FLSGP-T-86-006 C2

SGR-77

Guidelines for Beach Restoration Projects

Part II - Engineering

By Donald K. Stauble

Florida Sea Grant College

June 1986

PHYSICAL AND BIOLOGICAL GUIDELINES FOR BEACH RESTORATION PROJECTS

Part II

PHYSICAL ENGINEERING GUIDELINES

Beach Nourishment and Inlet Sand Bypass Projects

The Need for Guidelines
The Monitoring System

By

Donald K. Stauble
and
Jeffery Hoel

Department of Oceanography and Ocean Engineering
Florida Institute of Technology
Melbourne, Florida 32901

Sea Grant Project No. R/C 3
Grant No. NA 80AA-D-00038

Report Number 77
Florida Sea Grant College
June, 1986
Price $2.00

ACKNOWLEDGEMENTS

This project was made possible by a grant from the Florida Sea Grant College Program with support from the U. S. Department of Commerce, NOAA, and the Office of Sea Grant. Additional funding was provided by a grant from the U. S. Office of Coastal Zone Management, NOAA, through the Florida Office of Coastal Management, Florida Department of Environmental Regulation and Florida Department of Natural Resources, Division of Beaches and Shores. The U. S. Army, Corps of Engineers, Jacksonville District provided funding for the monitoring of the Indialantic/Melbourne Beach nourishment project.

Data on monitoring of beach nourishment projects was gratefully received from the following: Florida Department of Natural Resources, Division of Beaches and Shores; U. S. Army, Corps of Engineers, Jacksonville District; Tackney and Associates, Inc., Naples, Fl.; Arthur V. Strock and Assoc., Inc., Deerfield Beach, Fl.; Coastal Engineering Consultants, Naples, Fl.; Coastal Planning & Engineering, Inc., Boca Raton, Fl.; and Steven Gabriel for the Ocean City, N.J. project.

Other individuals who provided time, help and resources throughout this project include: Florida Institute of Technology graduate students Mark Hansen, Larry Parson, Fred Hushla, Wade Blake, Jeff Hoel, Don Paul Rance and Mike Dombrowski; Chris Jones, Florida Sea Grant; Mark Leadon, Lonnie Ryder and Jim Balsillie, Florida DNR, Div. of Beaches and Shores; Andy Hobbs, Lloyd Sanders, Charlie Stevens and Paul Rosen, U. S. Army, Corps of Engineers, Jacksonville District; and Pamela Sperling, Florida Department of Environmental Regulation.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

INTRODUCTION

All indications point to the continued rapid growth and development of the coastline of Florida and other populated coastal states. It has been reported, that the number of households in Florida have experienced an increase from 1.5 to 3.7 million from 1960 to 1980 with the seven fastest growing counties located along the coast (Smith, 1981). Some eighty percent of Florida's population is already living in its coastal counties. The projected growth of the state's population into the twenty first century may make Florida the third or fourth most populated state in the nation. With this growth in population, there are increasing pressures to develop beachfront property for residential and commercial purposes. The beach is one of the main drawing cards. However, it has been reported that more than 25% of Florida's 782 miles of beach is in a critical state of erosion (Campbell, et. al. 1980).

Shoreline erosion presents a two fold problem: 1) The beaches in their eroded state cannot support the important tourist, commercial and recreational industries that are vital to the State's economy. In 1984, an estimated $4.6 billion in sales was generated by beach related tourism and resident use (Bell and Leeworthy, 1986). It has been estimated that 65% of Florida's resident population over 17 years old participate in beach use on the average of 38 days per year (Bell and Leeworthy, 1984). This does not include the large number of visitors that utilize Florida's beaches daily. 2) Florida is experiencing a coastal building boom with the construction of beachfront condominiums and resort hotels along with expensive single family homes. These beaches in their eroded state can not provide protection to this significant investment in valuable upland real estate development or widely used and enjoyed natural resources of state and county beachfront park land from either a) the summertime tropical storms that have a high probability of occurrence along the Florida coast or b) the wintertime extratropical northeasters that can be equally destructive in their high wind, waves and storm surge. With the world wide trend in apparent sea level rise (Hicks, et.al., 1983 and Hoffman, et.al., 1983) combined with the increasing pressure to develop Florida's coast, the need to stabilize the beach against erosion is becoming a major coastal zone management priority.

Statement of Problem

Among the erosion control options available, beach nourishment and inlet sand bypassing have become increasingly popular over the past decade. Since 1975 there have been more erosion control projects in Florida than the rest of the coastal states combined, most utilizing some form of beach nourishment. This represents an investment of more than $100 million in federal, state and local funds (FSBPA, 1981).

Beach nourishment can be defined as the artificial addition of suitable sediment to an area of the coast that has a natural deficiency in sediment supply. Walton (1977) states that artificial nourishment has several advantages over "hard" engineering structures (ie. groin, jetty, breakwater, revetment or sea wall). Not only does this placement of fill material add to the coastal sand budget, but the wide berm is esthetically pleasing and it helps to naturally dissipate the erosive wave energy, without creating structural hazards to beach users. This additional sand also becomes a feeder beach to downdrift beaches.

Inlet sand bypassing projects can also be included as a means of erosion control similar to beach nourishment projects. In this particular type of project, sand is artificially transported by various means from the updrift side (borrow area) of the tidal inlet and placed on the beaches on the downdrift side. Tidal inlets, most of which are stabilized with one or two jetties, can act as a barrier to the natural sediment transport by interrupting the natural longshore drift of sand along the coast. Sand accumulates on the updrift side of these structures and results in increased erosion of the sediment starved downdrift side beach. Sand bypass projects have been implemented at many inlets on either a permanent or on an as needed basis primarily to maintain the navigational channel (Jones and Mehta, 1980). By periodic dredging of sediment deposited in or near the inlet or in sand traps designed specifically to collect sediment blocked from natural longshore drift, suitable dredged material is artificially placed on the eroding downdrift shoreline to bypass the inlet stabilization structure. These projects have the same considerations as beach nourishment projects, in that the suitability of the borrow material is an important factor in fill stability and that placement of this material as beach fill on adjacent downdrift beaches is for the purpose of renourishment and erosion control. This type of project is important to consider since the Florida east coast has some 18 inlets which connect bays, lagoons, rivers and waterways with the Atlantic Ocean. There are many more inlets on the gulf coast shoreline.

The source areas for beach fill material in Florida are usually sediments dredged from tidal inlets, offshore areas, or occasionally barrier island sands. The two most common placement techniques are hydraulic pumping through dredge pipe and trucking from borrow stock pile.

Approach to Problem

In the past few years, the high cost of project permitting and implementation, dwindling source of public funding and the question of effectiveness of present beach nourishment technology has lead to the need to develop guidelines addressing the monitoring of beach nourishment and sand bypass projects specifically to understand their performance and environmental impact. To assist in compiling this project monitoring information and to help determine requirements on the type of project data to be collected in the future, a coordinating committee of user groups within the state of Florida was formed. The committee membership consisted of representatives with both engineering and biological backgrounds from the U.S. Army Corps of Engineers, Jacksonville District Office, the Florida Department of Environmental Regulation, the Florida Department of Natural Resources, the Florida Sea Grant Coastal Engineering Specialist along with the authors of this study. Each group has its own specific interests and requirements in guidelines for both the design and regulatory tasks they are required to perform on a daily basis. One of the important tasks of the committee was to supply information on past projects. Although numerous beach nourishment projects nave been constructed, little evaluation of project performance or impact has been done.

Work to produce guidelines for the Florida Department of Natural Resources (DNR) was started in 1979 on erosion control and sand bypass projects (Suboceanic Consultants; 1979a, 1979b). Additional considerations on this topic are found in Stauble et. al. (1983b). A series of two documents (Stauble et.al., 1984a and Leadon,

1984) has been produced by the Florida DNR, Division of Beaches and Shores dealing with standardization of project monitoring as part of their erosion control and permit monitoring program.

According to Chapter 161, F.S., of the Florida Statutes, the Department of Natural Resources is responsible for beach and shore preservation. Chapter 161.091 establishes the erosion control fund account (ECA) where funds can be utilized to develop a comprehensive long-range, statewide plan for erosion control, beach preservation and hurricane protection. Emphasis of this program has been on funding beach restoration and renourishment projects, inlet sand bypassing and transfer projects, borrow sources availability studies and dune construction and preservation programs.

The Florida Department of Environmental Regulation also has a regulatory responsibility for beach nourishment projects. Chapter 253, F.S., establishes protection of the State's natural resources affected by dredging and filling activities and Chapter 403, F.S., allows for protection of water quality from such activities. Biological and environmental monitoring guidelines are of use to establish base line data, environmental impacts and recovery rates of organisms affected by nourishment projects.

The U. S. Army Corps of Engineers has been responsible for funding, design, construction and regulatory functions of past nourishment projects. The usual beach nourishment or sand bypass project on public beaches includes a match with federal and local dollars. Since 1975 approximately $32 million has been spent by the state of Florida for such projects. This large expenditure of money has been spent primarily on project implementation and construction. Only a few of the more recent projects have been required to adequately document project performance and monitor environmental changes. Due to manpower and funding limitations there is, to date, no detailed comprehensive and systematic state or federal program to insure performance monitoring of these federal and state funded projects. Privately funded projects also lack consistency in the documentation of past projects. Without this systematic collection of information on project performance and effectiveness, valuable data on physical and biological processes has been lost to the regulatory officials and engineering staff, on those projects that have not required monitoring. Of those projects that have included some sort of monitoring data, lack of standardization has limited the usefulness of data for interpretation and applicability to new project design and possible environmental effects.

The objective of this study is to design physical engineering performance monitoring standards for pre-construction, construction and post-construction project phases. The development of a data base of previous project performances will aid in future project design and add to our understanding of the viability of such erosion control programs. By reviewing the differences in monitoring techniques from the collection of past projects along with new field and laboratory data collection, it has allowed for the development of monitoring requirements and standardization of monitoring data collection, that will ultimately improve permitting procedures, including inhouse technical and regulatory review. Numerous projects have experienced delays in the past in the permitting process due to a lack of information available to the regulatory officals as to the behavior and impact of a project on the surrounding environment. These delays in project implementation and completion have resulted in economic loss by increasing design and labor costs in a period of rising inflation.

Jones and Mehta (1980) have indicated that the total increase in dredging costs has been 330% in sixteen years. Delaying a project in an area of critical erosion also increases the chance of structural damage and property loss due to the ever present threat of coastal storms. This present project is designed to approach the questions of assessment of project behavior on a broad front in order to formulate guidelines to assist the permiting, regulatory and design agencies in the permiting, design and implementation processes.

This report on the physical engineering aspects of beach nourishment and sand bypass is intended to be a companion piece to the investigation of biological monitoring guidelines in part I by Dr. Walter Nelson. The interactions of the biological concerns is closely related to the physical processes of beach nourishment and need to be addressed in order to completely understand the impact of a project on the complex coastal system.

NEED FOR GUIDELINES

Inventory of Selected Recent Beach Nourishment and Sand Bypass Projects

In historical perspective, very few beach nourishment and sand bypass projects were available with monitoring data collected as part of the project design. Walton (1977) and Hobson (1981) describe design considerations and details of many proposed beach nourishment projects but little has been done to follow up on the performance or even completion of these projects. Of the limited monitoring information from completed projects, no standardization of format content or reporting period was evident. An inventory of these selected projects completed in the state since 1975, was compiled using design memoranda, monitoring reports and actual field work. Using this background, a set of project performance monitoring standards was developed. These standards address the complete project including pre-construction, construction and post-construction time periods. As stated by Suboceanic Consultants (1979a, 1979b) the importance of establishing a program such as this is to 1) insure that erosion control projects are monitored on a systematic and periodic basis, 2) standardization of content, format and type of analysis to facilitate comparison and 3) provide a data base for future design and regulatory studies.

In order to assess the needs and requirements of project monitoring standards, a review of past project monitoring reports was undertaken. The first finding was the general lack of monitoring reports available for recent beach nourishment and sand bypass projects within the state. The following ten beach nourishment and inlet sand bypass projects were chosen because they had sufficient data on file either with DNR Division of Beaches and Shores, from monitoring reports obtained from project contractors or from actual collection of project field data:

- Boca Raton - Inlet transfer
- Captiva Island (South Seas Plantation) - Beach nourishment
- Delray Beach - Beach nourishment
- Hollywood/Hallandale - Beach nourishment
- Indialantic/Melbourne Beach - Beach nourishment
- Jupiter - Beach nourishment
- Ocean City, N.J. - Beach nourishment
- Pompano Beach - Beach nourishment
- Port Canaveral - Inlet transfer
- Stump Pass - Inlet transfer

Additional projects were selected from the literature where they could supplement data analysis. The great majority of projects reviewed either did not require monitoring or the data were inadequate or insufficient to describe post-nourishment behavior. Two of the larger projects within the state, Duval (Jacksonville Area Beaches) - Beach nourishment and Miami Beach - Beach nourishment did not have a systematic monitoring program but some data are available in field note format from the Jacksonville District Corps of Engineers office.

Until recently, there were no attempts to standardize project monitoring and it was sometimes difficult to compare projects directly since the data provided were obtained in various ways and presented in different formats. It became evident upon review of the limited data that were available, that there was a great dissimilarity in the type and content of data collection and analysis. All of the methods for describing project performance were valid and used standard engineering practices but due to the nature of analysis or data presentation cross comparison between project sites was extremely difficult and labor intensive.

This study organized data into five general categories as follows:

1. Project Description
2. Beach Survey Data
3. Sediment Analysis
4. Supplementary Data
5. Borrow Area Data

There were several inconsistencies in categories of information. Quite often there were omissions of data from one or more of the general headings.

Table 1 through 5 summarize the information about the projects and show the wide variability of data presentation including the borrow area monitoring information. Some of the borrow area reports were separate from monitoring reports and correlation of both on the same project proved difficult.

Project Descriptions

The projects selected for this study had a reasonable number of similarities in monitoring techniques while containing variations in location, wave climate, sediment characteristics and project size. This allowed for comparison of a wide spectrum of conditions found on sandy beaches. Project locations are on the lower east and west coasts of Florida and in Southern New Jersey (Figure 1).

Port Canaveral

Port Canaveral is located in Brevard County, just south of Cape Canaveral. There was a trend in accretion along this area until the man-made inlet and jetties were constructed in 1954 (Hunt, 1980). By 1958 noticeable accretion was observed updrift of the north jetty. Heavy beachfront development to the south of the inlet in the late 60's and early 70's along with several storms created a severe beach erosion problem on the downdrift shoreline. The U.S. Army, Corps of Engineers began a beach nourishment project in June, 1974 in conjunction with the dredging of the U.S. Navy Trident submarine turning basin. The fill material was pumped onto the beach south of the inlet for 3.4 km (2.1 miles) and was completed in March, 1975, with a calculated volume of 2,075,889 cubic meters of fill placed (Figure 2). Significant losses of fill material occurred during a storm in October of 1974. A large number of project specific profiles were established before and immediately after the project (Univ. of Florida, 1976). Six years after nourishment, profiles were taken at the DNR benchmarks R001, R008 within the project and at R016 as a southern control along with aerial photographic studies of the entire project to assess long term fill stability (Hushla, 1982). No systematic sediment studies were included in the monitoring reports.

Indialantic/ Melbourne Beach

Indialantic and Melbourne Beach are coastal towns in Brevard County on central

TABLE 1: PROJECT DESCRIPTION

Nourishment Project	Length of Project	Volume of Fill Placed	Nourishment Suitability (Calculated)	Pre-nourishment Baseline Data	Source Area – Method of Fill Placement	Completion Dates and Monitoring Length
Port Canaveral	3.38 km. (2.1 miles)	1,759,500 m^3 (2,715,000 yds^3)	-----	Shoreline retreat 3.04 m/yr (10 ft/yr)	Source: Port turning basin Hydraulic dredge	June 1974 – Mar. 1975 1 yr monitoring 7 yr follow up
Indialantic/ Melbourne Bch.	3.38 km. (2.1 miles)	195,060 m^3 (540,000 yds^3)	1.12 yds^3 borrow needed to replace 1.00 yds^3 native sand	Shoreline retreat 1.52 m/yr (5 ft/yr) before 1960 Stable since then	Source: Port turning basin Truck placement	Dec. 1980 – Jan. 1981 1 yr monitoring 5 yr continuous monitoring
Jupiter Island	7.62 km. (4.74 miles)	1973/1974 – 2,398,973 m^3 1977/1978 – 1,014,845 m^3	-----	Ave. rate of erosion = 197,289 m^3/yr	Source: Offshore borrow Hydraulic dredge	1973/74 #1 1977/78 #2 1981 follow up monitoring
Delray Beach	3.05 km. (1.89 miles)	1973 – 1,249,749 m^3 1978 – 536,188 m^3	-----	Shoreline retreat 1.52 m/yr (5 ft/yr)	Source: Offshore borrow Trucked from stockpile	July 1973 #1 Feb.–May '78 #2 36 month monitoring
Boca Raton	1.52 km. (0.95 miles)	Jan 1980/81 33,520 m^3 continuous as needed	Fill factor: 4.0	Beach south of inlet retreating 69.2 m in 4 yrs after 1975	Source: Weir sand trap; channel & ebb shoal Hydraulic dredge	1980 weir const 2 yr monitoring on beach
Pompano Beach	8.53 km. (5.3 miles)	1,459,621 m^3 (1,909,000 yds^3)	-----	Initial nourishment of 3.38 km. of bch. in 1970	Source: Offshore borrow Hydraulic dredge	Completed Aug. 1983 1 yr monitoring
Hollywood/ Hallandale	8.46 km. (5.26 miles)	1,514,432 m^3 (1,980,685 yds^3)	1.09 yds^3 borrow needed to replace 1.00 yds^3 native sand	Shoreline retreat 0.31 m/yr (1 ft/yr) 42,512 m^3 (55,600 yds^3) lost/yr	Source: Offshore borrow Hydraulic dredge	Nov. 1979 1 yr monitoring
Captiva	3.05 km. (1.89 miles) South Seas Plantation	501,195 m^3 (665,500 yds^3)	-----	-----	Source: Redfish Pass ebb tidal delta Hydraulic dredge	Oct. 1981 18 months monitoring
Stump Pass	1.83 km. (1.13 miles)	70,500 m^3 (92,205 yds^3)	-----	-----	Source: Inlet navigation channel Hydraulic dredge	Sept. 1980 3 yr monitoring
Ocean City, N. J.	3.6 km. (2.24 miles)	917,520 m^3 (1,200,000 yds^3)	-----	Almost continuous dredging in 1960's and 1970's by City owned dredge	Source: Great Egg Harbor Inlet flood tidal delta Hydraulic dredge	Oct. 1982 partial monitoring 1 yr profiles 3 yr sediments

TABLE 2: BEACH SURVEY DATA

Nourishment Project	Time Interval	BEACH PROFILES: Along the Beach Coverage	Along the Profile Coverage	Reference Monuments Utilized	VOLUME CHANGES USING PROFILE DATA: Time Interval	Along the Beach Coverage
Port Canaveral	6 months 1 year 7 year	Approx. 30 Project Profiles 30.48 m int.	Data point every 9.14 m	Dept. of Natural Resources (DNR); Project & Corps. of Eng. Benchmarks	Calculated every 4 months	Vol. change calc. for every 300m of nour. area
Indialantic/ Melbourne Bch	1 per week for 2 months every 3 mo. for 6 years	3 Project profiles 0.8km N & S. Controls 1.6km	Data point every 5 meters	DNR Benchmarks	Calculated every 3 months	Vol. change between profiles calculated
Jupiter Island	1 each 1973 & 1981	26 profiles 3 south 4 north of project	Data point evey 7.62 m onshore; 22.86 m offshore	Project Specific Benchmarks	Calculated once a year	Vol change calculated on Ave. every 335.28 m
Delray Beach	Once a year for 3 years	9 project 7 control split project 304.8 m intervals	Data point every 1.5 m	DNR & Project Benchmarks	1981 compared to 1980	Not Mentioned in report
Boca Raton	Quarterly in 1980 + once in Aug 82	19 total 7 north of inlet	From vegitation line to 9.14 m contour	Project Specific Benchmarks	Calculated once a year	Vol. change calculated on Ave every 152 m of study area
Pompano Beach	Post-const. & 1 year	29 profiles in project 2 control at 304.8 m intervals	Data points every 10 meters	DNR Benchmarks	Calculated at 1 year	Vol. change calculated on on Ave. every 304.8 m in project
Hollywood/ Hallandale	Every 3 months; Offshore profiles every 6 months	Profiles taken every 304.8 m	Data point every 6.1 m	Internal Project Benchmarks	Calculated every 6 months	Volume calc. for whole nour. area.
Captiva	Profiles taken every 6 months for 18 months	11 Project 4 S. Controls approx. 91.4 m intervals	Data points every 6.09 m	Internal Project Benchmarks	Calculated every 6 months	Volume change between profiles calculated
Stump Pass	1 year interval	8 profiles 6 in project north of Pass 2 south of Pass	Data point every 6.09 m offshore 15.2m	Project Specific Benchmarks	Calculated Approximately Every 12 months	Not mentioned in Report
Ocean City N.J.	10 months at 4 months intervals	30 profiles in project	Data points every 6 meters	Project Specific Benchmarks	Calculated every 4 months	Vol. change calculated on Ave. every 150 meters in project

TABLE 3: SEDIMENT ANALYSIS

Nourishment Project	SEDIMENT SAMPLING Time Interval	Along the Project Coverage	Along the Profile Coverage	GRAIN SIZE DISTRIBUTION Method of Separating Sediment	Statistical Parameters Used to Analyze Sediment	Additional Information
Port Canaveral	Samples taken pre-nourishment, 3 months, 7 months, 13 months	3 main sites in nourishment 2 supplemental 1 within; 1 south of fill	beach; beach-face; plunge-pt.; breaker-bar; -2.4; -3.7, -4.9 m offshore	Standard sieving	Median diameter w/ 1 quartile dev. & % shell material in depth of core determined	-----
Indialantic/ Melbourne Bch.	Samples taken every 3 months for 3 years	3 sites in nourishment; 2 controls, 1 north & 1 south	Dune base; high; mid; low tide; 61, 91, 122 m offshore of high tide	Standard sieving; intertidal composite samples used	Cumulative frequency and frequency curves; 4 moment measures	-----
Jupiter Island	------------------------No Sediment Analysis Mentioned in Report------------------------					
Delray Beach	pre (6/73) borrow (6/73) post (7/81)	3 sites in nourishment; 1 control site between 2 fill areas	Samples taken every 0.9 m; +4.6m at 2 sites; +5.5m & +3.7m out to -5.5 m	Standard sieving; project composite samples used	Cumulative wt. % coarser and composite curves drawn & compared to pre-nour. & borrow	-----
Boca Raton	Native beach sampled once; Borrow area cores once	------	------	Total project composite	Cumulative frequency curves	-----
Pompano Beach	Post-nourishment, 6 months, 1 year	Samples taken along every 5 th DNR line; 6 sites	Samples every 1.2 m contour intervals from +3.7 m to -6.1 m (NGVD)	Standard sieving; project composite samples used	Cumulative frequency curves	General sorting information supplied
Hollywood/ Hallandale	Samples taken pre-nourishment, 3 months, 6 months, 9 & 12 months	6 sampling sites in nourishment area	Samples taken at +2.1, +1.2, 0.0, -0.9, -1.8, -2.7, -3.7 m	Standard sieving; intertidal composite samples used	Cumulative frequency curves	-----
Captiva	Samples taken pre-, post-nourishment, 6 months, 12 & 18 months	3 sampling sites in nourishment area; 1 south of project	Samples taken every 0.9 m; +1.8 to -3.7 m	Standard sieving; intertidal composite samples used	Cumulative frequency curves	Analyzed sediment in borrow area before and after nour.
Stump Pass	------------------------No Sediment Analysis Done------------------------					
Ocean City N.J.	Samples taken Pre-, post-nourishment; every 3 months for 15 months	2 sampling sites in nourishment area; 1 south control	Samples at high tide, mid tide & low tide	Standard sieving intertidal composite samples used	Cumulative frequency curves and frequency curves	-----

