 2,000, population density is expected to reach 1,337 inhabitants per square mile, 29 fewer than the islandwide figure. If these projections prove accurate, Río Grande will have tripled its population density while the population density of the Island as a whole will have increased only 1.5 times.

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**SOME ECONOMIC ASPECTS OF
THE FAUNA OF THE
ESPIRITU SANTO RIVER ESTUARY**

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INTRODUCTION

The Espiritu Santo River estuary lies to the east of the town of Río Grande. It is made up of the Espiritu Santo and Río Grande rivers, forming a *riverine* type estuary that extends inland for six kilometers. The upper and middle limits of this estuary are composed of agricultural land used for the cultivation of sugar cane and for cattle grazing, while its lower reaches are bordered by *riverine* type mangroves, whose dominant species is the *Rhizophora mangle* (red mangrove). In some parts of the lower estuary, these mangroves extend onto land and such species as *Languncularia racemosa* (white mangrove) and *Avicennia germinans* (black mangrove) are found: in these areas, the mangroves extend inland for a considerable distance. The total area of mangrove in the estuary is estimated at 333.84 acres.

Residents of Río Grande and nearby towns such as Loíza and Luquillo use the estuary and its mangroves both for economic and recreational purposes. Commercial fishing and crabbing carried out in the estuary provide local fishermen with a major portion of their income. In addition, the area is used for sport fishing, pleasure boating and tourism, and the municipality of Río Grande discharges much of its liquid wastes into these rivers after they have been processed by a secondary treatment plant.

The main purpose of this paper is to explore some of the economic aspects of the fauna found in the estuary and its mangroves. A secondary goal is to examine the estuary's impact on Río Grande's economy, and establish the relationship of the estuary to its surrounding communities as well as its importance to these communities.

In order to understand the economic significance river estuaries have for the communities that surround them, it is important to have a clear picture of their biological importance to the ecosystem and to the commercially valuable animal life used by these communities.

As recently as 25 years ago, river estuaries and mangroves were considered flood-prone areas, useless waste land without economic value that served only as a breeding ground for mosquitoes. This mistaken view, held by a large segment of the population, influenced both industrial and residential development and has been responsible for the disappearance of a major portion of our mangrove resources and the pollution of our river estuaries. Some two-thirds of the Island's mangrove forests already have disappeared and at the present time it is estimated that only some 15,800 acres remain. Fortunately, this attitude toward estuaries and mangroves has changed as a result of the quantitative scientific studies that have been conducted regarding their biological importance.

River estuaries are now recognized as having a significant economic and productive value, and as being of vital importance for the crustacean, mollusc and fish reserves that represent an important economic resource for the Island. The high level of biological productivity of these areas has been recognized by marine biologists and oceanographers throughout the world.

A full 90 per cent of our fish and commercially valuable crabs inhabit these estuaries during one or more stages of their life cycles. This is true as well of such crustaceans as shrimp, freshwater fish, and certain molluscs, such as the oyster (*Crassostrea rhizophorae*). The larvae of these fish, crustaceans and molluscs are born in the estuaries or migrate to them, because they provide a habitat that is rich in food sources and offers protection from natural enemies unable to tolerate a brackish environment. These larvae remain in the estuaries throughout their juvenile stages and if they are estuary dwellers, remain during their adult stages as well. Thus the estuaries can be considered natural breeding grounds for the young of commercially valuable species. The livelihood of Puerto Rico's coastal fishermen, and particularly crabbers, depends on the ability of the estuaries to produce and protect these commercially valuable species.

The crustaceans, molluscs and fish found in the Espíritu Santo River estuary are characteristic of those found in all Puerto Rican estuaries. Of the abundant stocks of commercially valuable species, the most important are the blue land crab (*Cardisoma guanhumi*), the squatting land crab (*Ucides cordatus*), shrimp (five species of the *Macobrachium* genus), and such fish as the bass or labrax (*Centropomus spp.*), porgy (*Lutjanus spp.*), jareas (*Mugil curema*), barbudos (*Polydactylus virginicus*) and mojarra, or sea-fish (*Diapterus plumieri*).

Any factor adversely affecting these species and causing a reduction in their number will have an impact on the income of commercial fishermen and crabbers. Such businesses as restaurants and fry-stands also would be affected, since they depend on these fishermen for their supplies of fresh crabmeat. The direct economic impact such a situation would have on the municipality of Río Grande cannot be determined without a quantitative study of this aspect of the economy.

MATERIALS AND METHODS

The data used in this paper are drawn from a one-year study of the estuary's crustacean and mollusc fauna. The data concerning fish are limited and were obtained from a preliminary survey.

In the study mentioned above, six stations were selected from the mouth of the estuary to its upper limits. These stations covered mangroves, agricultural land and cattle-grazing land. In each of these stations, sectors were marked off on both sides of the river, extending to the beginning of the pasture or grassy area, and then subdivided into zones according to the vegetation predominant in each. The zones thus established were as follows: *Rhizophora* zone, in which the red mangrove predominates; *Languncularia* zone (*Languncularia racemosa*, or white mangrove); *Avicenia* zone (*Avicenia germinans*); *Acrostichum* zone (*Coccos nucifera*); and Grassy zone (*Panicum spp.*, *Spartina spp.*). Areas in which two species were equally predominant, or one only slightly more predominant, were designated as Transition zones between the two species. Finally, two zones were established designated as Aerial Root zone (in which the roots of the *Rhizophora mangle* extend toward the water), and the Aquatic zone, comprised of the river itself. The length of the sectors marked off varies according to the zones contained within them. Specimens were collected in each sector and the size of the stock was determined using the quadrant method for each different species. Thus, stocks could be determined quantitatively for nearly all of the species, with the exception of the *Goniopsis cruentata*, which is difficult to capture and had to be estimated in a semi-quantitative manner. In this specific case, the individual specimens contained in a given area (square meter) were counted with the aid of binoculars.

Physical and chemical parameters also were determined, including Ph, temperature, salinity, dissolved oxygen content, and the existing concentrations of such elements as Ca, Si, Na, Mg and K. These tests were conducted both in the substrata and in the water. An analysis was made of particulate size in the substrata, as well.

During the course of this study, a series of experiments was conducted which provided valuable data regarding ecological aspects of each of the species, with special reference to their reproductive habits and life cycles. The final results of this study will be published shortly.

RESULTS AND ANALYSIS

The data obtained regarding species with economic value for the population of Río Grande are examined in the following section. Because of limitations of space, the discussion will be confined to certain aspects of general interest.

The species with economic value found in the estuary may be divided into four principal categories, or groups, as follows:

Shrimp. Ten different species of shrimp were collected, in either juvenile or adult stages. Seven of these were typical of fresh water, one was a marine species and the rest estuarian. Of the ten species collected, eight have commercial value (See Table 1).

The marine species was identified as *Penaeus schmitti*, or white shrimp, and was reported recently for the first time on the Island (Canals, 1977). This shrimp enters the estuary during its post-larval stage and remains for six to nine months, after which the pre-adults return once again to the sea (Ewald, 1967). *P. schmitti* is not commonly found in the estuary during its adult stage, but may be seen in great numbers in the river mouth when the moon is full. Some fishermen take advantage of these bright nights to capture this shrimp in nets. They are used chiefly as bait, but occasionally are sold at five dollars per pound.

Freshwater shrimp, such as the guabaras (*Atya lanipes* and *A. innocous*), silgao (*Macrobrachium heterochirus*), camarón de años (*M. carcinus*), the coyunteros (*M. olfersi*, *M. crenulatum*), and the salpiche (*Xiphocaris elongata*) are commonly found in their juvenile stages because they have an estuarian life cycle. The upper reaches of the river are densely populated with adults of these species and some of them, such as *Atya lanipes* and *Xiphocaris elongata* are found in the river from birth. These shrimp are caught all along the Espíritu Santo River, especially during Lent, (low tide) and their sale price ranges from four to five dollars per pound.

The leopard shrimp (*Macrobrachium acanthurus*) and *Potimirin spp.* are the estuarian species; only the first has commercial value and is caught by fishermen either for their own consumption or for sale.

In addition to their economic importance, the value of the shrimp for the estuary's ecological balance and food chain is enormous. A study conducted by Iris Corujo (personal communication) shows that the larval shrimp are the major food of a great number of the fish varieties found in the estuary during their juvenile stages.

Since the freshwater larval shrimp have an estuarian life cycle and must emigrate to the estuary to develop into adults, any factor which prevents this migration will affect the upriver stock.

Crabs. Fourteen different species were captured, all of which are characteristic of mangroves or estuaries. Three of these are aquatic species, ten are semiterrestrial, and one species can be considered a true land crab. (See Figure 1). Of the 14 species found in the estuary, only two, the land crab (*Cardisoma guanhumi*) and the zambuco crab (*Ucides cordatus*), are of great commercial value. They also are highly prized as food by area residents.

Three other species could have commercial potential (the cocolías, or *Callinectes spp.*) and another, the phantom crab, found on the sand beaches at the river mouth, is used as bait in fishing for porgy and red grouper.

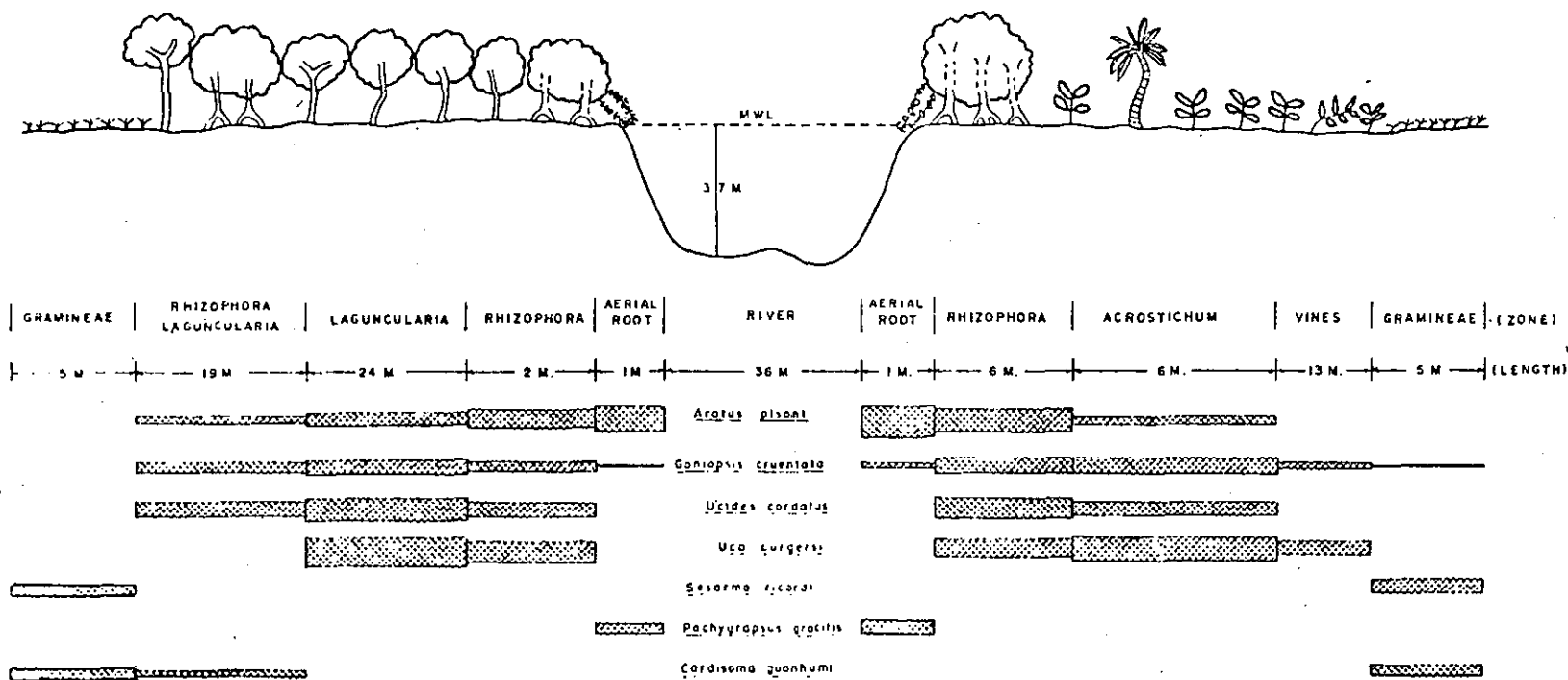
The land crab, or palancú, (*Cardisoma guanhumi*), is the species most highly prized by crabbers in the area. It has great commercial value, with the sale price ranging from twelve to fifteen dollars per dozen. The populations of this species, however, have greatly diminished in Puerto Rico in recent years. Factors that could have produced this situation include the disappearance of their habitat and over-capture. This crab inhabits areas above the high-tide line, and is found in all zones included in this area. The population is most dense in the *Avicenia germinans*, or black mangrove areas, and in the Grassy zones. This crab has been known to grow to a length of 84 mm., but examples of this size are extremely rare. The average size found in the Espíritu Santo River and its surrounding areas is from 50-60 mm. in length. In its juvenile stage, *Cardisoma guanhumi* inhabits the river-bank zones, especially in the Grassy zone, where the freatic level is not very deep. This is due to the crab's need to moisten itself periodically to avoid evaporation and dessication. In this zone, population density is 10 to 12 per square meter for juveniles and 1-2 per square meter for adults. In the *Laguncularia*, *Acrostichum*, *Avicennia* and Palm zones, the adults are more common. Depending on the area in which these zones are found, density varies from 3-4 to 1-2 for adults and juveniles, respectively.

The land crab is especially common during the rainy season, particularly during the month of May, when they mate. It is during this month that the first crab "runs" take place, when they leave their caves in order to mate. Additional runs occur from June to September, when the females travel in groups to the shores of the sea or the estuary to spawn. During these runs, the crabbers' catches are increased considerably.

The zambuco crab (*Ucides cordatus*) is very similar to the land crab, but smaller. Its average shell length ranges from 3-40 mm. It has a habitat totally different from that of the land crab, however, which can be described as mangrove areas that are periodically submerged by the tides. This crab is found chiefly in the *Rhizophora* zone, but also can be found in the *Languncularia* and *Acrostichum* zones when these

Figure 1: Relative Species Density of Decapods Crustaceans at the Rio Espiritu Santo Estuary.

STATION # 3 BETWEEN PIER AND CASTAÑON IRRIGATION CHANNEL



are submerged in water. In the estuary, the zambuco crab is found only in mangrove areas, and it is the species found in greatest numbers in the mangroves. It is slow and easy to capture. In the *Rhizophora* zone, the population density is 10-12 per square meter, while in the *Acrostichum* and *Languncularia* zones, the density is six and four per square meter, respectively. As mentioned above, however, they are found in these last two zones only when they are swamped by water.

This species remains submerged during the day if the tide is high, and emerges during the ebb, or low tide. It also will emerge following heavy rains during hot weather. Because of the scarcity of the land crab, estuary crabbers have been concentrating on this species, since its meat is equally valued. It is the species caught in largest number in the estuary and thus of greatest economic importance. The price varies from five to eight dollars per dozen, but is sold mostly in the form of meat at three dollars per pound. Some 25 crabbers interviewed work full-time at catching the blue crab and the zambuco crab. Each man's catch consists of five to six dozen zambuco crabs and two to four dozen blue crabs daily. This would represent a minimum total catch per man of 35 dozen zambuco crabs and 14 dozen blue crabs a week. These crabbers as a group have a weekly income of \$10,000.00. In one year, the sale of crabs can represent an income of as much as \$120,000.00 for 20 crabbers. Individually, their net income averages about \$6,000.00. It should be noted that these figures were obtained during the height of the crabbing season, and are not representative of a full year.

In addition, it should be taken into consideration that the crabs and their meat are sold to the many commercial establishments in the area that specialize in seafood. The crabbers are these businesses' only source of fresh crab meat.

Molluscs. Molluscs will not be discussed in this paper since only one species with commercial value (*Crassostrea rhizophorae*) is found in the estuary, and the populations are very limited. Area fishermen say the edible mussel (*Lucina pectinata*) was once common in the estuary, but these populations are very small at the present time. The reasons for this reduction are unknown, but one factor could be current changes as a result of dredging carried out in the area some years ago.

Fish. A very small number of different species was caught, but this is due to the fact that the data is from a preliminary study. A much more extensive study has been conducted by Iris Corujo, the results of which will be published shortly. In the preliminary study for the purposes of this paper, only 12 species were caught. The most common were the bass, or labraz, (*Centropomus spp.*, two species), the

jarea (*Mujil curema*), porgy (*Lutjanus spp.*) and the mojarra, or sea-fish, (*Diapterus plumieri*). Interviews with 20 fishermen revealed that 12 of them live solely on their income from fishing. Fishermen's income vary greatly, but the minimum range is \$60.00 to \$80.00 a week. In addition, the estuary is used extensively for sport or recreational fishing.

