WET-PIT MINING IMPACT ASSESSMENT:
COASTAL ZONE OF PUERTO RICO

by

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SUMMARY

In Puerto Rico, coastal zone sand deposits are exploited basically to satisfy aggregate demand by the construction industry. Since availability of inland deposits above the water-table have been almost exhausted, mining practices have extended below this level, developing wet-pits. This study documents coastal zone wet-pit sand mining and examines the impacts of these operations on ecosystems and ground-water hydrology. Twenty wet-pit mining operations, at various stages of development, were identified. Three sites, representing different coastal ecological zones, were chosen for complete study. Mining history, land use, hydrology, geology, soils, flora and fauna are described for these sites. Flora and/or fauna are described for four additional sites. Among the findings, this study suggests that: 1) wet-pit mining locally affects ground-water hydrology by changing flow patterns, lowering ground-water levels on dune areas and displacing salt/fresh water interface; 2) backfill material used to restore the site will not severely alter the ground-water system as long as it has similar hydraulic properties as the original extracted sand; 3) mining processes directly affect the ecological succesion of plant and animal populations; 4) since restoration is not aimed towards the recovery or development of wildlife habitat there is a valuable loss of ecological environments. Recommendations to better evaluate extraction applications, understand the potentially adverse environmental effects of wet-pit mining and minimize coastal zone impacts are strongly suggested be applied.

RECOMMENDATIONS

In Puerto Rico, the emphasis on construction presses the aggregate production industry for continued supply of prime material. Coastal zone deposits are exploited to satisfy the demand for sand. Since availability of inland deposits above the water-table have been almost exhausted, mining practices have extended below this level. Because there exists a significant untapped sand reserve below the water-table, it is expected that future resource demand will require the mining of these deposits. Therefore, to: (1) better evaluate extraction applications, (2) understand the operation's potentially adverse environmental effects, and (3) minimize coastal zone impacts, the implementation of the following recommendations to sustain, modify or supplement current regulations are strongly suggested:

1. Pertinent application requirements for this type of operation should be formulated by an inter-disciplinary Puerto Rico Department of Natural Resources (PR DNR) committee and added to the existing mining regulation.

2. With the objective of evaluating site conditions for mining (resource availability and potential impact) the following should be required:

a. A detailed mining plan, outlining extraction, backfilling and restoration procedures;

b. A topographic map, preferably at a scale of 1:500 and with 0.5m contour intervals, with representative cross sections. The existing land levels, proposed mining and restoration levels should be clearly indicated;

c. Representative boring profiles with lithologic descriptions and water-table indications;

d. A hydrologic/hydraulic study of the proposed extraction site indicating potential changes in: regulatory (100YR) flood level, localized surface drainage, storm wave swash, and subsurface hydrology in response to the proposed mining and mitigation procedures;

e. Samples of the material to be mined and proposed for backfill with their respective hydraulic properties.

3. Simple monitoring wells should be installed in a site to observe ground-water conditions before, during and after mining.

4. Extractions below the water-table should keep a significant buffer zone from mangroves and dunes. Regions further inland from the coast are ecologically more appropiate for mining.

5. Systematic field evaluations should be conducted by trained personnel to verify operational procedures and enforce the established regulations.

6. As in similar extraction activities elsewhere (DuBois and Towle, 1985), pre and post mining site surveys and impact assessments should be required for all sites. The literature received offers guidelines for this purpose.

7. It is recommended that wet-pits be backfilled as a step towards reestablishing previous ground-water flow conditions. Backfill material used should have similar hydraulic properties as the original extracted sand in order to minimize distortion in ground-water flow patterns. Wet-pits should also be backfilled and the mining site restored for safety and land reclamation reasons. If wet-pits are to be left open, they should be managed to support wildlife and/or safe recreational environments.

8. The PR DNR should establish criteria to define restoration procedures according to projected land uses. Specific site evaluations should be conducted to determine the most appropiate final land levels compatible with future developments based on requirements of law and interagency agreements.

9. Restorations should meet among others, the following main objectives (Morrison, 1982):

a. Prevention or reduction of wind and water erosion;

b. Provision of food and cover for a variety of animal species;

c. Improvement of the visual or aesthetic quality through reforestation.

10. Due to the high cost and intended purpose of the Performance Bond, the PR DNR should take measures to execute the bonds to ensure steps for adequate restoration of extraction sites. Otherwise, this requirement results academic.

11. Monitoring should be continued in the active operations where test wells have been installed. This would provide additional data on ground-water behavior as mining progresses.

12. Findings from this study provide valuable information on coastal zone wet-pit mining impact. Systematic observations should be continued in order to compile a reliable data bank on potential and observed local environmental impacts. Evaluation of immediate, long-term, and cummulative effects can then be used to prepare technically and politically objective public policy stategies.

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1.0 INTRODUCTION

Puerto Rico's coastal zone, which has been defined to extend 1km inland (PR CMP, 1978), has historically been an important source of sand for use in the construction industry for several reasons:

Accessibility: Topographically low and level terrain facilitates road preparation and transportation. Low population density allows a certain flexibility in site choices.

Availability: Deposits occur in known accretional environments with economically attractive storage capacities and resource renewal potential.

Minimum Equipment Requirements: Loose, uncemented deposits (in most cases) facilitate removal, preparation and dispatching (often without a sifting or storage phase).

Cleanliness: Typically, coastal sand requires only simple sifting techniques for sorting, ranging from a wide fixed mesh to vibrating belt equipment. Water is not employed and there is no need for establishing sedimentation ponds.

Market: High sand quality (varied grain sizes, low $CaCO_3$ and humus content) makes it attractive for a wide range of uses that include: the preparation of cement mix, cement blocks and pipes, road asphalt and plastering sand.

Coastal sand mining takes place in the intertidal zone, dunes, backdune and areas further inland (Fig. 1). Mining procedures extend from simple hand shoveling into awaiting trucks to complex set-ups involving various types of heavy equipment. Large extraction operations focus mainly on the backdune zone and inland

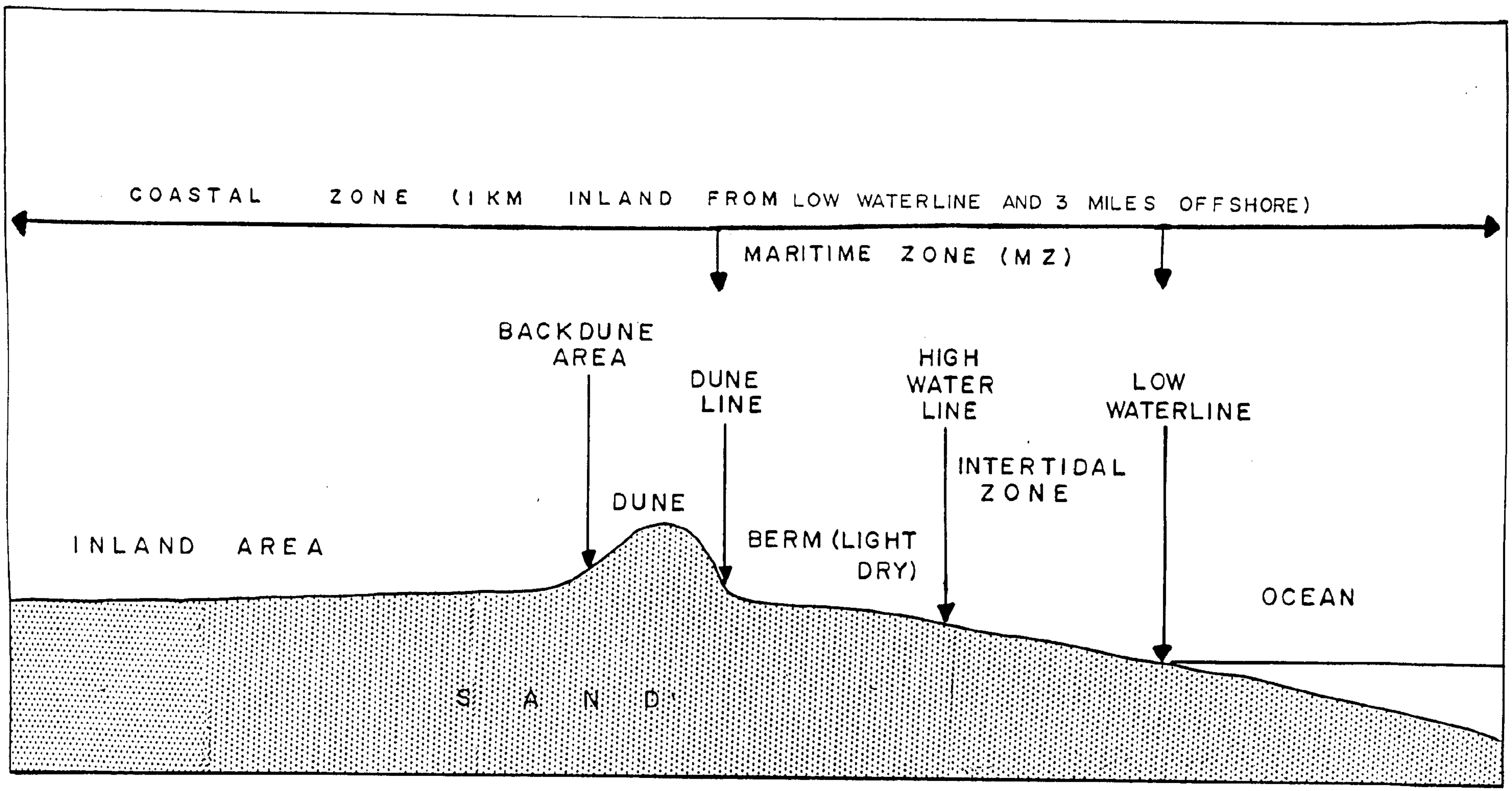


FIG.1. ANATOMY OF A TYPICAL BEACHFRONT WITH COASTAL AND MARITIME ZONE BOUNDARIES.

areas, and involve shallow surface scraping, up to one meter above the water-table, and open pit excavations up to four meters below the water-table (wet-pits).

The PR DNR is the government agency responsible for monitoring mining activities, among them sand extraction from the coastal zone. Direct supervision is rendered by personnel from one of the seven corresponding PR DNR regions. Time, experience and an increased awareness of the potential impacts generated by the mining process have permitted improvements in extraction techniques, methodologies, systematization of permit evaluations and the implementation of more detailed technical evaluation procedures. Nevertheless, these improvements have not been uniformly applied to all permit applications or active operations.

The economic value of the extraction industry in Puerto Rico has not been properly appraised. Complete data on the total quantity of materials mined to date from the island's tapped deposits, including those from the coastal zone, has not been compiled. Extractors are not required to report the actual amounts of sand mined, except when mining activities take place in public lands under the jurisdiction of the PR DNR (i.e. rivers, intertidal zone, submarine areas) in which case, a royalty to the government has to be paid. In particular, wet-pit operations focused in this study, are not subject to royalty payments. Therefore, a reliable total volume of sand mined each year from the coastal zone through wet-pit development is unavailable.

Historically, the short term economic gains associated with sand mining operations have generally overshadowed both short and long term environmental impacts. As a result, management approaches have been exploitive and have not properly integrated product demand, site selection and mining practices with limitations on the rate of resource replenishment and with potential environmental disturbances.

The magnitude of the environmental impact generated by wet-pit mining has not been systematically assessed. Continued inadequately quantified, managed and monitored extractions have resulted in substantial modifications of the coastal zone topography and ecologic balance. A review of the literature failed to identify a complete set of criteria that could be applied to mitigate negative environmental impacts resulting from wet-pit operations under local conditions. Very little background data exists about the impact of this activity on the coastal hydrologic and ecologic systems in Puerto Rico. The main points of diverse local studies are mentioned below.

The only field study that focuses on the possible impacts of sand scraping on ground-water flow was done by Zack (1983) for a site in Camuy. A battery of piezometers was installed bordering the Camuy mangrove to measure hydraulic gradients and salinity distribution. The author mentions that lowering of the sand dunes and inland areas altered the overland drainage to the forest, exposed the water table and promoted ponding. The study concludes that:

> "The removal of sand between the dunes and the Camuy mangrove probably affects the mangrove community only insofar as it has contributed to sand dune degradation. The effect that extraction has had on ground-water flow is minimal, and in itself, would not have been cause for concern with respect to maintenance of the mangrove community." (p. 20)

A brief theoretical report on the impact of wet-pit mining on ground-water was prepared by Vàzquez-Iñigo (1979). Based on the Ghyben-Herzberg Principle he concluded that since wet-pit mining is a superficial operation that does not alter the ground-water level, the location of the salt water-fresh water interface is not affected by this type of activity.

Soto (1982) evaluated the conditions of the beach strip fronting a wet-pit operation in the Añasco Bay (the site corresponds to pit #14 in the prepared inventory discussed later). He concluded that reducing the buffer zone between the maritime zone (MZ) and the operation from 50m to 6m would not have an adverse effect on the shoreline/coastal stability of the studied segment.

A geologic study that discusses mining methodology, availability of sand below the water-table and hydrologic characteristics of the sand to be mined and the limestone to be used for backfilling at a particular site was prepared by Vèlez (1983) (The site studied corresponds to pit #9 in the prepared inventory discussed later). This report constitutes, to the best of our knowledge, the first serious effort to compile the necessary technical information on which to base a sound permit decision. An interesting point made in this report is that results of a simple comparative test measuring permeability rates in the limestone and sand, showed that the in-situ limestone had a high permeability value that compared favorably with the sand.

At several potential mining sites test borings have aided the PR DNR to determine resource availability below the water-table. Findings (lithology and ground-water levels) have been included in reports incorporated in many of the case files.

In view of the need for information on mining impact and general technical guidelines applying to wet-pit sand mining in the coastal zone, the PR DNR Extraction Committee formally requested on March 14, 1985 that a study be undertaken.

Within this framework, the purpose of this task was to evaluate wet-pit operations to:

* Produce an island-wide inventory of extraction sites;
* Characterize abiotic and biotic aspects at selected mining sites;
* Compile a bibliography of relevant literature;
* Examine the criteria used by PR DNR for evaluating extraction sites, mining methods and restoration techniques;
* Produce a preliminary sand mining databank to aid in the technical decision making process;
* Describe the impacts of wet-pit mining on coastal hydrologic and ecologic systems; and
* Offer management alternatives to minimize adverse impacts on the island's coastal zone.

This report documents coastal zone wet-pit sand mining and examines the impacts of these operations on ecosystems and ground-water hydrology. Section 2.0 discusses the laws and regulations that apply to wet-pit mining. Mining processes and resulting impacts are described in section 3.0. The following two sections, 4.0 and 5.0, describe the methods used in this study, coastal wet-pit mining history and the criteria used to choose the sites discussed. General information, mining history, geology, soils, hydrology, flora and fauna for each of the monitoring sites is covered in section 6.0 and 7.0. Section 8.0 presents a discussion of mining impacts on wildlife habitat. The following section 9.0, lists a summary of findings and conclusions. Resulting recommendations from this task are included at the beginning of this report.

2.0 LEGAL ASPECTS

Prior to the creation of the PR DNR, the Puerto Rico Department of Public Works (PR DPW) regulated mining operations under the Sand, Gravel and Stone Act, Law No. 132 of June 25,1968. In 1972, by virtue of Law No. 23 of June 20, known as Organic Law, of the Department of Natural Resources, this responsibility was transferred to the newly created PR DNR. Later ammendments (Law No. 144 of June 3, 1976 and Law No. 54 of June 27, 1987) further modified Law No. 132.

In October 10, 1977 the Secretary of the PR DNR, under the authority conferred to him by Article XIX of Law No. 144, adopted a set of regulations on the extraction of materials from the Earth's crust. An ammendment to these regulations was approved on November 24, 1986. The purpose of these regulations is to:

> "...regulate the granting of permits for the extraction, excavation, removing and dredging of the components of the Earth's crust known as sand, gravel, stone, earth, silica, calcite, clay and any other similar component of the Earth's crust, that is not regulated as an economic mineral, in public and private lands, within the geographical boundaries of the Commonwealth of Puerto Rico." (Art. 1, PR DNR, 1978).

Unlike other mining activities, wet-pit mining involving backfill is not regulated. Specific provisions are listed only "In the cases where permission is requested for the excavation, removal or dredging of materials from the Earth's crust with the <u>express intention</u> of creating a pond or lake..." (Art. 6, PR DNR, 1978, emphasis ours). The only written reference authorizing extractions below the ground-water level implying the need to restore the area by backfilling and reforestation is through a "Note to the File" signed by the Earth's Crust Section Director on March 12, 1981 (Appendix I). This note includes specific provisions regarding application requirements and general technical procedures. Consequently, these procedures have been implemented as an intra-departmental norm.

The operational criteria for this type of extraction activity have been stipulated in the mining permits as Special Conditions and Limitations. They consist of particular mining methods and restoration procedures developed gradually through experience.

The extraction permit, signed by the Secretary or Authorized Person, legally binds the extractor to meet all the mining provisions (legal and technical) therein included. The Secretary is empowered to modify, suspend or revoke the permit if upon his judgement any of the permit clauses or provisions of applicable law are violated, or if the mining operation significantly altered the local environmental conditions (Art. 16, PR DNR, 1978).

By 1981 a special clause was being included in all wet-pit mining permits that stated that such authorization was subject to reevaluation once the PR DNR obtained the necessary data related to the impact of the mining process on the ecology and hydrology of the site. Depending on the conclusions reached, the PR DNR would decide whether to continue or suspend a given operation.

To guarantee the restoration of the extracted area, as stipulated in the extraction permit, a Performance Bond is required for all wet-pit operations. Although several mining sites have been abandoned without adequate restoration, as of this date the PR DNR has not executed a single Bond.

3.0 MINING PROCESSES AND IMPACTS

Process

According to mining procedures currently required by the PR DNR, sand extraction in the backdune zone and inland areas begins by using a front-end loader to remove material in a uniform manner, layer by layer, over the permitted work area. Using this scraping technique the maximum depth of operation, if not otherwise stated, is to 1m above the water-table or mean sea level (MSL), whichever is higher. The existing top soil is saved for later spreading during the restoration process. In most cases extractions must stay 50m away from the MZ, leaving a buffer zone where material cannot be mined or deposited. The width of this buffer zone may vary if a natural or man-made dune line exists, particularly if it falls within the dimensions established for remnant dunes (Width=10m, Height=8m, Slope=1H:1V, Art. 4, Sect. 4.2, PR DNR, 1978), or if a mangrove forest exists.

Further excavation develops a wet-pit, using a dragline to remove material from the bottom. Currently, the pits are allowed to have a maximum surface area of 2,000 m^2, preferably following a rectagular shape measuring 50m by 40m, though often the shape resulting from mining is irregular and awkward to measure. Pit depth is usually stipulated as not to exceed 4m.

Excavation pits have to be backfilled with approved materials at the end of the operation or simultaneously as the pits are moved within the site. The main criteria for backfill selection has been that it allow the free flow of interstitial water at all times. Authorized backfill material has ranged from limestone, solid fragments of igneous origin (e.g. granite, andesite, granodiorite) and/or serpentinite or volcanic sand, which may be combined with limestone, to a mixture of limestone and cement dust (with a 1:2 ratio, mixed previous to deposit). Other material may be presented to the PR DNR for consideration and approval. Although there have been pits almost completely backfilled with topsoil, this is not a desired practice for it signifies a waste of fertile material that should preferably be used for surface spreading and ground preparation for reforestation. In addition, even though illegal, construction debris and junk has been deposited in wet-pits, mainly with the idea of reducing the needed volume of authorized backfill; this lessens the cost of the backfill process, since adequate material often needs to be transported from a distant source.

Alternatives for the final elevation of the rehabilitated site include: (1) the pre-extraction land levels, (2) a minimum elevation of 1m above the water-table or MSL, or (3) adjustment to an intermediate elevation according to site characteristics. Option (1) has never been fully enforced. The usual practice has been to leave the sites lower than pre-extraction elevations, sometimes even below the 1m mark. In all cases, proper grading is required to allow adequate surface and subsurface drainage.

Areas potentially available for mining have in the past been divided into three equal parts and more recently, into portions of 5 cuerdas (4.85 acres or 19,615 m^2). Mining is authorized to begin in one lot at a time. Once the extraction in the first lot is near completion and most of the area backfilled, a technical inspection is conducted to determine if mining can continue into the adjacent lot. A complete restoration process consists of: 1) backfilling the wet-pit, 2) raising land levels, 3) uniformily distributing the original topsoil over the backfill, and 4) planting the disturbed area with local vegetation. Often restoration procedures stop, temporarily or permanently, at one of these stages.

Impact

Land preparation for mining in the coastal zone involves the total removal of existing vegetation. The land surface is often left exposed for months, representing a period of high vulnerability to surface erosion. As mining progresses, the backdune and inland topography become very uneven due to accumulation of processed and unprocessed material, continued scraping, and pit development.

Land perturbations due to mining can be distinguished in the field and from aerial photographs using the following identification criteria in comparison to adjacent terrain: (1) sparse and/or absent vegetation, (2) abrupt topographic changes such as sharp land cuts, depressions, and remnant uncut land, (3) signs of erosion and gully development, (4) wet-pits, (5) water ponding in low terrain, (6) piled material, (7) inland dune slope failure, and (8) machinery/processing plant.

The lowering of land levels by mining can increase flooding probability, particularly in already flood-prone areas, and may also result in long-term ponding. With respect to the issue of flooding, the Puerto Rico Planning Board (PR PB) has confirmed the applicability of Regulation No. 13 (PR PB, 1972) to mining permits. The PR PB state (Appendix II and III):

> 1) mining in areas identified as Flood-Zone 1 could be authorized if it is previously determined that such activity will not increase flood levels or velocity of the waters;
>
> 2) although normally, wet-pits do not reduce the hydraulic capacity of the area, a hydraulic analysis should be required for each potential mining site to show that mining will not alter the surface hydrology, forcing a reclassification of flood-zone susceptibility.

Some scraping operations have exceeded the maximum allowable depth, promoting temporary ponding when the water-table, usually directly controlled by tidal fluctuations, surfaces or when the high tide enters the lowlands. A case in point is located to the east of the urbanization Corales de Hatillo, north of Hwy #2 in the north coast. Indirectly, sites subject to these modifications become temporary wet-pits.

Several past sand extraction operations below the water-table have left open wet-pits. These areas that were not backfilled have become man-made lakes or ponds. Their current use varies from recreational purposes, as the northeast and northwest pits in Loiza (pits #2 and #3 in the prepared inventory discussed later) to areas of diverse wildlife sustenance, as in the northwest pit in Loiza.

4.0 METHODS

4.1 SITE SELECTION

An island-wide inventory of wet-pit extraction sites was prepared by means of a permit file search (Permits Office, PR DNR), conversations with past Permit Office directors and current employees, aerial photograph evaluations and field inspections of sites to verify information. From this pool of data the criteria to determine the type of study to be conducted for each site were formulated. Three sites were selected for detailed analysis and four for analysis of fauna and/or flora only. The remaining thirteen pits listed were subject only to the preliminary file inspection to determine applicability.

4.2 COMPLETE MONITORING SITES

Three sites representing different coastal ecological zones at different stages of the wet-pit mining process were chosen for detailed study. Pertinent permit files were thoroughly reviewed to become familiar with the peculiarities of each operation and to outline the site's mining history. Twelve field visits were made to each site between July 1987 and March 1988 for data collection. Surface photographs were taken to document site conditions.

Changes in land use and floristic composition were determined from aerial photographs corresponding to 1963, 1964, 1971, 1977, 1978, 1986 and 1987 at a scale of 1:20,000. Vegetation maps were prepared using some of these photographs to show the changes observed for each site before, during and after mining operations. The existing flora present in the extracted and undisturbed nearby areas was compared by means of vegetation profiles.

The biological study was limited to the most conspicuous macrofauna, vertebrate and invertebrate species found in both disturbed and undisturbed nearby areas. Bird count censuses were conducted by foot at dawn and dusk along predetermined transects. Field sightings were recorded to structure a species list for mammals, reptiles, amphibians, birds and crustaceans.

The United States Geological Survey, Water Resources Division (USGS WRD), conducted a hydrologic investigation of these sites to determine lithology, water quality, water levels, flow patterns and hydraulic properties of the shallow coastal aquifers. A total of sixteen test wells were drilled to depths ranging from 8.5ft (2.6m) to 37ft (11.3m); at least one well per site was installed near the open wet-pit and another in an undisturbed zone which served as control (according to site conditions at that time). The wells were monitored for changes in water levels and water quality from August to December 1987. Hydraulic tests (slug-injection) were completed in September 1987 to determine the hydraulic conductivity at each well site. Bathymetry and conductivity profiles were prepared for two of these wet-pits.

Site geology, soils, and susceptibility to flooding and the storm wave swash were described for each site using existing maps, field data and interpretation of drilling cores.

4.3 PARTIAL MONITORING SITES

Existing flora and/or fauna and land use were described for four open wet-pits, three of them in the same locality. Experimental fishing was done in one abandoned lake by members of the Marine Section, Scientific Investigation Area, PR DNR. Fish were sampled using a 275ft (83.82m) experimental gill net and a 50ft (15.24m) bag seine, kept in the water for 10.54 hrs. Three nets were located in the north part of the open-pit and three in the south. Captured fish were identified, measured, and weight. Three fishermen and residents were interviewed for fishing information.

4.3 LITERATURE SEARCH

Information related to wet-pit mining was requested from selected agencies and organizations both locally and outside Puerto Rico. A literature search was conducted through the Dialog Information Service via the University of Puerto Rico. All literature and documents received were analyzed and included in a bibliography list.

5.0. ISLAND-WIDE INVENTORY

Twenty open pit mining operations below the water-table, at various stages of development, were identified within the limits of the coastal zone. These have been geographically located and coded as described in Figure 2. Twelve operations (60%) have left abandoned open pits; three pits (15%) were backfilled; and five (25%) are active wet-pit operations (Table 1).

Prior to the establishment of the PR DNR in 1972, four operations of this type were authorized by the PR DPW in the municipality of Loiza. The sites have been identified in the field since the pits were left open and are clearly visible due to their size. They have been listed in the prepared inventory as pit numbers 2,3,4, and 5 (Table 1). Evidence of earlier extractions of this type were not found.

Towards the end of the 1970s the PR DNR began to authorize extractions below the water-table. During this time three permits were granted, distributed in three municipalities: Mayaguez, Loiza and Ponce (Carlos Santana and Leovigildo Vázquez, former directors of the Permits Office, pers. comm.). Because the Loiza pit is still open, its location was pinpointed using the 1977

FIG.2. INVENTORY MAP OF EXTRACTION SITES

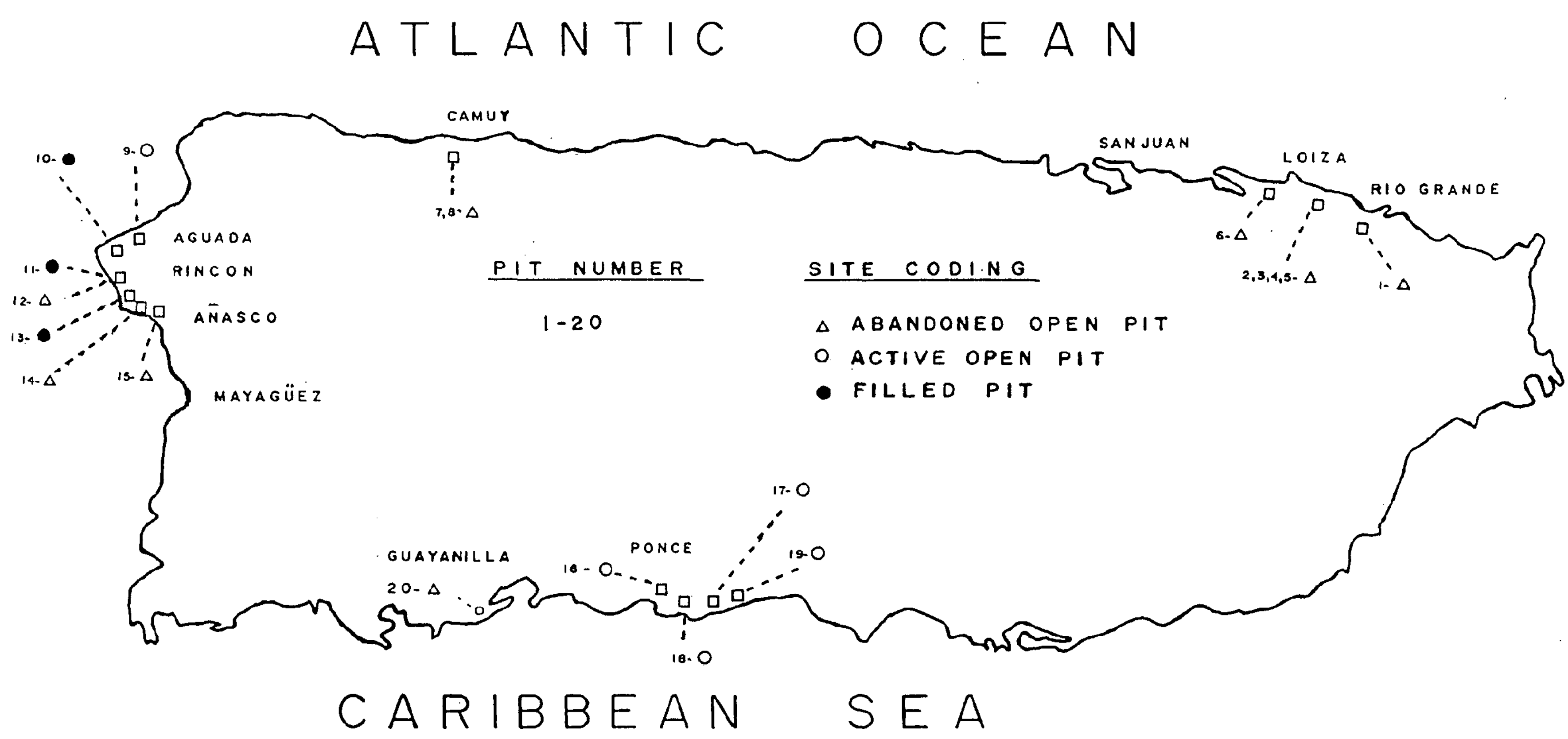


TABLE 1 - LIST OF INVENTORY SITES AND WET-PIT STATUS CODE (*)

PIT NUMBER	LOCATION	SELECTION CRITERIA(**)	TYPE OF STUDY
1 △	RIO GRANDE		FILE
2 △	LOIZA (NORTH-EAST PIT)	1.LOCATION (NORTH-EAST COAST) 2.ABANDONED OPEN PIT FOR APPROX. 20 YEARS 3.ADJACENT TO REMNANT DUNE 4.EXTREMELY LARGE AREA 5.RECREATIONAL USE	FLORA, FAUNA AND USES FILE NOT AVAILABLE
3 △	LOIZA (NORTH-WEST PIT)	1.CURRENTLY BEING USED FOR RECREATIONAL PURPOSES 2.WILDLIFE HABITAT (ENDANGERED AND PROTECTED SPECIES OBSERVED)	FLORA, FAUNA AND USES FILE NOT AVAILABLE
4 △	LOIZA (SOUTH PIT)		FLORA FILE NOT AVAILABLE
5 △	LOIZA (MOST SOUTHERN PIT)		FILE NOT AVAILABLE
6 △	LOIZA (PIT SOUTH OF LOIZA WASTE TREATMENT PLANT)		FILE NOT AVAILABLE

TABLE 1 (CONT.)

PIT NUMBER	LOCATION	SELECTION CRITERIA(**)	TYPE OF STUDY
7△	CAMUY (EAST PIT)	1.LOCATION (NORTH COAST) 2.ABANDONED OPEN PIT 3.FILLED PIT 4.TYPE OF BACKFILL MATERIAL (CRUSHED LIMESTONE) 5.ADJACENT TO UNMINED AREA, PROVIDING A POSSIBLE CONTROL SITE	DETAILED (***)
8△	CAMUY (WEST PIT)		FLORA
9○	AGUADA	1.LOCATION (WEST COAST) 2.ACTIVE OPEN PIT BEING BACKFILLED 3.TYPE OF BACK FILL MATERIAL (LIMESTONE) 4.UNMINED AREAS PROVIDING DETAILED COMPARISON INFORMATION	DETAILED (***)
10●	RINCON		FILE
11●	ANASCO		FILE
12△	ANASCO		FILE
13●	ANASCO		FILE
14△	ANASCO		FILE
15△	ANASCO		FILE

TABLE 1 (CONT.)

PIT NUMBER	LOCATION	SELECTION CRITERIA(**)	TYPE OF STUDY
16 ○	PONCE	1.LOCATION (SOUTH COAST) 2.ACTIVE OPEN PIT WITH BACKFILL IN PROGRESS 3.TYPE OF BACKFILL MATERIAL (CRUSHED SERPENTINITE AND LIMESTONE, CEMENT POWDER, CONSTRUCTION DEBRIS, SOLID GARBAGE, JUNK) 4.ADJACENT TO SEA, MANGROVE AND SALT FLATS 5.EXTRACTION AND PROCESSING SITE IN WETLAND AREA	DETAILED (***)
17 ○	PONCE		FILE
18 ○	PONCE		FILE
19 ○	PONCE		FILE
20 △	GUAYANILLA		FILE NOT AVAILABLE

(*) STATUS CODES: △ Abandoned Wet-Pit (Open)

○ Active Wet-Pit

● Filled Pit

(**) APPLIES TO SITES SELECTED FOR INDIVIDUAL MONITORING

(***) SEE APPENDIX IV

aerial photograph and corroborated to exist within the limits of the coastal zone. This pit has been identified as pit #6 in the prepared inventory. Case files for the Mayaguez and Ponce operations were not found to verify their exact locations or if they occurred within the coastal zone limits. Therefore, they were not included in the prepared inventory.

In the decade of the 1980s there was an increased interest in mining the sand deposits available below the water-table. Twelve (60%) of the extractions identified in this study were granted during this decade (Table 2). Mining operations have concentrated in the northwest coast, which could be explained by the following reasons:

Geology: The best sand deposits for construction purposes are of non-organic terrigenous origin; these have been widely distributed along the north-northwest coast. The deposits on the south are more saline and have a higher content of organic matter, making them less suitable for construction purposes.

Extractor: Most of the extractors that mined the island's surface sand deposits (e.g. dunes and inland areas) were located in the northwest area. Once these reserves were depleted, many extractors invested in the development of subsurface deposits.

Development: Many of the subsurface sand deposits that could have been exploited are no longer accessible due to the urban expansion. In other areas, private land owners have shown greater interest in urban developments rather than mining.

TABLE 2 - FIRST PERMIT DATE AUTHORIZING WET-PIT EXTRACTION

PIT NUMBER	FIRST PERMIT DATE
1	1983
2	*DECADE OF 1960
3	"
4	"
5	"
6	*BETWEEN 1972-77
7	1979
8	1981
9	1983
10	1985
11	1983
12	1982
13	1983
14	1982
15	1981
16	1978
17	1987
18	1987
19	1987
20	*DECADE OF 1970

(*) File not available

The three cases selected for detailed study, as outlined in Appendix IV, correspond to pit numbers: 7 (Camuy), 9 (Aguada) and 16 (Ponce) (Figure 3). Selection criteria was based on geographical location, operational status, type of backfill material used, size of mining area, existence of ecologically important systems in or nearby the extraction site representative of each area and proximity of unmined areas providing comparative information (Table 1).

Land uses, flora and/or fauna were outlined for pits #2,3 and 4 in Loiza. Vegetation changes are illustrated for pit #8 in Camuy. The selection criteria for these pits are described in Table 1. A study file of each of the remaining pits was prepared to obtain relevant permit information.

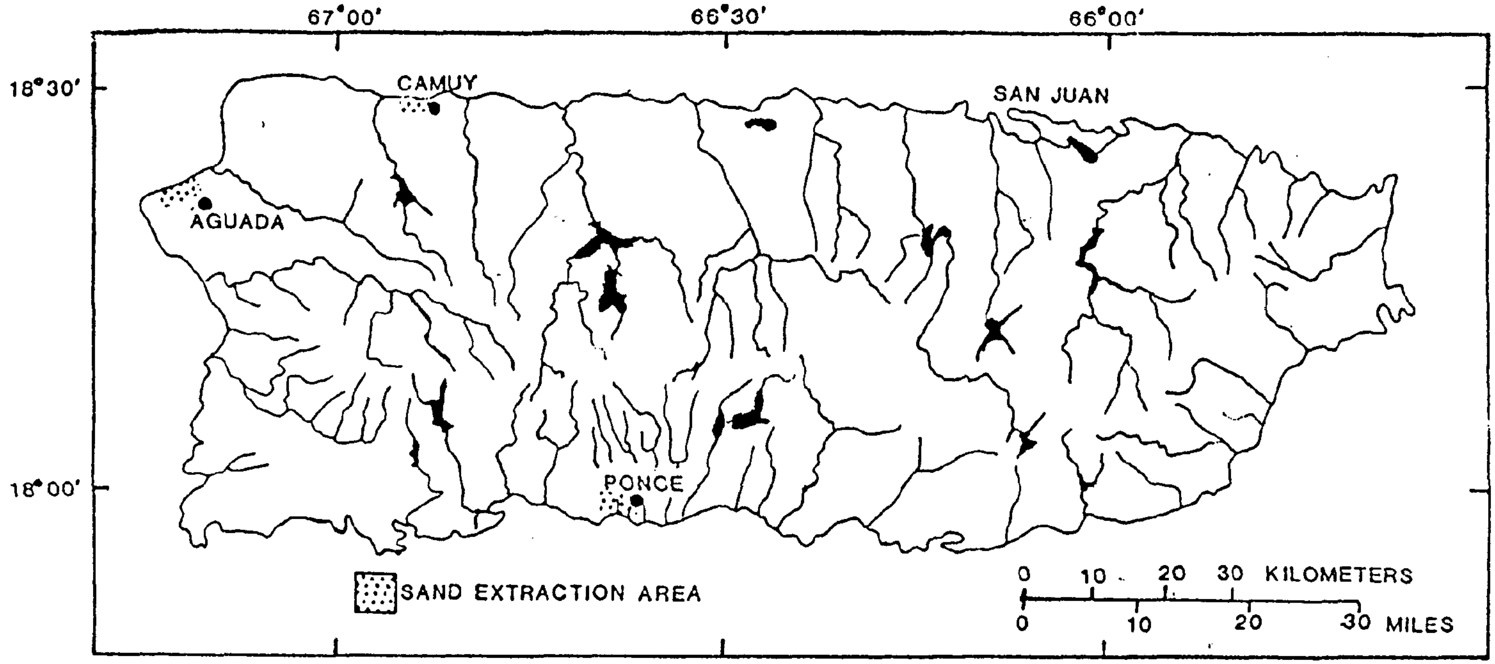


FIG.3. LOCATION OF SAND EXTRACTION SITES

6.0 COMPLETE MONITORING SITES

6.1 CAMUY

6.1.1 GENERAL INFORMATION

MUNICIPALITY: Camuy

PR DNR REGION: Arecibo

TOPOGRAPHIC MAP: Camuy Quadrangle (Fig. 4)

SITE ACCESS: Road PR-485, Km. 2.2, Bo. Membrillo

PIT NUMBER: 7 (Photo 1a)

PIT CODE: △ Abandoned Open Pit

APPROX. EXTRACTED AREA (*): 66, 793 m^2 (17 cuerdas)

AVERAGE DISTANCE FROM: MZ (*): 80 m

APPROX. SIZE OF PIT (*): 1,964 m^2 (0.5 cuerdas)

PIT DEPTH:
Max.: N/A
Min.: N/A

TYPE OF BACKFILL: Limestone, sand, topsoil

RESTORATION STAGE: Incomplete backfill Natural succession revegetation

ECOSYSTEMS:

Pre-mining: Hay fields, Coconut groves

Post-mining: Seasonal marsh, herbaceous swamp, coastal thicket

FLOODING SUSCEPTIBILITY (**): None

STORM WAVE SWASH: Not available

(*) Source: January 1987 aerial photograph
(**) Source: FEMA (1978)

6.1.2 MINING HISTORY

The date that extraction began is unknown, but file records indicate that by 1977 this area was being scraped. Towards the end of 1978 land levels were below that of PR-485 (access road), the water-table had been reached, and ponding was evident. In January 1979 mining was authorized to extend 3m below the water-table with a maximum wet-pit area of 25m by 25m. A 10m buffer zone was required from the axis of PR-485. The type of backfill material to be used and the final land elevations were not specified in the permit.

A January 1980 file report indicates that the area had been backfilled only up to the water-table, leaving a depression that to the south and north of PR-485 was about 6m and 3m, respectively, below its elevation. The preocupation of possible permanent ponding was brought to the attention of the Permit's Office.

In February 1980 a new permit was issued for a contiguous area to the south of PR-485. This permit did not authorize mining below the water-table and the extraction area was not allowed to be larger than 60m by 40m. This area was to be backfilled to land levels existing prior to this permit, calculated to average 2.0m above MSL. During the rest of this year several file reports mention that the area being extracted exceeded that authorized by the permit and that, in addition, restoration had not begun. On February 1981 the Department authorized mining to 3m below the water-table in this area; the pit area and backfill requirements stayed as previously described.

Later file reports indicate that backfill material was obtained from the limestone hills found to the south of the extracted site. Although, a large portion of the mined area had been restored, a wet-pit remained open.

A new permit sustaining the authorization to mine 3m below the water-table was issued on August 1981. The wet-pit surface area was not to exceed $900m^2$. The type of backfill to be used continued not to be specified. It was not until a permit signed in February 1983 that a backfill clause was included specifying possible fill material.

By September-November 1982 mining had ceased but the wet-pit remained open, measuring 30m by 40m. Salinity tests in the pits suggested saline conditions. In October 1983 mining was resumed; the allowable pit area was increased to 1,800 m^2. A July 1984 file report indicates that the open pit had a surface area of 2,050 m^2. On June 1985, based on recommendations emmitted by the Extraction Committee in May 1985, an additional permit was denied based on failure to appear at hearings held in the PR DNR to review permit violations. Since that date no mining has taken place. Currently, there exists an open pit in the east section of the site; the restored extraction area (to the west of the open pit and south of PR-485) is about 5 to 6 meters below the access road, PR-485.

6.1.3 GEOLOGY AND SOILS

According to Monroe (1963) the sand deposits mined in this site correspond to the Blanket sand deposits (Qbs) of Quaternary (Pleistocene) age that overlay the Camuy Formation (Fig. 5). This deposit consists of fine to coarse ferruginuous quartz sand; some of the material may be residual and slightly reworked sand derived from the upper member of the Camuy Fm. and from eolianite; some may have been blown inland from the beaches and recent dunes.

The limestone fill was obtained from the nearby hills identified as the Upper member of the Camuy Formation (Tcu) of Tertiary (Miocene) age (Monroe, 1963). This member is described to consist of chalk, sandy chalk, sandy limestone, sandstone, and very fine grained, powdery dolomite. Only the non-sandy parts of the member outcrop in the site quarry; it consists of white to orange chalk and limestone with abundant fossils; also, contains very finely cristalline, powdery limestone (Fig. 5).

The Soil Conservation Service (1982) has defined the following soil units found in the mined area (Fig. 5):

TP- Tropopsamments, hummocky. Deep, sloping, excessively drained sandy soils on ridges and small hills along the coast. These soils have very rapid permeability, and very low available water capacity. Runoff is very slow and the level of natural fertility is very low. Reaction is mildly alkaline to moderately alkaline throughout. Some areas of the unit are suitable as a source of sand for construction. Generally unsuited for farming.

RIC- Rio Lajas sand. Deep, gently sloping to sloping, somewhat excessively drained. It is in small valleys and on undulating hills on the coastal plains. Permeability of this soil is rapid, and the available water capacity is very low. Runoff is slow to medium. Natural fertility is low. Good roadfill, contains significant amounts of sand. Good topsoil. This soil is well suited for such pasture plants as stargrass, pangolagrass, and merkergrass. Mainly used for sweet potatoes, cassavas, and pigeon peas. Some small areas are in coconuts and tobacco. Crops on this soil respond to fertilizer applications.

6.1.4 HYDROLOGY

Six test wells were drilled in this site to gather lithologic, water quality, and water-level data. "Slug" injection tests were performed in all wells to determine relative hydraulic conductivities and/or transmissivities of the site. Well distribution, methodology, results of tests and well monitoring are described and summarized in tables and figures in Appendix V.

Test wells number 6, 7, 9, and 10 were drilled in backfilled areas. Test well number 11 was installed in an unmined area.

6.1.5 FLORA

In 1963, prior to the begining of mining, most of the upland site was dedicated to agriculture (hay fields) (Fig. 6, 7c). Other existing vegetation consisted of coconut palm groves located along the north end of the study site between Road PR-485 and cultivated lands (Fig. 6). These areas were later subjected to mining.

A semi-evergreen seasonal forest, located on the nearby limestone hills, was disturbed by mining. The extracted material was used for partial backfill of the areas subject to sand extraction.