TABLE 4: SUPPLEMENTARY DATA

Nourishment Project	Construction Activities Before and After Nourishment	Environmental Conditions Before and After Nour.	Aerial Photo. Coverage of Nourishment Area	Beach Width or Other Qualitative Measurements from Aerial Photographs	Additional Information
Port Canaveral	Jetty built at inlet-1954 dredging maintenance	Monitored storms before and after	Aerial photos from before, during, and 7 years after nourishment	Beach width and changes calculated from aerial photos	Beach recession rates calculated every 4 months
Indialantic/ Melbourne Bch.	-----	Baseline survey before; L.E.O. data monitored every 3 months	Aerial Photos: from before, during, 1, 7 & 11 months after nourishment	Beach width and area changes calculated from aerial photos	-----
Jupiter Island	-----	Photographs of project area	-----	-----	Retreat rate average 4.15 m/yr project retreat rates & shoreline position change
Delray Beach	Rock revetment built before nour.; sand fence placed at dune after nour.	Volume and shoreline retreat rates	-----	-----	Project erosion loss, retreat rates & shoreline positions
Boca Raton	1975 Inlet jetty added. In 1980 weir section added in north jetty	Survey included observations, photos, and sediment core samples	-----	-----	Beach immediately south of Inlet receeding 69.2 m in 4 years
Pompano Beach	Jetty built at Hillsboro inlet before nourishment	Volume and Shoreline retreat and accretion rates	-----	-----	Reported a loss of 58,110 m^3 or 4.4 m^3/ft/yr
Hollywood/ Hallandale	-----	None before; L.E.O. data monitored for 1 year period after nourishment	-----	-----	Beach alignment changes
Captiva	-----	Not mentioned in report	Examined flood channel before nourishment		Beach volume and mean high water line changes
Stump Pass	Maintenance dredging	Channel bathymetry showing scour and desposition	Channel location; fill and profile location	-----	Report on project following storm
Ocean City, N.J.	Eleven groins in project. built before nourishment	-----	-----	-----	-----

TABLE 5: BORROW AREA

Nourishment Project	Borrow Source	Bathymetric Survey	Sand Sample Pattern	Number of Samples	Sediment Analysis	Sampling Interval
Port Canaveral	Dredging of turning basin (barrier island sand)	Yes	Core in backbeach	Composite of backbeach and center of fill	Standard sieving; statistics	After fill placement
Indialantic/ Melbourne Bch.	Dredge spoil stockpile from Port Canaveral project	N/A	3 sites immediate post-placement on backshore	Composite of three surface samples	Standard sieving 1/4 phi interval	At placement
Jupiter Island	Borrow area 0.9 km directly offshore of project	-----	---------- No Sample Data Reported ----------			
Delray Beach	Borrow area 0.82 km directly offshore of project	Yes	Cores taken, pattern not reported	Not reported	Composite mean and standard deviation	Pre-nourishment
Boca Raton	Sand from Inlet weir sand trap, channel & offshore bar	Yes, depth intervals 1 foot	Not reported for sand trap, but alternate area of Lake Boca Raton	11 cores	mean 1.71 phi, beach mean 0.99 phi	1 survey
Pompano Beach	3 borrow areas offshore of project	-----	-----	-----	mean 1.75 phi	-----
Hollywood/ Hallandale	7 borrow areas; 1524 to 3048 m offshore of project	-----	---------- No Sample Data Reported ----------			
Captiva	Redfish Pass ebb shoal; 609.6 x 457.2 m borrow area	Transects 100' interval, depths listed 50' interval	4 corners & center	5 surface samples	Standard sieving; Cumulative frequency of individual & composite samples	Pre-, post-construction, 6 month 12 month
Stump Pass	Sand dredged from navigation channel	Yes, depths listed in 1/10 foot intervals	---------- No Samples Taken ----------			
Ocean City, N.J.	Great Egg Harbor Inlet flood tidal delta	-----	From discharge pipe on beach	1 surface sample	Standard sieving 1/4 phi interval	During construction

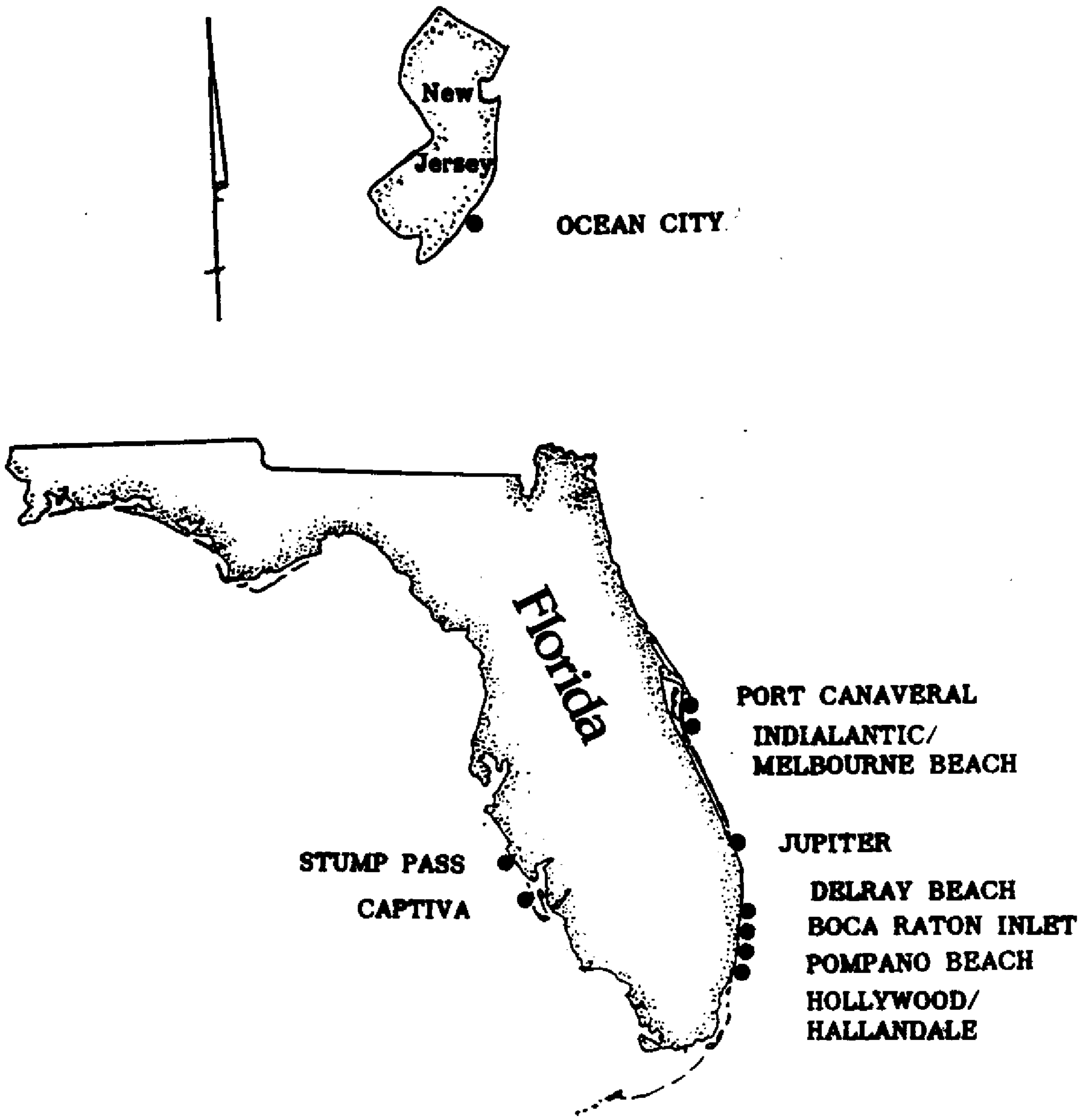


Figure 1. Location map of projects investigated in this study.

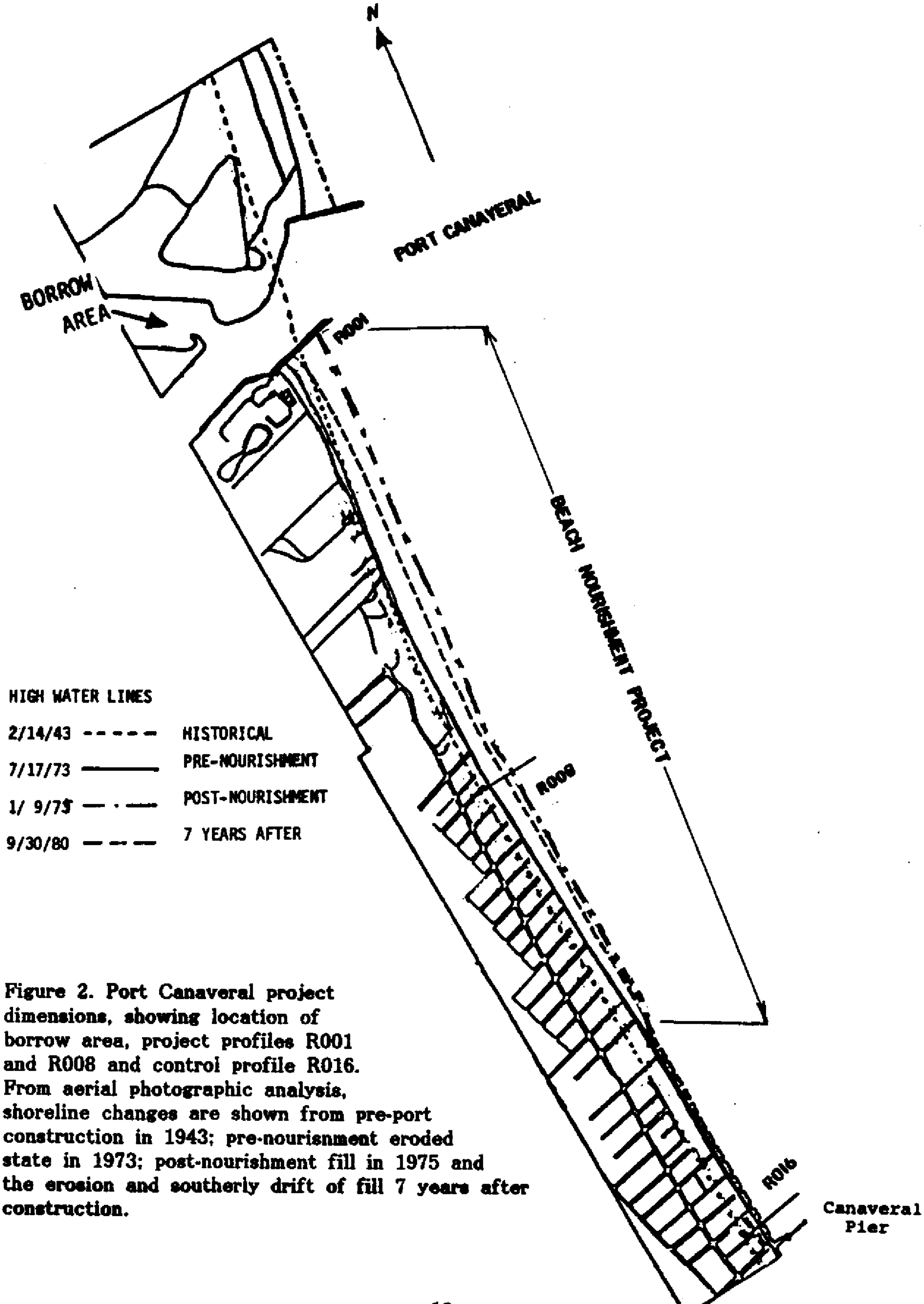


Figure 2. Port Canaveral project dimensions, showing location of borrow area, project profiles R001 and R008 and control profile R016. From aerial photographic analysis, shoreline changes are shown from pre-port construction in 1943; pre-nourisnment eroded state in 1973; post-nourishment fill in 1975 and the erosion and southerly drift of fill 7 years after construction.

Florida's east coast some 48 km (30 miles) south of Cape Canaveral. The location of the Indialantic/Melbourne Beach project and its borrow area 38 kilometers (23.6 miles) to the north at Port Canaveral are shown in Figure 3. The Indialantic/Melbourne Beach area is considered to be a high energy environment since it faces the open Atlantic Ocean and is subject to waves from distant storms. Wave data indicates that Melbourne Beach has a yearly mean significant wave height of 0.79 $\pm$ 0.25 meters (Jensen, 1983). Aerial photographic studies have shown that from 1943 to the summer of 1980, the high tide line had progressed landward about 30 m (Hushla, 1982). A beach nourishment project was done during the winter of 1980-81. The borrow material, dredged from the Port Canaveral Trident submarine turning basin during the Cape Canaveral beach nourishment project and stockpiled for future use, was trucked to the Indialantic site and placed in a design profile of 17m berm width, 3m berm elevation and a foreshore slope of 15:1.

The project placed around 413,000 cubic meters of fill material along 3.4 km (2.1 miles) beach. This project was done to insure the availability of a desirable recreational beach and to prevent storm damage to upland property (U.S. Army, 1978). In the first three months after beach fill placement there were very high loses due to storm activity, with scarping and fill berm cutback, until a stabilized profile occurred in May, 1981 (Stauble, 1982). This project had one of the smallest volumes of fill placed per kilometer of beach of the projects studied.

Beach profiles and sediment samples were collected from Florida Department of Natural Resources benchmarks sites R-126, R-129 and R-132 within the project limits, in addition to sites R-117 and R-140 which were control profile sites 1.6 km north and south of the project limits (Stauble et. al., 1983a). These control stations are used to determine the magnitude and direction of longshore redistribution of the fill materials. Profiles were collected before, during and immediately after construction. A series of post project monitoring profiles were taken, first on a weekly basis and as time progressed at monthly and finally quarterly intervals for five years (Stauble, 1982; Parson, 1982; Stauble et. al., 1983a and Hoel, in press).

Beach sediment samples were collected by scraping the upper few centimeters of sediment in plastic core liners and stored in plastic bags to await analysis. The samples used in the present study are from within-project sites R-126, R-129 and R-132. All samples were collected at hightide, midtide and lowtide positions on the beach, around the time of lowtide. Offshore samples were taken at 200, 300 and 400 feet seaward of the hightide line (Stauble et. al., 1983a; Hansen, 1982). These sampling positions on the beach profile vary laterally in distance throughout the duration of the study, but are hydrodynamically similar. Figure 4 shows how the sample positions change horizontally compared to a fixed reference point, but remain at the same tidal elevation and therefore within similar depositional environments.

Jupiter

Jupiter Island is located on the lower Florida east coast some 128 km (80 miles) north of Miami in Martin County. The Town of Jupiter, 9.7 km (6 miles) south of St. Lucie Inlet experienced shoreline erosion. A beach nourishment project was done along 6.4 km (4 miles) of beach, using sediment from an offshore borrow source starting in 1973 and finishing the southern portion in 1974 (Walton, 1977). A total of 2,398,973 cubic meters of fill was placed during these two years. Erosion continued and again

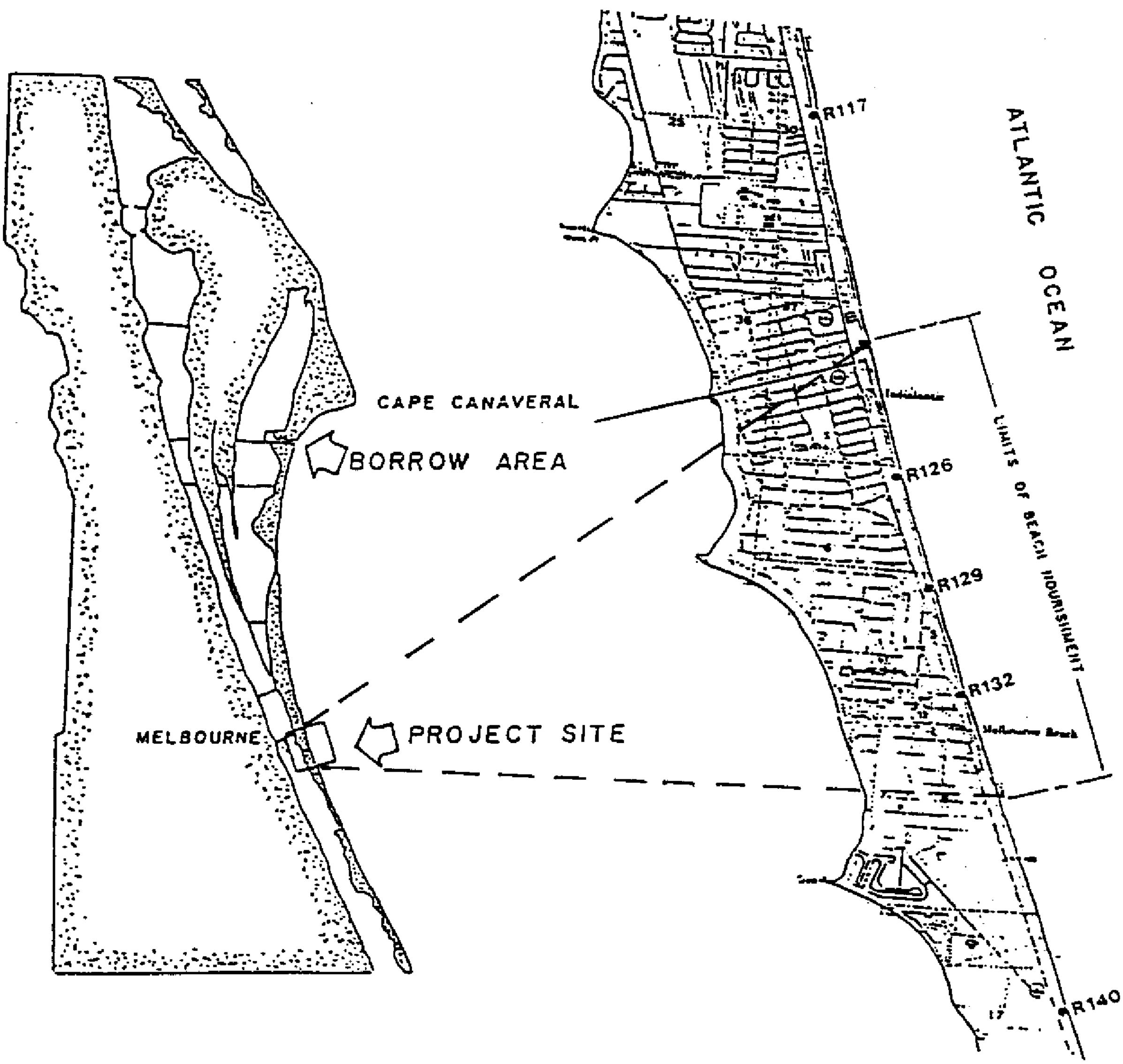


Figure 3. Indialantic/Melbourne Beach project dimensions, showing locations of the north and south control and within project study sites.

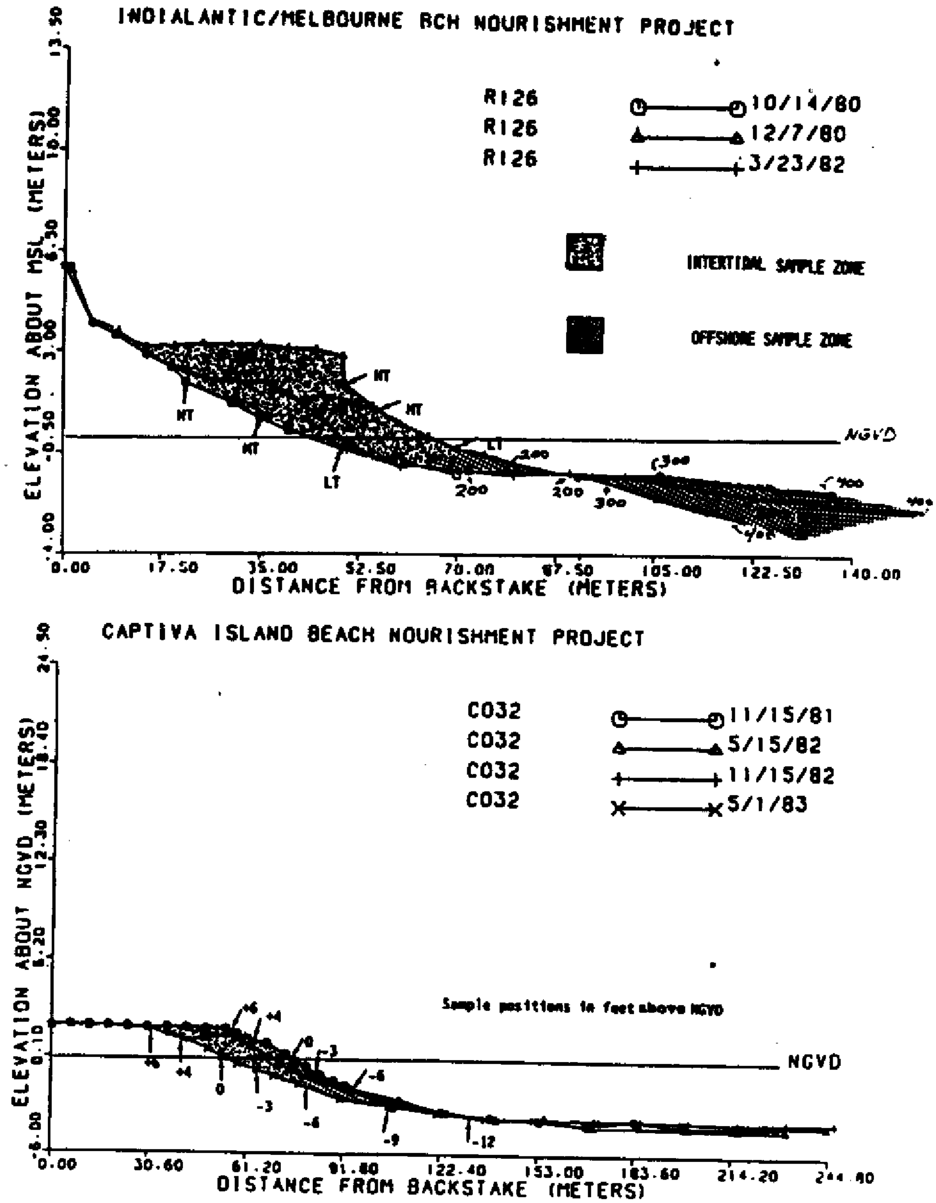


Figure 4. Sediment sampling locations on two of the projects from pre-construction thru post-construction, showing the change in intertidal and offshore sample position with change in profile shape while maintaining hydrodynamic zonation (Stauble et. al.,1984b)

starting in 1977 and finishing in 1978 an additional nourishment project was done in two segments in the center of the original nourishment project of 2.7 km (1.6 miles) and 2.2 km (1.37 miles) long (figure 5), with a combined volume placed of 1,014,845 cubic meters. A total of 26 profile lines were established at project specific profiles encompassing the two projects with controls on both the north and south sides of the fill and in the case of the 1977/78 project controls between the two project sections. Strock and Assoc. (1981d) reported that there was measurable longshore drift to the south with little drift to the north after the projects and recommended that by 1983, nourishment would be needed again. No sediment data or supplementary data was reported.

