

1982

A Methodology for Siting Coal Fired Thermoelectric Generating Facilities in Puerto Rico

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A METHODOLOGY FOR SITING
COAL FIRED THERMOELECTRIC GENERATING
FACILITIES IN PUERTO RICO

by

David J. McMahon II

A Thesis Submitted in Partial
Fulfillment of the Requirements
For the Degree of Master of
Arts in Marine Affairs

UNIVERSITY OF RHODE ISLAND 1982

MASTER OF ARTS THESIS
OF
DAVID JAMES MC MAHON II

APPROVED

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ABSTRACT

In the past, energy facilities on the Island of Puerto Rico have not been located in the best practicable sites. This is attributable to the absence of mandatory site selection procedures. This thesis has developed and tested procedures for siting 900 MWe coal fired thermoelectric generation plants. The procedures developed here permit the placement of these facilities within the existing legal regime, with a minimum of adverse ecological and socioeconomic impact.

The process has been designed to consider the entire Island of Puerto Rico for the suitability of siting a 900 MWe coal fired facility. This is accomplished through the design and use of a five-phase process. The primary goal of the process was to quickly reduce the total geographic area under siting consideration. This allowed for the identification of a number of "preferred areas" for a 900 MWe project. This provision allowed a majority of the effort and resources, involved in site selection, to be concentrated on those areas most suitable for facility development. This is particularly important in the case of Puerto Rico because the Island does not possess the physical or monetary resources to conduct financial and manpower intensive studies, compared to the continental United States.

It is equally important that siting procedures are responsive to the Island's environment. The environmental problems of Puerto Rico are particularly important due to spatial constraints. Due to its small size, the Island's residents perceive environmental change quickly. The lines of cause and effect are small and can be drawn with greater clarity than those for mainland areas.

The thesis has successfully designed and tested procedures that in practice will attain these goals. Ideally, the process culminates in the selection of the optimum site(s) for a 900 MWe facility. The procedures have also been designed with a high degree of general applicability. With minor alterations, the process may also benefit other Caribbean Islands in their energy development programs.

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I. INTRODUCTION

Site selection procedures must be designed to attain specific goals. The overriding objective is a determination of the optimum site for a particular facility. The optimum site is the area which will sustain facility operations with the least amount of adverse impact on the surrounding environments. The process must follow a logical sequence of events with complete documentation. It should successively reduce the total area under consideration and subsequently the total number of possible sites. At each successive stage of the evaluation the level of detail should also increase to concentrate the majority of effort on the specific areas most suitable for facility development.

The procedures presented in this paper have been specifically designed for a "model" 900 MWe coal fired electrical generation facility. The "model" has been derived from an actual design proposed for the Island of Puerto Rico by the Puerto Rican Electrical Power Authority (PREPA).¹ Although this paper inventoried and utilized actual areas on the Island of Puerto Rico, it was for demonstration purposes only; this project was not a site selection study. The focus of this work was to present a methodology for development of facility siting guidelines. In this way the study may also benefit other Caribbean Islands in their energy development programs, including: Jamaica, Dominican Republic, Cuba, and Barbados. Many of these islands share Puerto Rico's particular environmental, geographic, and economic characteristics.

This study attempted to be responsive to these types of characteristics.

In the course of designing procedures to locate a coal facility in Puerto Rico, a literature review of the "state of the art" was conducted. It became apparent that little work has been completed on facility siting for oceanic islands. A majority of the research which has been conducted is applicable only to continental land masses. In addition, much of the work concentrates on singular aspects of siting problems or outlines the need for process development. However, several publications have contributed to the development of this thesis.

One of the most comprehensive siting studies was completed for the Maryland Department of Natural Resources.² The study focuses on the development of screening methodologies to locate candidate sites for several types of major facilities. The study also develops assessment procedures to evaluate economic, fiscal, social and environmental factors in the siting decision. The major deficiency with this work, however, is its lack of general applicability. It is designed specifically for the State of Maryland. Therefore, it does not deal with the specific problems of siting in a diverse range of environments.

A second work that contributed to the thesis development is "Power Facility Siting Guidelines for New England".³ The Guidelines were helpful as an information resource. They provided a basis for establishing site evaluation criteria.

Although they served as an adequate overview of the issues which arise in siting decisions, they failed to provide guidance in the development of a complete siting methodology. In addition, the study deals best with specific issues particularly important for New England and not other areas.

The CTARP Facility Siting Report⁴ and The Southern Interstate Nuclear Board⁵ were other studies which were reviewed. These works, however, deal effectively with only a narrow range of siting issues important for coal facilities. The reports fail to develop procedures dealing with the wide range of problems encountered in siting decision. Similarly the U.S. Department of Commerce - "Facility Siting Guidelines"⁶ is deficient in dealing with the complexities of siting decisions. The study relies on case reviews and fails to develop specific techniques to mitigate facility location costs.

The Organization for Economic Cooperation and Development has also published several procedures used to locate major facilities.⁷ However, these studies were of limited benefit in the thesis development. The methodologies presented are limited in scope and tend to ignore socioeconomic aspects of siting decision. Moreover the procedures do not provide for rigorous documentation to justify site choice. This is a serious deficiency which can lead to delays or deferment of entire projects.

The numerous publications devoted toward the siting of nuclear facilities were also reviewed in the literature search.⁸ Although many of the studies have developed com-

comprehensive siting procedures, the concerns of nuclear siting are considerably different than those for fossil fuel plants. These studies are also devoted to facility location on continental land masses, therefore, were of little benefit in the development of a system for Puerto Rico.

The research most applicable to this thesis was a site study published by the Puerto Rican Electrical Power Authority (PREPA).⁹ The main criticism of this work is the lack of detail in the site evaluation portion of the process. This leads to bias in site selection. It is imperative that processes be developed in the academic realm rather than leaving the task to energy companies, such as PREPA. It is unlikely that truly unbiased procedures can be developed without independent research. If the methodology is prejudiced, the optimum site for a particular project will not be found. The system developed here is cognizant of this fact.

The procedures were designed to consider the entire Island of Puerto Rico for the suitability of siting a 900 MWe coal fired facility. There were five distinct phases in the process, including:

- 1) The primary exclusion stage. The stage was based on limitations presented by the "model". Based on restrictions presented by the model, large areas of the Island were deferred from facility siting consideration. This reduced the broad geographic unit, the Island of Puerto Rico, into "actual geographic units" which then could be considered for facility siting.

- 2) The inventory phase. An inventory was conducted on the amount and types of ecological and socioeconomic environments found in the "actual geographic units." This enabled the process to be responsive to the unique legal, ecologic, and socioeconomic factors present in Puerto Rico.
- 3) Legal analysis and secondary exclusion. The Commonwealth and Federal legal and regulatory regimes were examined as they related to environments identified in the inventory stage. This examination was initiated in relation to the limitations posed by these laws to major facility development. It was possible to exclude large portions of the "actual geographic units" based on these legal criteria. This resulted in a number of "preferred areas", which then could undergo further evaluation.
- 4) The primary evaluation stage. The emphasis of the process shifts from exclusion to evaluation in this part of the procedure. Areas were evaluated and numerically scored on the basis of generalized environmental and socioeconomic criteria. This results in a numerical ranking of the "preferred areas" which enabled comparisons to be made, and selection of four or five "actual candidate sites."
- 5) The secondary evaluation stage. The degree of detail and specificity was increased in this stage of the process. A second numerical ranking was established on the four or

five actual candidate sites. From this ranking the best site(s) for a 900 MWe facility on the island of Puerto Rico can be chosen in an actual site study.

The procedure is illustrated in Figure 1 and Figure 2.

The thesis developed is that site selection procedures for coal fired facilities may be constructed, to allow the placement of coal facilities within the existing legal regime, with a minimum of adverse ecological and socioeconomic impact. The thesis was tested through the development and use of the procedure described above. Through the use of this procedure, site features incompatible with facility development were identified. This resulted in a number of "preferred areas" available for facility siting. Site visits were made at Punta Higuero, one of the preferred areas. On the basis of work conducted during the site visits, the area was subjected to the evaluation phase of the process. Through this evaluation, and the subsequent identification of adverse and beneficial aspects of the area, it was shown how all "preferred areas" could be tested. This allows for quantitative and qualitative comparisons and may result in the selection of the optimum site(s) for coal fired facilities.

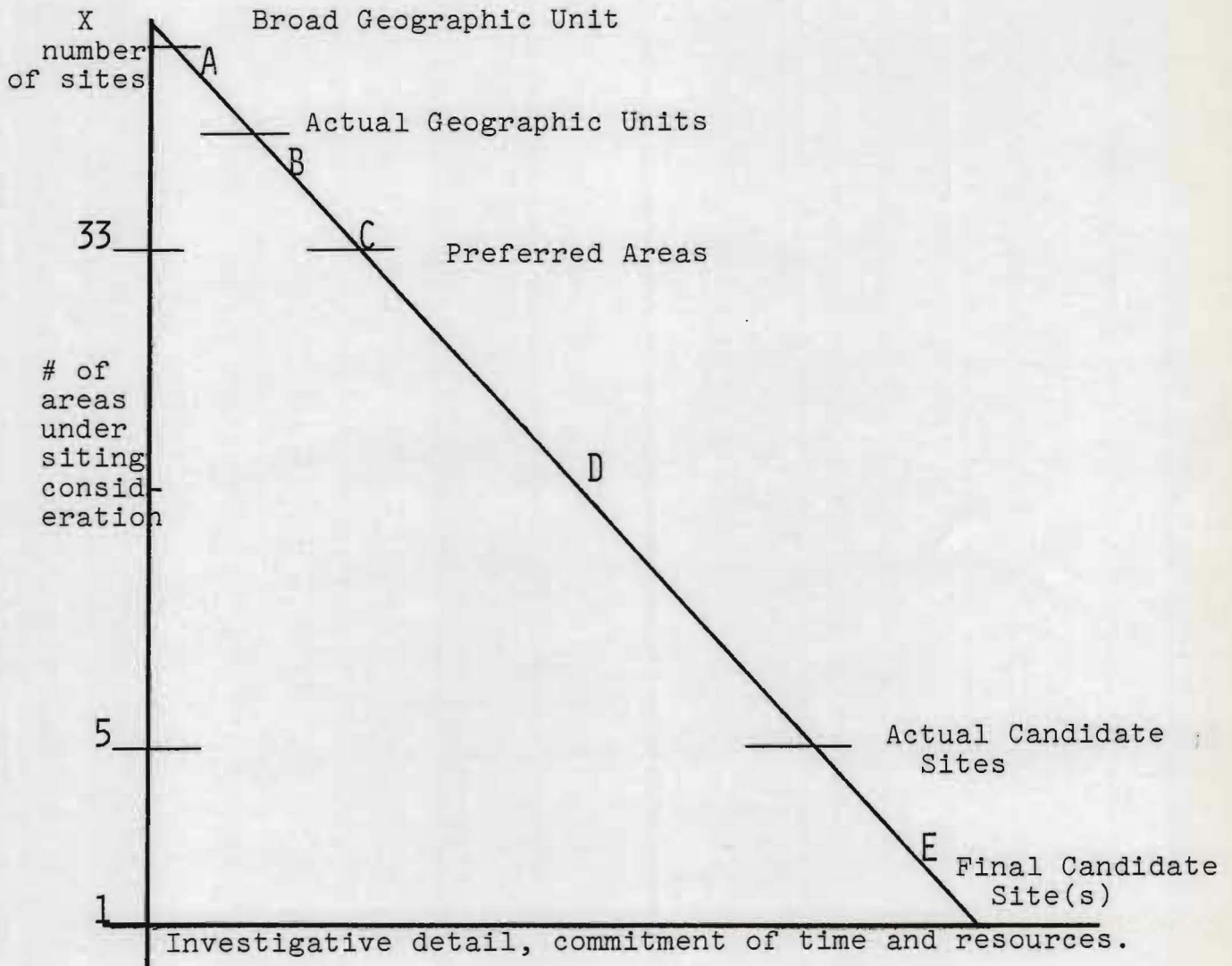
In the past, energy facilities on the Island have not been located in the best practicable sites. This is attributable to the absence of a mandatory siting procedure. For example, in the early 1970's, the Puerto Rican Water Resource Authority, the forerunner of PREPA, was forced to abandon plans for a nuclear power facility at Aguirre, on the south

- 1) Description of the project and primary exclusion stage:
 - a) Water Supply
 - b) Proximity to existing transmission corridors
 - c) Transportation access
 - d) Unfavorable topography

The broad geographic unit is reduced to actual geographic units.
- 2) Inventory state: Identify the natural and socio-economic environments proximate to the actual geographic units.
- 3) Legal Analysis and Secondary Exclusion: Commonwealth and Federal laws and regulations are examined to insure compliance. This will naturally exclude areas from siting consideration. The result is a number of "preferred areas" under consideration for coal plant siting.
- 4) The primary evaluation stage: Preferred areas are evaluated and scored on a number of broad site specific criteria. The top 4 or 5 areas become actual candidate sites. Screening Process is conducted through aerial overflights.
- 5) The secondary evaluation stage: Actual candidate sites are evaluated and scored on the most important ecologic and socio-economic criteria. Final candidate sites are reduced to the optimum site(s) for the project.

FIGURE 1

FLOW CHART OF THE METHODOLOGY FOR SITING 900 MWe
COAL FACILITIES IN PUERTO RICO



- A. Primary Exclusion
- B. Inventory
- C. Legal Analysis and Secondary Exclusion
- D. Primary Evaluation
- E. Secondary Evaluation

FIGURE 2

THE NUMBER OF AREAS UNDER SITING CONSIDERATION
 IN RELATION TO INVESTIGATIVE DETAIL, TIME AND
 RESOURCE COMMITMENT

coast. During the construction process it was discovered that geologic hazards in the area represented serious problems for this type of facility.¹⁰ The procedures developed and tested here are designed to alleviate these types of problems. Through the use of these procedures the best possible site may be chosen. This permits the coexistence of cost efficient energy facilities and the continued health of ecological and socioeconomic resources on the Island.

II. THE MODEL AND THE PRIMARY EXCLUSION STAGE

A. General Restrictions

The design of the model to be used in this study was limited by a set of general restrictions. These restrictions have been derived from criteria established by the Puerto Rican Electrical Power Authority.¹¹ The restrictions and their justifications are presented below:

- 1) The proposed facility must utilize the ocean as the condenser cooling water source.

Due to a scarcity of major freshwater resources steam-electric power facilities have been limited to coastal areas in Puerto Rico. This restriction has been substantiated by a report prepared by the Puerto Rican Environmental Quality Board and is acceptable under the Puerto Rico Coastal Zone Management Program.

- 2) The condenser heat removal system must utilize "once through" cooling.

The authority has determined the technology for design of salt water cooling towers has not achieved an appropriate level of operation reliability. In addition, salt drift from salt water cooling towers may result in adverse impacts on agricultural crops. This is due to high existing ambient background levels of salt drift from natural sources. As a direct result of this restriction, the selected site must be amenable to a successful 316(a) waiver application and 316(b)

demonstration under Clean Water Act Requirements,¹²

- 3) The selected site must be capable to support a generating capacity development as large as 900 MWe.

PREPA's generation plan identifies this capacity to meet projected load demands and reliability criteria for the near future.

- 4) Fuels to be utilized only include coal, oil or a combination thereof.

The rising costs of foreign oil imports have made electrical production with oil uneconomic. Nuclear fuels have been excluded as a short-term alternative due to possible siting, safety, and environmental hazards. As a result, PREPA has determined that coal will be the primary source of fuel for any energy facility constructed until 1990.

- 5) Hydroelectric power and other alternative technology sources (solar, wind, and ocean-thermal) are not to be considered in the siting decision.

Virtually all hydroelectric sites in Puerto Rico are fully utilized. Further exploitation of this source of power will not satisfy projected load demands. Alternative technology sources are attractive, however, PREPA has determined that operating experience with large capacity systems is insufficient, and existing technology with these systems is not adequate to supply reliable generation capacity for the 1980's.

- 6) Transmission voltages of 115 KV/230 KV through overhead circuits must be assumed.

PREPA has operated this type of system for many years. Their experience has shown that the nature of the Island's terrain favors overhead circuits on metal towers. Voltages greater than 230 KV are not necessary in view of the relatively short distances from source to load center.

B. Mandatory Site Criteria

In view of the restrictions which have been presented, a site for a 900 MWe facility must meet the following criteria:

- 1) Size. The size of the site is the first basic requirement. It must be large enough for the entire plant, including all accessory needs. A site of approximately 450 acres of land is required for a 900 MWe facility. This is broken down as follows:
 - a) 200 acres for the boilers, switchyard, coal pile, etc.;
 - b) 30 acres for port facilities; and,
 - c) 220 acres for ash disposal facilities.
- 2) Water Supply. An adequate water supply is a necessity. A 900 MWe facility requires approximately 17,000 gallons of water per minute. About 50 percent is actually evaporated. Water is needed for cooling, boiler feedwater, accessory use, and fire protection. A facility in Puerto Rico will use the ocean as the cooling water source. The

site must be located close enough to the sea to meet need requirements.

- 3) Proximity of the Site to Transmission Facilities. The next most important specification, after the two basic requirements of size and water, is the proximity of the site to existing transmission corridors.¹³ The ideal location for a generating station is one that is as close as possible to the load center. The need for transmission lines and additional substations is then minimized. However, because of the difficulty of siting large facilities in the proximate area of load demand, remote locations must be utilized. A location which is close to existing transmission corridors is vital if economic and environmental costs are to be minimized.
- 4) Waters Proximate to the Site. Access to navigable waters is another important specification. Access to waterways will decrease the costs of heavy equipment handling in construction. Navigable waters are also important for bringing the fuel supply to the facility. The availability of port facilities will decrease the costs and needs for other types of transportation.
- 5) Unfavorable Topography. PREPA has determined it is prudent to avoid areas in Puerto Rico for facility construction with twelve percent mean slope or 400-foot differentials in elevation.¹⁴ Power plant construction is more economic on relatively flat grades. As grades

increase in steepness, the amount of earthwork needed also increases. Consequently, all areas exceeding these specifications are to be excluded.