The aerial photo of January 1977 showed changes in cover distribution and plant associations due to sand scraping operations (Fig. 6). Sparse pioneer vegetation covered the extraction area, surrounded by a coastal thicket association (Fig. 6, 7a, 7b). This vegetation replaced part of the coconut groves and the hay monoculture that existed in 1963.

Between 1977 and 1987 considerable changes occurred in the study site and nearby areas (Fig. 6). The aerial photo of 1987 indicated the existence of four distinct community types corresponding to site topography and hydrologic zones: Open water (abandoned open pits; photo 1b), seasonal marsh (photo 1c), coastal thicket (photo 1d,1e), and herbaceous swamp (photo 1f). In addition, the aerial photo showed two barren land sections: one of them was an area corresponding to a filled wet-pit and the other to a limestone quarry. Findings from several surveys conducted during July 1987, February and March 1988, indicate that these conditions still exist.

CAMUY: PLANT SPECIES ADJACENT TO THE MINING AREA

I. Sand dune vegetation

Achryranthese aspera var. *aspera*

Bidens pilosa

Canavalia maritima

Chamaesyce buxifolia

Coccoloba uvifera

Ipomoea pes-caprae

I. stolonifera

Mariscus peduticulatus

Remirea maritima

Scveola plumieri

Spartina patens

Sporobolus virginicus

Trephrosia cinerea

Wedelia trilobata

II. Monoculture

Panicum sp.

CAMUY: PLANT SPECIES IN THE MINING AREA

I. Seasonal Marsh

Aeschynomene sensitiva

Cyperus liguralis

Lippia nodiflora

Sesbania sericea

II. Coastal thicket

Aeschynomene sensitiva

Bidens alba

Canavalia maritima

Chamaesyce orbifolia

Commelina diffusa

Cyperus ligularis

Ipomoea pes-caprae

Leucaena pallida

Lippia nodiflora

Ludwigia octovalvis

Mimosa pudica

Neptunia plena

Pavonia spicata

Pennicetum purpureum

Sesbania sericea

Stachytarpheta jamaicensis

Thunbergia alata

III. Herbaceous swamp

Typha dominguensis

6.1.6 FAUNA

Sixteen species representing four animal groups were recorded for this site during July 1987 and January 1988.

Amphibians, reptiles and mammals were found throughout the extracted site. Bird use of this site was limited to roosting and probably feeding. Only one avian species (common gallinule) used the wet-pit for nesting. Two chicks of this species and one adult were observed during the survey.

CAMUY: FAUNA OBSERVED

Amphibia

Bufo marinus
Leptodactylus albilabris

Reptilia

Ameiva exsul
Anolis pulchellus

Aves

Coereba flaveola	*Mimus poliglottos*
Columbina passerina	*Myiarchus antillarum* (Endemic)
Falco sparverius	*Petrochelidon fulva*
Gallinula chloropus	*Quiscalus niger*

Mammalia

Herpestes auropuntatus

Mus musculus

Rattus norvegicus

R. rattus

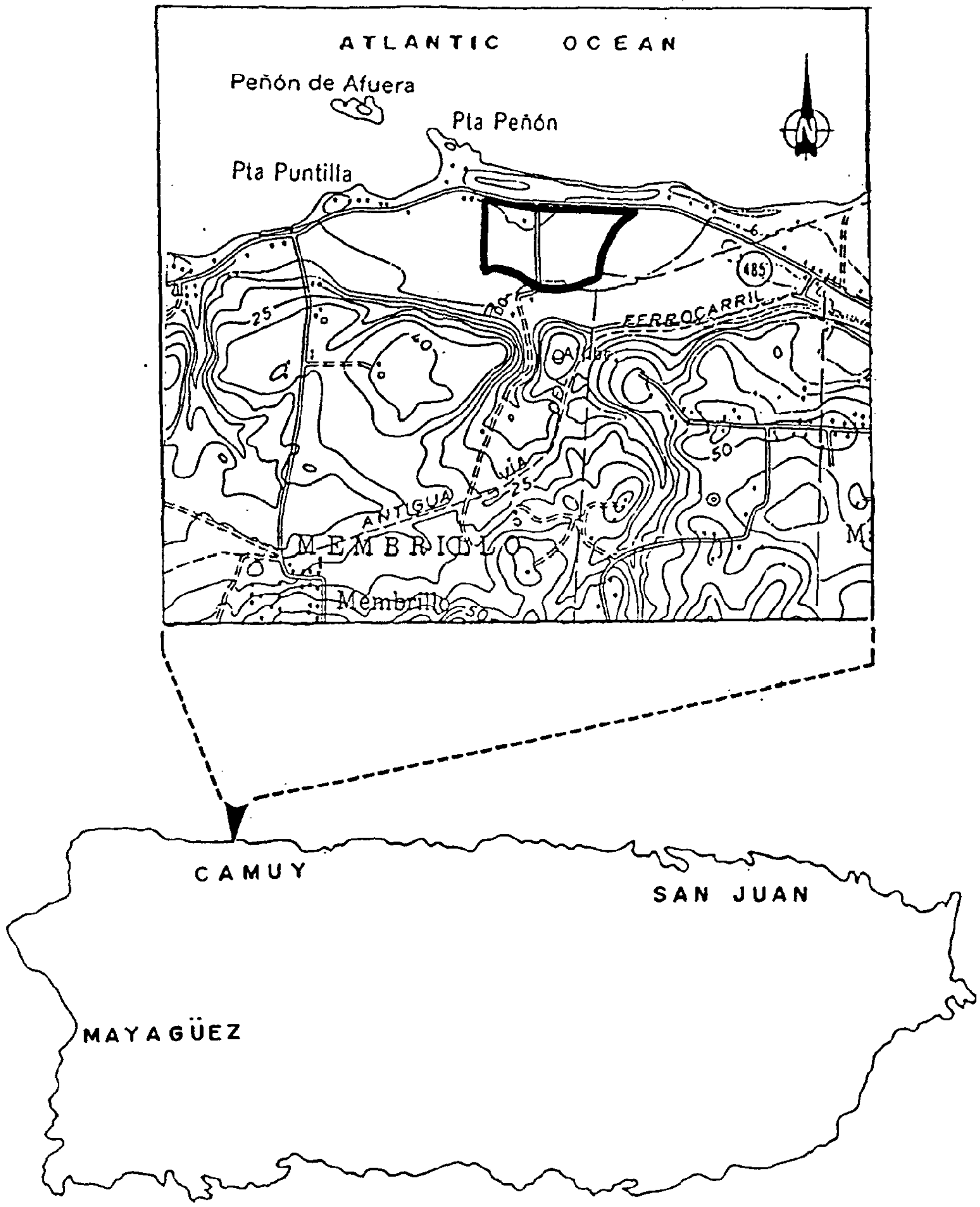
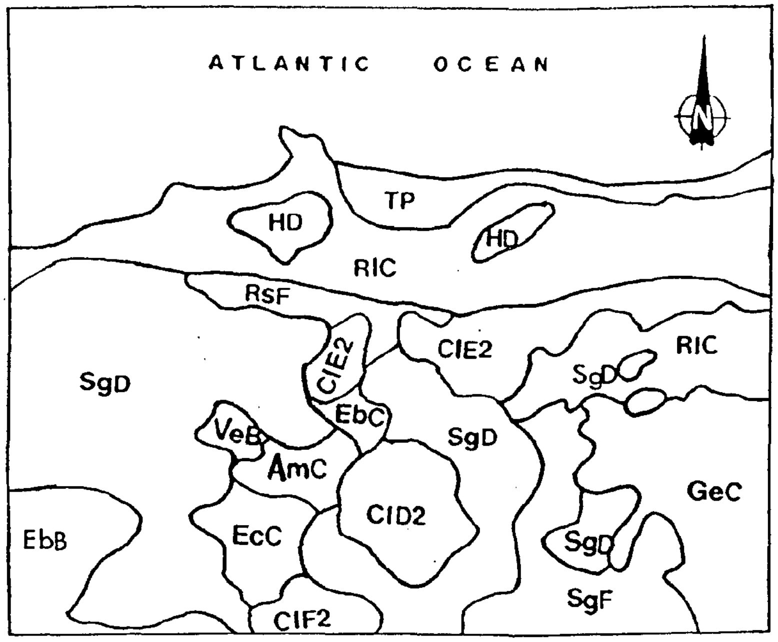
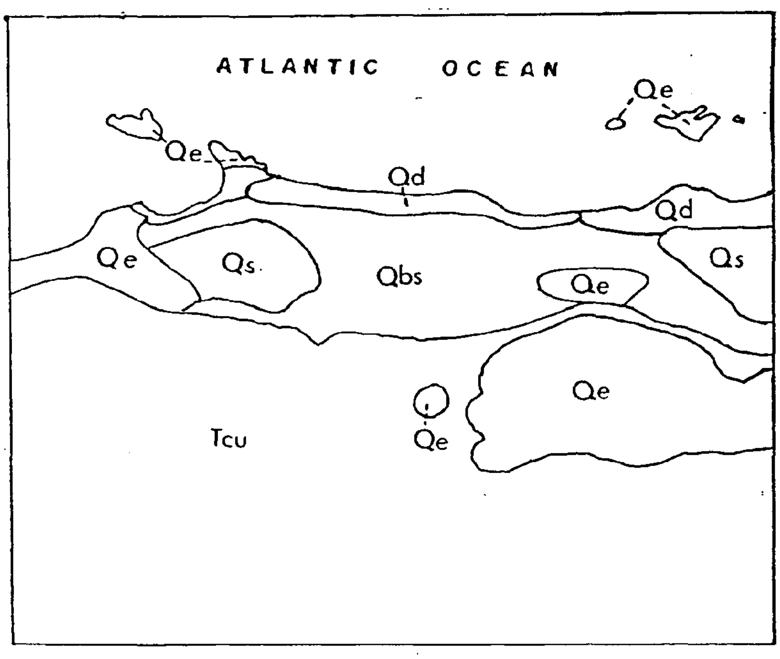


FIG.4. LOCATION OF CAMUY SITE (PIT NO. 7)
(U.S.G.S. 1972.)



SOIL MAP OF CAMUY SITE (PIT NO. 7)



GEOLOGIC MAP OF CAMUY SITE (PIT NO. 7)

FIG.5. SOIL AND GEOLOGIC MAPS OF CAMUY SITE.
(S.C.S. 1982; Monroe, W.H. 1963.)
(Key to symbols: Appendix VI)

FIG.6. VEGETATION MAP OF CAMUY SITE

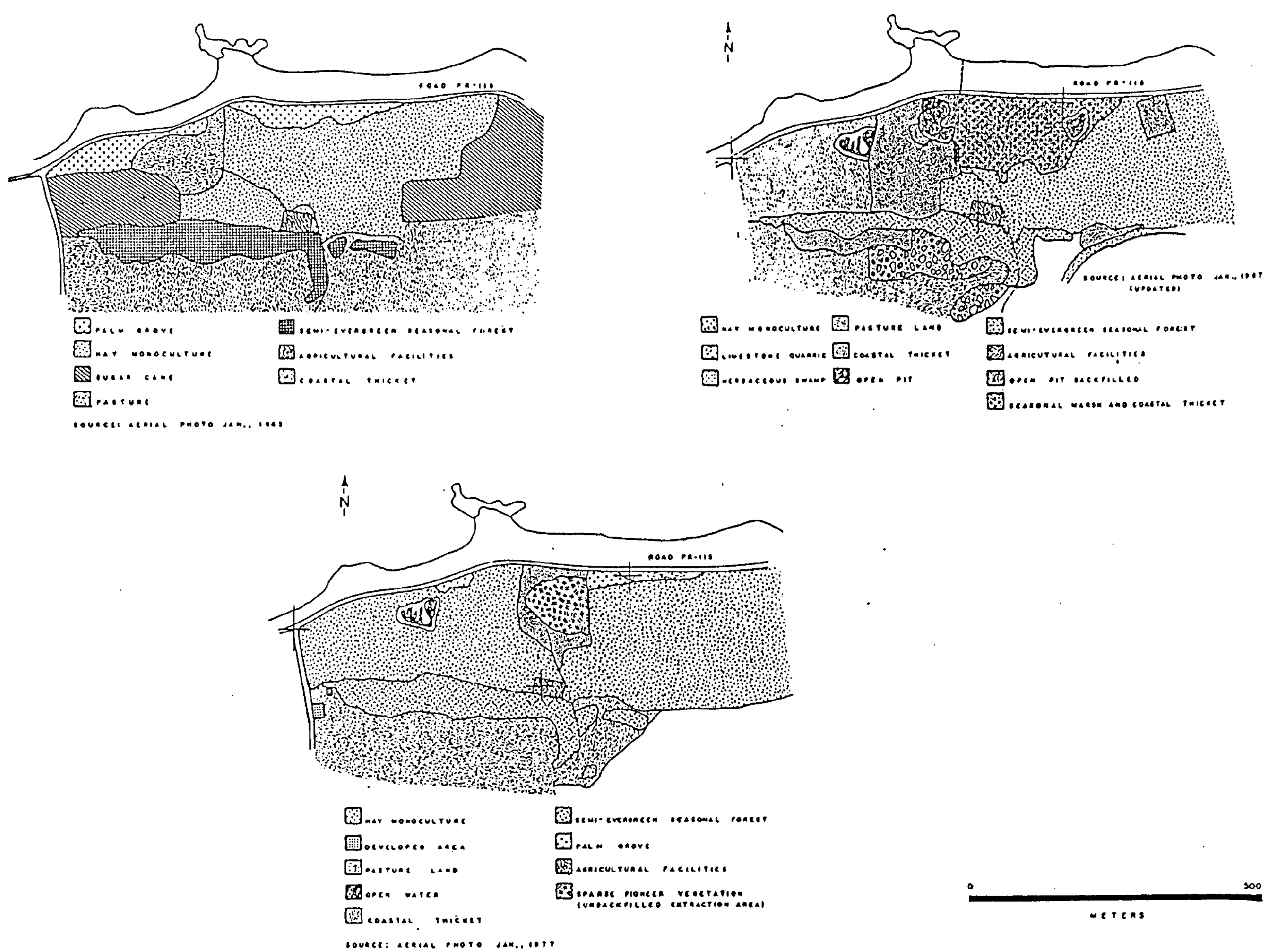


FIG. 7. CROSS SECTION ILLUSTRATING CHANGES IN PLANT ASSOCIATION AT CAMUY SITE.

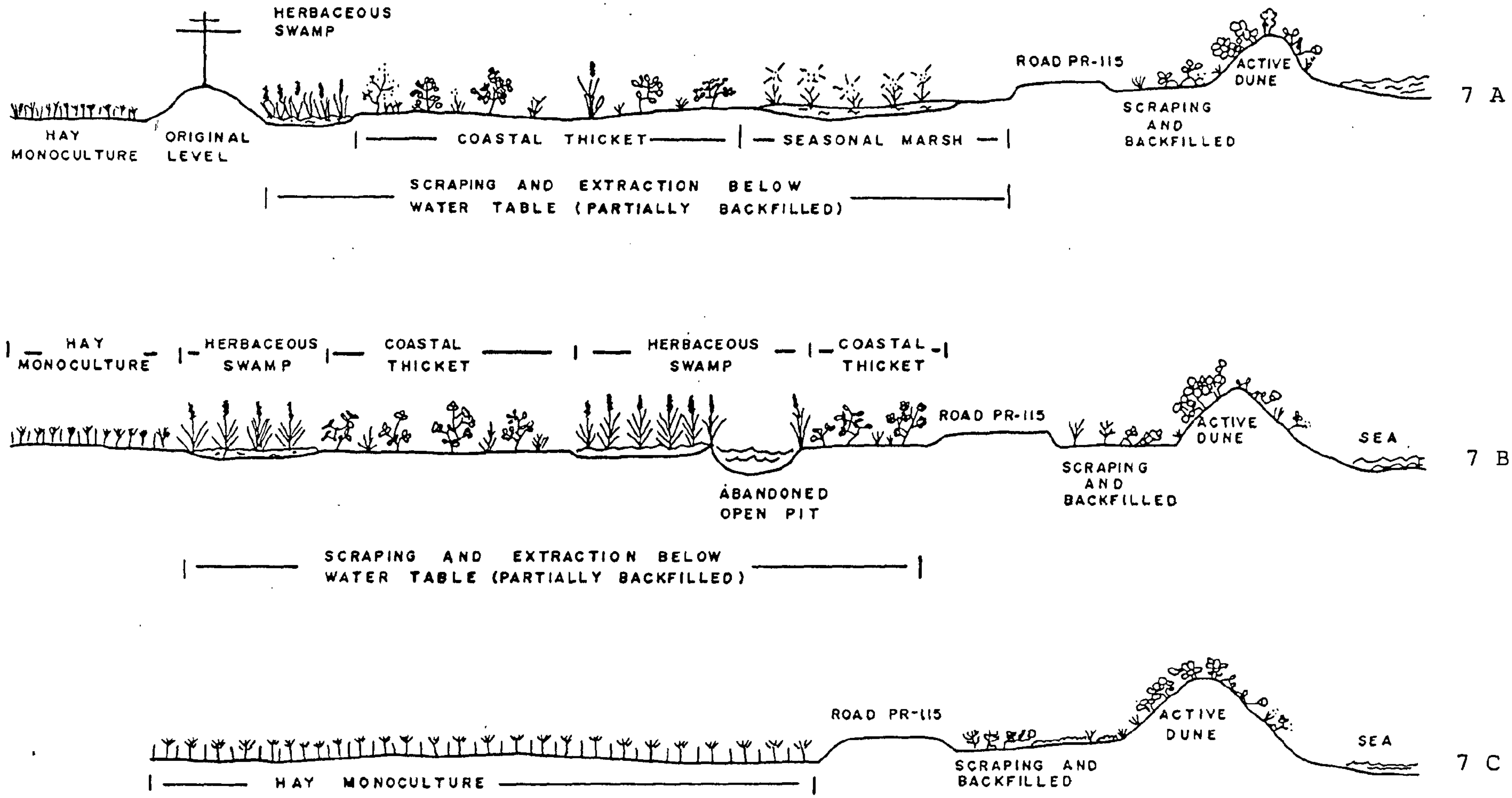


Photo 1a - Camuy site (Pit #7). Panoramic view towards the northwest. Abandoned wet-pit is seen in the background, to the right.

Photo 1b - Partial view towards the southeast.
Abandoned wet-pit found in the northeast portion of the site; a herbaceous swamp surrounds the wet-pit.

Photo 1c - Partial view towards the northwest. Seasonal marsh developed in part of the extracted area. Access Road PR-485 is located on top of higher terrain seen in the background.

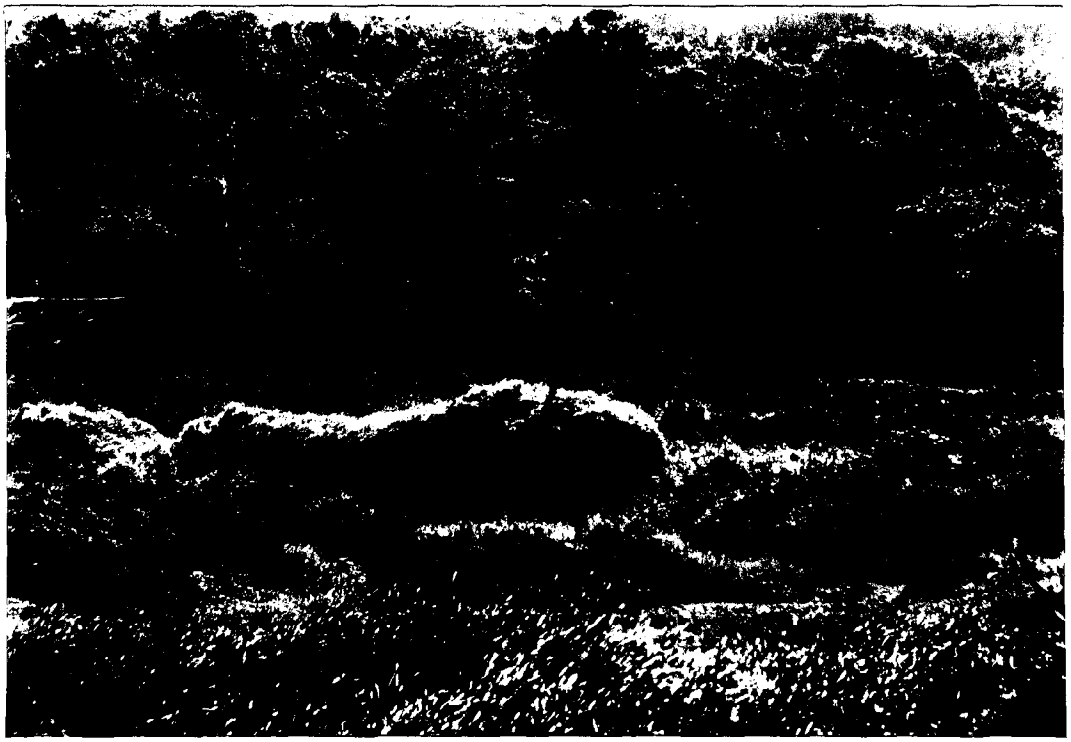


Photo 1d - Partial view towards the southwest. Coastal thicket and herbaceous swamp developed in part of the extracted area.

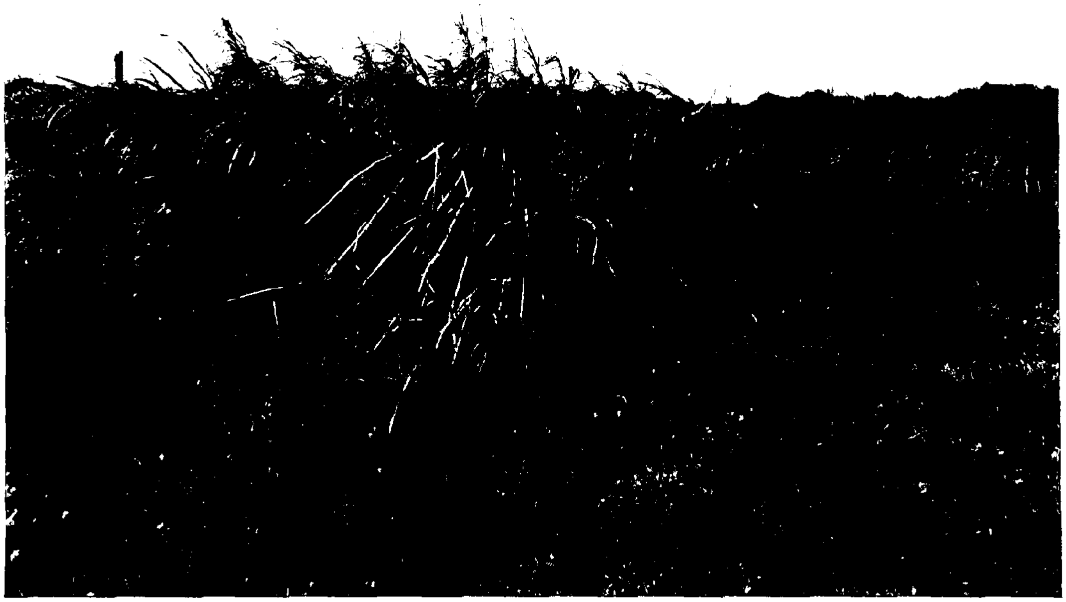


Photo le - Partial view towards the northeast
Coastal thicket developed in part of
extracted area.

Photo 1f - Partial view towards the southeast.
In the foreground, a herbaceous swamp
developed next to the abandoned wet-pit.

6.2 AGUADA

6.2.1 GENERAL INFORMATION

MUNICIPALITY: Aguada

PR DNR REGION: Aguadilla

TOPOGRAPHIC MAP: Aguadilla Quadrangle (Fig. 8)

SITE ACCESS: Road PR-115, Km. 17.0, Bo. Río Grande

PIT NUMBER: 9 (Photo 2a)

PIT CODE: O Active Open Pit

APPROX. EXTRACTED AREA (*) : 141,444m² (36 cuerdas)

AVERAGE DISTANCE FROM:
MZ (*) : 200m
Río Grande de Aguada: 20m

APPROX. SIZE OF PIT (*) 7,858m² (2 cuerdas)

PIT DEPTH (**):
Max.: 2.3m
Min.: 1.6m

TYPE OF BACKFILL: Limestone

RESTORATION STAGE: In process

ECOSYSTEMS AND USES:

Pre-mining: Sand dune vegetation, palm grove

Transitional: Sparse pioneer vegetation, open water

Post-mining: Barren land

FLOODING SUSCEPTIBILITY (***): Within the 100YR floodplain

STORM WAVE SWASH: Not Documented

(*) Source: January 21, 1987 aerial photograph
(**) Source: Field measurements (not adjusted to MSL)(Appendix V, Figure 22)
(***) Source: FEMA (1982)

6.2.2 MINING HISTORY

As mentioned earlier, Vèlez (1983) discussed in a preliminary geologic study the mining metholody, availability of sand below the water-table and hydrologic characteristics of the sand and limestone to be used for backfilling in this area. This information served as a useful tool during the permit evaluation period.

On May 1984 a three year permit was signed that included specific clauses for sand and limestone mining; the latter to be obtained from hills to the southeast of the sand extraction site. Among the required clauses, the extraction was to keep a 50m buffer zone from the Rìo Grande, to the west, and a 20m distance from the MZ, to the northwest. The wet-pit surface area was not to exceed 900 m^2, with a 2m depth. At this time, the restoration process required backfilling with limestone up to levels existing prior to the beginning of mining, an average of 4.0m above MSL.

An October 1984 file report indicates that the wet-pit was being backfilled with topsoil. In addition to this, during the following months the extraction extended beyond the first lot of 5 cuerdas authorized, without properly restoring the mined site and also, the pit exceeded the authorized size.

In response to an April 1985 permit ammendment requested by the extractor, in May 1985 the Department authorized an increase in pit size to 1950 m^2. The backfilling procedure was to consist of depositing limestone up to 2m above the water-table followed by 2m of top soil to define the topography that existed prior to mining.

Subsequent file reports indicate that the extractor continued to violate the permit clauses, particularly by not backfilling the extracted site to 4m above MSL and by not limiting the wet-pit size. After several communications between the PR DNR and the extractor and as a result of a PR DNR decision through the Extraction Committee, on April 1986 the permit clauses were oficially modified. Consequently, backfilling with limestone was approved to reach only 1.5m above the water-table followed by 0.5m of topsoil to reach the minimum permissible final land elevation of 2m above the water-table.

On October 1987 the extraction permit was renewed for one year. The buffer zone between the extraction and the MZ was reduced to 10m. This permit requires the extractor to rebuild with sand part of the existing dune to comply with the minimum residual dune dimensions. The final land restoration level was maintained at 2m above the MSL, with adequate inclination to provide good surface flow and minimize ponding. Mining is active at this time and progressing towards the easternmost section of the site.

6.2.3 GEOLOGY AND SOILS

The sand deposits mined in this site have been identified as Beach deposits (Qb) of Recent age (Monroe, 1969) (Fig. 9). They are described to consist of quartz sand, shell fragments, and scattered grains of other minerals resistant to weathering; cementation to beachrock is common; deposits inland from present shoreline are covered by a thin blanket of sand blown from present beaches and dunes; gently crossbedded, generally dipping toward the sea (0-5m thick).

The fill material for this site is obtained exclusively from the limestone hills to the south, identified as Cibao Formation (Tc). This unit is of Tertiary age (Oligocene-Miocene). In Monroe (1969) this formation was described as follows: Interbedded calcareous clay, soft earthy chalk, and hard very fine-grained calcarenite and soft nongranular limestone. Commonly fossiliferous. In areas near Aguada, the base of the formation contains irregularly bedded medium-grained calcarenite locally resting on a few meters of sandy gravel.

The Soil Conservation Service (1975) has defined the following units in the mined area (Fig. 9):

Cd- Cataño sand. Deep, nearly level calcareous soils occurring as strips along the coast in areas close to sea level, but above high tide. Permeability is rapid, the available water capacity is low, and fertility is low. They formed in sandy material consisting of shell fragments, quartz grains, and subrounded fragments of volcanic rock (loose, nonsticky and non plastic sand). Good roadfill. Poor topsoil. This soil is not suited for cultivated crops. Its use is limited mainly to pasture, coconuts, or wildlife habitat.

6.2.4 HYDROLOGY

Five test wells were drilled in this site to gather lithologic, water quality, and water-level data. "Slug" injection tests were performed in all wells to determine relative hydraulic conductivities and/or transmissivities of the site. Well distribution, methodology, results of tests and well monitoring are described and summarized in tables and figures in Appendix V.

Test wells were installed in the following areas: numbers 12, 13, and 14 in backfill; number 15 in an unmined sand site; and number 16 in the limestone fill deposit.

6.2.5 FLORA

Site vegetation prior to the begining of mining behind the backdune area was an upland type consisting of a coconut palm canopy with a weedy herbaceous understory (Fig. 10, 11). This former upland was the center of mining operations for this site (Photo 2b). Figures 10, 11a, and 11b illustrate the changes in vegetation due to mining, Pioneer vegetation covered the backfilled areas as wet-pit development advanced (Photo 2c), although a great portion of the backfill is still unvegetated (Photo 2d).

The sand dune was covered with dense shrubs, grasses, and sparse palms (Fig. 11). This system was partially altered when the backdune area was scraped and later capped with top soil removed from the adjacent extraction site (Fig. 11a)(Photos 2e, 2f, 2g).

The other system impacted by mining in this locality was a semi-evergreen seasonal forest, found on the nearby limestone hills (source of the backfill material). As long as sand extraction continues, this deposit will be mined for backfill and the plant association affected.

Other plant associations surrounding the extraction site have remained in unaltered conditions. To the south, there exists a wide area dedicated to sugar cane production. To the west, the river bank is characterized by typical riverine vegetation (giant grasses).

The mining operation is moving to the east, where remnants of the upland plant associations existing prior to mining are found (Photos 2h, 2i).

AGUADA: PLANT SPECIES ADJACENT TO THE MINING AREA

I Sand dune vegetation

Coccoloba uvifera
Cocos nucifera
Hymenocallis caribaea
Ipomoea pes-caprae
Spartina patens
Widelia trilobata

II Palm grove with littoral herbaceous understory

Coccoloba uvifera
Cocos nucifera
Ipomoea pes-caprae
Terminalia catappa
Spartina patens

AGUADA: PLANT SPECIES IN THE MINING AREA

Pioneer successional vegetation over backfill

Canavalia maritima
Catharanthus roseus
Chloris inflata
Crotalaria sp.
Cyperus ligularis
Euphorbia cyathaphora
Fimbristylis cymosa
Ipomoea pes-caprae
I. trilobata
Mimosa pudica
Panicum sp.
Sida sp.
Stachytarpheta jamaicensis
Vigna repens
Wedelia trilobata

6.2.6 FAUNA

A total of eight species representing three families were recorded during July 1987 and March 1988, which included the following: crustaceans (1 sp.), reptiles (2 sp.), and birds (5 sp.). Fregata magnificens is included in the Watch List of the Puerto Rico Natural Heritage Program (PR NHP) and Pelecanus occidentalis is listed as an endangered species by Federal and State laws.

Several borrows of ghost crab were found adjacent to the extraction site in a palm grove area. Pioneer vegetation was an important feeding habitat for Zenaida Dove and finches. The close proximity of the Rio Grande River explains the presence of estuarine-marine avifauna like the frigate and brown pelican, which used the river for feeding.

No fauna was recorded in the active mining operation area.

AGUADA: FAUNA OBSERVED

Crustacea

Ocypodes sp.

Reptilia

Anolis cristatellus

A. pulchellus

Aves

Fregata magnificens (PR NHP Watch List)

Lonchura punctulata

Pelecanus occidentalis (Endangered)

Progne dominicensis

Zenaida aurita

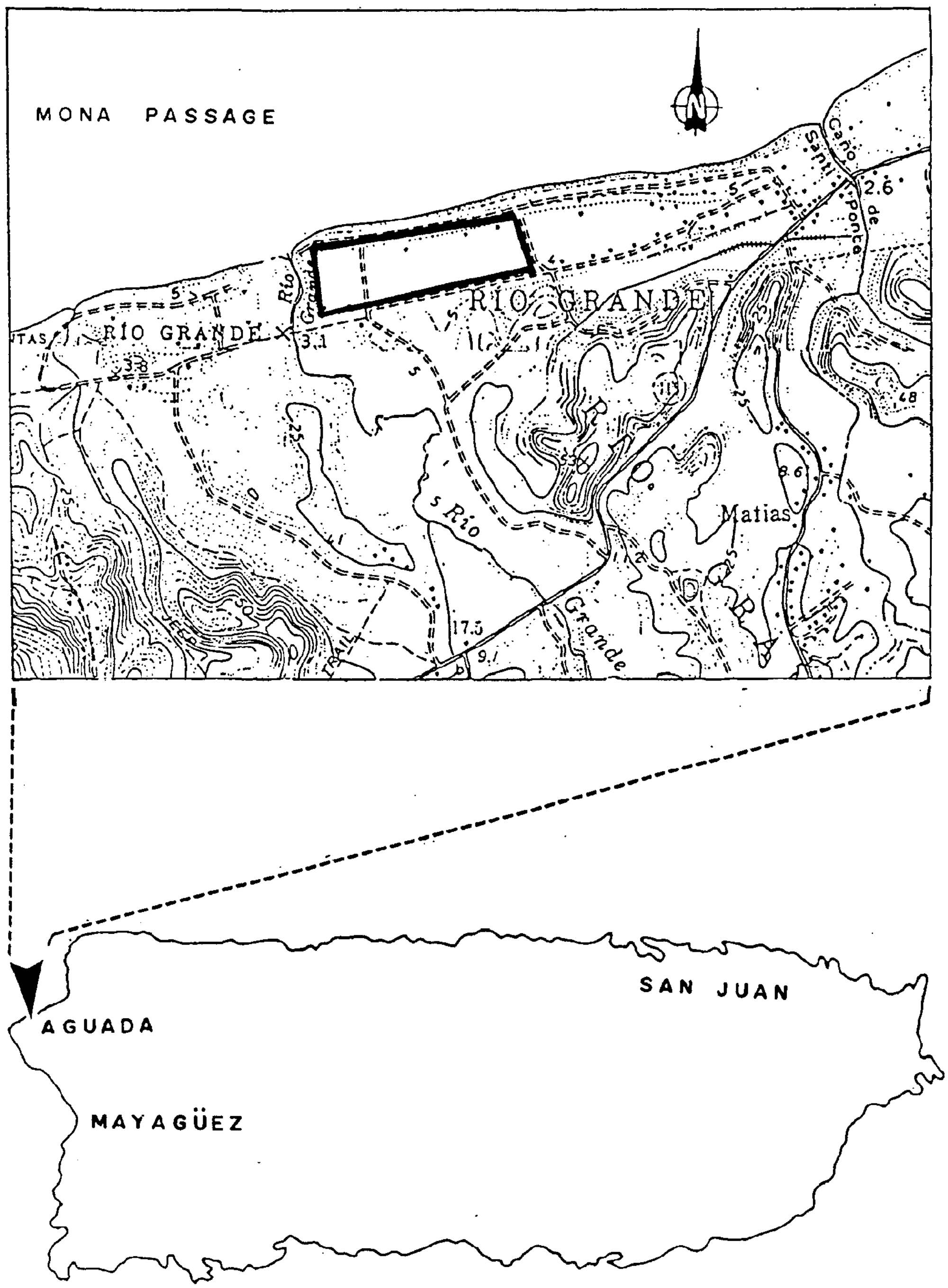
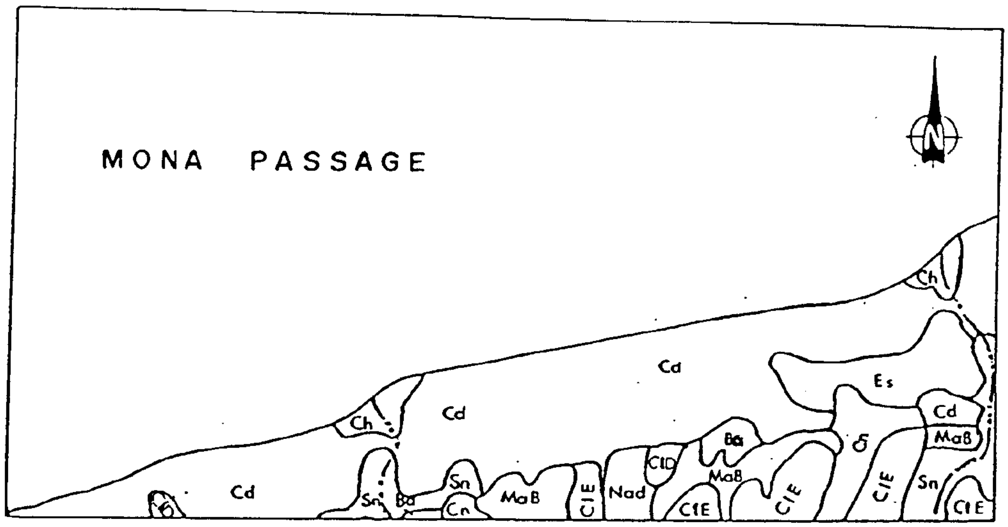
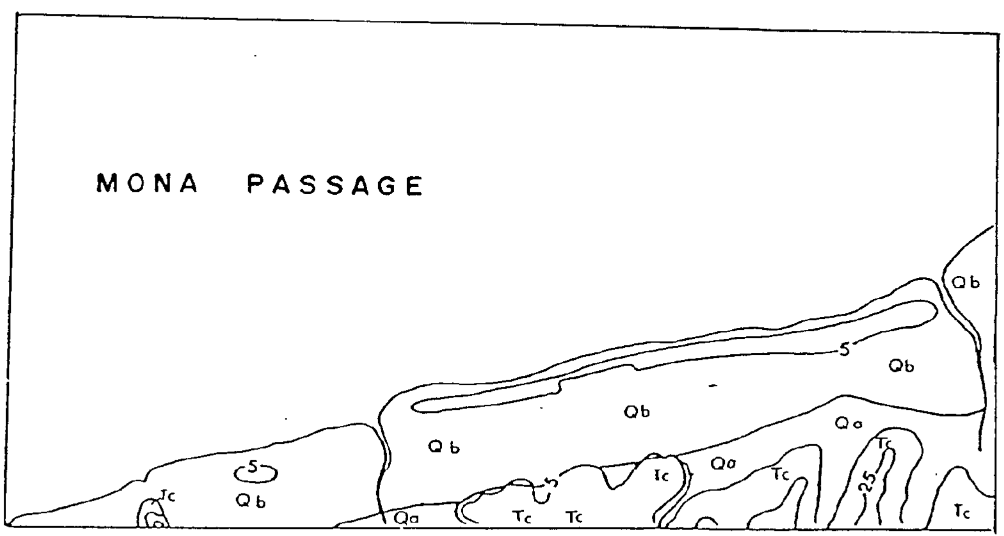


FIG.8. LOCATION OF AGUADA SITE (PIT NO.9)
(U.S.G.S. 1960.)



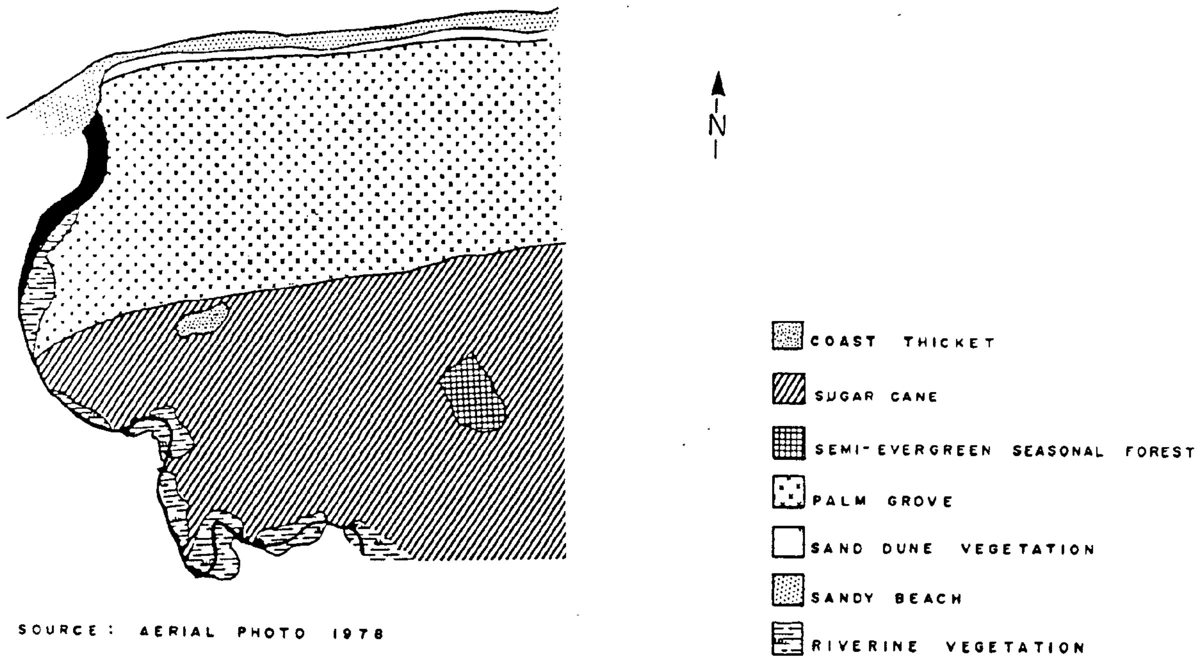
SOIL MAP OF AGUADA SITE (PIT NO.9)



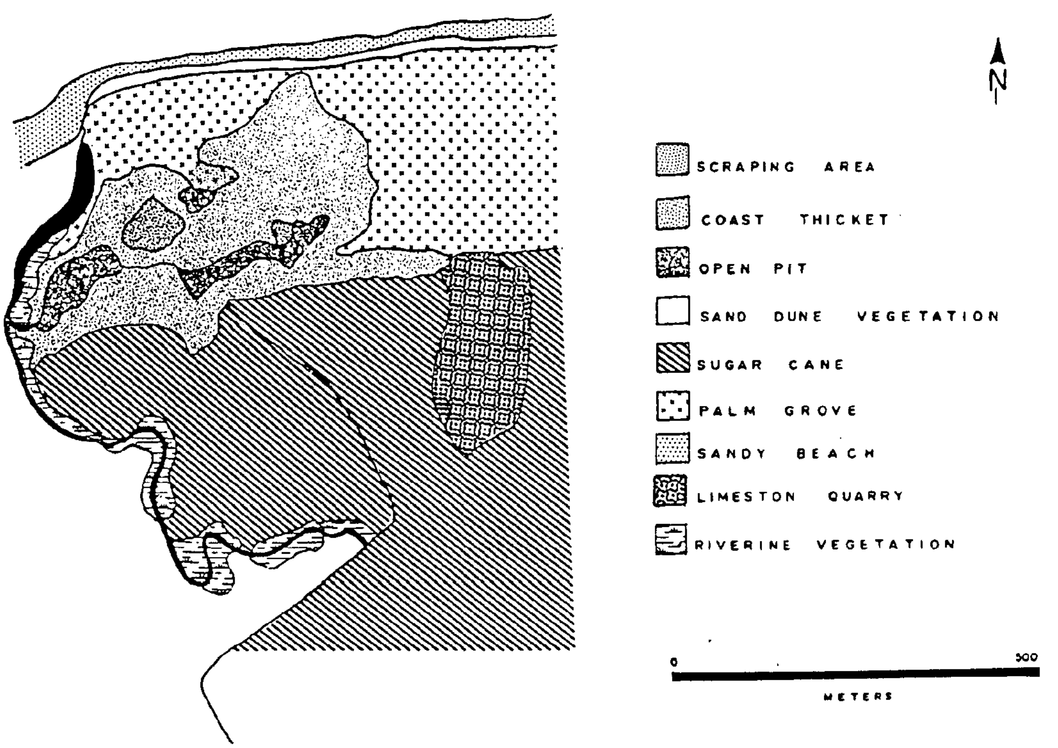
GEOLOGIC MAP OF AGUADA SITE (PIT NO.9)

FIG.9. SOIL AND GEOLOGIC MAPS OF AGUADA SITE.
(S.C.S. 1975; Monroe, W.H. 1969)
(Key to symbols: Appendix VI)

FIG.10. VEGETATION MAP OF AGUADA SITE

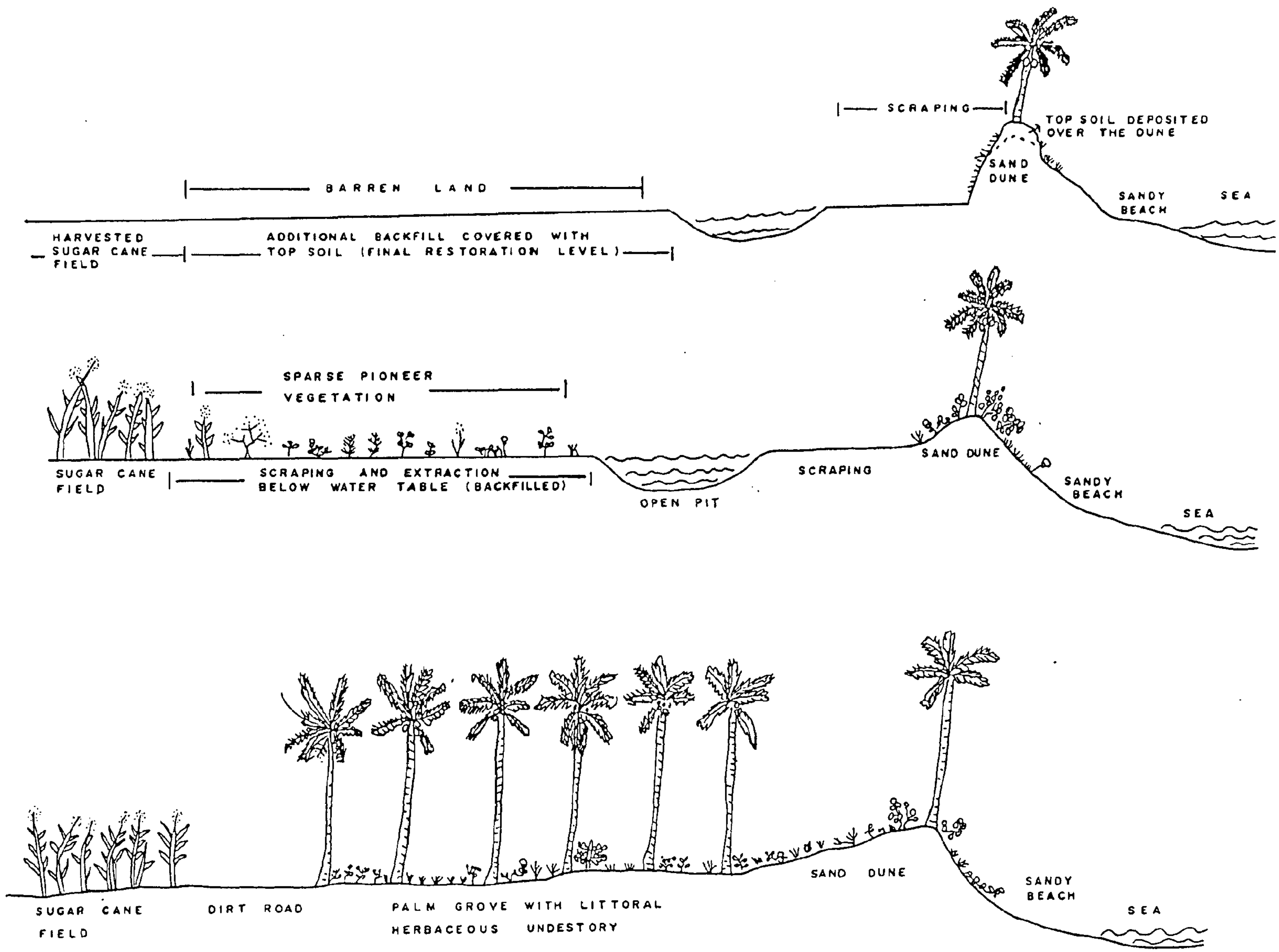


SOURCE: AERIAL PHOTO 1978



SOURCE: AERIAL PHOTO 1987

FIG.11. CROSS SECTION ILLUSTRATING CHANGES IN PLANT ASSOCIATION AT AGUADA SITE.