Delray Beach

Delray Beach is located approximately 75 kilometers (47 miles) north of Miami on the east coast of Florida, in Palm Beach County and some 13 km (8 miles) south of South Lake Worth Inlet. An original nourishment project was done along the entire 4.93 km (3.0 miles) of the city's beach in 1973, with the placement of 1,249,749 cubic meters of sand from an offshore borrow source. By 1976 the beach had experienced significant erosion of the fill. A second project was completed in March of 1978 on two stretches of city beachfront, one to the north and the other near the southern end of the city limit (Figure 6). Again, an offshore borrow site was used and the fill was pumped to shore at the northern end of the project and distributed along the project, with a reported volume of 536,188 cubic meters fill placed (Strock & Assoc., 1976).

The project monitoring consisted of sixteen profile sites. The first project used project specific benchmarks while the second project used the DNR monuments. Two profiles to the south of the project were used as controls in this area of predominately southerly littoral drift. The monitoring consisted of only three profile sampling intervals in July of 1979, 1980 and 1981. Wave energies here are similar to that of Indialantic but are somewhat less due to protection offered by the Bahamas and its surrounding shoals. Wave data shows Delray Beach having a yearly mean significant wave height of 0.69 ± 0.20 meters (Jensen, 1983).

The sediment data used in this study were profile composite samples constructed from elevations +9 to -3 ft. from sites R-177, R-180, R-184 and R-187. The borrow material was dredged from a nearby offshore source. Information for this project came from the 12, 24 and 36 month study reports by Arthur V. Strock & Associates, Inc. (1979, 1981a, 1981b).

Boca Raton

The Boca Raton Inlet is located along the southeastern coast of Florida, in Palm Beach County and is 65 km (40.4 miles) north of Miami near the Palm Beach/ Broward County line. The net littoral drift is to the south. The north jetty of the inlet was blocking the drift, resulting in accretion against the north jetty while erosion was occurring to the shoreline south of the inlet. Flanking of the north jetty and shoaling of the inlet navigation channel and growth of a sandbar at the mouth of the inlet became a problem which required frequent dredging. In 1975, the north jetty was extended to counter the flanking motion of the littoral drift and was successful in maintaining the navigation channel. However the erosion continued on the southern beaches. In 1980 a weir section was constructed in the north jetty to allow some sand

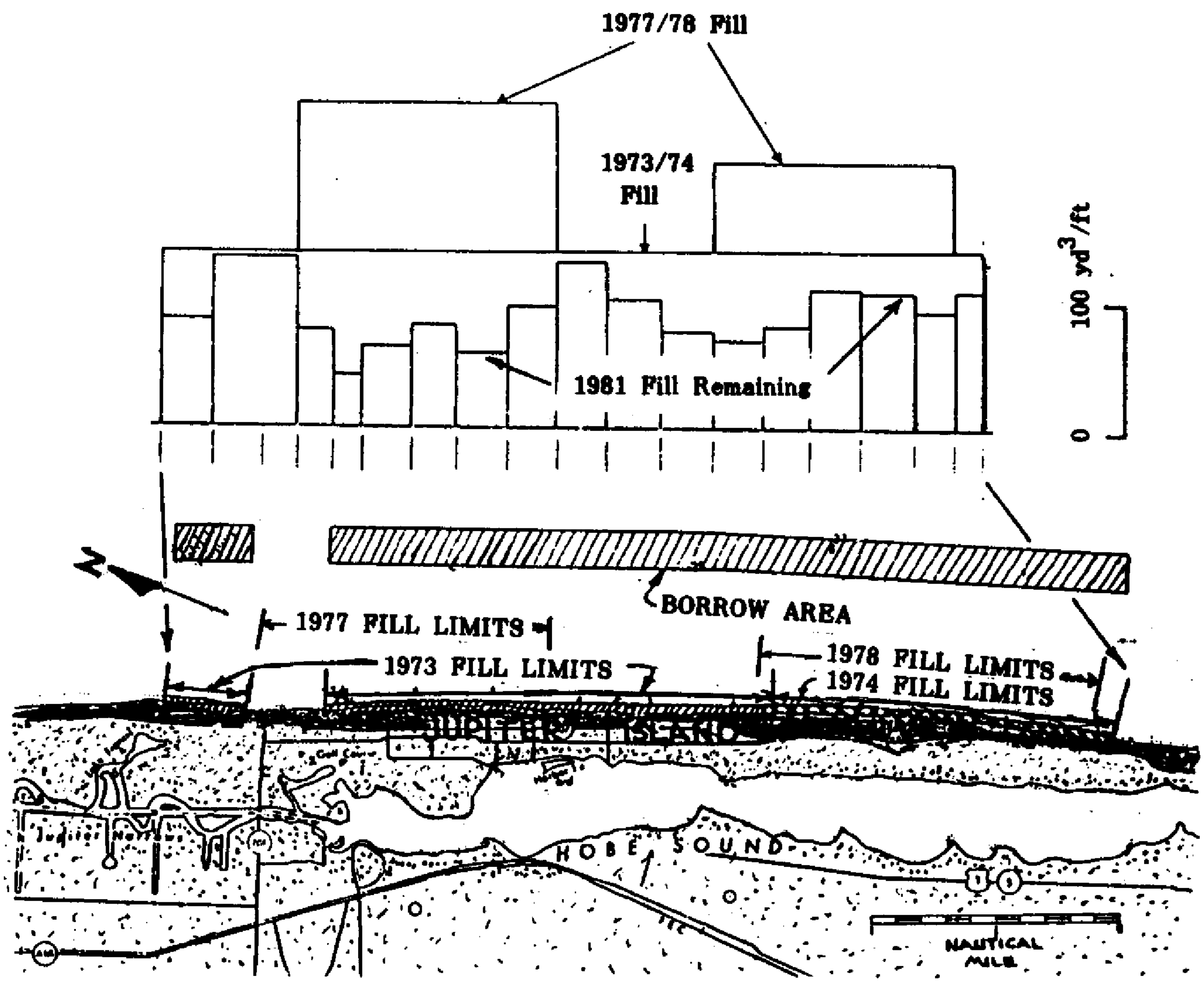


Figure 5. Jupiter Island project dimensions, showing locations of the offshore borrow area, the 1973/1974 nourishment and the 1977/1978 nourishment (after Strock and Assoc., 1981d).

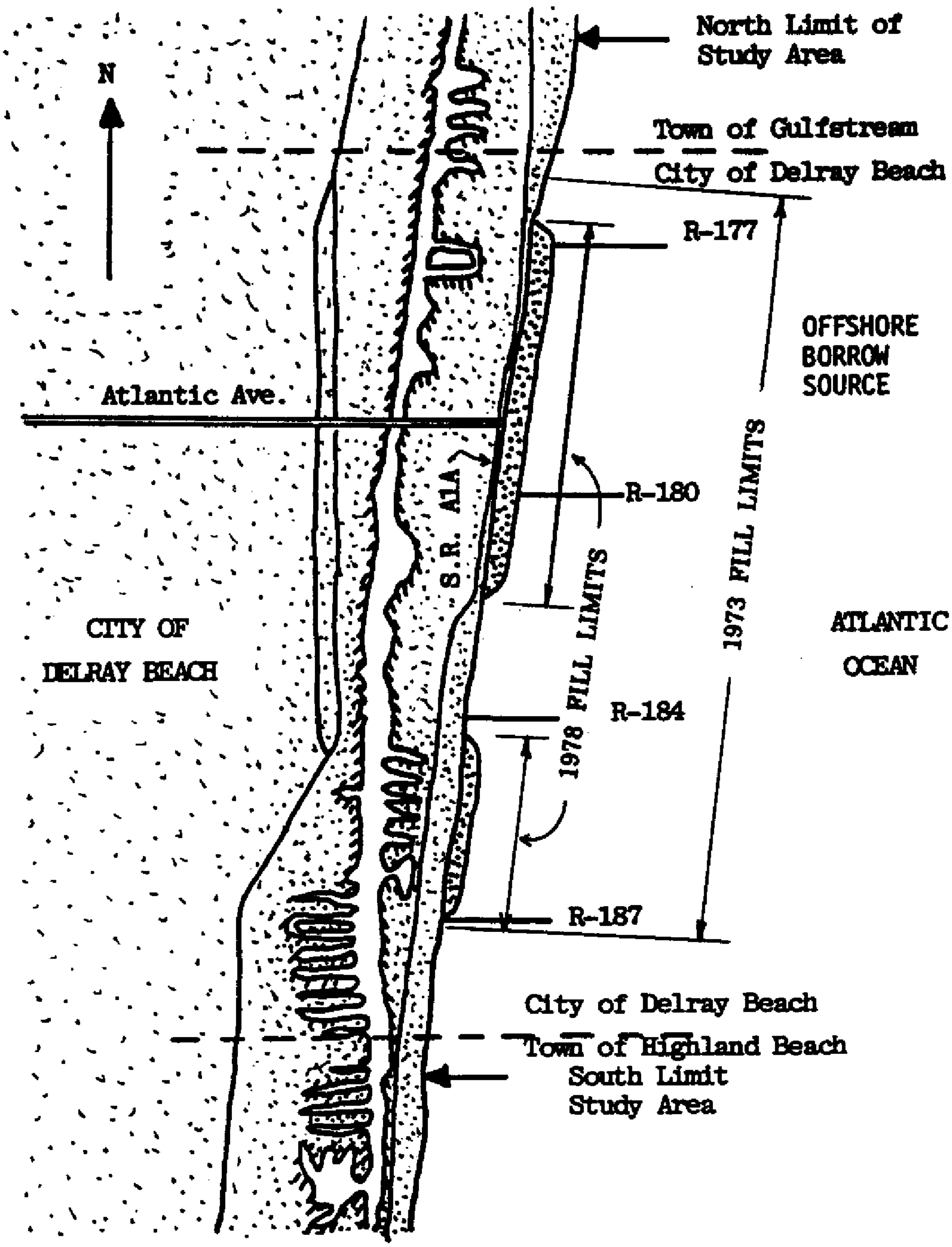


Figure 6. Delray Beach project dimensions, showing area of the offshore borrow, and profile locations used in this study (after Strock and Assoc., 1976.).

to flow into the inlet (see Spadoni et. al., 1983 for engineering design). The City of Boca Raton has maintained a dredge for many years to keep the navigation channel open. After construction of the weir, a dredging improvement program was initiated to periodicly dredge the sand trap at the base of the weir and the offshore sandbar and pump the sand to the south side of the inlet to the eroding beach area in the form of a sand bypass system (Figure 7). A study of this bypass operation was conducted by Strock and Assoc. (1981c, 1982, 1983) during 1981/1982. The report includes evaluation of the inlet and offshore shoaling by bathymetry studies, dredge transfer volumes and beach erosion /accretion of the north and south beaches with profiles. This project is different from the other projects examined in this study in that this is an ongoing project with dredging being done on an almost continuous basis as the conditions warrant.

Pompano Beach

Pompano Beach is located in Broward County, on South Florida's east coast 38 kilometers (23.61 miles) north of Miami. An initial nourishment project was completed in 1970 of 4.83 km (3 miles) of beachfront. The source of sediment was from an offshore borrow area that was dredged and pumped to shore. Continued erosion created the need to renourish this area again in 1983. The construction extended south from Hillsboro Inlet to the southern limits of Lauderdale-by-the-Sea and was completed in August of 1983 (Figure 8). This second project placed 1,459,621 cubic meters of fill material along 8.53 km (5.3 miles) of beach (Coastal Planning & Engineering, 1985). The purpose of this project was to provide coastal storm protection and a recreational beach for this highly populated coastline.

Monitoring on the second project consisted of surveying 28 profiles at 1/4 km intervals within the project and two control profiles to the south of the project limits using DNR monuments. These profiles were taken immediately after nourishment, six months and one year after project completion. High erosion rates were found south of the inlet in the northern sections of the project. This section of coastline, as well as most of the Florida east coast has a predominately southerly drift area.

Sediment samples were collected along six of the profile lines at 4 foot contour intervals from the back beach to the -20 foot contour. Project composite sample statistics calculated from all samples except the -20 foot contour from all the profiles studied were calculated and only this project averaged data was reported. This project had a reef in the offshore area at the -16 foot contour. Observations indicate that the fill was becoming coarser with time and pockets of fine silt material were observed in certain areas offshore between the -8 and -16 foot contour.

Hollywood/Hallandale

The cities of Hollywood and Hallandale are located 25 km (23.75 miles) north of Miami Beach and this section of coast has a yearly mean significant wave height of 0.54 $\pm$ 0.11 meters (Jensen, 1983). The pre-construction beach 5.5 km (3 miles) south of Port Everglades inlet was determined to be inadequate for recreational use and too narrow to provide storm protection to this highly populated coast. Construction was done during the summer and fall of 1979. More fill was placed at the southern end of the project to provide storm protection to the existing shorefront structures. The project length was 8.46 km with 1,514,432 cubic meters of fill placed.

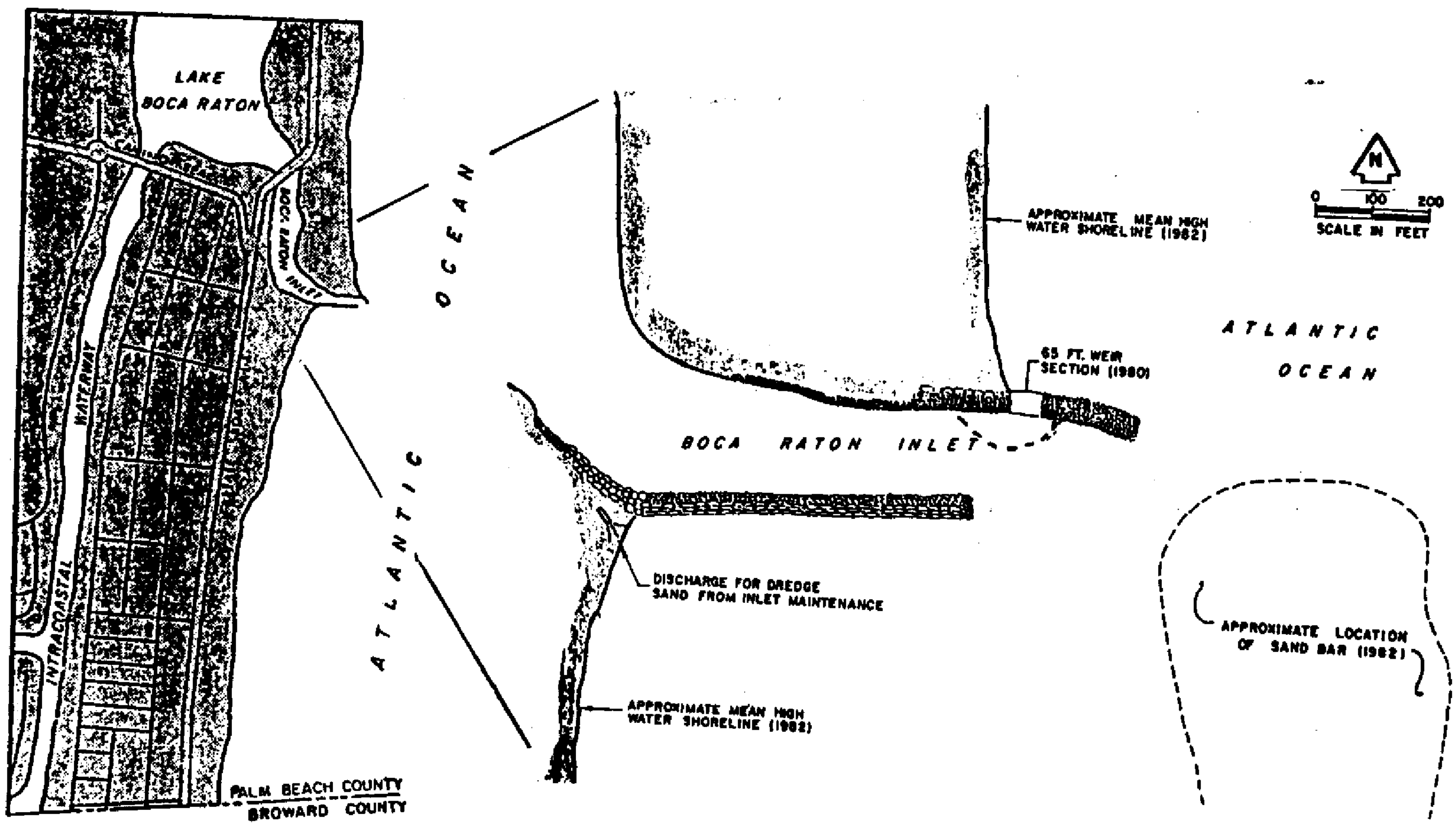


Figure 7. Boca Raton sand bypass project dimensions, showing location of weir at the north jetty and adjacent sand trap. Dredge pumps from sand trap, inlet channel and offshore sand bar to the discharge pipe located on the south beach (after Strock and Assoc., 1981c).

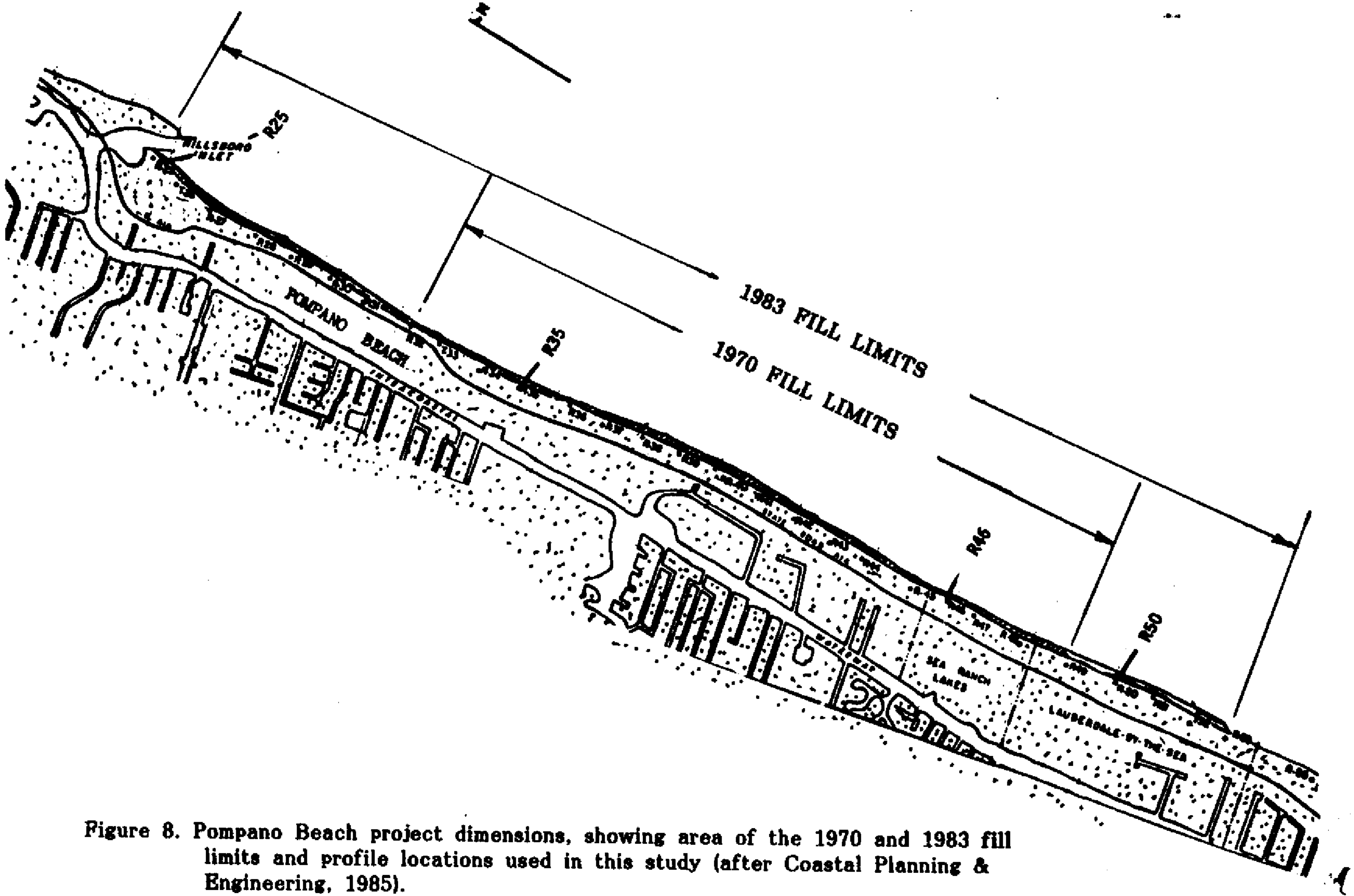


Figure 8. Pompano Beach project dimensions, showing area of the 1970 and 1983 fill limits and profile locations used in this study (after Coastal Planning & Engineering, 1985).

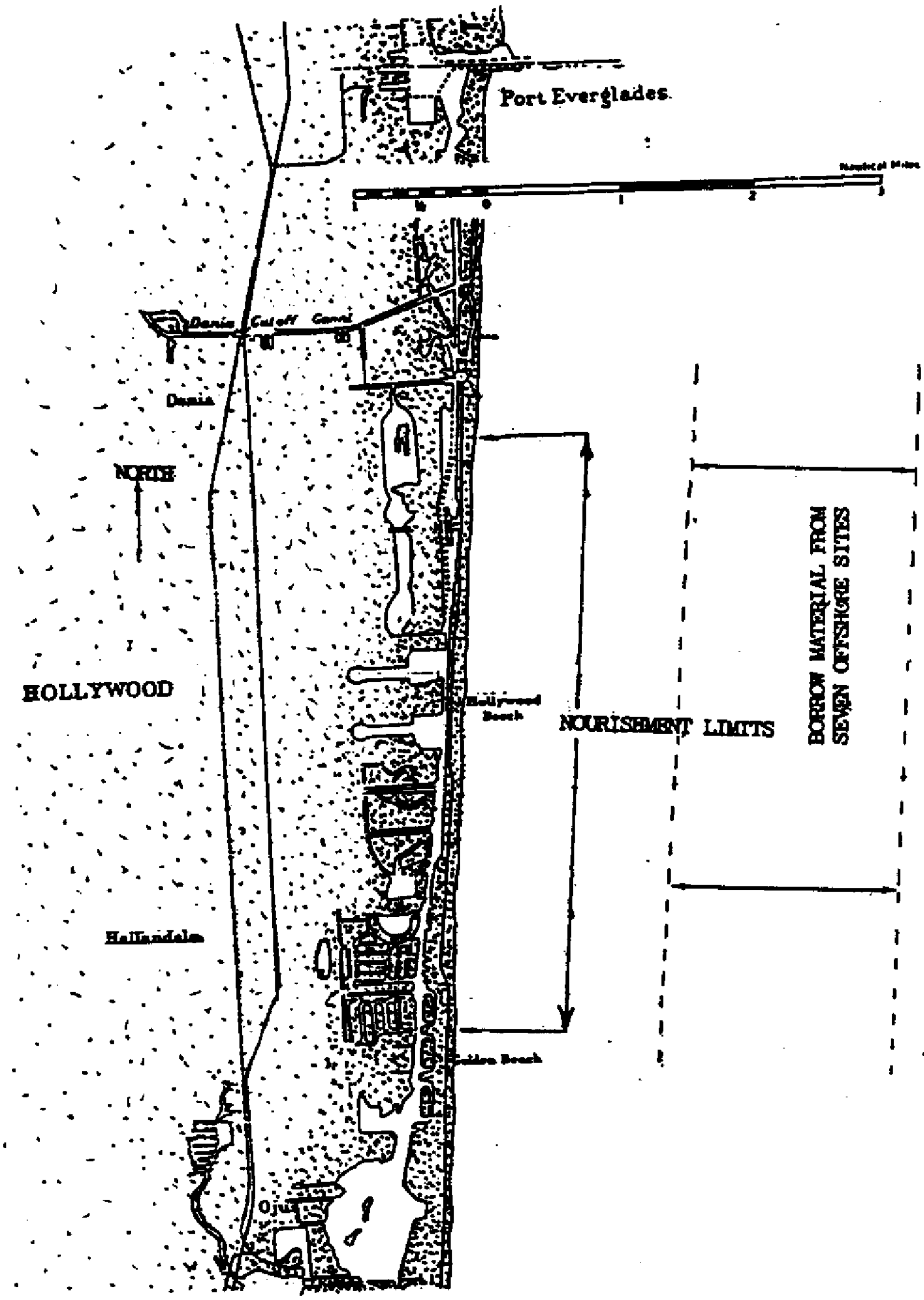


Figure 9. Hollywood/Hallandale project dimensions, showing area of the fill limits and borrow area used in this study.