CONCLUSIONS

1. The Espiritu Santo River estuary has great economic importance for many residents of Río Grande.
2. It also is used for purposes of tourism and recreation.
3. The crab fauna has the greatest economic importance.
4. The estuary is vital to the freshwater shrimp in its larval stage.
5. Any change adverse to the estuary's ecology will be reflected in its productivity, with a resulting impact on the incomes of those residents who make their living from the catching of fish and crustaceans.

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**ECOLOGICAL DESIGN
OF RESERVOIRS FOR
PREVENTION OF BILHARZIA**

BY

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We have a dramatic evidence that development of water resources on the south coast of Puerto Rico provoked a severe epidemic of the parasitic disease, bilharzia. This disease is spread by fresh water snails which populated the reservoirs and canals of the South Coast Irrigation System, causing severe disease in the nearby population. Thus new reservoirs planned for Puerto Rico, especially those in bilharzia zones, should be carefully designed and operated to minimize the spread of bilharzia.

A wealth of epidemiological information available on schistosomiasis in Puerto Rico made it possible to trace historical trends in the distribution of the disease. Using a variety of diagnostic methods, many islandwide surveys have been made on the prevalence of the infection, including a final series of three identical skin-test surveys terminating in 1976. The various surveys were analyzed chronologically and the geographical distribution of the parasite was discussed in light of several major programs related to development of the island.

From a few scattered foci present in the early twentieth century, the extent and intensity of the disease increased on the south coast after construction of sugar irrigation systems in 1914. After 1953 this major endemic area was brought under control while a new endemic area was developing in the eastern portion of the island, due to creation of rural communities known as "parcelas." This increased transmission caused by the parcelas had been counteracted in other parts of the island after the Second World War by the widespread construction of water supply systems and by filling of wetlands and channelization of streams on the growing suburban fringes of the major cities. Finally, an expanded snail control program of the 1970's covered most of the newer foci created by the parcelas, except for a small area on the north coast, east of San Juan. (Figure 1).

By 1976 only about 100,000 persons carried the parasite, mostly children with asymptomatic infections. They lived primarily in the northeastern municipalities of Río Grande and Luquillo, with isolated groups in the Naguabo and Yauco areas, as well as scattered remnants throughout the classical endemic areas. Complete control of the disease should be accomplished in a few years if the newer drugs become available for wide scale use in Puerto Rico. (Figure 2).

Figure 1: History of Schistosomiasis in Guayama, Puerto Rico.

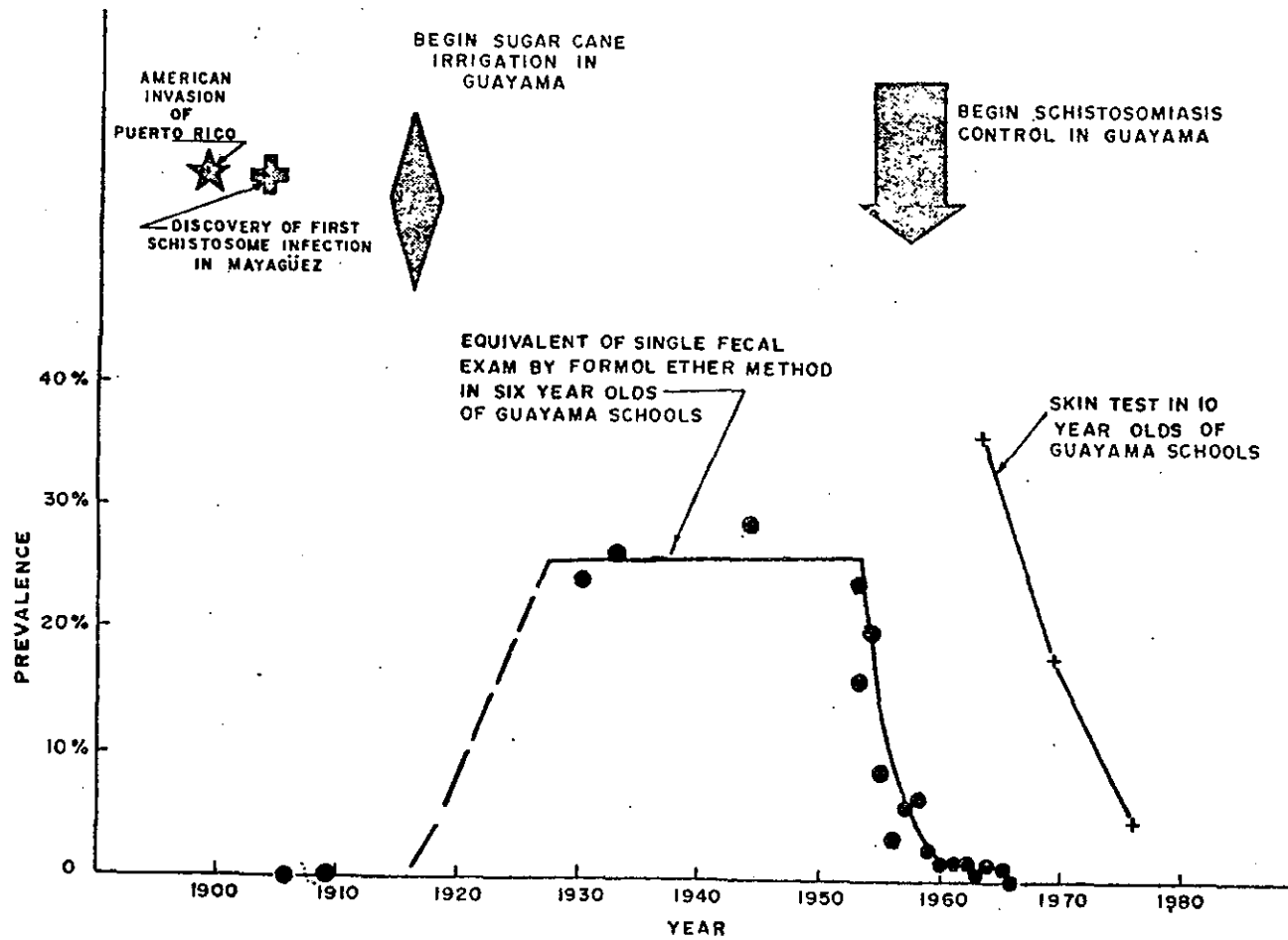
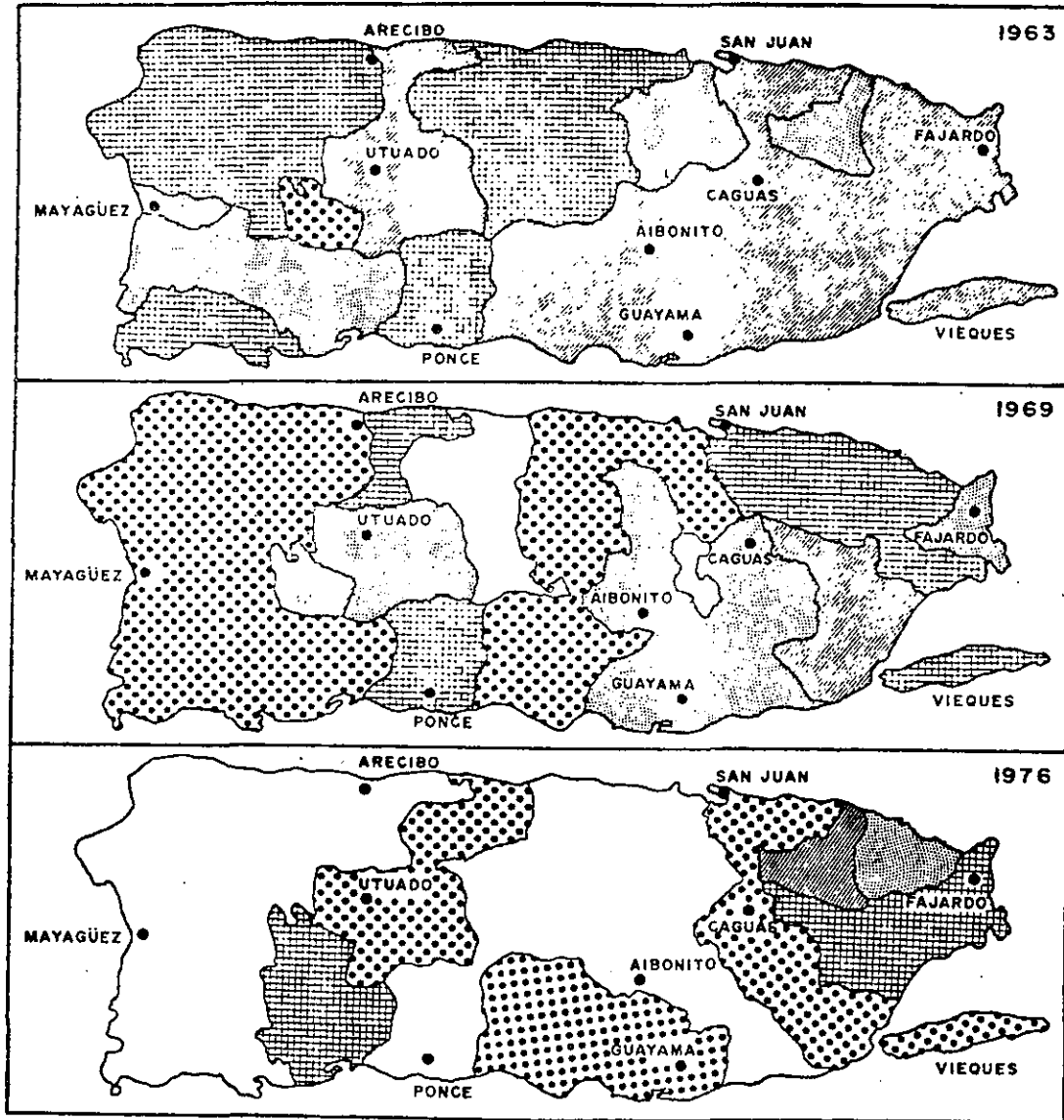
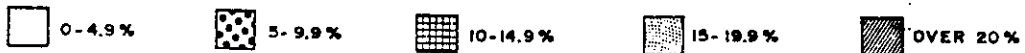


Figure 2: Prevalence of Schistosomiasis in Puerto Rico from Skin Test Surveys, 1963-1976



LEGEND FOR PREVALENCE



THE HUMAN WASTE PROBLEM

IN RURAL ZONES OF A

HIGH RAINFALL WATERSHED

BY

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Sanitary facilities in rural Puerto Rico conventionally refer to a cesspool (pozo muro) soil absorption system (CSAS) or a septic tank-soil absorption system (ST-SAS)

The purpose of this paper is to describe features of rural zones or bands which can contribute to planning problems due to these conventional methods. Most of the remarks which follow pertain to technical descriptions of current sanitary treatment technology, methods of assessing a zoned impact in a water shed, and a suggestion or two for alleviation of some rural problems.

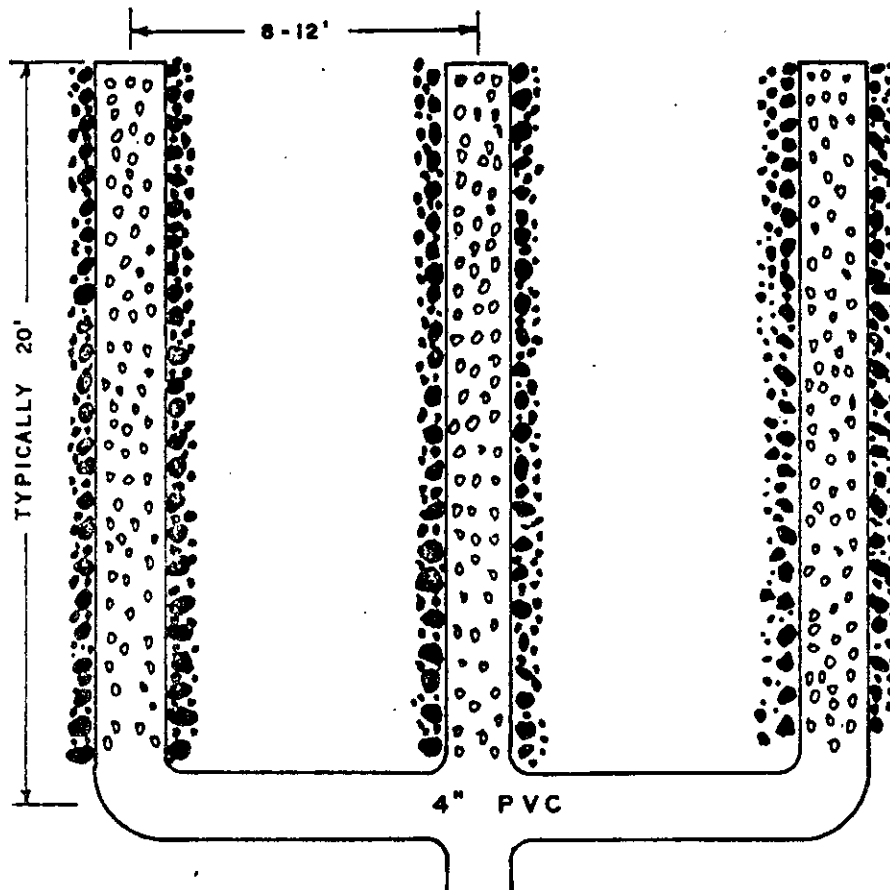
Figure 1 shows a classic "pozo muro" design, executed in cinder block and very capable of handling many rural wastes provided that periodic maintenance is undertaken. Influent is from above, and with stone baffling around the effluent sections, lifetime before pumping can be 15-25 years. The ST-SAS is more or less the same, but upper drainage does not go directly through wall openings. Instead, a level field is used (Figure 2) and distribution of effluent goes through 1/4" - 3/8" diameter holes in 4/6 inch PVC pipe. In general, the ST-SAS gives a more even and uniform distribution. It has certain other advantages for sandy soils or mound construction if a high water table is a feature of the landscape or if periodic soil-saturation from heavy rains is a prominent climatic feature.

Local practice uses tricks to extend the designs of each type of system. Broad-leaved plants such as those of the Musa family (plantains and bananas) can be planted around the pozo muro or at the edge of an ST-SAS leaching field - Figures 3 and 4. Vegetables and pineapple also do well, and the plants can evapo-transpire a good deal of moisture, prolonging the lifetime of soil characteristics which are desirable.

The following considerations should be taken into account when planning location of family unit plants and/or shared facilities of 5-10 units in small rural barrios.

Soil characteristics are important with respect to 3 factors. Permeability is low in superficial expanding clays common to the high rainfall water-shed. That is not good. Usually 60 minutes/inch percolation of surface water is considered the lower limit. Nevertheless some modern practices permit rates as high as 120 min/in. Sometimes upper soil horizons of tight clay give way to high permeability undersurface and vice versa. That possibility should be checked. An unsaturated soil column of 3 ft. is considered the practical minimum; the column may be 10 ft. for very coarse soils. These considerations are summarized in Figure 5.

Topographic characteristics mostly concern slope or average slope of drainage fields (Figure 6). In general, the limiting slope for an effective ST-SAS is 25 per cent.



1. 1/4" - 3/8" HOLES
2. PLANE LAND AREA
3. DEPTH OF 1 1/2' - 2'
4. ROCK PACKING, 1 1/2' DEEP 6" WIDE
5. GRASS, FORB GROUND COVER OR: MUSA, PINEAPPLE, SQUASH, NON-LEAFY VEGETABLES
6. AVOID CLOSE PROXIMITY: AVOCADO, MAHOGANY, ETC.
7. ADVANTAGE OF VERY EVEN DISTRIBUTION

Figure 2: Top View "Pozo Septico" showing distribution drainage field.