11 A

11 B

11 C

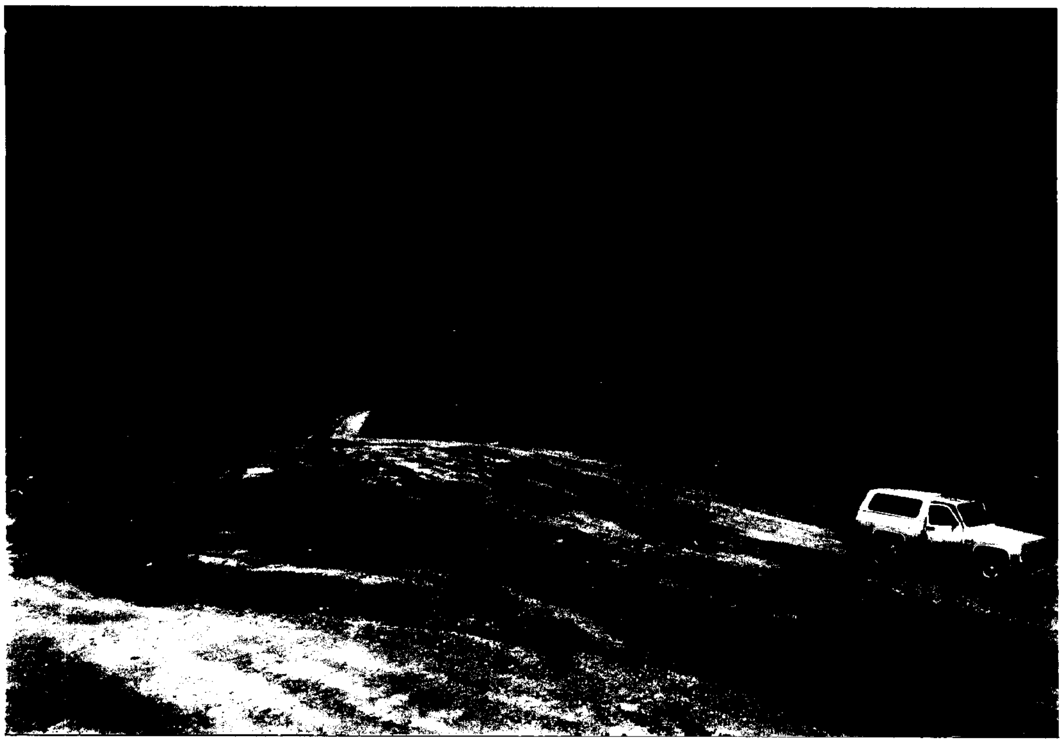


Photo 2a - Aguada site (Pit #9). Panoramic view towards the north.

Photo 2b - Partial view towards the north.
Upland subject to mining.

Photo 2c - Partial view towards the northeast.
Sparce pioneer vegetation growing on
top soil spread over limestone fill.
The duneline can be seen in the background.

Photo 2d - Partial view towards the east.
Unvegetated area that has been back-filled with limestone and a topsoil layer. The coconut palm groves in the background define the unmined section.

Photo 2e - Partial view towards the east.
Scraped backdune.

Photo 2f - Partial view towards the east. Dune capped with top soil; remnant upland palm grove is seen in the background.

Photo 2g - Close-up of dune vegetation being
covered with top soil.

Photo 2h - Partial view towards the north. Active wet-pit found in the eastern portion of the site. The duneline is seen in the background.

Photo 2i - Partial view towards the north.
To the left, a sand scraped section,
in the foreground, a remnant upland
subject to mining.

6.3 PONCE

6.3.1 GENERAL INFORMATION

MUNICIPALITY: Ponce

TOPOGRAPHIC MAP: Pta. Cuchara Quadrangle (Fig. 12)

PIT NUMBER: 16 (Photo 3a)

APPROX. EXTRACTED AREA(*): $125,728m^2$ (32 cuerdas)

APPROX. SIZE OF PIT (*): $7,858m^2$ (2 cuerdas)

TYPE OF BACKFILL: Limestone, cement dust, const. debris, junk

RESTORATION STAGE: In progress

FLOODING SUSCEPTIBILITY (***): Within the 100YR floodplain

STORM WAVE SWASH: Not documented

PR DNR REGION: Ponce

SITE ACCESS: Road PR-2, Km. 256.8, Bo. Canas

PIT CODE: O Active Open Pit

AVERAGE DISTANCE FROM:
MTZ (*): 150m
Mangrove Forest: 0m

PIT DEPTH (**):
Max.: 2.2m
Min.: 1.6m

ECOSYSTEMS AND USES:

Pre-mining: Deciduous seasonal forest, seasonal marsh, mangrove swamp

Post-mining: Young thorn scrub, salt flat, open water, barren land

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(*) Source: January 2, 1987 aerial photograph
(**) Source: Field measurements (Adjusted to MSL) (Appendix V, Figure 21)
(***) Source: FEMA (1981a)

6.3.2 MINING HISTORY

Mining in this area began before October 1977. A file report indicates that the extraction site was covered by approximately 1m of water and that the pits had been partially backfilled with junk. A February 1977 file report indicates that extractions previous to 1971 created wet-pits that were backfilled with construction debris and junk.

In April 1978 mining depth was authorized to reach 50ft (15.24m) at a maximum sand extraction rate of 1,000m^3 daily. The maximum wet-pit size authorized was 25 by 50m (1250m^2). The type of backfill material to be used was not specified.

This permit was renewed in September 1979. The extractor continued to backfill with solid construction debris and limestone. By November 1980 most of the land east and south of the extraction site had been backfilled and covered with vegetation. Nevertheless, a ponded area measuring 10 by 15m (approx.) existed to the southwest of the wet-pit.

In November 1980 a three year permit authorizing a wet-pit depth of 5m was issued; the pit size required continued to be 50 by 25m. The type of backfill and final land levels were still not specified. In August 1983 the extractors requested to backfill with a mixture of cement dust and limestone at a 2:1 ratio as authorized at another extraction site (pit #18). This was approved by the PR DNR on September 1983. A November 1983 file report indicates that the pit measured over 8,500m^2 with an approximate maximum depth between 3.65 and 4.57m. By December of this year the backfill material was changed to consist mostly of igneous fragments and/or serpentinite and/or other approved material. The maximum pit area was increased oficially to 2,000m^2 in May 1984 and once again a mixture of cement dust and limestone was authorized as backfill.

During the following years pit size violations continued and the extractors were fined by the PR DNR in February 1984. In May 1985 results of five test borings done in potential mining areas within the site (Jaca, Sierra and Rivera, 1985) were submitted. This data establishes the maximum water-table depth at 4.0m in addition to supplying an analysis of sample composition. In July 1985 a new permit was issued. The pit depth was reduced to 4.5m and backfill material was allowed to consist of either of the above described rock types. A 50m buffer zone from the MZ was required. These conditions were kept in the permit issued in December

1986 which is still in effect. This operation has been continually having problems obtaining a balance between extraction and backfill rates. Consequently, they have often incurred in violation for exceeding the maximum pit area and for backfilling with unauthorized material. The operation has extended into the adjacent mangrove forest to the south. Currently mining is progressing to the east.

6.3.3 GEOLOGY AND SOILS

The coastal zone deposits mined in this site consist of Quaternary Beach deposits (Qb), Alluvium (Qa), and Swamp deposits (Qs); all of Holocene age (Krushensky and Monroe, 1978) (Fig. 13). The Qb and Qa deposits contain sand, cobbles, pebbles, clay and sandy clay is found in the alluvium. The swamp deposits are largely mangrove swamps, having a mixture of sand, clay, and carbonaceous debris from mangrove trees.

The limestone fill was mostly obtained from the Ponce Limestone (Tp) of Tertiary (Miocene) age. This limestone is described to be very pale orange to grayish-orange generally crystalline calcarenite, containing abundant fossils; thickness is more than 200m (Krushensky and Monroe, 1978).

The Soil Conservation Service (1979) has defined the following units in the mined area (Fig. 13):

Mr- Meros sand. Nearly level soil on benches along the coast at an elevation slightly above sea level. The soils formed in textured sediment that was derived from volcanic rock, sea shells, and coral. Mapped areas include a few narrow strips of beach sand that has been reworked by waves, and small areas of soils that have a calcareous surface layer. Runoff is slow; this soil is not subject to erosion. Very low available water capacity and natural fertility. Good roadfill; fair sand amounts; poor topsoil due to its sandy texture.

Se- Serrano sand. Also a nearly leveled, poorly-drained saline soil on the coastal plains near the beach in the semiarid area. The soils formed in coarse textured to moderately fine textured sediment over coarse textured sediment. Mapping includes narrow strips of beach sands that are reworked by the waves and a few areas of nonsaline Meros soils. Runoff is slow.

6.3.4 HYDROLOGY

Five test wells were drilled in this site to gather lithologic, water quality, and water-level data. "Slug" injection tests were performed in all wells to determine relative hydraulic conductivities and/or transmissivities of the site. Well distribution, methodology, results of tests and well monitoring are described and summarized in tables and figures in Appendix V.

Test wells number 1 and 2 were drilled in backfilled areas; wells number 3, 4, and 5 were installed in unmined areas.

6.3.5 FLORA

The aerial photo interpretation (1971, 1986, 1987) of this site reveals that pre-mining site conditions were significantly modified (Fig. 14). In 1971, before mining began, three major floristic associations were present in the study site (Fig. 14, 15a). The upland portion sustained a deciduos seasonal forest interrupted by a seasonal marsh. In the southern portion of the site there was a mangrove forest.

The aerial photos of 1986-87 show that upon extraction, the seasonal marsh areas became: salt flats, shallow ponds (Photo 3b), upland areas covered by scrubs and mangrove swamps dominated by Conocarpus erectus (Fig. 14)(Photo 3c). The deciduous seasonal forest changed to sparse young-thorn scrub mixed with salt flats (Fig. 15b)(Photo 3d). The inner part of the mangrove swamp, recently extracted and backfilled, is being covered by sparse pioneer vegetation, although a great portion of the backfill is still unvegetated (Photo 3e, 3f, 3g).

The northern portion of the extracted area was backfilled approximately ten years ago. At present, the mining is taking place in the southern section in an east-west direction over the salt flat areas (Photos 3h, 3i). As the open pit is being filled, material is deposited on adjacent mangroves and mudflats (Photos 3j, 3k).

Historically, the mangrove swamp deposits were subject to hand shoveling (Fig. 15b). This type of mining created several shallow ponds that up to this date lack emergent vegetation (Photo 3l). The effect of this extraction will not be considered in this study.

PONCE: PLANT SPECIES ADJACENT TO THE MINING AREA

I Land dune vegetation

Calotropis procera

Canavalia maritima

Coccoloba uvifera

Ipomoea pes-caprae

Spartina patens

Sporobolus virginicus

II Basin Mangrove

Avicennia germinas

Laguncularia racemosa

Rhizophora mangle

III Berm

Batis maritima

Sesuvium portulacastrum

Spartina patens

Sporobolus virginicus

IV Seasonal marsh

Frimbistylis cymosa

Lippia nodiflora

Sesuvium portulacastrum

Sporobolus virginicus

V Deciduous Seasonal Forest mixed with seasonal marsh

Bucida buceras

Capparis flexuosa

Cephalocereus royeni

Cyperus ligrualis

Eliocharis rostellata

Ficus citrifolia

Frimbistilys Cymosa

Lippia nodiflora

Malchra alceifolia

Pithecelobium unguis-cati

Prosopis pallida

Sporobolus virginicus

PONCE: PLANT SPECIES IN THE MINING AREA

I Salt Flat

Avicennia germinas

Batis maritima

Sesuvium portulacastrum

II Pioneer successional vegetation over backfill

Amaranthus sp.

Argemone mexicana

Chloris barbata

Cleome viscosa

Datura sp.

Heliotropium curassanicum

Ricinus communis

Sonchus oleraceus

Sporobolus virginicus

III Young thorn scrub

<u>Leucaena glauca</u>	<u>Prosopis pallida</u>
<u>Leucaena leucocephala</u>	<u>Sesbonia sericea</u>

6.3.6 Fauna

A total of 63 species were reported for this site as a result of surveys conducted on July 14-17, 1987 and January 22-23, 1988. The following animal groups and numbers of species were represented: Crustaceans (5), Amphibians (2), Reptiles (4), Birds (48) and Mammals (4).

Five species found are endemic, two are listed by Federal and State Laws as endangered or threatened. Another species is included in the Watch List of the PR NHP.

The salt flats and shallow pond areas were heavily utilized by herons, egrets, plovers and sandpipers as feeding and roosting habitats. The periferal zone served as nesting for Least Tern. Four active nests were found during the July 15, 1987 survey. Mangrove swamp and associated unvegetated shallow ponds were used by crabs, semi-acuatic and terrestrial avian species. The remnant of a deciduous seasonal forest served as habitat for resident avian species and is of primary importance in attracting migrating birds such as the wood warblers. Avifaunal use of the backfilled area closer to Road PR-2 was limited to exotic species. Reptiles, amphibians and mammals were found throughout the extraction site and adjacent areas as well. No fauna was found at the active mining operation area.

PONCE: FAUNA OBSERVED

Crustacea

Goniopsis cruenttata	Uca burgersi
Sesarma sp.	U. rapas
	U. thayeri

Amphibia

Eleutherodactylus coqui (Endemic)

Leptodactylus albilabris

Reptilia

Ameiva exsul	Anolis pulchellus
Anolis cristatellus	A. stratulus (Endemic)

Aves

Actitis macularia

Ardea herodias

Arenaria interpres

Bubulcus ibis

Buteo jamaicencis

Butorides striatus

Casmerodius albus

Cathartes aura

Charadrius wilsonia

C. semipalmatus

C. vociferus

Coereba flaveola

Columbina passerina

Crotophaga ani

Dendroica adelaidae

D. coronata

D. palmarum

D. petechia

D. tigrina

D. striata

Egretta caerulea

Egretta thula

Egretta tricolor

Falco sparverius
(PR NHP Watch List)

Fregata magnificens

Himantopus mexicanus

Lonchura cucullata

Loxigilla portoricensis

Mimus polyglottos

Mniotilta varia

Myiarchus antillarum
(Endemic)

Myiopsitta monachus

Quiscalus niger

Pandion haliaetus

Parula americana

Passer domesticus

Pelecanus occidentalis
(Endangered)

Pluvialis squatarola

Seiurus noveboracensis

Setophaga ruticilla

Sterna antillarum (Endangered)

Tiaris bicolor

T. olivacea

Tringa melanoleuca

Tyrannus dominicensis

Vireo latimeri (Endemic)

Zenaida asiatica

Z. aurita

Mammalia

Herpestes auropunctatus

Mus musculus

Rattus norvegicus

R. rattus

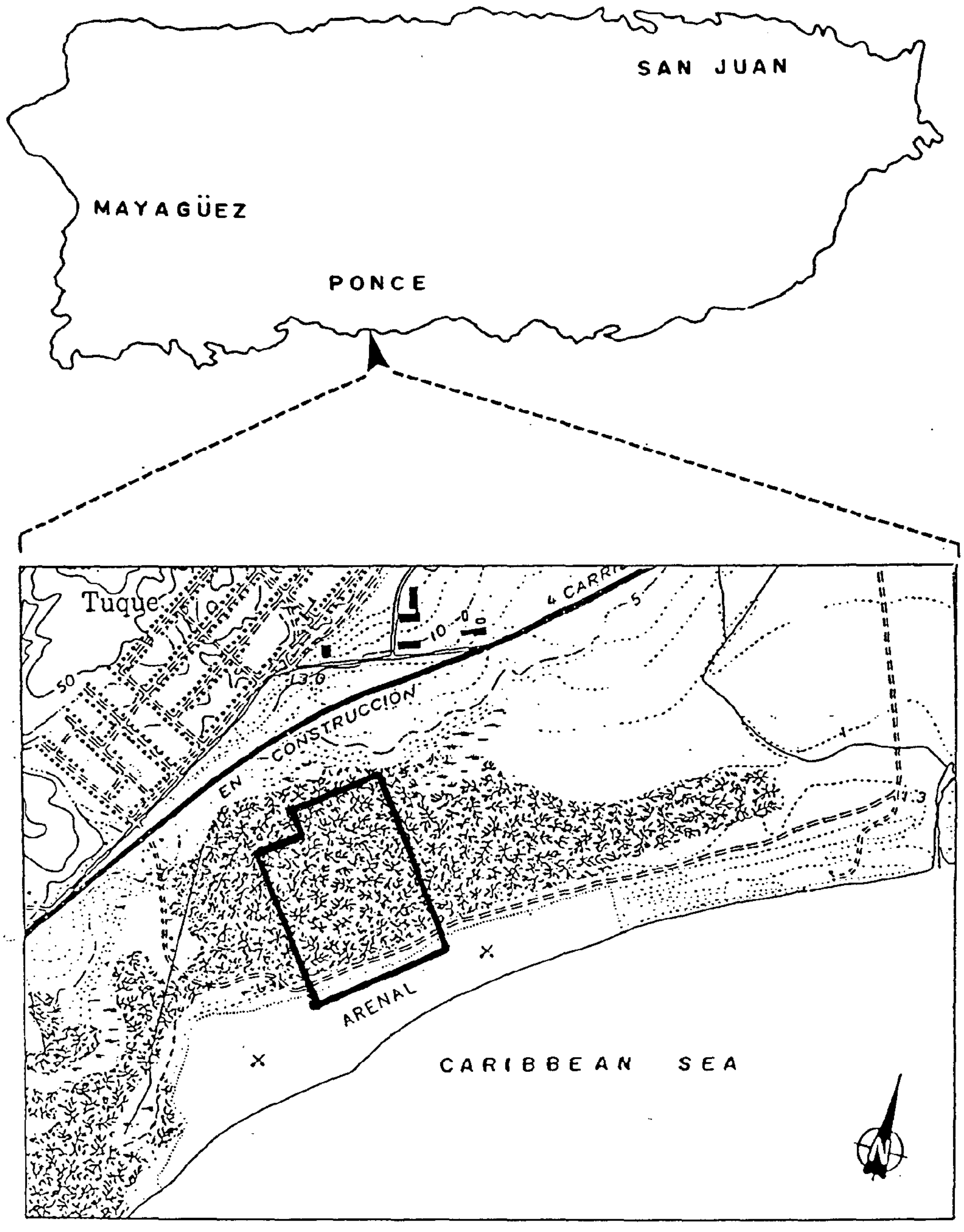
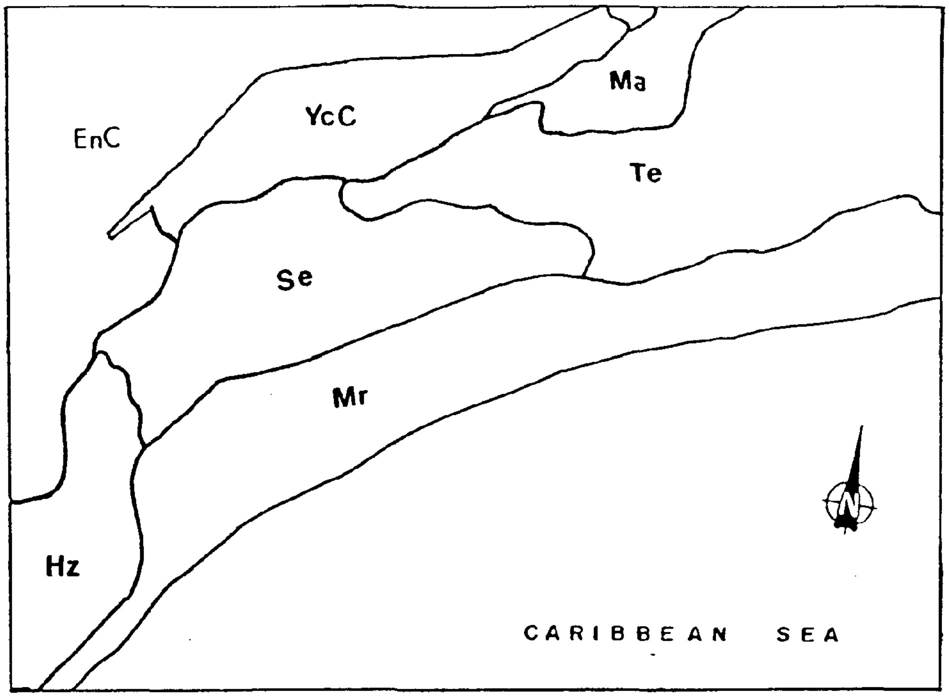
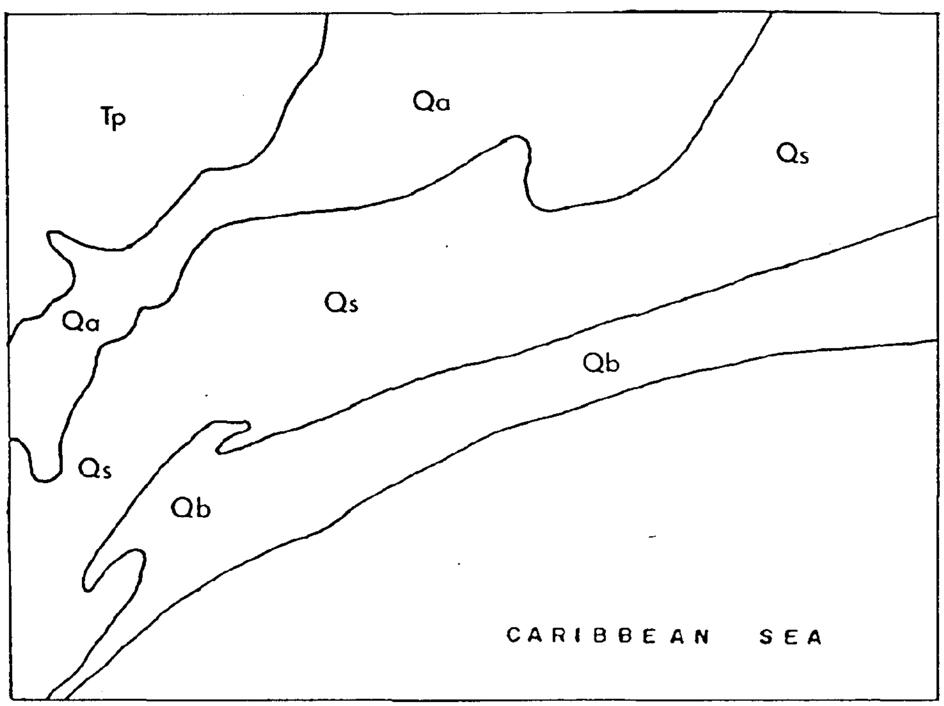


FIG.12. LOCATION OF PONCE SITE (PIT NO.16)
(U.S.G.S. 1962)



SOIL MAP OF PONCE SITE (PIT NO.16)



GEOLOGIC MAP OF PONCE SITE (PIT NO.16)

FIG.13. SOIL AND GEOLOGIC MAPS OF PONCE SITE (S.C.S. 1979; KRUSHENSKY, R.D. AND MONROE, W. H. 1978)(Key to symbols: Appendix VI)

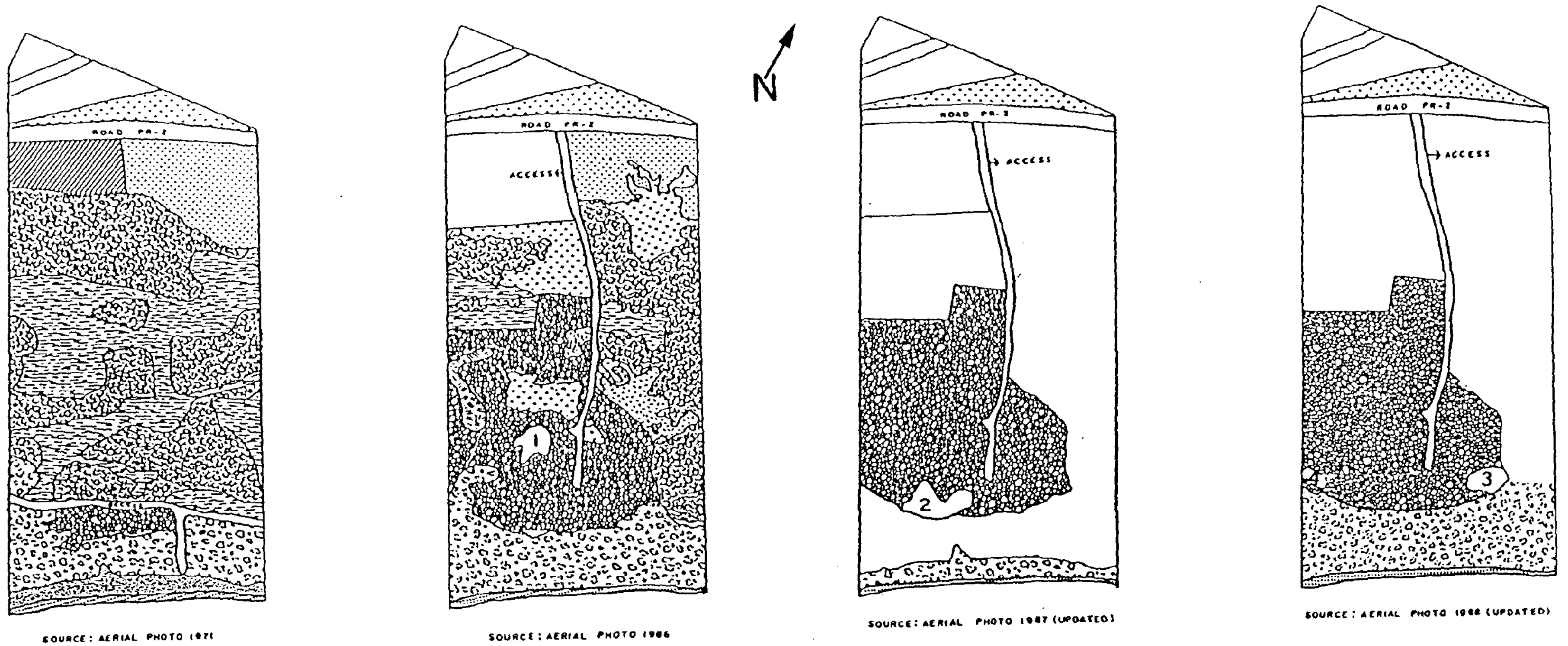


FIG.14. VEGETATION MAP OF PONCE SITE

0 — 300 METERS

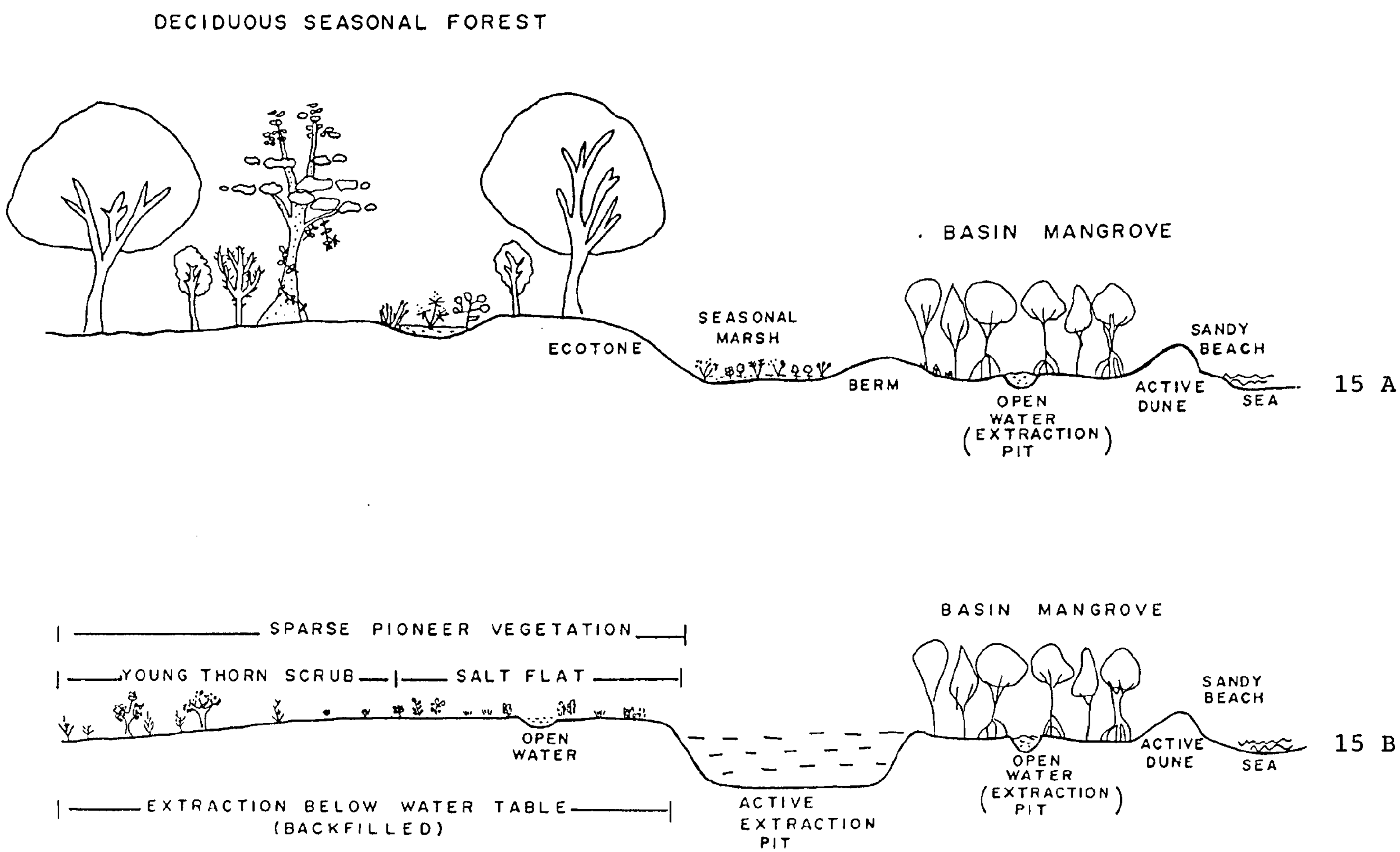
SAND BEACH
SPARSE SCRUB
SEASONAL MARSH
DECIDUOS SEASONAL FOREST

THORN SCRUB
JUNK
BACKFILLED
SCRAPING AREA

MANGROVE SWAMP & SHOVELING EXTRACTION OPEN PIT
SCRAPING & EXTRACTION BELOW WATER TABLE (PARTIALLY BACKFILLED) SPARSE PIONEER VEGETATION

ACTIVE OPEN PIT
1-JAN., 1986 2-FEB., 1987 3,4-MAR., 1987-88

FIG.15. CROSS SECTION ILLUSTRATING CHANGES IN PLANT ASSOCIATION AT PONCE SITE.



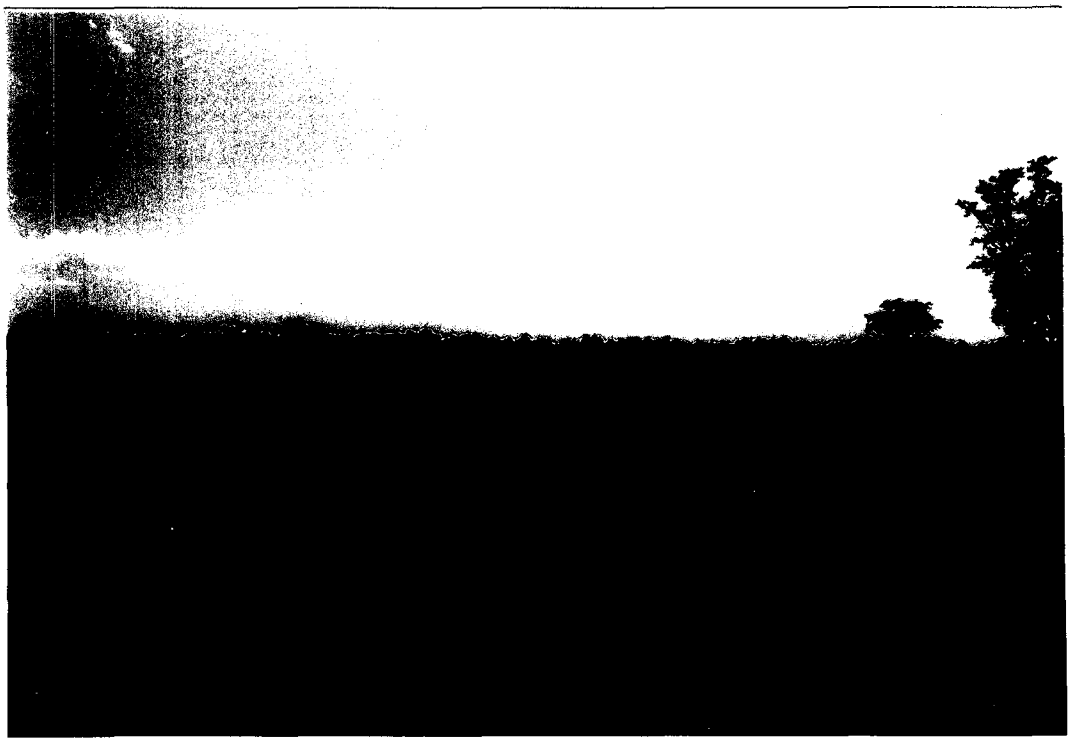


Photo 3a - Ponce site (Pit #16). Panoramic view towards the south.

Photo 3b - Partial view towards the south. Created shallow ponds being filled with limestone.

Photo 3c - Partial view towards the east. Backfilled area. To the left, a stand of Conocarpus erectus, surrounded by salt flats species; remnants of the deciduous seasonal forest is seen in the background.

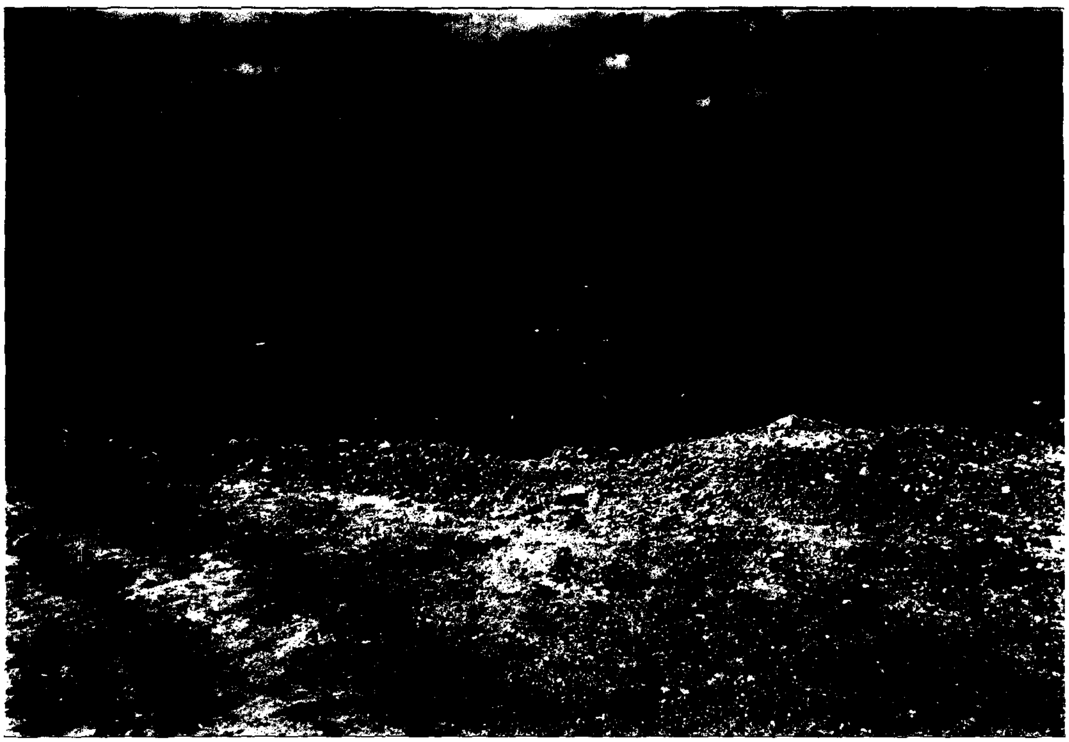


Photo 3d - Partial view towards the south. Created salt flats being covered with limestone backfill ; sparce young-thorn scrub is seen in the background.

Photo 3e - Partial view towards the west. Inner part of the mangrove swamp being covered with limestone fill.

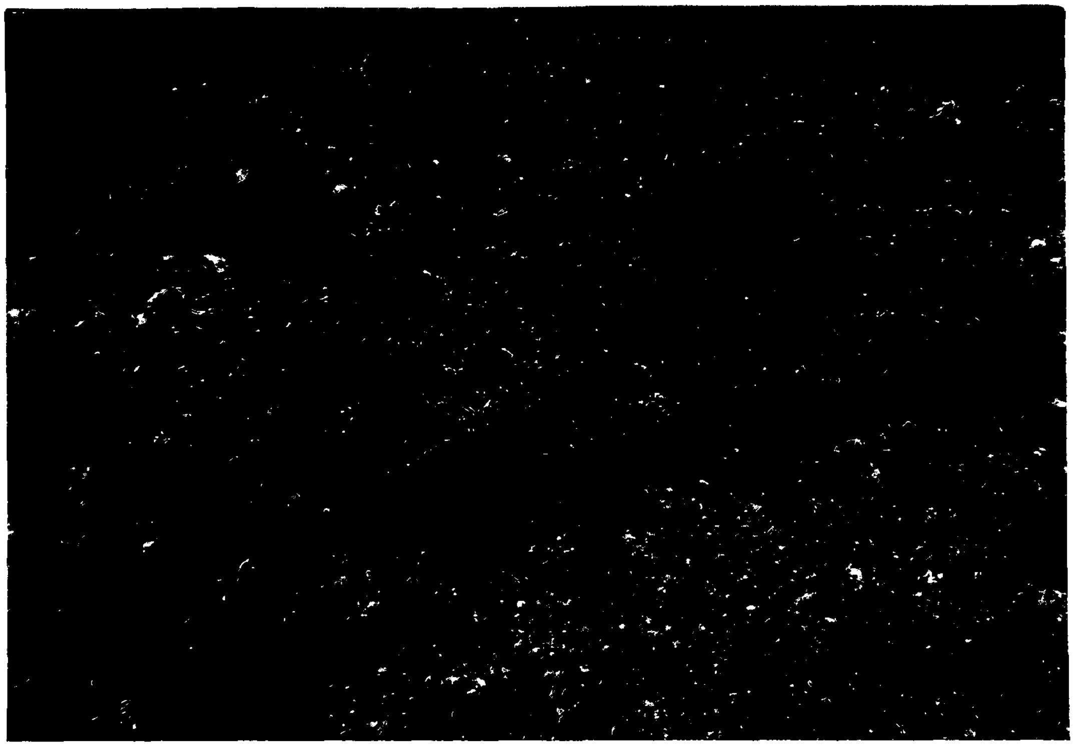


Photo 3f - Sparce pioneer vegetation growing on limestone backfill.

Photo 3g - Partial view towards the east. Unvegetated backfilled area; remnant of the deciduous seasonal forest is seen in the background.

Photo 3h - Partial view towards the west. Active wet-pit found in the western portion of the site. Mangrove and salt flats can be seen in the background, to the left.

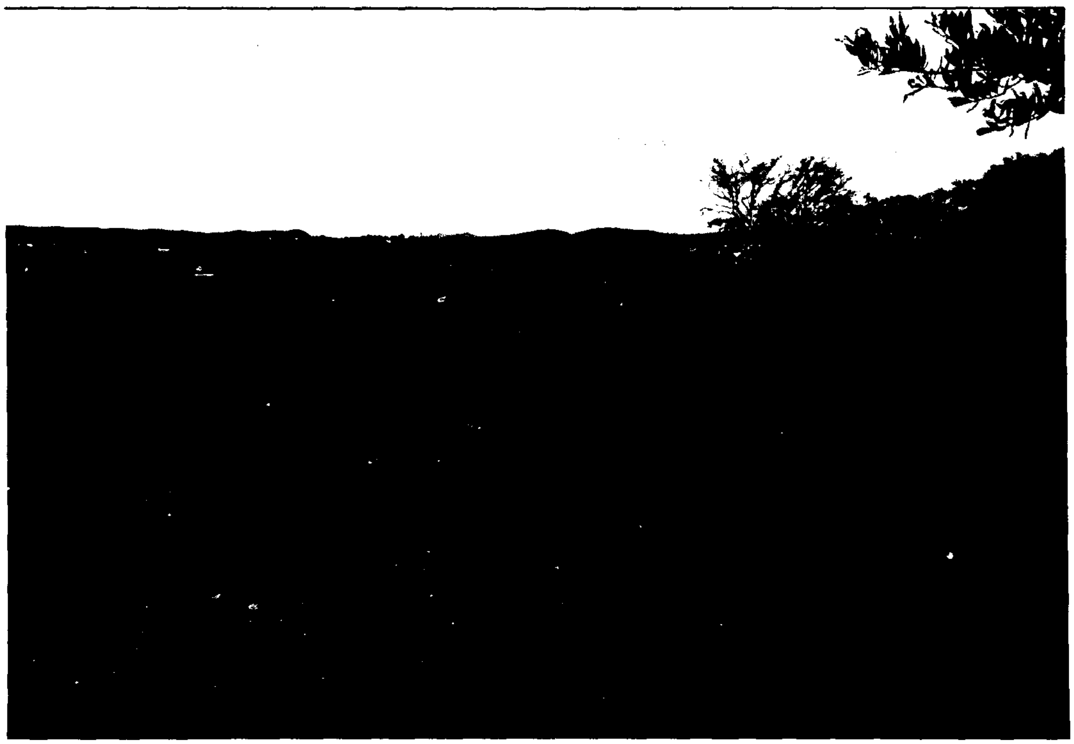


Photo 3i - Partial view towards the northeast. Wet-pit found in the eastern section is being backfilled. In the background, to the right, is a deciduous seasonal forest; to the left, a stand of *Conocarpus erectus*.