The borrow material was dredged from seven sites 1500-3000 meters offshore (Figure 9). No beach profiles were provided in the reports. However, the change in the mean high water line from pre- and post-construction, and every three months up to one year after project completion was presented. Data on the volume of fill placed and remaining after one year was also included, as well as information on the wave climate.

Sediment data were obtained from 3, 6, 9 and 12-month monitoring reports done by Suboceanic Consultants, Inc. (1980, 1981). Six profile sites were studied by Suboceanic Consultants, but sediment data from only one site in the center of the project (site R-31) was provided in the report. Sediment data used in this study included samples from +7 to -9 ft. elevations along the profile.

Captiva

Captiva Island is a barrier island located on the west coast of Florida, 158 kilometers (98 miles) southeast of Tampa Bay, in Lee County. This section of the coastline is classified as a moderate wave energy area (Tanner, 1960). Yearly mean significant wave heights at Clearwater, 170 kilometers to the north, were 0.33 $\pm$ 0.22 meters (Univ. of Florida, 1982, 1983, 1984). The northern tip of Captiva island had been experiencing significant erosion as adjacent Redfish Pass, a natural inlet, varied in shape and volume in the ebb and flood tidal shoals through shifting sediment transport processes. An attempt to stabilize Redfish Pass was initiated by South Seas Plantation, with the construction of a sea wall and jetty on the south side of the inlet. This effort did not stabilize the beach downdrift of the pass, so a restoration project was completed in October 1981 on the northern 3.05 km of beach. The project had its borrow area located in the ebb tidal delta of Redfish Pass (Figure 10). The borrow area is indicated by the solid rectangle, while the dashed rectangle indicates the limits to which the borrow area was surveyed. Approximately 501,195 cubic meters of material was pumped hydraulically onto the beach from the dredge on the ebb shoal. The inlet south jetty was the northern limit of the project. The net drift direction on the west coast of peninsular Florida is to the south but there are seasonal and localized drift reversals on this highly segmented coast.

The monitoring program included pre- and post-construction, 6, 12, and 18 month surveys of the beach and borrow area, as well as analysis of sediment samples. Eleven profile sites within the project and four downdrift control profiles were included in this detailed series of reports. Beach volume changes were also calculated. The borrow area bathymetry and sediment changes in this 1 1/2 year study were also documented (Tackney and Assoc., 1982, 1983a, 1983b).

Sediment data were reported from four monitoring profiles, three within the project and one control. Only one profile site near the center of the project was used in the present study due to constraints in data analysis time. Profile site 32+07 near the mid point of the project was chosen as a representative profile line within the project limits. Sediment data were reported from +6 to -12 foot elevations.

Stump Pass

Stump Pass is located 128 kilometers (73 miles) south of Tampa in Charlotte County on the Gulf of Mexico. The Pass opens the southern end of Lemon Bay to the Gulf and is bordered on the north by Manasota Key and on the south by Knight Island (Figure 11).

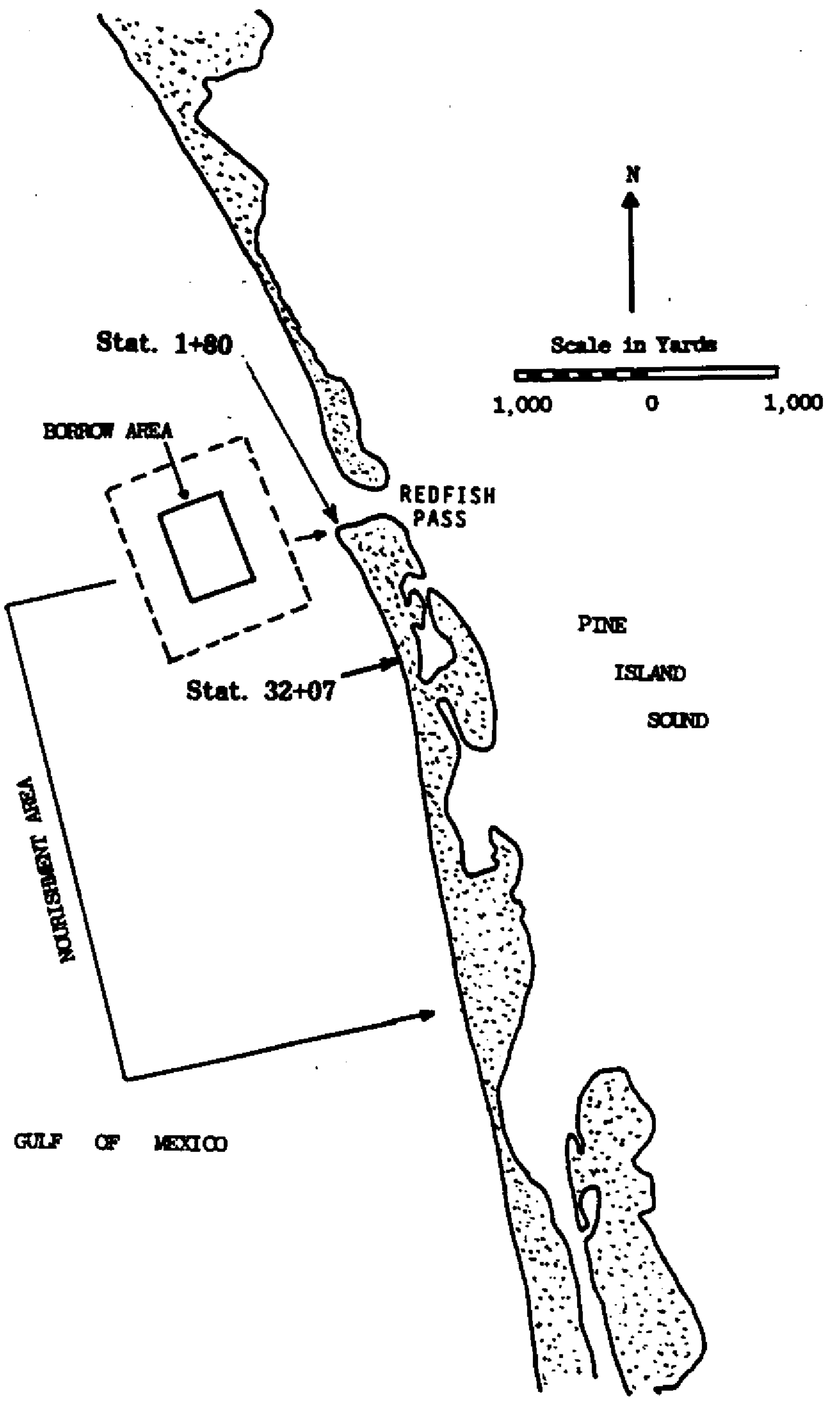


Figure 10. Captiva project dimensions, showing borrow area on the ebb tidal delta of Redfish Pass, sample station 32+07 used in this study and fill limits on the northern end of the island adjacent to South Seas Plantation (after Tackney and Associates, 1982).

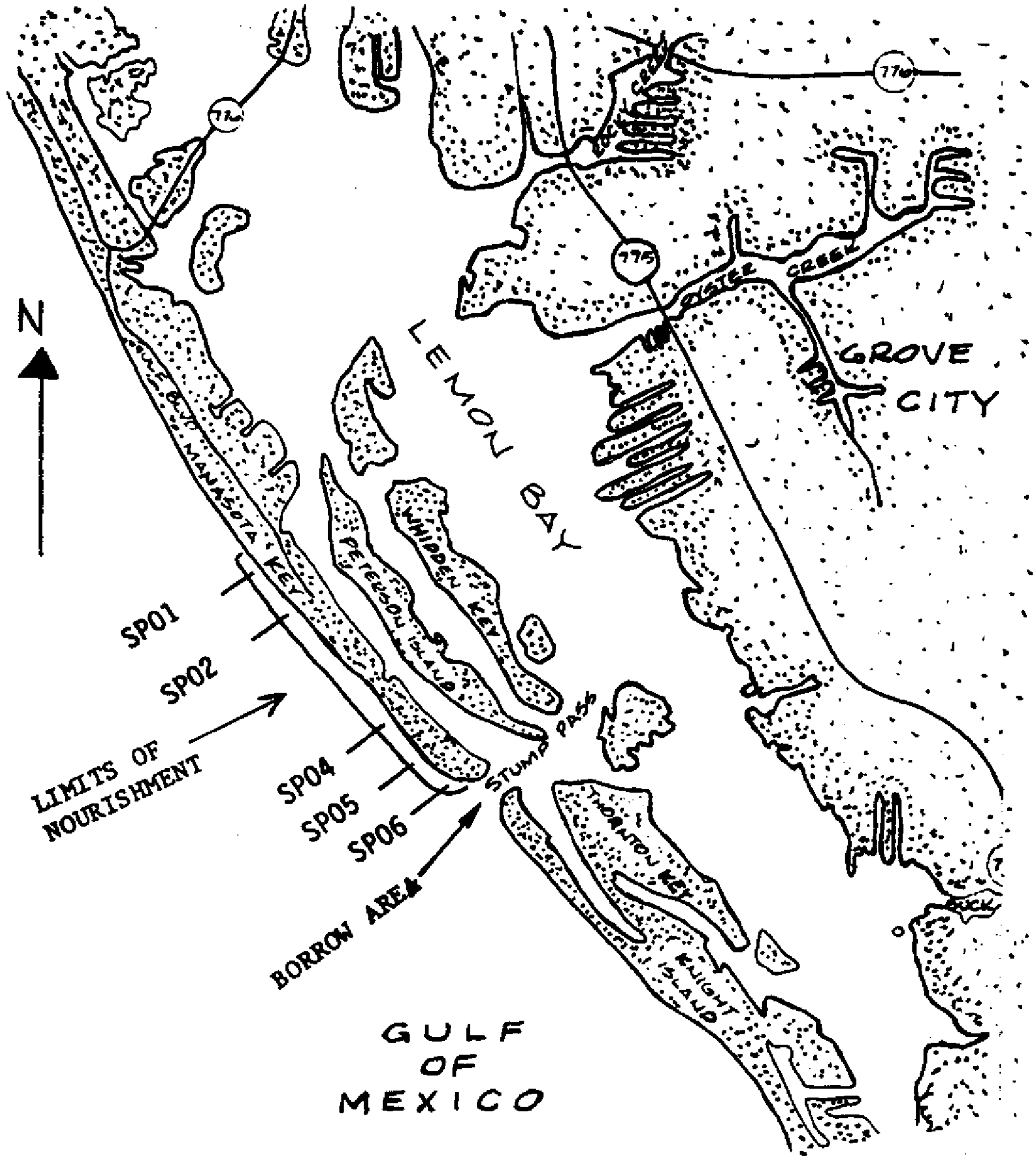


Figure 11. Stump Pass project dimensions, showing borrow area in the navigation channel of the Pass, profile locations and fill limits on the south end of Manasota Key (after Coastal Engineering Consultants, 1981).

Historical records and project monitoring indicate that the Pass has a natural tendency to migrate to the south (Coastal Engineering Consultants, 1982). The beach nourishment resulted from the maintenance dredging of the throat section of the Pass for navigation purposes. Suitable dredge material was placed on the north side State park beach in the summer of 1980. The beaches to the north of the inlet have exhibited considerable erosion in the past. The project pumped approximately 70,500 cubic meters of sand onto 1.83 km. of beach.

Project monitoring consisted of a total of eight beach profile locations, six on the north side of the Pass in the project area and two control profiles on the beaches south of the Pass. One of the southern profile stations was lost due to the shift of the inlet to the south. The monitoring consisted of a pre-construction sampling period and once a year for four years after the project completion (Coastal Engineering Consultants, 1981, 1982, 1983 and 1984). In addition to the beach profiling, bathymetric surveys and tidal and current measurements of the Pass were conducted. No sediment data was reported on from either the borrow area or the beach fill area.

Ocean City, N.J.

Ocean City is located about 16 kilometers (10 miles) south of Atlantic City on the southern New Jersey coast. This area is considered to have a high energy wave climate, with a yearly mean significant wave heights of 0.64 ± 0.07 meters (Jensen, 1983). The borrow area was located in the southern portion of the flood tidal delta of Great Egg Harbor Inlet. The city occupies the entire length of Peak's Beach, a 12.8 km (8 mile) long barrier island bounded on the north by Great Egg Harbor Inlet and on the south by Corsons Inlet. A drum stick shaped island, the north central portion of the beach has experienced significant erosion over the years. Numerous coastal erosion control structures have been constructed, including an extensive groin field on the northern third of the island. In addition, several nourishment projects were done in the 1950's (Watts, 1956) and earily 1960's. For a period in the 60's and 70's the City owned and operated its own dredge and conducted an ongoing nourishment program pumping material onto the beach from many borrow areas in the bay behind the island on an almost continuous basis. This program was discontinued with the demise of the city-owned dredge in the late 1970's.

Erosion continued to occur and, in order to restore the beach to an adequate width to protect shorefront property and support the summer tourist trade, another project was conducted in the summer of 1982. This project covered 3.60 km (2.24 miles) of shorefront on the northern portion of the island with 917,520 cubic meters of sand dredged from the flood tidal delta of Great Egg Harbor Inlet (Figure 12).

Profiles were obtained by Ocean City survey crews 3, 6 and 12 months after project completion (Gabriel, 1983). No profiles were available prior to nourishment. The beach survey consisted of thirty profiles within the project area, many taken between rubble mound groins. The groins act to create pocket beach like conditions, which made interpretation of the data difficult.

Sediment samples were collected independent of the profiles at hightide, midtide and lowtide positions at project locations at 5th and 11th Streets and at a southern control site at 27th Street on a quarterly basis for a year after the project. Drift directions along the southern New Jersey coast are seasonal with a drift to the north

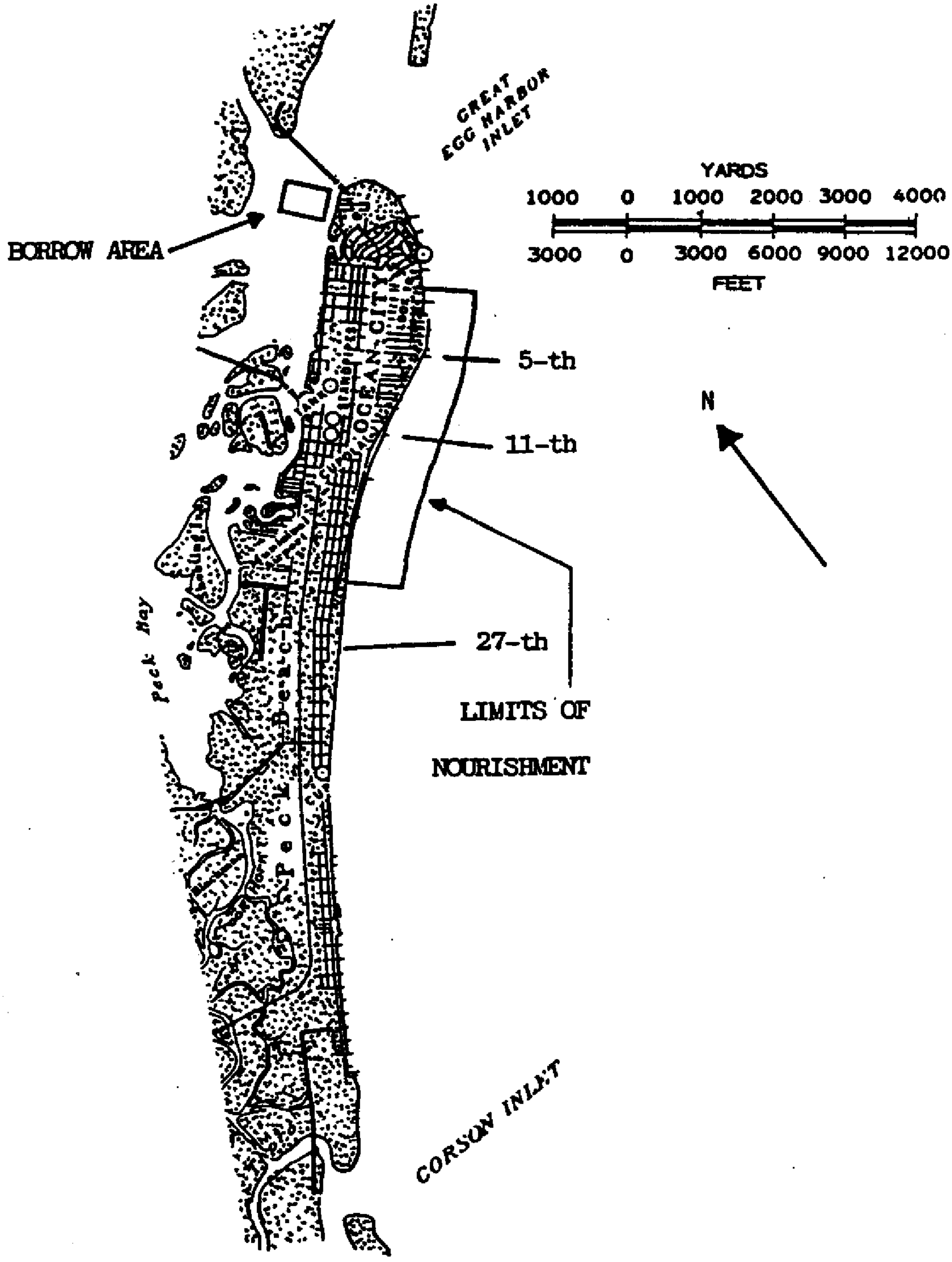


Figure 12. Ocean City, N.J. project dimensions, showing borrow area in the flood tidal delta of Great Egg Harbor Inlet, project and southern control sample locations and fill limits on the the north end of the island.

in the summer and a drift to the south in the winter, with a net drift to the south over the year. This drift is interrupted on the northern section of the island due to the size and number of groins. Project intertidal sample composites using data from 5th and 11th Streets were created to reduce variability in grain-size created by this extensive groin system within the project area.

An examination of numerous past beach restoration and inlet sand bypassing projects has revealed a distinct lack of monitoring and compilation of field data on project performance and its resulting biological impact. This lack of standardization of important project monitoring data collection and reporting has made the task of evaluating project performance and environmental impact next to impossible. A review of the literature indicates that there has been a development of theoretical design criteria on these types of projects, but little has been done on field verification.

This compilation of data performed on recently completed projects to assess the fill sediment redistribution and profile response has shed new light on project behavior, identified important monitoring criteria and provided a calibration of the standard design criteria. The initial problem found with this review of existing projects was to identify projects where data collection and analysis were of sufficient detail and were archived in an retrievable format. Many project specifications did not require monitoring or if they did, were of a general nature. Of the limited monitoring information, no standardization of format, content or reporting period was evident. Unfortunately all aspects of project monitoring were not mutually comparable on each project. Therefore several different projects were used for the physical and biological analysis. These projects lacked standardization in: 1) project monitoring requirements, 2) reporting interval, 3) report content, and 4) data analysis and presentation. The trend in the more recent projects completed in the state of Florida has been to require monitoring of both pre- and post-construction aspects. This type of data is proving to be useful in assessing project suitability and impact. New observational and experimental data were collected by Florida Institute of Technology personnel to supplement this lack of monitoring data.

Most (but not all) of the projects are located at erosion sites in close proximity, downdrift of inlets. Inlets have long been recognized as a major cause of interruption in the longshore drift of sediment, resulting in erosion problems for beaches downdrift of these inlets. The behavior of beach fill and inlet sand bypass projects can be influenced by the proximity to these inlets. Project locations along barrier island segments in relation to an inlet are as follows:

- Boca Raton, Sand bypass to south beach at inlet.
- Captiva Island, Beach nourished immediately south of Red Fish Pass.
- Delray Beach, Beach nourished 13 km (8 miles) south of South Lake Worth Inlet.
- Hollywood/Hallandale, Beach nourished 5.5 km (3 miles) south of Port Everglades.
- Indialantic/Melbourne Beach, Beach nourished 38 km (23.6 miles) south of Port Canaveral Entrance.
- Jupiter, Beach nourished 9.7 km (6 miles) south of St. Lucie Inlet.
- Ocean City, N.J., Beach nourished 1.22 km (0.76 miles) south of Great Egg Habour Inlet.
- Pompano Beach, Beach nourished immediately south of Hillsboro Inlet.
- Port Canaveral, Beach nourished immediately south of Port Entrance jetty.
- Stump Pass, Inlet sand transferred to adjacent north shoreline.

Components of the Monitoring Process

Beach restoration by artificial placement of fill material is usually accomplished either by the placement of sediment, obtained from a borrow area, on an eroded beach (beach nourishment) or by maintenance dredging of inlet navigation channels or sand traps with subsequent placement of this material on the downdrift beach to maintain artificially the longshore sand transport blocked by inlet coastal engineering structures (inlet sand bypassing) . However, questions concerning the high cost of construction, appropriateness of using public funds and the long term effectiveness of projects have led to an array of technical, fiscal and permitting obstacles to successful completion of projects.

The important components that need to be considered in understanding the performance and "success" of a beach nourishment or sand bypass project will be discussed in this section. Collection of monitoring data should include the three areas of importance in a project, 1) the borrow area, 2) the nourishment area and 3) littoral environmental conditions. Monitoring in each of these project areas should address the complete project, including pre-construction, construction and post-construction time periods. The development of project monitoring standards is designed to support the following regulatory and design functions:

1) Systematic evaluation of project applications,
2) Assurance of project design compliance at completion,
3) Systematic evaluation of project performances,
4) Maintenance of monitoring data base of beach nourishment and inlet sand bypass projects and
5) Development of special studies or reports on status/achievements of the beach erosion control programs.