Figure 3:

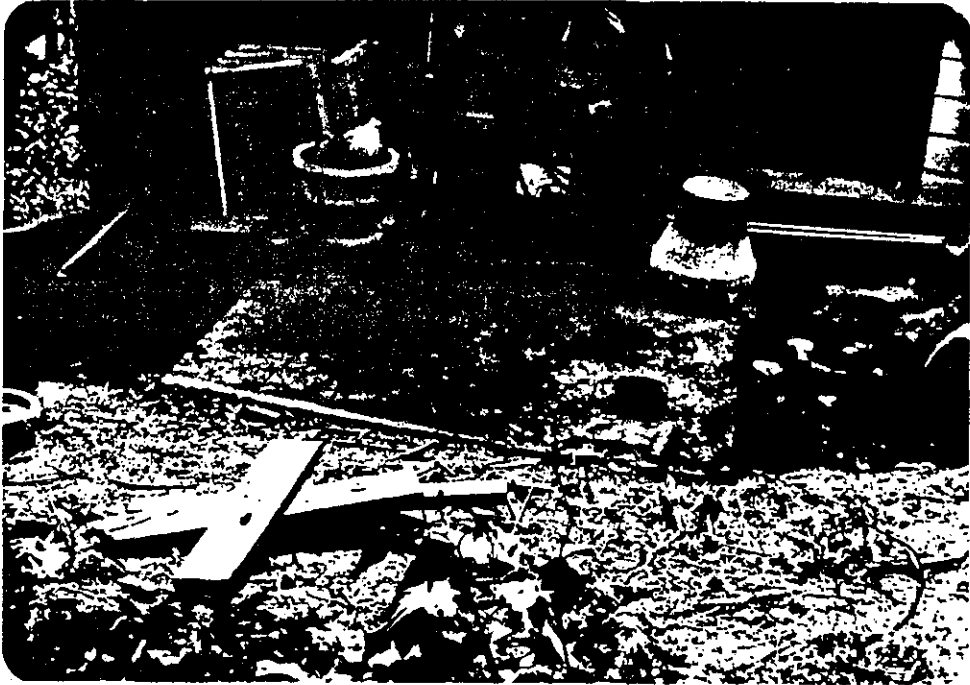


Figure 4:



Soils:

PERMEABILITY

120 min /in minimum ST-SAS

60 min /in minimum pozo muro

DEPTH TO CREVICED BEDROCK

2'-3' - fine-grained soil

10' - coarser soil (expanding clay,
tuffaceous, etc.)

DEPTH TO IMPERMEABLE LAYER

3' - adequate

FIGURE V

Topographic: LIMITING SLOPE ST-SAS

25% (may have to level)

LIMITING SLOPE POZO MURO

40-45% (Provided 12-15' depth provided)

DESIGN LIMITATIONS POZO MURO

Upslope side left permeable

Downslope side impermeable

FIGURE VI

Consequently, some terrain levelling may be necessary if such a system is employed in Puerto Rico, particularly in higher areas of the Río Espíritu Santo River (RESR) basin. Actually, a pozo muro is effective at up to 45 per cent slope provided that it is sufficiently deep (12-15 feet) so either system requires some earth moving.

Additionally, several design modifications can be employed in some extreme cases.

Geology of the area can be very important, particularly in areas characterized by stratigraphy including massive andesitic or granitic formations such as found in the RESR basin. In general, shallow bedrock closer than six feet from the surface is limiting. Unstable, very heavily weathered soils (quite common in the RESR basin) contribute to drainage clogging, or washout of underfield sections. Soil breakdown which occurs naturally at a very slow rate can be greatly accelerated by exposure to wastes from the drainage field. Accumulation of soil organisms wastes can also clog the field, causing early failure. This is less prevalent in construction featuring graded rock baffling. These design considerations are summarized in Figure 7.

Finally, perhaps the most important engineering unknown which must be determined is an accurate picture of the hydrology of the area for which sewage disposal tanks are being designed. This is summarized in Figure 8. Seasonal high ground water can be very high in land masses draining an area receiving over 200 inches of water per year (such as El Yunque at the source of the principal drainage system of the RESR basin). The accepted limit for the drainage field of an ST-SAS is three feet below the bottom of the drainage trenches. Higher than three feet can cause failure from which field recovery is very slow, or even irreversible. Lateral land use can very much influence the system. Heavy cropping or maintenance of cleared areas along the sides of the drainage fields contributes to failure in heavy rains. Mountainous modifications of the pozo muro can be made, but more earth-moving and brickwork is again required. To accomplish this, an outer-walled tanks is constructed, and two floors may also help. Flooding causes pollution of streams through failure of drainage fields. As a consequence, excessive fertilization of water bodies and adjoining land areas takes place. This latter effect has been exploited for centuries by farmers in the Yalu, Mekong and Po River valleys, among others, and, until construction of the Aswan dam, in the Nile river valley.

Let us consider landscape and land use planning options which can be used in order to cope with pollution caused by failure of human waste treatment plants in rural communities of the RESR basin (Figure 9). Pollution of streams from leaching field failure causes excessive fertilization of estuaries. Is this desirable? Can it be tolerated for brief periods during the year? According to data accumulated by the Terrestrial Ecology Division it is being tolerated at this time.

Geology: SHALLOW BEDROCK

**Bedrock closer than 6ft. from surface
is limiting**

UNSTABLE SOILS

Sandy soils - high water table

**Fine, highly hydrated sediments (swamp,
tidal estuaries)**

SOIL BREAKDOWN

Capillary clogging

Shifting

Ion Exchange in clays (Common here)

BLOCKAGE

Accumulation of biomass (microorganisms)

Precipitation of metal sulfides

**Excretion of slimy polysaccharide gums by
soil bacteria**

FIGURE VII

Hydrology: SEASONAL HIGH GROUND WATER

Limit 3' below bottom of drainage trench
Failure of field at 24"

LATERAL LAND USE

Cropping soil can impede recovery

MOUNTAINOUS MODIFICATION

Walled baffle Pozo Muro (lower wall on
downslope side)

FLOODING

Pollution of streams: (heavy)

Excessive fertilization of estuaries:
(useful ?)(harmful ?)

Strategies: (contain ?)(live withit?)
(try to channel it?)

FIGURE VIII

Planning elements to consider are: locate the "best" areas for SAS treatment using soil, topography, geology and hydrology characteristics. Perform necessary modifications of land. Try to connect 5-10 living units to a single sewage line and use gravity feed to channel to a single drainage line and use gravity feed to channel to a single drainage field. No more than one field can be constructed every two acres. Use design considerations such as maintained access roads for provision of tank pumping (by the municipality) every five years.

Or, locate the most convenient right-of-way and channel all sewage to a central processing plant and eliminate rural or semi-rural drainage fields altogether. This option is very expensive.

Finally, carry out on-site inspections of all rural fields, determine which are failing and require re-design and re-structuring of the associated facility. New designs should include modification of traditional modes of construction to reflect the realities of topography, soils, etc. Where this cannot be carried out, individually, owing to these same realities, conduits for transportation of wastes should be constructed to channel sewage to a separate treatment plant.

In developing new sections of a municipality, one of the planner's first considerations is model development. This model should not only include traditional elements such as estimates of the number of persons, number of dwelling units etc., but should begin to include geographical information on adjacent land areas suitable for SAS drainage fields, if central sewage collection and treatment is not economically attractive.

Illustration and exercise: Construct a mylar overlay showing areas characterized by soils having light to moderate limitations as septic tank absorption fields, for the RESR basin. After overlay, demonstrate which rural barrios are amenable to community or shared facilities, and which will need closed sewer tranference of sewage to a central processing plant. Hint: Use the 1969 National Co-operative Soil Survey maps.

ACKNOWLEDGEMENTS

I wish to thank Pedro Gelabert, Director of the Commonwealth of Puerto Rico Environmental Quality Board, for the privilege of serving as a reviewer of options prepared for rural zones of Puerto Rico under Project 208 Isla - Clean Water. I would also like to thank the Project 208 team (particularly Alberto García Moll) for its patience and understanding as well as prompt handling of information requests.

I could not fail to acknowledge the U.S. Environmental Protection Agency for supplying much of the engineering data used in the preparation of this report. The publications produced for the EPA Technology Transfer Seminar Program were very helpful and recommended for anyone interested in pursuing the subject further.

I wish to acknowledge Dr. William R. Bhajan for his helpful discussions of rainfall and coliform bacteria data related to conclusions that the estuary of the Espíritu Santo River is heavily fertilized.

Finally, I would thank my friends and neighbors in barrio Carraizo Alto for providing historical viewpoints of rural sanitation practices in Puerto Rico.

**PRECIPITATION DISTRIBUTION
AND RAINGAGE NETWORKS
IN THE LUQUILLO MOUNTAINS**

BY

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INTRODUCTION

Spatial distribution of precipitation in Puerto Rico demonstrates nearly an order of magnitude of variation from the driest to the wettest areas. For example, the southwest coastal section receives less than 90 cm (35 in.) annually while 60 miles to the northeast the peaks of the Luquillo mountains have been reporting amounts exceeding 635 cm (250 in.) in a year (Calvesbert, 1970). Two stations in the Luquillo mountains, El Yunque peak and USWB Station at El Verde (1000 M and 100 M elevation respectively) are separated by a horizontal distance of 5 Km. A twelve-month precipitation record from February 1976 to February 1977 showed 432 cm (170 in.) had fallen at El Yunque while only 102 cm (40 in.) was measured at El Verde. Certainly this and other dramatic variations make spatial estimates of precipitation difficult in tropical montane rain forests such as that in the Luquillo mountains.

Other investigators have studied the frequency of rain events in these mountains. Wadsworth (1948) reported a total of 1,635 rain showers on 269 days of a year at La Mina while Baynton (1968) recorded measurable precipitation on 350 days during a year at Pico del Oeste. Weaver, Byer, and Bruck (1973) recorded precipitation on 349 days, 70 per cent of these days received less than 1.25 cm (0.5 in.) of precipitation. All of the above data were taken near the high peaks of the Luquillo mountains. Knowing the spatial extent of these data is necessary to apply them in management decisions.

Clements and Colón (1975) have demonstrated the importance of the abundant, light, frequent showers in maintaining a nutrient supply to the forest canopy at El Verde in the Luquillo mountains. Their data indicate that the first 0.75 mm (0.03 in.) of precipitation would yield the greatest concentration of nutrients available for foliar absorption.

Again, knowing the spatial distribution of light shower frequency becomes vital to knowing the magnitude of foliar absorption in a forest ecosystem.

Bogart et. al. (1964) regard precipitation in terms of a hydrologic budget. They reported runoff to be much higher in the mountain watershed than in lower drainage areas. They stress that their conclusions are based on few data points and state that further research is necessary. River and Stream discharge is being monitored and annually published in the *Water Resources for Puerto Rico, Part I, Surface Water Records* by the USGS. The most significant missing component is the spatial distribution of precipitation, particularly in the poorly accessible high-precipitation areas of the mountains.

All previously mentioned investigations were basically point investigations. No thorough attempt has been made to measure precipitation on a spatial basis. With a knowledge of the spatial distribution of precipitation, management of our natural systems become more predictable. Similarly, intelligent planning for future natural resource management demands a thorough understanding of the system without which the wildlands can easily be overexploited, permanently altered, and hence rendered unproductive.

It is for these reasons that a study was undertaken to determine the precipitation input into the entire forested watershed of the Río Espíritu Santo. The purpose is to determine spatial precipitation patterns over that watershed and develop a data base to more easily estimate the number and spatial distribution of rain gages necessary to monitor precipitation patterns and spatial amounts in the mountains of Puerto Rico.

MATERIALS AND EXPERIMENTAL DESIGN

The basic instrument used was a storage rain gage constructed from an eight inch diameter plastic funnel connected to a five gallon collapsible water bottle by a flexible hose. The funnel was held above the canopy by an aluminum arm attached to a tree top. Each funnel was placed sufficiently above or away from the canopy so that precipitation to the funnel was unobstructed.

The number of stations and monitoring intervals were determined primarily by logistic and manpower constraints. The watershed is remote, mountainous, and accessible by temporary trails. These characteristics combine to make monitoring difficult and at times dangerous. Therefore, a network of twenty rain gages monitored biweekly was decided upon.

The twenty storage rain gages (stations) were placed in staggered rows at 0.75 Km intervals across the watershed. When lines connect adjacent stations, a web of 23 identical equilateral triangles is formed. (See Figure 1.) Each triangle has an area of 0.28 Km² and the total network 6.44 Km². The watershed in question of 5.87 Km² is, except for small areas, included within the network.

This design has the advantage of easily converting point data to spatial data. The three points which make up each triangle may be averaged to yield a precipitation depth for the area of the triangle. It can be shown that, for the grid network in Figure 1, the equilateral has the smallest ratio of area to corner points of any polygon that can be drawn. This is desirable when assigning a precipitation to an area. The most data points for the smallest area renders a more accurate value for that area.

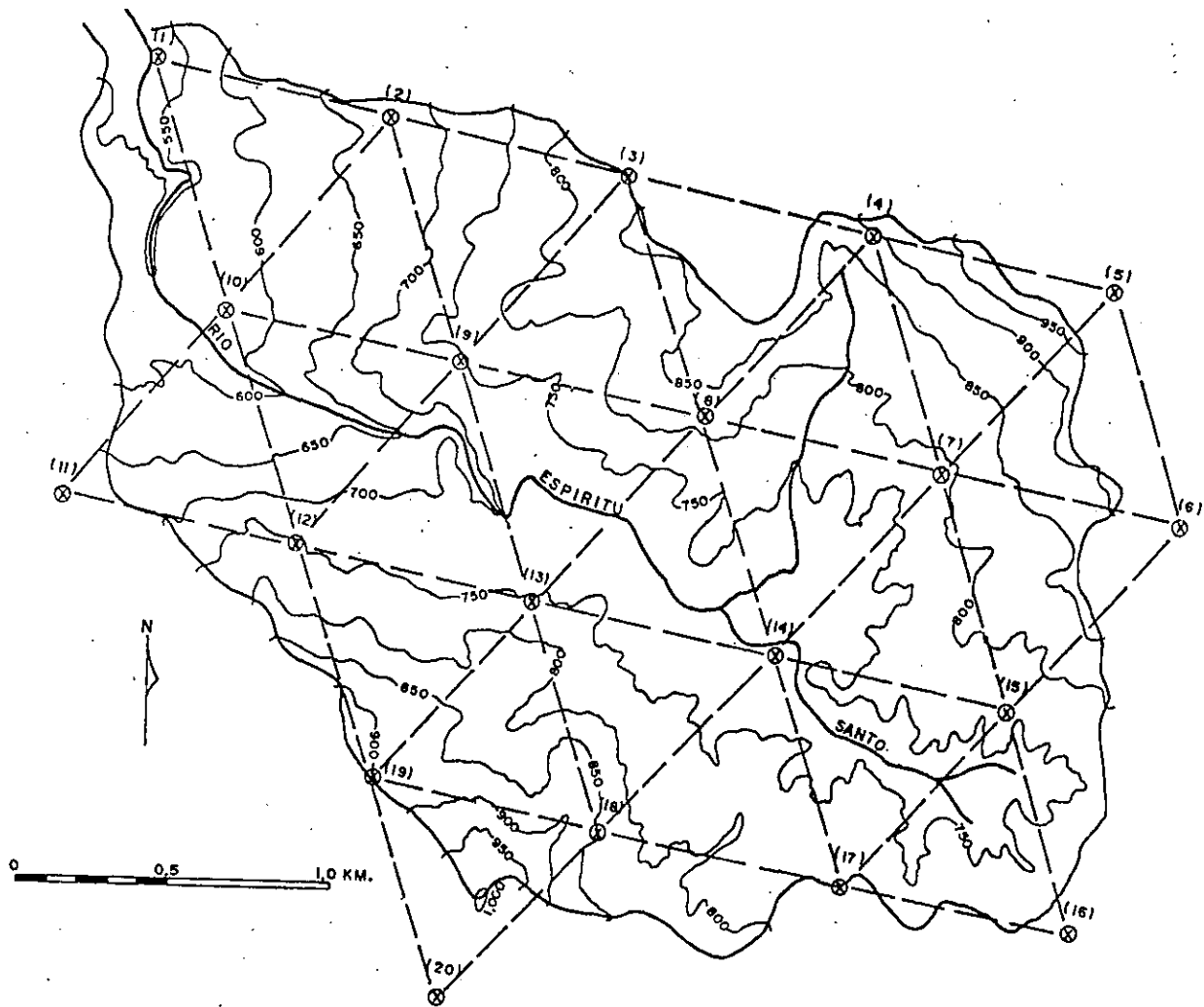


Figure 1: The position of numbered rain gages is superimposed on a contour map of the forested Espírito Santo River Watershed. Dashed lines connecting adjacent rain gages illustrate the structure of the triangle grid.

All stations were checked by the authors from February 1976 to February 1977. After each monitoring, intercepted volumes measured at each station were converted to an equivalent precipitation in centimeters and inches and catalogued for analysis.

ANALYSIS

The concept of grid density is basic to this analysis. Two types are used, number of Sta./Km² and number of Triangles/Km². The station sensitivity yields point data which is sensitive to precipitation variations. This type of grid should be used if isohyets are desired. The triangle grid is used to assign an average precipitation depth to an area. Because the resulting precipitation depth is derived by averaging, its sensitivity to extremes is reduced.