C. Primary Exclusion

Through the use of the restrictions outlined above, the first phase of the exclusionary process can be applied. The activities which occurred with the model and the general restrictions on these activities partially reduced the total area under siting consideration. It was evident that all potential sites must be: (1) within ten miles of the coast; (2) close to existing transmission corridors; (3) within ten miles of existing or potential port facilities; and, (4) not having greater than twelve percent mean slope or a 400-foot differential in elevation. Table I explains the first step in this process.

All of the areas which fall under the restrictive categories can be visually portrayed to show the areas deferred in this stage of the process. This was accomplished through the use of U.S. Geologic Survey 7.5 minute topographic maps projected on to a base map of the Island. Figure 3 is a visual example of this stage of the process. All of the black shaded areas on Figure 3 are actual geographic units derived from the broad geographic unit (the entire Island) examined in the primary exclusion stage.

A primary goal for a site selection procedure was to quickly reduce the total area under consideration and subsequently the total number of possible sites. Achievement

TABLE I

NEEDS AND RESTRICTIONS OF THE MODEL AFFECTING
THE SITING LOCATION

<u>Restrictions</u>	<u>Affects on Geographic or Area Requirements</u>
1. Water Supply	The site must be within 10 miles of the coastline to reduce costs and maintain adequate supplies.
2. Proximity to existing transmission corridors	The site should be close to existing transmission corridors to reduce costs.
3. Transportation	Coal must be imported so the site must be within 10 miles of existing or potential port facilities.
4. Unfavorable topography	The site cannot have greater than 12 percent mean slope or more than 400 foot differential in elevation for construction purposes.

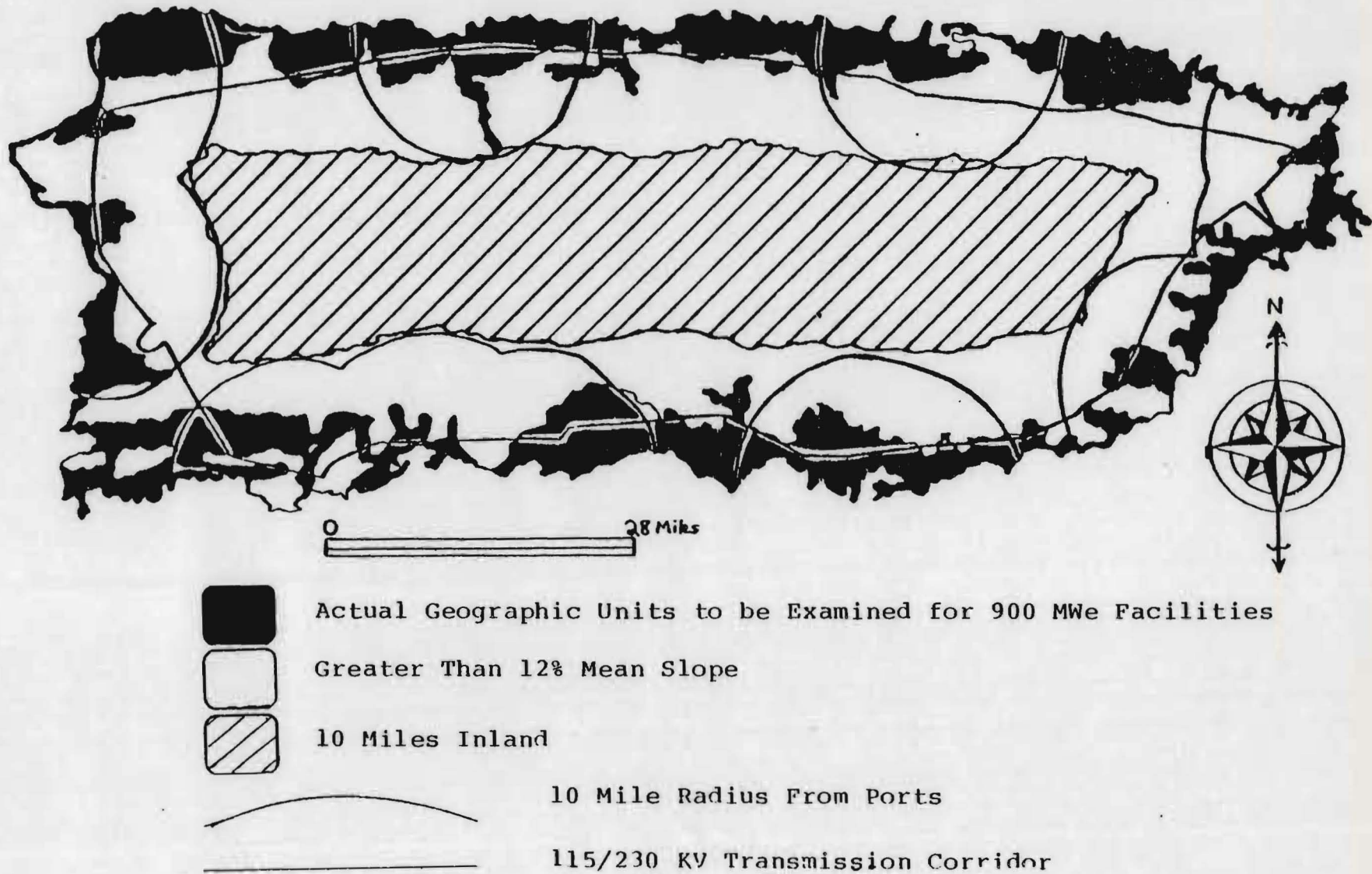


FIGURE 3

ACTUAL GEOGRAPHIC UNITS UNDER SITING CONSIDERATION AT THE
 CONCLUSION OF THE PRIMARY EXCLUSION STAGE

of this objective enables a majority of the effort and resources to be committed to the study of those areas most suitable for facility development. The areas identified as actual geographic units could then be examined to identify and analyze the resources which may suffer adversely from coal facility siting.

III. THE INVENTORY STAGE

A. Natural Systems Inventory

It was vital to conduct research into the specific nature of the island's coastal environments so that site selection procedures could be responsive to the island's natural ecology and socioeconomic situation.

Puerto Rico is the easternmost island of the Greater Antilles. It lies between the Atlantic Ocean and the Caribbean Sea. Various factors influence the location of natural systems in Puerto Rico's coastal areas which are a function of this unique location and its geologic origin.¹⁵ The Island was created about 100 million years ago as a result of volcanic action. As a result, half of Puerto Rico's surface consists of mountains and hills with slopes of 45 degrees or more. The relatively level coastal plain comprises one-third of the land areas of Puerto Rico and 80 percent of all level land on the Island.¹⁶ The mountainous topography and the pattern of northeasterly trade winds control the distribution of rainfall. Vegetation is in turn influenced by precipitation patterns. Rainfall is concentrated over the Sierra de Luquillo in the east and over the western mountains. The coastal plains, which receive the heaviest precipitation, are in the west, southeast, and along the northern coast. Consequently, vegetation of the north and west coast is classified as subtropical moist forest while the south and southwest coasts are classified

subtropical dry.¹⁷ In addition to topographic and meteorological factors, the shape and orientation of the Island, the width of insular shelf, and river discharge influence the type and location of natural resources found along the coast.¹⁸

Puerto Rico's coastal waters are a resource of tremendous importance. They are essential for the economic transportation of goods, they provide recreation, are essential for the tourist industry, and support other coastal resources, including: reefs, mangroves, fisheries, dunes, and beaches. They also serve the cultural and biological function of isolating the Island and giving Puerto Rico a special identity. Coastal waters include freshwater and saltwater lagoons, swamps, bays, and the ocean.

Coral reefs are one component of the system supported by coastal waters. Reefs are valuable since they serve multiple functions. Coral reefs offer protection to the coast from wave action, constitute a food resource for marine life, and provide for recreation, tourism, and scientific investigation. These systems play an important role in coastal ecology because of their interaction with other ecosystems.

Coral reefs are among the most biologically productive ecosystems. They contain corals as well as a large variety of benthic organisms. They provide habitat for large numbers of juvenile fish, and shelter the majority of fish and crustaceans that are commercially extracted from Puerto Rico's coastal waters.¹⁹ The reefs are fragile and can be easily destroyed by marine or land-based activities. Reefs

are created by colonies of corals, which are living organisms. They are similar to other tropical marine communities, because they are extremely sensitive to environmental changes. During construction and operation of a coal facility sedimentation from dredging, sewage, oil, thermal, and chemical pollution can threaten these systems.²⁰ After a reef dies, wave action progressively destroys its crest effectively removing the protective barrier. Care must be taken in the selection of coastal facilities to site them away from reef communities. Once disturbed these communities are greatly impacted affecting the reef itself as well as dependent marine life and shoreline processes of the surrounding area.

Mangrove wetlands are a multi-purpose resource providing varied benefits. Historically, mangroves were viewed as areas of low economic productivity. They were also the breeding area for the malarial mosquito and their filling was regarded as a public good. Today as a result of increased scientific study and ecological awareness it is recognized that mangroves serve several purposes:

- 1) They act as buffers against natural disasters;
- 2) They are refuges for wildlife;
- 3) They are nursery areas for marine life;
- 4) They are valuable fishing and shellfishing areas;
- 5) They are a source of organic detritus; and
- 6) They are natural water purification systems.

Mangroves have a specialized root system, which form an in-

tertwined mass beneath the water surface which retard water movement and trap suspended materials.²¹ Much of the organic material is produced by the mangrove itself which is in the form of leaf and twig fall which accumulate and raise the soil level. Continued accumulation of soil, particularly by sea-fringing mangrove stands, builds the shoreline seaward. During this process, the rich substrate provides habitat for a large variety of organisms which are eaten by marine life, including crab and oysters.²² Some commercially important species, such as snapper, are found among the mangrove roots while other fish spend part of their life cycle here during breeding and spawning. Some estimates state 60 to 70 percent of fish production in Puerto Rico is dependent on the reef and mangrove systems which fringe the Island.²³ In addition, mangroves form nesting habitat for many species of native and migratory birds, both game and protected species.

Mangroves can be harmed by dredging, filling, s. dimen-
tation, oil spills, and other pollutants associated with
coal plant activities.²⁴ Mangroves tend to trap and concen-
trate pollutants which can affect microscopic organisms and
alter an entire coastal ecosystem. There are five kinds of
mangroves in Puerto Rico, each with different characteristics,
values, and management needs (Table II). However, all man-
groves require protection against willful destruction and
should be preserved, protected, and restored to the maximum
extent possible.

The beaches of Puerto Rico are coastal resources of great

TABLE II

TYPES OF MANGROVE FORESTS IN PUERTO RICO

<u>MANGROVE TYPE</u>	<u>LOCATION</u>	<u>CHARACTERISTICS</u>	<u>VALUE</u>	<u>POSSIBLE USES</u>
Overwash mangrove	South Coast	Overwashed by daily tides; most "marine" of mangroves; dense red prop roots; multiplicity of island; dominated by red mangroves.	Wildlife refuges; fishing; purification of overwash waters; production of organic detritus.	Protect these areas as regeneration is slow. Use for indirect services--refuges, fishing, cleaner and calmer marine waters.
Fringe mangrove wetlands	South Coast	Found along shorelines, canals, rivers, lagoons; dominated by red mangroves; two variations--coastal and inland.	Protection of shorelines; "land building"; high rate of organic exports; wildlife habitat.	<p><u>Coastal fringe wetlands:</u> Timber production possible, even limited clear-cutting. Recovery rapid. Production of oysters and shellfish. Recreational facilities, homes, other structures on stilts possible with sufficient buffer and other safeguards.</p> <p><u>Inland fringe wetlands:</u> More valuable as supporters of fish and other marine life. Limit use to recreation, fishing, study, selective cutting.</p>
Scrub mangrove wetlands	South Coast	Smallest (less than 2m. tall) of mangrove forests; least productive; grow on hypersaline soils where no other plant can; red or black mangroves predominate.	Water storage and quality control; soil stabilization; panoramic; wildlife support.	If disturbed, regeneration is extremely slow often more than 50 years.

TABLE II (Continued)

<u>MANGROVE TYPE</u>	<u>LOCATION</u>	<u>CHARACTERISTICS</u>	<u>VALUE</u>	<u>POSSIBLE USES</u>
Riverine mangrove wetlands	North Coast	Found in saline portions of flood plains of rivers and other freshwater courses. All species, but red mangroves predominate.	Exceptionally high resource values; organic exports; water quality control; wildlife habitat; flood buffers.	Timber production, and sewage recycling possible, if precautions are taken to maintain natural productivity.
Basin mangrove wetlands	North Coast	Found inland in depressions where water movement is slow, or flat areas inundated only by highest tides. Black mangroves predominate.	Efficient nutrient traps; link with downstream fisheries.	Sewage recycling and timber production possible as long as normal water levels, tidal inundation and overland sheet-flows are maintained; season recreation.

Source: U.S. Department of Commerce NOAA/OCZM.
Puerto Rico Coastal Management Program and
Final Environmental Impact Statement.

importance. They vary from beach pockets to broad deposits many kilometers in length.²⁵ The beaches are of greatest importance to recreation and tourism because 100 kilometers of the 608 kilometers of beach on the coast are prime recreational areas. Beaches are also important for the protection of natural resources as some of these areas are prime nesting grounds for leatherback and green turtles. Sand dunes are also an element of Puerto Rico's beach system. Dunes along beaches of the north coast once provided protection against the loss of life and property as well as naturally limiting coastal erosion. Due to massive sand extraction, few dunes now remain which has increased the possibility of storm damage in areas subject to flooding during hurricanes and other storms.

The primary concerns relating to coastal development and the preservation of beach systems in Puerto Rico include:

- 1) The prohibition of dune destruction and further extraction of sands;
- 2) The prevention of the closure of prime recreational beaches near coastal development projects; and
- 3) The prevention of erosion and water pollution associated with coastal development which impact the quality of Island beaches.²⁶

Puerto Rico's wildlife species are a significant coastal resource. Many species, including some endangered ones, are dependent on coastal habitat. The Federal endangered species list includes a number of terrestrial and marine species

found in Puerto Rico's coastal zone. Species and subspecies listed as of October 1, 1980 are shown below:²⁷

- 1) Puerto Rican Whip-poor-will (Caprimulgus noctitherus)
- 2) Puerto Rican Parrot (Amazona vittata)
- 3) Puerto Rican Boa (Epicrates inornatus)
- 4) Yellow-Shouldered Blackbird (Agelaius xanthomus)
- 5) Plain Pigeon (Columba inorata wetmore)
- 6) Hawksbill Turtle (Eretmocheyls imbricata)
- 7) West Indian Manatee (Trichelus manatus)
- 8) Leatherback Turtle (Dermodocheyls coriacea)
- 9) Brown Pelican (Pelecanus occidentalis)
- 10) American Perigrene Falcon (Falcon peregrinus anatum)
- 11) Humpback Whale (Megaptera novaeangliae)
- 12) Sei Whale (Baleanoptora borealis)
- 13) Finback Whale (Baleanoptora physalus)
- 14) Sperm Whale (Physeter catadon)
- 15) Atlantic Ridley Turtle (Lepidocholys)
- 16) Golden Cogui (Eleutherodactylus jasper)
- 17) Culebra Giant Anole (Anolis roosevelti)
- 18) Mona Boa (Epicrates monensis monensis)
- 19) Mona Grand Iguana (Cyclura stejnegeri)

Puerto Rico's coastal wildlife resources are diminishing due to habitat destruction, disturbance, hunting, predation, pesticides and other chemicals. The importance of wildlife is recognized in the Commonwealth's Wildlife Law. Through scientific approaches, the Commonwealth seeks to preserve

wildlife resources in view of maintaining an adequate balance between the rights of citizens to hunt wildlife and the needs of the State to avoid, as a result of urban and economic development, the extermination of wildlife species.²⁸

Approximately 300 species of reef fish are commonly found in Puerto Rico's coastal waters. Fifty of these species constitute the bulk of the commercial and recreational fishing catch. The principal families include the snappers (Lutjanidae), groupers (Serranidae), grunts (Pomadasyida), parrotfish (Scaridae), jacks (Carangidae), trigger fish (Balistadae), goatfish (Mullidae), and squirrel fish (Holocentridae).²⁹ The stocks are found from shore to a depth of 40 fathoms. Grunts, groupers, and snappers are the most important reef fish landed in Puerto Rico, and the west and south coasts are the principal fishing grounds for these species. The reef fish industry, although small, is important to the rural economy. In 1977, inshore landings constituted 4 million pounds with a value of 2.3 million dollars.³⁰ Recreational divers also constitute an important segment of user groups. The quantity of fishes taken by recreational divers has not been established, but indications point to a substantial catch. The reefs, mangrove areas and lagoons are important ecological areas for this fishery. These areas are habitat and nursery grounds for a majority of reef fishes and should be protected from coastal facility development for this purpose.

Three species of spiny lobster are found off the coast

of Puerto Rico: Panulirus argus, the Caribbean spiny lobster; Panulirus guttatus, the Caribbean spotted spiny lobster, and Panulirus laevicauda, the smooth tail spiny lobster. These three species differ considerably in biological characteristics with the latter two species comprising an insignificant percentage of the commercial and recreational total catch.³¹ Juvenile and adult P. argus, 35mm to 130mm carapace length, are gregarious during daylight hours. They are found congregated in holes, caves, and under ledges associated with living hermatypic corals and rocky outcroppings. Individual lobsters leave these daytime shelters to forage at night. The spiny lobster is important as an industry food source, and for recreation sport. In 1978, reported lobster landings were over 450,000 lbs. with a value over one million dollars.³² Current recreational catch figures are not available, but may constitute a significant proportion of the fishery, particularly in terms of total income to the regional economy.