Borrow Area Monitoring Specifications

The borrow area, where the fill material is obtained that will be placed on the beach, is an important area for consideration in nourishment projects. Some inlets with sand bypass problems have specifically designed sand traps to collect sediment for downdrift placement on the beach. Regardless of the source, this sand must be of suitable quality and quantity to be considered for transfer to the eroding beach area. Often this information is collected before or during the permitting stage and is included in the project's general design report. These reports are not always filed at the same agency responsible for project performance monitoring and it is difficult to relate this data to subsequent monitoring reports.

The monitoring of the source area of beach nourishment and inlet sand transfer sediment is important to:

1) Assess the suitability of the proposed borrow material for erosion control purposes as beach fill.

2) Assess the effect of sediment removal on the borrow area and adjacent areas due to changes in the coastal processes brought about by this removal.

3) Assess recovery of the borrow area through time and its suitability for future source of renourishment as needed.

Types of Borrow Areas

There are several types of borrow areas that may be suitable for supplying compatible beach sands and which are near to the beach requiring nourishment. These included:

1) nearshore shelf sand deposits,
2) cape associated shoal sand ridges,
3) inlet flood and ebb tidal deltas,
4) estuarine bottom deposits or
5) upland sources on a barrier island or mainland sand deposit.

For sand bypass projects, the borrow area is usually:

1) the inlet navigation channel,
2) inlet flood and ebb tidal deltas and
3) designated sand trap area, (ie. updrift jetty structure with pump acting as a littoral barrier - South Lake Worth Inlet, a wier structure with sand trap - Boca Raton Inlet, flood tidal delta and sand trap - Sebastian Inlet).

(See Jones and Mehta, 1980 for additional sand bypassing systems in Florida).

Figure 13 illustrates several types of borrow areas used in recent beach nourishment and sand bypass projects investigated for this study. Most of these borrow sites have been areas of high energy in the geological past, where suitable grain size sands were deposited. At the present time these regions may be under the influence of lower energy regimes and have additional non-suitable grain sizes deposited over or mixed with the suitable grain sizes for beach sands. It is therefore important to identify the location and extent of the useful sediment and identify any environmental impacts from the dredging process. Each borrow area has its unique properties that need to be identified to successfully obtain a permit and design a useful monitoring program.

Borrow Area Sampling

Several erosion control projects, particularly in South Florida have used sediment from environmentally sensitive borrow areas. Major concerns with borrow areas are the bathymetry and its relationship to the bottom sediment and organism types and the effects of dredging on the physical and biological environment of the borrow pit and surrounding area. In the past, some projects have monitored only pre-dredging phases to obtain suitability data. Post-dredging monitoring of the borrow area has recently been required on more projects, mainly for a biological impact assessment. The longer term sedimentological effects suggest that the subaqueous borrow pit fills in with finer grain sizes spilling in thru transport by bottom currents (Dalrymple, 1970 and Nelson et.al., 1982). This may prevent the use of the borrow area for future projects and change the biological environment.

Sediment sampling

A study of both depth and area of the borrow site should be conducted with the use of cores to determine the quality and quantity of available sand. Sediment cores of a length sufficient to penetrate below the depth of dredge scour should be taken as close as possible to the bathymetric survey. The number and location of these cores are

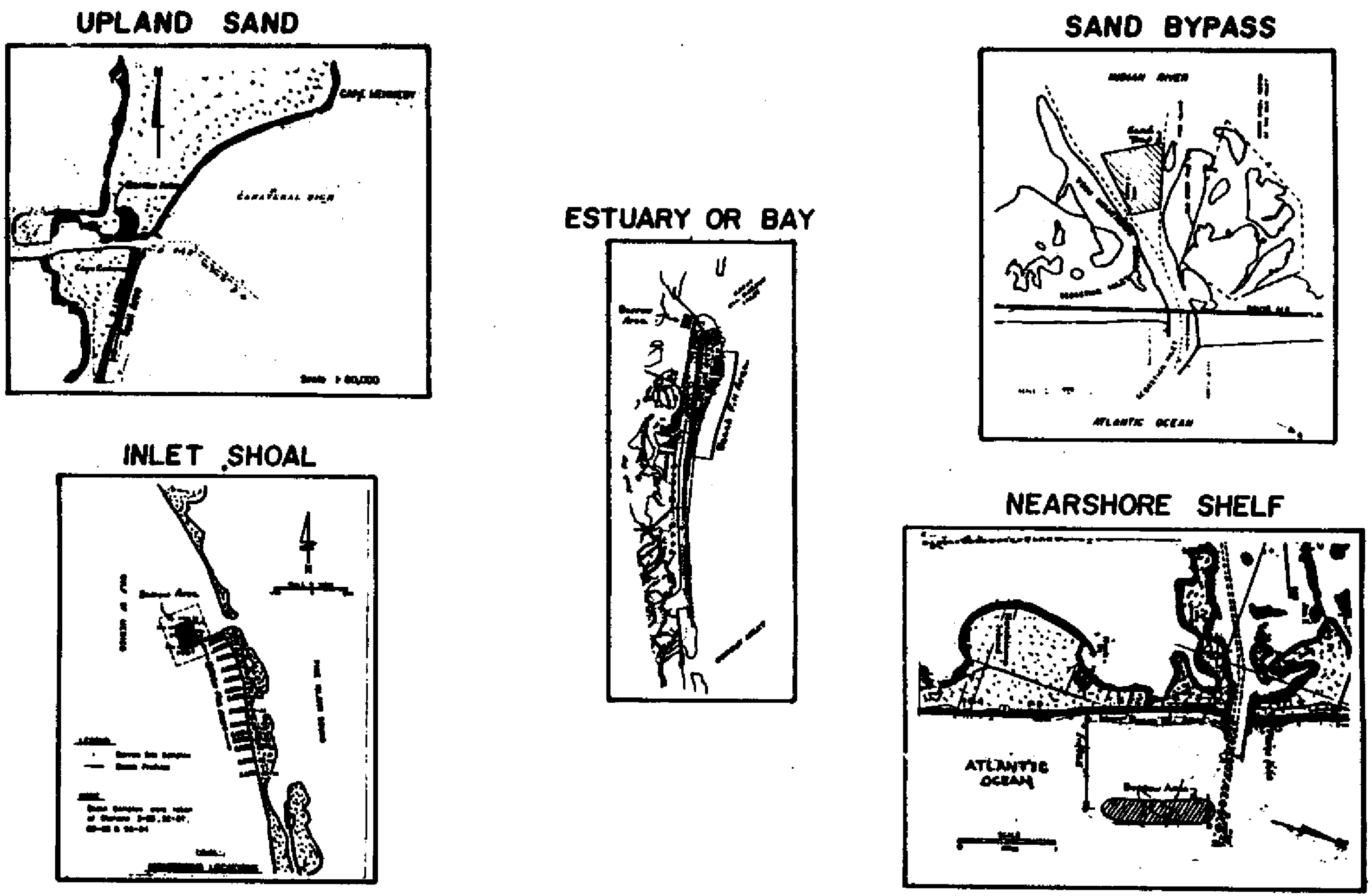


Figure 13. Examples of several different types of borrow areas used for beach nourishment and inlet sand bypass projects

determined by borrow area specific complexities, variation of sediment distribution and suitability requirements. A sufficient number of cores should be located in the boundaries of the borrow area to give an adequate picture of the stratigraphic variability within the area. Changes in the depositional environment in the recent geological past could result in a complex stratigraphy, with the possibility of numerous nonsuitable sediment layers occurring within the boundaries of the borrow area. Control area cores may be needed to assess the impact of this dredging on the surrounding ecology and coastal processes.

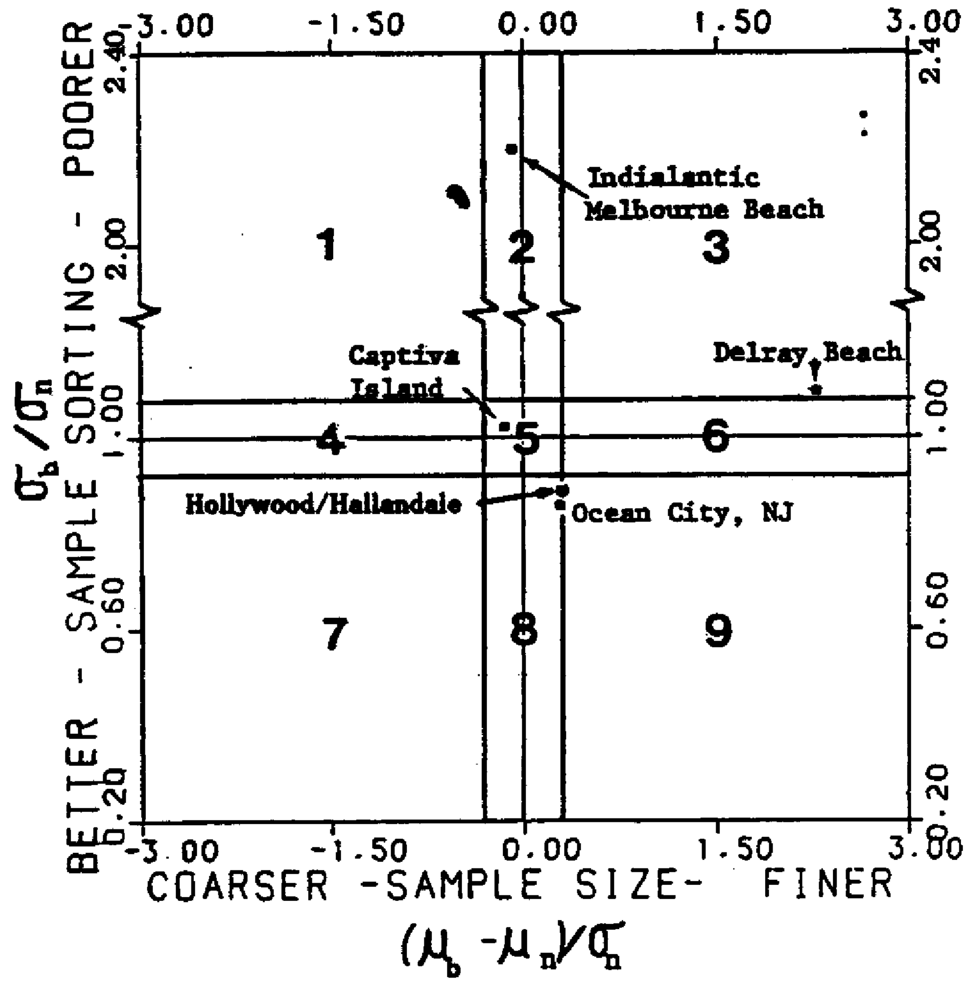
Laboratory analysis usually consists of splitting the cores and archiving one half of the core for future reference. A core log of the core's stratigraphy including the lithology, color and grain size variation with depth along with other pertinent information about the layering within the core will aid in identification of fill suitability and biological activity in the borrow area. The number of separate sediment samples to be chosen for coarse and fine grain size analysis to be run on each core will be determined by the complexity of the stratigraphy of the core. Composite grain size statistics can then be calculated for the borrow area sediment using the technique described in the Shore Protection Manual (U.S. Army, 1984).

Within the core or horizontally thru the area to be dredged, care should be taken in constructing a composite sediment, which is in essence a mean value. It may become necessary, depending on the environmental concerns, to avoid as much as possible non-suitable grain size (i.e. too coarse or too fine) deposits of the borrow or to separate what is suitable to be placed as beach fill with what is determined unsuitable that is to be placed in an alternative dredge spoil site. This presents a definite problem for the dredging operation but has recently been required by some State regulatory officials, concerned with high turbidity levels created by dredging fine grained material that could cause adverse impact both to the borrow and beach placement area organisms. From the core log data a three dimensional picture of what is contained in the borrow area can be obtained. With this knowledge, a better dredging operation can take place and compliance with permit requirements for avoidance of nonsuitable grain sizes and possible turbidity problems can be accomplished.

An analysis of the borrow area sediment sampling and analysis in this study showed a wide variability from project to project (Table 5). Some of the projects reported composite samples of cores taken from the borrow area, others summarize vertical and horizontal distributions with core descriptions while some used only surface sediment composites or individual samples from the area of fill placement. The borrow material from the projects examined was obtained from various environments. Indialantic/ Melbourne Beach had borrow material with a similar mean grain-size but was more poorly sorted and was sediment dredged from a barrier island to produce a harbor area. Delray Beach had much finer borrow material whose sorting was slightly poorer than the native beach and was from an offshore source area. Hollywood/Hallandale had a borrow that was slightly better sorted and contained finer material owing to its offshore origin. The borrow at Captiva Island was almost identical to the native beach and was obtained from an ebb tidal shoal. At Ocean City, NJ, the borrow was slightly finer and better sorted than the native beach and was dredged from a flood tidal bay source. When comparing native and borrow materials in Table 6, it can be seen that there was more variation in the sorting values than there was in the mean grain-size. Mean and sorting values are given in Phi Units (ϕ) where $\phi = -\log_2 d/d_o$ with d the grain size in mm and d_o being a standard grain diameter (i.e. 1 mm). Figure 14 illustrates the variability of

TABLE 6: Mean Grain Size and Sorting Values for Various Types of Composites Calculated from Projects in phi units.

	PROFILE		INTERTIDAL		OFFSHORE		PROJECT PROFILE COMPOSITE	
	μ	σ	μ	σ	μ	σ	μ	σ
PORT CANAVERAL								
PROJECT COMPOSITE								
PRE							2.00	1.72
BORROW							1.59	1.61
1 YEAR							N/A	
INDIALANTIC/MELBOURNE BEACH								
R 126, R 129, R 132								
PRE	2.01	1.05	1.62	0.72				
BORROW							1.59	1.61
1 YEAR	1.92	1.06	1.44	0.88				
DELRAY BEACH								
PROJECT COMPOSITE								
PRE 6/73							1.02	0.57
BORROW 6/73							2.27	0.67
8 YEAR 7/81							1.91	0.75
POMPANO BEACH								
R 26, R 30, R35, R40, R45, R50								
PRE							0.75	----
BORROW							1.73	----
6 MONTH							1.50	----
1 YEAR							1.35	1.35
HOLLYWOOD/HALLANDALE								
R 31								
PRE	1.21	1.24	0.32	0.94	2.10	0.79		
3 MONTH	1.50	1.18	0.58	0.83	2.43	0.61		
6 MONTH	1.66	1.46	1.17	1.26	2.14	1.49		
9 MONTH	1.70	1.13	1.10	1.15	2.29	0.72		
1 YEAR	1.30	1.34	0.69	1.02	1.92	1.35		
CAPTIVA								
Sta. 32+07								
PRE							1.53	1.63
BORROW							1.20	1.72
POST	1.61	1.38	1.09	1.43	1.99	1.20	1.52	1.45
6 MONTH	1.55	1.45	0.87	1.51	2.06	1.18	1.49	1.41
1 YEAR	1.51	1.36	0.78	1.36	2.06	1.06	1.46	1.43
18 MONTH	1.38	1.41	0.76	1.38	1.85	1.23	1.42	1.47
OCEAN CITY, N. J.								
5th. st., 11th. st.								
PRE 7/82			2.55	0.58				
BORROW							2.72	0.50
POST 8/82			2.58	0.68				
1 MONTH 9/82			2.67	0.42				
3 MONTH 11/82			2.48	0.51				
9 MONTH 5/83			2.44	0.37				
1 YEAR 8/83			2.55	0.45				
15 MONTH 11/83			2.45	0.54				



KEY— Relationship of the borrow material relative to the native material.

1— Coarser, more poorly sorted
2— Same mean, more poorly sorted
3— Finer, more poorly sorted
4— Coarser, same sorting
5— Same mean, same sorting
6— Finer, same sorting
7— Coarser, better sorted
8— Same mean, better sorted
9— Finer, better sorted

Figure 14. Native-to-borrow comparison chart (see text for explanation). (After Blake, 1984)

native-borrow relationship in four of the projects with available data along with nine possible native-to-borrow relationships.

Turbidity monitoring

Turbidity monitoring of dredging activity in the borrow area has recently been included in project monitoring requirements to study the impact of dredging activities on adjacent biological environments. Data on turbidity standards is not well documented and the present limits of acceptable turbidity are set close to natural background levels in some areas and may impose undue restriction on the dredging process. More study is needed on identification of background levels in both the borrow area and the beach fill placement area and criteria for determination of acceptable project generated turbidity. Collection of turbidity data from the Sebastian Inlet bypass project, in progress at the time of this writing, indicates that natural surf zone turbidity levels in the vicinity of the fill placement are often above the current State standard of 29 NTU's (Nephelometric Turbidity Units) above background. Turbidity levels may also naturally exceed the standards in the borrow area depending on wind and tidal current conditions. While extreme turbidity levels created by the dredging process need to be avoided, a better understanding of natural fluctuations under varied environmental conditions and organism tolerance limits are needed.

Hydrographic survey

A hydrographic survey using fathometer or bottom sled and range locating equipment should be conducted prior to and immediately after the project of the borrow area and surrounding area including a nearby control area. This hydrographic survey, preferably relating to land based profile benchmarks or range lines, can be used to construct bathymetric maps. This information is useful to identify, in a three dimensional framework, the area, location and depth of suitable sediment and to delineate non-suitable borrow material areas to be avoided in the dredging process. This information is useful for obtaining permits and is usually required in the permit application but it should also be included in the pre-nourishment report for comparison with post dredging monitoring.

Sampling and reporting schedule

The time schedule of surveys and reporting on borrow area monitoring information should include:

1) Pre-nourishment borrow area survey to be included in the pre-project base line study report,
2) Post-nourishment borrow area survey to be included in the as-built monitoring report and
3) The 6, 12, 24, and 36 month borrow area surveys to be reported in the respective monitoring reports.

A survey immediately after project completion of the bathymetry and sediment data will establish a starting point for borrow area behavior. This post-nourishment survey and subsequent monitoring surveys of surface sediment samples collected with a grab type sampler will be sufficient to identify the change in sediment characteristics as the borrow area recovers and in conjunction with biological analysis of the environmental impacts (Nelson, et. al.,1982). The number and location of samples should be the same throughout the monitoring period. Grain size composite statistics of mean and sorting should be included in the specified reports.

A six month and 12 month survey of borrow area bathymetry and sediment grain size distribution will be required to assess borrow area behavior. Long-term monitoring at 24 and 36 months will assess the filling in of the borrow area and suitability of reusing the area for renourishment in the future. Control areas are important to establish natural background conditions as the borrow area recovers. These areas should be chosen to be representative of pre-nourishment conditions within the study area. Littoral drift direction and prevailing currents should be taken into account in the choice of the control areas. Physical monitoring data could also be useful in assessing the future use of the borrow area for additional maintenance of the project or for new projects in the same coastal area. To give a complete history of the project, the borrow area must be included in any monitoring guidelines.

Fill Suitability Determination

Pre-dredging sediment surveys of the borrow area are very important for assessing the suitability, based on the theoretical models outlined in the Shore Protection Manual (U.S. Army, 1984). At present the selection of suitable borrow material is based on theoretical calculation procedures, of which the grain size characteristics of the borrow area are a major component (Hobson, 1977). Before this study, little systematic follow-up has occurred on the behavior of a project or whether the model correctly predicted fill retention.

In order to analyze fill suitability, a representative sediment sample needs to be collected from the beach where the fill is to be placed. This is called the native beach sample and presumablely represents the natural grain sizes found on that beach prior to nourishment. Composite samples appear to give the best results since there is usually a variability in grain sizes in both the borrow and native beach sediments (see sediment analysis section for further information on this subject) .

The fill factor models

Once sediment data is obtained for the native beach and the prospective borrow material, a method is needed to determine how suitable the material will be for placement on the beach. Several beach-fill models have been established to calculate an "overfill ratio" or fill factor which is defined as the volume of borrow material required to produce a unit volume of usable fill material with the same grain size distribution as the native material (Krumbein, 1957; Krumbein and James, 1965; Dean, 1974; James, 1974, 1975 and Hobson, 1977). These beach-fill models require two parameters for calculations: the mean grain-size which is a measure of the central tendency and the sorting which is a measure of the spread of the grain sizes about the mean.

Currently there are three beach-fill models described by the Shore Protection Manual (U.S. Army, 1984): (1) The Shore Protection Manual (SPM) Method proposed by Krumbein and James (1965), (2) The Dean Method (Dean, 1974) and (3) The Adjusted Shore Protection Manual (Adjusted SPM) Method developed by James (1975). All three can be calculated by graphical methods as are shown in Figure 15.

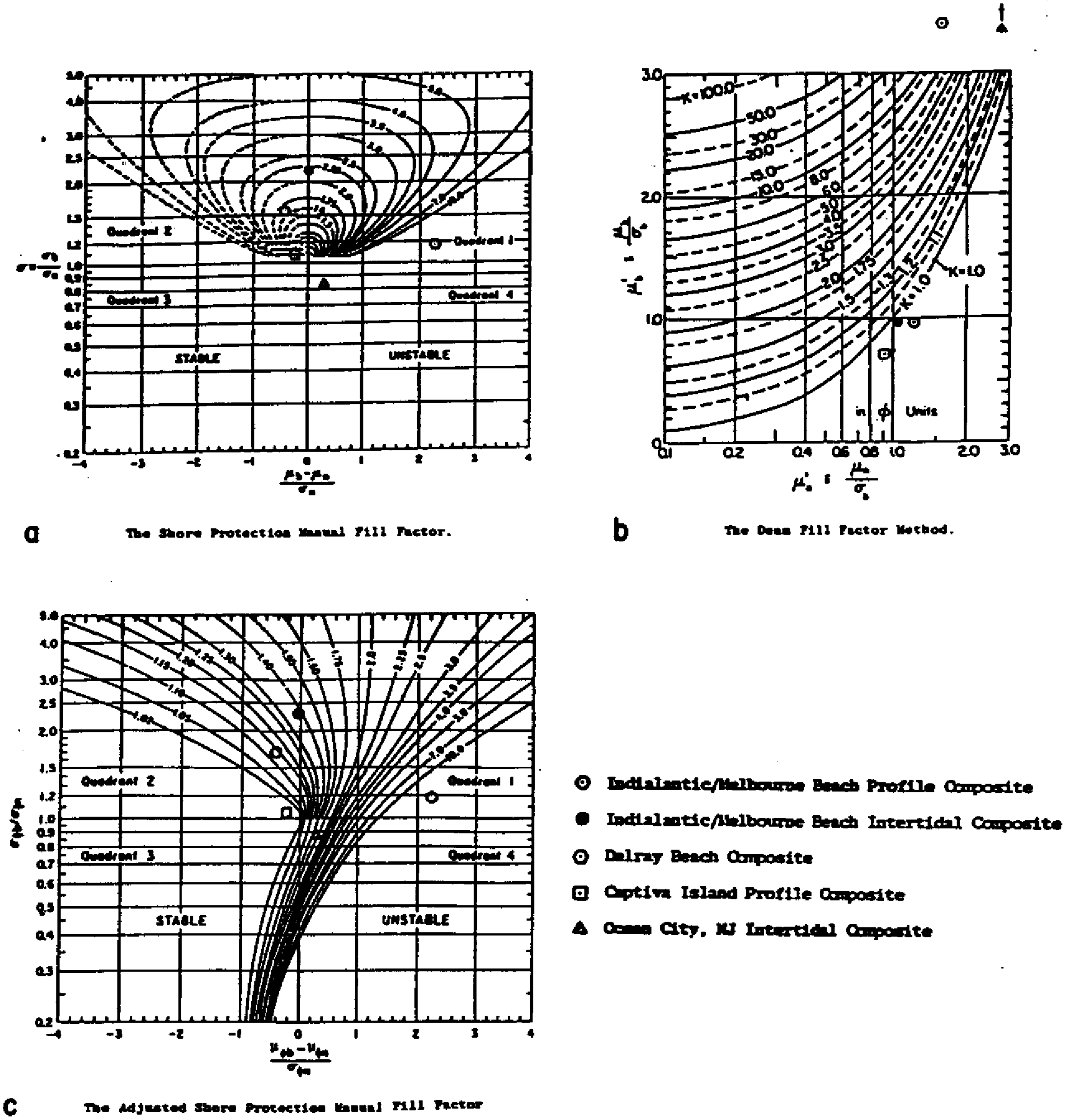


Figure 15. Graphs used in the plotting of the a. Shore Protection Manual, b. Dean and c. Adjusted Shore Protection Manual fill factors showing values from four of the projects and how they differ depending on the type of sediment statistical data used (after U.S. Army, 1984).