The analysis must proceed on two fronts, one dealing with distributions based on point data and the other with spatial depths based on triangle averages. In all comparisons, existing stations are used which limits diversity and coverage of grid densities to be tested. On all tested grid densities, the equilateral triangle configuration was maintained. The surface coverage was also maintained as close as possible to that of the original grid coverage, i.e., 6.44 Km². The actual grid density was calculated from a new grid network. Configurations were calculated from the area enclosed by the new network.

The original twenty stations and 23 triangle grids were reduced to 6 stations and 4 triangles, 4 stations and 2 triangles and finally 3 stations and 1 triangle. See Tables 1 and 2 for a listing of corresponding areas and densities.

The point data were analyzed as follows: Annual participation was calculated for each station and that number properly placed on a map of the watershed. Isohyets were drawn according to the following criteria: At least two stations must lie on either side of the line. The smallest isohyet interval was determined for the 20 station grid. The number of intervals between isohyets were counted and assigned to that grid density. The same procedure is carried out for the other grids. A greater number of intervals represents a more efficient grid in determining the precipitation distribution.

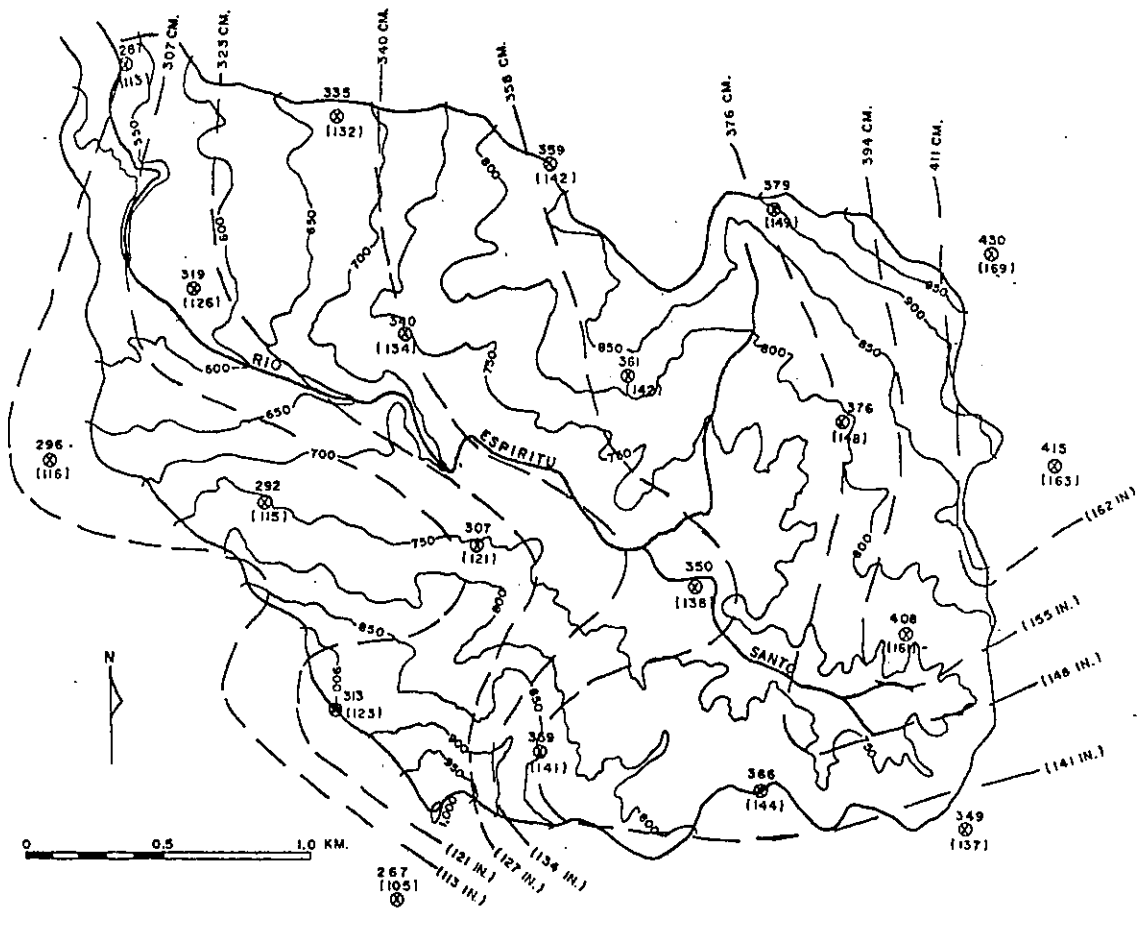
For the triangle analysis, the average precipitation depths are calculated for the area covered by the new triangle grid and the same area using the original 0.28 Km² triangles. These are labeled "Calc. Precip." and "Actual Precip.", respectively, in Table 2. The depths are compared for each grid density and between grid densities. The mean precipitation depth for the original grid is used as a standard; deviations from that mean represent a lesser efficiency.

RESULTS

Precipitation Distribution. Figure 2 shows the precipitation distribution based on one year of data. The watershed lies on the leeward side of the Luquillo mountain range, basically with elevations decreasing to the west. This manifest itself through decreasing precipitation from East to West. Perturbations in this pattern occur particularly in the Southwest section where sharp topography radically alters the homogeneity of the valley. Precipitations ranged from a high of 429 cm (169 in.) at El Yunque to a low of 267 cm (105 in.) on a peak on the southern border. Both sites are at approximately the same elevation, therefore the position is an important factor regardless of elevation.

Station 15, on the immediate leeward side of the low N-S ridge, demonstrates the very localized increase in precipitation which has widely been reported to occur under similar circumstances.

Figure 2: Isohyets and station precipitation in cm. and (in.) are shown for one year of record in the forested Espíritu Santo Watershed.



GRID DENSITY

Table 1 presents the results from the station grid analysis. This table shows that a high density of stations are necessary to accurately monitor precipitation variations in this area.

No. of Stations	Sta./Km ² Grid Density	No. of Interval	(in) Width of Interval
20	3.1	7	7
6	1.3	2	20
4	0.8	2	15
3	0.7	1	50

None of the other grids could favorably approach the number of intervals resulting from the 20 station grid. Unfortunately grids between 6 and 20 stations could not be tested with the existing grid arrangement. The theoretical minimum number of stations which could achieve 7 intervals is 9 stations under the criteria given here. In nearly all situations, a much higher number would be needed. The authors suggest a grid of approximately 15 to 20 stations in this size area (2.3 Sta./Km² to 3.1 Sta./Km²) to achieve a 25.4 cm (10 in.) interval.

TRIANGLE GRID ANALYSIS

Table 2 shows the results of the triangle grid analysis. This table is in sharp contrast to the previous table in that total precipitation may be reasonably well estimated from a few stations dispersed throughout the study area.

No. of Triangles	No. of Triangle/ Km. Grid Density	cm Calc. Precip.	cm Actual Precip.	Km ² Area	% Error
23	3.6	350.0	350.0	6.47	0
4	0.9	332.2	341.1	4.50	3
2	0.4	336.6	345.2	5.07	3
1	0.2	327.9	341.1	3.40	4

These data suggest that if a 4 per cent error can be allowed, a single triangle consisting of three stations (low density grid) may be adequate for determining the spatial precipitation depth over a large area.

Two important considerations should be borne in mind when using these data to develop a low density grid. First, this analysis was made with the philosophy that the area in question changed to conform to the grid; in most real applications, the grid must be designed to conform to the area. Second, calculated precipitation depths were applied to areas within triangle boundaries; they may well apply outside those boundaries.

CONCLUSION

These data strongly suggest that precipitation distributions in the Luquillo mountains require a high density monitoring network to sufficiently delineate varying precipitation regimes. In contrast, a very low density monitoring grid in triangle format is sufficient to approximate spatial precipitation depths. We suggest that a density of 2.3 Sta./Km² to 3.1 Sta./Km² would be adequate to achieve a 25.4 cm (10 in.) isohyet interval in these mountains. A much smaller density of 0.2 triangles/Km² or 0.7 Sta./Km² is suggested as necessary to monitor the spatial amount of precipitation to within ± 5 per cent of the real value.

These suggested densities and triangular distributions are recommended for areas where there is little or no prior knowledge of the precipitation climate of the region. An investigator with an *a priore* knowledge could easily design a more efficient monitoring network to meet his specific needs.

Finally, we suggest that our grid densities may be valid in similar regions of high orographic rainfall.

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**HYDROLOGY OF THE
ESPIRITU SANTO RIVER BASIN**

BY:

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INTRODUCTION

Our current knowledge of the hydrology of the basin is very limited. One of our main concerns in this initial research effort was to determine or establish the general relationship between rainfall and streamflow. A survey of the literature available in Puerto Rico revealed that very little, if any, effort has been concerned with this important relationship. Also attempts to determine this relationship to date have not been successful.

Estimates based upon average annual data were presented by Bogart (1964) for 10 upland areas using data compiled by the Water Resources Authority (See Table 1 and Figure 1).

Table 1: Average annual rainfall, runoff, and water loss in mountain areas of Puerto Rico. (Data from PRWRA records after Bogart, 1964).

STREAM		DRAINAGE AREA SQ. MILES	RAINFALL INCHES	RUNOFF INCHES	WATER LOSS INCHES	RAINFALL-RUNOFF % OF RAINFALL
<u>RIO</u>						
VACAS	LAGO GARZAS	6.2	92	63	29	32
TORO NEGRO	LAGO GUINEO	1.6	108	81	27	25
MATRULLAS	LAGO MATRULLAS	4.4	95	61	34	36
GRANDE DE MANATI	CIALES, Gaging Sta.	128	73	26	47	64
DE LA PLATA	LAGO CARITE	7.9	83	53	30	36
DE LA PLATA	LAGO COMERIO	135	69	24	45	65
RIO HICACO	GAGING STATION	1.3	211	180	31	15
GRANDE PATILLAS	LAGO PATILLAS	25.2	75	45	30	40
JACAGUAS	GUAYABAL	43.4	80	34	46	58
YAHUECAS	GAGING STATION	15.5	81	36	45	56

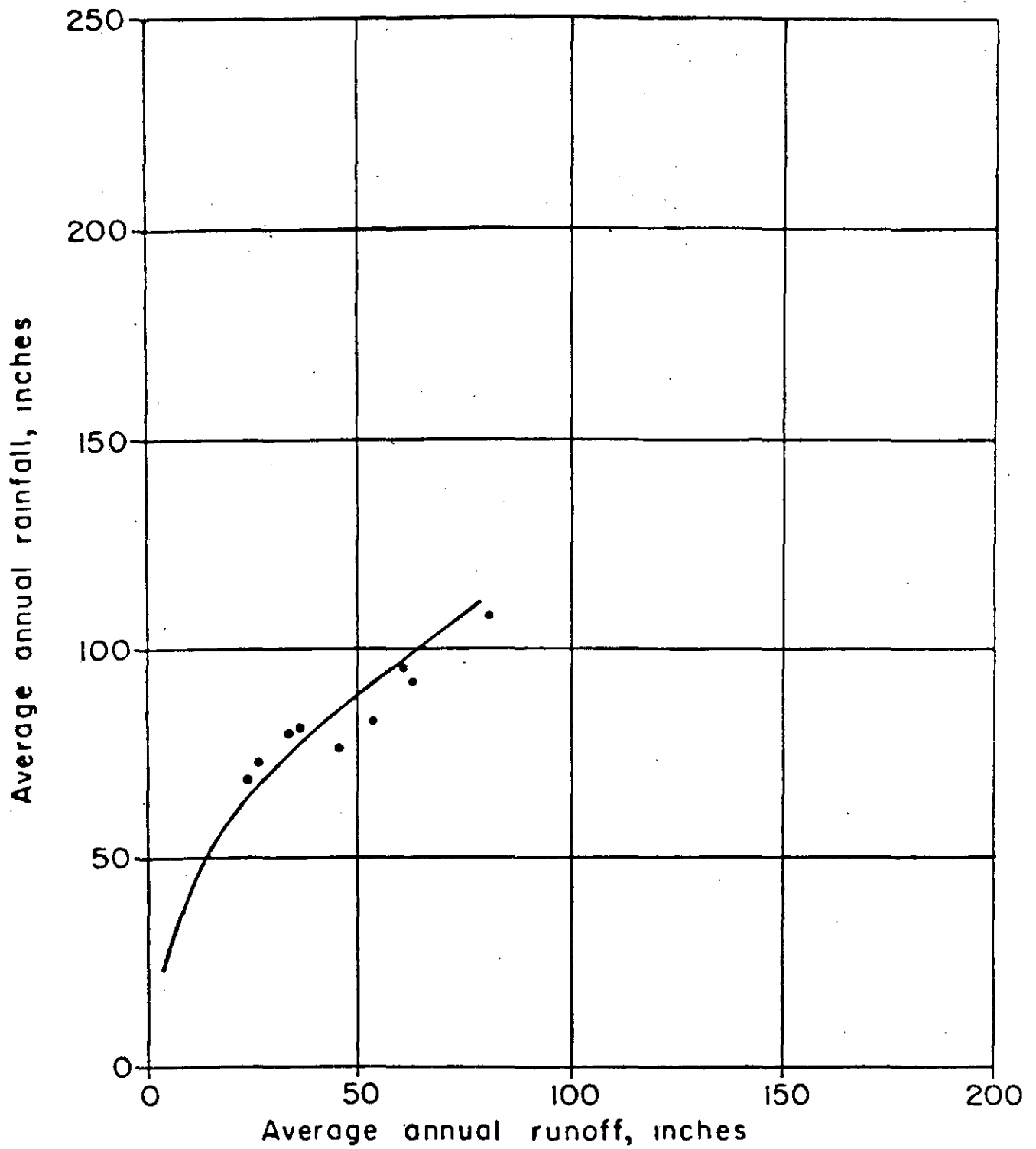


Figure 1. Average annual rainfall and runoff of 10 areas
Data from PRWRA records (after Bogart, 1964)

While the data suggest the general relationship, much more detailed measurements would be required to provide reliable, predictive equations that could be used for management purposes. Such generalizations should be used for informational purposes only. Unfortunately, they often become a part of the planning process and are used in the estimation of the water budget, which could lead to serious consequences. Throughout the report, caution was emphasized in the interpretation and extrapolation of the relationships set forth. Frequently it was not possible to evaluate the relationship between rainfall and runoff due to insufficient rain gages in a drainage basin. In some cases, only one rain gage was in operation where stream discharge measurements were being made. The following is cited from the discussion by Bogart (1964) on stage and discharge.

“Even though the total rainfall at the Río Hicaco gaging station (in the Luquillo Mountains) is much greater than that on most of the Island, the daily variation of discharge is fairly typical of what might be expected on most small streams in the mountain areas of the Island. It is obvious from the graph (graph not reproduced in this report) that one or two observations per day is not likely to provide a reliable average flow for a day on which heavy showers occur. a continuous recorded therefore is essential”.

“The average daily runoff at the Hicaco gaging station is compared to the daily rainfall a mile south (downstream) of the gaging station and 560 feet lower in altitude, in the following table.

	S e p t e m b e r - 1952						
	18	19	20	21	22	23	24
Rainfall, inches	3.34	.39	.40	.28	.72	1.27	2.77
Runoff, inches	1.02	.57	.67	.39	.75	1.80	3.03

The inconsistency between rainfall and runoff is to be expected when the rainfall is measured at only one gage, but the comparison illustrates the inherent weakness in rainfall-runoff comparisons in Puerto Rico. Not only does much of the rainfall occur in short local showers, but the terrain is so mountainous in the interior of the Island that interpolations between rain gages will not necessarily represent the average rainfall on drainage basins. Rainfall data can yield only general estimates of streamflow and then only for long-term averages. On the other hand, a gaging station equipped with an automatic continuous water-level recorder and properly operated, will yield a reliable record of the actual streamflow. And it is stream flow that concerns the designer of water facilities”.

The last water research investigations have followed the course they have for the last 75 years. Of the cooperating government agencies, three are directly concerned with the utilization of freshwater. One of the original functions of the Water Resources Authority was to develop the headwaters of rivers and provide electrical energy. Therefore, it was concerned more with how much water was flowing from the selected rivers rather than the relationships between rainfall and runoff. Hence, the investigations from the first part of the century have been directed toward the measurement of streamflow for the design, construction and maintenance of reservoirs.

The Aqueduct and Sewer Authority was established as a public corporation in May, 1945, for the purpose of providing the people of Puerto Rico with an adequate water and sanitary sewer service. Thus the agency has been interested in how much water will be needed to supply the required needs of the people. The Puerto Rico Industrial Development Company assists and aids industry in meeting their water demands.