The forests that once covered Puerto Rico's coasts are greatly reduced. At the time of its discovery in 1493, Puerto Rico was nearly 100 percent forested. Most lowland forests have now been cleared for agriculture. Of the coastal forests that do remain, most are mangrove wetlands, pterocarpus forests and the dry forest at Guanica. Pterocarpus forests exist in scattered locations on the Island and are usually found landward of mangrove wetlands. The Guanica dry forest is a unique resource area located in the southwest portion of the Island. The forest is exceptionally fragile with no counter-

part in Puerto Rico. More than 80 percent of the forest is surface limestone rock. Rainfall is scarce and temperatures are high. Nevertheless the area is rich in plant life with 346 genera and 761 species of plants and trees found in the forest. Forty-eight of these species would virtually disappear from Puerto Rico if lost at Guanica and sixteen of these species are found nowhere else in the world. Birds are also abundant with half of all species of land birds in Puerto Rico represented.³³ This forest is regarded as a field laboratory for a wide range of scientific research and special care has been taken to exclude coastal development from this unique natural reserve.

To determine the amount of resources found in Puerto Rico's coastal areas, a resource inventory must be conducted. This inventory is helpful in the site selection process by identifying those areas which may suffer adverse impacts from coal facility activities. Table III is an example of the type of inventory which may be conducted. It was developed from information found in the Puerto Rico Coastal Management Program and Final EIS, The National Technical Information Service Regional Inventory; South Atlantic, Gulf, and Puerto Rico Regions, and the Puerto Rico 900 MWe Coal/Oil Fired Project Site Selection Study.³⁴ The information derived in this stage of the process may be utilized to defer important natural areas on the Island from siting consideration in latter stages of this process.

B. Social and Economic Inventory

In addition to information on natural environments, the

TABLE III
INVENTORY OF NATURAL COASTAL RESOURCES ON THE ISLAND OF
PUERTO RICO BY SECTORS*

<u>RESOURCES</u>	<u>NORTH</u>	<u>NORTHEAST</u>
1. Unique Coastal Waters	Cienaga Tiburones (Marsh), Laguna Tortuguero (Salt/Fresh Water Lagoon), Laguna Rica (Salt Water Lagoon), Laguna Los Conzos (Salt Water Lagoon), Laguna Puerto Nuevo (Salt/Fresh Water Lagoon), Pontano Del Cibueo (Marsh), Cienaga Prieta (Marsh), Laguna Mata Redonda (Salt Water Lagoon), Sabona Seca (Marsh), Laguna San Juan (Salt Water Lagoon).	Laguna La Torrecilla (Salt Water Lagoon), Laguna Pinones (Salt Water Lagoon), Loiza (Marsh), Cienoga Baja (Marsh), Pantano De Easenada Comezon (Marsh), Laguna Aqua Pretas (Salt Water Lagoon), Laguna Grande (Salt Water Lagoon).
2. Coral Reefs	None	San Jorge, Las Marias, Vacio Talega, Iglesias, Miquillo, Embarcadero, Borrás, Las Cabezas, La Cordillera, Palominito, Zancudo.
**3. Mangrove Communities	Palmas Altas (16), La Boca (44), La Esperanza (25), Rio Cibuco (564), Rio La Plata (34), Mameyal (73), Rio Cocal (299), Rio Boyamon (39), Las Cucharillas (75), Pueblo Viejo (51), Rio Puerto Nuevo (34), Martin Pena (165).	Laguna San Jose (171), Cangrejos (201), Pinones (3511), Rio Herrera (79), Rio Espiritu Santo (334), La Picua (6733), Rio Mameyes (95), Punta La Bandera (25), Rio Juan Martin (26), El Convento (75),
4. Dunes	San Juan Area has an important dune system.	Isla Verde has a system.
5. Beaches	Approximately 43 miles of beach. 5 miles of this area is under critical erosion.	Approximately 18 miles of beaches. No critical erosion problem.
6. Critical Wildlife Habitat	Cano Tiburones and Laguna Tortuguero	The Caribbean National Forest. Also all mangrove areas have importance for wildlife.
7. Major Fishing Grounds	A spiny lobster fishery exists off Arecibo	Spiny lobsters are abundant off San Juan.

<u>RESOURCES</u>	<u>SOUTHEAST</u>	<u>SOUTH</u>	<u>SOUTHWEST</u>
1. Unique Coastal Waters	None	Mar Negro (Bioluminescent Bay)	Bahio Fosforescente (Bioluminescent Bay), Manso Jose (Bioluminescent Bay), Laguna Salinas (Salt Water Lagoon), Laguna Rincon (Salt Water Lagoon), Laguna Cartagena (Fresh Water Lagoon/Marsh), Laguna Guaniquila (Salt Water Lagoon).
2. Coral Reefs	Media Mundo, Humacao, Maunado	Guayama, Pastillo-Santa Isabel-Aquirre, Caja De Nuertos, Ratons	Fanduco, Unitas, Guayanilla, Media Noche, Margarita, Bagueron.
**3. Mangrove Communities	Ensenada Hondo (553), Rio Daguiada (417), Bahia Lima (19), Rio Anton Ruiz (750), Punta Conalelro (32), Punta Tuna (16), Punta Viento (113).	Las Marcas (10), Puerto de Jobos (796), Cayos Caribe (244), Mar Negro (122), Cayos de Barco (1673, Punta Arenas (68), Cayo de Ratones (44), Cayo Mata (54), Balia de Jouca (63), Punta Petrona (471), Playa Cortado (34), Cayo Barberia (79), Punta Cabullon (105), Laguna de las Salinas (35), Bahia de Tallaboa (88).	Bahia de Guayanilla (48), Puerto de Guayanilla (332), Cana Gorda (109), Faro de Guanica (17), Bahia de Guanica (33), Ensenada Las Pordas (12), Punta Manglillo (14), Bahia Montalva (98), Bahia Fosforescente (70), La Pargera (1063), Bahia Sucia (102), Cano Boyueron (513), Bahia de Bogueron (56).
4. Dunes	None.	Ponce, Jauca.	None.
5. Beaches	Approx. 13 miles of beaches. No critical erosion.	Approx. 30 miles of beach. Little erosion is found in this sector.	Approximately 18 miles of beach.
6. Critical Wildlife Habitats	Cuichilla de Ponduras and the Sierrra de Guadarraya are important areas for wildlife	The extensive mangrove community in this area is important for wildlife.	Dry forest at Guanica, Cabo Rojo National Wildlife Refuge, and Bogueron Bird Refuge.
7. Major Fishing Grounds	Off Punta Puerca spiny lobster habitat is good,	Spiny lobster habitat is found off Salinas	This area also constitutes an important fishing area. Spiny lobster habitat is found off Cabo Rojo.

TABLE III (Continued)

<u>RESOURCES</u>	<u>WEST</u>	<u>NORTHWEST</u>
1. Unique Coastal Waters	Laguna Cueva (Fresh Water Lagoon/ Marsh), Laguna Jayuda (Salt Water Lagoon), Pantana De Sabaneta (Marsh).	Pantano De Espinar (Marsh).
2. Coral Reefs	Tourmaline, Mayaguez, Rincon.	None
**3. Mangrove Communities	Punta La Mela (103, Puerto Real (59), Punta Carenero (177), Laguna Jayuda (75), Cano Corazones (211), Cano Boquilla (63).	Maleza Alta (18), Bayuras (41), Maracayo (38), Carrizalos (23), Tiburanos-Islote (112).
4. Dunes	None	Punta Borinquen, Punta Agujereada, Punta Jacinto, Punta Sardina, Punta Penon, Punta Maracayo.
5. Beaches	Approximately 27 miles of beach.	Approximately 20 miles of beach. No critical erosion problems are found in the majority of this area.
6. Critical Wildlife Habitat	There are few important areas here outside of the mangrove communities	There are relatively few important areas for wildlife found here in comparison with the rest of the Island.
7. Major Fishing Grounds	This area is the principal grounds for reef fish. Important spiny lobster habitat also lies off the coast of Mayaguez.	Important habitat for the spiny lobster fishery lies off Aquadilla.
Source:	Derived from Puerto Rico 900 MWe Coal/Oil Fired Project Site Selection Study, The Puerto Rican Coastal Management Program and Final EIS, and NTIS Tech. Rept. Regional Inventory, South Atlantic, Gulf and Puerto Rico Regions U.S. Army Corp. of Engineers. *These sectors were derived on the basis of topographical, ecological, and socioeconomic characteristics. The sectors were formulated and presented in a "Description of Coastal Features" in the Puerto Rico Coastal Management Program and Final EIS. The geographic areas the sectors represent is as follows: North, Rio Grande de Arecibo to Boca de Congrejos; Northeast, Boca de Congrejos to Rio Demajagua; Southeast, Rio Damajagua to Rio Grande De Patillas; South, Rio Grande De Patillas to Rio Tallaboa; Southwest, Rio Tallaboa to Punta Guaniquilla; West, Punta Guaniquilla to Rio Culebrinas; Northwest, Rio Culebrinas to Rio Grande de Arecibo. **Mangrove Communities are measured in cuerdas. 1 cuerda equals .97 acres.	

social and economic environments of Puerto Rico's coastal areas must be identified. Social and economic characteristics are important considerations in coal plant siting. In the past, these environments have been neglected in siting decisions. Several sectors must be examined and identified including:

- 1) Major population centers;
- 2) Industrial concentrations;
- 3) Agricultural areas;
- 4) Recreational and tourism resources;
- 5) Transportation systems; and
- 6) Cultural and historic sites of the Islands coastal areas.

Archeological studies on the island have determined the first inhabitants of Puerto Rico arrived during the first century A.D. By the time of the Spanish conquest, in the fifteenth century, the island's population was between 60,000 and 100,000 people. A large proportion of these people were located along the coast and through the level land of the interior valleys. These occupancy patterns have continued to this time. The island of Puerto Rico's three largest urbanized areas are port cities. These include San Juan, Ponce, and Mayaguez.³⁵ The level coastal plains surrounding these developing urban centers are subject to continuing pressures to accommodate a society that is increasingly urban and industrialized. For example, most of the existing industrial areas of Puerto Rico have coastal locations. Some of these industries must have coastal locations to function.

Examples include ports, shipyards, power plants, and the extraction of coastal minerals.³⁶ Other types of industry are strongly benefited by a coastal location. These are industries which are dependent upon large quantities of imported products, or industries serving, or served by water dependent plants. These are 7 existing major industrial areas in Puerto Rico, including:³⁷

- 1) San Juan;
- 2) Ponce;
- 3) Mayaguez;
- 4) Yabucoa;
- 5) Aguirre
- 6) Gyanilla; and
- 7) Arecibo.

In addition, there are other areas on the Island specifically reserved for industrial development. These are areas which may not be used for other purposes.

Puerto Rico's agriculture is also dependent upon coastal lands. In 1980, approximately 270,000 fully mechanized acres were suitable for tillable land.³⁸ These lands are located almost exclusively in the coastal plain. Puerto Rican agriculture has a historical basis in the traditional sugar cane, tobacco, pineapple, and coffee operations. However, agriculture has run into increasing problems in the past 30 years. This is related to poor farming techniques, low labor productivity, and loss of prime agricultural lands to other uses. Approximately 9,000 acres per year are lost to urban,

industrial and residential encroachment each year.³⁹

The Island's coastline offers a diverse range of recreation and tourism opportunities. The sea and coastal lands cater to many interests due to the wide variety of coastal features found on the Island. The beaches are a primary attraction but other features include mangroves, lagoons, freshwater swamps, rocky shores, and scenic vistas. Tourism has grown to assume considerable importance in the Puerto Rican economy. In 1977, over 13 million visitors came to Puerto Rico, with expenditures exceeding \$400. million.⁴⁰ Tourism is now the third largest sector in the Puerto Rican economy. Recreation is also important to the native population. The 1977 revision of the Island's Comprehensive Outdoor Recreation Plan identifies 2049 fully developed recreation sites.⁴¹ The large number of developed recreation areas is related to a significant increase in water-based recreation in recent years. This interest, and demand for facilities, is projected to enjoy continued growth with increasing urbanization and income on the Island.

The primary highway network in Puerto Rico lies around periphery of the Island on the flat coastal plain. The Puerto Rico economy has grown substantially since the 1940's and an increase in automobiles has paralleled this growth. For example, in the period 1970 to 1975 the number of vehicles increased by 67 percent.⁴² New expressways have also been built, this has increased the accessibility of many parts of the coast from urban centers.

Railroads play a minor role in Puerto Rico's rural transportation system. The only railroads in operation on the island are narrow-gage trains which are primarily used to haul sugarcane to the mills during the harvest season. Railroads are unimportant in the movement of goods as this is accomplished almost exclusively by trucks.

Puerto Rico's ports constitute a vital link between ocean shipping and the inland transportation network. The Island imports most of its foodstuffs, as well as manufactured goods and raw materials. Table IV is an inventory of facilities and equipment of Puerto Rico's major ports.

San Juan, Ponce, and Mayaguez are the major seaports in Puerto Rico. In 1975, total commerce moving through these ports was approximately 10,500,000; 550,000; and 290,000 metric tons, respectively.⁴³ Other important ports include Jobos Harbor, Guanica, Guaynilla, Yabucabo, and Guayama. These ports handle a variety of commodities including bulk sugar, fertilizers, fuel oils, liquid chemicals, and grain. The Island's dependence on seagoing trade is such that expansion and modernization projects are underway at these ports and other harbors to ensure the continued growth of the Island's economy.

Puerto Rico's airports are another critical element of the transportation system. The airports are especially important to the tourist industry. There are ten existing airports on the Island with San Juan International the largest and most utilized airport.⁴⁴ This airport has been

TABLE IV
INVENTORY OF FACILITIES AND EQUIPMENT AT
PUERTO RICO'S MAJOR PORTS

<u>PORT</u>	<u>TOTAL BERTHS</u>	<u>GENERAL CARGO FACILITIES</u>	<u>SPECIALIZED^b CARGO FACILITIES</u>
San Juan	41	33	8
Ponce	7	5	0
Mayaguez	2	2	0
Jobos Harbor	1	0	1
Guanica	1	1	0
Guayanilla	3	2	1
Yabucoa	1	0	1
Guayama	2	0	2

a. General Cargo Facilities include: General Cargo, Container, RO/RO, and Lash.

b. Specialized Cargo Facilities include: Dry Bulk, Liquid Bulk, and Passenger

Source: U.S. Department of Commerce, Economic Study of Puerto Rico, pp. 403.

called the gateway to the Caribbean. Borinquen Airport, formerly Ramey Air Force Base, located in Aquadilla, is another important facility because it has the longest runway in the Caribbean. In addition, it has an extensive infrastructure including 1,000 housing units, recreation facilities, pools, and beaches.⁴⁵ Major steps are now being taken to fully develop the potential of this facility.

The Island's coastline also includes a rich heritage of historic and archeological sites. The Institute of Puerto Rican Culture has designated numerous historic monuments in Old San Juan, as well as 13 historic sites in other parts of the coast. There are 35 archeological sites on the coast with a number being pre-Columbian settlements whose exact locations have not been determined.⁴⁶ The general policy of the Commonwealth towards these resources is to avoid the destruction, mutilation, deterioration, or demolition of important cultural resources designated by the Institute of Puerto Rican Culture.

To identify the social and economic resources of the Island, for energy siting purposes, an inventory must be conducted. This inventory aids the siting process by identifying those resources which may aid the siting of facilities, such as the highway network and ports, and those resources which may be impacted adversely by a facility, such as recreational areas or historic sites. Table V is an example of the type of inventory which can be conducted. This inventory used a number of resources, including: The Puerto Rican Coastal Management Program and Final EIS; the 1977 Census for

TABLE V

INVENTORY OF THE COASTAL SOCIOECONOMIC ASPECTS OF
PUERTO RICO BY GEOGRAPHIC SECTORS

<u>ASPECTS</u>	<u>NORTH</u>	<u>NORTHEAST</u>
1. Urban Concentration	San Juan Metropolitan Area, largest of the Island's urban areas. Population of 943,500 in 1975. Manati, Vega Baja and Vega Alta, 50,000 to 100,000 residents.	Fajardo, 50,000 to 100,000 inhabitants,
2. Centers of Large Employment and/or Industrial Activity Heavy.	Large chemical and pharmaceutical operations, Caribbean Gulf Oil Refinery located in Bayamon, Puerto Rico Drydock and Marine Terminals San Juan.	Industrial Port at Fajardo,
3. Agricultural Activity within 10 miles of the Coast.	1,300 farms. Intensive cultivation of pineapple and sugar cane.	700 farms.
4. Tourism and Recreational Opportunities.	San Juan, the Island's preeminent tourist destination. Developed under the P.R. Recreational Administration, are the beaches Isla Verde, Cerro Gordo, Sardinena, Punta Salinos, Polo Saco, Ensenado Sombe, Escambron.	Caribbean National Rain Forest, La Cordillea Islands, Luquillo Beach, developed under the P.R. recreation administration.
5. Major Traffic and Transportation Systems.	Roads - Rts. 2 and 22; Airports: East of Arecibo and in San Juan there are public airports, and there is an international airport in San Juan; San Juan has industrial and commercial seaports and there is a commercial port in Arecibo.	Roads - Rts. 1, 3, and 26. No public or international airports. There is a commercial seaport in Fajardo.
6. Cultural/Historic Sites,	There are 19 important cultural historic sites in the San Juan area. These include historic and archeological sites and shipwrecks.	There are 3 important cultural/historic sites in this area.