The SPM method, developed by Krumbein and James (1965), compares the ratios of weight percentages of the native-to-borrow composites across the range of observed grain-sizes to determine the grain-size at which the ratio is a maximum (critical grain-size). One major problem with this method is the assumption that the coarse, more stable fraction will be winnowed away to create the compatible grain size distribution.

To overcome problems with the SPM method, Dean (1974) proposed a second method to calculate a fill factor. His approach assumes that selective sorting will winnow fine materials from the fill until the mean of the modified fill equals the native mean. This model predicts stability for all grain-sizes when the borrow materials are coarser and more poorly sorted than native sediments, even though the finer grain-sizes will be removed by winnowing. The SPM method implies that selective sorting will occur in both coarse and fine size fractions, whereas Dean's method implies only removal of material in the finer size classes.

James (1975) created a third fill factor model to correct the basic problems of the first two. This model, known as the Adjusted SPM method, assumes the fill factor to be equal to the "critical ratio" of the SPM method, except when the borrow is coarser than the native sediments. This results in a modified grain size distribution which is as close as possible to the proportions of the native distribution in the finer size classes, but retains the borrow characteristics of the coarser size classes. Typically, the Adjusted SPM method produces fill factors less than the SPM method but greater than Dean's method (Hobson,1977).

Each of the fill factor approaches uses many of the same assumptions:

(1) Sediments native to the beach are considered to be the most stable for the environment.
(2) Local sorting processes act upon the entire volume of fill to achieve a grain size distribution similar to native sediments sometime after fill placement.
(3) Sorting processes change the fill material into native-like sediments by winnowing out a minimum amount of the original fill.
(4) Grain size distributions of the native and borrow sediments are assumed to be normally distributed to simplify calculations (Hobson, 1977).

There is some question as to the validity of these assumptions. The native and borrow sediment distribution was not found to be normally distributed in the projects studied. A typical borrow vs. native frequency curve shows that there was usually excess material in the coarse fraction consisting mostily of carbonate shell and in the fine fraction due to the lower energy environment of the borrow area (Figure 16). Most of the fill was deficient in the medium sand sizes typically found on the native beach (Stauble et. al. 1984b).

A post-nourishment fill estimate was calculated from the projects to provide a technique to determine the accuracy of the various beach fill models. The fill factor is defined as the volume of borrow material required to produce a unit volume of stable fill material. A fill factor of 2 would mean that 1/2 of the borrow material was unstable, so twice the design volume of sediment would have to be placed on the beach to result in the design beach. The assumption is, that over the course of the first year of the project, most of the unstable fill material will be winnowed out. The post-nourishment fill estimate is the reverse of this calculation. If 50% of the fill

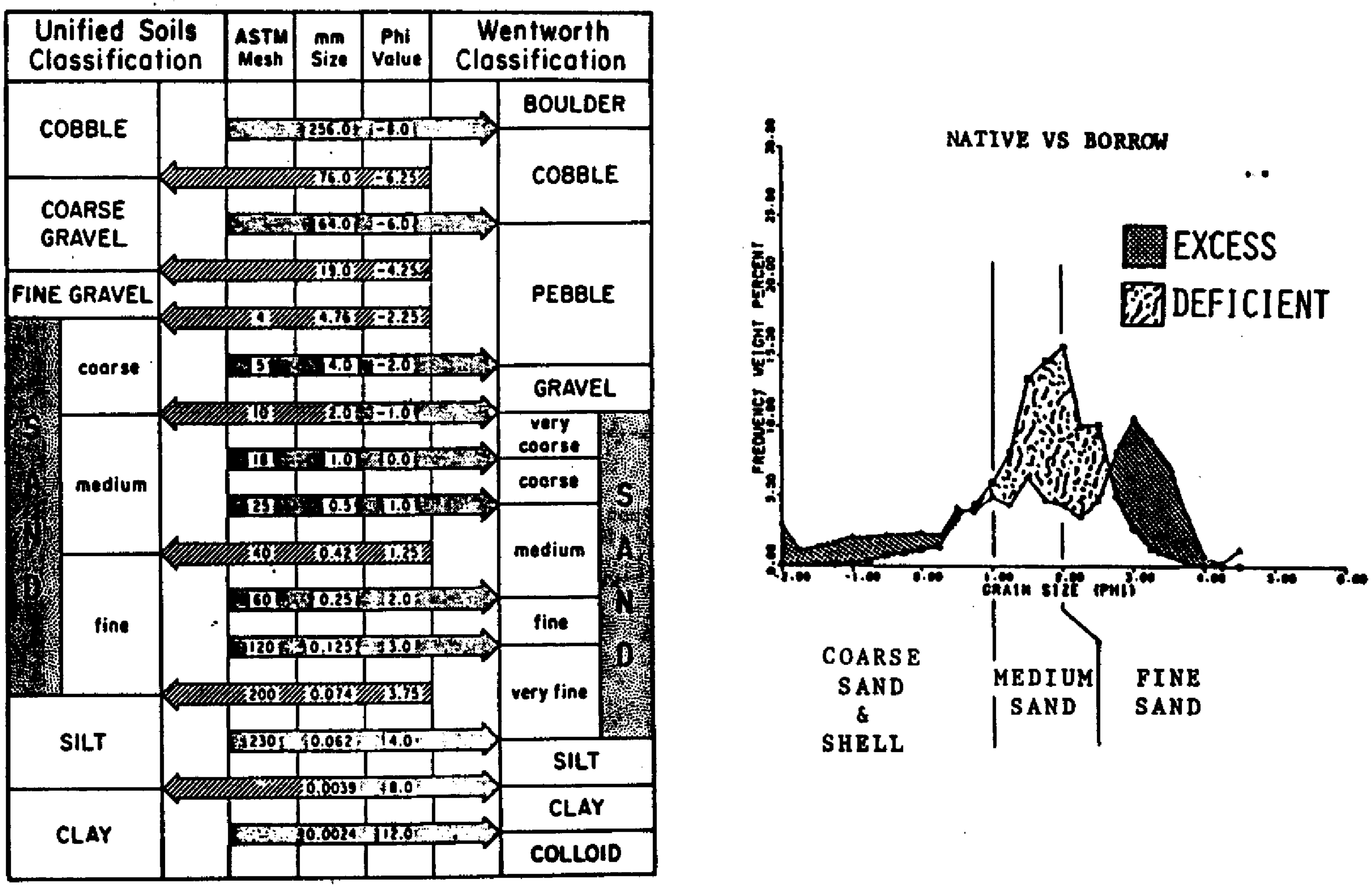


Figure 16. Sediment frequency curve comparing a grain size distribution of a native beach sand with a borrow area sand showing that the borrow has excess coarse (usually composed of shell) and fine material, with a deficiency in the medium sand found on most native beaches. Table from U.S. Army (1984), comparing the various grain size classification schemes commonly in use today.

is lost from a project after one year, then a post-nourishment fill estimate of 2 is assigned to that project. By comparing what actually happened to the fill with what the models predict, one can get a better idea of each model's accuracy.

With these values of actual fill behavior estimates, a comparison of the three fill factor models was undertaken to see which one estimates fill behavior the best. Hobson (1977) suggested using a safety factor with the Adjusted Shore Protection Manual Method to account for the proportions of material finer than sand (>4 phi or <0.0625 mm), since these mud sizes are considered unstable on the beach and are lost soon after fill placement. The safety factor, G, can be calculated to account for these unstable sizes, using:

$$G = \frac{100\%}{\beta \text{ phi}} \times R(a) \qquad (1)$$

where: β = % of sediment expected to remain (in phi units)

While Hobson (1977) suggests the use of 4 phi or % sand size contained in sample, Stauble et.al. (1984b) found that the use of 3 phi (0.125 mm) or % size larger than very fine sand gave a better match to the actual losses in material in the projects studied. The use of G has the effect of increasing the Adjusted fill factor when there are percentages of sediment finer than sand (>4 phi) or as found in this study material finer than fine sand (>3 phi). These values still fall between the Dean and SPM fill factors as predicted.

It was found in all of the study projects that the borrow material contained a maximum of only 3% mud-size particles and the cut off point of 4 phi was insignificant when using the safety factor G. After analyzing the post nourishment fill behavior it was discovered that most of the material finer than 3 phi was winnowed from the fill on most of the projects. A calculated safety factor using the 3 phi cut off was used and gave results close to the post-nourishment fill estimates. Table 7 summarizes the fill factor calculations and compares them to the post fill winnowing estimate. The fill factor calculations only take into account sediment losses due to grain size parameters and do not take into account onshore/offshore and longshore transport processes.

The renourishment model

James (1974) established a technique to predict how often renourishment will be needed and to evaluate the long-term performance of different fill materials. This technique involves the use of a mass-balance equation which compares material going into and out of the nourishment area. This equation is:

$$R_J = \exp\left[\Delta \left[\frac{\mu_b - \mu_n}{\sigma_n}\right] - \frac{\Delta^2}{2}\left[\frac{\sigma_b^2}{\sigma_n^2} - 1\right]\right] \qquad (2)$$

where: R_J = ratio of predicted borrow material erosion rate to present erosion rate of native material (prediction of when renourishment will be required).

μ and σ = phi mean and phi sorting parameters

Project Site Composite Type	Post-Nour. Fill Est.	R(s) SPM F.F.	R(d) Dean F.F.	R(a) Adj. F.F.	R(a) with G 4 phi	R(a) with G 3 phi
Indialantic/ Melbourne Bch.						
profile	2.17	1.65	1.00	1.10	1.11	1.40
intertidal	2.17	2.20	1.00	1.38	1.40	2.10
Delray Beach Project	1.7	>10	15	>10	----	----
Hollywood/ Hallandale intertidal	1.09	----	----	1.09	----	----
Captiva intertidal	1.22	1.02	1.00	1.01	1.01	1.20
Ocean City, N.J. intertidal	No Volume Lost Estimates Available	unstable	----	1.75	1.75	2.3

Table 7. Post-nourishment fill estimates; Shore Protection Manual, R(s); Dean, R(d); Adjusted Shore Protection Manual, R(a); and Adjusted Shore Protection Manual, with safety factor (G) of 4 and 3 phi; fill factors calculated for projects using the various composite combinations. (After Blake, 1984)

b and n - subscripts referring to borrow and native sediments
Δ - dimensionless parameter related to selective sorting (winnowing) in the environment.

James suggests that the range of delta values (Δ) may be from 0.5 to 1.5. He recommends that calculations of the renourishment factor use a value of 1.0 for the delta parameter and that the calculated values should be regarded as only approximate (James, 1975). The "delta" value can be computed from the following equation:

$$\Delta = \frac{\mu_n - \mu'_n}{\sigma_n} \qquad (3)$$

where: μ_n - the native mean before an erosional event.
μ'_n - the native mean after an erosional event.
σ_n - the sorting of the native material, where
$\sigma_n = \sigma'_n$ is assumed true (James, 1974).

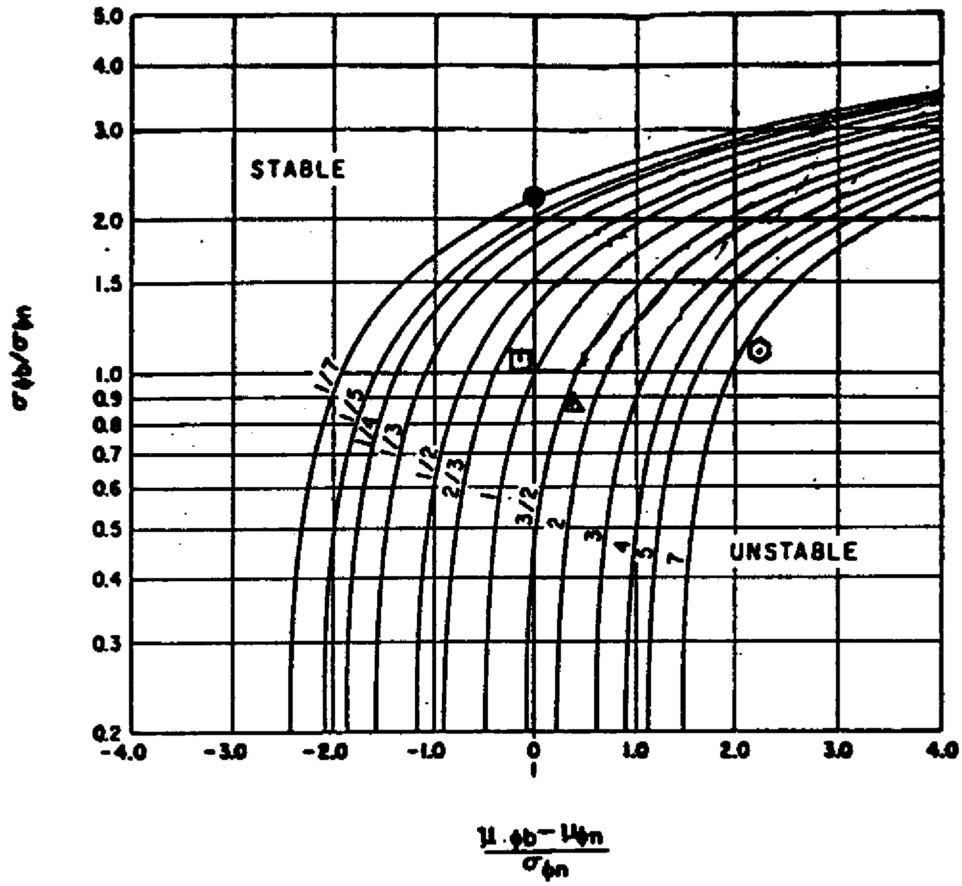
The delta value was computed using equation 3 for each of the projects from data obtained before and after erosional events as best that can be determined for projects where data was available. This value gave a better estimate of fill behavior than an assumed value of 1.0. It is recommended that a delta value should be calculated for each nourishment project to accurately apply this model. Usually, a beach requiring nourishment is undergoing an erosional period, so by taking sediment samples before and after a storm event prior to nourishment, the delta value can be determined using equation 3 and a renourishment factor can be computed from equation 2. A graphic method for obtaining a renourishment factor is shown in figure 17 where the delta factor of 1.0 is assumed. The ability to use the calculated delta factor is not included and it is recommended to use the equations to obtain a valve of R_J. Table 8 shows the values obtained for the renourishment factor in the projects that had sufficient data on erosional events.

Nourishment Area Monitoring

Although some guidelines are available for selecting project design parameters, (Dean, 1983) states, efficient procedures are required to improve the capability to realistically estimate the design life of the nourishment project, make quantitative trade-offs between alternate borrow source materials, establish optimal allocations of available funding between sand and stabilization structures, and predict the slope adjustment that will occur due to placement of nourishment material on a slope steeper than that of the equilibrium profile. Beach profile data before, immediately after and at specific intervals throughout the monitoring period are important to understand the behavior of the fill. By collecting a history of elevation changes, the following information can be obtained:

1) The state of the pre-nourished beach
2) The volume of fill placed along the project
3) The areas of erosion and accretion of fill material after placement.
4) Long-term need to renourish the project beach

The goals of this section are to provide a better understanding of how a beach



(where Δ= 1.0)

● Indialantic/Melbourne Beach Intertidal Composite

⊙ Delray Beach Composite

⊡ Captiva Island Profile Composite

△ Ocean City, NJ Intertidal Composite

Figure 17. Four of the projects are plotted on the graph used to find the renourishment factor developed by James (1974) assuming a delta value of 1.0. (After Blake, 1984)

	INDIALANTIC/ MELBOURNE BEACH	DELRAY BEACH	HOLLYWOOD/ HALLANDALE	CAPTIVA ISLAND	OCEAN CITY, N.J.
A	$\Delta = 1$ $R_J = 0.26$	$\Delta = 1$ $R_J = 7.40$	No BORROW DATA	$\Delta = 1$ $R_J = 0.77$	$\Delta = 1$ $R_J = 1.50$
B	$\Delta = 0.26$ $R_J = 0.87$			$\Delta = 0.03$ $R_J = 0.99$	$\Delta = 0.06$ $R_J = 1.02$

Table 8. Comparison of Renourishment Factor (R_J) values, A) assuming a delta value of 1.0, using the graphic method in figure 17 with B) calculated delta values using equation 3 and substituted in equation 2 to calculate R_J.

responds to an artificial nourishment project through time, and recommend a monitoring technique for future beach nourishment projects. To achieve these goals, an evaluation of beach profile behavior from several recent beach nourishment projects was achieved by actual profile monitoring from local projects, as well as obtaining profile data from monitoring reports of other projects. This study evaluated profile data on project beaches before, during and after the nourishment project in order to develop guidelines for beach fill redistribution monitoring of future projects. An study of a model beach profile response developed by Dean (1977) using actual beach nourishment data was also reviewed. Evaluation of beach restoration project response to physical parameters thru an examination of the relationships between the fill volume loss after nourishment and the physical variable parameters was achieved using U.S. Army Corp of Engineer Atlantic Coast Hindcast wave data (Jensen, 1983), University of Florida wave data (Univ. of Florida, 1982, 1983, 1984), profiles, volume losses, and native-borrow grain size information from monitoring reports and field data. An empirical relationship between volume loss after nourishment, and the physical parameters is proposed.

Profile Redistribution Monitoring

The use of repetitive beach survey techniques is a valuable method for monitoring the profile behavior of a nourished beach (Everts, Dewall and Czerniak, 1974). Profiling has demonstrated to be very useful in understanding beach reorientation while monitoring a beach nourishment project. Detailed profiling is essential when documenting the initial rapid cut back period. A volumetric analysis also supplies information on rates and magnitude of fill erosion.

Engineering monitoring reports and field collection of profiles from several recent beach nourishment projects provided the data used in this study. It was difficult to find projects that had enough usable profile data to make a comparison study feasible. Currently, there is no standardization in project profile monitoring and it was sometimes difficult to compare projects directly since the data provided were obtained over different spatial and temporal periods and presented in different formats. At the Indialantic/Melbourne Beach Project for example, beach profiles were surveyed at a high temporal rate for an extended period including before, during, and immediately after the completion of the project and regularly for a four year period. Other project data, obtained from engineering monitoring reports, exhibited many different sampling intervals and data reporting scales. All comparisons and calculations were made by replotting all data to a common format.

A standardized profile collection and reporting system will provide an important data base of comparable project beach elevation changes from the immediate project fill behavior to long-term coastal changes. By using an established benchmark system such as the Florida Department of Natural Resources, Division of Beaches and Shores or National Geodetic Survey benchmark system, long-term repeatability of profiles can be accomplished. This type of data base will easily allow reestablishment of profiles if renourishment becomes necessary or long term project evaluation is required, as has been the case in several of the projects examined in this study. With this type of profile data collection using a common baseline, analysis of coastal processes, such as longshore drift volumes and direction and the calculation of shoreline recession rates can be simplified.

From reviewing the past projects, a pattern of required data collection emerged. The optimum suggested time schedule outlined for profiles, includes:

1) a pre-nourishment survey of the existing beach
2) an immediate post-fill profile to be used as the as-built profile and be the starting project profile for monitoring purposes.
3) 3, 6, 9 and 12 months
4) 18 and 24 months
5) 36 month

Many of the past projects did not include information on the pre fill beach or immediately after fill placement (sometimes called the as-built profile) in a monitoring report. This data was usually filed in a separate location, if at all, making additional work to recover and correlate this data. This type of data is important in the calculation of the volume of fill placed and is a good starting point to measure volume of fill redistribution over time. Most monitoring starts with a three month survey; thus, important and sometimes major changes in the first three months of the project (Stauble, 1982) are not documented. While collecting profile data on such a short time interval at the beginning of a project may give insight into rapid profile readjustment, it may prove to impractical logistically or economically unfeasible. Therefore, monitoring surveys with a minimum of profiles on a quarterly basis for the first year and on a half year basis for the second year seemed to give the best information on the project behavior. A few projects included one profile at the third year or longer interval, which gave long-term profile readjustment information and insite into the interaction of the fill with the prevailing coastal processes. This information is of value in any renourishment project planning and design.

The importance of control profiles located outside of the actual fill placement area, is often overlooked in project monitoring requirements. These control profiles should be included in the project specifications inorder to study the natural changes in erosion or accretion occurring in the area adjacent to the project. Any major longshore transport of fill material will also be documented. The control sites should be far enough updrift and downdrift of the project to be out of the direct influence of fill placement. Drift directions on both coasts of Florida are seasonal with a predominant net yearly direction (usually to the south) but certain beaches have net yearly northerly drift directions especially adjacent to inlets. Those projects that included control profile data gave useful information on alongshore redistribution of the fill material. In most of the projects the alongshore fill redistribution appeared to be as significant as the onshore/offshore fill movement.

At jettied inlets the usual project design is to bypass sediment downdrift by artificial means to sediment starved areas. On inlet sand bypass projects, particularly at jettied inlets, only a downdrift control profile needs to be studied if fill is placed adjacent to the jetty. If the borrow area is adjacent to or near the updrift beach a control profile will be needed to monitor the effect of the removal of borrow sand on the updrift beach. If the fill placement area is a significant distance from the downdrift jetty, an updrift control profile near the jetty may be required.

Profile specifications

In order to relocate profiles they should be tied in with an established monument. Contractors should obtain the location elevation and profile angles of all monuments within the control and project area. The number of profiles used will be determined by the project size and its suspected impact on adjacent areas. For monitoring purposes, a useful rule of thumb, is to use a benchmark close to every 0.8 kilometers (0.5 miles) of project length. Variation on this number could depend on length of project or need to take more detailed measurement, say near existing or proposed coastal erosion structures.

Pre-nourishment profiles should be taken before construction to document the native sand elevations. The number of these profiles needed should correspond to the number of as-built profiles that are required to assess project specification compliance. Specifications for as-built profiles may require using every monument within the project (for example, in Florida, DNR monuments are approximately 304.8 meters (1,000 ft.) apart). If additional profile lines are needed, they should be referenced off of these existing monuments. Comparison of pre-nourished profiles to as-built profiles are often used to identify the volume placed on the project for fiscal accountability to the contractor by the regulating agency.