While these agencies have been concerned with the question of "how much water", no one has given serious consideration to "how much is being received" via rainfall and what is the relationship between the two. It appears that the installation and measurement of rainfall with rain gages developed independently from the various water resources programs. As of 1960, over 80 stations across the Island were reporting rainfall on a daily basis. Over the years this network has provided valuable data with regard to the general rainfall distribution of the Island

Table 1. Average Annual Precipitation and Its Distribution Based on the Water Resources Authority Analysis (Bogart, 1964)

Average Annual Rainfall, inches	Area Square Miles	Percent of Island Area
30	130	3.8
40	258	7.6
50	195	5.7
60	396	11.6
70	923	27.0
80	765	22.4
90	453	13.2
100	179	5.2
100+	121	3.5
	Total	3420*

* Includes the Islands of Vieques, Culebra and Mona.

While this type of tabulation provides an overview, it is of little value in more detailed hydrological studies of a basin, such as the Río Esíritu Santo.

The effect of slope has not been properly evaluated in any of the hydrological studies conducted on the Island. That it is important in the consideration of rainfall input to an area can be deduced from a theoretical treatment of rainfall adjusted for slope as shown in Table 2.

Table 2: The relationship between slope and effective rainfall.
Base is 254 cm (100 in.) per year.

Percent Slope	Effective Rainfall	% of Theoretical
2.5	253.7 cm	100
10.0	253.0	100
26.0	245.9	97
40.0	235.7	93
53.0	224.5	88
80.0	198.4	78
100.0	179.6	71

In the 1971 annual report, the Environmental Quality Board presented a breakdown of land area by percent slopes (See Table 3).

Table 3: Land Area by Percent of Slope, Puerto Rico.
(1971 Annual Report, Environmental Quality Board)

Percent of Slope	Area (cuerdas)	% Total Study Area *
0.5	404,773	19.2
6.15	178,451	8.4
16.35	343,738	16.3
36.45	383,414	18.1
46.59	177,352	8.4
60 or more	626,413	29.6
Total	2,114,141	100.0

* The study excluded the offshore islands as well as some 85,000 cuerdas in "urban or non-productive use".

SOURCE: 1950 Rural Land Use classification, as reported in R. Field. The Preservation of Agricultural Land in Puerto Rico (Planning Board:1968).

Approximately one third of the land is classified as having slopes in excess of 60 per cent. If a mean of 80 per cent is assumed (See Table 2), this would mean that the effective rainfall received is only 78.1 per cent of that received incident to a horizontal surface. In absolute terms, 254 cm annually as measured by a standard rain gage would only be worth 198.4 cm. of effective rainfall, when adjusted for slope. This is a reduction of approximately 56 cm (22.0 inches) on an annual basis. In many instances, the slopes in the mountainous areas may exceed 100 per cent (45 degrees) and where slopes would approach 170 per cent (60 degrees) the reduction in rainfall would be 50.7 per cent.

Within the study area, adequate rainfall records are lacking for hydrological studies. Probably the earliest record of rainfall on the northwest slopes of the Luquillo Mountains was that reported by Wadsworth (1970). This gage was operated from 1912 to 1960 at or near El Verde, which is at the entrance to the Luquillo National Forest at an elevation of 195 m. During this period, the average annual rainfall was reported to be 3280 mm (129 in.). Raingages were operated from 1942 to 1945 on the upper Espiritu Santo River and at Ciénaga Alta. Rainfall records have been maintained at the El Verde Field Experiment Station since 1963, with a gap in the record from 1968 through 1969. Again, as with the Island studies, no attempt was made to determine the relationships between rainfall and streamflow in this area. Today, the gage at the El Verde Field Experiment Station is the only one in operation on the northwest slopes of the Luquillo Mountains.

ESPIRITU SANTO RIVER BASIN

Within the study area, data are available for two stations on the Espiritu Santo River. Station number 638 which is located in the lower reaches of the river about one mile upstream from Highway 3 and Station number 633 which was situated inside the forest and near the El Verde Experimental Field Station. However, station 638 was discontinued in 1974.

Station 638 was established by USGS in 1950, and is located at an elevation of 40 feet MSL draining an area of 8.62 sq. mi. Only annual flow measurements were made from February 1959 to April 1963. Since 1966, complete records are available for stream discharge.

The six year average from 1967 through 1972 was 58.1 cfs-day which is equivalent to 91.53 inches per year or 42,090 acre feet per year. During the period of record, the maximum measured discharge was 10,200 cfs on October 21, 1972, while the minimum observed was 5.0 cfs on April 8, 1970. A summary of the yearly records is given in Table 4.

Table 4: Surface Water Records for Station Number 638 on the Espiritu Santo River. Values are in cfs.

Year	Annual	Mean	Max.	Min.	CFSM	Inches	Acres Feet
1968	20,667	56.5	643	6.1	6.55	88.96	40,990
1969	25,959	71.2	1250	7.9	8.26	112.15	51,540
1970	32,821	89.9	1340	5.0	10.40	141.66	65,100
1971	16,724	45.8	631	6.5	5.31	72.18	33,170
1972	17,537	48.0	533	7.5	5.57	75.69	34,790
1973*	17,654	48.4	952	6.5	5.61	76.21	35,017

* Preliminary Data

Station number 633 had the highest CFSM value reported for the Island during the calendar year 1972. Generally, the stations with the highest CFSM values are found in the eastern part of the Island and at the higher elevations.

In 1975, a climatological study was initiated in the upper reaches of the Espiritu Santo River (forested area) to determine the spatial and temporal distribution of rainfall over this 1400 acre tract of forest. (Refer to Section on Climatology) and correlate rainfall with streamflow records from Station 633.

Unfortunately, we soon learned that Station 633 was discontinued in 1974 and no further records would be available. Thus, the opportunity to establish the relationship between rainfall and streamflow was dealt an unexpected defeat.

We then turned to an indirect approach to investigate the relationship and the results are encouraging for the first phase. The streamflow records for USGS Station 642 (Rio Grande, south of the town), Station 638 (0.5 m. south of Highway e on the Espiritu Santo) and Station 633 (inside the forest) were summarized according to the years of record (See Table 6). The results are given in terms of average daily cfs values for each year. The data were then subjected to a correlation-regression analysis to examine the relationships among the stations.

Table 7 summarizes the general relationship between Station 638 and 633 for the years of common record, 1969-1973. Using Station 638 (lower station on the river) as the independent variable, we examined the potential of predicting streamflow at Station 633 (upper basin, which was eliminated in 1974). The results obtained show an extremely high correlation, $R^2=0.944$ and the equation derived is:

$$\text{Est. Flow Sta. 633} = 6.687 + 0.39335X$$

where:

6.687 is a constant and

X = streamflow at Sta. 638

Table 6: Streamflow Records Rio Grande Basin. Average Daily CFS.

Station	642	633	638
Drainage area-Sq. M.	7.31	2.23	8.62
<u>Year</u>			
1967	34.5	18.0	41.7
1968	58.8	29.3	56.5
1969	88.5	37.6	71.2
1970	102.3	40.5	89.9
1971	—	25.3	45.8
1972	31.1	24.0	48.0
1973	—	25.4	48.4
1974	—	28.7	55.9
1975*	—	24.3	44.7
1976*	—	25.4	47.6

* Water Year is October through September.

Table 7: Correlation Regression Analysis. Station 638 versus 633.

Year	X		Y	Percent
	638	633	633	Deviation
1969	71.2	34.7	37.6	7.7
1970	89.9	42.1	40.5	3.5
1971	45.8	24.7	25.3	2.4
1972	48.0	25.6	24.0	6.7
1973	48.4	25.7	25.4	1.2
1974	55.9	28.7	*	
1975	44.7	24.3	*	
1976	47.6	25.4	*	

* Station eliminated

Applying this equation, the estimated values for Station 633 were calculated for the years of record and are shown in Table 7 under column Y. The estimated values deviated from the actual values as shown under the heading Percent Deviation in Table 7. Taking into consideration the various uncertainties involved, the general agreement is excellent. Thus, utilizing the equation developed for the relationship, we are able to estimate streamflow at the point previously monitored as Station 633 by utilizing the continuing records of Station 638.

In view of these results, our next step is to examine the relationships on a more detailed basis and then reconstruct or estimate the discharge of Station 633 for the one year period in which we monitored rainfall over the upper basin. These data will then be utilized to examine the relationship between rainfall received over the upper basin and the resultant discharge. If successful, this will be the first case of documenting the relationship between rainfall and streamflow in Puerto Rico.

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**COMPREHENSIVE TECHNIQUES FOR
INVENTORY AND ANALYSIS
OF NATURAL RESOURCES**

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INTRODUCTION

The environmental design process may be defined as the creative alteration of the existing natural and man-made environment, with the intention of bettering the community's quality of life. For the designer, the starting point of his efforts is the physical environment as he perceives it to exist and to require an imaginative and useful reorganization. There is, of course, room for lengthy debate concerning the correct ordering of human priorities and aspirations in order to determine what indeed would constitute an improvement in the community's quality of life. There can be little doubt, however, concerning the potential which our "designed" environments have for intruding upon, even for disrupting existing natural and social systems. We intend and hope for the best, but the general result of our design efforts is probably in every instance a mixed bag of positive and negative impacts on previously existing conditions.

While creative imagination can never be replaced as a fundamental component of the design effort, it must be guided by rational processes, and these rational processes need to be stimulated and informed by sensitive observation and reliable scientific information. The creative act is a primal process which remains largely a mystery, but the validity and relevance of the physical products of the creative act must meet the test of rational thinking. In a word, the environmental designer ought to be held accountable for the impacts upon the existing environment which result from the application of his creativity. Though it may sound redundant at first thought, we can say that the environmental designer ought also to be an "environmentalist," concerned not only with initiating changes in the existing physical environment, but also with the short and long range impacts of his efforts upon it.

ENVIRONMENTAL DESIGN AND HOLISTIC THINKING

The holistic view that has so often enlightened researchers in ecologically oriented fields when they begin to sense the intricacies and far reaching implications of their findings is by no means new to design professionals. Environmental design is fundamentally holistic in its comprehension of the relation of the whole to the parts of an environmental system; and the design process is iterative and autogenous in its method. As in natural systems, a small alteration in an environmental design—be it a building, a park, a town or a region—can set off a chain reaction which will require readjustments throughout the whole. A large alteration or several significant changes in the design may cause such an unbalance in the system that it may be preferable to scrap the initial overall concept and begin again. The similarity and suggestiveness of the ecosystem as a model for the design process has led some to identify man-made environments as ecosystems. Many environmental designers find themselves conversing comfortably with holistically-oriented scientists from the ecological and social sciences.

Not only "seeing the system as the whole of all the parts" is virtually intuitive to the environmental designer, so too is "putting the whole thing together from its parts." This certainly implies that the competent designer is a capable "coordinator" of a large number of facts and details. But "putting the whole thing together from its parts" is not a simple additive process; rather, it is an iterative one, whereby the designer attempts to follow the lines of influence and feedback stimulated by the internal adjustments of small components of the system to each other and to the whole. Reaching a reasonably stable balance within the parameters of the time and funds available for solving the problem, and within the limits of his creative talent, the designer allows the system to "gel" and proceeds to finalize drawings for construction.

Exactly when and under what conditions the designer brings the system to "gel" implies a practical dimension, as does his selection of scientific and technical data which is relevant to the project at hand. This perhaps explains a difference in orientation between the designer and the basic researcher. The former must eventually, often sooner and rather arbitrarily, establish a cut-off point for analysis and creative fermentation to get on with the construction of his environmental design, while the latter begs for more time to pursue his investigations to their logical conclusion or beyond. Nevertheless, people involved in basic research in ecologically-oriented fields are usually delighted when designers show sincere interest in their data and the desire to apply them to the design process. The designer seems at times to simplify the researcher's complexities, but he does indeed move on to put the whole thing together and to give it practical application. To say that we are encouraging a multidisciplinary effort here is to underestimate our intention; I would be more inclined to state that researchers and designers of the environment need one other.

PUTTING THE WHOLE THING TOGETHER

The competent environmental designer has at his disposal a number of advantages which are closely associated with his talents and education. His long and comprehensive study and application in the design process, in basic science and engineering, and in the humanities and social sciences complements and enhances his respect for what the senses of his body tell him, his marriage of creative intuition with logical thought, and his ability to communicate both by word and pictures. He will usually insist upon seeing how something works as well as being told how it works. Since he is an environmental designer, he will often sense an affinity to scientists involved in the study of environmental data and issues. He is, moreover, a likely candidate for bringing together their findings in a comprehensive, graphic and analytical way. Above all, he is compelled by mutual interest to apply their findings to the design process itself, if it is to lead to a responsible and enlightened reordering of the physical world.

METHODOLOGY FOR RESOURCE ANALYSIS AS A BASIS FOR DESIGN DECISIONS

1. To comprehend the major components of the natural and human environmental systems in a specific region;
2. To emphasize the dynamic character of these components as opposed to viewing them as fixed or static conditions;
3. To summarize the most reliable and detailed environmental research for graphic modeling without oversimplification;
4. To translate all information to a unified graphic form so that the various components may be viewed and studied as integral parts of a system;
5. To devise an analytical technique that brings numerical and conceptual models nearer to the physical environment as actually experienced in everyday life;
6. To document the presentation so that it will readily lead back to the basic research data, and so that corrections in the presentation can be made in light of an altered or enlarged data base;
7. To aid the designer in the estimation of human deployment of resources as an essential parameter of the design process and of probable impacts of predetermined uses upon the environment: (a) from the point of view of the intrinsic capability of the natural and human systems for supporting these uses and/or impacts; (b) from the point of view of the best alternatives among proposed uses in light of estimated impacts; (c) from the point of view of the formation of public policy for areas of special or unique value as natural or social systems.

Although the list of major components of the system under study will vary according to locale and objectives, it will generally include the following:

- | | |
|--------------------------|-------------------------------------|
| 1. Topography | 9. Points of social interest |
| 2. Slopes by percentages | 10. Climatology |
| 3. Geology | 11. Microclimatology |
| 4. Soils | 12. Environmental pollution |
| 5. Hydrology | 13. Present land use |
| 6. Fauna and Flora | 14. Present land ownership |
| 7. Ecosystems | 15. Socio-economic data |
| 8. Scenic values | 16. Master plans adopted or studied |

It can be seen that many of the components listed above are in themselves comprehensive in nature, having several sub-components; and also that among several of the major components there are reciprocal dependencies that resist oversimplification - for example, the sequence: soils, slopes, hydrology, geology, flora. All the components are in fact interrelated, and those researchers who are accustomed to carry on specialized study in one or two areas should quickly become aware of this. Indeed, this is one of the objectives of the methodology.

Basic data is received from specialists and their assistance is given in its interpretation and organization. A translation is then made, often only after considerable thought and effort, from the numerical and conceptual models of the specialists to the graphic analogues of the presentation. Where graphic models are already utilized by specialists, the translation is usually easier. In those areas where data does not yet exist — such as Scenic Analysis, Points of Social Interest, or Microclimatology — the design professionals carry out the needed investigations.

A base map is prepared by tracing the prominent features of a C&GS map(s) of the study area, in ink on drawing mylar. Topography is not usually included on the base map drawn at this scale. The required number of mylar copies of the base map is reproduced on a standard Ozalid plan copier using mylar which is glossy on the upper face and matte on the reverse side. Information is applied to the reverse (matte) side of the mylar in the form of colored areas using Eagle "Prismacolor" pencils, following a consistent system of coding. Some data is applied to the glossy side of the base map in the form of logos attached with glue. Each major component of the area under study is graphically presented on one or more of these mylar maps.

In addition to the maps, the "dynamic section" is also employed. This is a graphic, multicolored section taken at indicated points through the map, and shows dynamic processes and relations not readily discerned in the maps themselves. Pictorial drawings, charts, and lists with appropriate symbols are also employed to enhance and amplify the information presented on the maps. In some cases, such as the Soil Capability study or Scenic Analysis, drawings of highly informative matrices are presented in order to further document the internal analysis of a major component. The maps and drawings are mounted on white drawing panels of the same size (30" X 40" for example) with a logo-title block to give further visual unity to the whole presentation.

The materials employed in the presentation are not costly, and they are readily available: drawing mylar, colored pencils, india ink, glue, white drawing presentation board. Copies of the presentation can be circulated among interested researchers and designers in the form of colored slides which can be protected to the actual size of the original panels. Primary and secondary research materials which have been utilized in the preparation of the inventory and presentation of data are carefully indexed for quick reference at any time, and for proper documentation of sources and their future use.

Analysis of the information contained in the inventory and its presentation actually begins as it is reviewed for summary and conversion to graphic analogue form. It is especially important that those who prepare the mylar inventory maps and other visual devices be the same persons, or that they work closely with those who collate and review the data to be presented in the inventory. This constant exposure to all of the data will contribute greatly to their comprehensive grasp of the many components involved, and will facilitate a more effective analysis of the data that takes place when the inventory presentation is completed.