Photo 3j - Partial view towards the north. Filled area adjacent to mangrove, mudflats and shallow ponds.

Photo 3k - Close-up of mangrove, mud flats and shallow ponds being covered by limestone fill.

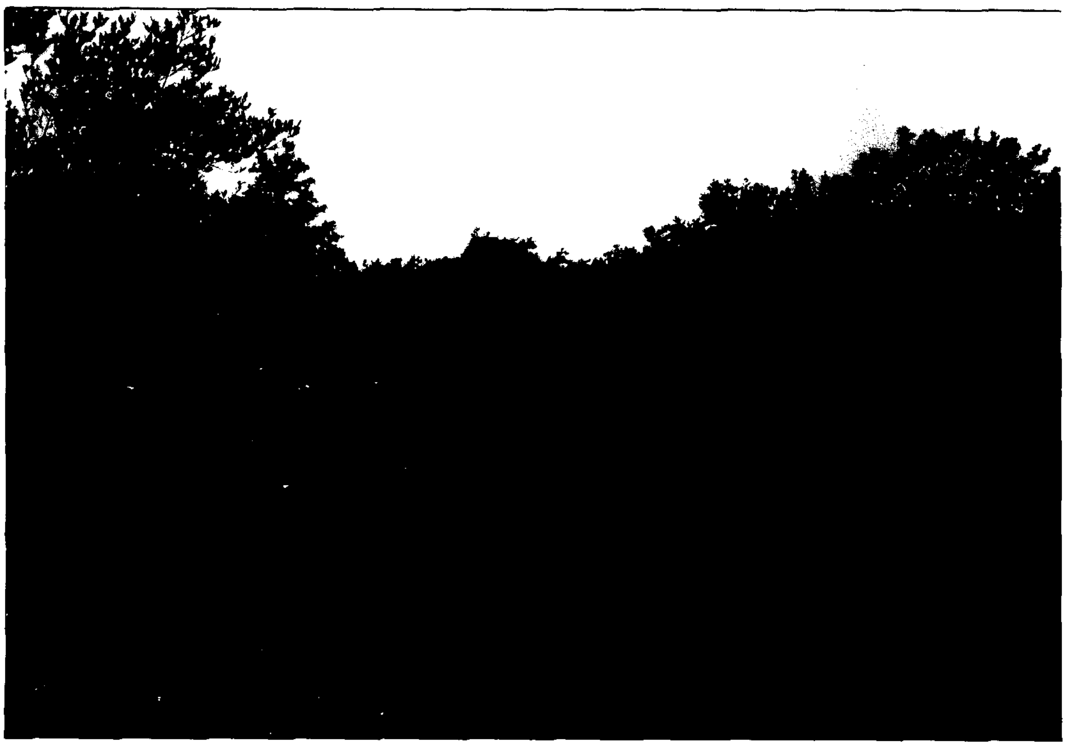


Photo 31 - Partial view towards the south. Shallow ponds created in the inner area of the mangrove forest.

7.0 PARTIAL MONITORING SITES

7.1 LOIZA

7.1.1 GENERAL INFORMATION

MUNICIPALITY: Loiza

TOPOGRAPHIC MAP: Canóvanas Quadrangle (Fig. 16)

PIT NUMBERS: 2,3,4

APPROX. EXTRACTED AREA (*):
Same as size of Pits indicated below

APPROX. SIZE OF PIT (*):
Pit #2: 157,160m^2 (40 cdas.)
Pit #3: 43,219m^2 (11 cdas.)
Pit #4: 35,361m^2 (09 cdas.)

TYPE OF BACKFILL: N/A

RESTORATION STAGE: None

PR DNR REGION: San Juan

SITE ACCESS: Road PR-187, Km 8.5, Bo. Medianía Baja

PIT CODE: Δ Abandoned Open Pit

AVERAGE DISTANCE FROM:
MZ (*): Pit #2: 80m
Pit #3: 20m
Pit #4: 880m

PIT DEPTH:(**)
Max.: Pit #2: 22.7m
Min.: Pit #2: 1.0m

ECOSYSTEMS AND USES:

Pre-mining: Palm groves
Agriculture

Post-mining: Open-water and herbaceous swamp; Recreational and fishing

FLOODING SUSCEPTIBILITY (***):
Pit #2: Within the 100 and 500YR floodplain
Pit #3: Within the 500YR floodplain
Pit #4: Within the 100YR floodplain

STORM WAVE SWASH: Not documented

(*) Source: January 24, 1987 aerial photograph.
(**) Source: Bathymetry map prepared by Surveying Section, PR DNR (September 1977)
(***) Source: FEMA (1981b)

7.1.2 MINING HISTORY AND USES

According to available information, sand extraction in these pits took place before 1972. The pits were never backfilled and they now serve various purposes as indicated in Table 1.

7.1.3 FLORA

Mining, agriculture, residential and turistic developments have modified the floristic components of the area since mining took place. Therefore, it is difficult to determine the direct changes resulting from the extractions. However, the open bodies of water and the surrounding swamps can be attributed as being products of wet-pit operations.

Prior to mining and development, the site vegetation consisted basically of Palm groves. Currently, as shown in figure 17, there are many plant associations present at this site.

7.1.4 FAUNA

Fourteen species were recorded for pits #2 and #3. The following animal groups and number of species were represented: amphibians (2), reptiles (3), birds (4), and fishes (5).

Fresh-water fish was recorded for pit #2 during April 4, 1988. Common gallinule used this pit for nesting. Three chicks and two adults were observed.

Terrestrial and semi-aquatic birds, amphibians, and reptiles were seen using transitional areas for roosting, cover, and feeding.

Several individuals of antillean painted turtle were observed around wet-pit margins covered by Typha dominguensis.

In pit #3 only two aquatic birds were observed: common gallinule and caribbean coot, which is one of the critical elements of the PR NHP and a candidate to the Federal List under category number two.

LOIZA: FAUNA OBSERVED

Amphibia

Bufo marinus

Leptodactylus albilabris

Reptilia

Anolis cristatellus

A. pulchellus

Pseudemy terrapen

Aves

Bubulcus ibis

Butorides striatus

Fulica caribaea (PR NHP Watch List)

Gallinula chloropus

Piscis

Gobiomorus dormitor

Lepomis sp.

Micropterus salmoides

Tilapia mossambica

T. rendalli

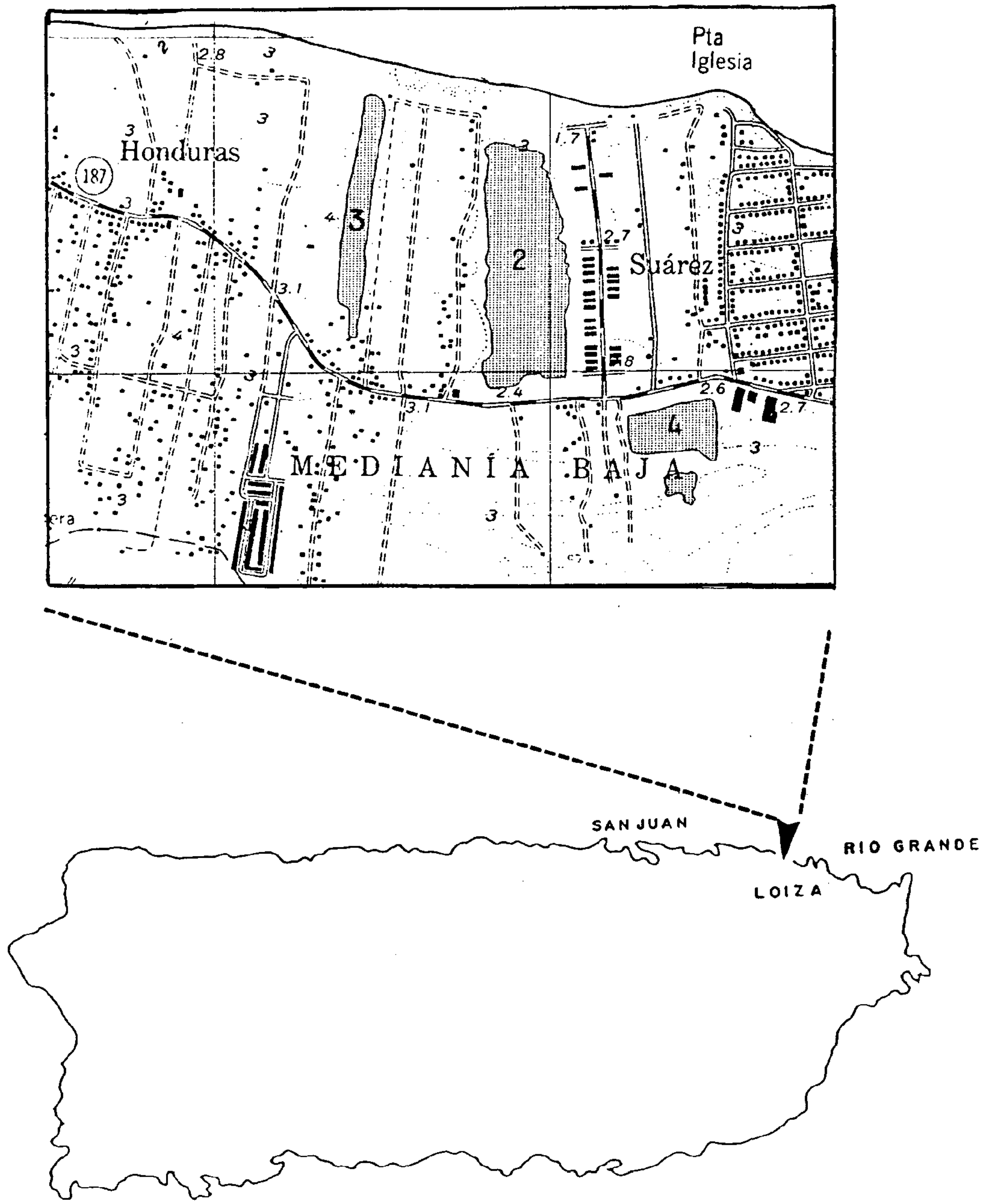
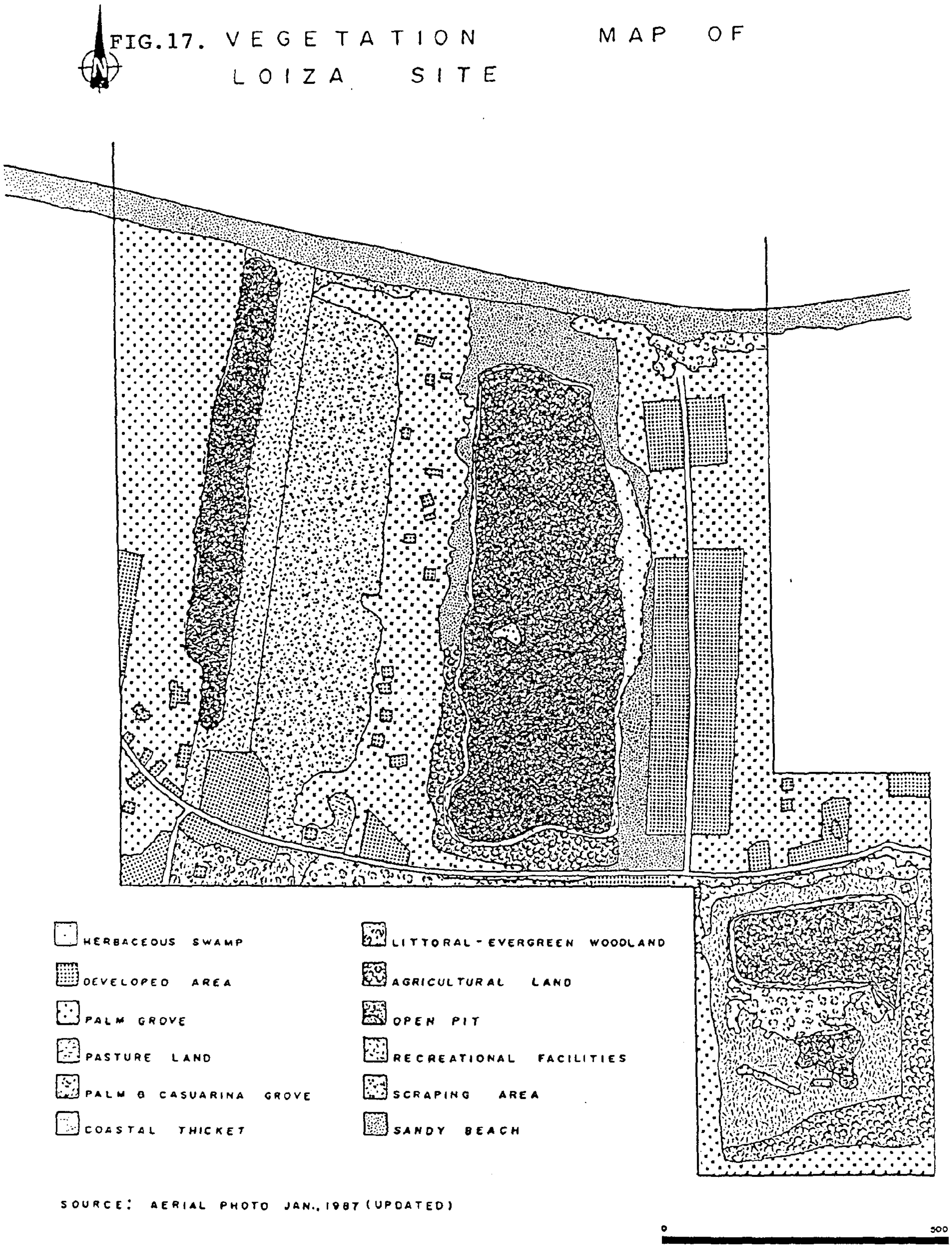


FIG.16. LOCATION OF THE LOIZA SITES (PITS NO 2,3,4)
(U.S.G.S. 1963)

FIG.17. VEGETATION MAP OF LOIZA SITE



SOURCE: AERIAL PHOTO JAN., 1987 (UPDATED)

8.0 IMPACTS ON WILDLIFE HABITAT

Mining directly affects the ecological succesion of plants and animals and wildlife habitat. Study findings that support this are discussed below:

1. **Wetlands turned into upland systems.** At the Ponce site, a mangrove swamp and a seasonal marsh were filled as a result of mining operations that raised land level.

2. **Xerophytic upland systems turned into wetland and open water systems.** The Camuy and Loiza sites, where wet-pits have been left open, are examples.

3. **Man-modified wetlands improved wildlife use of these areas.** As a result of sand scraping in Ponce the existing wetland was altered, creating shallow ponds and salt flats favorable for sustaining semi-aquatic fauna.

4. **Unmanaged man-made wetlands provided limited wildlife support.** Use of the Camuy site by characteristic wetland species was poor. No fish were found in the abandoned wet-pit. This may be partly explained by: a) the absence of diverse habitats, b) low nutrient concentrations and organic matter input to the pond, c) small size of the abandoned pit, in addition to d) it being a closed system. In contrast, the number of characteristic wildlife wetland species found in the Loiza pits was greater; fish species found were introduced. Both sites sustain a comparable overall number of species, although the Loiza sites are about fifteen years older than the Camuy site. This suggests that unless abandoned wet-pits are specifically managed to support wildlife, their potential use for this purpose will be greatly reduced.

5. **Removal of food, nesting sites and escape cover areas for wildlife through the mining process.** In Ponce, a Least Tern nesting area was destroyed and roosting and feeding areas for various aquatic and semi-aquatic organisms were dug out and backfilled. In Aguada, forage areas for the Zenaida Dove and exotic finches were backfilled, and ghost crab burrows were destroyed.

6. **Removal of secondary succesion vegetation and destruction of wetland at several sites.** Deciduous seasonal forest, seasonal marsh, mangrove swamp, and coastal thicket were completely removed.

7. **Natural vegetation succesion occurred at sites where restoration had not been completed or at abandoned sites.** Invasive pioneer vegetation spread rapidly and hindered the regeneration of pre-existing vegetative cover. In Camuy, most of the area is covered by herbaceous pioneer vegetation that was established at least five years ago. In contrast, the vegetation cover found in the northern part of the Ponce site (one of the oldest mining areas) is sparse and dominated by Prosopis. Because of the dry climate, natural succession is expected to be slow in the south coast.

8. **At active extraction sites, natural succesion is hindered when the restoration process, interrupted for a time, is resumed.** Generally, there is a time lapse between the begining and completion of the restoration process, that may extend many months, even years. During this time, pioneer vegetation is established. This attracts wildlife, especially avian species that feed or nest in early succession vegetation, as observed in the Ponce and Aguada sites. Because restoration procedures are not aimed to create or preserve wildlife habitat, most incidental habitats created at these times are later destroyed when restoration is resumed.

9. **Areas under active mining were found to have no wildlife.** Similar findings have been described by Spaulding and Ogden (1968). Surface mining activities cause constant disturbance and displacement of wildlife. In some areas this situation is more critical than others, depending on species diversity, population size and whether the area was used for foraging, nesting or roosting activities.

9.0 SUMMARY OF FINDINGS AND CONCLUSIONS

1. Twenty wet-pit mining operations were identified within the limits of Puerto Rico's coastal zone. Twelve (60%) wet-pits have been left open; three (15%) have been backfilled; and five (25%) are active operations.

2. Wet-pit mining operations have proliferated during this current decade. Most of the operations have concentrated in the northwest coast of the island.

3. The current regulations to control the extraction of materials from the Earth's crust do not contain specific criteria for permit evaluation, operational methods and restoration requirements for wet-pit mining.

4. Review of the mining history at selected sites reveals several management problems:

a. There is a lack of consistency in the mining and mitigation procedures established in different mining permits, even for the same or similar sites.

b. Extraction, backfilling and restoration procedures are not always enforced;

c. Extraction operations are permitted to continue, even though violations persist.

5. There are inadequate technical data to properly evaluate proposed mining sites, techniques and environmental impacts.

6. Sand mining operations disrupt the natural coastal zone landforms. Many past extractions have left open pits; the PR DNR has never executed a Performance Bond to backfill and restore mining sites.

7. Land levels are lowered by mining. Therefore, flooding probabilities increase in already flood-prone areas. The PR PB has confirmed the applicability of Regulation No. 13 to mining operations. They require of the PR DNR to determine if the proposed mining activity will significantly increase flood levels or velocities.

8. Wet-pit mining of coastal sand deposits can locally affect the ground-water hydrology of coastal zones. It can result in the lowering of water levels at the dune area with eventual migration inland of the freshwater-saltwater interface. The extent to which this will occur depends on climatic and hydrogeologic conditions of the area. With the information obtained, it is not possible to determine a critical pit size or a maximum length of time a pit should remain open before significant changes begin to take place.

9. At present, wet-pits are required to be backfilled. The general practice has been to backfill extracted sites to the minimum requirements (1m above MSL). The most common fill material used is limestone, followed by residual sand, volcanic sand and topsoil. Construction debris, junk, and cement dust was corroborated to have been used in some places.

10. Backfill used to restore the site will not severely alter the ground-water system, as long as the fill material has similar hydraulic properties as the original extracted sand. When local hydraulic conductivities in the aquifer are significantly altered by the backfill used, natural ground-water flow patterns will be permanently distorted.

11. In the area of Camuy, the sand-extraction site has been partially backfilled with apparently high permeable material. As a result, surrounding heads in the local shallow aquifer have probably been permanently depressed.

12. In Aguada, sand mining operations appear to have caused local changes in the hydrology of the site. The area where sand extractions have occurred was backfilled with materials of lower permeability than the original sand deposits. As a result, a water-table mound apparently has developed which seems to have inhibited a decline of water levels in the adjacent dune. The water-table mound could probably have also inhibited migration of seawater into the open pit.

13. The wet-pit in Ponce has locally increased the aquifer permeability. As a result, surrounding water levels in the aquifer and in the dune have dropped by as much as 3 feet.

14. Mining processes directly affect wildlife habitat and the ecological sucession of plant and animal population:

a. In Ponce, a productive system in terms of structure and function that provided habitat for aquatic, semi-aquatic, and terrestrial species was altered. The extraction modified and expanded part of the wetland, turning it into feeding and nesting areas. Final restoration displaced the species found in the wetland.

b. Although the coastal vegetation once present at the Aguada site was described by Lugo (1983) as apparently unproductive in terms of its low structural complexity, it provided stability to the beaches and dunes. Using adjacent areas exhibiting similar pre-mining conditions for comparison, it can be determined that fauna species present in the extracted area previous to mining was scarce. Naturally revegetated extraction sites became a source of food and attracted an increased number of terrestrial species. Final restoration displaced the species found in the extracted area.

c. The Camuy and Loiza sites, both originally upland systems, were turned into wetland and open-water systems.

15. Current restoration practices do not incorporate efforts to mitigate loss of fish or terrestrial habitat through either selective planting of appropiate species or creation of replacement habitats.

16. Wet-pit mining impact on wildlife habitat is site specific and is dependant on extraction and restoration procedures. Unless abandoned wet-pits are specifically managed to support wildlife, their potential use for this purpose will be greatly reduced.

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APPENDIX I:
"NOTE TO THE FILE" AUTHORIZING EXTRACTIONS BELOW THE WATER-TABLE, MARCH 12, 1981

DE RECURSOS
NATURALES

1981

PARA EL EXPEDIENTE

En el día de hoy 12 de marzo de 1981 se efectuó una reunión con el Dr. Fred V. Soltero Harrington, Secretario del Departamento de Recursos Naturales, para someterle a su consideración una petición del Sr. Joaquín Ceballero para extraer material de la corteza terrestre bajo el nivel freático (ver carta del 11 de marzo de 1981). A esta reunión asistieron; el Sr. Edgar Rosario, Secretario Auxiliar Int. del Area de Operaciones, el Ing. Carlos M. Santana, Asesor Técnico del Area de Operaciones y la señora Glenda Hernández, Directora de la Oficina Regional de Aguadilla.

De esta reunión se desprende lo siguiente:

1. El Dr. Fred V. Soltero Harrington autorizó a que se extrayera material bajo el nivel freático.
2. Se le exigirá un "Performance Bond" de $100,000 dólares.
3. Se le permitirá crear fosas no mayores de 30M x 30M.
4. Se dividirá la finca en tres (3) partes iguales y se autorizará la extracción en la primera tercera parte (1/3). Una vez efectuado los trabajos en esta parte, se efectuará una inspección para determinar si amerita o si merece, desde el punto de vista técnico el continuar los trabajos en el resto de la finca.
5. Deberá presentar al Departamento un plan de restauración y reforestación al area para la consideración del mismo.
6. Deberá presentar al Departamento un plan de trabajo para la consideración del mismo.
7. Deberá presentar al Departamento evidencia de los contratos que efectúe para obtener el relleno que utilizarán en los trabajos de restauración.
8. Se le asignará un guardian de la Región de Aguadilla, el cual estará presente en el lugar de extracción y someterá un informe semanal de los trabajos allí autorizados.
9. Deberá someter recomendaciones de la Oficina de Conservación de Suelos para la restauración del área.

Rafael Jaime, Jefe Sección
Corteza Terrestre

Estado Libre Asociado de Puerto Rico, Departamento de Recursos Naturales
OFICINA Avenida de Muñoz Rivera, Parada 3, San Juan, Puerto Rico
DIRECCION POSTAL Apartado 5887, Puerta de Tierra, Puerto Rico 00906

APPENDIX II:
PLANNING BOARD LETTER
DATED JUNE 24, 1980

ESTADO LIBRE ASOCIADO DE PUERTO RICO
OFICINA DEL GOBERNADOR
JUNTA DE PLANIFICACION

CENTRO GUBERNAMENTAL
EDIF. NORTE AVE. DE DIEGO
APTDO. 41119, SAN JUAN, P.R.
TELEX

24 de junio de 1980

Hon. Fred V. Soltero Harrington
Secretario
Departamento de Recursos Naturales
Apartado 5887
Puerta de Tierra, Puerto Rico 00906

Estimado señor Soltero Harrington:

En atención a lo planteado en su comunicación del 13 de junio de 1980, le confirmamos que efectivamente el Reglamento Sobre Control de Edificaciones y Desarrollo de Terrenos en Zonas Susceptibles a Inundaciones aplica a los permisos para la extracción de material de la corteza terrestre.

La extracción en zona inundable 1 se podría autorizar si se determinara previamente que dicha actividad no tendrá el efecto de aumentar el nivel de inundación o la velocidad de las aguas. Cada caso debe ser estudiado y evaluado en sus méritos.

Cordialmente,

Miguel A. Rivera Ríos
Presidente

1979 AÑO DE LOS PANAMERICANOS

24495

APPENDIX III:
PLANNING BOARD LETTER
DATED NOVEMBER 22, 1985

ESTADO LIBRE ASOCIADO DE PUERTO RICO
OFICINA DEL GOBERNADOR
JUNTA DE PLANIFICACION

Centro Gubernamental Minillas, Edif. Norte
Ave. De Diego, Pda. 22
Aptdo 41119, San Juan, P.R. 00940 - 9985

22 de noviembre de 1985

Ing. Ruth D. Carreras
Secretaria Auxiliar
Area de Planificación
Departamento de Recursos Naturales
Apartado 5887
San Juan, Puerto Rico 00906

Me refiero a la solicitud que nos hace en su reciente comunicación en cuanto a la aplicabilidad de las disposiciones del Reglamento de Planificación Núm. 13 a los casos de solicitudes de permisos de extracción de material de la corteza terrestre en terrenos que radiquen en zonas inundables.

Sobre el particular le informo que las disposiciones del referido reglamento aplican a todas las áreas inundables para las cuales esta Junta de Planificación haya adoptado Mapas de Zonas Susceptibles a Inundaciones o Mapas de Zonas Provisionales Inundables. Los usos que se propongan en estas áreas, sean en estructuras o sobre el terreno, deben cumplir con las disposiciones reglamentarias establecidas. En el caso que nos ocupa, son de particular aplicación, sin limitarse a ellas, las disposiciones contenidas en la Subsección 6.02 (Usos en Zona-1).

Aunque normalmente, estas charcas no restan capacidad hidráulica, en la Zona-2 se debe requerir que se demuestre mediante un análisis hidráulico que otras áreas adyacentes en Zona-2, no pasarán a formar parte del cauce mayor del río o quebrada y por ende deban ser reclasificadas a Zona-1.

Estamos a su disposición para servirle.

Cordialmente,

Adalberto Colón

Adalberto Colón
Vice-Presidente

APPENDIX IV:
OUTLINE: TASK 7.2

OUTLINE: TASK 7.2

LITERATURE SEARCH

1. Library research in local agencies and universities
2. Information request from selected agencies and organizations outside Puerto Rico
3. Preparation of reference file
4. Acquisition of relevant articles
5. Reading, analysis and application of articles

DEVELOPMENT OF METHODOLOGY AND DATA BASE

1. Island-wide inventory of extraction sites
   a. Permit file research (Permits Office, DNR)
   b. Form preparation in large index cards to include key file information per study case
   c. Aerial photo evaluation and field inspection of areas to verify file information, as needed
   d. Preparation of inventory map of extraction sites to include general site location, pit code
2. Evaluation and selection of monitoring sites
3. Individual monitoring site study and description
   a. Detailed analysis of maps (topographic, geologic, hydrologic, soil, ecologic, others) and photos (aerial and land)
   b. Field work to collect data to prepare detailed site description: study of the physical, chemical, biologic, and ecologic parameters of each site
   c. Determine quantity and location of observation wells to be installed per selected site, establish a monitoring program

OUTLINE: TASK 7.2 (CONT.)

d. Tabulation of collected pit data to include but not be restricted to the following:

   1) Open-pits active/inactive

      a) bathymetry   b) flora/fauna distribution
      c) adjacent ground-water levels/conductivities
      d) conductivity   e) experimental fishery

   2) Closed pit areas

      a) type and distribution of backfill
      b) ground-water level in filled areas and adjacent terrain
      c) ground-water conductivity
      d) flora/fauna distribution
      e) land use

e. Preparation of detailed map of each monitoring site to include identification of past and present extent of work area, fill, vegetation and well distribution, location of nearby bodies of water, and other pertinent data

f. Detailed study of gathered monitoring site information

   a) Integration and analysis of collected data
   b) Summary of findings
   c) Recommendations based on findings

APPENDIX V:
PROGRESS REPORT: GENERAL HYDROGEOLOGY OF SELECTED COASTAL SAND EXTRACTION SITES IN PUERTO RICO

PROGRESS REPORT

General Hydrogeology of Selected Coastal Sand Extraction Sites in Puerto Rico

By
Arturo Torres-Gonzalez,
Bruce Green
and
Angel Roman-Mas

UNITED STATES GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
SAN JUAN, PUERTO RICO

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INTRODUCTION

In July 1987, the Puerto Rico Department of Natural Resources (PRDNR) requested the assistance of the United States Geological Survey (USGS) to conduct a hydrologic investigation of sand extraction sites along the coast of Puerto Rico. The PRDNR regulates the sand extraction industry by granting permits and approving extraction sites, techniques and rehabilitation methods. The department lacked the technical means to evaluate the effects of sand extraction by open-pit mining on the ground-water hydrology of coastal zones.

The USGS study addresses the lithology, water quality, water levels, flow patterns, and hydraulic properties of coastal aquifers in sand-extraction areas located in Ponce, Camuy and Aguada (fig. 1). These comercial sand extraction sites represent different coastal ecological zones on different stages of the open-pit mining process. Previous studies (Zack 1982) indicate that sand extraction from dunes can lower water tables and cause degradation of adjacent environments.

A total of sixteen test wells were drilled to depths ranging from 8.5 feet to 37 feet. The wells were monitored for changes in water level and water quality from August to December 1987. Hydraulic tests (slug-injection) were completed in September 1987 to define the hydraulic properties at each well site. Data compilation and analysis, through early 1988, culminated in this final report.

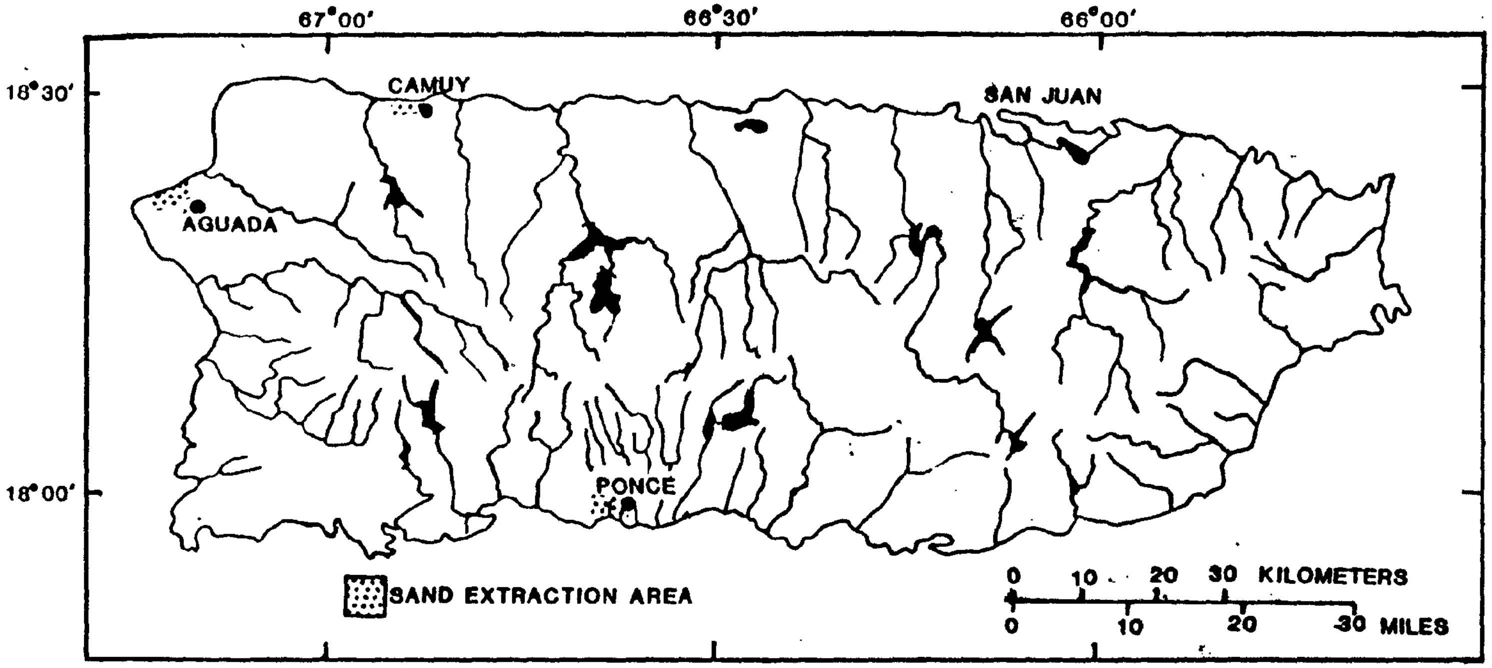


Figure 1.-- Location of sand extraction areas included in this study

TEST WELLS

A total of 16 shallow test wells were drilled in the Ponce, Camuy, and Aguada study areas (fig. 1) to gather lithologic, water quality, and water-level data .

Test wells no. 1, 2, 3, 4, and 5 were drilled in Ponce, east of Laguna de las Salinas and south of El Tuque community in Barrio Canas (fig. 2). The wells were drilled to depths ranging from 14 feet to 37 feet, generally in a sandy matrix. All test wells except no.3 collapsed at the bottom when drill stems were removed out of the borehole. Casings of PVC with 5-ft long screens were installed at each hole (figs. 5 to 9).

Test wells no. 6, 7, 8, 9, 10, and 11 were drilled in Camuy, south of Punta Penon in Sector Membrillo (fig. 3). The wells were drilled to depths ranging from 9 feet to 19 feet in a site mostly characterized by limestone fill material. Wells no. 6, 10, and 11 collapsed at the bottom when drill stems were removed. Location of screens are shown in Figures 10 through 15.

Test wells no. 12, 13, 14, 15, and 16 were drilled in Aguada between Rio Grande on the west and Cano de Santi Ponce on the east (fig. 4). The wells were drilled to depths between 15 feet and 42 feet into sand deposits and limestone. Test wells no. 12, 14, and 15 collapsed at the bottom when drill stems were removed from the hole. Location of screens are shown in figures 16 through 20.

General Lithology

The general lithology of test wells 1 to 16 is described below:

TW-1 PONCE: The upper 5 feet of the well was fill material consisting of dark-yellow sand mixed with organic matter and limestone rubble. The lower 7 feet were medium-grained sand changing to fine sand mixed with gravel.

TW-2 PONCE: From 0-4 feet medium to fine sand with organic material, from 4-9 feet fine sand with increasing quantities of shells.

TW-3 PONCE: Clay mixed with fine sand and shells from 0-4 feet changing to dry to moist clay with limestone rubble and shell fragments to the bottom at 37 feet.

TW-4 PONCE: Dark-yellowish sand was found from 0-4 feet followed by fine to medium gray-green sand to 29 feet. Limestone occured from 29-34 feet.

TW-5 PONCE: Gray-green sand mixed with shells changing to predominantly sand to 10 feet.

TW-6 CAMUY: Light brown coarse sand mixed with some organic material 0-4 feet. This changed to cemented sand to the bottom of the hole at 9 feet.

TW-7 CAMUY: A dark yellow-brown sandy clay mixed with topsoil was found to 3 feet. Cemented sand to the bottom at 8.5 feet.

TW-8 CAMUY: The entire depth of 11.5 feet was composed of silty sand with some cemented sand.

TW-9 CAMUY: Topsoil with limestone fragments and sand to 3 feet, followed by sandy, silty clay to 7 feet. From 7 feet to the bottom, coarse-cemented sand was encountered.

TW-10 CAMUY: The entire length was composed of dark yellow-brown silty sand mixed with limestone rubble.

TW-11 CAMUY: Yellow-brown clay with topsoil predominated from 0-4 feet. From 4-9 feet clayey sand changed to mostly sand. Cemented sand with yellow-orange clay followed to the bottom at 16 feet.

TW-12 AGUADA: Predominantly yellow-brown sand with traces of cemented sand the entire hole.

TW-13 AGUADA: Dark yellow-brown fine sand from 0-3 feet. Dark yellow limestone was found to the bottom of the hole at 14 feet.

TW-14 AGUADA: Mostly fine sand with traces of limestone rubble 0-3 feet. A dark orange limestone followed to the bottom of the hole at 15 feet.

TW-15 AGUADA: Sand with topsoil was found 0-3 feet. Medium-grained sand changing to coarse grained sand continued to the bottom at 11 feet.

TW-16 AGUADA: A hard yellow-orange limestone was found the entire 23 feet of the well.

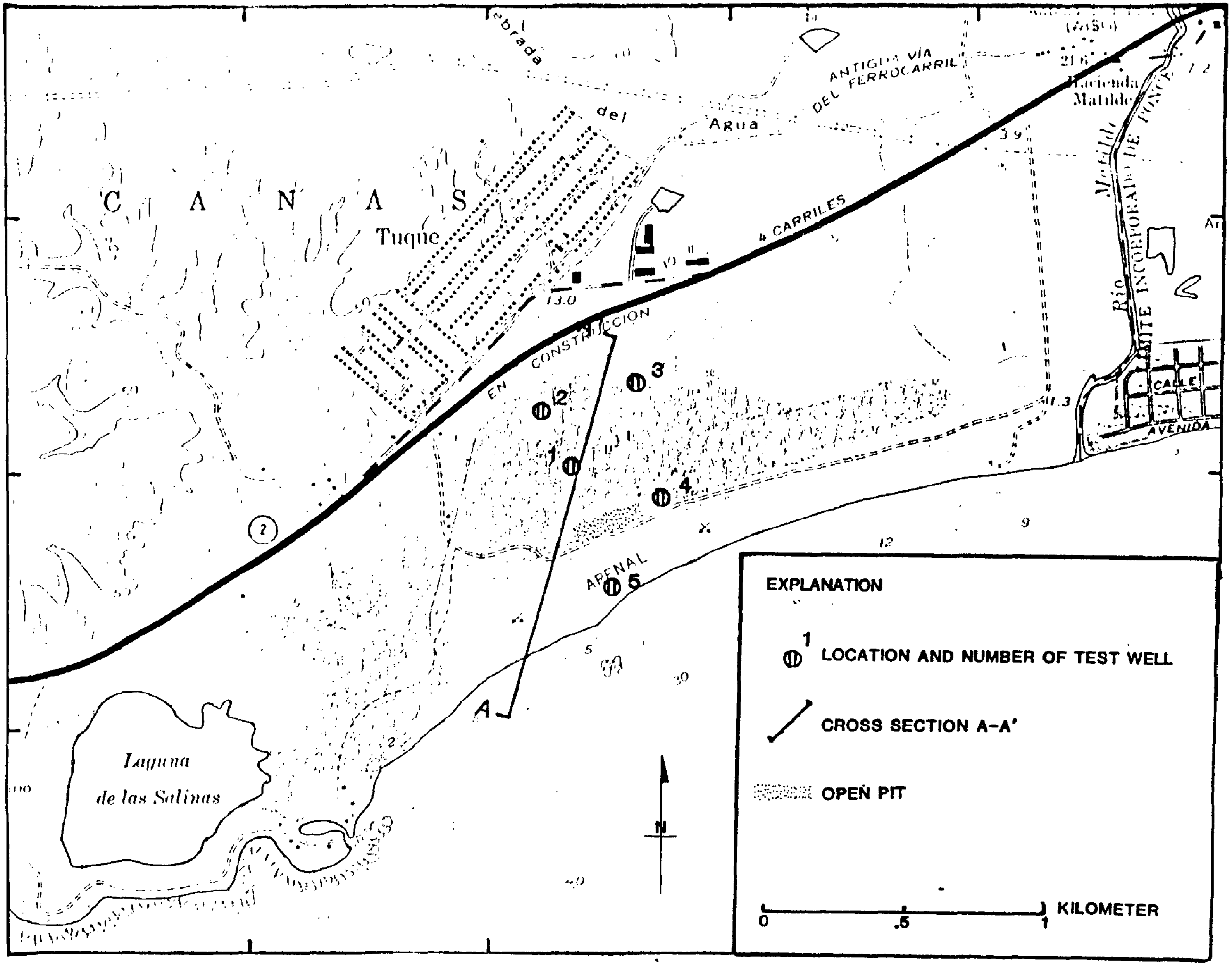


Figure 2.--Location of test wells in the Ponce sand-extraction site,

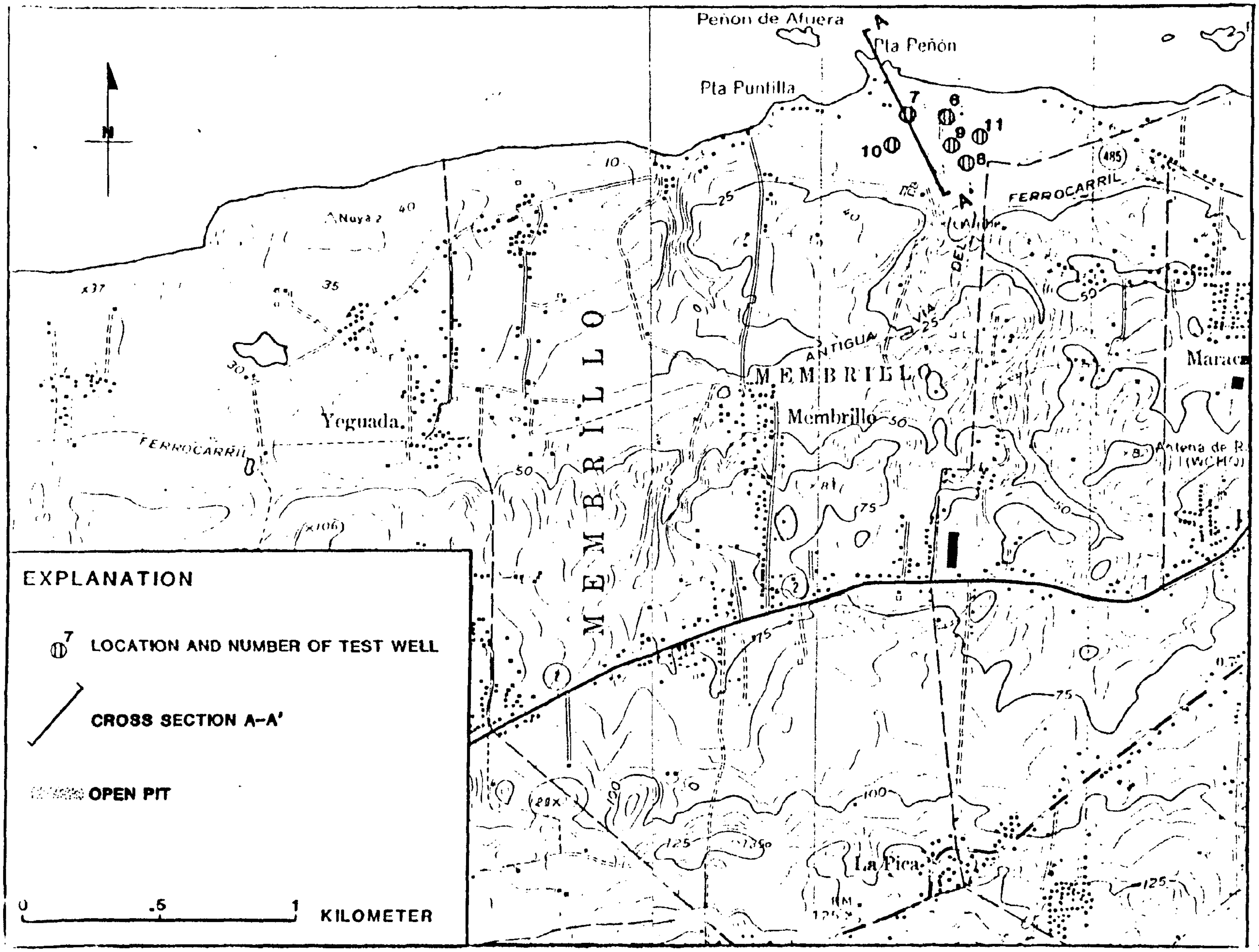


Figure 3.--Location of test wells in the Camuy sand-extraction site.