The profiles used to monitor post-fill behavior should be a selected subset as mentioned above, with a 0.5 mile spacing as needed of the same profiles used in this pre-nourishment/as built. Monitoring additional offshore continuation of the profiles is desirable at least twice a year to assess elevation changes out to wave base. Onshore/offshore sand transport, bar formation and migration and long-shore sand transport information can be constructed from this data base.

Profile specifications should follow established profile formats and instructions. All profiles need to be referenced to NGVD (National Geodetic Vertical Datum) via the closest established benchmark. Standard transit, rod and tape survey techniques are the most common method for profiles from dune crest out to seaward limit of the rodman's abilities to maintain a station. Starting the profile at or landward of the dune crest will document dune elevations and assures measurement of dune retreat if it would occur during storm events.

Offshore profiles using boat, range finding equipment and fathometer or bottom sled should continue the monitoring profiles out to the seaward limit of sand transport. The use of bottom sleds are preferred because of their higher accuracy. The depth to the seaward limit of sand transport can be calculated using the method developed by Hallermeier (1981). Often fill material will be transported seaward of land survey capabilities and will need to be documented.

Ideally, more frequent surveys should be done to document the effect of storms on these projects and the rate of post storm recovery compared to adjacent areas where the fill was not placed. However, the financing of these additional surveys may be difficult. Comparison of control profiles to project profiles after storm events often show larger amounts of dune erosion outside of the fill area. An assessment of storm protection afforded by the project can then be made. A review of profile data collected in the area of the Indiaiantic/Melbourne Beach and Port Canaveral projects after the Thanksgiving weekend 1984 storm using reestablished project and control profiles showed significant berm erosion but little damage or scarping of the dune base while areas of the county outside of the projects experienced around five meters of dune base retreat.

Location maps of the project should include profile locations, limits of fill, associated erosion control structure location and control sites. Borrow areas and inlet sand bypass location maps also should be included where applicable.

Short term post construction monitoring

During the initial phases of fill placement relatively high losses are to be expected. The rapid cut back period is attributed to the continuous exposure and resorting of the unstable portion of the borrow material. This behavior has been observed by Winton, et, al. (1981), and Stauble et. al. (1983a). Shuisky and Schwartz (1979) describe a theoretical exponential processes of beach stabilization after beach nourishment or other rapid perturbation in coastal processes and Allison (1981) examines a theoretical shortening of the natural stabilization time with expeditious nourishment. In the Indialantic/Melbourne Beach Project, (Stauble, 1982; Stauble et al., 1983a) it was found that the volume loss rates were greatest immediately (from one tidal cycle up to one week) after the placement of the borrow material. In a special study to document the suspected initial rapid erosion rates, Stauble (1982) spaced the time intervals between profiling from immediately after dumping on a weekly basis during the first three months. The profile intervals were gradually lengthened to monthly intervals after relative stabilization occurred. With this rapid slope readjustment, the beach attempts to achieve a state of equilibrium with the dominant wave conditions. The initial rapid readjustment phase is followed by a state of relative stabilization some three months after placement, which is a result of the borrow material having a slope and sediment texture more suited to the local prevailing wave climate (Stauble, et. al, 1983b).

In most project monitoring, there was no documentation of before or during nourishment profiling, and the intervals of profiling began after nourishment was beyond the intial rapid readjustment period. It must be realized, that the standard type of profile monitoring done in the past and the new profile schedule proposed earlier in this report does not provide adequate data for understanding initial loses and the rapid readjustment processes that occur as the fill is reshaped in to a condition of dynamic equilibrium by the coastal processes. While presumably cost prohibitive to be required on all future projects, selected projects should attempt to study in more detail this initial rapid readjustment for a better understanding of fill berm design and placement techniques.

Long term monitoring

The success of a beach nourishment project cannot reasonably be measured only in terms of percent retention of material within project limits, at a specified period after placement. An unstablized beach nourishment project will experience losses from the ends of the projects, due to a longshore sediment transport to the neighboring beaches. In effect the nourished area acts as a "feeder beach" to the adjacent shoreline segments (Dean, 1983).

In evaluating the project profiles it was observed that the construction slopes were seldom the same as design slopes or natural slopes. This was because of the working limitations of the equipment used to place and shape the fill, and also due to the selective sorting of fill by waves and currents which naturally shaped the profiles after nourishment. This subsequent behavior of the slope depends on the characteristics of the fill material and the nature of the wave climate (U.S. Army, 1984). During project profile reshaping several similarities were observed from project to project. Fill migrated offshore and alongshore, moving the slope of fill closer to the natural slope of that particular beach and usually formed an offshore bar. Thus, the fill was retained in the system and aided in dissipation of wave energy.

The volume of beach fill remaining after one year and an analysis of profile change over the long term were analyzed on seven of the projects that reported profile data in a usable format. It is important to evaluate the effects of the representative wave height, beach fill length and volume, with the percent of fill retained over time. Monitoring periods ranged from one year up to seven depending on the project. Each project had site specific coastal processes and some had other erosion control structural interactions that affected the behavior of fill.

In the Port Canaveral project two profile sites were used to represent the northern end and the center of the project limits, due to limited nature of long term data taken seven years after project completion. This data analysis was supplemented by several sets of aerial photography covering the entire project length (Hushla, 1982 and Stauble, et. al. 1983b). The total observed volume remaining two months after completion of the project was 1.3 million cubic meters or 79.4% of the volume placed above N.G.V.D. The majority of the fill was placed in the region just south of the jetty (see Figure 2 for pre, post and seven year later shoreline base map constructed from the aerial photography). The profiles show there was erosion in the area near the center of the project at site R008 with berm overwash heightening the berm elevation. A southerly drift of fill material was observed with accumulation on the southern control profile R016 (Figure 18). The observed volume remaining six years later was 1.2 million cubic meters or 70% of the placed fill. With the majority of erosion during this period in the center half of the project, the northern section of fill was more than likely stabilized due to the protection afforded by the Canaveral harbor and its jetties and a wave shadow zone of the Cape Canaveral offshore shoals. It may be concluded that the erosion of the fill is feeding the southern portion of the study area, ultimately nourishing the beaches south of the fill area. Based on this erosion rate and migration of the fill, the life of this project might be concluded to be at least ten years if unrenourished.

Three profile sites were used to represent the Indialantic/Melbourne Beach project. The total calculated volume of material placed on the beach was 195,060 cubic meters. There was a dramatic variation in the amount of material placed on each site, with more than 50 percent of the total fill placed on the northern section and the remaining fill placed in the center and southern portion (Stauble et. al., 1983a). One year after completion of the fill, a loss of 107,433 cubic meters was calculated, indicating 44.9% of the fill was remaining. This project was under construction from the winter months of October 1980 to January 1981 and the profiles were taken within twenty-four hours after fill placement at each profile site. If all the profiles were taken (as is customary in other projects) following completion of the entire project or even three months after project completion the total volume loss could be calculated as 50,284 cubic meters or a loss of only 25.8% of the fill. This difference in volume loss demonstrates the importance of taking profiles immediately after placement on each individual profile not after completion of the entire project. One year after the project, the littoral processes had resorted the fill to the southern portion of the

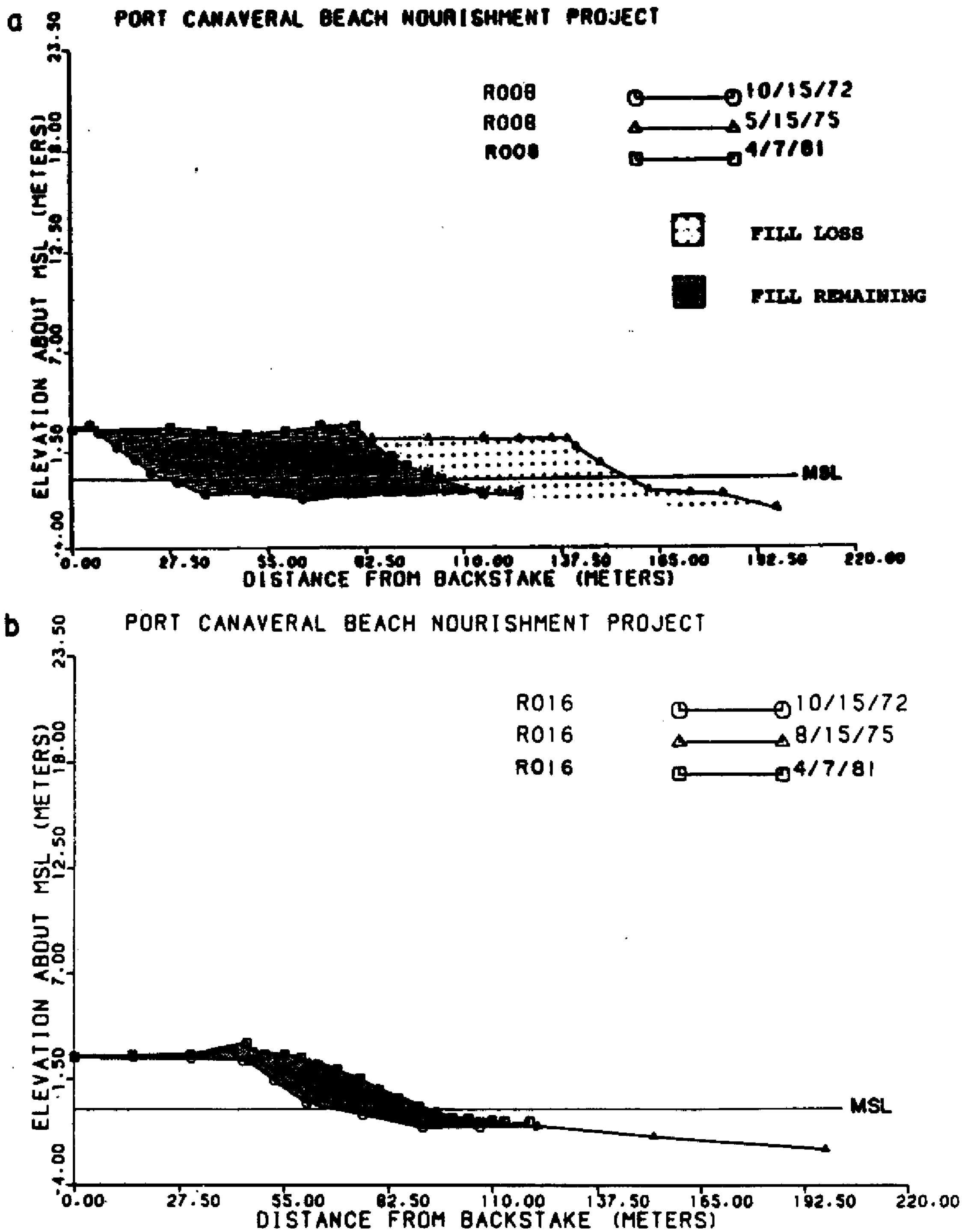


Figure 18. Beach profiles from the Port Canaveral project showing a) the pre-nourished 10/15/72, post-nourished 5/15/75 and seven year 4/7/81 response of the fill at site R008 near the center of the project. The southern control profile (R016), b) shows the effect of southerly drift of fill over the long term with accretion near the Canaveral pier. Pre- and post-nourished profiles from Univ. of Florida (1976). (After Hushla, 1982)

project and southern control owing to the net drift to the south along this beach.

During the second year of monitoring, from 1/82 to 1/83, there was an observed volume loss of 1,432 cubic meters. The only observed erosion during this period was in the center of the project. The accretion to the north of center may be attributed to the fill having a groin effect trapping the littoral drift from the north. The accretion to the south could be due to the southerly migration of the fill in the project. Over the third year there was a gain of 7,460 cubic meters. This trend of accretion was probably due to a large portion of fill moving offshore during the winter and migration back onshore during the summer accretionary period. During the final year of monitoring from 4/84 to 1/85, the project had considerable erosion. Over the period 106,434.5 cubic meters of sand was redistributed offshore and along the coast, meaning 0% of the fill remained in the fill placement area three years after completion. This removal of fill was the result of the severe Thanksgiving weekend storm of 1984. Figure 19 shows the loss of fill from the berm but shows that the seaward most point on the profile has more sand than during the placement of fill. There is a need to continue profiles further than wading depth to assess the offshore changes out to the seaward limit of sand transport. The project was able to provide storm protection for upland properties during the storm because of this movement of sand into the nearshore area. In profiles along the Brevard coast, the two nourished areas at Indialantic/Melbourne and Port Canaveral had no dune scarping indicating the project areas were providing protection.

A common misconception among the general public and some permit agencies is that the initial high rate of change in the fill profile is a loss of fill from a project because the sand is no longer visible on the berm and beachface. The waves redistribute the fill sediment to the nearshore area into a profile more in equlibrium with the wave climate. This causes waves to break further offshore and disipate their energy sooner, thus it is still part of the project. Judging the project "sucess" from immediate post-storm profiles is inappropriate. Later profiles, after seasonal reajustment of this storm erosion should be used to judge the volume of fill remaining in the project area.

Five profiles were used in the study of the Delray Beach project and were representative of the northern control profile, the northern fill area, the zone between the two fill areas, the southern fill area and the southern control point (refer to project map in figure 6). This project had two separate construction periods covering different stretches of coast in 1973 and 1978. The 1978 nourishment fill volume change was calculated from 6/30/79 to 6/30/80, since the data was not collected until one year after fill placement. Representative profiles of the two fill areas showed a total volume loss of 332,724 cubic meters two years after completion of the project (Figure 20). During this period erosion was found at the northern fill area and northern control profile. Accretion was found at the southern fill area and along the beach inbetween the two fill sites (Hoel, in press). This accretion may be attributed to the southerly drift. Erosion at the southern control profile could be due to the fill having a groin effect interfering with the littoral drift south of the project. Shemdin et. al. (1976) found that placement of the fill extended the shoreline seaward at Jupiter Island, consequently interfering with the prevailing littoral drift and induced a net deposit updrift. During the third year of monitoring, the northern control area, northern fill and the area directly downdrift of the south construction area showed a trend towards accretion. The volume of fill removed over

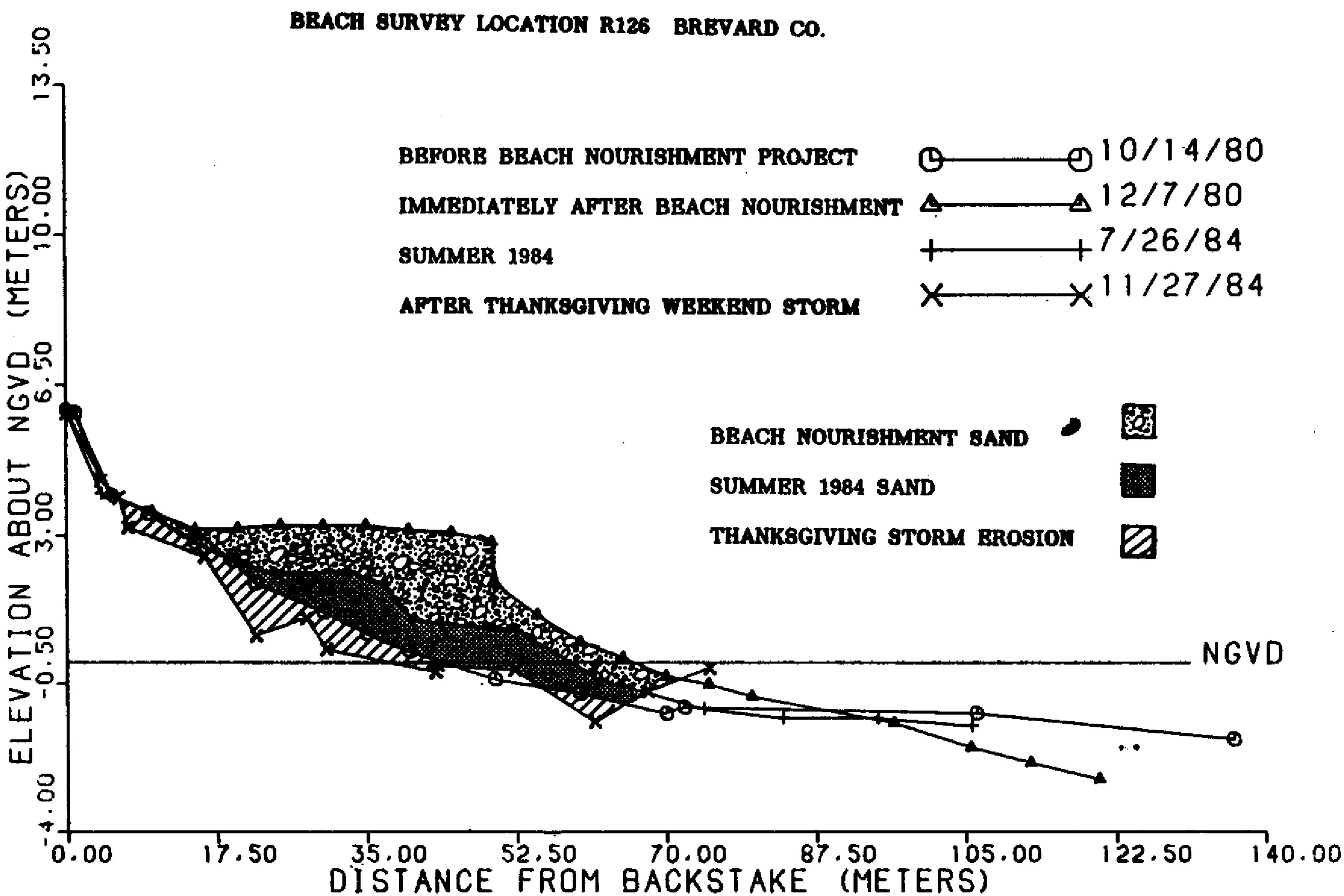


Figure 19. Representative beach profiles at site R126 from the Indialantic/Melbourne Beach project showing the amount of fill placed and the long term behavior of the fill, including the response to the severe storm four years after project completion.

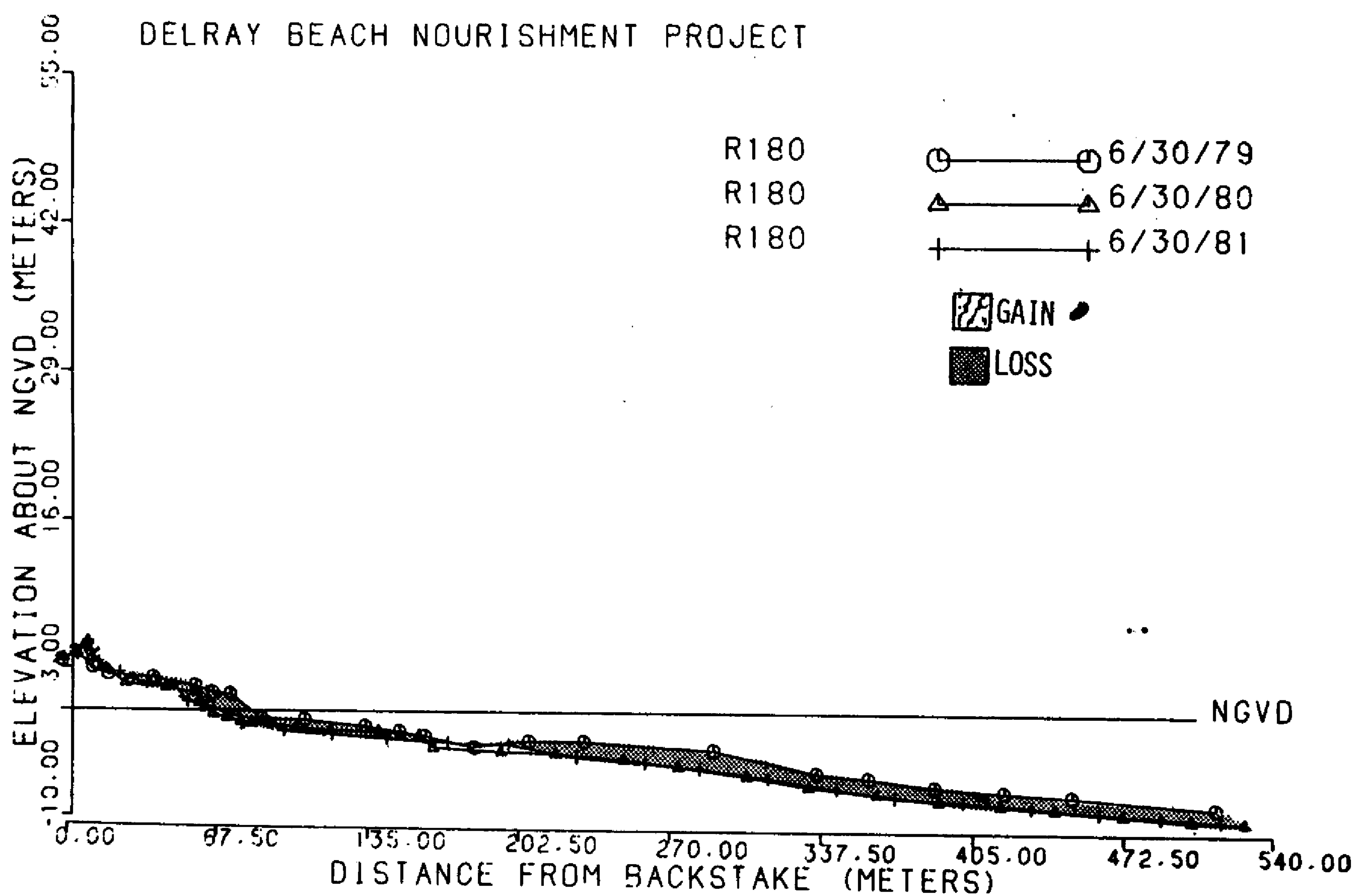


Figure 20. Representative beach profiles at site R180 from the Delray Beach project showing the redistribution of fill for three sucessive years after the fill placement in 1978 (from Strock and Assoc., 1979; 1981a; 1981b).