To organize the data depicted in the mylar inventory maps in a consistent way, and to facilitate the application of a comprehensive analytical technique that may be applied to diverse kinds of data, a system similar to the method of Ian McHarg (in *Design With Nature*) has been adopted. Among the colors and tones employed to depict varying

conditions and processes on each map, the darker shades are generally used to represent factors which, when impacted by the development projects proposed by man, would present maximum difficulties and costs, or that would threaten those areas more appropriately left in a state of preservation because of intrinsic natural or social values. A very steep slope, for example, would be shown as a darker tone, as would flood-prone land or an area containing rare flora or fauna. Our method departs from that of Professor McHarg in one aspect: While he employs maps as overlays with the intention of identifying the variation of accumulated density, as many transparencies are added to the pile, in order to determine intrinsic capability of potential impact in the face of development, we find that this method becomes unwieldy and illegible when more than a few overlays are combined. We proceed, then from the maps through numerical matrices which represent the varying intensities of "tones", to summarize the numerical tones of all the maps, and then return to a graphic representation of the resultant matrix. In applying this numerical technique, we are well aware of the fact that the numbers themselves represent nothing more nor less than the judgements we have initially made before converting the tone densities to numerical equivalents.

The analysis of each major component in the resource inventory is accomplished by placing over each mylar map another mylar sheet ruled off in squares, the sides of which represent a known scaled distance on the map (for example: 0.5 kilometers). The fineness of this grid, which we call the "matrix grid" can be adjusted to fit the scale and objectives of the study. Each square is identified with conventional matrix notation, i.e. $A = (a_{ij})$, which provides a method of location on the maps and facilitates computer programming for the summing of corresponding squares in a large number of individual matrix grids.

As the blank matrix grid is placed over each map and aligned with it, reference is made to the information that appears within each square, and to the information contained in the dynamic sections, diagrams, charts and even in the original sources of the data, in order to assign a scalar value to the individual square for the map being analyzed. Once all the squares in a major component mylar map have been evaluated in this manner, the numerical matrix which results can be read into the computer for storage under the title of the component. The computer program follows the simple routine of adding the corresponding squares of all the map matrix grids to produce a final matrix which models numerically the sum of intensities of all of the major components. From this final numerical matrix, a map can be prepared which represents with varying densities of tone the degree of resistance or accommodation to development (or other assumed factor) of the sectors of the area under study.

Those accustomed to rather sophisticated mathematical models employed in specialized areas of study may feel uncomfortable with the simple value scales which we employ in our method. Without engaging in a lengthy discussion concerning scientific epistemology and the question of the validity of abstract models for empirically observed data, we should point out that: (1) practical decision making and the establishing of public policy usually involves people who quickly bypass complex models and demand to know, "Should we develop? Yes, no or under what circumstances? (2) experience

shows that we can handle the nuances of graded scales at the practical level from two to perhaps a maximum of fifteen or sixteen shades of value; (3) the decisions concerning the allocation or deployment of resources count heavily upon summary conclusions derived from base-line data, a process we will have already followed in the preparation of the inventory presentation; (4) our method will be useful in its application to a particular area to the degree that we have analyzed neighboring areas as well; (5) we can and should return to the basic data for clarification and amplification of tentative decisions based upon the matrix analysis.

We have chosen a scale of 1 to 5 as a numerical representation of a series of five tones or intensities of color. To give meaning at the design and planning level, we tentatively adopted the Florida scheme, identifying "5" as representing "preservation" where no development or negative alteration in the natural system should take place; "3" as representing "conservation" where certain controlled development or human activity may be allowed to take place when natural systems can absorb them without serious negative impact; and "1" as representing "development" where carefully conceived development projects can be accommodated with minimal impact. The values "2" and "3" are intermediate terms for borderline cases. The adjustment of the scale as a whole, that is, a definition of just how much and what kind of development the designation "1" envisions, or just how extreme our preservation efforts ought to be for areas designated as "5", will depend upon the overall "holistic" view of the area under study, the dominance of one or several highly determinant factors, and public policy considerations viewed from the regional or island-wide perspective.

PERSPECTIVE OF THE METHODOLOGY

If the method outlined above were to accomplish nothing more than to make specialists, designers and planners aware of the intricacies and mutual dependence of the various components of natural and social systems, it would more than justify the effort and small expense involved.

For the most part, the data base for making the inventory and analysis already exists for many areas. That it should be interpreted and utilized for a practical purpose needs no argument. Furthermore, as data is translated into the graphic analogue form, gaps and inconsistencies often appear. The method can then be viewed as a corrective and motivational device for specialists.

In the case of the designer, the inventory and analysis creates in him an enhanced environmental consciousness, and it provides him with a comprehensive tool for altering natural and human systems according to their own natures and built-in economies. He has the opportunity to give substance to the self-designation "design ecologist."

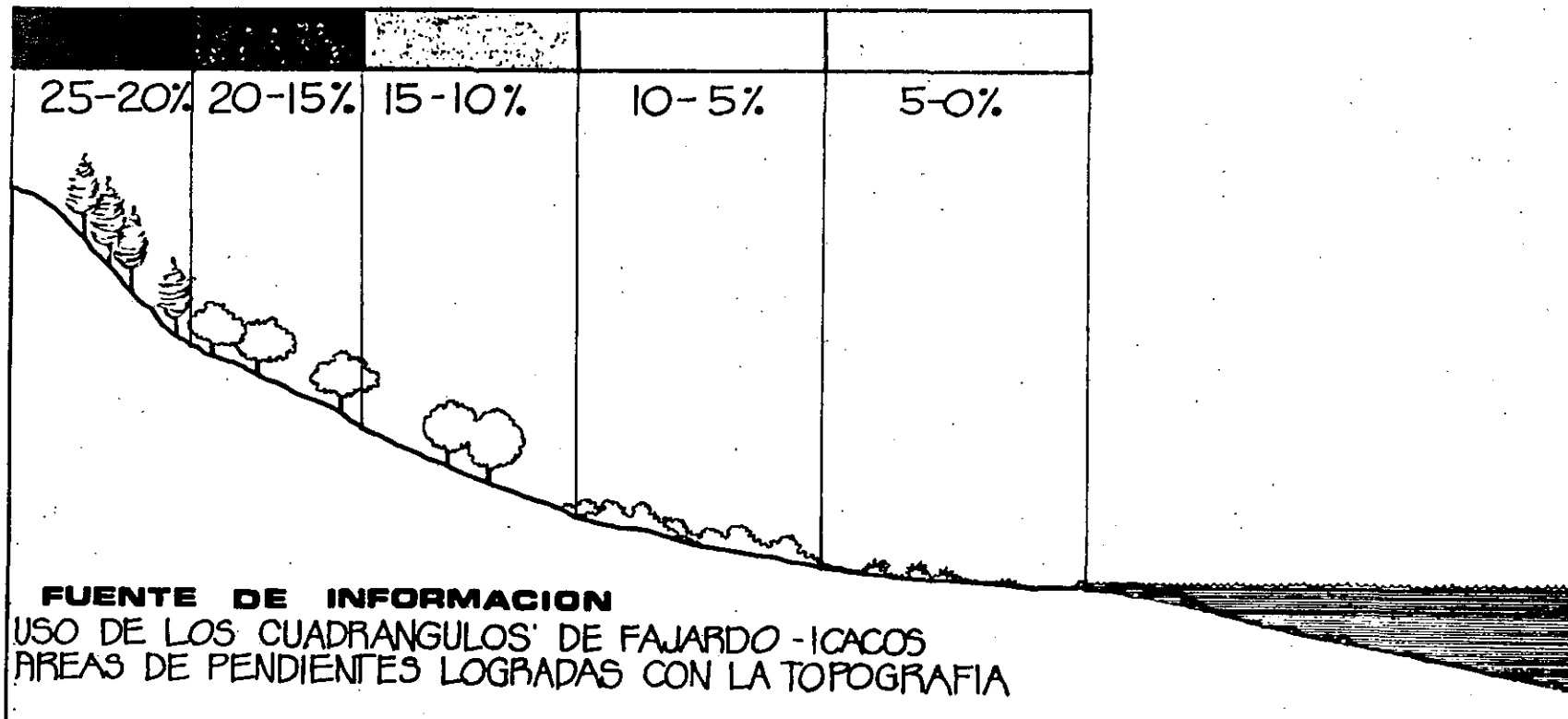
As a middle term between practical comprehensive decision making and a data base often compartmentalized into diverse areas of specialization, the method is analogical but accurate, qualitative without ceasing to be quantitative, simple without being simplistic, and above all it is economical and available.

GRAPHIC ILLUSTRATIONS

Four black and white photographs of original 30" X 40" full color panels with mylar maps, a typical "dynamic section", and a graphic legend are included in this report.

Plate No. 1 is a reduced illustration of the map of slopes by percentages (Mapa de Pendientes) for a study of the Fajardo-Icacos area of Puerto Rico. Shown are the 30" X 40" presentation panel with the mylar colored map frame mounted. Below the map (left to right) are the logo-title block, the legend showing tones representing slopes by percentages with notes on suitability for different uses, and a graphic legend relating the slopes as specified by percentages to actual visual appearance of the slopes. Plate No. 2 is an enlarged photo of this graphic legend.

Plate No. 3 shows the presentation panel for the major component "hydrology" (Hydrología) from the Tortuguero area study. Flood plains, bodies of water, recharge zones, run-off, etc. are indicated. Below the framed mylar map is a "dynamic section" (shown in an enlarged view in Plate No. 4) depicting the complex aquifer and underground water system in the area, the balance of pressure between the fresh water overlay and the salt water penetration from the nearby sea. Included in this section is a representation of the topography and general vegetation types, as well as the geological structure as it bears upon hydrology.



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**THE CORPS OF ENGINEERS EXPERIENCE
IN WATER RESOURCES PLANNING
IN PUERTO RICO**

BY:

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INTRODUCTION

Unlike most of the ongoing studies in the United States, the water resources management studies in Puerto Rico are subject to special Congressional authorization. Puerto Rico enjoys a unique position since 1970 when Congress gave the Corps of Engineers broad authority to address the water resources problems and needs of Puerto Rico, in cooperation with the Commonwealth Government. Dr. Antonio Santiago Vázquez was then the Secretary of Public Works, and he and others such as Prof. Leonard Dworsky of Cornell University were instrumental in securing this program for the Commonwealth. In this legislation, Section 204 of the 1970 Flood Control Act, Congress provided for a cooperative effort between the Corps of Engineers and the Commonwealth Government. The legislation was very broad and pertained to both inland drainage basins and coastal areas. It requested preparation of plans for the development, utilization, and conservation of water and related land resources.

The Corps of Engineers responded by the establishment of a special study group in the San Juan Area Office, which has had a staff of seven to ten professional planners and engineers since 1972. This study group coordinates its efforts with all appropriate Commonwealth agencies, with the Department of Natural Resources as the principal contact.

Implementing the mandate given by Congress in 1970 has proven interesting and beneficial both for the Corps and the Commonwealth. From a conceptual standpoint, the Corps fully realizes that much good planning has been undertaken by the Commonwealth of Puerto Rico over the years, and we would certainly not presume to diminish the importance of past and present Commonwealth planning efforts. On the contrary, we have always been willing and interested in coordinating all our planning efforts with those of the various Commonwealth agencies involved in water resources management.

In the beginning, I would say that we suffered from inexperience and a real lack of appreciation for local problems and institutions. It has taken us almost six years to produce the Ponce study report if you go back to the very origins of the group effort. Thus, one cannot really say that we have been a threat to the livelihood of other water resources planners up until now.

At the present time Dr. Emilio Colón and his staff in the San Juan Area Office have the following studies in various stages of completion:

1. The Island Wide Water Supply Study examines the water supply needs of all the other municipios outside the Ponce region for the next 50 years. It is 50 percent complete.
2. A flood control study for the Río Piedras/Río Puerto Nuevo was initiated this year and is about 30 percent complete.
3. We will initiate a flood control study for the entire basin of the Río Grande de Loíza this month. It will take three years to complete.

4. Dr. Colón's staff just completed a reconnaissance report for improving flow conditions in the Martin Peña Canal. We are recommending both dredging and flow augmentation and funding for construction appears eminent.

5. The Puerto Rico—Virgin Islands Pipeline Study is also just getting underway. It is a multi-purpose study examining aspects of water supply, flood control, irrigation, hydroelectric power and recreation in Eastern Puerto Rico.

6. Reconnaissance level flood control studies under section 205 (Small Flood Control Projects) also have been completed recently in four areas in south Puerto Rico and the reports are under review at higher headquarters. The four areas are Arroyo, Peñuelas, Yauco, and Sabana Grande.

7. A Detail Project Report has been started for solving the flood problems of Coamo. This is the result of an approved section 205 Recon Study.

In addition, the District staff in Jacksonville has studies in progress for beach nourishment at el Tuque and Punta Salinas, navigation improvement in San Juan and Ponce Harbors; aquatic plant control for the entire island; and several flood plain studies for the Federal Flood Insurance Administration.

The following section will examine in detail the Ponce Study, completed at a cost of more than \$2 million.

PONCE REGIONAL WATER RESOURCES MANAGEMENT STUDY

The first major product of the Cooperative Study Program is the Ponce Regional Water Resources Management Study. The primary objective of the study was to develop and evaluate alternative water resources management plans which will meet the future needs and goals of the fourteen municipality region along Puerto Rico's south coast. The study included water supply, wastewater management (on a limited basis), flood control, recreation, environmental enhancement, and hydroelectric power potential.

The study area consisted of the following municipalities: Guánica, Yauco, Guayanilla, Peñuelas, Ponce, Juana Díaz, Villalba, Santa Isabel, Coamo, Salinas, Guayama, Arroyo, Patillas, and Maunabo. These 14 municipalities encompass an area of about 734 square miles, with a 1970 census population of about 440,356 persons.

After receiving Commonwealth guidance, the first step in the development of the study was the completion of a plan of study. The first edition of the plan of study was published in March 1974 and copies were furnished to interested Federal, Commonwealth and Municipal bodies concerned with planning and related land resources in the south coast area. Their review and subsequent comments were incorporated in a revised publication in July 1974.

Intended to be a viable and dynamic tool for use by planners, the plan of study outlined and discussed study objectives, work tasks, federal and non federal participants coordination and public involvement procedures, estimated costs and manpower

Wastewater reuse potential involves utilization of all or part of the effluent from the three regional sewage treatment plants currently planned for the area in the municipalities of Guayanilla, Ponce, and Guayama. The effluents can be used with no further treatment other than the secondary treatment afforded at the plant, can be used exclusively for irrigation, and can be piped to storage lagoons near the fields where they are to be used. These waters will not be introduced into the existing main irrigation canal system nor used for municipal and industrial purposes. We are pleased that EPA regulations issued last year specify reuse and land treatment as the preferred method of wastewater treatment.

Evaluation of the study area aquifers has shown, generally, that groundwater development has equalled or exceeded safe yields. In a few limited cases, some groundwater sources have been proposed to be replaced by either surface sources, wastewater reuse or management measures in order to develop an integrated distribution system.

The low demand water supply plans were developed to provide the study area with 349 mgd by the year 2035. These needs are divided into 230 mgd for agriculture, 55 mgd for municipal and 84 mgd for industrial users. Development of water resources within the study area would be sufficient to meet the future water demands.

The high demand water supply plans were developed to provide 525 mgd to the study area by the year 2035. All four plans proposed require the construction of reservoirs which may have significant environmental impacts during their construction phase and involve interbasin transfer from outside the study area. The interbasin transfer of water can be a major issue under the economic, social well-being and environmental evaluation. Additional available developable groundwaters are from irrigation return flows and were estimated to reach some 22.1 mgd.

The flood control plans of the Ponce Regional Study have been directed to seven river basins along the south coast of Puerto Rico in the vicinity of seven communities in those river basins. They are: Río Yauco, in the vicinity of Yauco; Río Guayanilla, near Guayanilla; Río Matilde, near Ponce; Río Coamo, near Coamo; Río Salinas, near Salinas; Río Guamaní, near Guayama; and Río Nigua, near Arroyo.

Three flood control alternative plans were developed for each stream. The plans address different levels of protection.

In addition to the structural improvements proposed under each of the flood control plans, nonstructural measures were also considered. Most significant is the implementation and enforcement of Planning Regulation No. 13 for the Control of Building and Land Development in Floodable Zones by the Puerto Rico Planning Board and the implementation of the Federal Flood Insurance Program. Both measures are assumed to have been implemented for all the plans.

A summary of the highlights of the Ponce regional study findings follows:

INSTITUTIONAL ARRANGEMENTS

The present institutional framework needs to be streamlined, and the large number of agencies involved with primary functions dealing with water and related land

resources, need to be reduced to better solve the problems related to the development and management of the water resources of the study area.