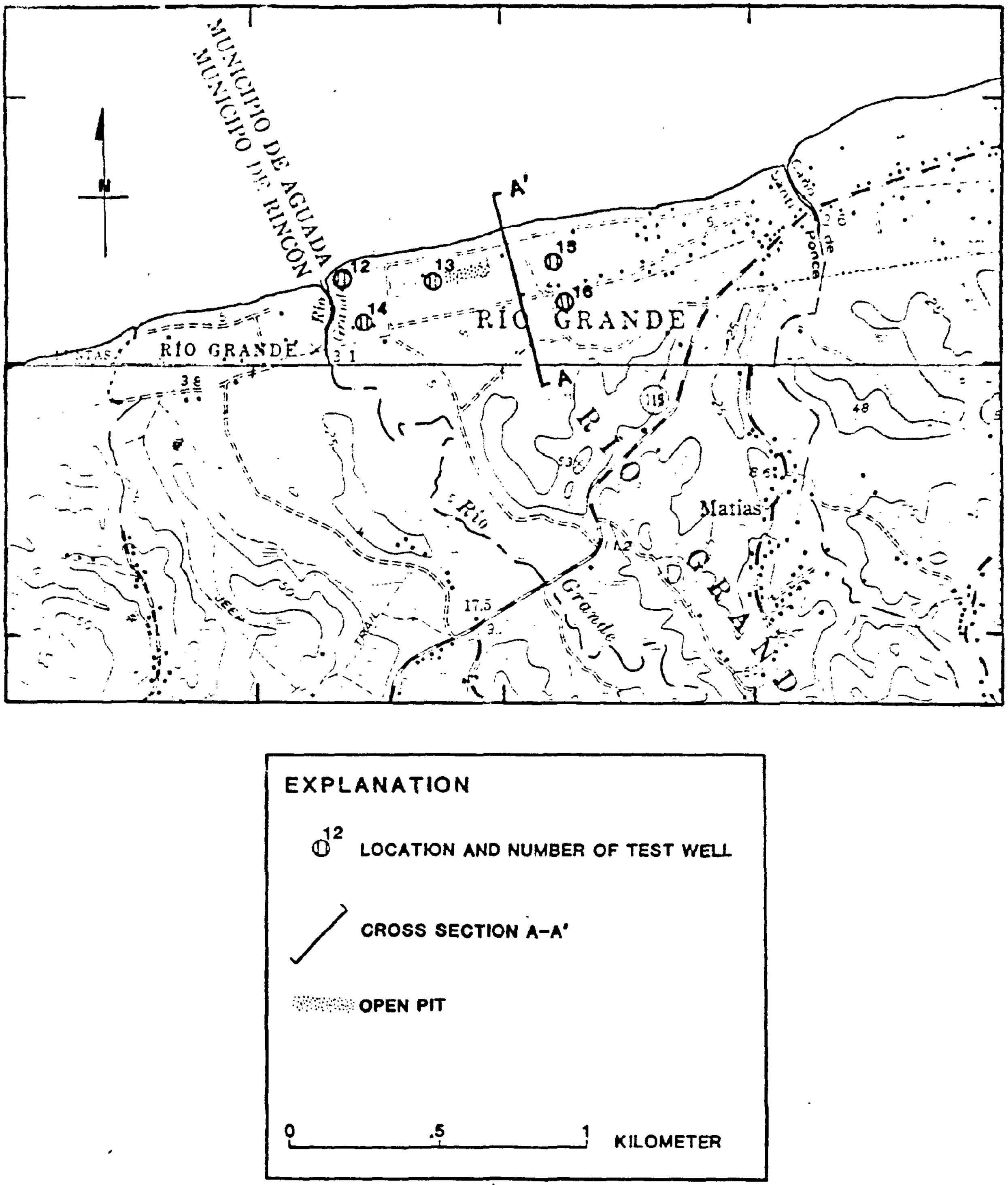


Figure 4.—Location of test wells in the Aguada sand-extraction site.