TABLE V (Continued)

<u>ASPECTS</u>	<u>SOUTHWEST</u>	<u>WEST</u>	<u>NORTHWEST</u>
1. Urban Concentration	Guanica and Guayanilla, 50,000 to 100,000 inhabitants	Mayaguez, third largest metropolitan area, and Cobo Rojo, San German, and Harmiqueres 50,000 to 100,000 inhabitants	Aguadilla and Isabella, 50,000 to 100,000 inhabitants and Arecibo with 25,000 to 50,000 inhabitants.
2. Centers of large Employment and/or Industrial Activity Heavy	Pharmaceutical industries	Industrial and commercial ports at Mayaguez. Major beer breweries	Commercial port at Aquadilla
3. Agricultural Activity Within 10 miles of the Coast	1,600 farms. Extensive level fertile lands suitable for mechanized agriculture.	1,750 farms. Area around Anasco is a rich agricultural area	2,950 farms
4. Tourism and Recreational Opportunities.	Dry forest at Guanica; mangroves of La Perquera, Boqueron, and Pithaya; Reefs of Margarita and Turromote; Cobo Rojo Nat'l Wildlife Refuge; Boqueron Bird Refuge; Extensive Rec. Beaches.	Best surfing on the Island, centered in Punta Higuero area. Recreation beaches at Boqueron and Anasco.	Boqueron Airport and its facilities have tourism potential.
5. Major Traffic and Transportation Systems.	Roads - Rts. 2. No public or international airports There are industrial seaports in Bahia de Guayanilla and in Bahia de Guanica areas.	Roads - Rts. 2. There is a public airport in Mayaguez; There are also commercial and industrial seaports in Mayaguez.	Roads - Rts. 2. There is a large air facility at Boqueron. This was formerly Ramey Air Force Base (US); there is an industrial seaport in Aguadilla Bay.
6. Cultural/Historic Sites	There are 7 important sites in this area.	There are 8 important sites in this area.	There are 4 sites centered in Aguadilla and Arecibo.

Source: Puerto Rico Coastal Management Program and Final EIS; U.S. DOC Economic Study of Puerto Rico Vol. 2; U.S. DOC 1974 Census of Agriculture, Puerto Rico. Note: The sectors utilized here are the same as in the inventory for natural resources.

TABLE V (Continued)

<u>ASPECTS</u>	<u>SOUTHEAST</u>	<u>SOUTH</u>
1. Urban Concentration	Humacao and Yabucoa, 50,000 to 100,000 inhabitants,	Ponce, second largest metropolitan area, population of 128,333 in 1970. Juana Diaz, Guayama, and Arroyo, 50,000 to 100,000 inhabitants.
2. Centers of large Employment and/or Industrial Activity Heavy	Manmade harbor at Yabucoa serves the Sun Oil Refinery and related industries. Also Roosevelt Roads, the largest military base on the island is located here.	CORCO Oil Refinery located at Penuelas, Philips Oil Refinery located in Guaymas.
3. Agricultural Activity within 10 miles of the Coast.	1,500 farms. Intensive cultivation of sugar cane, predominate land use in this sector	800 farms
4. Tourism and Recreational Opportunities	Humacao Beach development under the P.R. Recreation Administration,	Arroyo and El Tugue are recreation beaches developed under the P.R. Recreation Administration.
5. Major Traffic and Transportation Systems	Roads - Rts, 3, 30, 31, There is a public airport in Humacao; there is a commercial seaport in Pta Lima and in the Humacao areas, and there is an industrial seaport in Guayames	Roads - Rts, 3, 52, and 2; there is a public airport near Ponce; there are commercial seaports in Guayamas and Ponce; there are industrial seaports in Ponce, Aguirre, and in the Pta Ola Grande areas.
6. Cultural/Historic Sites	There are 2 important archeological sites in this area	There are 11 important sites in this sector,

Agriculture for Puerto Rico from the U.S. Department of Agriculture; the U.S. Department of Commerce, Economic Study of Puerto Rico, and the author's personal observations.⁴⁷

IV. LEGAL ANALYSIS AND SECONDARY EXCLUSION

A primary goal of site selection procedures is to choose a site which is amenable to the existing legal and regulatory regime of the particular region. Site choice, in certain areas of Puerto Rico is regulated by a number of legislative and regulatory programs of resource management and land use. On the basis of the legal objectives and policies set forth by the Commonwealth, and Federal Government, certain coastal environments are deemed unsuitable for coastal facility development. As a result, a number of the actual geographic units, identified in the primary exclusion stage, can be deferred from siting consideration in the secondary exclusion portion of the process. In secondary exclusion, the applicable laws and regulations affecting the siting decision were identified. These laws then were utilized to exclude areas and resource units identified in the inventory stage of this process. This resulted in the identification of a number of preferred areas available for coal facility siting.

The areas and resource groups identified in the inventory stage, which are analyzed here, are listed below:

- 1) Coastal waters
- 2) Coral reefs
- 3) Mangrove communities
- 4) Beaches
- 5) Dunes

- 6) Wildlife
- 7) Fish, crustaceans and other marine life
- 8) Population centers and special dedication areas
- 9) Transportation systems
- 10) Cultural/Historic sites
- 11) Federal lands

To resolve the conflicting demands on these resources in Puerto Rico, the Commonwealth has enacted numerous laws concerned with planning and resource management. This legislation, and other Federal Laws, regulate the uses of these resources and the regime which dictates their use are discussed below to aid in the selection of sites which comply with Commonwealth and Federal policies.

A. Coastal Waters

Puerto Rico's coastal waters are a source of tremendous importance. These waters include fresh and salt water lagoons, swamps, regular and bioluminescent bays, and the ocean. The Puerto Rican Environmental Quality Board (EQB) is the Commonwealth agency responsible for water pollution control.⁴⁸

The existing water quality standards and accompanying regulations applicable to Puerto Rico have been established and are enforced by EQB. The existing regulations were enacted in accordance with Law No. 9 of June 18, 1970.⁴⁹ The regulatory goal is to preserve, maintain, and enhance the quality of the water of Puerto Rico, including coastal waters, compatible with the social and economic needs of the Commonwealth. Two

major objectives of the regulations promulgated by EQB, are to:

- 1) Prescribe water quality standards; and
- 2) Designate the uses for which the various waters shall be maintained and protected.

As a result, the Board has established four different water quality classifications each with specific standards. Three types; SA, SB, and SC are dedicated to coastal water quality.⁵⁰ Category SA includes bioluminescent bays and lakes. These are coastal waters whose existing characteristics shall not be altered in order to preserve the existing natural phenomena. These waters are not to be used for any activity that may be detrimental to the existing natural phenomena. Category SB includes the majority of coastal waters and lagoons on the Island. These are water for uses where the human body may come in direct contact with the water (such as complete body submergence); and for use in propagation and preservation of desirable species. Class SC are coastal waters for uses where the human body may come in indirect contact with the water (such as fishing, boating); and for use in the maintenance of desirable species. The EQB water quality standards also include an anti-degradation requirement. "Waters, whose existing quality is better than the standards established... will be maintained at such quality. These and other waters of the Commonwealth will not be lowered in quality unless it has been affirmatively demonstrated to the Board that such a change is justified as a result of necessary economic or

social development and will not interfere or become injurious to any assigned uses made of, or presently possible, in such waters."⁵¹

It is well established that the construction and operation of coal fired facilities may contribute to the degradation of proximate water quality.⁵² These degradations are in the form of sedimentation, turbidity, and thermal and chemical discharges. It is also apparent that power plants are to be restricted to waters with an SC classification, or for indirect contact purposes. As a result, all areas of classified SA and SB are to be excluded from further siting consideration. Figure 4 graphically shows this step in the process.

B. Coral Reefs

Coral reefs are one component of the system supported by the Island's coastal waters. These communities may be heavily impacted by the activities associated with any type of coastal development. As a result, the Commonwealth has adopted policies to protect these fragile ecosystems. The Objectives and Policies element of the Puerto Rican Planning Board's Island-wide Land Use Plan has established, as a general policy, the avoidance of activities and developments which may cause the deterioration or destruction of coral reefs.⁵³ The most serious threats to reefs from coal facility projects are in the form of sedimentation from water-based excavations for intake and discharge systems and chemical and thermal discharges from operation activities.⁵⁴ It is evident that the Commonwealth wishes to prevent reef destruction by siting facilities away from coral communities. Therefore, the pro-

cedures designed here defer all areas proximate to known coral reefs. Figure 4 graphically shows the amount of area deferred in this portion of the process.

C. Mangroves

Mangrove communities are extremely productive natural areas that serve a variety of ecological functions. Three-quarters of Puerto Rico's original mangroves have been destroyed and some of the remaining stands are now threatened.⁵⁵ The activities associated with coal facility development have the potential to adversely impact mangroves. This fact has been realized by the Commonwealth, and policies are in place to protect these areas from many types of development projects. The Objectives and Policies element of the Puerto Rican Planning Board's Land Use Plan has established, as a general policy, "the avoidance of activities...which could cause the deterioration or destruction of mangroves."⁵⁶ The EQB also passed a mangrove resolution in 1974 which stated a need to "preserve, protect, and as far as possible, restore the mangroves of Puerto Rico."⁵⁷ In addition, to supplement the policies stated above, and to increase the certainty of their application, additional policy has been established. The Puerto Rico Coastal Management Program has recommended that the following mangrove wetlands be designated natural reserves because of their extent, uniqueness, and complexity:

- 1) Constitution Bridge Mudflats;
- 2) Pinones Forest;
- 3) Rio Espiritu Santo;

- 4) El Faro;
- 5) Ceiba State Forest;
- 6) Jobos Bay and Mar Negro;
- 7) Punta Petrona;
- 8) Guanica Forest;
- 9) Lo Parguera;
- 10) Boqueron; and
- 11) Laguna Joyuda.⁵⁸

The Coastal Management Program states that alterations to these areas shall be limited only to minor incidental public service facilities, restorative measures, or scientific research.⁵⁹

In addition, any alteration to other mangroves in Puerto Rico is to be limited to the maximum extent practicable. However, the following may be allowed:

- 1) Essential military facilities;
- 2) Expansion of existing ports or airports;
- 3) Entrance channels for marinas; and
- 4) Those portions of coastal dependent energy facilities that cannot be located on dry land or in open water areas.⁶⁰

Federal law also protects against the filling of most mangroves in Puerto Rico. All filling in wetlands requires a permit from the Army Corps of Engineers. Corps regulations (42 CFR 37122-37164) discourages the unnecessary alteration or destruction of wetlands, including mangroves.⁶¹

As a result of these Commonwealth and Federal policies, the site selection procedure developed here considered sites containing wetlands with caution. The eleven areas recommen-

ded for natural reserve status (discussed above) were initially excluded from further siting consideration. This is demonstrated in Figure 4 at the end of this chapter. Mangroves were also evaluated in later stages of this process due to their high ecological value.

D. Beaches and Dunes

Puerto Rico's beaches and dune systems are important for recreation and tourism as well as for the protection of natural resources. The primary impacts on beach systems from coal facility development are air, noise and water pollution from construction and operational activities. In the past, beaches in the proximate area of major facilities in Puerto Rico have also been closed to the public for safety and security reasons. The Objectives and Policies element of the Planning Board's Land Use Plan established a policy on beaches in 1977. This policy attempts to avoid the unnecessary loss of options for future use of beach resources resulting from development activities.⁶² This is to be accomplished through the avoidance of building and other construction, in beach areas, which would impede the free physical access to these areas, prohibit the appreciation of panoramic view and prevent free access to and enjoyment of the sun by the citizenry. The Puerto Rican CZM program has also established a policy for governmental and private shorefront development. Where practicable, developments should be designed to facilitate rather than obstruct shoreline access by the general public.⁶³

Sand dunes are an integral element of some of Puerto Rico's beach systems. Dunes, particularly in the north coast, once provided protection against hurricanes and other large storms. However, due to massive sand extraction activities to supply the construction industry on the Island, these resources have been seriously depleted. As a general policy, the Planning Board's Land Use Plan prohibits activities which may cause the deterioration or destruction of dune systems.⁶⁴ Commonwealth law also prohibits the extraction of sand, from dunes, on public or private property, without a permit from the P. R. Department of Natural Resources.⁶⁵ In addition, man-made alteration of dunes within coastal high hazard areas is prohibited by Federal flood insurance regulations, although alterations not shown to increase the potential for flood damage are excluded.⁶⁶

As demonstrated above, the intent of Commonwealth and Federal policy towards beach and dune systems is clearly directed towards continued access and preservation. Therefore, the site selection procedures designed for the Island must recognize this intent. All beach and dune systems on the Island were excluded from coal facility siting consideration on this legal/regulatory basis. Figure 4 graphically demonstrates the areas deferred in this stage of the process.

E. Wildlife

The Wildlife found in Puerto Rico's coastal areas are a limited yet extremely valuable natural resource. The Common-

wealth Department of Natural Resources, and other agencies either own or have custody over significant wildlife coastal habitats. These include the Guanica Forest and the Boqueron Bird Refuge, as well as the Boca de Congrejos and the Cano Tiburnos wetlands. In addition, the Federal Fish and Wildlife Service has a National Wildlife Refuge in the southwest, at Dabo Rojo. The Federal military base at Roosevelt Roads also provides an important habitat.⁶⁷

The Commonwealth has recognized the value of wildlife in its Wildlife Law. It states that an adequate balance shall be maintained between urban and economic development and the extermination of wildlife species on the Island.⁶⁸

The Island-wide Land Use Plan has also established, as a general policy, the avoidance of activities which may cause the deterioration or destruction of habitats of endangered species.⁶⁹ The Endangered Species Act of 1973, passed by the U.S. Congress, also protects wildlife on the Island.⁷⁰ The Act provides the authority by which the Secretary of the Interior or the Secretary of Commerce may determine whether a species is endangered or threatened.⁷¹ The Act contains the provision for considering certain areas as "critical habitats."⁷² The animal or plant of concern need not be present in the particular area for such designation.⁷³ As a result of these designations, all areas designated critical areas for wildlife were deferred from siting consideration. In addition, all National and Commonwealth parks and forests were deferred because of their public use potential and for

the habitat that they provide for all the Islands game and protected species.

F. Fisheries

The fish and crustaceans of Puerto Rico are a valuable natural resource. They support a small, yet important in local terms, commercial fishing industry. The resource also provides for recreation for a large number of divers, both tourists and local population. The primary habitat of in-shore fish and crustaceans is the coral reef. The best fish habitat is found along the south and western coast of the Island. The primary concern for the siting of coal facilities and marine life is protection of this habitat. It has been well established that the activities which occur, with construction and operation of major facilities, may significantly impact this habitat. The preservation of reef habitat is essential for the maintenance of lobster and reef fish communities. The Coastal Zone Management Plan for Puerto Rico has identified areas of particular concern including reef habitat and inshore nursery areas.⁷⁴ These areas are listed in Table VI, and because of this designation were deferred from consideration for coal plant siting.

G. Population Centers and Special Dedication Areas

The population centers of Puerto Rico are, to a great extent, located in the coastal plain. The purpose of siting procedures is to reduce to the maximum extent possible, the negative externalities which will be imposed on the total

TABLE VI

AREAS OF PARTICULAR CONCERN DESIGNATED BY THE PUERTO
RICAN CZMP FOR REEF FISH AND CRUSTACEANS

- 1) Arrecife La Cordillera
- 2) Bosque Esatal de Ceiba
- 3) Pantano de Humacao
- 4) Arrecifes de Guayama
- 5) Bahia de Jobos
- 6) Lo Parguera
- 7) Boqueron

Source: Puerto Rico Coastal Zone Management Program
and Final Environmental Impact Statement.

island population from coal facility development. To attain this goal, coal facilities should not be sited in areas of high population. For this reason all populated areas were deferred from siting consideration in this portion of the process. Although no statutes can be cited which dictate this exclusion, these areas are deferred here because it is an appropriate point in the discussion to do so. If coal facilities are located in populous regions serious problems may occur in construction phases due to relocation problems, increased traffic, congestion, and housing problems. During operational states, the facility could impose risks to human health and have aesthetic and other adverse impacts.

Puerto Rico's Island-wide Land Use Plan dictates that certain lands, in coastal areas, are to be dedicated specifically for coastal industry and agriculture.⁷⁵ To assure compliance of this process with the Land Use Plan, all agricultural and industrial lands dedicated for these purposes were deferred from siting consideration. The Planning Board has reserved lands for industrial development to avoid the unnecessary loss of options for future use of these resources.⁷⁶ In addition, lands where the agricultural production potential has been classified as ranging between I and IV by the U.S. Soil Conservation Service were also reserved.⁷⁷ These areas are graphically excluded on the maps at the end of this chapter.

H. Transportation Systems

There are numerous concerns related to transportation and the development of major energy facilities. For coal fa-

cilities, the proximity of suitable port facilities is a necessity to allow for the arrival of coal shipments in an economical manner. Adequate roads are also required to bring in workers, equipment, and heavy machinery. Although these transportation elements are a large consideration in facility siting, this portion of the process was concerned with laws and rules which may limit facility siting for transportation related reasons. The U.S. Federal Aviation Administration (FAA) is the Federal authority concerned with airports. The FAA identifies standards for obstructions and definition of acceptable radius of such obstructions near airports. Based on the experience of major facility sites in other areas of the U.S., the FAA recommends a two-mile deferment radius of obstructions, such as smoke stacks, near airports.⁷⁸ The procedures designed here recognize this recommendation and subsequently all areas within two miles of airports on the Island were deferred from siting consideration.

I. Cultural/Historic Sites

Cultural, historic and archeological sites are an important aspect of the Island's environment. The sites are invaluable for the lessons they may teach future generations about past events, peoples, and the way of life. The Institute of Puerto Rican Culture has designated numerous historic monuments in Old San Juan as well as in other parts of the coast. In addition, there are 16 sites in Puerto Rico's coastal areas that are included in the National register of

Historic Places and are maintained by the National Park Service.⁷⁹ The Objectives and Policies of the Planning Board's Land Use Plan has established, as a general policy, the avoidance of the "destruction, mutilation, deterioration, or demolition of important cultural resources such as archeological deposits, historic sites, and/or building...declared by the Institute of Puerto Rican Culture."⁸⁰ In addition, sites on the National Register of Historic Places are protected by the National Historic Preservation Act of 1966, as amended, against disturbance by Federal, and Federally funded projects.⁸¹ The Federal Archeological and Historic Preservation Act of 1974, similarly protects archeological sites.⁸² Because of the extreme value of cultural/historic areas, and due to the legislative intent directed towards their preservation, all areas of cultural/historic significance were deferred from facility siting consideration.