Also, present water charges below the actual costs of development and delivery, and considered as an indirect subsidy to agriculture, industry and individual consumers, limit the expansion of the system and promotes inefficient use of the resource.

Land Use. The adoption and implementation of the Planning Board's Land Use Plan will allow Commonwealth officials to adopt a water resources management plan compatible with those presented in the Ponce report.

Water Supply Management. There is sufficient water within the study area to support a modernized agriculture with some 50,000 acres of land under irrigation as well as a moderate growth in the industrial sector and the municipal water demand.

Greater future development would require the transfer of water from the north coast of the island and a relatively high capital investment.

The public should be educated about the water-conserving capabilities available with certain appliances and fixtures. Conservation measures, however, cannot be solely depended upon to reduce the demand for water.

Higher sugar yields can be obtained through the establishment of modern irrigation practices and considering plant consumptive requirements in water applications.

Wastewater Management and Reuse. Treated effluents from the planned Regional Treatment Plants offer an excellent opportunity as a source of water for irrigation. There will be available significant volumes of treated wastewaters concentrated in a few localities which are a source of water for irrigating crops. The reuse of treated wastewaters provides both additional volumes of water and nutrients for the crops.

Some of the water supply plans call for the reuse of treated wastewater for irrigating agricultural lands. By the year 2000, there is a potential of approximately 64 mgd of treated wastewater that can be allocated to irrigating some 15,000 acres. Since the cost of treating the wastewater is considered as a sunk cost, treated wastewater provides one of the cheapest source of water for agriculture.

Despite the proven economic advantages and technological viability of wastewater reuse, the Commonwealth Government has not yet established its policy on this area. This is a most urgent policy issue that the Commonwealth Government should consider.

Flood Plain Management. Flood plain regulations (Planning Board Regulation No. 13) and flood insurance should be implemented immediately. A public awareness program on the evacuation of flood-prone areas as well as warning systems would help to reduce damages to areas subject to flooding.

Encroachment into the flood plains should be avoided except for uses compatible with frequent flooding. Strong emphasis must be placed on the need for structural improvements because much of the flood plains have already been developed and developable lands on the island are a limited and scarce resource.

requirements, and other items concerned with stating the study problems and identifying approaches to their solutions.

We also developed a public involvement plan as part of our intent to bring the public in as a full partner in the planning process. One of the principal objectives of this public involvement program was to learn first-hand the concerns of citizens in the region and the relative priorities placed on these concerns.

A major element of the public involvement program was the creation of a study assistance committee. Membership of this committee consisted of the study manager, study area mayors, legislators and other public officials, and affected special interest groups, private citizens, and any other groups and responsible individuals wishing to voice their opinions for the purpose of influencing the planning process. Special interest groups represented in this committee included members of environmental, industrial, trade associations, professional, consultant, and educational institutions. The primary function of this committee was to communicate the desires, concerns, and opinions of the various publics to the study team by means of meetings, workshops, seminars, and correspondence.

It was not an easy task to keep everybody informed. We had over 1,200 individuals, agencies, organizations, and commercial and industrial firms on our mailing list before the study was completed.

The planning process of the study included four identifiable steps.

1. Problem Identification
2. Formulation of Alternative Plans
3. Impact Assessment, and
4. Evaluation.

Several interactions of these steps took place. With each cycle, more emphasis was placed on the next step.

Through an extensive coordination and public involvement effort, both structural and nonstructural plans were formulated to address one or more of the planning objectives. After alternative plans were formulated, the economic, social, environmental, and institutional impacts of these plans were developed.

Seven water supply plans were developed to meet the needs of two future scenarios for the study area. Three plans for a low demand level, and four for a high water demand level. Plans developed for each scenario range from management measures to capital intensive measures including, where applicable, wastewater reuse. Each plan covers a 50 year planning period beginning in 1985, and has an interim plan to cover the time required to review, design, and begin the implementation of the plans.

All plans took into consideration the Portugués and Cerrillos Reservoirs, a multi-purpose water resources development project currently being developed in Ponce by the Commonwealth of Puerto Rico and the Federal Government.

Management measures considered in the plans include pricing, public awareness, groundwater regulations, plumbing codes, and fixtures.

Outdoor Recreation. The recreational plans considered under the PRWRMS will open new possibilities to the residents of the study area for the enjoyment of outdoor recreational activities.

Hydroelectric Power. Conventional large scale hydroelectric power developments sites are no longer available in projects related to the study area. Opportunities exist for generating small amounts of electric power using interbasin diversion schemes.

Opportunities exist for developing adequate pumped storage systems, but only when inexpensive excess energy is available.

Environmental Enhancement. Development has removed much of the study area's vegetative cover. High levels of erosion can be readily observed with the resultant premature filling of existing reservoirs.

A large scale reforestation program could be developed for the production of commercial timber and protective cover. This would also provide additional habitats for wildlife.

CONCLUSIONS

Let me turn to some general conclusions I have formulated as a result of our study experience to date. I am sure that there is little doubt that the Government of Puerto Rico recognizes the need for adequate management of its water resources. The decision to embark on the Ponce Study with active participation from Commonwealth agencies is an example of how interrelated water planning problems were dealt with in a coordinated fashion. So, it can be done. A final product is available and decision makers not only have its conclusions but also recommendations to implement the plans. All of these, however, will gather dust on the shelf if we fail to realize that in the final analysis serious constraints are placed on those called upon to implement these plans.

I want to touch briefly now upon three of these constraints.

1. Any one who has dealt with government for any length of time soon learns that financing large scale endeavors in Puerto Rico is a major problem. The difficult economic situation affecting the island during the last few years has curtailed many important projects. Water resources construction programs are mainly financed by bond sales which depend on the U.S. market conditions and Puerto Rico experienced serious difficulties in the sale of bonds during the last years.

The system for charging fees for the services PRASA and PRWRA provides does not help either. PRASA's pricing system has traditionally been used only to collect operating revenues and to pay off capital improvements bonds but not to realize revenue for investment in new facilities or as a mechanism that would encourage the conservation of water. Water rates should reflect the real cost of producing, treating,

and delivering water to specific users and this should include the construction of new plants. But people are always reluctant to pay more for a basic commodity such as water and political opposition can be expected to hamper the possibilities of establishing adequate pricing structures.

As for as water supply goes, federal funding generally is not available. The Farmers Home Administration can help with small rural water systems but in the last few years the trend in federal legislation has been to funnel other categories of funds through the local governments and in terms of broader authorities which allow them to be used in a much more flexible manner. Therefore, if a mayor does not understand clearly the water problems of his area he may allocate funds for other activities. On the other hand in terms of waste water treatment facilities we have seen a significant increase in federal funds, which has resulted in Puerto Rico having some difficulties finding the required 25% matching funds.

Thus, in summarizing my first point, project financing, I would say that the prospects are bleak that not much new construction can be expected in the near future for water supply. On the other hand, construction of wastewater treatment facilities is probably moving as fast as funds can be efficiently utilized.

2. Another constraint affecting the water resources activities in Puerto Rico is the existence of some eight Commonwealth agencies dealing with the subject. We have PRASA-PRWRA- Planning Board-Natural Resources-EQB-Ports Authority-Transportation and Public Works-Permits & Regulations. Efficient coordination mechanisms are lacking as well as common criteria for evaluating objectives and alternatives. The picture is further complicated when we add numerous federal agencies that also influence the Commonwealth's planning, financing and implementation activities. This influence is felt basically in terms of regulations, availability of matched resources to carry on selected activities and areas of total federal responsibility by law which overlap with local areas or responsibility.

3. Finally, it is a fact that government policies are articulated and decisions made within a context of competing needs and scarce financial resources. We find competing needs with respect to water supply, flood control, and wastewater treatment on one hand and such basic requirements as education, health care, and economic stimulus on the other. In order to be able to deal effectively with these competing needs it is of the utmost importance that there be a clear and well coordinated water policy for Puerto Rico. The Governor, within the context of his overall development strategy must take appropriate steps to establish clear and sound priorities which will serve as a guide to other government instrumentalities which through their actions can affect the water resources policy. These bodies include the Legislature, the Bureau of the Budget, PRASA, DNR, regulatory agencies and other agencies with responsibilities overlapping or affecting the development of water resources. For this to occur we are well aware that first someone has to recognize that such need exists and then take a leadership role in terms of doing something about it. Our agency is willing to be of assistance but

this is clearly a decision to be made at the Governor's level, with input and advice from all those concerned. I have limited myself to these three basic problem areas, but there are others. If the Government can focus on these salient issues and take appropriate steps, we would find ourselves moving ahead in a much swifter manner in dealing with water resources problems. The Corps hopes that the final version of the Ponce Study, to be published soon, will be of help towards this end.

RIVER BASIN PLANNING:
METHODOLOGIES AND INSTRUMENTS
AN ANALYTICAL APPROACH

BY

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INTRODUCTION

River basin planning, as it has evolved in the United States and other parts of the world, is not currently practiced in Puerto Rico. This is so for a variety of reasons, the most important being the structure, elements and process of the Island's planning system, and the physio-geographic characteristics of its natural environment. This does not mean, however, that river basin planning could not be carried out here. The key is to determine those elements of river basin planning compatible with Puerto Rico's particular conditions and adapt the river basin planning process to the Island's needs. The problem, then, is to establish the bases, or the frame of reference, within which such planning activities could be applied locally. Of necessity, this process would focus primarily on the U.S. experience, because of the nature of the relations between Puerto Rico and the United States and because of the pervasive role of the federal government in the management of Puerto Rico's natural resources.

This paper aims at suggesting the ways in which river basin planning could be applied here, and how the findings of the research being conducted by the Center for Energy and Environmental Research can be incorporated into that planning process.

THE CEER AND THE PLANNING PROCESS

A survey of the work being carried out by the CEER in the Espiritu Santo River Basin suggests the need to tune that research effort to the planning structures and processes carried out in Puerto Rico. Perhaps this can best be done by defining what the CEER is not. The CEER is not an operative, normative or planning agency; it is a center for scientific research. As such, its main responsibility is scientific investigation and its output a wealth of data and information that could be useful in the planning process and the formulation of public policy. The data and information collected and interpreted by the CEER could enhance and greatly improve the policy-making process, but the planning process as such belongs elsewhere and the policy decisions are outside the realm of the CEER. The CEER is neither more nor less than a scientific and advisory entity; its role is to provide data and intelligence, on the margin of the day-to-day policymaking process. It is vital, however, that this data and information amassed by the CEER be taken into consideration in Puerto Rico's planning process and in the formulation of public policy.

THE CONCEPT OF RIVER BASIN PLANNING: ORIGIN, OBJECTIVES AND CHARACTERISTICS

The field of regional planning, at least in the United States, grew out of the concept of river basin development. The most outstanding examples of U.S. regional planning involve some of the nation's vast drainage basins.

The concept of regional planning has a distinctly developmentalist origin; it was intended to permit the development of physical resources, and it revolved around overall development in very large river basins, covering thousands of square miles, defined as planning regions. This development was multipurpose in nature, and included such aspects as flood control, development of navigational capacity, generation of hydroelectric energy, irrigation, recreation, water purification, erosion control, reforestation, and the exploitation of mineral resources.

The classic example of this developmentalist approach is, of course, the Tennessee Valley Authority. The TVA is a government entity created in 1933 by an Act of Congress in response to the need to provide economic recovery during the Great Depression. The TVA is unique in that it is independent of any other federal department or agency and enjoys substantial administrative autonomy. It has been the most successful of the U.S. experiments in river basin development planning; it also has been the most controversial.

River basin planning, then, was initiated in response to the need for social and economic development in backward areas. The development and exploitation of natural resources were seen as a logical and effective means of spurring economic recovery and growth. Subsequently, river basin planning has been expanded to include environmentalist concerns such as water quality management and conservation, and development of recreational resources. In sum, the development of river basin planning has been a dynamic process, from its origins in the economic crisis of the 1930s as a utilitarian means of generating economic activity, to the environmentalist thrust of the 1960s and 1970s.

Now, let's examine the characteristics of the river basins that have been selected as planning subjects.

In the first place, river basin planning is generally associated with vast extensions of land. In the United States, for example, river basins extend over several counties and/or states, a situation that gives rise to the need to involve a large number of public officials at all levels of government in the planning process. This aspect will be examined in greater detail below.

In the case of the St. Lawrence River Basin, two nations are involved, the United States and Canada; the Tennessee Valley Authority extends over seven states. A similar situation exists in the river basins of Mexico, although the jurisdictional overlapping is of a different nature.

As an example of the extent of individual river basins in the United States, the Mississippi River Basin covers 1,243,700 square miles, while the Columbia River Basin

covers 258,000 square miles. The Tennessee Valley Authority has jurisdiction over a 39,000 square mile area and the Willamette River Basin in Oregon covers 11,400 miles.

Another characteristic associated with the river basin as a subject of planning is the endowment of natural resources within its confines. The major resource of a river basin, of course, is water. The river basins in the United States have as a primary function the provision of vital fresh-water reserves for residential, industrial and agricultural use. They also provide water for the generation of hydroelectric power, for navigation and recreation. In addition, river basins are important sources of agricultural land and forest reserves, fish and wildlife.

THE ROLE OF THE FEDERAL GOVERNMENT

The federal government has played a central role in river basin development in the United States: first, because of the heavy funding commitment necessary to carry out this kind of development, and secondly because of the adoption of a national objective for the development of river basins endowed with natural resources and the transference of the powers necessary to carry out such development. The deliberate effort of the federal government, under the mantle of the New Deal, to develop poverty pockets made available the financial resources needed to begin a development program at the river basin level. The availability of funds in itself, however, is not sufficient to permit this kind of development; the administrative power and the will are needed as well.

As stated earlier, the vast river basins that have been selected as the subjects of development planning in the United States cross city, county, state and even national lines. Any effort to implement comprehensive development plans for these river basins, then, of necessity involves a complex pattern of overlapping jurisdiction at the various levels of government and some workable scheme of administration must be devised to bring all of these jurisdictional levels into harmony.

In the case of the TVA, the problem was solved in a novel manner by creating an independent and administratively autonomous public entity that bypassed the jurisdictional complexities within the river basin's boundaries. The Act of Congress that created the TVA in 1933 had the effect of creating a kind of regional department of natural resources in the Tennessee Valley. The TVA is a "federal agency which assumes the form of a government corporation, and it is at the same time a regional agency with broad powers for the integrated development of water and resources related to water. It has been called, with good reason, a regional department of natural resources." (Martin et al., p. 255).

The TVA was to provide for the seven-state area it comprises a comprehensive, overall resources management previously carried out in a disjointed manner by a whole range of government agencies, each acting independently of the other. The carrying out of a development program, concentrated in a river basin drainage area, by a single regional agency, then, was an innovation and the creation of the TVA represented a totally new approach to natural resources management in the U.S.

The most significant aspects of this new approach were twofold: the transference and consolidation within a single regional agency of the disparate functions of the federal government; and as a result, the establishment of a public policy, or national objective, aimed at promoting the comprehensive development of a river basin.

Despite its success, the TVA, and especially its hydroelectric power generating function, has been a center of controversy since its inauguration. As a matter of fact, the independent federal entity created to carry out a specific regional development program represented by the TVA has not been duplicated in subsequent regional planning efforts.

In terms of river basin development, other administrative schemes have since been implemented with varying degrees of success. These include the basin inter-agency committee, exemplified by the Missouri River Basin, and the interstate compact agency, exemplified by the Delaware River Basin. Perhaps because of its controversial nature, the TVA remains the sole example of a federal public corporation created to handle river basin management; nevertheless, it continues to be the most successful of these experiments.

THE PLANNING PROCESS AND GOVERNMENTAL STRUCTURE IN PUERTO RICO

The above overview of the development of river basin planning in the United States, the characteristics of the basins themselves, and the instruments devised to implement this kind of regional development planning suggest at a glance some very basic differences with the kind of planning carried out in Puerto Rico.

Both the planning process and the provision of government services in Puerto Rico are centralized, not in a single agency but within the central governmental structure. Unlike the United States, where no tradition of national planning exists, Puerto Rico's planning system is geared to carry out centralized-comprehensive planning.

The kind of regional approach to development planning that produced the TVA—an independent agency to administer the overall development of a selected region—would be very difficult to carry out within Puerto Rico's existing planning structure. The interagency and interstate arrangements devised for the management of other important U.S. drainage basins also would be extremely difficult to implement here: Puerto Rico's planning system preempts those possibilities. Its centralized governmental structure eliminated the jurisdictional overlapping characterizing U.S. development planning. Even the municipalities, the only local political entities with some jurisdictional role in the Island's river basins, have only very limited responsibilities. Perhaps even more to the point, the fund-raising capacities of the vast majority of these municipalities are severely limited. Thus while their powers, in terms of development planning are not necessarily limited by law, they are constrained by a lack of resources.