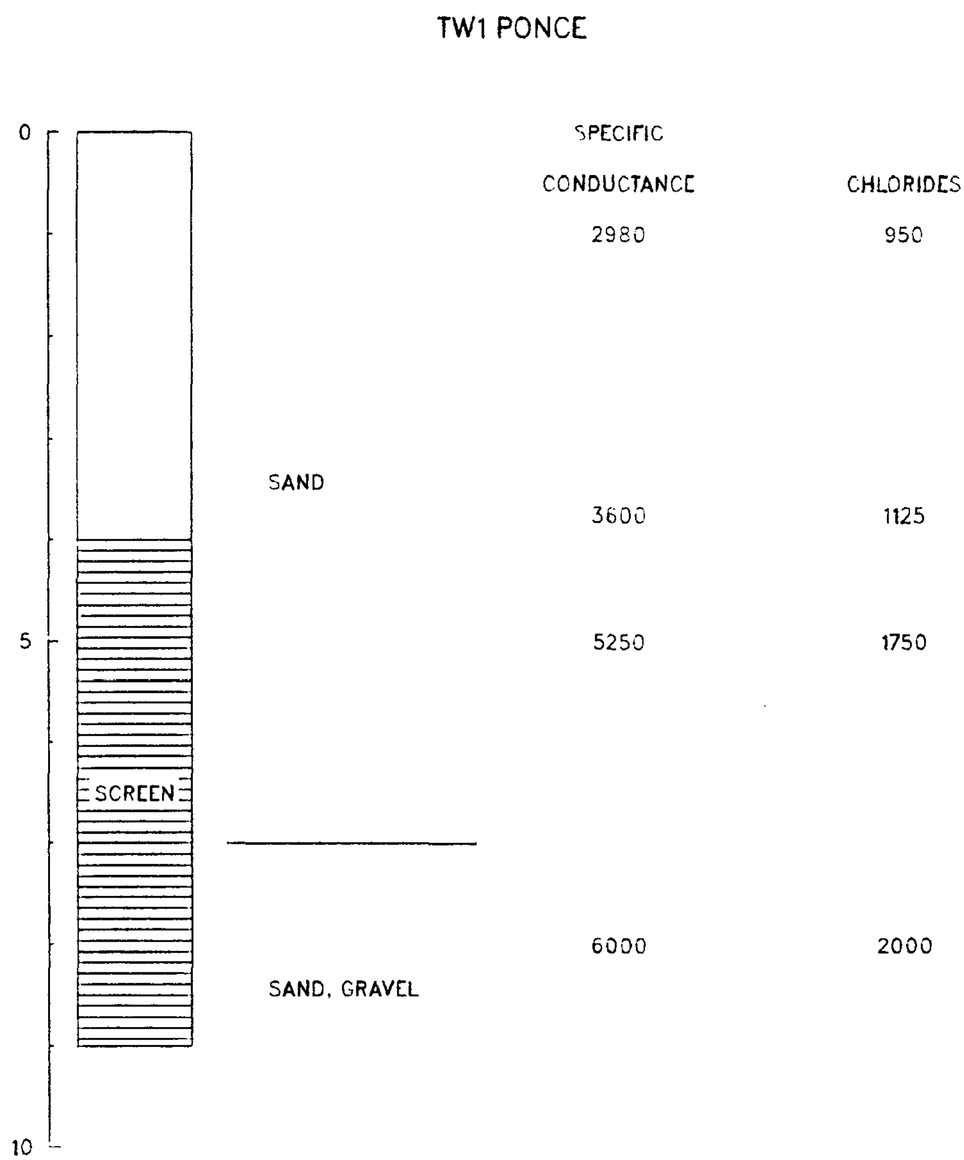


FIGURE 5.--LITHOLOGY AND WATER-QUALITY DATA
FOR TEST WELL 1 AT PONCE

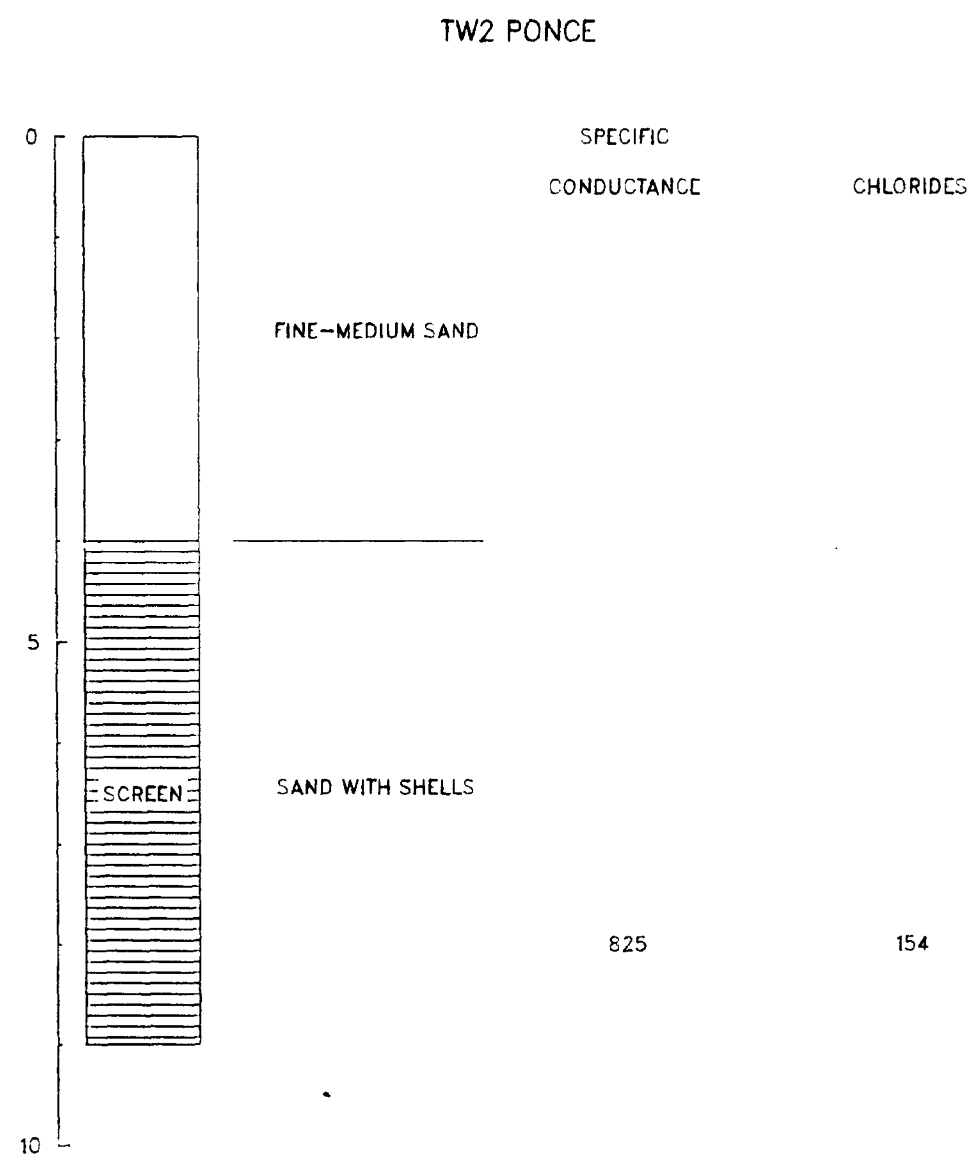


FIGURE 6.-- LITHOLOGY AND WATER-QUALITY DATA
FOR TEST WELL 2 AT PONCE

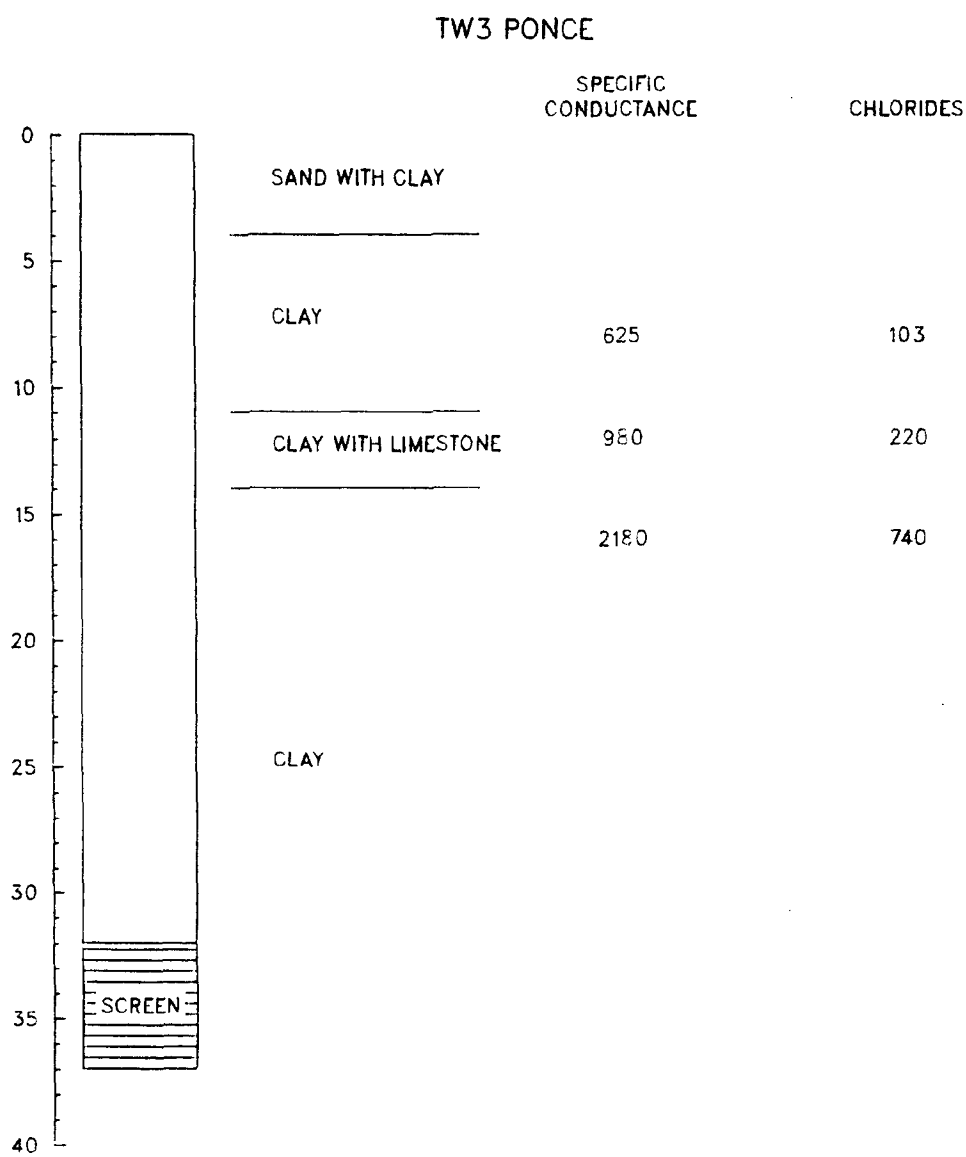


FIGURE 7.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 3 AT PONCE

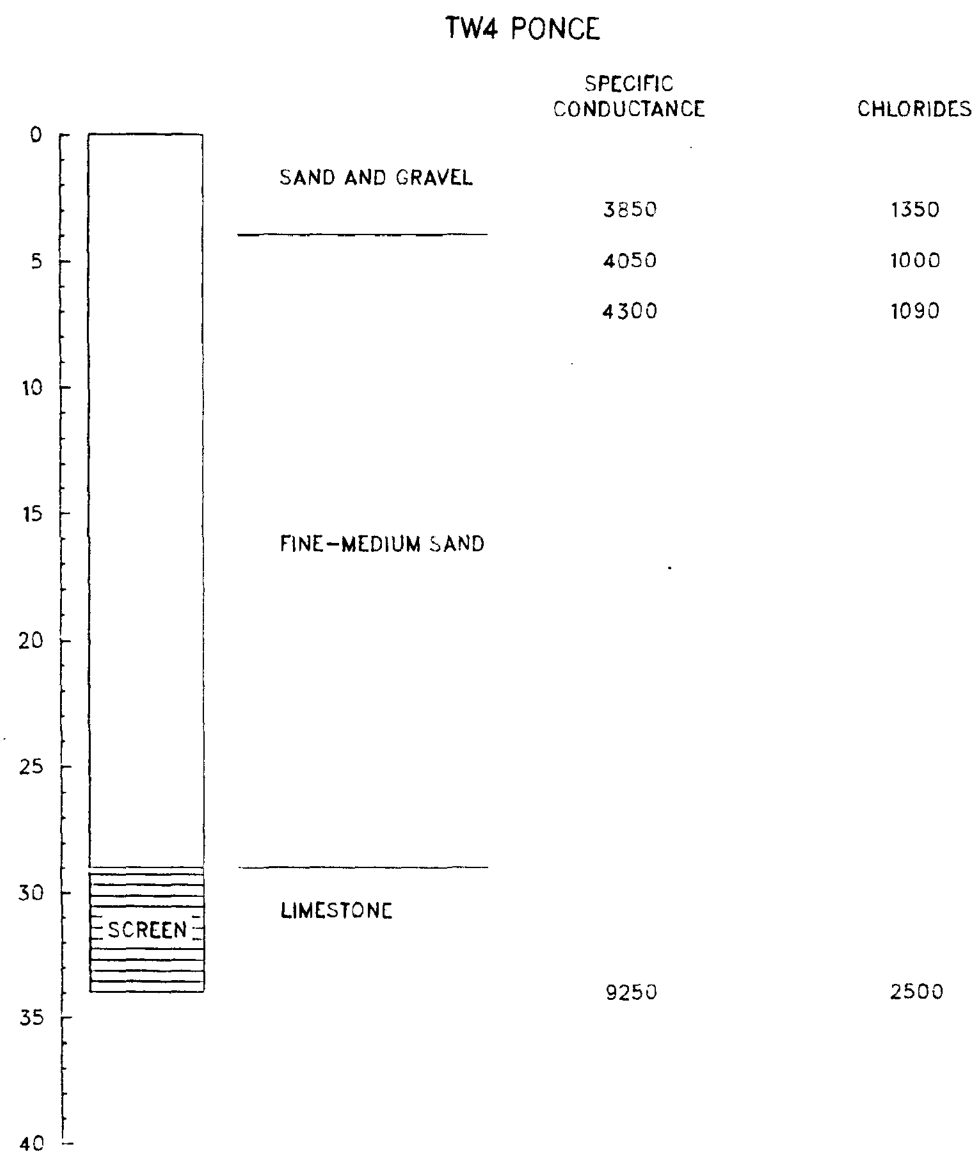


FIGURE 8.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 4 AT PONCE

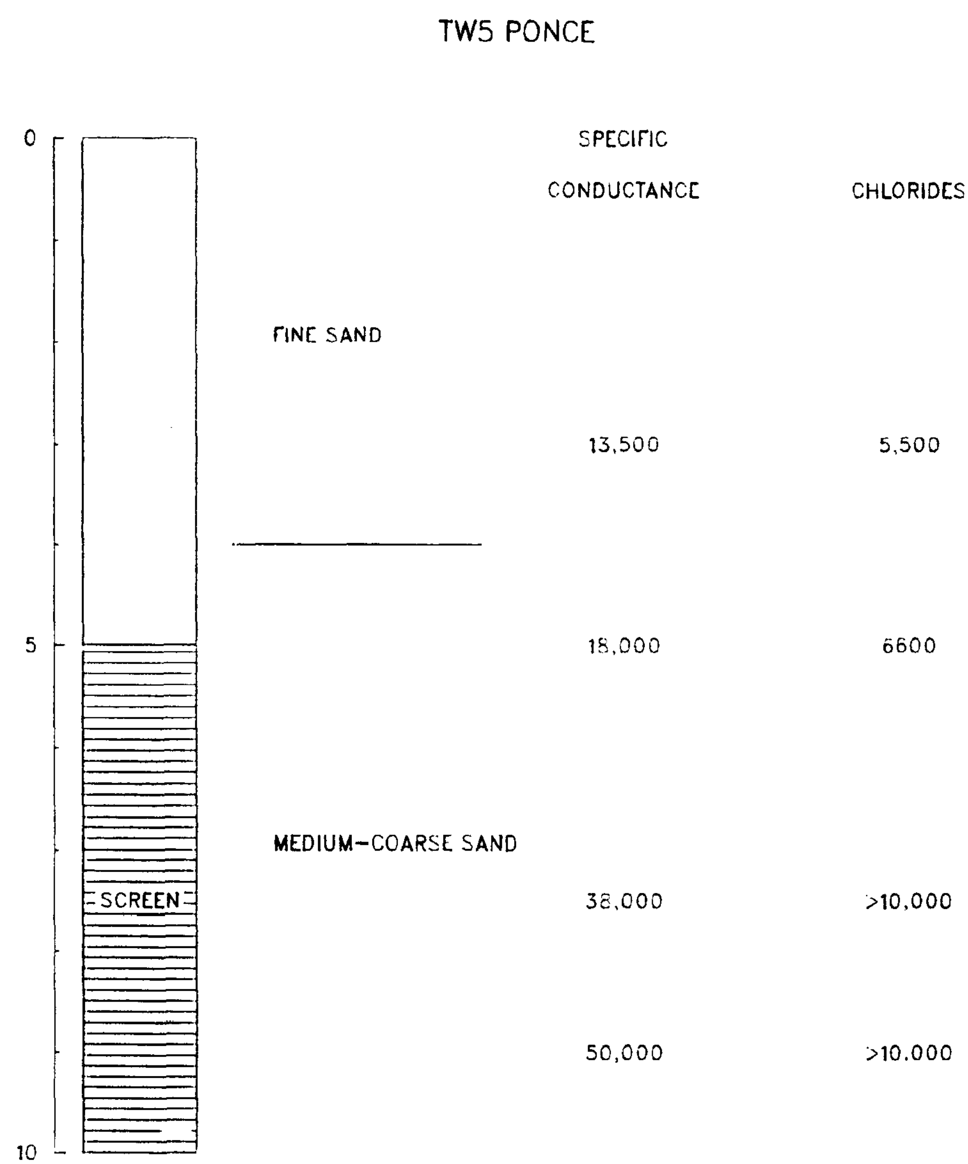


FIGURE 9.--LITHOLOGY AND WATER-QUALITY DATA
FOR TEST WELL 5 AT PONCE

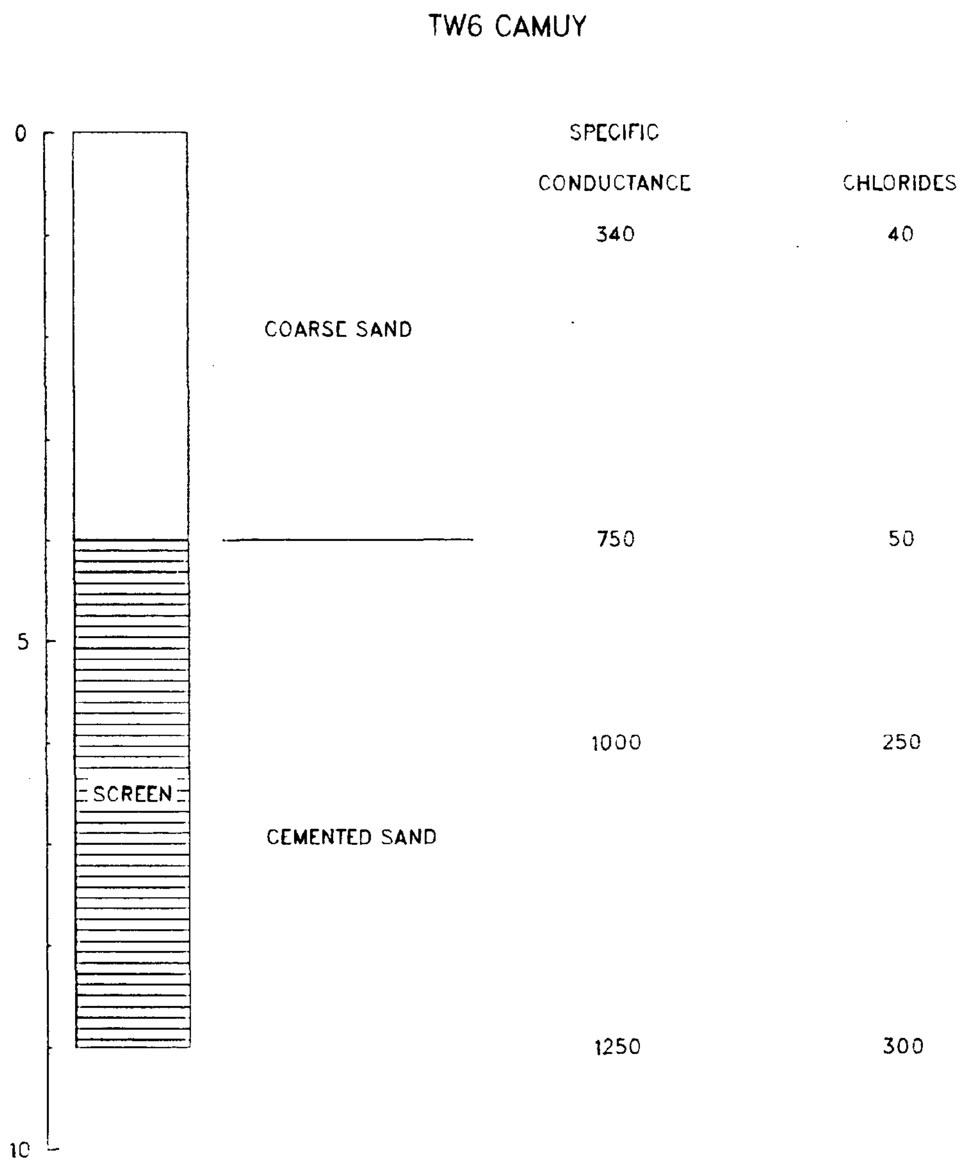


FIGURE 10.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 6 AT CAMUY

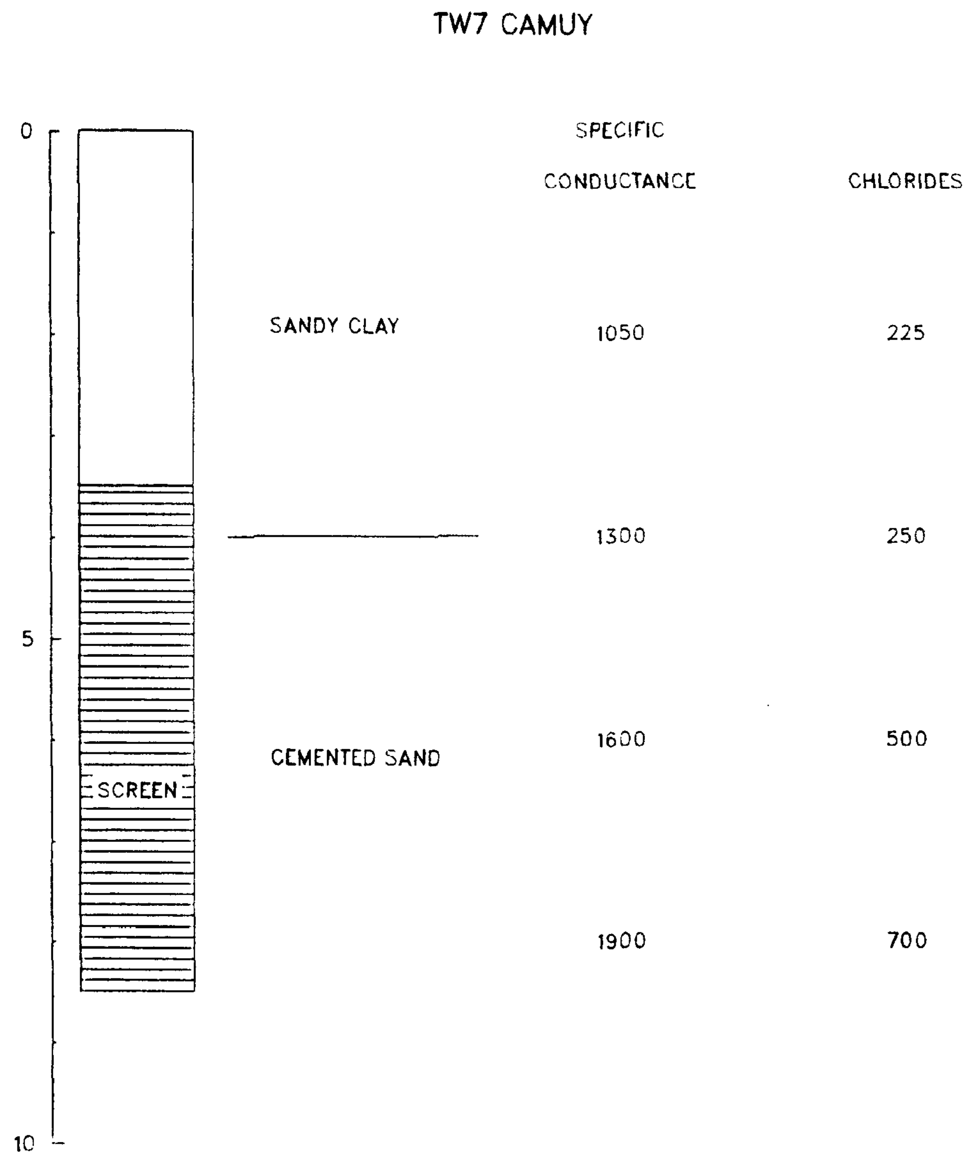


FIGURE 11.—— LITHOLOGY AND WATER—QUALITY DATA FOR TEST WELL 7 AT CAMUY

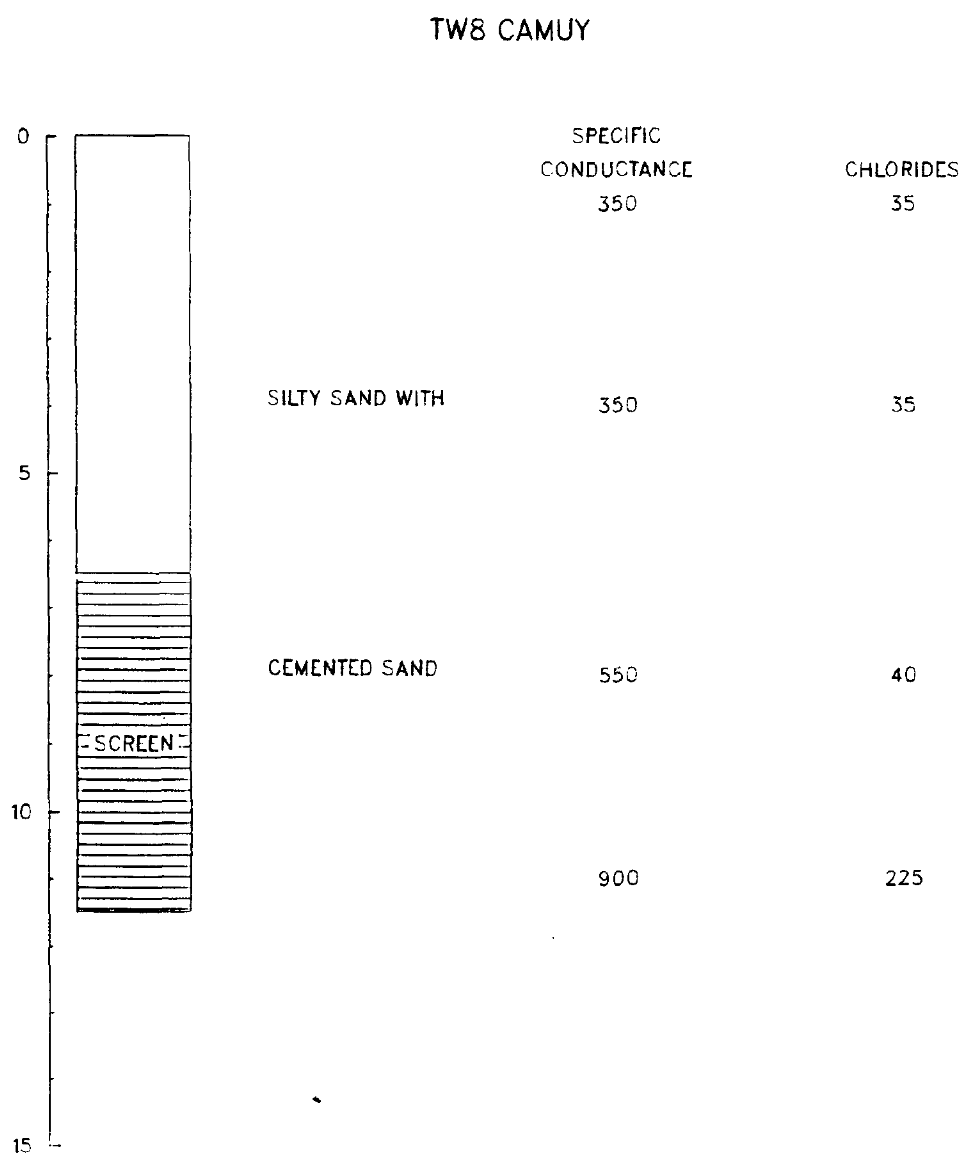


FIGURE 12.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 8 AT CAMUY

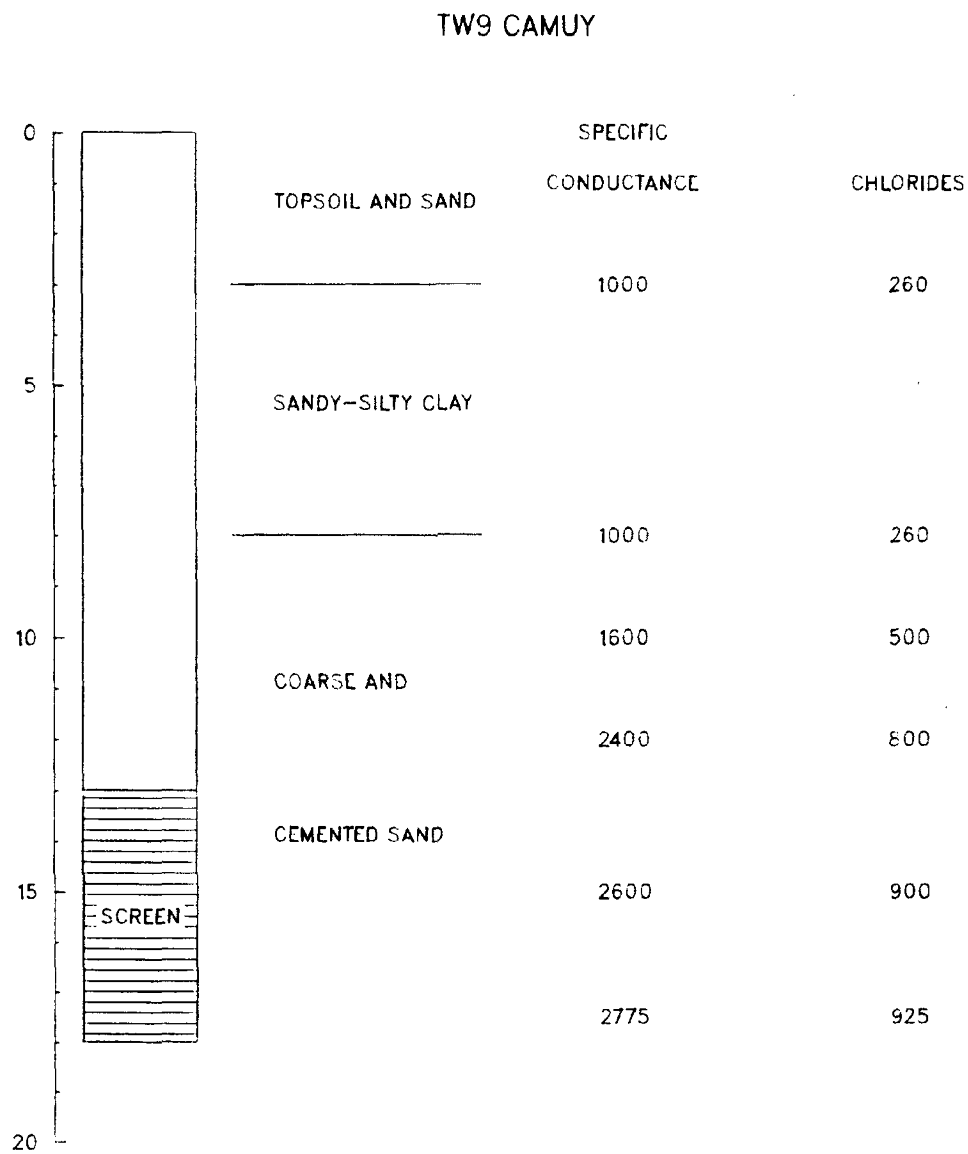


FIGURE 13.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 9 AT CAMUY

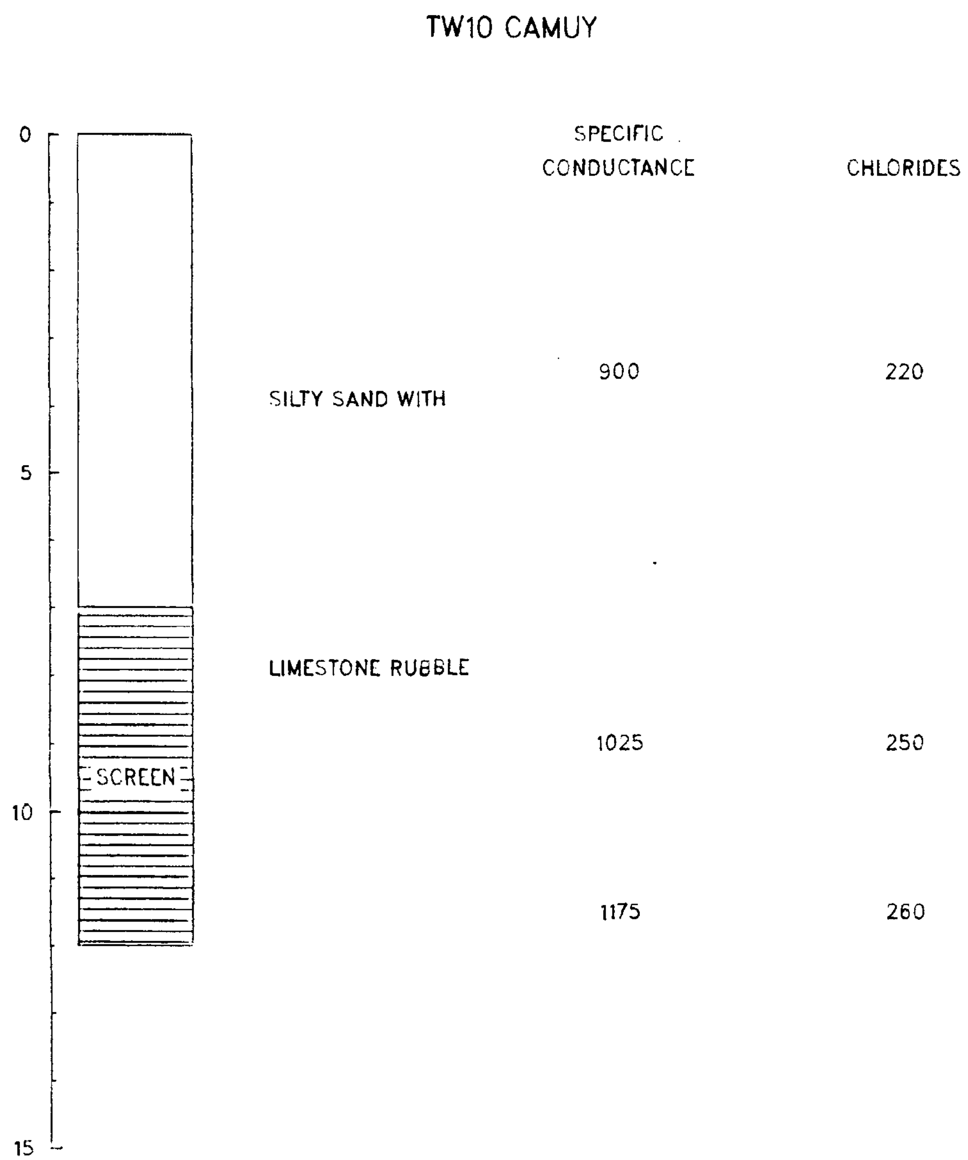


FIGURE 14.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 10 AT CAMUY

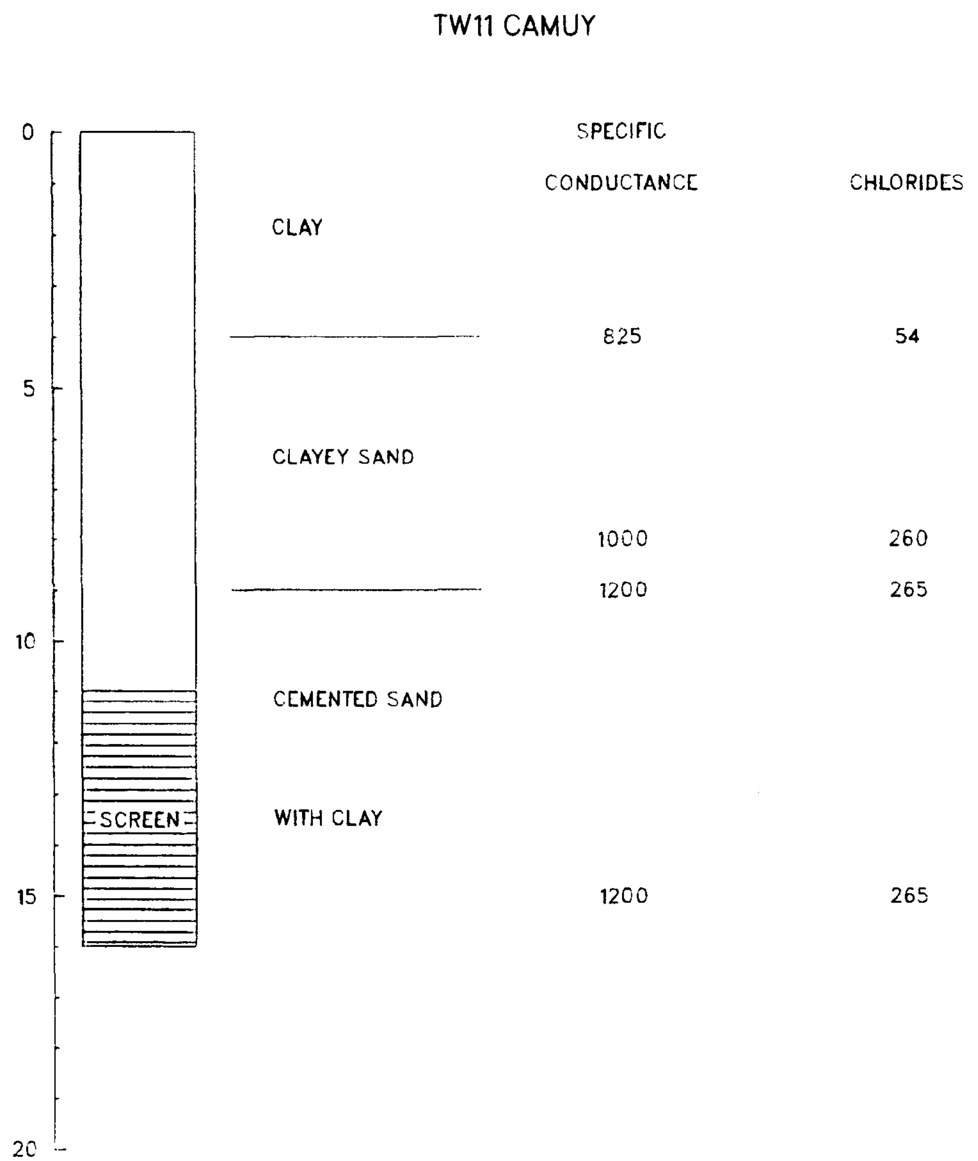


FIGURE 15.--LITHOLOGY AND WATER-QUALITY DATA
FOR TEST WELL 11 AT CAMUY

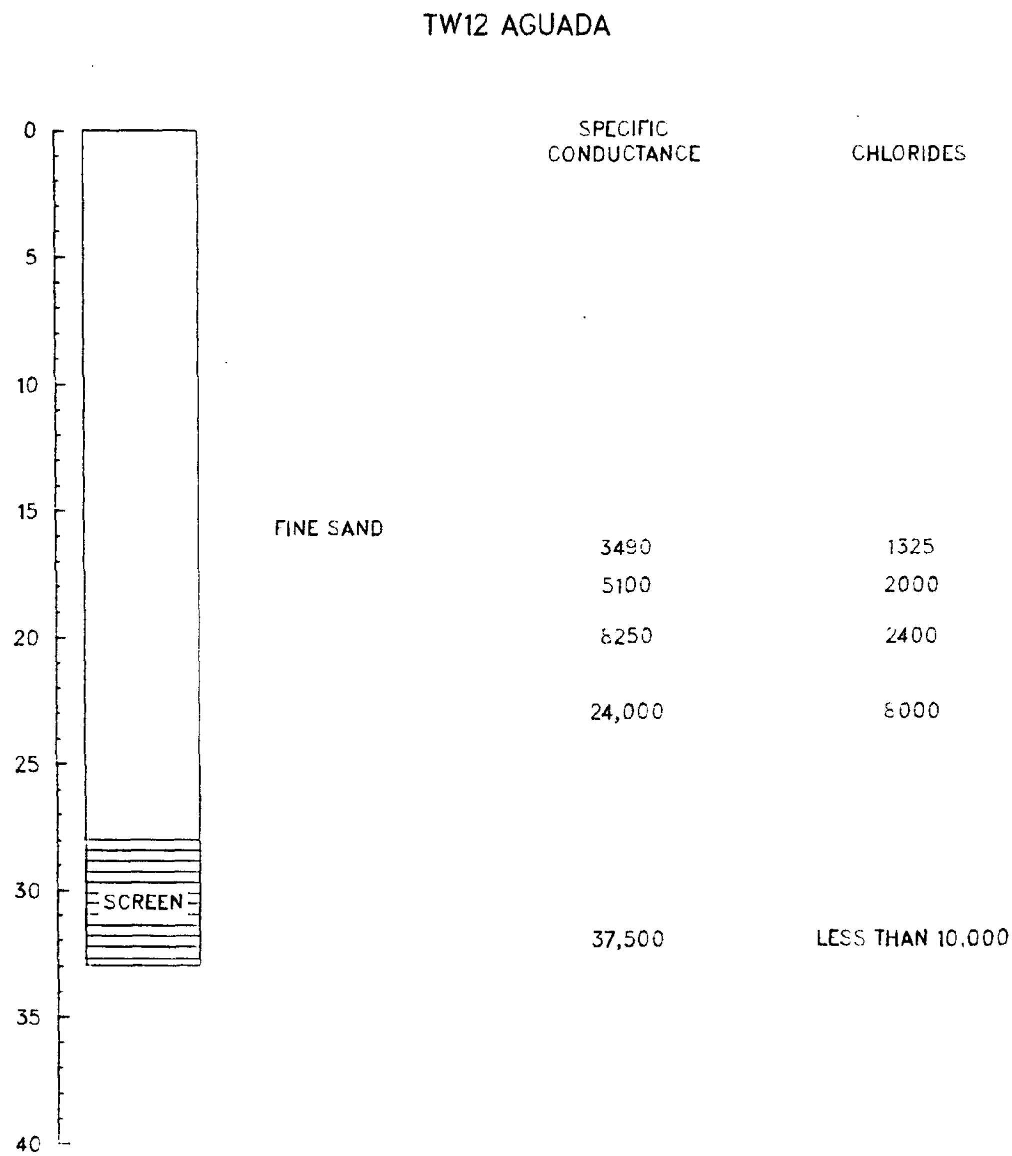


FIGURE 16.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 12 AT AGUADA

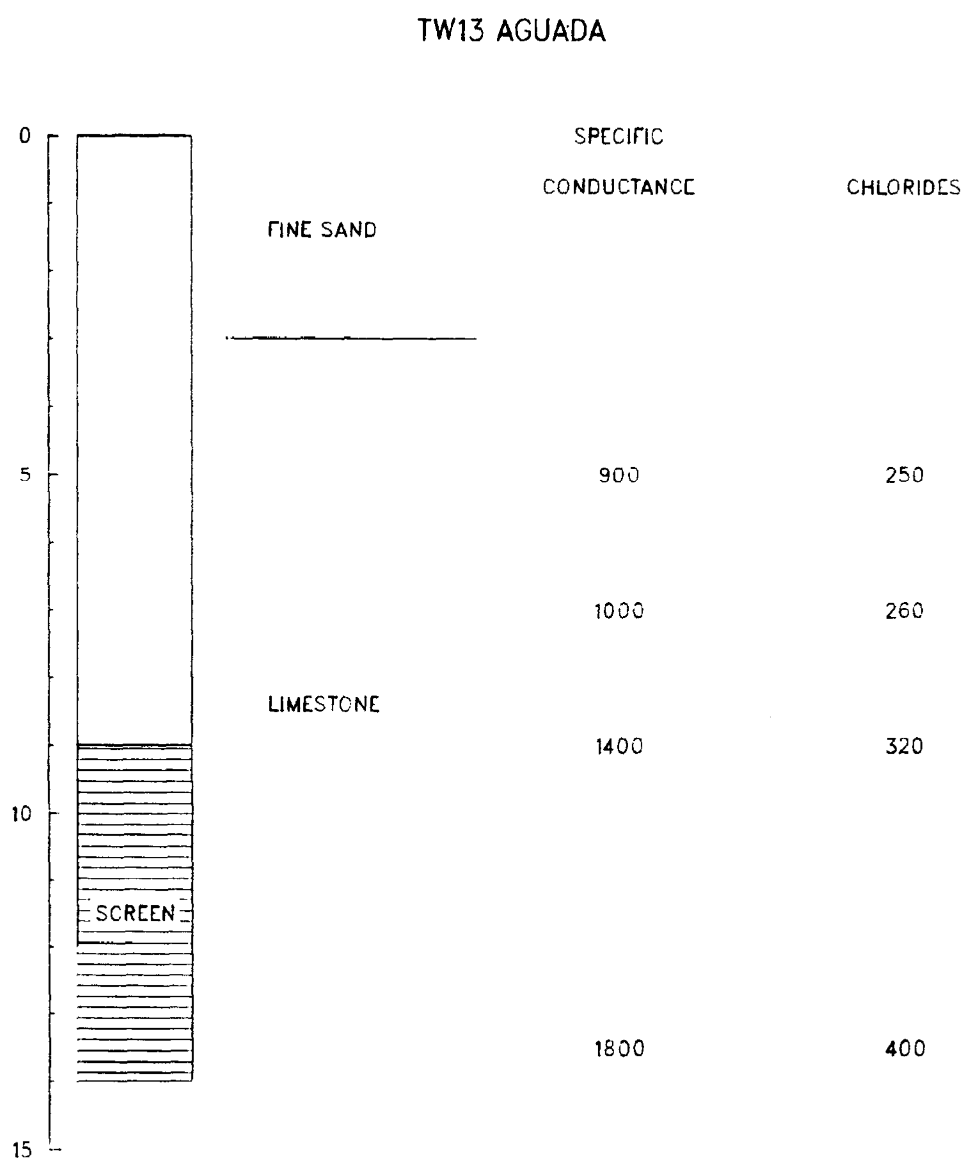


FIGURE 17.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 13 AT AGUADA

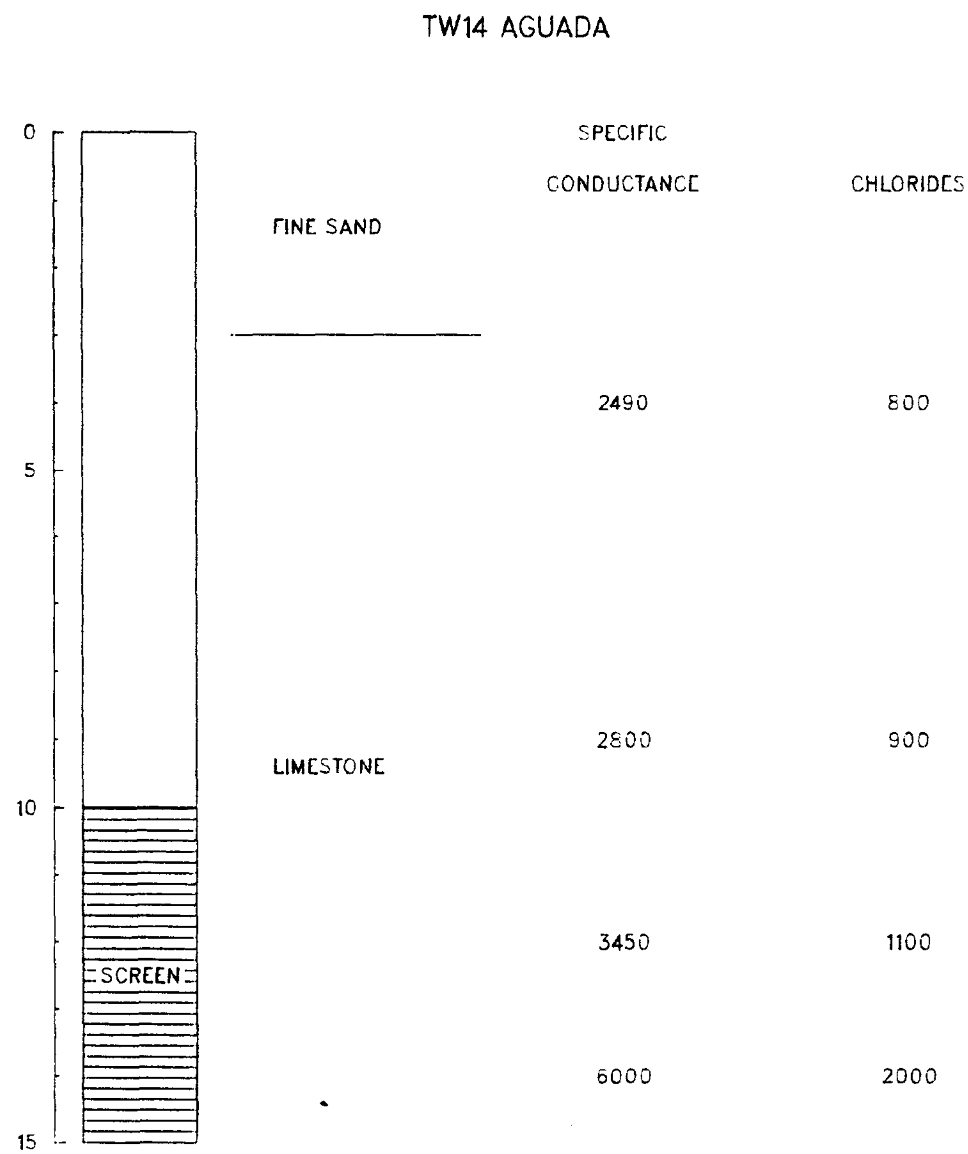


FIGURE 18.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 14 AT AGUADA

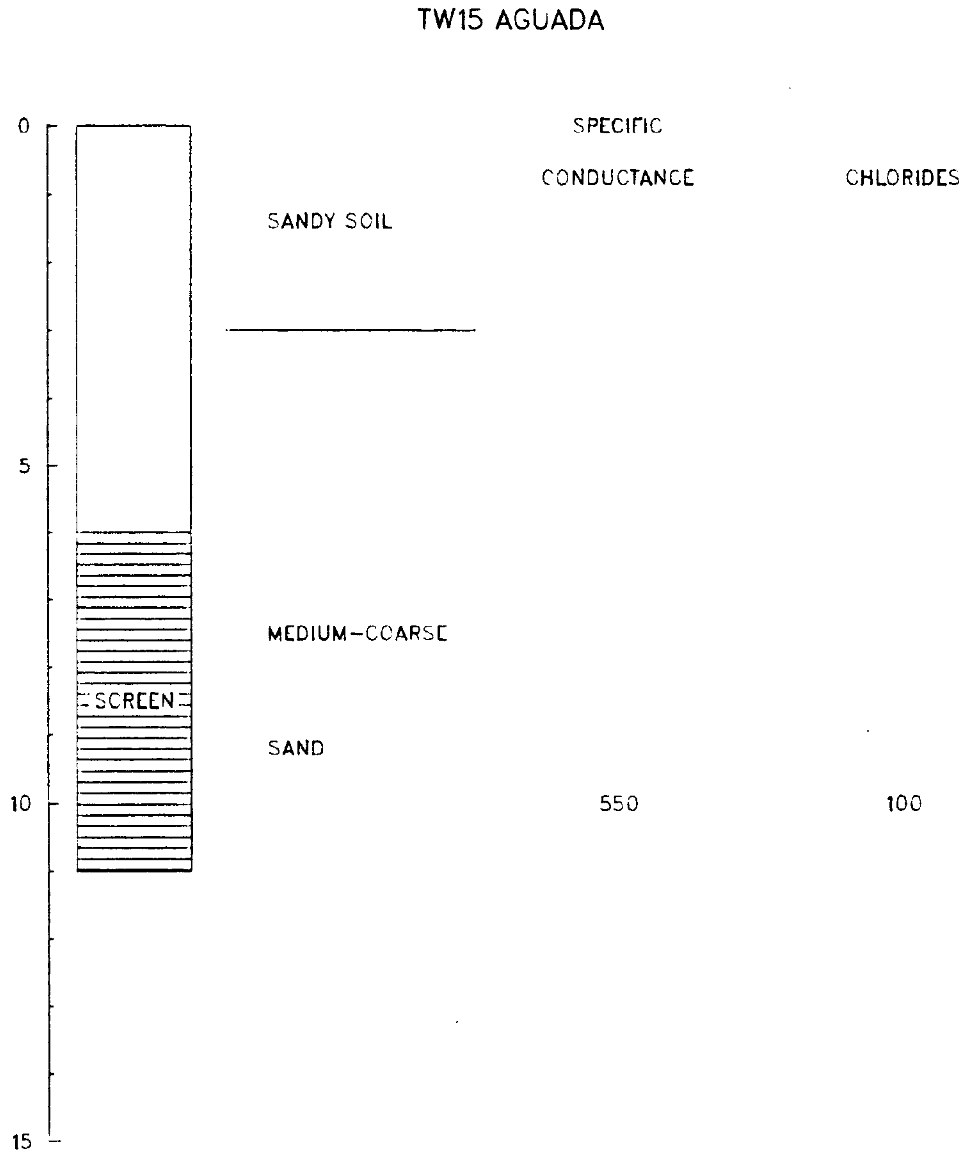


FIGURE 19.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 15 AT AGUADA

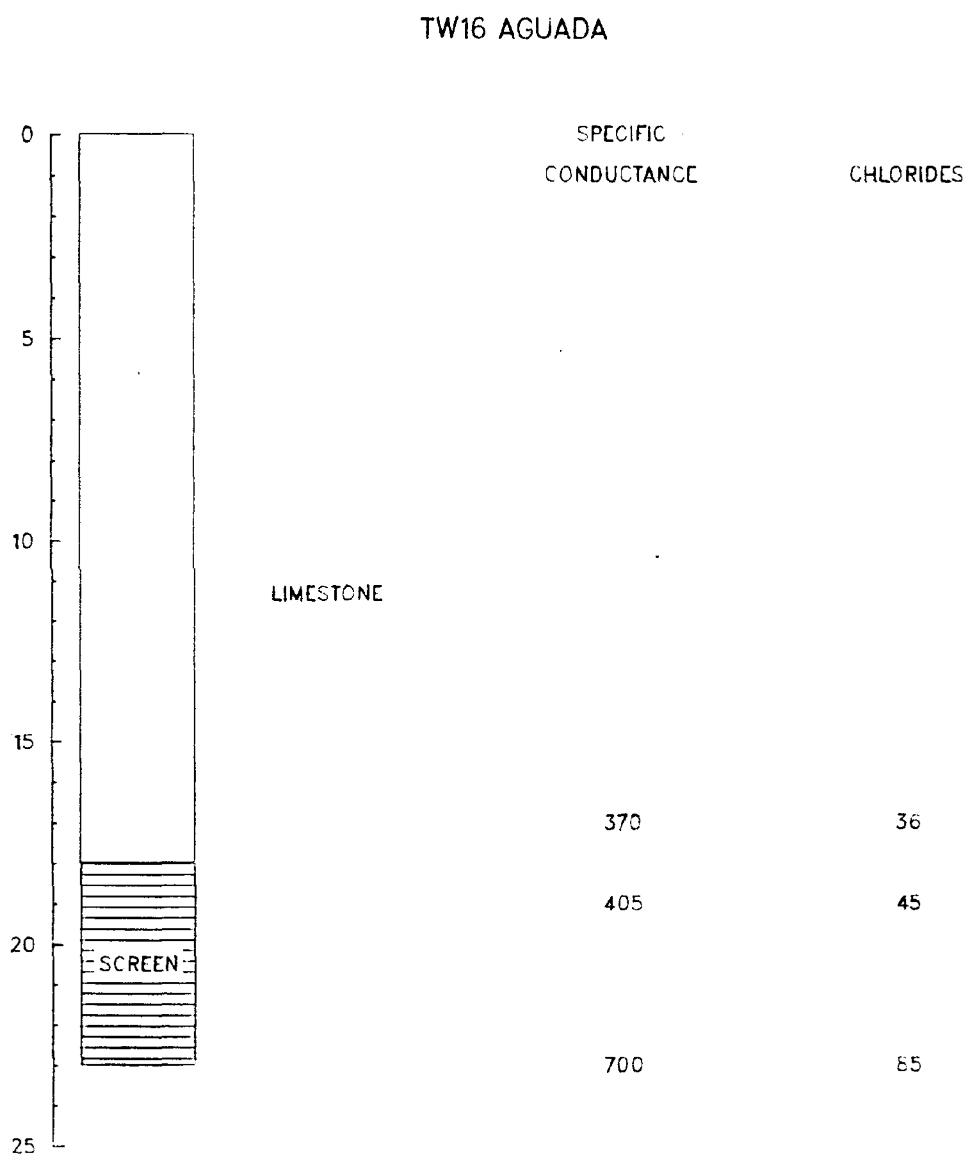


FIGURE 20.--LITHOLOGY AND WATER-QUALITY DATA FOR TEST WELL 16 AT AGUADA

WATER QUALITY

Water quality analyses for this study were limited to specific conductance and chloride determinations for specific depth samples collected at each test well during a field trip on November 1987 (figs 5 to 20). Samples were also collected for active open pits found in Ponce and Aguada (figs. 21 and 22). Specific conductance was field measured while chloride analysis was conducted at the USGS laboratory using the specific-ion probe technique.

Chloride and specific conductance increase toward the coast and with depth as a result of seawater intrusion. In Ponce, as a response to the drier climatic conditions, a very thin freshwater lens and a more inland freshwater-saltwater interface is observed in comparison to Aguada and Camuy. The thicker freshwater lenses at Camuy and Aguada, due to higher rainfall, inhibit the inland migration of the interface.

The highest values for specific conductance and chloride were obtained at Ponce. In test wells at Ponce, specific conductance values ranged from 625 to 50,000 microsiemens per centimeter, whereas chlorides ranged from 103 to greater than 10,000 miligrams per liter (figs. 5 to 9). Specific conductance in the open pit at Ponce increased with depth from 1350 at the surface to a maximum of 14,000 usiemens/cm at a depth of 6 feet (fig.21). In Camuy test wells specific conductance ranged from 340 to 2,775 usiemens/cm whereas chlorides ranged from 40 to 925 mg/l (figs. 10 to 15). In the Aguada test wells specific conductance ranged from 370 to 37,500 usiemens/cm and chlorides ranged from 36 to slightly less than 10,000 mg/l (figs. 16 to 20). In the open pit at Aguada, values of specific conductance remained constant at 500 usiemens/cm both areally and with depth (fig.22).

Based on a conceptualized model of coastal zones, it is possible to infer that sand extraction by the open-pit method may affect the relative position of the freshwater-seawater interface. The removal of saturated sand deposits can locally alter the permeability of the aquifer matrix thus, allowing the interface to either move inland or seaward. The overall displacement of the interface will be defined by the duration of the open pit mining and the hydrogeologic characteristics of each site. The inland migration of the interface and the resulting increase in salinity may stress the local ecosystems. In arid areas, such as Ponce, displacement of the interface results in the development of hypersaline conditions. This would result in damage to the nearby mangrove forest which is already at the limit of its adaptive capabilities. The displacement of the interface also affects the freshwater lens within the sand dunes and its plant community. The health of the plant community and its stabilizing function on the dunes would be compromised.

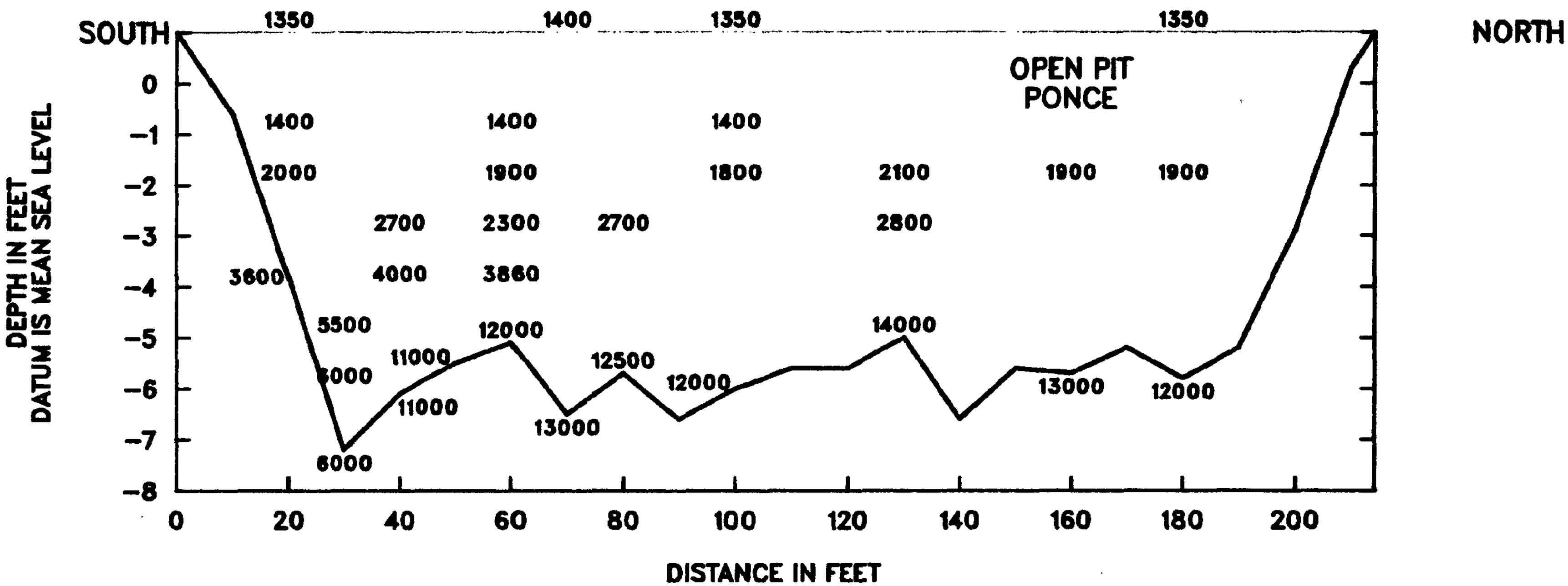


Figure 21—Specific conductance distribution for open pit in the Ponce sand extraction area.

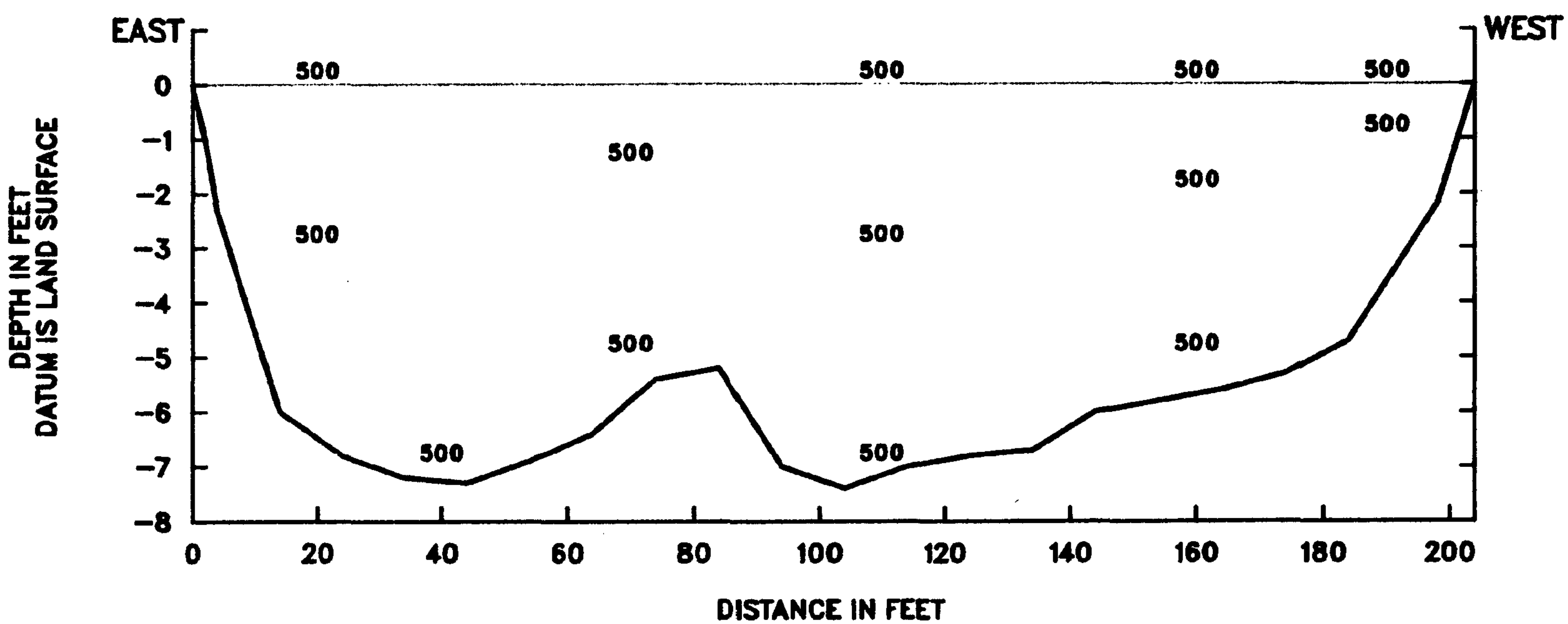


Figure 22--Specific conductance distribution for open pit in the Aguada sand extraction area.

WATER LEVELS

All test wells were measured for water levels on at least two separate occasions. The first set of measurements was obtained immediately upon completion of the drilling and development of the wells. A second set of measurements was conducted on December 1-5, 1987 during a field reconnaissance with personnel of the P.R. Department of Natural Resources.

Water levels were plotted on topographic maps (scale 1:20,000) to delineate water-table contours and ground-water flow lines (figs. 23, 25, and 27). Cross sections were also constructed to describe general hydrogeologic features of the sites (figs. 24, 26, and 28).

Sand extraction operations in Ponce apparently have caused a distortion in the direction and movement of ground water at the site. Flow lines near test well no. 5 appear to converge (fig. 23) to an open-pit excavation that acts as a drainage feature to the local ground-water system. Prior to the excavation, local flow lines in the vicinity of the pit were generally parallel. The effects of the open pit on the water-table surface can also be observed in the hydrogeologic section shown in figure 24. The water level in the dune, near test well 5, dropped about 3 feet as a result of the excavation pit. This pit has locally increased the permeability in the aquifer and acts as an open-evaporation reservoir which drains water from the local ground-water system thus depressing the surrounding heads in the aquifer.

In the Camuy sand-extraction site the configuration of the water-table surface (fig. 25) apparently responds to the high permeability of the backfill material. The test wells were drilled and developed in an area which had been completely excavated and subsequently partially backfilled with foreign material (limestone rubble and boulders). The fill, with its corresponding structural arrangement making it relatively permeable, replaced sand deposits apparently of lower permeability. As a result of this backfilling with permeable material, surrounding heads in the aquifer probably could have been depressed not only temporarely but, also on a permanent basis. Although the regional pattern of ground-water movement is northward, the flow lines in figure 25 suggest a localized movement slightly northwest toward the extraction zone. The aquifer at this site exhibits a relatively flat water table (fig. 26) which is typical of highly permeable zones. The hydrogeologic cross section shows also the difference in elevations between the previous and existing land surfaces.

Sand extraction operations in the Aguada site apparently have caused changes in the hydrology of the area. Three existing hydrogeologic features in the area seem to exert some control,to varying degrees, in the hydraulics of the ground-water system; (1) the unextracted sand deposits on the east that are of relatively

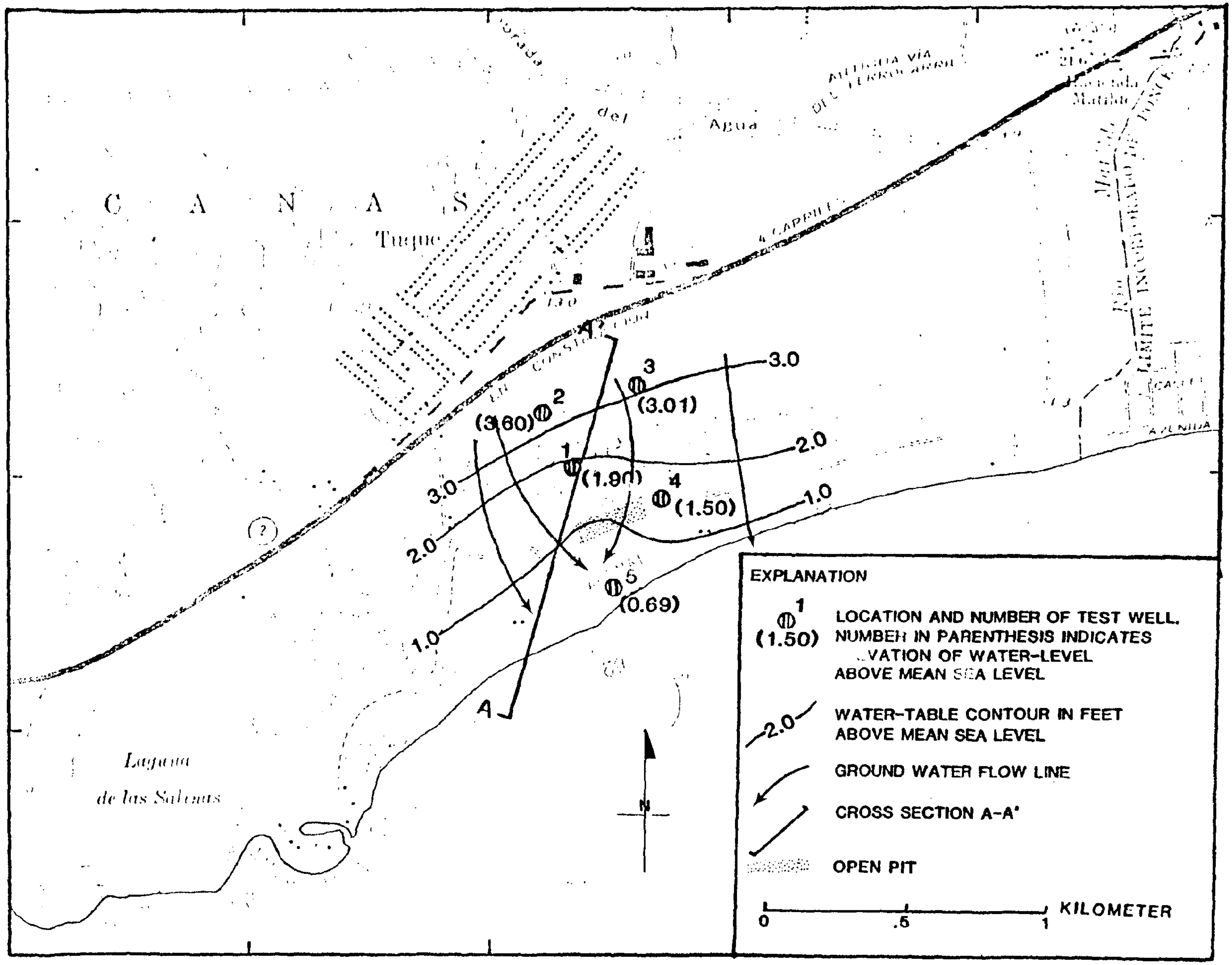


Figure 23 Water-table configuration map in the Ponce sand-extraction site.

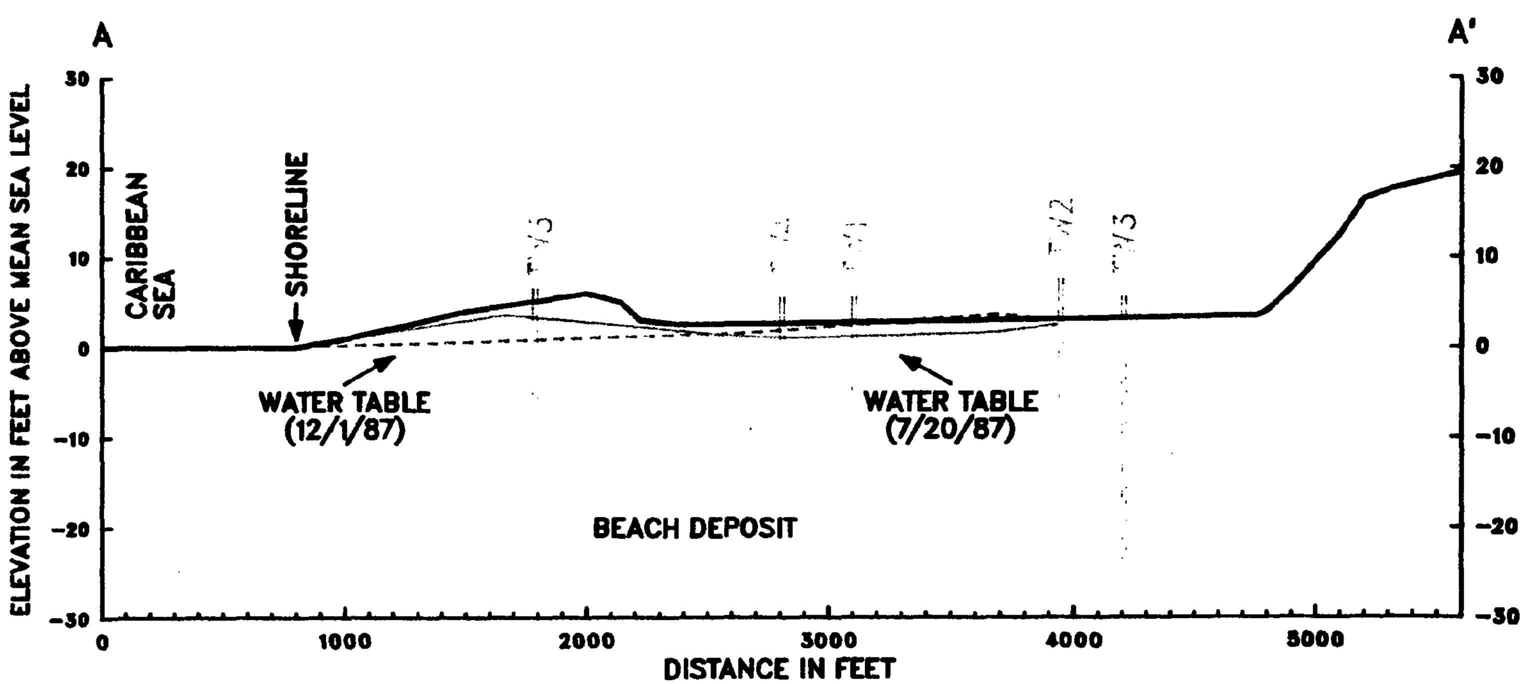


Figure 24---Hydrogeologic cross section A-A' along the Ponce sand-extraction site.

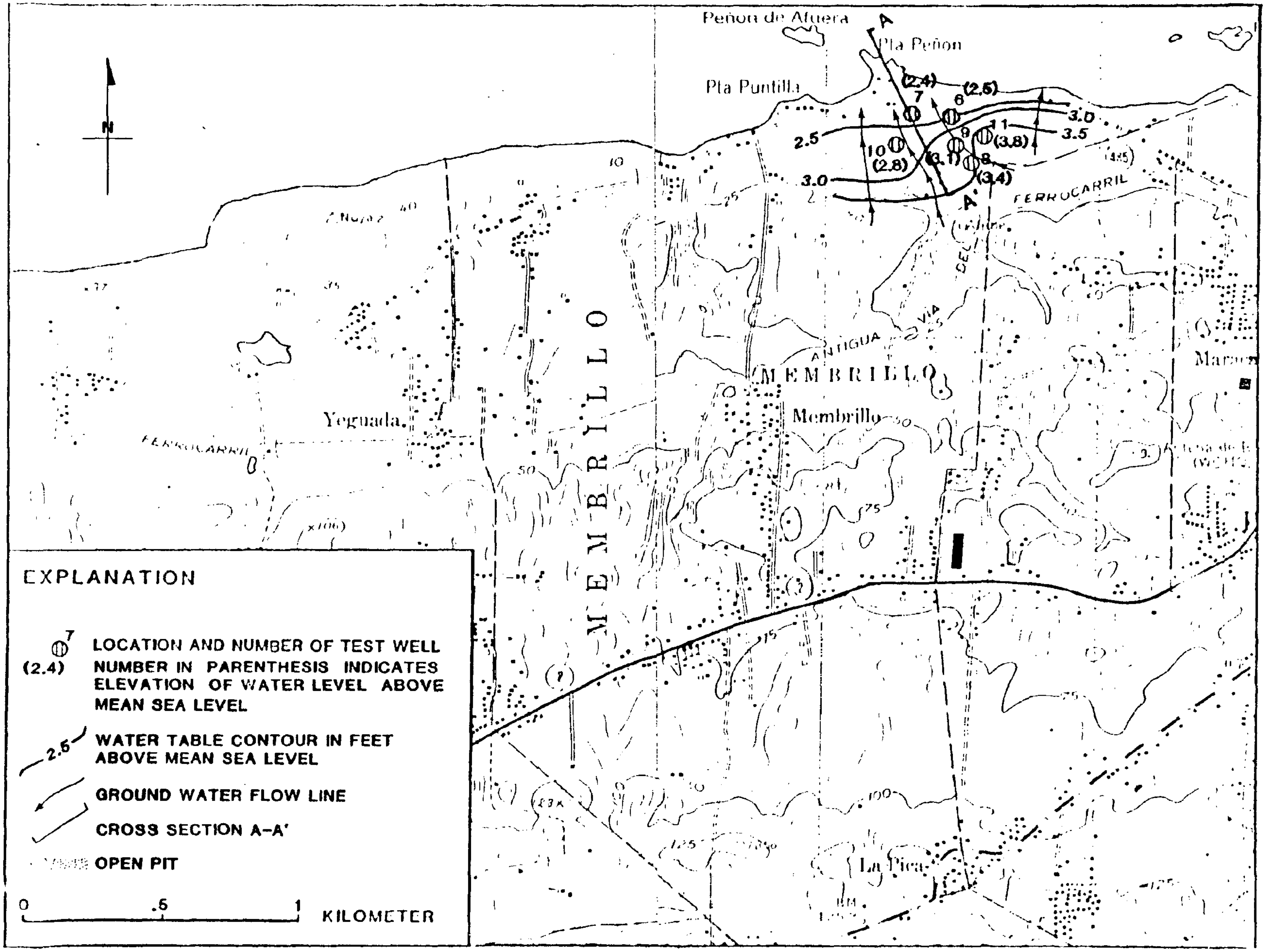


Figure 25 Water-table configuration map in the Camuy sand-extraction site.

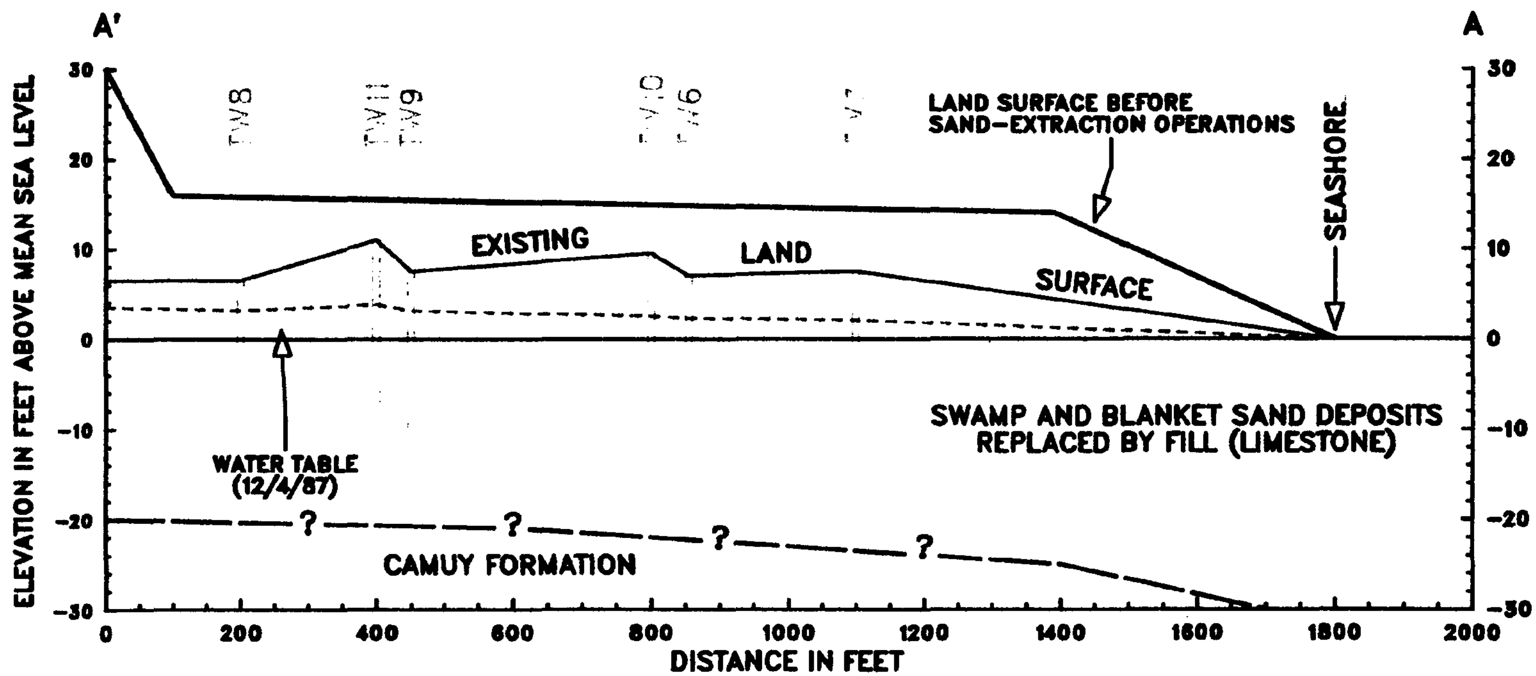


Figure 26--Hydrogeologic Cross Section A-A' in the Camuy sand-extraction site.

high permeability, (2) the limestone unit underneath (Cibao Formation) that is also very permeable, and (3) the backfilled material apparently of relatively low permeability. The sand deposits seems to be the most conspicuous hydrologic feature. Their high permeability permits greater movement of ground water through this area causing the flow lines to converge (fig. 27). Hydraulic gradients along these sand deposits are relatively flat (fig. 28). On the other hand, the western portion of the study area, where sand extraction operations have occurred and the site backfilled with lower permeability material, is characterized by steeper slopes and the existance of a localized water-table mound. Flow lines in this particular area exhibits a pattern of divergence (fig.27). Water levels in the dune apparently have not been depressed by sand extraction operations (contrary to what occurred in Ponce) as they still remain high (fig. 28). The water-table mound described above probably has maintained the water levels from dropping in the dune.

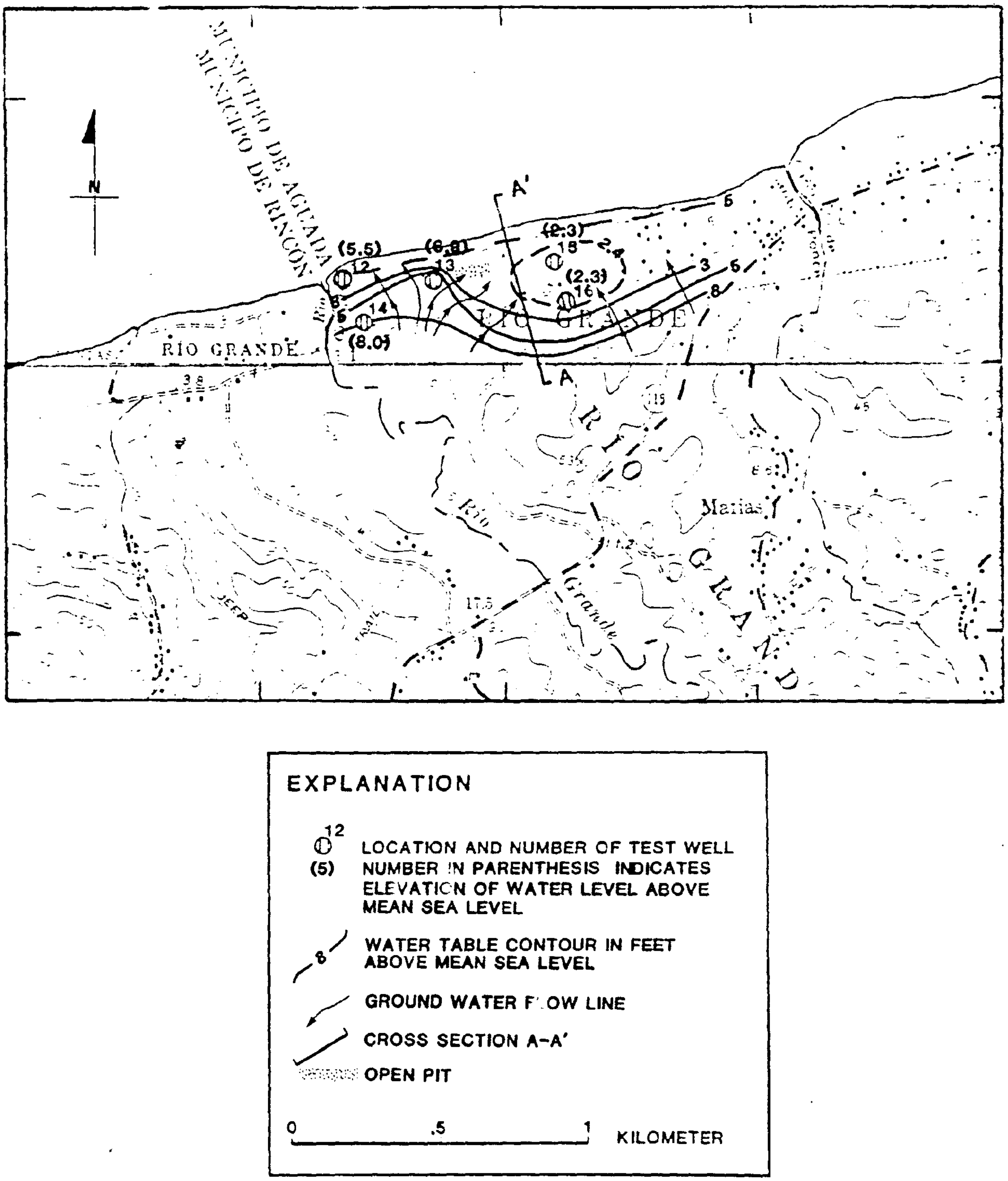


Figure 27 Water-table configuration map in the Aguada sand-extraction site.