J. Federal Lands

The final category of areas to be excluded in the legal analysis stage are Federal lands. A majority of the areas to be excluded are those managed by the U.S. Department of Defense (DOD). The DOD manages military reservations with the understanding that the use of these lands is to be restricted to military purposes.⁸³ As a result, military reservations were not included as potential sites for facility siting. Other Federal Lands which were excluded include those under the management of the Department of Transportation, Department of Agriculture and the Department of the Interior. These are

areas such as lighthouses, agricultural experiment stations, and national parks. Similarly these areas were deferred from siting consideration.

K. Secondary Exclusion

Through the use of existing Commonwealth and Federal laws and regulations it is possible to exclude large geographic areas from the siting study. Table VII summarizes the categories of area excluded and the laws and regulations which apply.

Traditionally, the application of exclusion criteria is accomplished graphically, as demonstrated in the primary exclusion stage. Areas with the characteristics described in Table VII are projected on a base map of Puerto Rico. Figure 4 is an example of this technique. The areas listed on Figure 4 have been derived from several sources, including: Puerto Rico Coastal Management Program and Final IES: U.S. Department of Commerce, Economic Study of Puerto Rico; U.S. Federal Aviation Administration, VFR Terminal Area Chart, Puerto Rico and the Virgin Islands; U.S. Department of Interior, Historic Conservation and Recreation Service, National Register of Historic Places; and U.S. Department of Agriculture, 1976 Agricultural Census of Puerto Rico.⁸⁴ To facilitate comprehension of the total amount of geographic area excluded in this stage of the process, Figure 5 has been compiled. All dark shaded regions were areas excluded in the secondary exclusion phase. This area and the areas excluded in the primary exclusion process were then aggregated;

TABLE VII

CATEGORIES OF COASTAL RESOURCES EXCLUDED IN THE SECONDARY EXCLUSION STAGE
AND THE APPLICABLE LAWS AND REGULATIONS

	<u>Law or Regulation</u>	<u>Area Deferred</u>
1) Coastal Waters	Commonwealth Law #9 June 8, 1970.	All SA and SB classifications
2) Coral Reefs	Policy 18.04 Islandwide Use Plan	All Coral reefs
3) Mangroves	Policy 18.04 Islandwide Land Use Plan; EQB Mangrove Resolution CZM Natural Reserve Designation; Reg. COE 42 CFR 37122-37164.	All mangrove swamps
4) Beaches	Policy 18.04 Islandwide Land Use Plan; Policy established by P.R. CZM Plan.	All beaches
5) Dunes	Policy 18.04 Islandwide Land Use Plan; Federal Flood Insurance Regulations	All Dunes
6) Wildlife	Commonwealth Wildlife Law; Policy 18.04 Islandwide Land Use Plan; Endangered Species Act	Designated critical areas and all Federal and Commonwealth National Parks and Forests.
7) Fish and Crustaceans	CZM Plan, Areas of Particu- lar Concern	Particular Concern Areas
8) Population Centers	None	All population centers
9) Transportation Systems	FAA Recommendation for Obstructions Near Airports	2 mile radius from all airports
10) Cultural/Historic Sites	42FR6317,6362; Islandwide Land Use Plan Policy 18.04/ 16 USCS 469; 16 USCS 433	All Cultural/Historic Area
11) Federal Lands	Informal Agreement	All Federal Lands
12) Dedicated Agriculture/ Industrial Areas	Law No. 75, June 24, 1975, sec 14.	All Areas so designated designated

Figure 6 is an example of this technique. When the results of primary and secondary exclusion are compiled the result is 33 preferred areas for coal facility siting. Table VIII is a listing of the preferred areas and the municipalities to which they pertain.

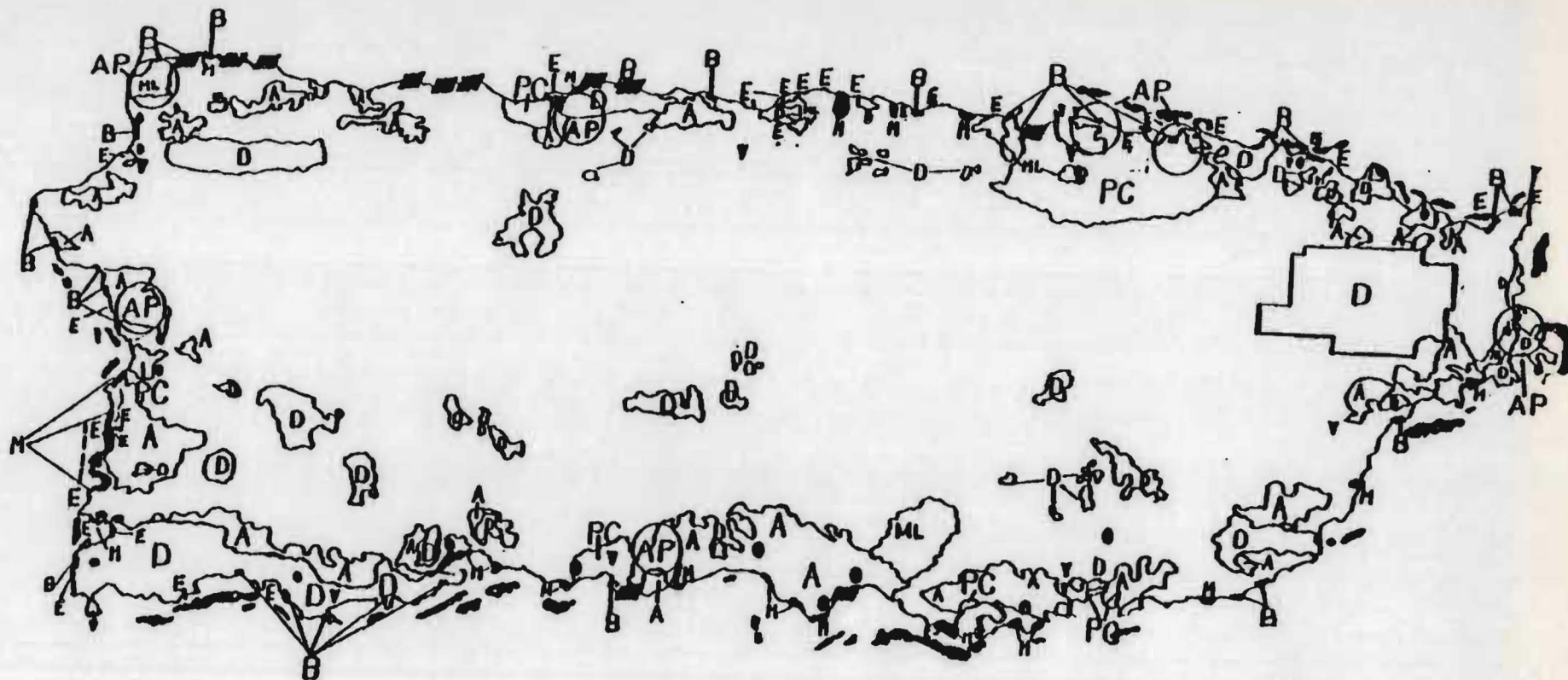
A primary goal of site selection has now been attained. Through the use of legal and regulatory criteria, large geographic areas have been deferred from siting study. The focus of the process next shifted to the evaluation of the 33 preferred areas to determine the optimum site for a 900 MWe coal fired facility.

TABLE VIII

PREFERRED AREAS BY GEOGRAPHIC SECTOR AND THE MUNICIPALITIES THEY PERTAIN TO

<u>Sector</u>	<u>Number</u>	<u>Municipality</u>
<u>West:</u>	1	Aguada
	2	Rincon
	3	Anasco
	4	Anasco
	5	Mayaguez
	6	Cabo Rojo
	7	Cabo Rojo
<u>S. West:</u>	1	Cabo Rojo/Lajas
	2	Guanica
	3	Guayanill
	4	Penuelas
<u>South:</u>	1	Juana Diaz
	2	Santa Isabel
	3	Salinas
	4	Patillas
<u>S. East:</u>	1	Maunabo
	2	Humacao
	3	Naguabo
	4	Naguabo
<u>N. East:</u>	1	Fajardo
	2	Fajardo
	3	Luguillo
	4	Rio Grande
	5	Rio Grande
	6	Loiza
<u>North:</u>	1	Dorado
	2	Vega Alta
	3	Manati
	4	Barceloneta
	5	Hatillo
<u>N. West:</u>	1	Camuy
	2	Quebradillas
	3	Aguadilla

Total Number of Preferred Areas Equals 33.



Key:

D - Dedicated Areas

B - Beaches

M - Mangroves

E - Critical Coastal Waters

A - Agricultural Lands

I - Industrial Areas

PC- Population Centers

AP- 2 Mile Radius from Airports

FG - Inshore Fishing Grounds

ML - Military Lands

▀ Dunes

● Historic Sites

▼ Archeological Sites

👤 Coral Reefs

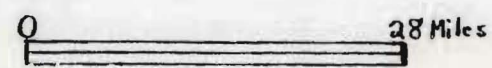
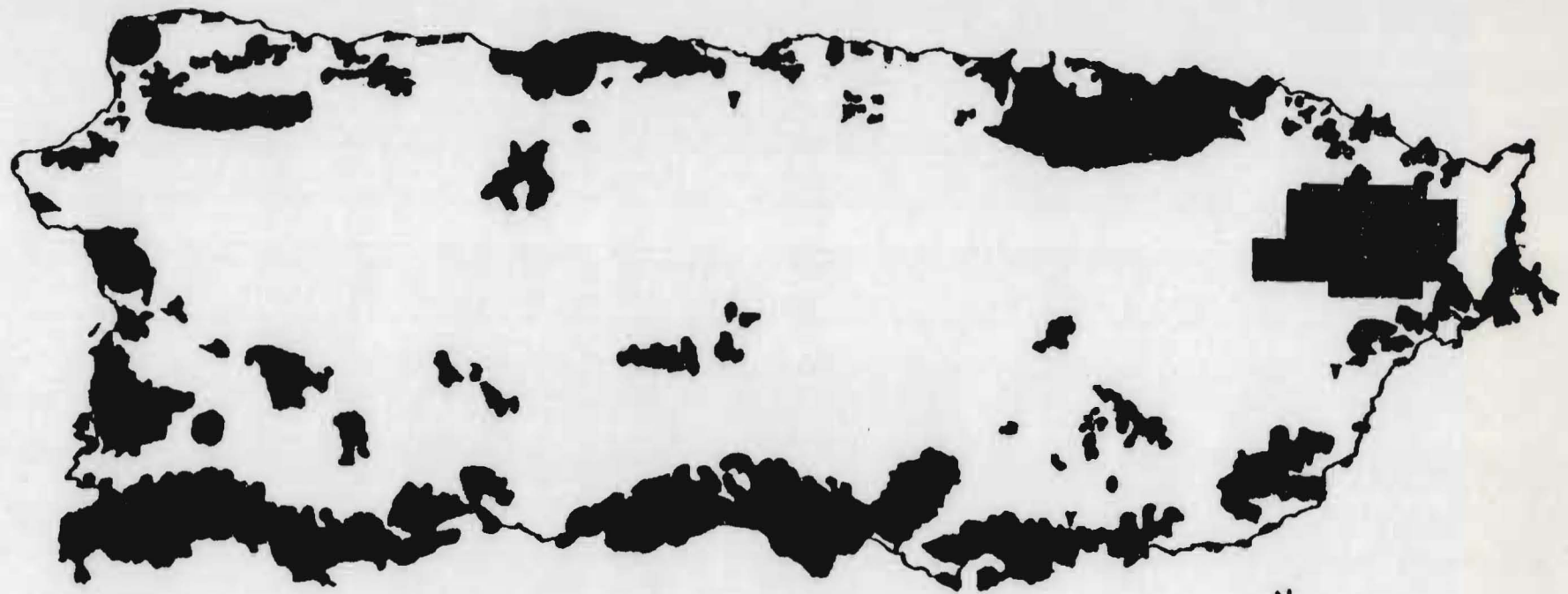


FIGURE 4

RESOURCES DEFERRED FROM SITING CONSIDERATION IN THE
SECONDARY EXCLUSION STAGE



Areas Eliminated (Corresponds To Areas Marked On Map 2)

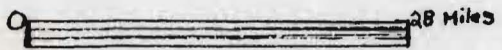


FIGURE 5

GROSS REPRESENTATION OF AREAS DEFERRED FROM SITING CONSIDERATION
IN THE SECONDARY EXCLUSION STAGE

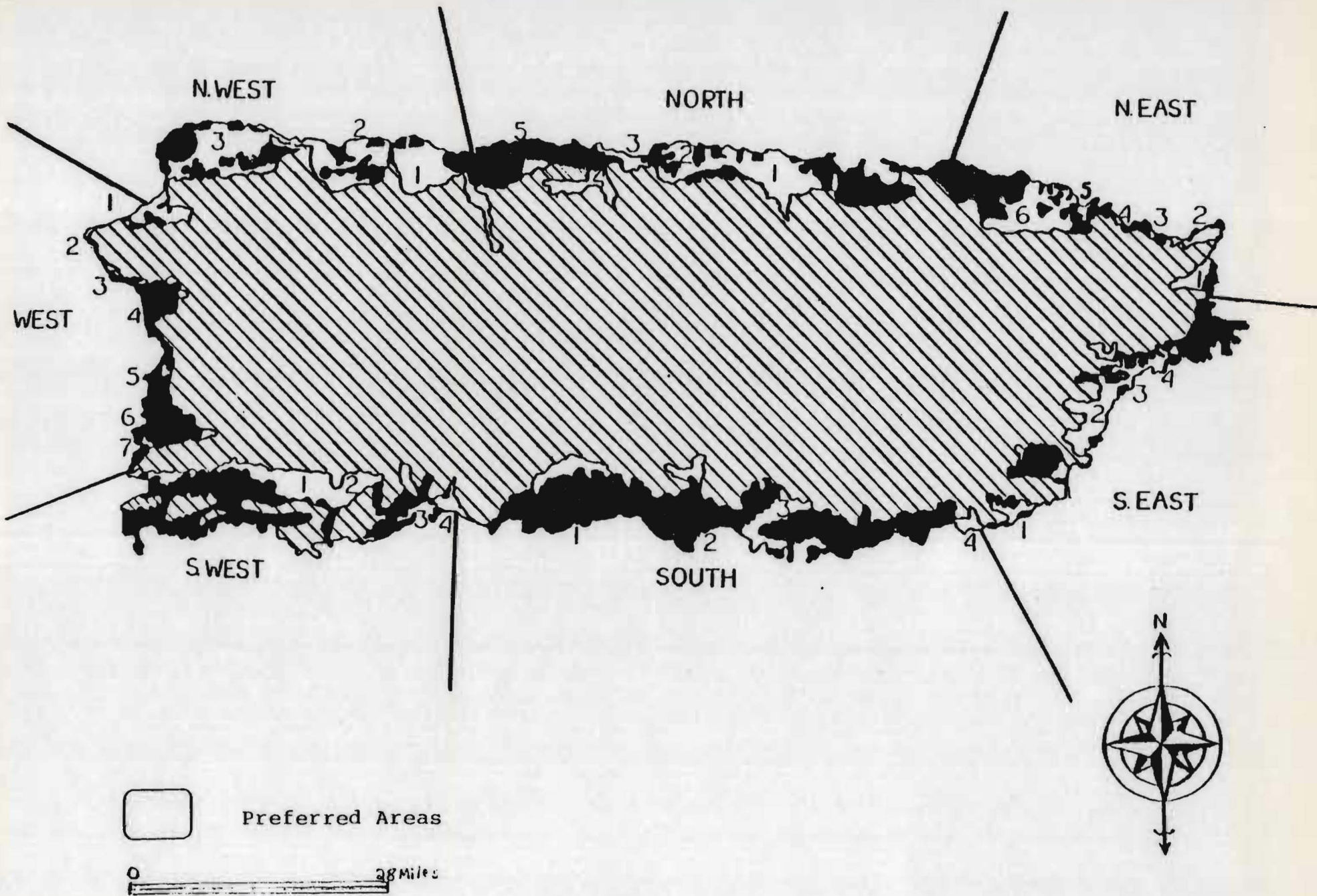


FIGURE 6

33 PREFERRED AREAS FOR 900 MWe FACILITY SITING DERIVED FROM THE PRIMARY AND SECONDARY EXCLUSION STAGES

V. THE PRIMARY EVALUATION STAGE

The primary and secondary exclusion stages, coupled with the inventory and analysis functions of this process exemplify a concise exclusionary methodology. Through this methodology it was possible to defer a majority of the geographic area on the Island from coal plant siting consideration. This was accomplished through the application of broad-based non-site specific criteria. The areas eliminated from consideration were those judged to be least compatible with facility development.

The focus of the primary evaluation stage is a shift from the use of exclusionary criteria to evaluation. At the conclusion of the exclusionary process, a number of "preferred areas" was compiled for further study. One of these areas underwent initial evaluation in this stage of the process through the application of narrow site specific criteria. The following criteria was developed to evaluate preferred areas:

- A) Sufficient acreage for plant development;
- B) Additional site availability;
- C) Proximity of downwind air pollutant receptors;
- D) Proximity of sensitive noise receptors;
- E) Aquatic ecology;
- F) Terrestrial ecology;
- G) Land use;
- H) Transportation availability and disruption; and
- I) Coastal hazards

These categories evaluate important ecological and socio-economic aspects. To enhance the evaluation and to provide a basis for comparison, a numerical scoring system was devised for use with each of these criteria. A specific area can then be evaluated and scored in relation to each of these categories. This resulted in a total score which allows comparisons to be made between "preferred areas" leading to the selection of actual candidate sites. The numerical system was developed to reflect the importance of ecological and socioeconomic factors in the siting decision. However, some categories may be of greater importance than others. For this reason the categories of greatest importance have been assigned a greater total numerical weight. The system and the rationale behind its development is described below:

A) Sufficient acreage for plant development	Rank
1) Areas with less than 450 acres of suitable terrain.	0
2) Areas with 450 to 1400 acres of suitable terrain.	1
3) Areas with more than 1400 acres of suitable terrain.	2

Rationale: The 900 MWe model utilized in this thesis requires a minimum site size of 450 acres.⁸⁵ The acreage requirement includes land for the complete physical plant, accessory needs, and onsite solid waste disposal. Therefore, 450 acres is the minimum acreage requirement, the land must be suitable for construction purposes. Construction suitable

bility may be defined as no more than 400 foot differential in slope across the proposed site.⁸⁶ It is judged to be beneficial if a site has extra acreage available.⁸⁷ Puerto Rico is an island with high topographic relief. A possibility exists that portions of a site will not be suitable for facility construction. Thus, the availability of extra acreage adds flexibility to the construction process. The greater amount of extra acreage increased this flexibility and the areas desirability for coal plant siting. These facts are demonstrated in the ratings for acreage requirements.