The planning process in Puerto Rico is conceived as a multilevel, multisectoral system, integrated and coordinated by the Planning Board. With its reorganization in 1975, the Planning Board was established as a coordinating and integrating body, with its chief responsibility the provision of an overview of future development, both in the formulation and evaluation of policy and strategy. Thus, sectoral plans are subject to Board review and approval, to insure their compatibility with overall planning goals, objectives and strategies.

The Planning Board relies on five basic planning instruments to carry out its coordinating and integrating function:

1. *Comprehensive Development Plan.* The purpose of this plan is to establish the policies and strategies necessary for the comprehensive development of the Island, taking into consideration the most pressing social, economic, physical and environmental problems. The process includes evaluation of existing public policies, and recommendations regarding future allocation of available resources.

2. *Land Use Plans.* The goal here is the establishment of policies and standards for the management of land and water resources compatible with the policies and strategies established in the Comprehensive Development Plan to guide both public and private investment in land and water resources.

3. *The Four Year Investment Program.* This program provides a financial analysis mechanism that, together with the Land Use Plans, will permit the gradual implementation of the Comprehensive Development Plan.

4. *Planning Regulations.* These shape the public policies established by the Board, offer guidance and establish standards for the channeling of social, environmental and economic activities.

5. *Periodic Reports to the Governor.* The Board submits periodic reports to the Governor and the Legislature on the country's most pressing problems, the results and consequences of existing policies, and on the most important physical, social and economic changes occurring in the development process.

These instruments provide the Puerto Rican government with the means to carry out long-range, comprehensive planning for the various sectors of the Island's development; theoretically, the centralized governmental structure, in turn, makes such planning feasible.

There are several important elements outside Puerto Rico's planning process that have an effect on that process. Chief among these is the role of the federal government in Puerto Rico's planning system. The federal government, of course, plays no formal part in that process but in practice its impact is significant. For example, the U.S. Army Corps of Engineers has jurisdiction over all navigable waters, making it necessary to involve them in any planning effort at the river basin level, since most of these are connected to coastal areas. In addition, U.S. legislation regarding water quality and pollution control regulations are binding on the Island. This legislation affects land use, development and investment priorities, with significant impact on drainage basins.

The federal government has a direct impact as well on the local government's funding capabilities because of the administrative requirements and constraints included in the grants-in-aid that make up a sizable portion of the development funds available to the local government.

THE RIVER BASIN AS A SUBJECT OF PLANNING

The above sections provided a general view of the development of river basin planning and the different planning instruments available in the United States and Puerto Rico for the implementation of development planning. It would now be appropriate to examine how these concepts can be applied to the Espiritu Santo River Basin.

As noted above, the river basin has been set aside, in the United States and other countries, as a planning region, or subject of the planning effort, without regard to the political boundaries it crosses. We have mentioned examples where a single river basin includes several cities and counties, several states, and even more than one nation, as in the case of the St. Lawrence River Basin.

The planning efforts that have been carried out in these great drainage basins involved a variety of planning instruments, but in all cases the concept is that of comprehensive planning; a global, all-encompassing scheme designed specifically to handle all aspects of development of the subject of planning. In the case of the TVA, as mentioned above, the federal government went so far as to create a public corporation with fiscal independence and bond-issuing capabilities to carry out this comprehensive planning for a single river basin.

In general, both theory and experience have shown that a river basin should meet the following tests in order to be a viable subject of comprehensive planning:

1. Contain an endowment of natural resources that could form the core of a development program.
2. Contain a clientele for the benefits—and the costs—of such a development program.
3. Be of sufficient size to make development of its natural resources feasible and have access to a large enough market to justify the costs of such development. This market could exist within the geographical confines of the river basin or at a viable economic distance from the river basin.

The following section will explore the degree to which the Espiritu Santo River Basin can be considered a subject of planning, in terms of its compliance with these conditions.

THE ESPIRITU SANTO RIVER BASIN AS A PLANNING SUBJECT

It can be seen at a glance that the Espiritu Santo River Basin does not meet all of the conditions that have been present in river basin planning elsewhere. Its size limitations alone represent a significant factor—the river basin encompasses only 10.6 square miles, while the river basins that have been treated successfully as planning subjects cover vast lands areas comprising thousands of square miles.

In addition, Puerto Rico's planning structure militates against the implementation of the kind of comprehensive river basin planning practiced elsewhere. Regional planning as such is not practiced in Puerto Rico; planning regions do exist, of course, within Island planning but they are operational or administrative in nature.

There is no public policy in existence involving the comprehensive development of the Espiritu Santo River Basin, nor is there a comprehensive policy for the development, preservation or conservation of its natural resources.

Rather, the various aspects of the river basin and its natural resources are included in the pertinent islandwide policies or programs established by the different government agencies, such as the Department of Natural Resources' coastal zone program and water resources management programs of the Aqueducts and Sewers Authority. In addition, the federal government is involved in some aspects of resources management in the Espiritu Santo River Basin, through its management of El Yunque national forest reserve.

The lack of a comprehensive public policy for resources management specifically designed for the Espiritu Santo River Basin, however, should not be interpreted as implying that no public policy exists that affects the river basin. Several local and federal agencies have established public policies that affect the basin; what does not exist is a public policy that treats the river basin as a single planning subject and covers all aspects of the development, management, preservation and conservation of its natural resources.

As a result of this approach, situations arise in which a clear conflict can exist. For example, the U.S. Army Corps of Engineers recommend the damming of reservoirs in the river basin at the time that CEER has produced evidence of a high incidence of bilharzia in the area. The implications of this conflict are obvious: A reservoir project cannot be evaluated without taking into consideration its effects on the ecosystem of the area in which it is to be carried out. An interchange of information and data is vital because planning is a process, it is not a document. Indeed, an effective planning process can exist without necessarily resulting in a document.

In addition to the kind of conflict described above, the Espiritu Santo River Basin is affected by public and private development projects conceived and carried out without regard to its ecosystem. The river basin has undergone rapid urbanization, a process that is still continuing, and there is a high degree of mobility among area residents. Tourism, residential, and industrial and commercial development all pose problems in terms of the management, conservation and preservation of natural resources which can be resolved or minimized through adequate planning. The key question at this point, of course, is what kind of planning can be carried out for the Espiritu Santo River Basin within the limits of existing administrative and political schemes, and the scale on which that planning can be carried out.

THE ESPIRITU SANTO RIVER BASIN AS A UNIT OF ANALYSIS

Given the limited size of Puerto Rico's river basins, the centralization of the Island's planning structure and the very restricted powers and funds of the municipalities in which these river basins lie, the planning necessary to guide their development while protecting and conserving their delicate ecosystems can be carried out by using the river basins as units of analysis rather than planning subjects. Within this concept, several river basins together could constitute a single subject of planning.

The primary purpose of establishing the river basin as a unit of analysis is to facilitate the management of the natural resources, including the environment, contained within the basin.

The Espiritu Santo River Basin is fortunate in that it already is being used as a unit of analysis, in the sense that it has been the subject of continuing study by scientists at the Center for Energy and Environmental Research. As a result, the specific studies necessary for resources management planning in the river basin have been, and are being, carried out.

In order to achieve a working partnership between this scientific research effort and the planning process, the CEER study should be extended from the identification of the river basin's resources, their characteristics and composition, to a delineation of the kinds of dangers to which each are subject. In other words, the study effort should provide planners with precise information regarding the limits of tolerance of the various natural resources contained within the river basin, and the degree to which those limits have been reached in each case. It should identify and classify the sources of environmental damage and pollution affecting the river basin, and provide alternatives for the management, use, conservation and development of the natural resources contained within the river basin.

CHARACTERISTICS OF THE ESPIRITU SANTO RIVER BASIN

The Espiritu Santo River Basin is ideally suited to its role as unit of analysis for resources management planning on an islandwide basis. Within its relatively small geographic extension, the river basin offers a vast variety of social, economic, ecological and environmental characteristics that provide planners with a microcosm of the entire island. In effect, it provides the social scientist with a giant test tube in a natural-setting laboratory. The implications of this condition in terms of public policy should not be underestimated.

The river basin has an additional advantage in that it is wholly contained within a single political entity: the municipality of Río Grande.

In specific terms, the river basin contains the following elements:

1. Two of the Island's most important forest reserves, El Yunque and El Verde, are partially within and adjacent to the river basin.
2. The highest precipitation rate in Puerto Rico and the physiographical characteristics necessary for the damming of reservoirs.
3. A high incidence of bilharzia in the Espiritu Santo River.
4. Good agricultural land.
5. A high level of industrial development.
6. A rapid urbanization process with a concomitant increase in the region's population, and a significant migration pattern.
7. Marine and terrestrial ecosystems of unique ecological value.
8. Proximity to metropolitan San Juan; the river basin is only 15 miles from the Capital.
9. Good access routes; a major highway divides the river basin into two zones.
10. A high rate of both public and private construction activity.
11. One of the highest risk flood-prone areas on the Island.
12. A high degree of tourism development adjacent to the river basin; at least one hotel currently is operating adjacent to the river basin in the municipality of Río Grande and boating excursions down the river are offered.

All of these characteristics, then make the Espiritu Santo River Basin ideal as a unit of analysis for resources management planning. It can be viewed as a scale-model of the Island for the scientific research being conducted by the CEER; in addition, it provides the conditions for all manner of analysis and simulation at the theoretical level.

As mentioned above, the value, in terms of public policymaking, of such a microcosm used as a unit of analysis is enormous. The case of the Willamette River Basin in Oregon provides an excellent example of the valuable lessons to be learned from such an approach.

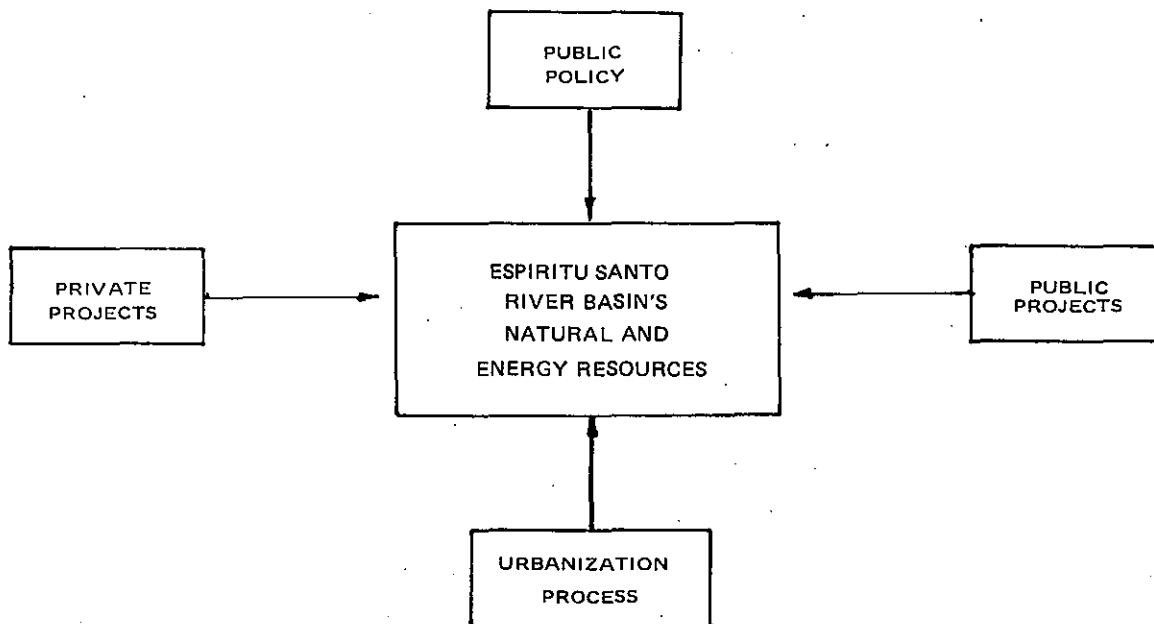
The U.S. Geological Survey recently completed an extensive evaluation of that river basin, in which the chief finding was that the indiscriminate application of water treatment will not in itself insure compliance with the water quality standards established in federal legislation. This finding implies that the establishment of rigid standards and regulations on a nationwide basis probably would result in unnecessary costs in some cases, and in failure to satisfy those standards in others. The USGS also found that the information and data obtained through existing monitoring systems are inadequate for pinpointing the critical interrelationships of cause and effect that control water quality problems in rivers. The study concluded that intensive evaluation of key conditions and problems is necessary in order to make decisions regarding river basin management.

The implications of this study for resources management, of course, are that studies must be carried out in specific areas before any single project can be implemented. The socioeconomic structures of rivers and their drainage basins are dynamic in nature, and the processes that affect them are the result of the interaction of natural factors complicated by human activities, and the changes these activities produce. This interaction creates problems at the local level that, once they are thoroughly analyzed, often can be resolved at the local level.

The following sections examine how the river basin as a unit of analysis can function in a practical way with specific reference to the Espiritu Santo River Basin, and suggests some schemes of intervention in the planning process for a more effective management of the basin's natural resources.

DEFINITION OF THE RIVER BASIN AS A UNIT OF ANALYSIS FOR PLANNING

First of all, the flow of decisions arising from the different decisional units outside the river basin, that have an impact on its natural and energy resources, must be recognized. This process can be demonstrated graphically as follows:



Public policies regarding land development and economic development strategy, as well as the desire on the part of private enterprise to carry out its development projects, all have their impact on the river basin and its natural resources.

A dramatic example of this process was provided on the very day the seminar on river basin planning was being held, when the government granted approval for vast residential-tourism complex in Río Grande. One might well ask if this decision, with all of its implications for the public interest, would have been taken if studies regarding the river basin's ecological, social and economic systems had been conducted and their results made known, and if organized special interest groups dedicated to the protection and conservation of the river basin's natural resources and environment had existed.

The sad truth is that at the present time the Espiritu Santo River Basin has neither the instruments nor the mechanisms to protect itself from decisions taken outside the river basin that affect it in very basic ways. Since the area contains a series of natural resources and facilities, classifiable as extrasystemic areas of interest, that attract outside decisional units, one can expect these decisions to proliferate as improved means of transportation and the development of nearby employment centers intensify Río Grande's urbanization process.

The above appreciation of the situation confronted by the Espiritu Santo River Basin should not be interpreted as a pessimistic view of its possibilities in terms of planning. It is rather a realistic framework within which we can seek pragmatic solutions to the problem within the context of Puerto Rico's existing planning structure.

As mentioned above, Puerto Rico's planning system is centralized and does not lend itself to the kind of independent, regional development exemplified by the TVA and the other administrative schemes devised elsewhere to develop and manage a river basin. The purpose of this paper, however, is not to suggest ways of changing the Island's planning system or the planning instruments available, but to show the methodological approach can be improved within the existing system at the river basin level, so that these planning instruments function well.

SCHEMES OF INTERVENTION IN THE PLANNING PROCESS

The focus of the planning effort for the Espiritu Santo River Basin should be one of advocacy planning rather than comprehensive planning. Within this concept, two basic strategies can be adopted:

1. Data and information gathered by the CEER in its research efforts, including information regarding the tolerance levels of the river basin's natural resources, should be made available to planners at the central level, to insure that the research findings are taken into consideration in the planning process.

2. Public awareness should be developed in the river basin area, regarding the basin's natural riches and what could happen if they are not protected.

The first step in implementing these strategies is to identify the major actors in the decisionmaking process and in the carrying out of the policies and decisions that are established.

Basically, these major forces fall into three distinct groups:

1. The public agencies, commonwealth and federal, that are involved with the plans, programs and projects that affect the Espiritu Santo River Basin.

2. Those sectors within private industry that currently have development projects in the area or that may have them in the future.

3. Interested pressure groups, such as social and religious organizations, civic clubs, environmentalists, ad hoc groups and other associations of citizens with the interest and

desire to protect and preserve the Espiritu Santo River Basin within the development process.

Once these three major forces have been identified, of course, the final step is to determine how each aspect of the environment—the social, economic and physical—affects each of these groups and they in turn affect the environment.

This identification will produce the information necessary to determine how to reach each group, what data is needed by each, and how each can be involved in the goal of protecting and preserving the natural and energy resources of the Espiritu Santo River Basin.

The process functions in the form of a chain: The research produces data and information, leading to public awareness and pressure, producing greater care in the decision making process, which leads to a reduction of environmental damage. This pragmatic solution, the use of advocacy planning in the Espiritu Santo River Basin, can be carried out effectively within the existing planning system and can produce great benefits for the area in terms of the protection and preservation of its precious natural resources.

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