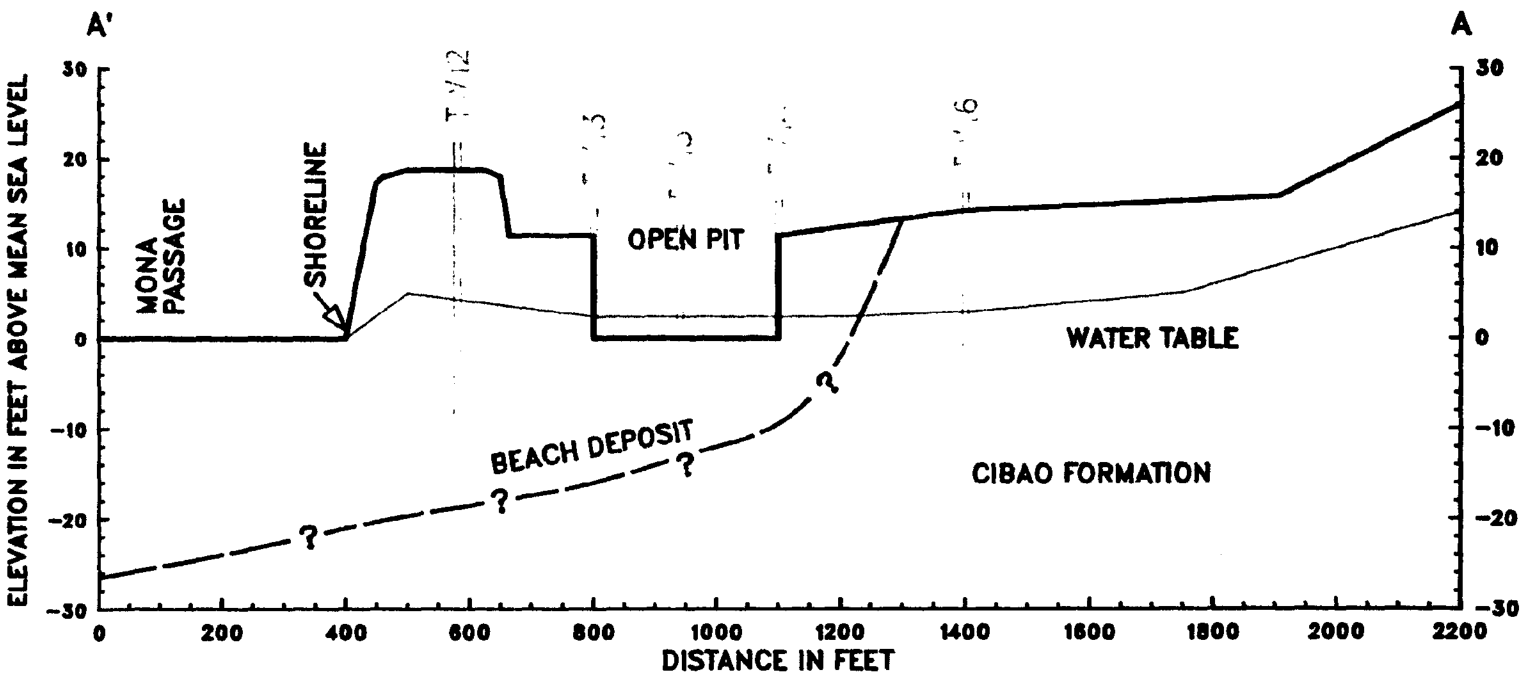


Figure 28—Hydrogeologic cross section A–A' along the Aguada sand–extraction site.

Hydraulic Tests

"Slug injection" tests were performed at all 16 well sites on Sept. 1-3, 1987 to determine relative hydraulic conductivities and/or transmissivities of the formations near the screened area of the wells.

The basic premise of the "slug method" as defined by Cooper, et. al.(1967) in "Response of a Finite-Diameter Well to an Instantaneous Charge of Water" is: "In areas lacking either flowing wells or wells equipped with pumps, it may be desireable to obtain at least an estimate of the transmissivity of the aquifer by use of the so-called "slug method". In this method a known volume or "slug" of water is suddenly injected into or removed from a well and the decline or recovery of water level is measured at repeated intervals during the ensuingd minutes".

The equipment necessary to perform the tests is: 1) a calibrated bucket with a funnel tube on the bottom, 2) steel and electric measuring tapes, and 3) a pressure transducer coupled to a micro-logger. The pressure transducer is a titanium alloy probe connected to a 400 ft cable that reads water pressure above the probe in pounds per square inch (PSI) and converts it to water level in feet above the probe. This is connected to a portable micro-logger that reads the signals from the transducer up to 30 times a second and displays the information in a time/water level format. The micro-logger can be programmed to specific starting water levels and ranges and measures changes in head to 0.01 inches.

At the beginning of a test, the probe is placed to a specified depth below the surface of the water in the well and secured. The static water level is then measured and noted. The calibrated bucket is then filled with a certain quantity of water, usually 1 to 3 gallons. The bucket is then placed over the well with the funnel tube inside the opening at the top of the well. At a prearranged time, the micrologger is started and the plug pulled from the bucket, allowing the water to fall "instantaneously" into the well. The water level rises immediately and then starts to fall as the water seeps into the formation. The micrologger reads the changes in levels at specific intervals and converts them to a semi-log cycle format. The "recovery" is plotted later as a semi-log curve (Appendix A,B, and C) and serves as the basis for the determination of transmissivity (T).

Water levels are monitored during the test and when they return to static conditions, the test is completed. The data from each test is stored on a channel in the micro-logger and transferred into the main United States Geological Survey computer.

H/Ho CURVE MATCHING METHOD

The basic transducer data is used along with a computer program and a graphics plotter to generate a semi-log graph of the recovery curve of each slug test. Due to the nearly vertical slope of many of the curves, an extension of the type curves for values of H/Ho and Tt/r^2=beta was developed from a table in an article by Papadopulous, et.al. (Aug.1963) titled, "On The Analysis Of Slug Test Data" Water Resources Research p.1088,. The values for beta are 10^{-6}, 10^{-8}, and 10^{-10}. The time (t) point is determined using the traditional matching curves method, except that the x-axis of both curves are kept in line. Transmissivity (T) is derived using the formula:

$$T = \frac{1.0(r_w^2)}{t} \times 86{,}400 \text{ sec./day}$$

Where r_w = the radius of the well in feet (4 inches)

t = time in seconds

RESULTS OF HYDRAULIC TESTS AT WELLS IN SAND EXTRACTION SITES AT PONCE, CAMUY AND AGUADA

The results of the slug tests are described in terms of hydraulic conductivity (K) with units of feet per day (ft/d). Hydraulic conductivity is defined as:

> "A medium has a hydraulic conductivity of a unit length (feet) per unit time (day) if it will transmit in unit time a unit volume of ground water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradiant of unit change in head through unit length of flow."

There are many factors which affect the hydraulic conductivity of a formation. Highly conductive materials such as sand, porous limestone, shells, or gravel can be interbedded or intermixed with clays, silt, or other marterials which will lower K. Compaction, fractures, localized porosity, grain size, sorting and shape of sand and/or gravel all influence hydraulic conductivity.

Computed hydraulic conductivities (K) for test wells 1 through 5 at Ponce ranged from 65 to 320 ft/d (Table 1 Figure 29 , Appendix A). The wells with a lower K (test wells 1,3 and 4) are in fine to medium sand and clayey sand. Test wells 2 and 5 have a higher K, 220 and 320 ft/d, respectively. The difference is due to coarse sand and shells in the area, which are frequently associated with a higher conductivity than clayey sand. Figure 29 delineates hydraulic conductivity contours in the Ponce extraction site.

Test wells 6 through 11 at Camuy have hydraulic conductivities ranging from 15 to greater than 320 ft/d (Table 1, Figure 30, Appendix B). These wells were drilled in loose, coarse sand to cemented sandy material. As mentioned above, depending on the tightness, grain size, etc., compaction and or fracturing of the cemented sands; K can vary considerably. Test wells 7 and 11 have the lowest K (40 and 15ft/d, respectively). Clay in test well 7 and the hard compacted nature of the cemented sands in TW 11 contribute to the lower hydraulic conductivity. Test well 10, with a K value of 105 ft/d, consists of hard silty sand, more conductive than test wells 7 and 11 but is affected by its silty nature. Test wells 6 and 8 both had higher K values (>320 ft/d). Although the materials in which the wells were drilled consist of sand and cemented sand, the disposition of sandy layers within the cemented sand along with possible fractures, produce higher K values. Figure 30 delineates hydraulic conductivity contours in the Camuy site.

TABLE 1 HYDRAULIC CONDUCTIVITIES AT TEST WELLS IN SAND EXTRACTION SITES AT PONCE, CAMUY AND AGUADA

SITE	DEPTH (ft)	SCREEN INTERVAL (ft)	TRANSMISSIVITY (ft2/d)	HYDRAULIC CONDUCTIVITY (ft /d)	SCREEN INTERVAL MATERIAL
			P O N C E		
TW-1	12	7-12	340	65	MEDIUM SAND AND GRAVEL TO FINE SAND
TW-2	9	4-9	1100	220	MEDIUM TO FINE SANDS WITH SHELLS
TW-3	37	33-37	430	85	CLAYISH SAND
TW-4	9	4-9	360	70	FINE SAND
TW-5	10	5-10	1600	320	FINE-MEDIUM SAND TO SHELLS,COARSE SAND
			C A M U Y		
TW-6	9	4-9	>1600	>320	EOLINITE-CEMENTED SANDS
TW-7	8	3-5	200	40	SAND AND CLAY CEMENTED SAND
TW-8	11.5	6.5-11.5	>1600	>320	SAND/CEMENTED SAND
TW-9	18	13-18	345	70	COARSE AND CEMENTED SAND
TW-10	12	7-12	530	105	HARD SILTY SAND
TW-11	16	11-16	80	15	HARD CEMENTED SAND
			A G U A D A		
TW-12	33	28-33	35	7	SILTY SAND
TW-13	14	9-14	320	65	LIMESTONE AND CEMENTED SANDS
TW-14	15	10-15	160	30	LIMESTONE
TW-15	11	6-11	775	150	MEDIUM GRAIN SAND
TW-16	23	18-23	>1600	>320	LIMESTONE WITH CLAY

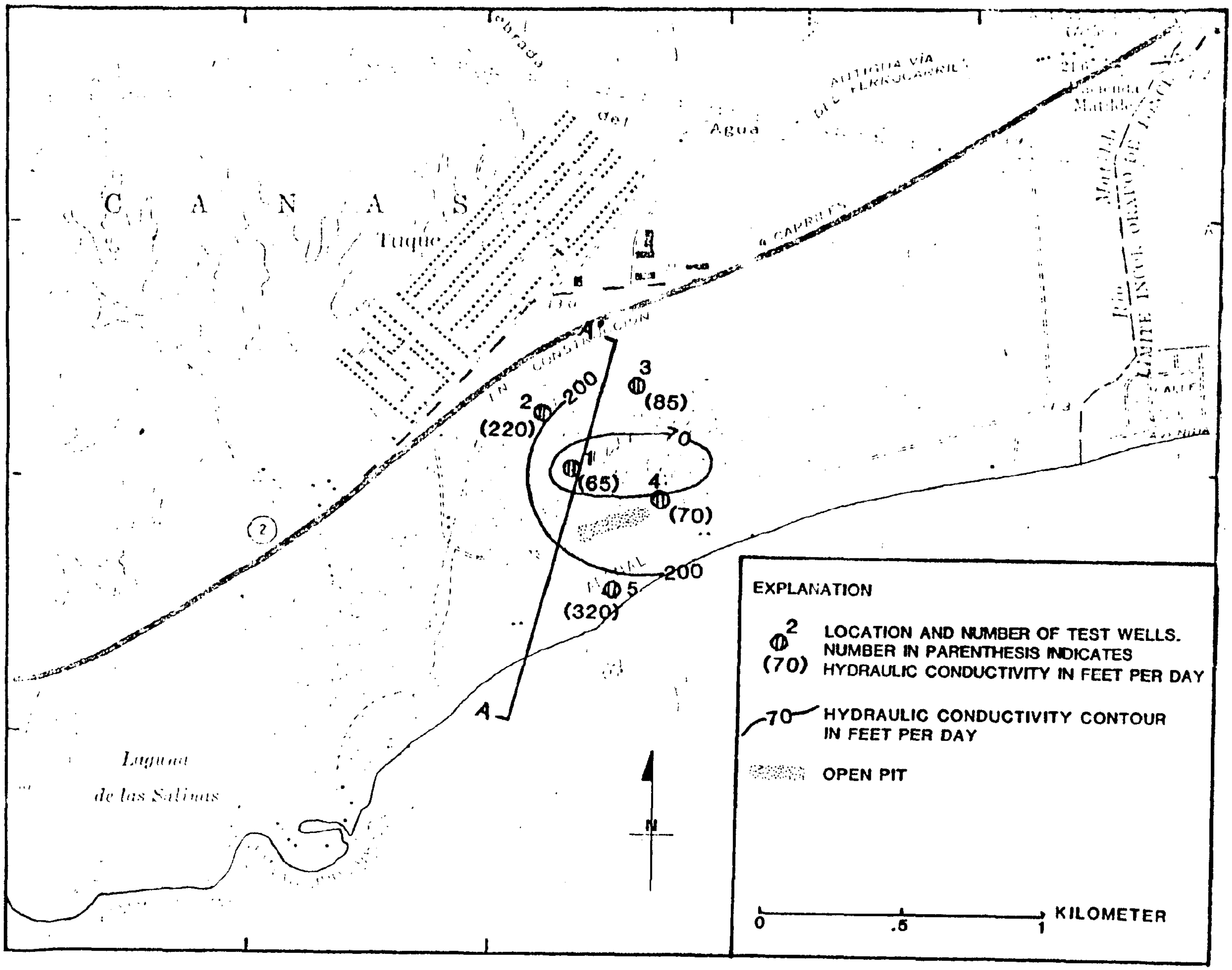


Figure 29 Hydraulic conductivity computed for test wells in the Ponce sand–extraction site.

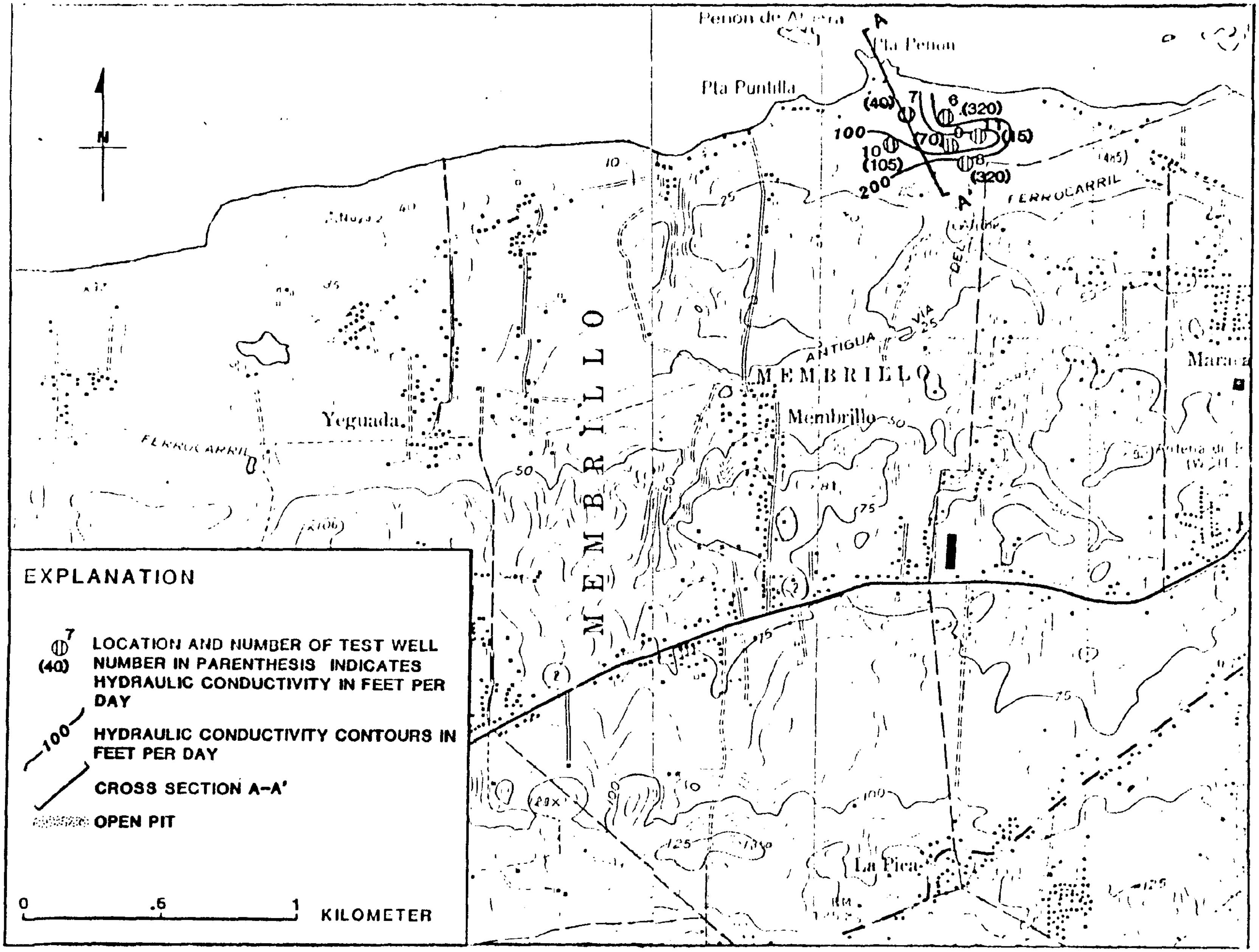


Figure 30 -Hydraulic conductivity computed for test wells in the Camuy sand-extraction site.

The hydraulic conductivities of test wells 12 through 16 at Aguada ranged from 35 to >320ft/d (Table 1, Figure 31, Appendix C). Test well 12, with a K value of 7ft/d, consists of silty sand that limits the flow of water. Test wells 13 and 14 with K values of 65 and 30 ft/d are in limestone with varying amounts of clays or interbedded cemented sands which influence K values. Test well 15, with a K of 150ft/d, is composed of relatively pure medium-grained sands with little silt or other materials to lower K values. Test well 16, with a K value of >320 ft/d, has mostly pure porous limestone with some clay. The porosity was not greatly affected by the clay, resulting in the higher hydraulic conductivity. Figure 31 delineates hydraulic conductivity contours in the Aguada site.

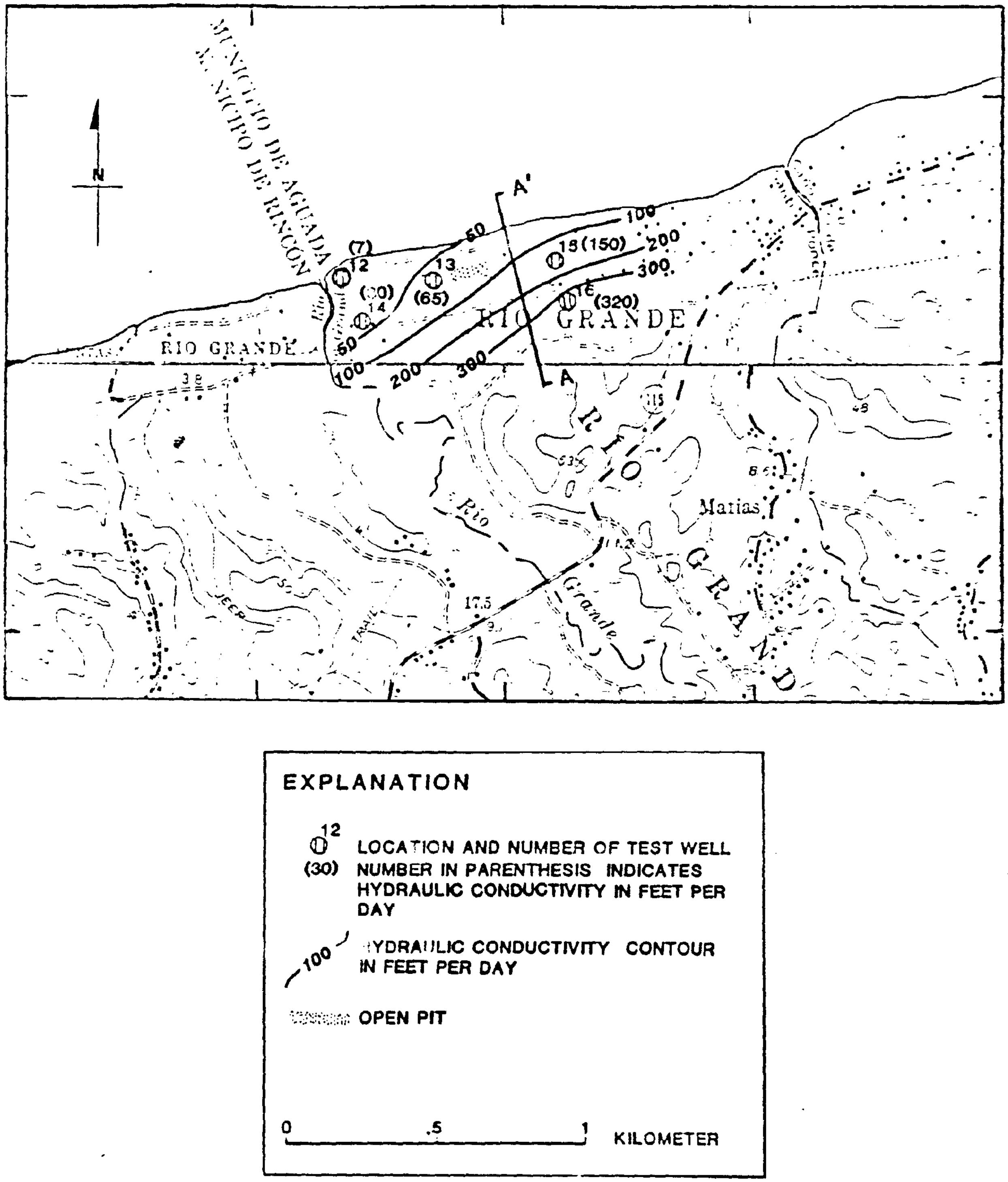


Figure 31 .Hydraulic conductivity computed for test wells in the Aguada sand–extraction site.

SUMMARY AND CONCLUSIONS

A total of sixteen test wells were drilled in sand-extraction areas at Ponce, Camuy and Aguada. These were cased, screened, and surveyed to mean sea level. The depth of wells ranged from 9 feet to 37 feet. The lithology varied slightly among the three areas and consisted mainly of combinations of sands, clays and/or limestone.

Water quality samples were taken from the sixteen wells and two open pits at Ponce and Aguada and analysed for specific conductance and chlorides. Specific conductance from the wells varied from 340 to 50,000 usiemens/cm in Ponce, 340 to 2775 usiemens/cm in Camuy, and 370 to 37,500 usiemens/cm in Aguada. Chlorides ranged from a minimum of 36 mg/l in a well at Aguada to a maximum of over 10,000 mg/l in Ponce. Water samples from the open pits revealed a pronounced stratification with depth of specific conductance at the pit in Ponce (from 1400 to 14,000 usiemens/cm) and a uniform distribution (500 usiemens/cm) both areally and with depth in the pit at Aguada.

Water levels were measured twice during the period of study. Water-table contour maps and cross sections were constructed to describe ground-water flow patterns at the sites and how these could have been affected by the sand-mining operations.

"Slug" injection tests were performed to determine hydraulic conductivities at all well sites. The lowest value of 7 ft/d was found at Aguada in a silty sand matrix. Values of over 320 ft/d were found in all three areas in sites containing sand deposits mixed with shells or other highly permeable materials.

Open-pit mining of coastal sand deposits seems to locally affect the ground-water hydrology of coastal zones. It can result in the lowering of water levels at the dune area with the eventual migration either inland or seaward of the freshwater-saltwater interface. The extent to which this will occur depends on climatic and hydrogeologic conditions of the area.

Backfill techniques to restore the site will not severely alter the ground-water system, as long as the fill material has similar hydraulic properties as the original extracted sand. When local hydraulic conductivities in the aquifer are significantly altered by mining operations, ground-water flow lines are distorted either temporarely or permanently, depending on existing hydrogeologic conditions.

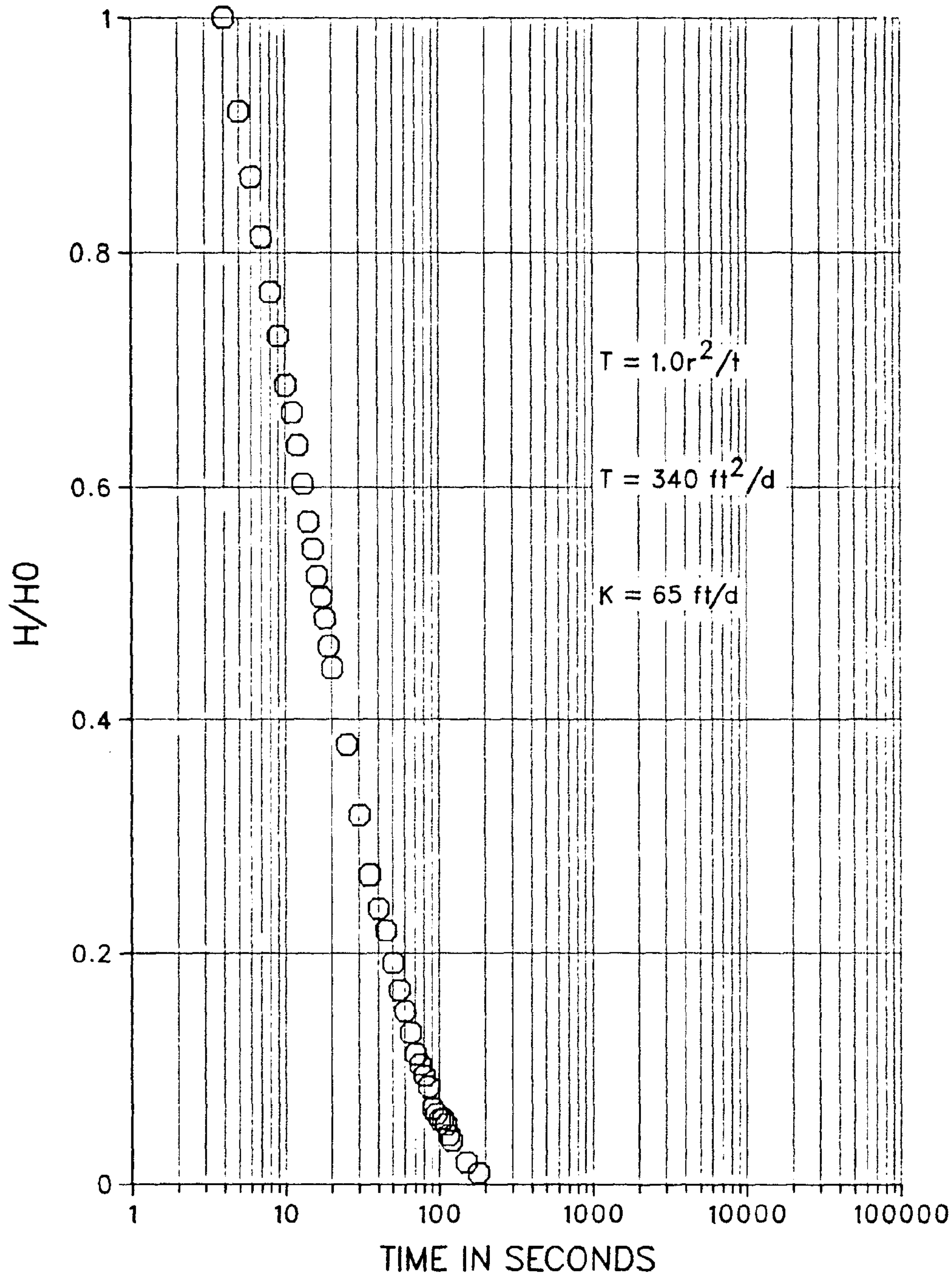
The open pit in Ponce, near test well 5 remains uncovered with backfill material and has locally increased the aquifer permeability. As a result, surrounding water levels in the aquifer and consequently in the dune have dropped by as much as 3 feet.

In the area of Camuy, the sand-extraction site has been partially backfilled with apparently high permeable material. As a result, surrounding heads in the aquifer probably could have been depressed not only temporarely but, perhaps also permanently.

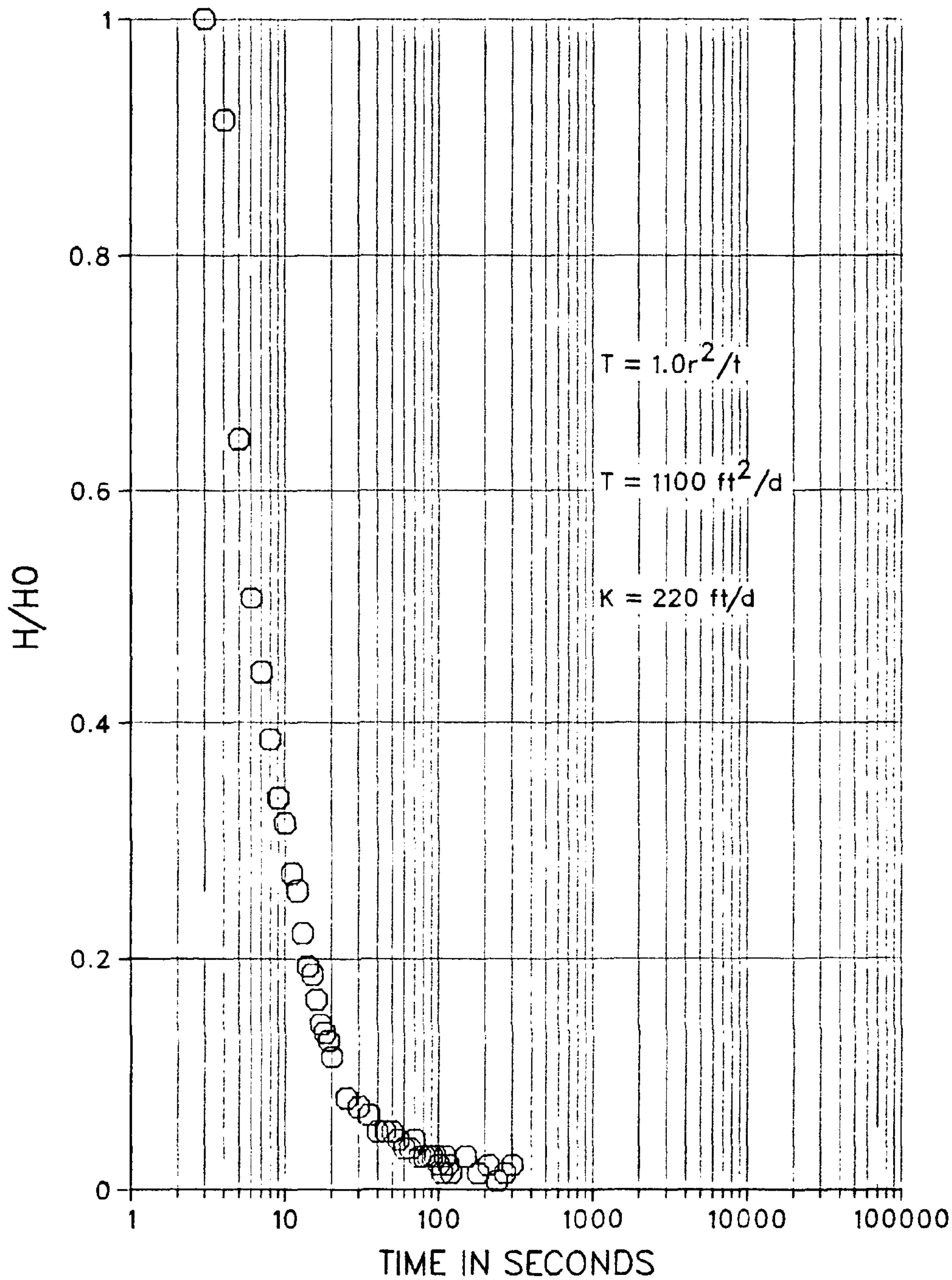
In Aguada, sand mining operations appear to have caused local changes in the hydrology of the site. The area where sand extractions have occurred was backfilled with materials of lower permeability than the original sand deposits. As a result, a water-table mound apparently has been developed which seems to have inhibited a decline of water levels in the adjacent dune. The mound could probably has also inhibited migration of seawater into the open pit.

APPENDIX A

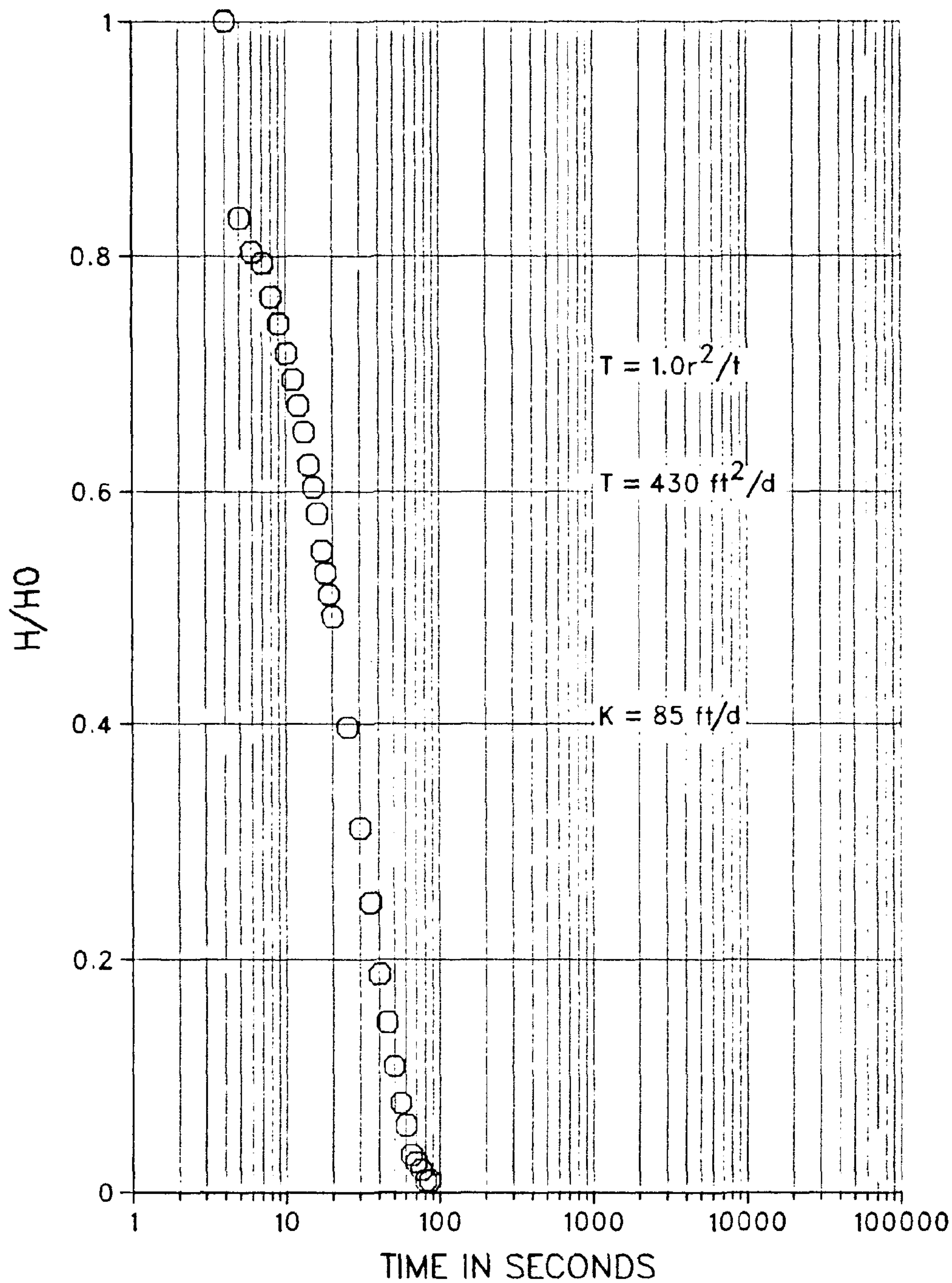
Hydraulic Conductivities from Slug Tests In Test Wells 1–5 at Ponce



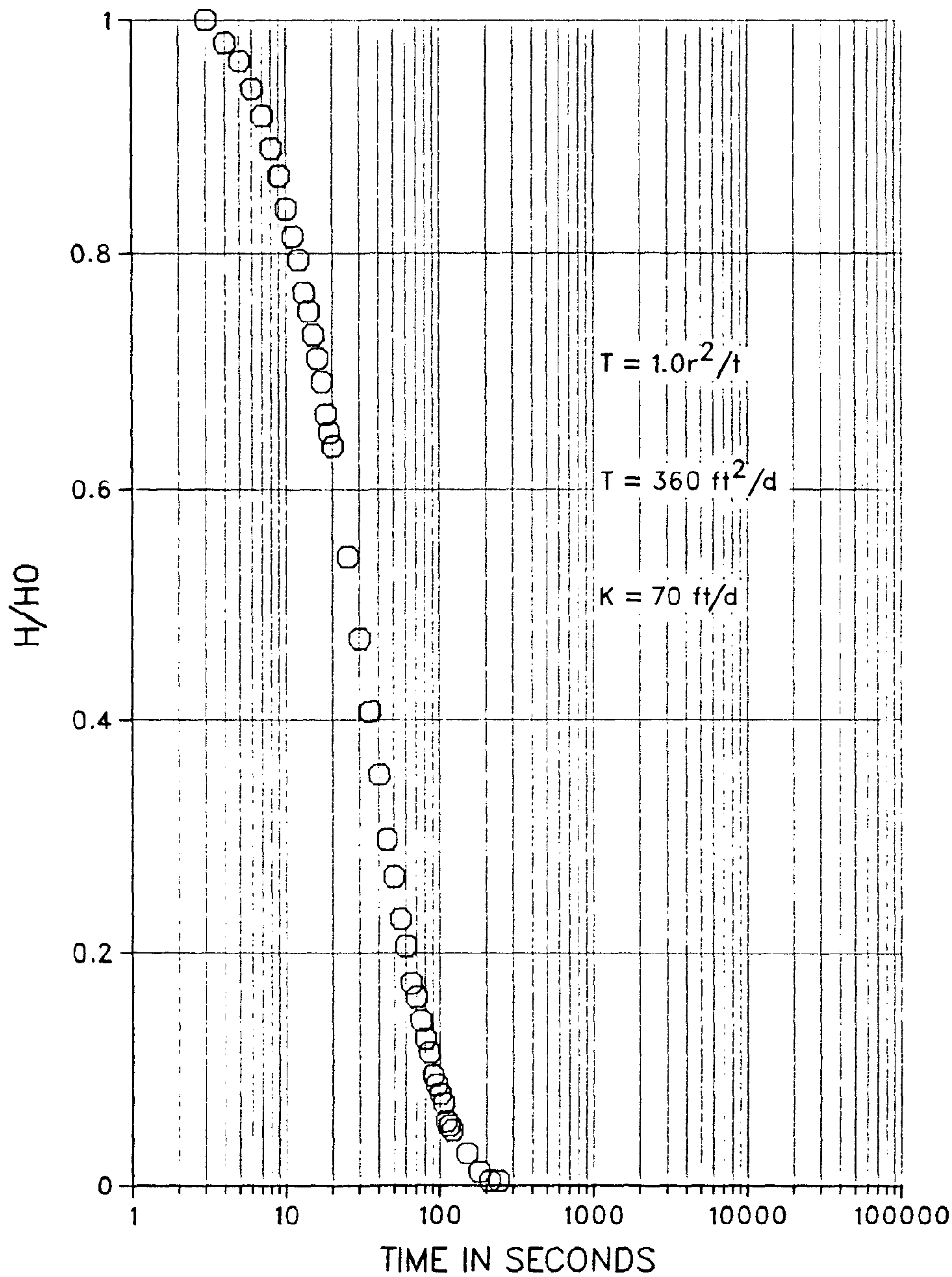
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 1 AT PONCE



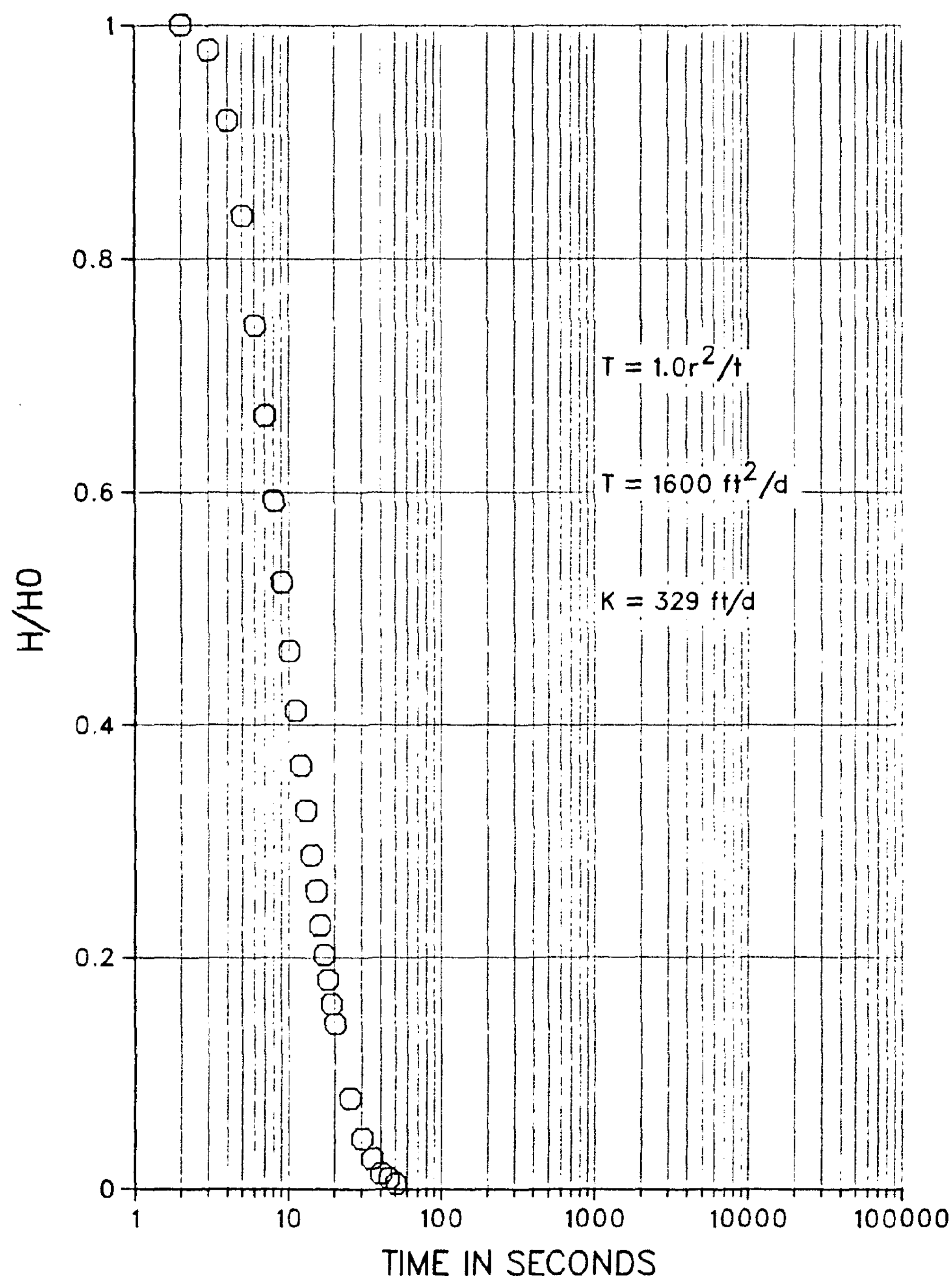
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 2 AT PONCE



HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 3 AT PONCE



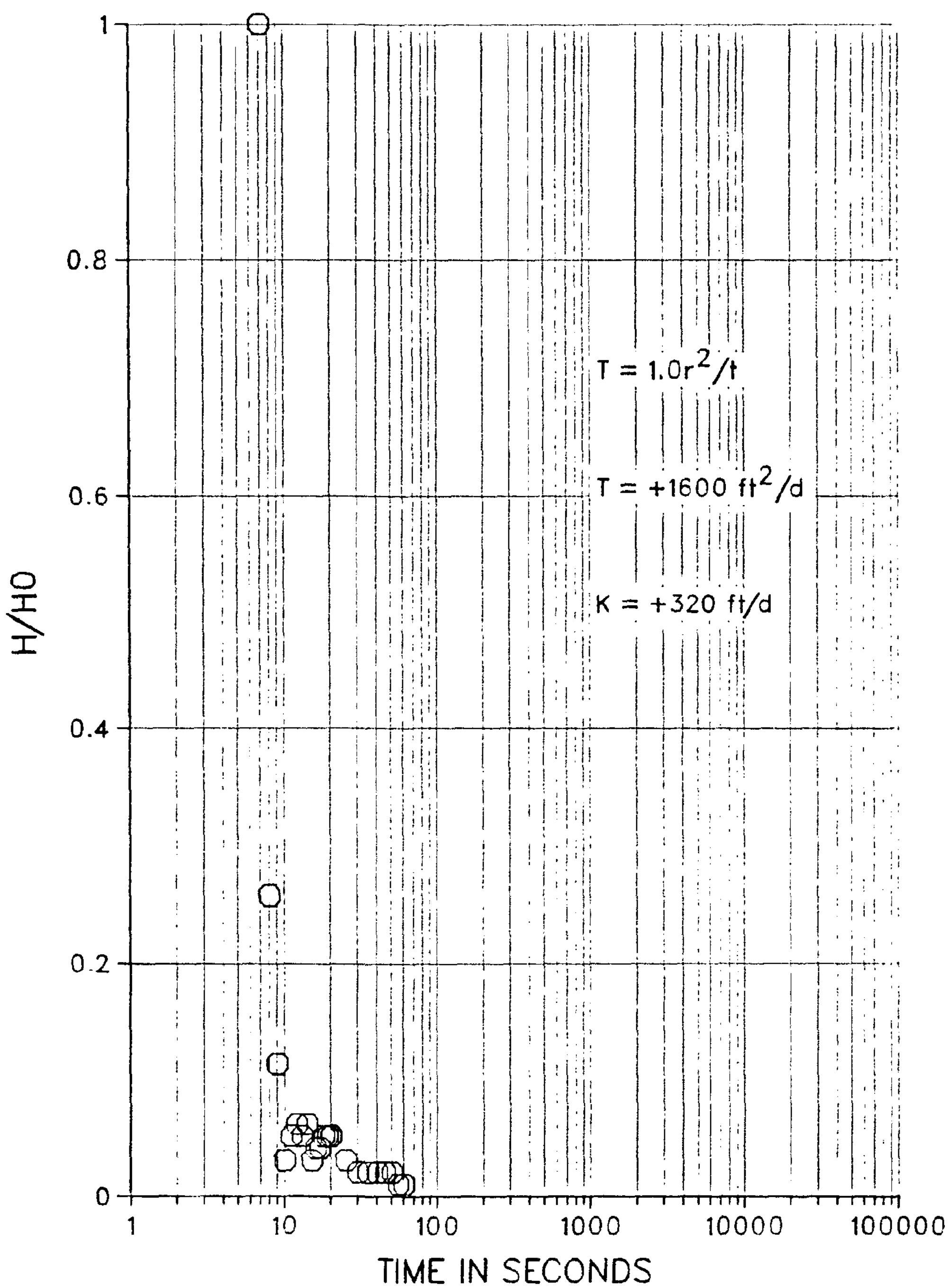
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 4 AT PONCE



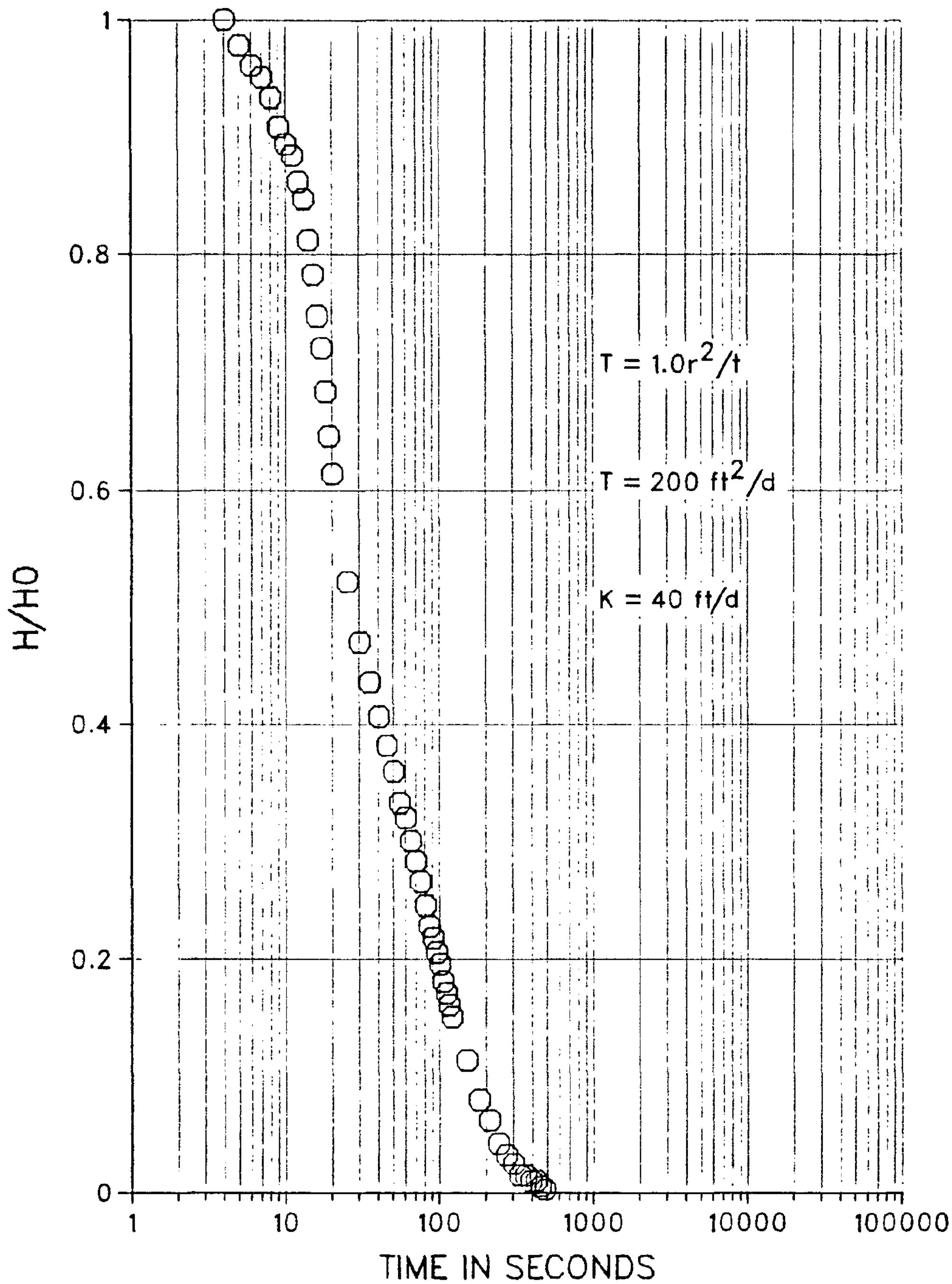
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 5 AT PONCE

APPENDIX B

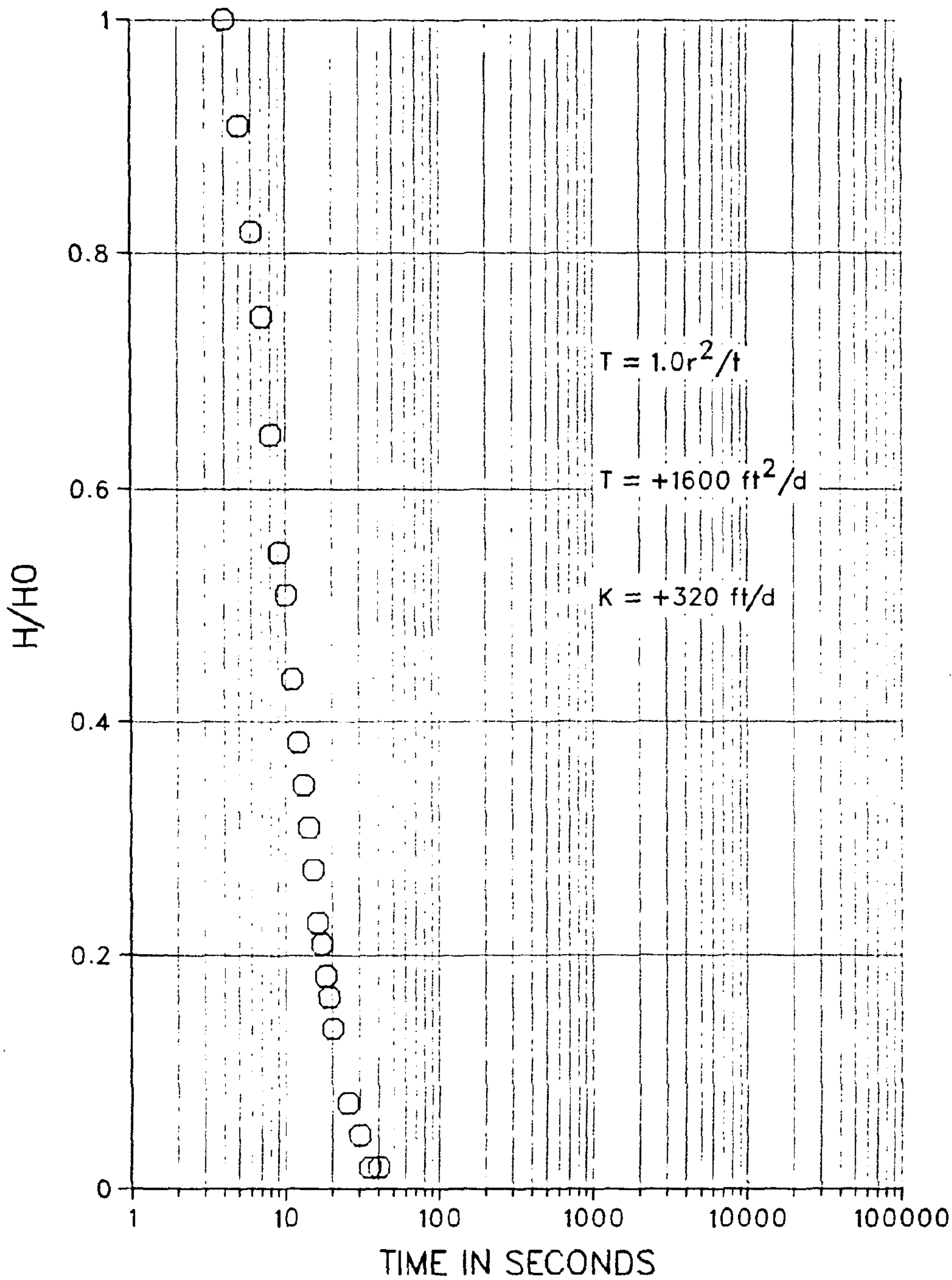
Hydraulic Conductivities from Slug Tests In Test Wells 6–11 at Camuy



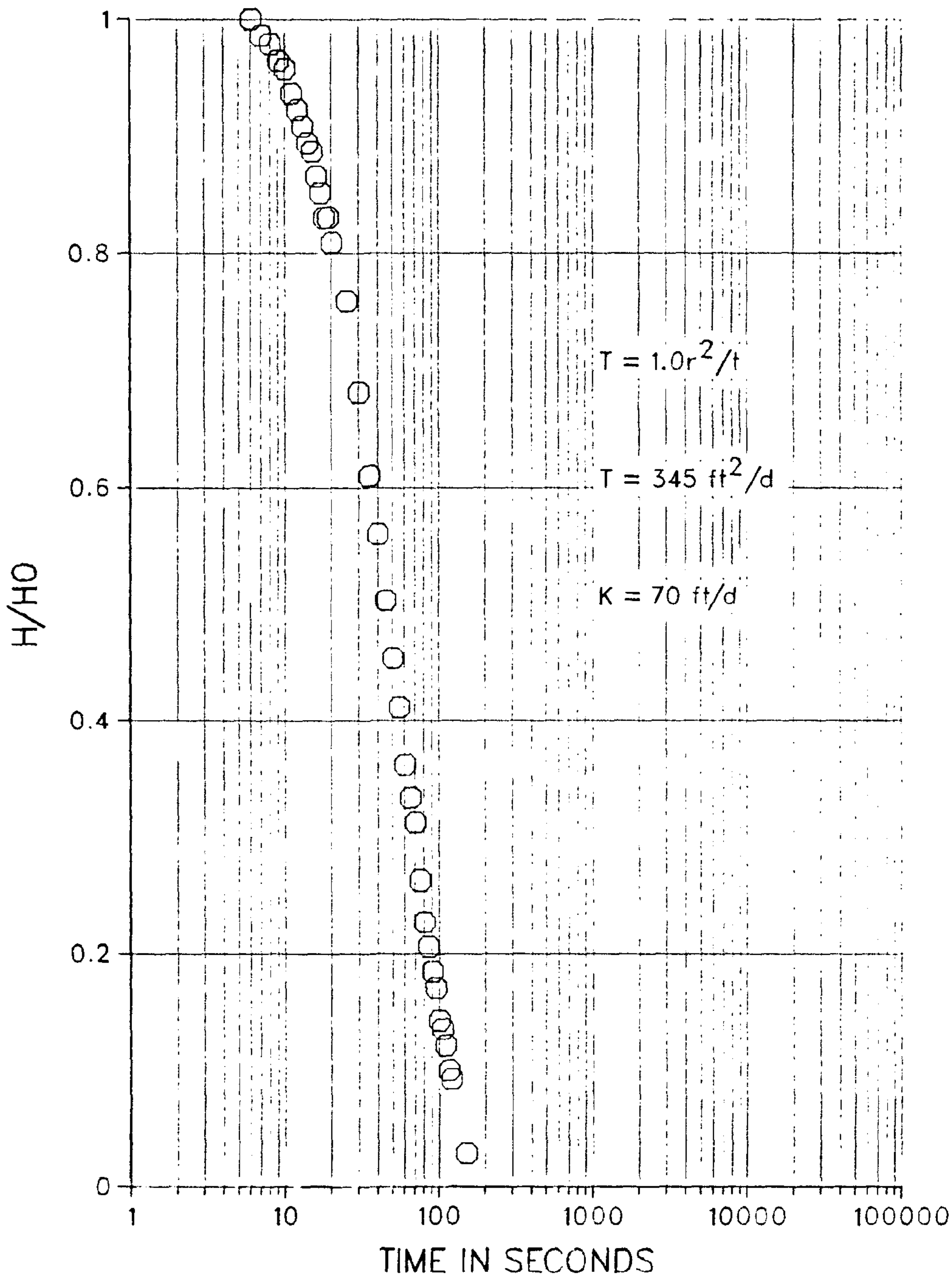
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 6 AT CAMUY



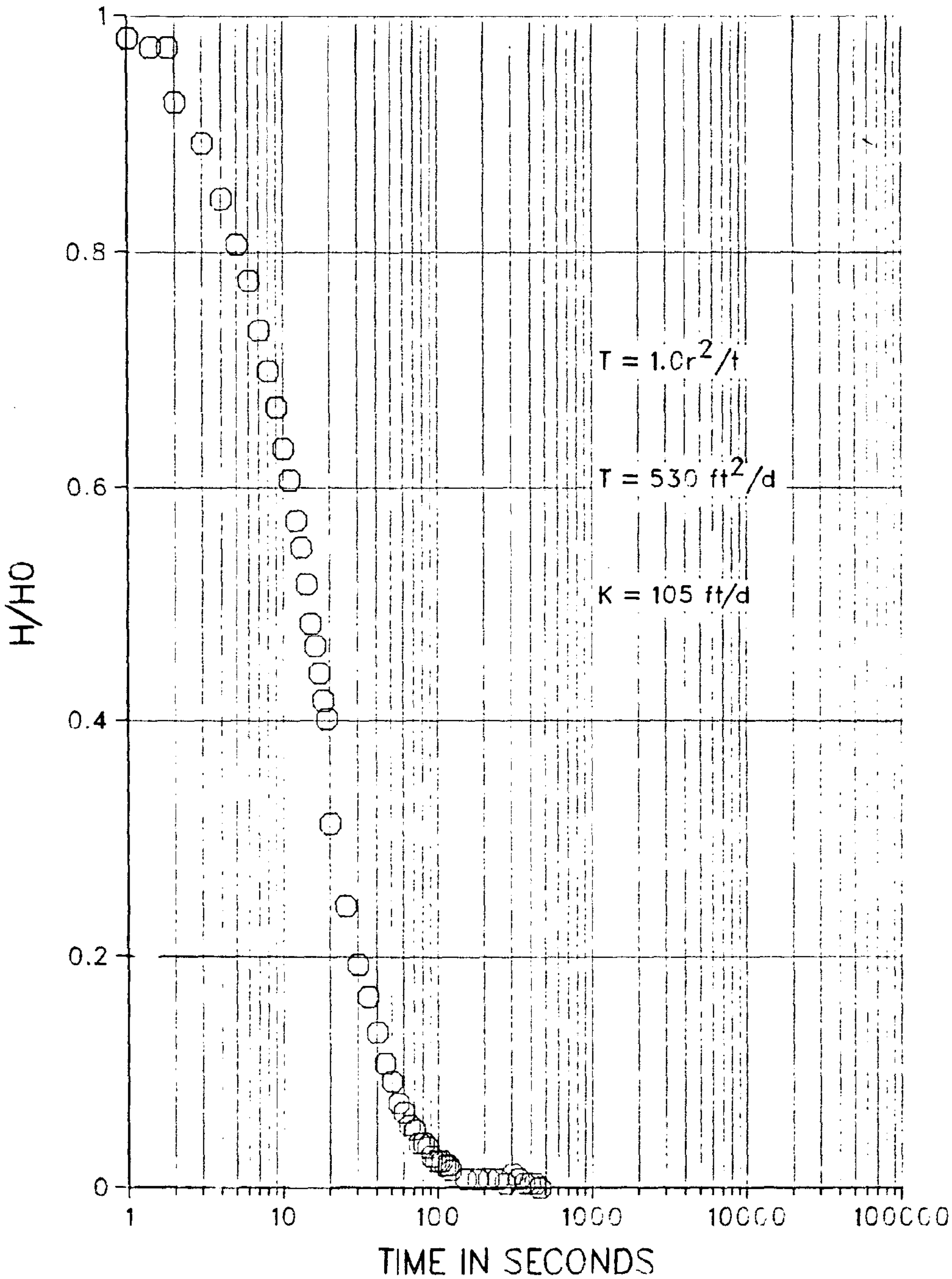
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 7 AT CAMUY



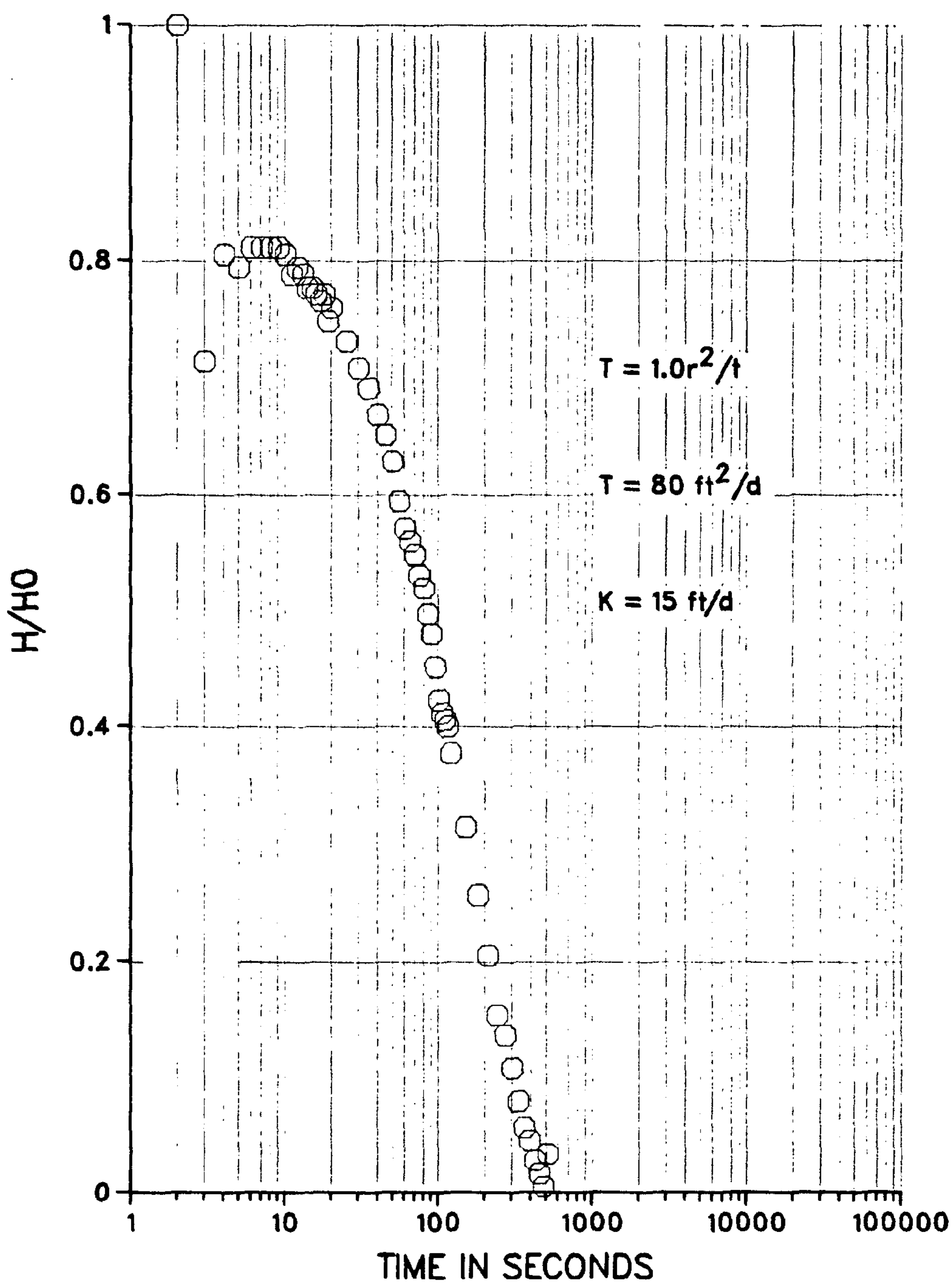
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 8 AT CAMUY



HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 9 AT CAMUY



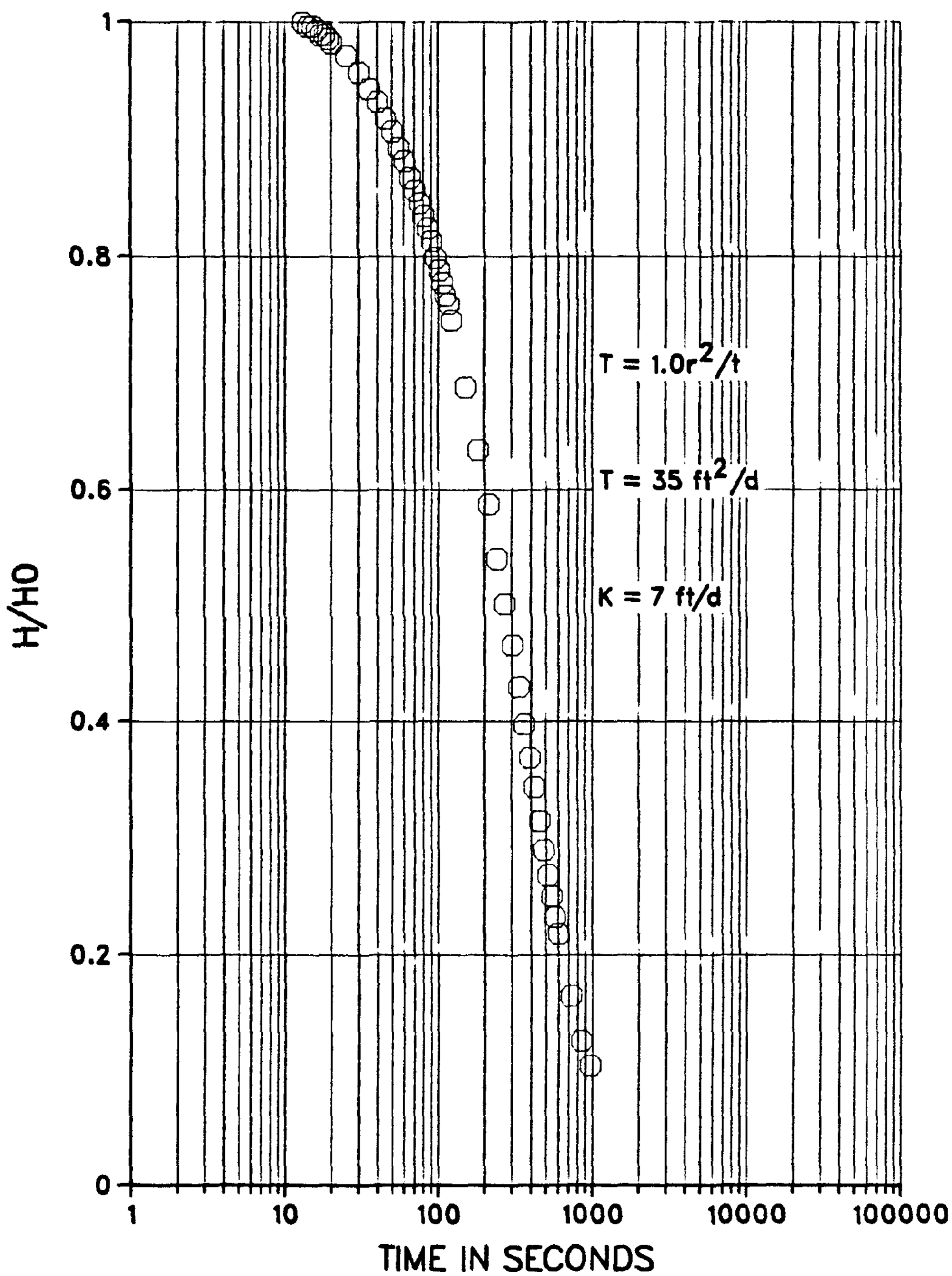
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 10 AT CAMUY



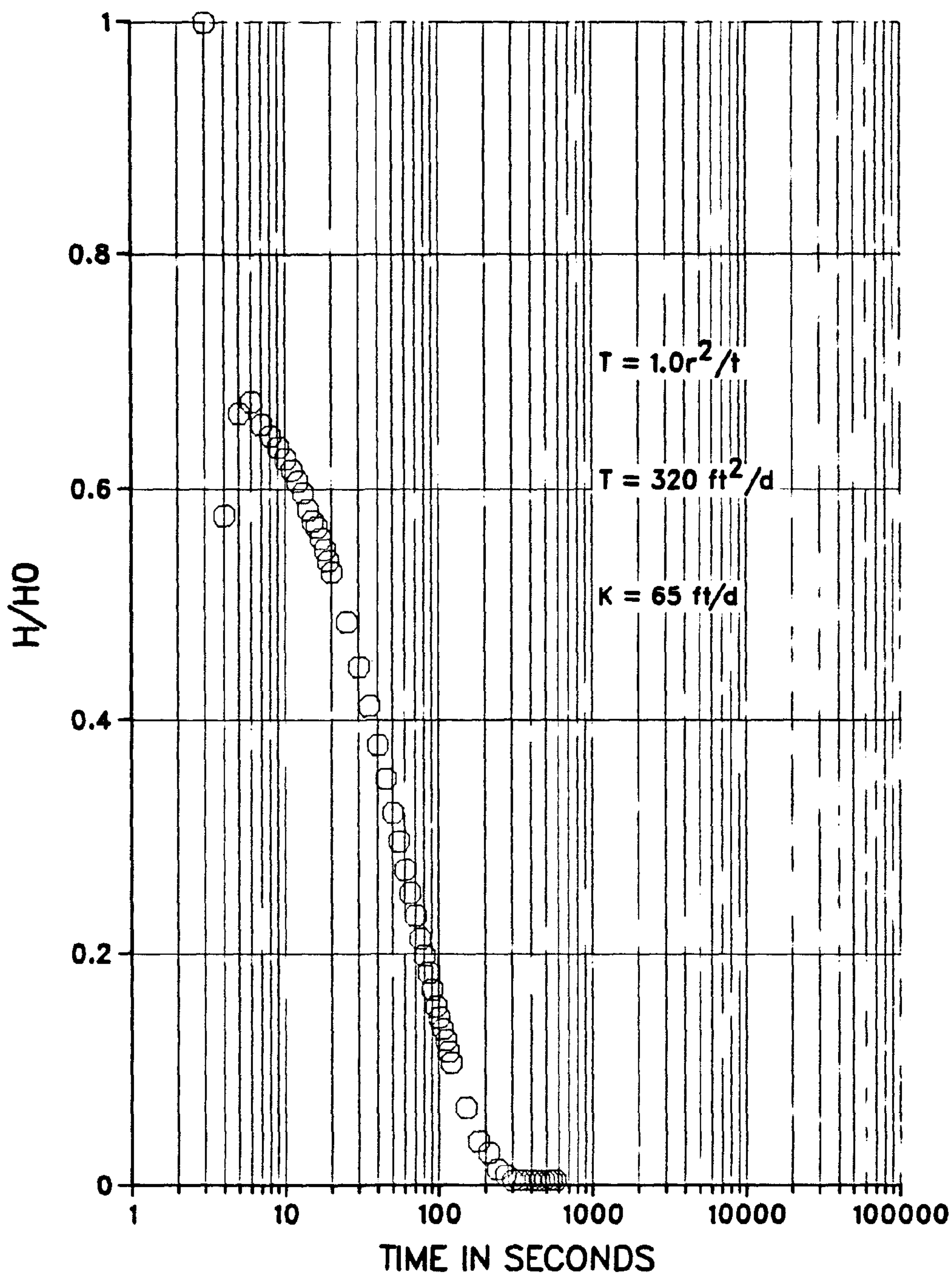
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 11 AT CAMUY

APPENDIX C

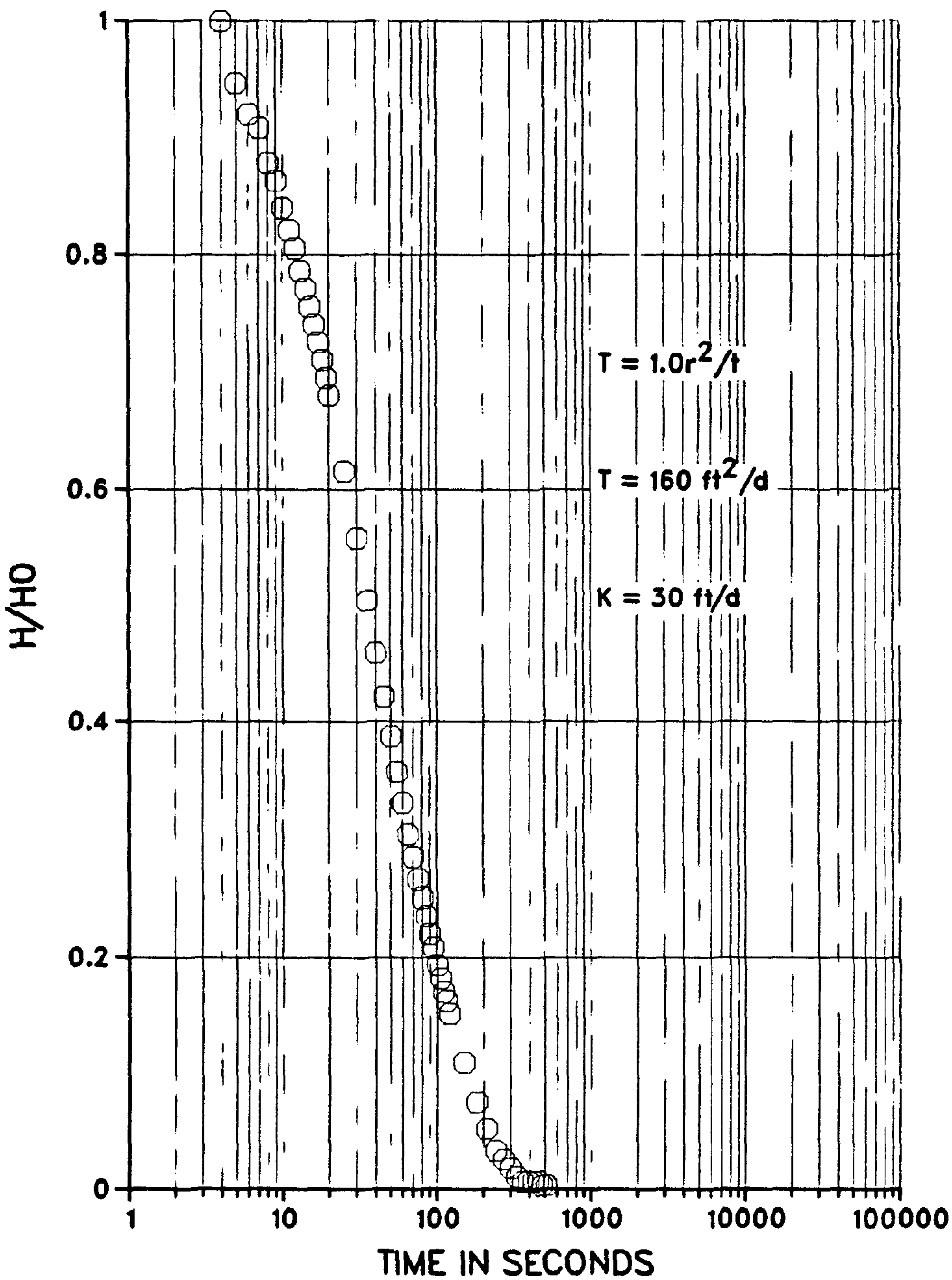
Hydraulic Conductivities from Slug Tests In Test Wells 12–16 at Aguada



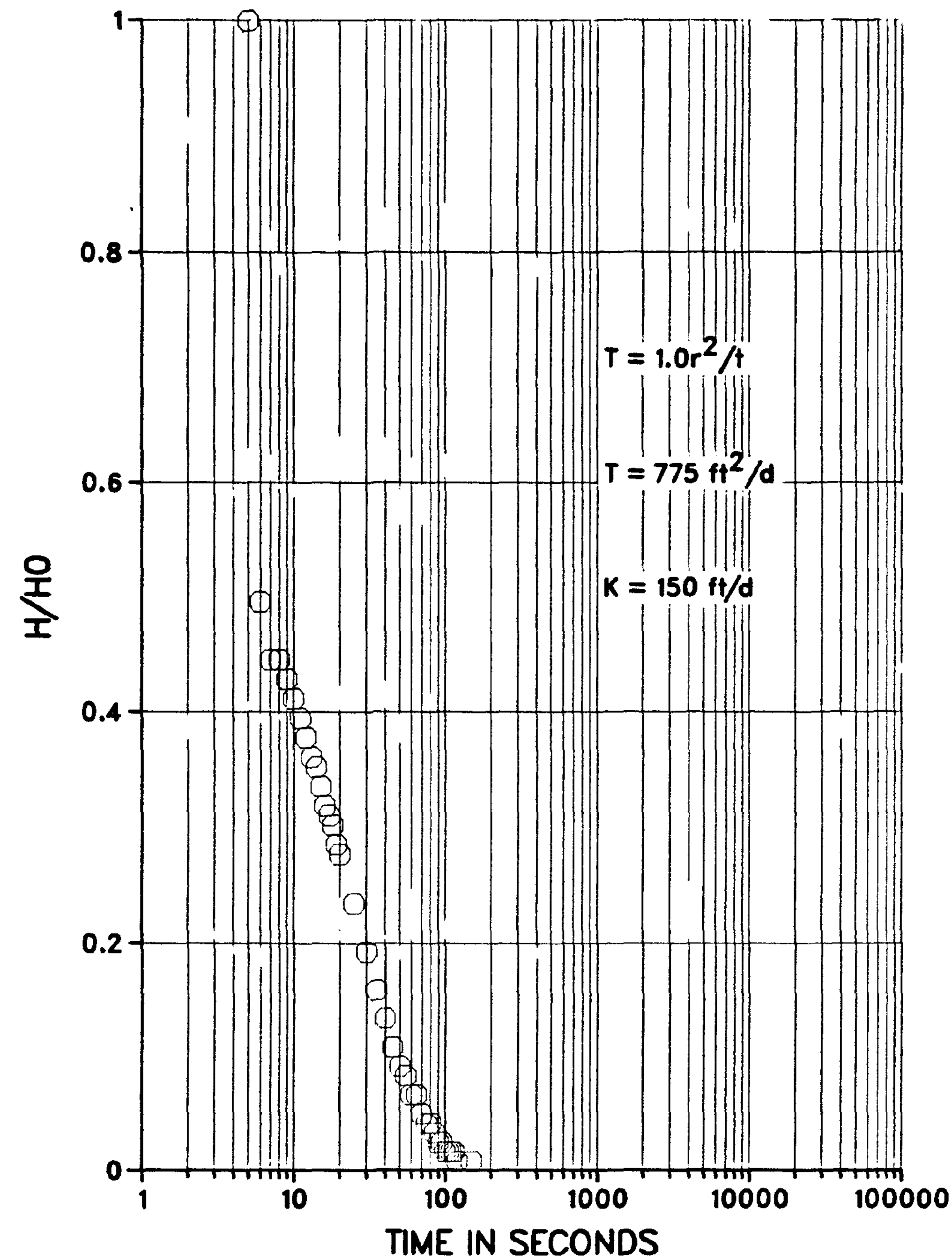
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 12 AT AGUADA



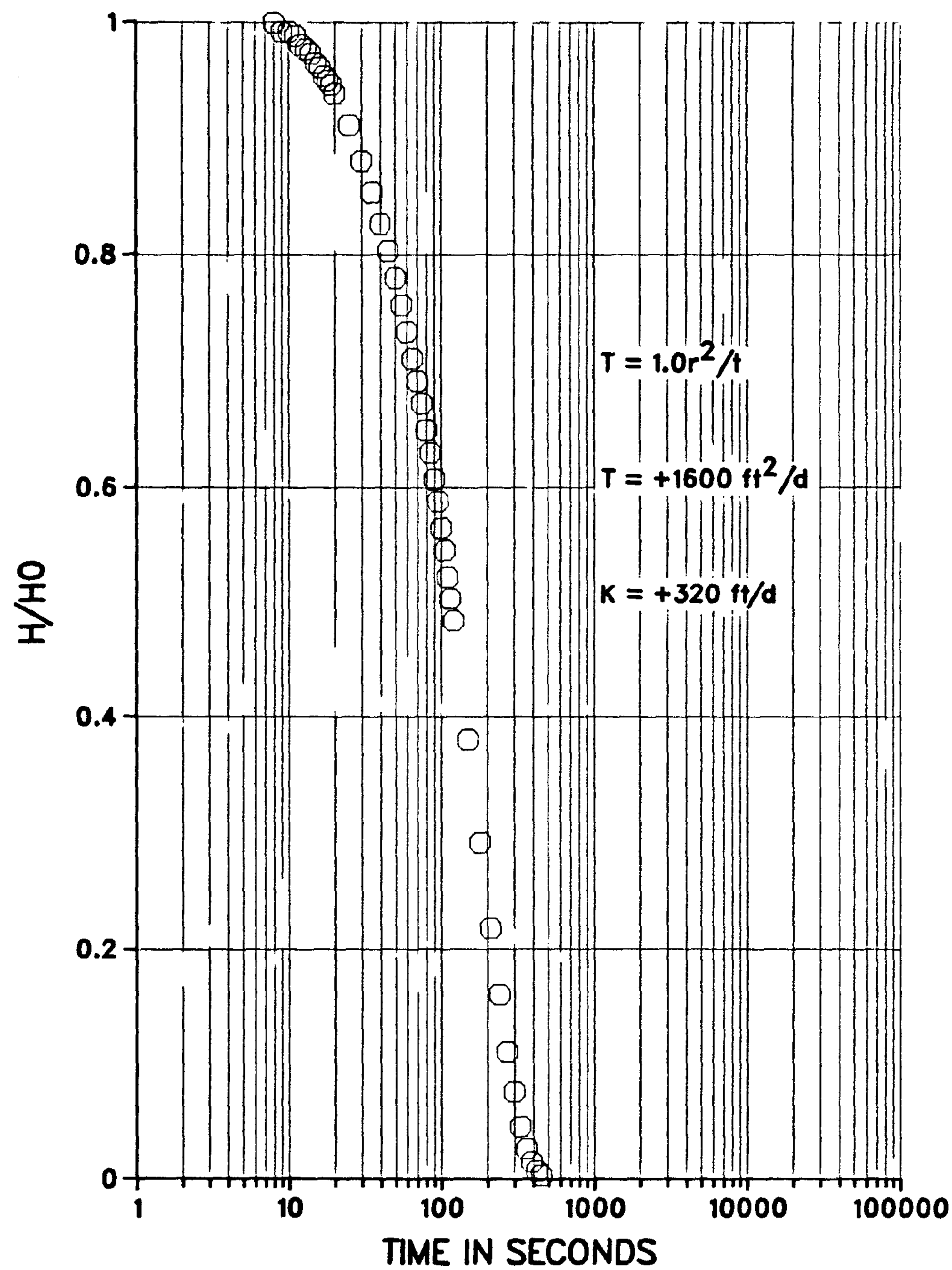
HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 13 AT AGUADA



HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 14 AT AGUADA



HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 15 AT AGUADA



HYDRAULIC CONDUCTIVITY FROM "SLUG" TEST
IN TEST WELL 16 AT AGUADA

APPENDIX VI:
GEOLOGIC AND SOIL NOMENCLATURE

GEOLOGIC NOMENCLATURE

*Qa-	Quaternary	Alluvium
*Qb-	Quaternary	Beach Deposits
*Qd-	Quaternary	Sand Dunes
*Qe-	Quaternary	Eolianite Deposits
*Qs-	Quaternary	Swamp Deposits
*Qbs-	Quaternary	Blanket Sand Deposits
*Tc-	Tertiary	Cibao Limestone
*Tcu-	Tertiary	Camuy Limestone
*Tp-	Tertiary	Ponce Limestone

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* Referred to in text

SOIL NOMENCLATURE

CAMUY

*TP- Tropopsamments

HD- Hydraquents

*RlC- Rio Lajas Series, sand

ClE2- Colinas Series, clay loam

RsF- San German Series, gravelly clay loam

SgD- San Germån Series, gravelly clay loam

EbB- Espinosa Series, sandy clay loam

EcC- Espinosa Series, clay

AmC- Almirante Series, clay

VeB- Vega Baja Series, silty clay

EbC- Espinosa Series, sandy clay loam

GeC- Guerrero Series, sandy clay

ClD2- Colinas Series, clay loam

PONCE

EnC- Ensenada Series, gravelly clay

Ma- Machuelo Series, clay

Te- Teresa Series, clay

*Mr- Meros Series, sand

*Se- Serrano Series, sand

Hz- Hydraquents, saline

YcC- Yauco Series, silty clay loam

SOIL NOMENCLATURE (Cont.)

AGUADA

Ch-	Cidral Series, coastal beach sand
*Cd-	Cataño Series, sand
Sn-	Santoni Series, clay
Ba-	Bajura Series, clay
MaB-	Mabi Series, clay
ClE-	Colinas Series, clay loam
Nad-	Naranjo Series, clay
Es-	Espinal Series, sand
Cn-	Coloso Series, silty clay loam

* Referred to in text