B) Additional site availability.	Rank
1) No additional preferred areas are located within 5 miles.	0
2) One additional preferred area exists within 5 miles.	1
3) Two or more additional preferred areas exist within 5 miles.	2

Rationale: The location of alternative sites within a 5-mile radius which may be suitable for coal plant siting increases the attractiveness of a particular area. As previously stated, detailed investigations may uncover unfavorable characteristics at a particular site. Other areas proximate to a particular site increase the flexibility available in the siting decision, and may result in more ecologically sound decisions. If necessary, it may be possible to shift some needs of the project to an alternate location. This might discourage unsound eco-

logical decisions because viable alternatives in the proximate siting location are available. This allows portions of a project to be shifted away from an area without incurring large scale ecological problems.

C) Proximity to sensitive air pollutant receptors	Rank
1) The site is located less than 5 miles upwind of sensitive air pollutant receptors..	0
2) The site is located 5-10 miles upwind of sensitive air pollutant receptors.	1
3) The site is located greater than 10 miles upwind of sensitive air pollutant receptors.	2

Rationale: The existence of sensitive receptors (populated areas) proximate to the facility, in the prevailing trade winds, is not conducive for coal facility siting.⁸⁸

Although there is some degree of variation in local wind patterns the meteorological regime of Puerto Rico is quite consistent.⁸⁹ Therefore, the prevailing trade winds were utilized in this evaluation category. Sulfur oxides, nitrous oxides and particulates are injected into the atmosphere from the power plant stack. Due to the consistent meteorological regime, a majority of the gases and particulates will travel with the prevailing winds.⁹⁰ If populated areas lie in the prevailing pathway, unacceptable health problems could result. This is reflected in the numerical system. Another component of this category is the "distance factor." Studies have shown

that a site more than ten miles from an air emission source will not realize significant adverse impacts on ambient air quality.⁹¹ This factor is also represented in the numerical value.

D) Proximity of sensitive noise receptors

	Rank
1) The site is located less than 3 miles from housing developments, recreational beaches, or public parks and forests.	0
2) The site is located 3 to 5 miles from housing developments, recreational beaches, or public parks and forests.	1
3) The site is located greater than 5 miles from housing, beaches, or public parks and forests.	2

Rationale: Although these criteria do not represent a detailed noise assessment, a generalized evaluation of noise pollution on housing units and public use areas was provided in this category. Because of the large number of areas under evaluation during this stage of the process, it is not feasible to perform detailed studies on all "preferred areas." However, this category allows some measurement of noise impacts to be attained for comparative purposes. A cutoff value of 5 miles was selected because studies have shown that noise impacts for conventional coal plants are insignificant beyond this distance.⁹²

E) Aquatic ecology	Rank
1) Percentage of the substrate covered by platform reef structure	
71-100%	0
21-70%	1
0-20%	2
2) Percentage of the substrate covered by <i>Thalassia</i> beds	
71-100%	0
21-70%	1
0-20%	2
3) Percentage of the substrate covered by algal mat	
41-100%	0
0-40%	1
4) Percentage of the substrate composed of sand or rubble	
71-100%	2
21-70%	1
0-20%	0

Rationale: The composition of the benthic community is partially controlled by the nature of the substrate. If the substrate is altered, it may lead to changes in species composition and important ecological processes.⁹³ The importance of the substrate was recognized in this evaluative category and was assigned a greater total numerical weight. The areas are ranked by the types and percentages of existing substrate. The greater the percentage of platform reef, *Thalassia*, or algal mat increased the possibility of undesirable ecological impact from the construction of intake and discharge systems. The areas with small areas of platform reef, *Thalassia* beds, and algal mat typically allow the routing of these systems with little adverse effects. Algal mat has been shown to be

more resistant to the problems which may occur and this is reflected by a smaller net numerical value.⁹⁴ The presence of large areas of sand/rubble substrate is more suitable for development and this is also reflected by the rating system.

F. Terrestrial ecology

	Rank
1) Percentage of wetlands on the site	
21-100%	0
1-20%	1
0%	2
2) Percentage of woodlands on the site.	
71-100%	0
21-70%	1
0-20%	2
3) Effect on mangroves	
a) Mangroves are immediately downwind or are in the vicinity of the planned thermal discharge	0
b) Mangroves are not immediately downwind or in the vicinity of the planned thermal discharge	1

Rationale: The large areas of wetlands, coastal forests, and mangroves found on the Island were mapped and deferred from siting consideration in the secondary exclusion stage. However, it is probable that isolated concentrations of these resources will be found at a particular site. Facilities may be sited in the presence of small areas of wetlands and woodlands with little major impact.⁹⁵ However, as the percentage of these resources increases, the potential impact also increases.

The ranking system reflects this trend. The wetlands ranking considers the unique character of wetlands and their greater sensitivity to disruption.⁹⁶ Woodlands are less sensitive and more abundant and this is reflected in the ranking scale.⁹⁷ The importance of mangroves was evaluated in a general manner as the largest stands were mapped and deferred from siting consideration in the exclusion stage of the process. The wetlands, woodlands, and mangroves of the Island are a fragile, valuable, and limited resource. Because of their value and limited nature they have been assigned a higher total numerical weight. This allowed the category to exert a greater influence on the siting decision than other criteria used in this stage.

G) Land use

	Rank
1) Housing density	
a) More than 1 house per 5 acres	0
b) Less than 1 house per 5 acres but more than 1 house/20 acres	1
c) Less than 1 house/20 acres	2
2) Agricultural uses	
a) Site contains or neighbors active farm lands	0
b) Site is not proximate to active farm lands	1
3) Industry	
a) Site is distant to existing heavy industrial activity	0
b) Site is proximate to existing heavy industrial activity	1

- | | |
|---|------|
| 4) Recreation | Rank |
| a) Site neighbors lands with public use or potential for recreation | 0 |
| b) Site is not proximate to an area with recreational uses or potential | 1 |

Rationale: All areas were evaluated on on-site housing density. Generally, the greater the on-site housing density, the greater the socio-economic impact of dislocation.⁹⁸ The operation of a coal facility also has the potential to disrupt agricultural activities and/or destroy crops. Areas devoted to the production of specialty crops such as citrus, banana, or plantain may be particularly impacted. Puerto Rico's agricultural lands are diminishing at an alarming rate.⁹⁹ Any activities which may speed this decline should be avoided. Also the location of an area proximate to existing heavy industrial activity may be beneficial. If an area is already degraded, to some extent, pollution and preemption impacts may be less than siting a facility in a pristine environment. This fact was reflected in the rankings. Although all recreational areas have been eliminated from siting consideration, the location of a coal facility proximate to these areas may be detrimental. This fact is also considered in this portion of the process.

- | | |
|--|------|
| H) Transportation availability and disruption | Rank |
| 1) Port accessibility | |
| a) Existing port or barge access more than two miles from the site | 0 |

	Rank
<ul style="list-style-type: none"> b) Existing port or barge access less than two miles from the site 	1
2) Road/Highway sufficiency	
<ul style="list-style-type: none"> a) Extensive construction is required to upgrade and repair existing roads, or to link the site with the existing ground transportation system. 	0
<ul style="list-style-type: none"> b) Adequate road/highway systems exist proximate to the site 	1
3) Transportation route disruption	
<ul style="list-style-type: none"> a) Site is crossed by one or more paved public highways 	0
<ul style="list-style-type: none"> b) Site not crossed by paved public highways 	1

Rationale: Site accessibility to various transportation facilities is an important consideration in minimizing transportation costs to the facility site. More importantly, site accessibility is important in minimizing environmental impacts associated with extensions of existing transportation facilities. The two mile breakpoint for port accessibility is based on engineering judgments on the costs and benefits of transporting materials to the site.¹⁰⁰ The breakpoints for road/highway access are more generalized. However, if major new construction or repair is required to link the site with existing transportation systems this is not viewed as beneficial. This fact is reflected in the ranking system. Transportation route disruption is also included in this sec-

tion of the process. If the site is crossed by paved roads, there is potential for disruption and adverse socio-economic effects.¹⁰¹

I. Coastal Hazards

	Rank
1) Sites in areas with more than 2 adverse features	0
2) Sites in areas with 1 or 2 adverse features	1
3) Sites with no known adverse features	2

Rationale: The coastal hazards of Puerto Rico fall into three categories: coastal flooding; geologic hazards, and coastal erosion.¹⁰² Each site was evaluated for its flooding and erosion potential. In addition, possible geologic hazards at each site were examined. Geologic hazards include: faults or zones of tectonic structures and folds; limestone formations; and overburden conditions such as flood-plain deposits of present and ancient drainage. Areas that contain one or more of those hazards were assigned a lower number in the ranking scale.

J. Primary Evaluation of Punta Higuero

The criteria developed above can be utilized to review one of the "preferred areas" derived in the secondary exclusion state. This was accomplished through the use of USGS 7.5 Minute series, topographic quadrangle maps depicting the preferred area. Through the use of these maps, and the criteria which has been established, a numerical value was assigned to the site. It should be restated that the values computed here are approximations. They were the result of

the application of broad on-site specific criteria. Their principal value is for comparison and the selection of actual candidate sites. The actual candidate sites are those 4 or 5 "preferred areas" which have the highest scores after the primary evaluation criteria had been applied. However, a failsafe measure should be conducted before moving to the secondary and final evaluation stage. The failsafe consists of helicopter overflight assessments by trained teams of evaluators. It is necessary to examine the 4 or 5 highest scoring "preferred areas" to check the results derived from the topographic maps. Recent activities may be underway in an area that are not included in the USGS maps. For example, overflights may reveal the construction of new commercial or housing developments, vacation condominiums, or marinas which render the area incapable of supporting the facility with minimum effects. In this way, resources for detailed evaluation will be concentrated on those areas most compatible with coal facility development.

To test this portion of the process, one of the "preferred areas" derived in the secondary exclusion stage was evaluated here. Because the focus of this thesis is directed towards the development and testing of a model process, all of the preferred areas were not discussed. The financial resources and time limitations of this did not allow for the detailed on-site investigations required for an actual site selection study.

The area selected for evaluation was Punta Higuero. It is located in the western sector of Puerto Rico and was a

"preferred area" identified in the secondary exclusion stage. This area had been selected primarily, because it is this area which the author has the greatest familiarity. Determinations can be formulated on the author's personal experiences in the area during the winters of 1979-80, 1980-81, and 1981-82.

Punta Higuero is a small residential community of a few thousand residents. Land use is primarily residential with a fair amount of subsistence agriculture. The power plant site has been highlighted and presented on Figure 7. This has been derived and enlarged from a USGS 7.5 minute topographic map. The land use at the site is primarily cattle grazing with a few residences. There is one major structure on the site. This area was the site of the experimental Boiling Nuclear Superheater (BONUS) power reactor plant. The decommissioned facilities occupy a few acres of the site. The land is owned by PREPA and is fenced in and guarded. The beach area adjacent to the BONUS site and to the east and south is heavily used, especially in the winter months. Due to its unique geographic location and other oceanographic factors, this area has consistent large ocean waves that are excellent for the sport of surfing. Each winter large number of surfers travel from places around the globe to surf the waves at Punta Higuero. This area was the site of the 1968 world championships and a second professional contest was held in March of 1982. Surfing and the large number of surfers who travel to the area have become a significant economic activity for the Punta Higuero area.

The first category to be applied concerns the acreage requirements for the facility. Through the use of the USGS map and a planimeter (an instrument used for area size determinations) it has been found that this site is 550 acres. This results in a score of 1. The topography consists of a narrow coastal plain lying below very steep hills. It is apparent that it will be difficult to site a 900 MWe unit into this area, both because of the small amount of land available, and the nature of the terrain.

The next consideration is additional site availability. From the map compiled in the secondary exclusion stage it is apparent that one additional preferred area is found within 5 miles of Punta Higuero. This is in the vicinity of Calvache and is approximately three and one-half miles away on a straight line basis. This results in a score of 1 for this evaluation category.

The proximity of sensitive air pollutant receptors downwind is a special concern for coal fired facilities. This site is an excellent one from the point of view of residences in the stack plumes pathways. However, due to the heavy recreational activity which occurs on the beaches proximate to this site, the area is unacceptable. The site is located on a point of land protruding into the sea. When the trades are blowing the stack plume will be carried away from residential areas but directly across the beaches. As a result a score of 0 is recorded.

Proximity of sensitive noise receptors is the fourth area of evaluation. The Puntas site is not desirable for its

noise sensitivity. There are a large number of homes within one-half mile of the proposed site, and the Town of Rincon, with a population of 11,770, lies two and one-half miles from the site. Therefore, a score of 0 is recorded for noise receptors.

An important category for evaluation concerns aquatic ecology. The benthic habitat in this area will be evaluated solely on the author's personal experience. The author has conducted dives throughout the waters adjacent to the site and is intimately familiar with the types and approximate percentage of substrate found here. The benthic habitat is typical of an exposed high energy surf zone. Starting from the lighthouse marked on Figure 7 and moving northeast up to the abandoned intake structure for the Bonus reactor, the substrate is primarily sand with small patches of hard bottom. For this area the ranking would be as follows:

- 1) Percentage of platform reef structure equals 0-20%.
This would result in a score of 2;
- 2) Percentage of substrate covered by Thalassia beds equals 0-20%. This would result in a numerical value of 2;
- 3) Percentage of substrate covered by algal mat equals 0-40%.
This would result in a score of 1; and
- 4) The percentage of substrate composed of sand would equal 71-100% and a score of 2.

ighthouse

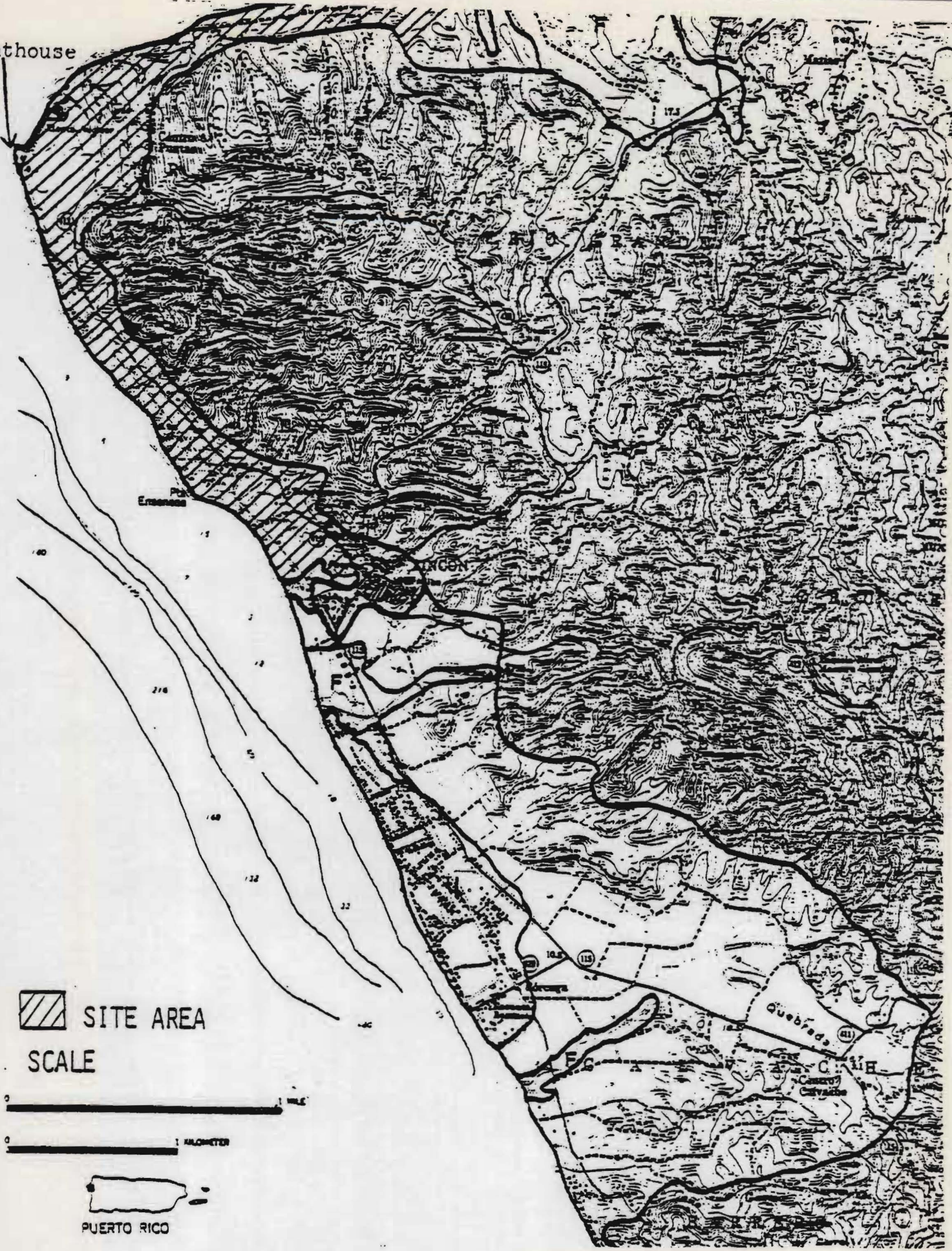


FIGURE 7
 USGS 7.5 MINUTE TOPOGRAPHIC QUADRANGLE OF RINCON
 SITE WEST 2

The total score for aquatic ecology in this portion of the proposed site would be 7 points out of a possible 7. This area has a low ecological sensitivity and would be the best location for submerged intake and discharge structures. In contrast to this portion of the site, the area from the south of the lighthouse to the end of the site near Rincon is more sensitive. This area has large percentages of algal covered hard bottom and some patches of hard corals with small sand patches. The score for this portion of the site would be as follows:

- 1) Percentage of platform and other reef would be approximately 21-70% with a score of 1;
- 2) There is between 0-20% of *Thalassia* present. This would result in a numerical value of 2;
- 3) Percentages of algal mat present would be between 91-100% with a value of 0; and
- 4) There is 0-20% of the substrate covered with sand with a score of 0.

The total score for this portion of the site is 3 out of 7 possible points. At the conclusion of the primary evaluation phase, the rating for the more advantageous site will be represented. This should be the case for all site selection studies as long as the area identified is large enough to support the intake and discharge system and not impact other communities in the proximate area.

The next criteria to be applied concerns the terrestrial ecology of the proposed site. The terrestrial ecology of

Puntas is acceptable for coal facility siting. There are no substantial wetlands on the site (score of 2), and the percentage of woodlands is only between 0-20% (score of 2). In addition, there are no mangrove stands immediately downwind or in the vicinity of the probable thermal discharges (score of 1). Therefore, the total for Puntas for this section of the evaluation is 5 points out of a possible score of 5.

The next area of consideration concerns land use. The first subcategory is the density of housing across the proposed site. The area is virtually uninhabited and little socio-economic impact would be generated through forced relocation. Therefore, a score of 2 was recorded for this subsection. Concerning agriculture, portions of the site are used for the grazing of cattle. This would constitute proximity to neighboring farm lands (score of 0) under strict application of the criteria, but this does not constitute a serious problem and could be qualified in the final total by explanation. In addition, there is no industrial activity proximate to the site. It is virtually pristine and pollution free. It is not beneficial to site facilities in these types of areas. Facilities should be sited in areas already degraded which reduces the severity of preemption impacts (score of 0). Finally, the site neighbors a beach with heavy recreational use. The placement of the facility proximate to the beach may result in pollution and restricted access and is unacceptable (score of 0). The Puntas site is not favorable for facility siting in relation to land use criteria. Out of a

possible score of 5, only 2 points were awarded with serious problems accruing from the industrial and recreational viewpoints.

The next category of evaluation concerns transportation availability and disruption. Regarding port accessibility, the closest port is 8 miles away in Aguadilla. Port or barge access adjacent to the site would require extreme modifications including breakwater construction, blasting, and dredging as a result of the heavy swell activity along this part of the coast. This is viewed as a serious deficiency and a score of 0 is recorded. In regard to road/highway systems, an acceptable network is in place. Large cane trucks use the highways linking the site, and an existing road exists to the site proper. This road was constructed for the BONUS reactors construction. Therefore, a score of 1 is recorded. In addition, the only road which crosses the site is the one connecting the BONUS reactor with Route 413. This road is primarily used by surfers and other tourists and is not a public highway as defined in the system (score of 1). The total score for this portion of the process is 2 points out of a possible 4. However, the lack of port and barge access must be considered a serious deficiency.

The next category concerns coastal hazards including: flooding and erosion potential and geologic hazards. The Punta Higuero site is subject to oceanic flooding and erosion due to its exposed nature and the heavy wave action in the area. In addition, the Great Southern Puerto Rico Fault

runs almost directly across this area. Although there has been no movement across this fault in recent geologic history, this was not viewed advantageously for major facility siting.¹⁰³ Because of these conditions a score of 0 was recorded.

After the final category of criteria has been evaluated, the results should be tabulated. Table IX is an example of this procedure. Out of a total of 31 points the Punta Higuero site has scored 18 points. If this process was done on all "preferred areas" a numerical basis would be in place to compare these areas. In this way, the four or five highest scoring areas would be selected as "candidate sites." The "candidate sites" are those which are subjected to detailed evaluation which will yield the optimum site for the facility.

A final consideration should be developed at this point. If all "preferred areas" were to be evaluated it might be advisable to exclude areas on the extremely low numerical value of a particular factor. For example, in the Punta Higuero case the lack of port or barge accessibility is not beneficial for this site. This will require the construction of on-site port facilities which would be costly in ecological and economic terms. Another alternative would be the construction of railways which has further potential for ecological harm. A situation such as this might require the exclusion of this site in an actual site selection study.

TABLE IX

SUMMARY OF POSSIBLE AND ACTUAL SCORES FOR
THE CRITERIA OF PRIMARY EVALUATION

	<u>Rank</u>
1) Sufficient acreage for plant development	Possible 0-2 Actual 1
2) Additional site availability:	Possible 0-2 Actual 1
3) Proximity of downwind air pollutant receptors:	Possible 0-2 Actual 0
4) Proximity of sensitive noise receptors:	Possible 0-2 Actual 0
5) Aquatic Ecology:	Possible 0-7 Actual 7
6) Terrestrial Ecology:	Possible 0-5 Actual 5
7) Land Use:	Possible 0-5 Actual 2
8) Transportation availability and disruption:	Possible 0-4 Actual 2
9) Coastal Hazards:	Possible 0-2 Actual 0
	<hr/>
Total	Possible 31 Actual 18

VI. SECONDARY EVALUATION STAGE

At the conclusion of the primary evaluation stage, it is possible to identify the areas most capable of supporting a 900 MWe facility through the use of the numerical ranking system. The areas selected for further study, termed actual candidate sites, will undergo further evaluation in the secondary evaluation portion of the process. By utilizing the evaluation processes formulated here it is possible to identify the best possible site(s) for the 900 MWe facility.

In this stage of the procedure, precise site specific ecological and socioeconomic factors were evaluated, weighed and scored. The evaluation system has been formulated through comprehensive literature evaluation of environmental impact analysis techniques. Various systems have been compiled and modified for the particular characteristics of a 900 MWe project and the unique geographic and environmental aspects found in Puerto Rico.¹⁰⁴ Upon examination of the available impact analysis systems it became apparent that no single technique of environmental evaluation was appropriate to solve the problems of facility siting in Puerto Rico. Most systems deal well with only a few of the elements of impact analysis for a tropical island environment. A system has been designed which will deal with these special characteristics. The system provides for visualization of the consequences of the activities and tradeoffs involved. Any system of impact evaluation involves the use of value judgments. The particular advantage of this system is the results are

quantified in a numerical format.¹⁰⁵ This provides for an increased measure of public scrutiny and review of the value judgments utilized in this process. The format is also presented in an easily understandable manner which will facilitate public review.

This portion of the process will evaluate five of the most important ecological and socioeconomic factors of coal facility siting for Puerto Rico. This was done in greater detail than the work completed in the primary evaluation stage. These factors include:

- 1) Terrestrial ecology;
- 2) Aquatic ecology and water quality;
- 3) Air quality;
- 4) Socioeconomics; and
- 5) Aesthetic considerations.

These factors were aggregated and quantified through the use of a numerical ranking system. The goal was to compute a single number which will allow quantitative comparisons of the candidate sites. For each of the five general categories, a checklist of integral components was constructed. Each of these components can then be evaluated for relative compatibility with coal facility construction and operational activities. Compatibility is defined as:

- 1) High compatibility, no negative impacts are expected (score of 2)

- 2) Low compatibility, some negative impact is expected (score of 1)
- 3) Incompatible, major negative impacts are expected (score of 0)

The number which represents relative degree of compatibility is then multiplied by a weighing factor. The weighing factor represents the importance of the particular component to the overall category under evaluation. This modifies the degree of compatibility to the relative importance of that particular component. The weighing factor ranges from 1 (lowest physical, ecological or social importance) to 4 (greatest physical, ecological, or social importance). In an actual site selection study, it is extremely important to construct the weighing factors on the judgments of several experts in the physical and social science fields, preferably with experts with familiarity and experience in the area under siting consideration. It is probable that disagreement will arise among the experts, in the valuation of weighing factors in an actual site study. The best means available to reach consensus on these values is multiattribute utility analysis (MAU).¹⁰⁶ MAU was developed to deal with the problem of disagreement over the relative importance of various goals in public policy decisions. Its purpose is to provide assistance to parties struggling to reduce their differences in decisions. MAU acts as a check against decision-makers impressionistic and intuitive insights. It has been most widely used for the purpose of forecasting the best course of

action in a decision. Therefore, it can be valuable as a tool in the determination of evaluation weights. It is suggested that this method be adopted in determining these weights. However, for the purposes of this thesis, weighing factors were developed and assigned on the basis of the author's personal experience in Puerto Rico and through work with the relevant literature.

Once the degree of compatibility has been multiplied by the weights, a compatibility index (CI) was derived for the particular component under consideration. The individual CI's can then be aggregated for a total compatibility index (TCI) for each of the five major components. A second weighing factor was then developed to modify the importance of a particular category in relation to the other five under evaluation. Again this should be computed through the use of multiattribute utility measurement. These numbers were then added which results in a site compatibility index (SCI) for each of the actual candidate sites under evaluation. Through the use of this procedure the best possible site(s) may be selected for a 900 MWe facility in Puerto Rico.

It would be extremely beneficial if this portion of the process could be tested for workability on one of the actual candidate sites. Although this would be extremely desirable, it is impossible for the author to conduct such an evaluation. The evaluation process is highly technical and must be accompanied by extensive site work by individuals with expertise in the physical and social science fields. This lack of

testing, however, is not viewed as detrimental to the validity of these procedures. The procedures are presented in such a manner as to demonstrate how positive and negative aspects of a site are identified and scored. It is felt that the depth of evaluative procedures insures the workability of the system.

A. Terrestrial Regime

The first category of resources to be assessed in this portion of the process is the terrestrial regime of candidate sites. This is accomplished through the development of a site features checklist and the scoring system described above. The checklist and the rationale utilized for its development is presented below--

Will the proposed project have high, low or no compatibility with the following terrestrial features?

Component	Degree of Compatibility	X Weights
	High (2), Low (1), None (0)	1-4 =CI
A) Coastal Formations		
1) Sandy Beach		4
2) Rocky Beach		3
3) Formations (caves, rock sculptures		2
4) Dunes		4
5) Rocky outcrops		2
6) Natural bridges		2
7) Volcanic features (Lava flows, hot springs, mudpots		1
B) Hazards of Coastal Lands		
1) Soils and slopes, stability and soil loss		2

2) Subsidence, groundwater removal, karst topography, flood plain deposits	2
Weighing Factor = CI	
C) Natural Features (removal for commercial purposes)	
1) Sand	1
2) Gravel	2
3) Minerals	1
D) Biota:	
1) Rare or Endangered Species	4
2) Mature Forest	3
3) Unique Habitat	4
4) Food Source	3
5) Water Source	3
6) Breeding Grounds	3
7) Refuge or Preserves	4
8) Migration Routes	3
9) Mammals	3
10) Birds	3
11) Reptiles	2
12) Amphibians	2
13) Insects	2
14) Other invertebrates	2
15) Plants	2
Total Compatibility Index (TCI) =	

Rationale: The development of the terrestrial checklist has attempted to incorporate all of the elements found in Puerto Rico's coastal systems. It should be stressed that the weights assigned are approximations that were utilized for demonstration purposes. In many cases they are value judgments based on the author's intuitive feelings. As such, they are subject to change in the event that this process is used for an actual site selection study.

- Subcategory A, coastal formations can be assessed largely

through the use of USCG 7.5 minute topographic maps. However, on-site investigations are required to determine the presence, extent, and location of features such as rocky outcrops, natural bridges, and volcanic features. It must be determined to what extent coastal formations will be preempted by facility construction activities. This will be reflected in the compatibility indexes. This portion of the process was perhaps the least complicated, although an essential one, to preserve physical features.

The coastal lands category includes components concerning slope stability, soils, and the geology of candidate sites. Due to the volcanic origins of Puerto Rico, much of the coastal plain is adjacent to steep slopes and cliffs. Any activity involving vegetation removal, soil disturbance and change in slope steepness and length may impact the stability of these areas. Soil loss and stability of slopes resulting from erosion can be predicted by the Universal Soil Loss Equation: $A = RK(LS) CP$.¹⁰⁷ The amount of soil loss (A) is based on the measurement of each variable in the equation, as defined below:

A = Soil loss from sheet and rill erosion measured in tons per acre per year

R = Rainfall factor (a measure of the intensity, duration and frequency of rainfall) R is computed by an erosion index which may be based on average figures and long term observations.

- K = Soil erodibility factor (a measure of the susceptibility of a given soil to erosion). The K factor is the erosion rate per unit of erosion index for a specific soil in a cultivated continuous fallow on a 9 percent slope, 72.6 feet long. It includes the combined effects of the soil characteristics that influence water intake and its ability to resist detachment and transport by rainfall and runoff.
- L = Slope length factor. Runoff increases as slope length increases, resulting in greater soil loss. L is measured from the point of origin of runoff to the point of deposition or the point where runoff enters an identifiable channel.
- S = Slope gradient factor. Generally, the steeper the slope, the greater the soil loss. The velocity of runoff is greatest on steep slopes where water has the greatest force.
- C = Cropping management factor. This factor accounts for the effects of plant or mulch cover and soil surface conditions at the site. Cultivated and smooth surfaced areas have higher degrees of soil loss than vegetated areas.
- P = Erosion control practice factor. This factor takes account of conservation practices which may be incorporated in the project. These include interceptor terraces and contour strips of vegetation.

To carry out this task the investigators should have a thor-

ough working knowledge of hydrology, soil science, and aerial photographic interpretation. Other necessities include soil surveys of the area and the appropriate tables and charts to calculate the variables in the Universal Soil Loss Equation.

Subsidence is the vertical collapse of the ground surface. In Puerto Rico, this phenomena may occur from the removal of groundwater and/or construction in areas of karst topography or flood plain deposits. The extraction of groundwater reduces the fluid pressure in the underground reservoir that tends to support overlying earth material. This process occurs at relatively shallow depths (less than 200 feet) over areas as large as hundreds of square miles. Although the reduction in fluid pressure may be relatively small, it leads to an increased stress between grains of earth material and to a decrease in void space. The final result is compaction and a change in the physical properties of earth material.¹⁰⁸ The dissolution of subterranean earth materials is another cause of subsidence.¹⁰⁹ In regions of karst topography, not uncommon in Puerto Rico, carbonate rocks such as limestone and dolomite are soluble, and subterranean voids can form when they dissolve. This lack of support of overlying rocks may lead to collapse and the formation of sinkholes.¹¹⁰ Areas with these characteristics are unfavorable for major facility siting. A third cause of subsidence is related to the presence of "mud waves." Present or ancient flood plain deposits, if loaded by structures may cause subsidence. The forces incurred from the structures may be transformed laterally along the fine-grained sediments. These sediments may

be pushed up into a mud wave which may damage the structure and surrounding roads and dwellings.¹¹¹ Areas which may be prone to these three types of subsidence may be identified through the use of regional data. The best which can be done is to identify the hazard prone areas and note their incompatibility in the assessment matrices.

Subcategory C includes natural features which may be removed for commercial purposes. In most areas it is not appropriate to site facilities in areas where valued natural features may be found. In Puerto Rico, there are limited commercial mineral resources. In the past 100 years, small mining ventures have extracted some minerals from the Island, however, most of those operations were marginal, based on easily accessible, high yield deposits of limited size.¹¹² The major mining activity today is centered on the extraction of sand and gravel for the construction industry. Most of these deposits however, are near depletion and the only major sources remaining are those which are naturally replenished by the sea.¹¹³ The variables to be considered in assessing the effects of coal facility siting on the natural features include definition of the presence and actual location of these resources on or near the candidate site, and the economic value of these resources. This may be accomplished through the use of regional geologic data and possibly minor exploratory activities. The results of the assessment are then estimated and recorded in the compatibility index.

The next area of evaluation in this portion of the process is the biotic composition of candidate sites. The first,

and potentially most important element of this portion of the process concerns rare or endangered species. The Endangered Species Act of 1973 (16 U.S.C. 1531-1543: 87 Stat. 884) provides the authority by which the Secretary of the Interior or the Secretary of Commerce may determine whether a species is endangered or threatened.¹¹⁴ The presence of an endangered or threatened species (fauna and flora) on or near a candidate site is viewed as a serious deficiency for a particular site and the siting of facilities in that area.¹¹⁵ To determine the presence of rare or endangered fauna or flora on a particular candidate site, a literature search and field survey should be conducted. The assessors should compile a list of the locations and names of the types of rare or endangered species which will be affected adversely by the project activities and score these sites appropriately in the compatibility index.

Although rare and endangered species are a major component of the terrestrial environmental assessment, there are numerous other elements which must be considered. These elements are found in the compatibility index for the terrestrial environment. A comprehensive field survey must be conducted before biological investigations begin to determine the compatibility of elements of the biotic environment with the proposed project. However, before the field investigation is conducted, the investigators should obtain answers to a series of questions which are listed below. The answers to these questions and the results of field investigations, will allow

values to be computed in the compatibility index for the biotic environment. The primary questions include:

- 1) What is the geographic size of the proposed project site?
- 2) What portion of the site is involved in the proposed project?
- 3) Will the project and its associated activities be short term or long term?
- 4) What is the biotic character of the portions of the site involved?
- 5) How will the project affect existing flora?
- 6) How will the project affect existing fauna?
- 7) How will the project influence the ecology of the various habitats?¹¹⁶
- 8) What information exists on the biota of the area?

By answering these questions and conducting field investigations, it is felt that adequate values may be entered into the compatibility index to evaluate the biotic communities present in areas of candidate sites.

B. Aquatic Ecology and Water Quality

The value of water resources lies in their natural function as aquatic ecosystems and their potential for use by man in all aspects of life.¹¹⁷ Destruction or degradation of these resources disrupts the balanced nature of aquatic life, which results in a loss of, or stress to, vegetation

and wildlife. It also limits man's opportunities of using a valuable natural resource. Therefore, it must be determined if the proposed project will have high, low or no compatibility with the sites aquatic ecology and water quality.

Degree of Compatibility X Weights

Component

High (2), Low (1), None (1) 1-4 = CI

A) Coastal Waters

1) Open sea	2
2) Estuaries	3
3) Bioluminescent waters	4
4) Mangrove swamps	3
5) Other tidal wetlands	3
6) Non-tidal wetlands	3
7) Riverine systems	3
8) Tidal creeks	3
9) Other surface waters	2

B) Water Quality

1) Temperature	4
2) Salinity	3
3) pH	2
4) Turbidity	3
5) Color	3
6) Odor	3
7) Dissolved oxygen	4
8) Heavy metals	3
9) Salt water intrusion	2
10) Nutrients	3
11) Runoff	2
12) Surface flow variations	2
13) Surface water quality	3
14) Groundwater quality	3
15) Groundwater quantity	3

C) Natural Features

(removal for commercial purposes)

1) Fish and crustaceans	4
2) Shellfish	4
3) Sand and Gravel	3
4) Algae	2
5) Oil and/or gas	2
6) Other minerals	1

Degree of Compatibility X Weights

Component

High (2), Low (1), None (0) 1-4 = CI

D) Aquatic Marine Life

1) Endangered species	4
2) Fish and crustaceans	3
3) Shellfish	3
4) Algae and other plants	2
5) Marine mammals	4
6) Corals	4
7) Mangrove communities	3
8) Invertebrates	2
9) Amphibians	2
10) Unique habitat	3
11) Breeding grounds	3
12) Nursery areas	3
13) Migration routes	3
14) Food source	3
15) Food chains	3

Total Compatibility Index (TCI) =

Rationale: Subcategory A, the coastal waters component, attempts to list all types of surface waters likely to be encountered at any of the candidate sites under evaluation. Because all candidate sites are located in coastal regions, the main focus of this portion of the evaluation was on aquatic marine waters. Although many of these water types have been eliminated in previous stages of the process, it is possible that small isolated types of these water bodies may be encountered. The assessment should be carried out by biological assessors through complete field investigations of the candidate sites. The water types are noted and mapped and compatibility is measured through the use of existing data on the types of impacts which may be expected. The values are then recorded in the compatibility matrix.

To conduct a water quality impact assessment, all applicable water quality criteria must be known. Water quality criteria is distinguished from standards as the levels of specific concentration of constituents which are expected, if not exceeded, to assure the suitability of water for specific uses.¹¹⁸ The activities which must be performed by water quality impact assessors must follow the general procedure described below:

- 1) Perform a preliminary review of the existing environment and the proposed project;
- 2) Select environmental indicators to be used for describing the environment and gauging the effects (see the compatibility index);
- 3) Describe the existing environment by providing quantitative descriptions of each indicator using existing data sources;
- 4) Conduct field sampling programs to complete the description of the environmental setting; and
- 5) Make predictions of the effects of project activities on water quality in the compatibility matrix.¹¹⁹

Subcategories C and D of this portion of the evaluation deal with the commercial exploitation of resources found in coastal waters and biotic assessment of marine life. Although an extremely important part of the evaluation -- the bulk of the work may be carried out through literature

searches and field surveys, as previously described. A large amount of literature is available on the impacts of coal facility construction and operation on marine communities.¹²⁰ Therefore, a detailed discussion of the methods which could be utilized were not presented in this procedure.

C. Air Quality

Maintaining the quality of air resources is a principal concern related to major facility development. Degradation of air quality may have adverse effects upon property, vegetation, wildlife and human health and well being. These concerns are particularly important for coal facilities. Even with the best control technology there is likely to be significant emissions associated with operation of coal plants.¹²¹ Air pollutant effects from coal fired facilities are likely to be strongest under adverse topographic and meteorological conditions.¹²² The power plant stack is a chimney designed to remove combustive gases and entrained particles from the plant area. The gases and particles are injected into the atmosphere, which causes dispersion. However, dispersion patterns of the plume may be affected by the topography of the surrounding area. Wind direction, velocity and mixing patterns caused by variations in the local topography may affect the ground-level concentration of pollutants. The primary influence of topography is, however, on the meteorological regime of the surrounding region.¹²³ The meteorology of the site ultimately determines the ground-level concentrations of the stack effluent. The worst case possible is an event

called plume fumigation. This event occurs when the stack gas plume is trapped at the bottom of an inversion layer. Stack gases mix downward rapidly fumigating the ground within the plume center.¹²⁴

In Puerto Rico, the meteorological regime is relatively consistent. Northeast trade winds usually blow from mid-morning to somewhere after sunset. Although local variations are possible, this regime is consistent enough to determine the net movement of the dispersed plume. For this reason, this portion of the evaluation identified elements of meteorology and topography which allowed for the best case for facility siting, or maximum plume dispersions, in the down-wind direction. Does the proposed project have high, low, or no compatibility with the following elements that provide for the sustenance of acceptable air quality for candidate sites?

Degree of Compatibility X Weights = CI

<u>Component</u>	High (2) Low (1) None (0)	1-4
A) Emission Scenarios		
1) Spatial distribution of sources		3
2) Types of pollutants emitted		3
3) Emission rate		3
4) Variation of emissions		3
B) Meteorological Scenario		
1) Local surface wind speed and direction		3
2) Local surface atmospheric stability		3

<u>Component</u>	Degree of Compatibility X Weights = CI			1-4
	High (2)	Low (1)	None (0)	
3) Mixing depths				3
4) Solar insulation				3
C) Topography				
1) Facility location in relation to topography				4
2) Hills and ridges				3
3) Valleys				3
4) Oceanic effects				3
D) Air Chemistry				3
E) Population Centers and recreation facilities				4

Total Compatibility Index (TCI) =

Rationale: The air quality impact of a new source may be evaluated through the use of models. Models simulate the relationships between air pollutant emissions and the resulting impact on air quality.¹²⁵ The input to the model include data concerning emissions, meteorology, and air chemistry, which are determined by formulating impact scenarios.¹²⁶ When pollutants are emitted into the atmosphere, they are immediately diluted, transported, and mixed with the surrounding air. The role of air quality modeling is to represent these processes mathematically. The models are mathematical formulations that simulate the dispersion process and calculate

the increase in concentration of pollutants due to emission from the facility. These models are designed to relate emissions of primary pollutants to the resulting air quality. The performance of the model will be dependent on the user, the input data, the model and its application. Therefore, the results will not be absolute. However, it is felt that these models will provide for some measure of comparison on the effects of coal facility siting, in different areas, on the Island of Puerto Rico.

D. Socio-economics

The construction and operation of a coal fired facility in Puerto Rico has the potential to exert serious socio-economic impacts on communities in or near the siting location. Some of these impacts may be positive such as increased employment and income.¹²⁷ However, negative impacts may also result. During the construction phase of the project, a boom and bust situation may arise. Large public investment may be required to provide services for workers who may leave the area before taxes have fully covered new investment costs. The magnitude of this effect is dependent upon the initial population of an area and on the adequacy of existing housing and services. Impacts may also be generated on the local population by workers who remain to operate the facility. As a local population grows, per-capita spending must also increase for public goods and services.¹²⁸ In addition, a major facility project may impose other costs on the community. Some of those impacts are easily quantified such as a start-

ling increase in inflation. Other costs, however, may be more difficult to quantify. Major changes in traditional lifestyles, increased traffic and congestion, and increased pollution may result. It is necessary to address these impacts so comparisons can be developed in the site selection process. The procedure to facilitate these comparisons is presented below: Does the proposed project have high, low, or no compatibility with the following socio-economic elements of the Island's environment?

		Degree of Compatibility X Weights = CI	
<u>Component</u>	High (2) Low (1) None (0)	1-4	
A) Demographics; size and composition of the local population.			
1) Construction phase		4	
2) Operational phase		3	
B) Economic, income and employment			
1) Rise in the level of total employment and income		3	
2) Distribution of changed employment and income		3	
3) Benefits accruing to local residents versus immigrants		3	
4) Utilization of underemployed persons		2	

Degree of Compatibility X Weights = CI

<u>Component</u>	High (2) Low (1) None (0)	1-4
5) Continued profitability of existing area employers		3
C) Community service use		
1) Health care facilities		3
2) Parks and recreation facilities		3
3) Schools		4
4) Police and fire protection		4
D) Fiscal impact		
1) General government costs		3
2) Public safety costs		3
3) Public works costs		2
4) Parks and recreation costs		3
E) Housing Impact		
1) Existence of adequate housing and rental units		3
F) Social well being and the quality of life		
1) Retention of normal/traditional pace of life		3

<u>Component</u>	Degree of Compatibility X Weights = CI			1-4
	High (2)	Low (1)	None (0)	
2) Lack of congestion and overcrowding				2
3) Price stability				3
4) Retention of life styles				3
5) Activities for immigrants				2

Total Compatibility Index (TCI) =

Rationale: There are three basic steps that must be followed to predict changes in the socio-economic environment and assessment of the impacts of these changes from coal facility siting.¹²⁹ The first step is to collect the pertinent data and information that will enable description of the environmental setting. This generally requires the use of various sources of information such as U.S. Bureau of Census Reports, government and planning agency data, chamber of commerce projections, local bank information, and research conducted at local universities. The next step is the identification of critical socio-economic factors (see the compatibility index) that are important to the local environments.¹³⁰ The third step involves the quantitative prediction of the changes which will result from a major facility being sited in the various environments.¹³¹ This may require conduction of polls and surveys regarding these potential impacts which will infer what consequences will result from the proposed development. This is generally a lengthy time-consuming exercise.

However, it results in values for the elements listed in the matrix which can then be used to compare candidate sites.

E. Aesthetics

Aesthetics may be described in terms of the uniqueness of elements in a field of view, the composition of those elements, and the viewers response to the view.¹³² Due to the highly perceptive and subjective nature of this factor, it is one of the more difficult categories of the environment to analyze and measure. However, aesthetics are an important consideration in energy facility siting particularly for an island, such as Puerto Rico, which is highly dependent on the tourist industry.

The aesthetic quality of a particular area may be degraded by substitutions, subtractors, and additions to the physical environment by facility construction and operational activities. Impacts may be temporary or permanent in nature. Permanent impact may be generated by building construction, roads, vegetative alterations and most prominently, the coal facility's stacks. Temporary or short term impacts may be generated by construction equipment and workmen on the site, as well as facilities for offices and storage. For the purposes of this assessment, permanent impacts will constitute the focus of this portion of the process. These types of aesthetic impacts are the most serious, and have the greatest probability of disrupting the visual environment. Does the proposed project have high, low or no compatibility with the following components of the aesthetic environment at candidate

sites?

Degree of Compatibility X Weights = CI

<u>Component</u>	High (2) Low (1) None (0)	1-4
A) Color		2
B) Texture		1
C) Water form features		3
D) Land form features		3
E) Vegetative features		2
F) Architectural features		2
G) Visual character		3
H) Landscape variety		2
I) Scale		3
J) Regional setting		2

Total Compatibility Index (TCI) =

Rationale: The method of aesthetic impact evaluation is composed of the following facts:

- 1) Identification of site related visual characteristics;
- 2) Identification of the visual characteristics of a 900 MWe coal facility;
- 3) Synthesis of the data recorded above to elicit public response to the probable changes which will result; and
- 4) Construction and utilization of a viewer survey to determine the degree of impact from siting activities.¹³³

The site and the project can be represented through the use of architectural drawings for the viewer survey. Each person surveyed should be asked to supply his or her visual preference rating for the proposed development and for the present appearance of the site. Each preference can be recorded by a five level rating system for the proposed devel-

opment and for the present appearance of the site. Each preference can be recorded by a five level rating system for the proposed development. Through surveys carried out at all candidate sites, it will be possible to determine the aesthetic compatibility with development and thereby a means of comparison when the values are recorded in the compatibility index.¹³⁴

F. Secondary Evaluation

When each of the five main categories have been evaluated, a TCI should be in place. This score represents the total weighted compatibility of the actual candidate sites under consideration. A second weighing factor must now be developed, for the five major categories, to represent the importance of a particular category in relation to the other five. In an actual site selection study the weighing factor should be calculated through multiattribute utility techniques. However, for the purpose of this study the author's judgment is the sole criteria utilized. Table X is an example of this exercise. The results of this procedure is a site compatibility index. For every candidate site under evaluation the total compatibility score is multiplied by the weighing factor which results in an adjusted total compatibility score. These scores are added and result in a SCI which will reflect the compatibility of siting a 900 MWe facility at a particular site and the attendant environment. From these scores, the optimal site for a 900 MWe facility in Puerto Rico may be chosen. This stage is the culmination of a lengthy ex-

TABLE X

CALCULATION OF WEIGHING FACTORS FOR THE
FIVE CATEGORIES UNDER EVALUATION

	(Weights 1-4)	Adjusted Total Com- patibility Index
1) Terrestrial Ecology (TCI)	X 2	=
2) Aquatic ecology water quality (TCI)	X 4	=
3) Air quality (TCI)	X 4	=
4) Socio-economics	X 3	=
5) Aesthetics (TCI)	X 1	=

(SCI) Site Compatibility Index =

clusionary and evaluation procedure. Although the site chosen will not be completely compatible with all environmental elements of a particular area, the site will meld into the environment with the greatest compatibility or least total impact.

VII CONCLUSIONS

The focus of this thesis has constituted the formulation of a siting procedure, for coal fired thermoelectric facilities, on the Island of Puerto Rico. Subsequently, an attempt was made to prove that a methodology could be developed, applicable to the Island, which would minimize ecological and social costs for potential sites for coal fired facilities. Ideally, the process culminates in the selection of the optimum site(s) for a 900 MWe facility. The thesis which has been developed, is found to be affirmative. Procedures have been formulated which in practice, will lead to the solution of the optimum site(s).

A primary goal of site selection is to quickly reduce the total geographic area under siting consideration. This allows for the identification of a number of "preferred areas" for a particular project. This provision allows a majority of the effort and resources, involved in site selection, to be concentrated on those areas most capable of supporting facility development, with a minimum of environmental costs. This goal is particularly important for island entities such as Puerto Rico and other Caribbean islands. These islands do not possess the physical or monetary resources to carry out financial and manpower intensive siting studies, compared to the continental U.S. It is extremely important to quickly reduce the total area under consideration so monies and time can be devoted to the evaluation of the most appropriate sites. Furthermore, it is equally important that the

site study is responsive to the island environment. The environmental problems of oceanic islands are particularly important because of the geographic constraint of size. Once the natural resources of an island are depleted, its population cannot seek new communities to enjoy fresh reserves for water, waste disposal and recreation. Because most oceanic islands are small, their residents perceive environmental change quickly. The lines of cause and effect are small and can be drawn with greater clarity than for similar areas on the mainland. Therefore, it is particularly important that facilities are located in ecologically sound sites. It is felt that the process designed here is responsive to these concerns.

Due to the short chains of cause and effect in island entities, it is equally important that siting procedures are fully documented. In the past, the principal site selection criteria for major facilities, generally was; engineering feasibility, and the cost of land. Ecologic and social concerns were typically the last criteria to be examined. As a result, heavy environmental damage has occurred in many areas of Puerto Rico and the United States. This fact contributed to increased environmental awareness in major facility development. For example, in Puerto Rico there are many environmental interest groups who are concerned with energy development. The author is aware of two; Amigos Del Ambiente and Mission Industrial who have both voiced their opinions over coal fired facility development on the Island. Groups

such as these have led to an increased role by private citizens and citizen groups in public policy decision, such as energy facility siting. It is extremely important that siting decisions are fully documented to justify the siting decision and maintain community support. Loss of support or negative public opinion can lead to costly delays, and/or deferment of entire projects. The procedures designed here are cognizant of this fact. The format is a step by step procedure which excludes areas in an incremental fashion. Substantive evidence is provided at each step to justify site choice and the methodology resulting in this choice. It is critical in the primary and secondary evaluation stages of this process to have substantive evidence because of the value judgments and weighted criteria which must be utilized. The advantage of this particular methodology is that the results are quantified. This allows easy comparisons and comprehension by those interested in the siting decision. This may expedite the siting process, and possibly reduce the need for costly litigation which occurs when a strict descriptive method of site choice is utilized.

The procedures developed here are also innovative in that they may be readily adapted to computer technologies. A facility siting problem is complex for several reasons. First, there are many objectives which must be optimized simultaneously. This makes it conceptually difficult from the analyst's perspective as well as the decision maker. The second complexity is the size of the problem. The evaluation of a broad

geographic unit, such as an island, in search of an optimum site for a particular project is a complex problem. Thirdly, the facility component-location relationship may create a large number of siting alternatives (i.e., the physical plant, on-site solid waste disposal, transmission routing). For those reasons it may be advantageous to meld the process with a computerized facility location model. A model of this type has been developed by Brookhaven National Laboratories which may be compatible with the procedure designed here.¹³⁵ The model selects locations, sizes, and types of facilities while considering ecologic and social criteria. The model designed at Brookhaven could be modified for the specialized requirements of oceanic islands which could lead to greater efficiency in site choice and data gathering and storage. Whether or not Puerto Rico has the capability of using such a system, however, is an open question.

The process designed here is also valuable because of its general applicability. Although the procedure has been designed specifically for a 900 MWe facility for Puerto Rico, it is not invariant. By modifying certain process elements, the model could be a valuable framework for other oceanic islands and possibly for locations on continental land masses.

In completing this thesis, it was discovered that a majority of the research conducted on facility siting either concentrated on singular aspects of siting problems or outlined the need for process development. It is imperative that processes be developed in the academic realm rather than leaving the task to energy companies. The only means in

which unbiased siting methodologies can be developed is through independent research. If the methodology used in site choice is biased, the optimum site for a particular facility will not be found. The system developed here is comprehensive and unbiased. It is also one of the only systems that allows for more than cursory treatment of social elements of facility siting. If implemented, it is felt this procedure will result in optimum site choices. However, it must be stressed that a process is only as good as the implementors who utilize it. If bias enters into process implementation, the optimum site will not be found. However, the procedures are designed to allow for public scrutiny of the methodology which will allow defects to be identified and thereby optimize site choice.

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