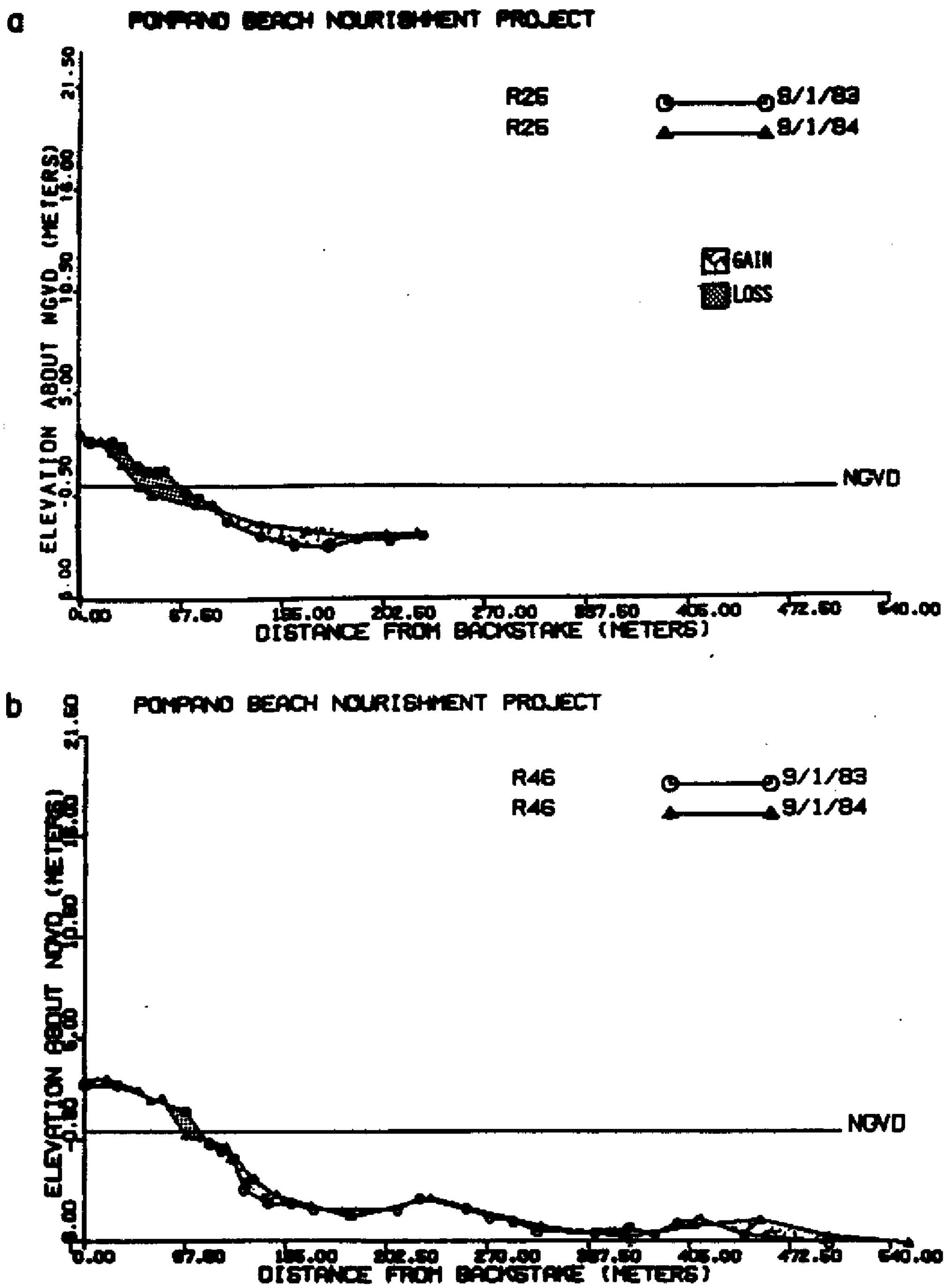


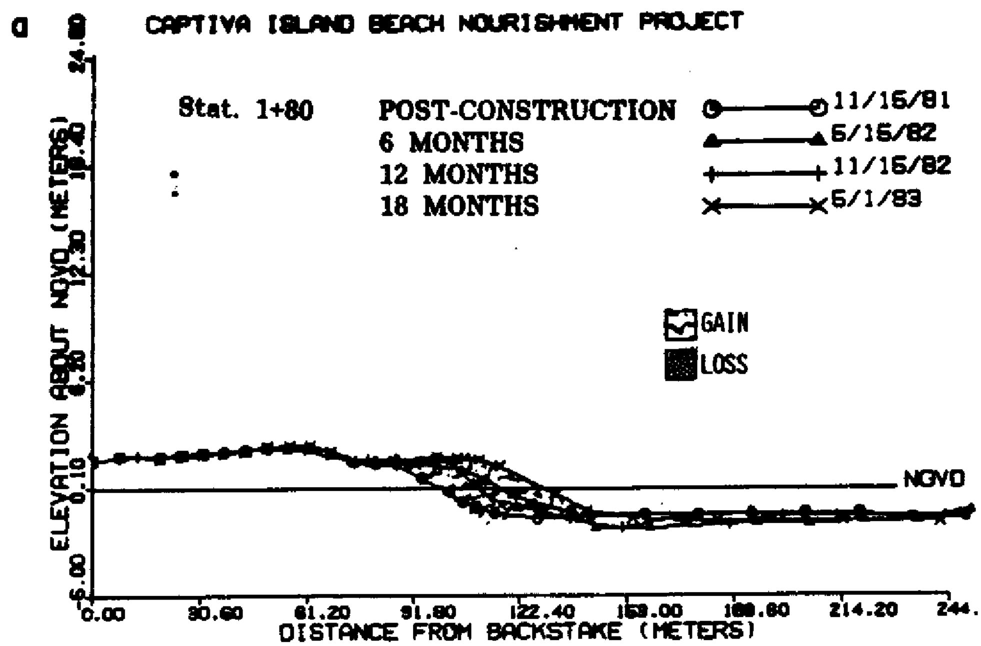
Figure 21. Representative beach profiles from the Pompano Beach/Lauderdale-By-The-Sea project, showing the post-construction and 1 year later profile at a) R26 near Hillsboro Inlet and b) R46 in the southern portion of the project (from Coastal Planning & Engineering, 1985).

the third year was 66,008 cubic meters. A total erosion of 398,733 cubic meters was measured in the fill placement area, meaning three years after completion of the project only 26% of the fill remained. Because of this low retention rate of fill, a third nourishment project was completed in 1984. The poor performance was probably due to the borrow containing a large excess of fine grained material with a deficiency in the larger sand-sized fraction (Blake, 1984).

Four profiles were used to study the Pompano Beach project. The volume change for the first year from 9/1/83 to 9/1/84 was a removal from the fill placement area of 182,856 cubic meters leaving 87.5% of the fill remaining after one year. A majority of the fill was eroded at the southern and northern limits of the project with a little accretion in the middle (Hoel, in press). The beach profiles have shown an general trend towards accretion from NGVD to the -3 meter contour, with the exception of the southern area which has exhibited erosion since construction (Figure 21). This nearshore accretion is due to the coastal processes reshaping the profile into its more natural equilibrium slope. There was no evidence in this project of either sheltering of the northern portion due to the inlet jetty, or that the southerly drift redistributed the fill at the extreme southern portion, as was the case at Port Canaveral. There was not enough information to make any predictions in the trends of the erosion and accretion in this particular project.

In the Captiva Island project study, four representative profiles were selected from within the construction limits and a southern control profile, after evaluating the trends of all the profiles along the project. Six months after completion of the project, 93.7% of the fill remained, with a removal of placed fill of 31,790 cubic meters (Hoel, in press). During that time, erosion occurred along profiles in the center of the project and accretion occurred north and south of this erosion area (Figure 22). The predominant littoral transport in this project area is estimated to be to the south (Tackney and Assoc., 1982) and the accretion at the south end of the project and control area was consistent with these estimates. Accretion at the north end of the project, may indicate a localized drift reversal to the north due to wave refraction over the ebb tidal delta and/or tidal currents in Redfish Pass. This produced the somewhat unusual condition of having northerly transport at the north end and southerly transport at the south end of the project. During the next six months from 5/15/82 to 11/15/82, another 18,679 cubic meters of fill was removed, bringing a total of 50,469 cubic meters for the year after the project. This erosion left 89.9% of the initial fill remaining. Accretion generally occurred at the north end of the project area, and the remainder of the project was subject to erosion. A storm occurred in June 1982 and it is believed that a major portion of the erosion during this second six-month monitoring period was attributed to that storm.

During the third six-month monitoring period from 11/15/82 to 5/1/83, 6,892 cubic meters were measured to be removed from the fill placement area. This brought the total amount of fill removed to 57,361 cubic meters after one and a half years leaving 88.6% of the fill remaining in the fill placement area. Accretion was still measured at the north end of the project and erosion at the south end. Further south of the study area there also was reported accretion (Hoel, in press). A seasonal drift reversal exists where during the winter season, the primary wave activity tended to be out of the northwest resulting in sediment transport to the south and during the summer months the wave activity tended to be out of the southwest, resulting in transport to be north. Another feature to note is that, there was a general decrease in the amount



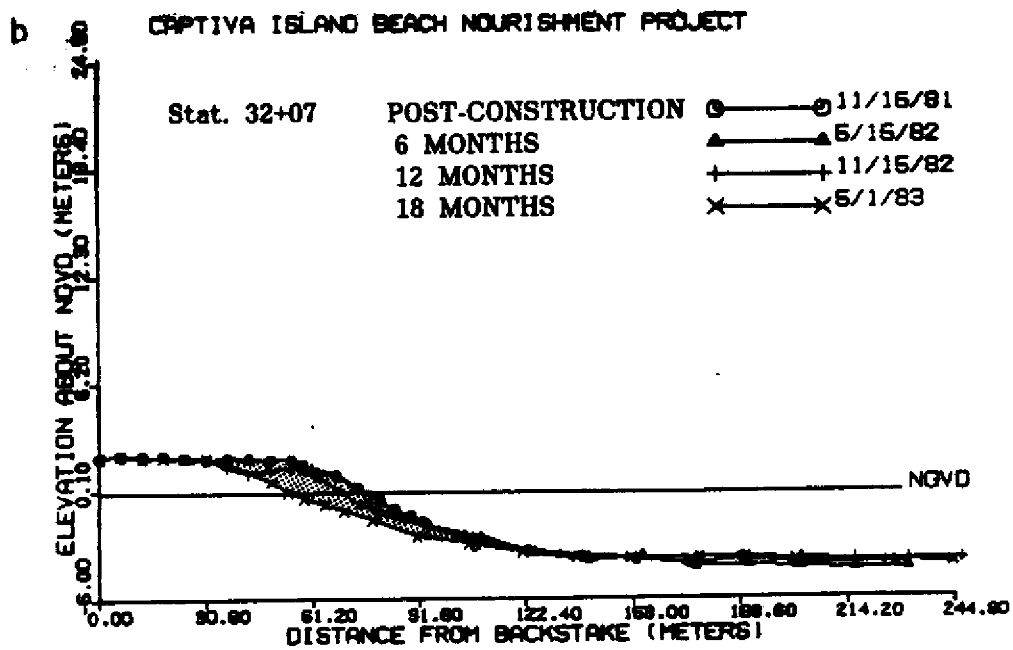


Figure 22. Representative beach profiles from the Captiva project, covering the period from post-construction thru 18 months after placement at a) Station 1+80 located at the north end of the project adjacent to the Redfish Pass jetty showing gain of fill and b) Station 32+07 in the middle of the project showing loss of fill (from Tackney and Associates, 1982; 1983a; 1983b).

of fill lost over each period, indicating the project was stabilizing and reaching equilibrium. This project can be considered successful based on its' 88.6% retention rate of fill after one and half years.

In the Stump Pass project, five profile sites were reviewed which represented zones along the project. Only 38,000 cubic meters were placed on the north beach. Two months after placement no fill remained with a measured net erosion of 15,153 cubic meters comparing the profiles before nourishment with after the nourishment. There was some accretion at the north and center of the project, however, the general trend was erosion. During the first year of monitoring, the erosion continued, with another 6,597 cubic meters was removed from the fill placement area. In the second year, from 10/2/81 to 12/21/82, erosion moved 77,028 cubic meters of sand out of this area. According to the monitoring reports (Coastal Engineering Consultants, Inc, 1982), this loss of fill was the result of the severe storm events during the winter of 1982, in which some of the sand overwashed landward of the dunes. During this time, the Pass continued to migrate to the south. A comparison of the 1979 pre-nourishment profiles and the 1982 profiles shows a wider beachface as a result of nourishment, but there is significant deepening of the offshore profiles (Figure 23). During the final period of monitoring, 12/21/82 to 2/15/84, the project showed accretion of 80,155 cubic meters of sand. This accretion was most likely due to the entire pass migrating south with a net southerly littoral drift in the area of the project. This project was not successful because of the small volume of fill and the dynamic area in which it was placed.

At the Ocean City, N.J. project site there are eleven rubble mound groins which interrupt the net southerly littoral drift. Each set of groins acted as a pocket beach, with little sand movement around each groin. For this reason fifteen profile sites were used to study fill behavior within each zone between groins. The first set of profiles were taken two months after completion of the project and a second set of profiles were taken during the following winter, five months after project completion. Over these three months, 180,707 cubic meters of sand were removed from the fill placement areas. In an attempt to estimate the loss from the time of fill placement, two months before the first available profiles, a somewhat tentative assumption was used of a constant linear erosion trend (Hoel, in press). A total fill volume removal was calculate to be 280,707 cubic meters from the time of fill placement with 69% of the initial fill remaining. This is probably a conservative estimate, since the erosion was most likely not linear although the flat beach slope and fine grain sizes present in the fill formed a profile close to the native beach. The net southeast littoral drift, resulted in the northern portion of each groin pocket experiencing a greater volume of erosion than the southern portion of the pocket. An analysis of the third profile data set taken eleven months after project completion showed a gain in volume of 78,564 cubic meters and increased the amount of fill remaining to 80.5% over the 11 month period. This trend of accretion is probably due to a large portion of the fill moving offshore during the winter, then the offshore bar migrated onshore bringing the fill back into the beach in the summer months. There is a measurable seasonal cycle in this area with the migration of beach sand to the offshore bar during the winter storm periods and a return migration of a swash bar onto the beach during the summer low wave conditions (Stauble, 1973). Figure 24 shows the profile changes in a representative profile from the middle of the project.

Nourishment response to physical parameters

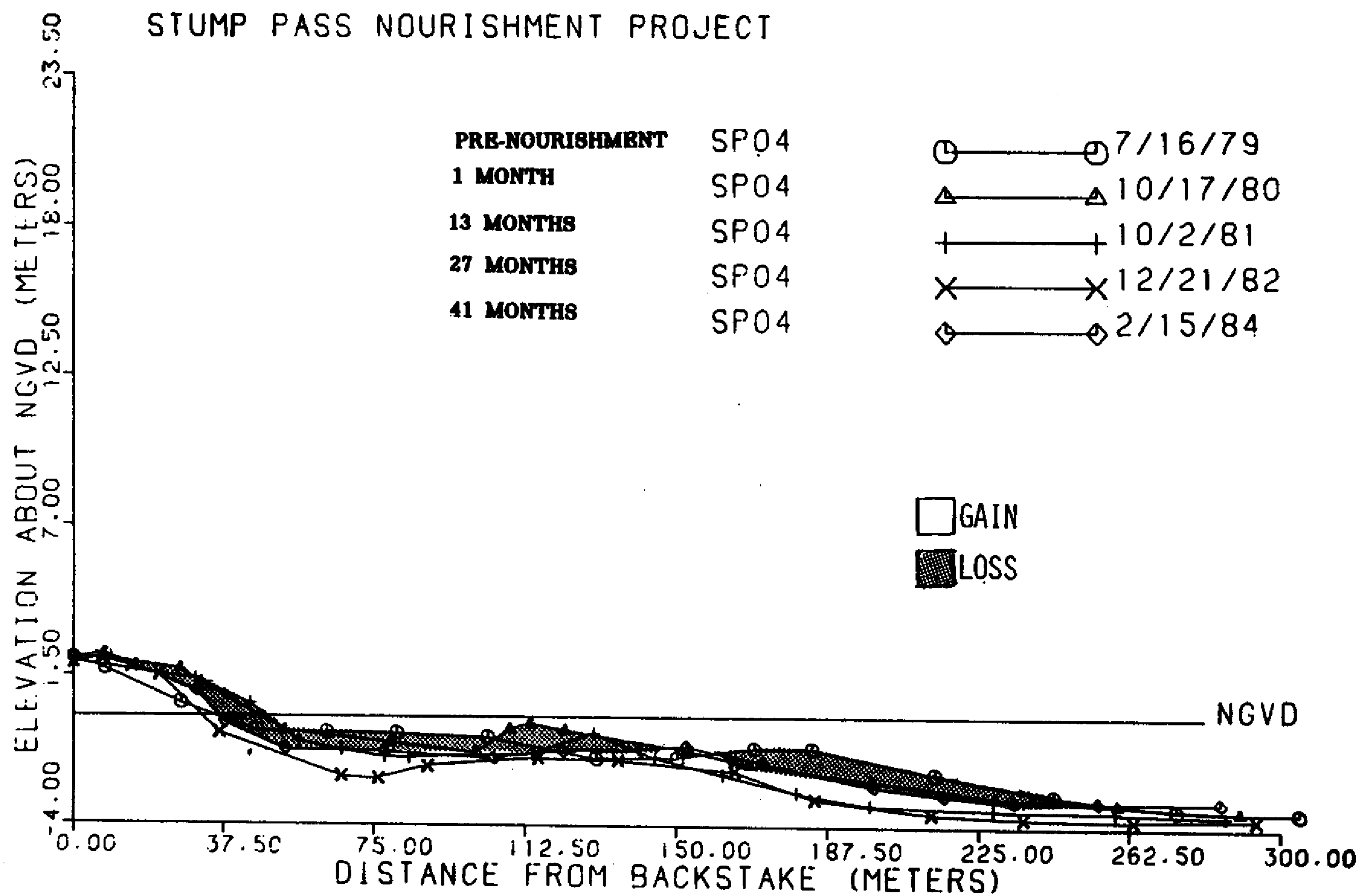
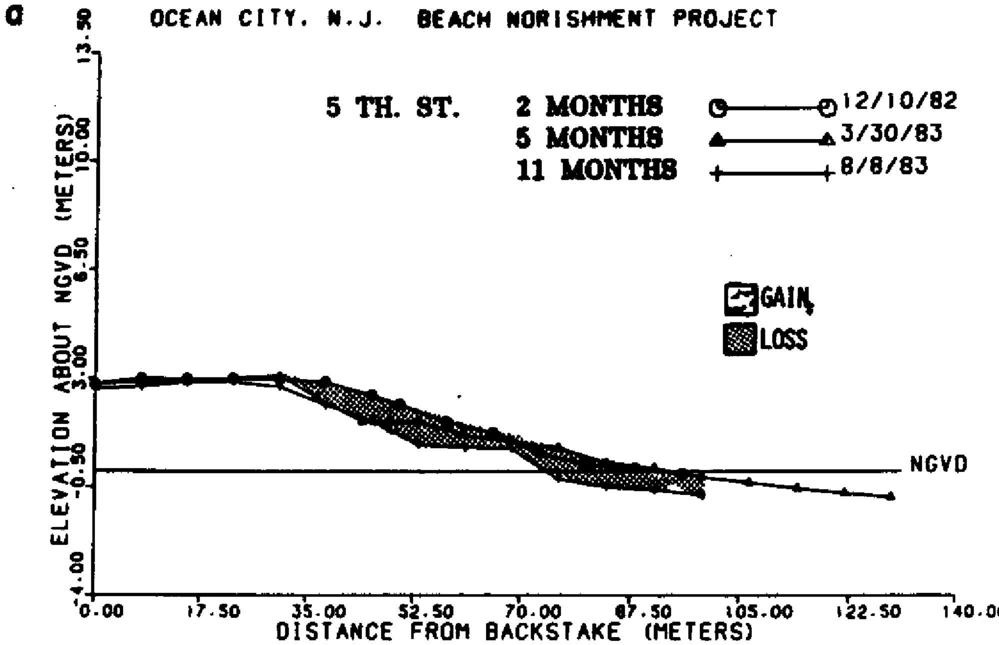


Figure 23. Representative beach profiles from the Stump Pass project, at site SP04 in the middle of the fill placement area covering the period from pre-nourishment thru three years after placement (from Coastal Engineering Consultants, 1981; 1982; 1983; 1984).



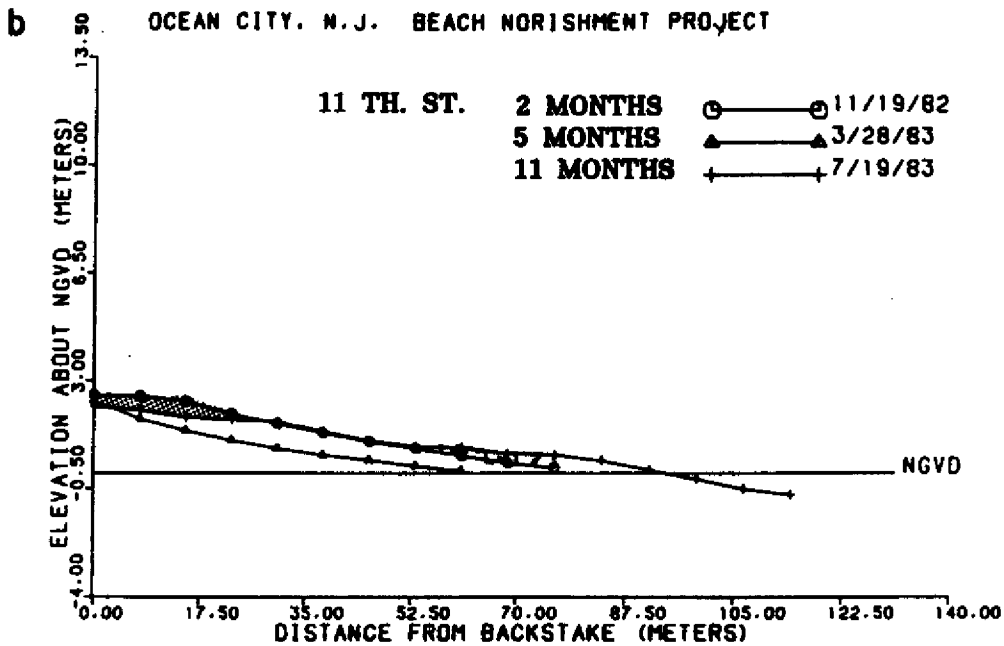


Figure 24. Representative beach profiles at the Ocean City, N.J. project, from three months thru 11 months after fill placement at a) 5 th. St. located at toward the north end of the project and b) 11 th. St. in the middle of the project showing fill redistribution differences in two of the numerous groin pockets (from Gabriel, 1983).

One of the more important aspects of a beach is the dynamic nature of its beach profiles that continuously respond to the coastal processes acting upon it. In a beach nourishment project, the processes of waves and longshore drift, as well as the sediment grain size, and amount of fill used are very important elements in reshaping the nourished beach and in the beaches ability to retain the fill placed. The "success" of a nourishment project cannot only be measured in terms of percent retention. In order to evaluate the reviewed projects, the percent of fill remaining after one year was used as a standard. Although a one year designated period may be too short of a time to judge the total response of the beach to nourishment, the data could be calculated for all the projects and was a common factor in which to evaluate the projects. Physical parameters such as wave heights, length of projects, total volume placed and volume placed per length of beach were available for the majority of the study projects and their effects on each project were evaluated. There may be other forces that are important in each project, such as effects of storms but due to lack of available and reliable data they could not be examined in this study. The causes of original erosion a each project site may cause other distortions in the data analysis. Therefore, the projects were categorized into three types: a) non-inlet adjacent projects that were some distance from the nearest inlet, b) unstabilized-inlet adjacent projects that were located next to inlets with no structural control, and c) stablized-inlet adjacent projects that have one end of the project begining at the inlet downdrift jetty.

The first factor examined was the effect of wave height on a nourished beach. It is known that waves have an important effect in shaping beaches, but little is known about how they effect the amount of fill lost after a nourishment project. In figure 25a the mean significant wave height for each project (Jensen, 1983 and Univ. of Florida, 1983, 1984, 1985) was plotted with the percent of project fill remaining after one year. It appears waves have an erosional effect on the projects but there is no direct relationship between just mean significant wave height and fill remaining. By observing projects with similar wave height (i.e. Captiva vs. Stump Pass, Pompano vs. Delray Beach, and Port Canaveral vs. Indialantic/Melbourne Beach) there is a large percentage variation of fill remaining. Since all of these projects were placed on eroding beaches, a plot of the highest significant wave height (Jensen, 1983 and Univ. of Florida, 1983, 1984, 1985) signifying storm wave climate effects at each location vs. percent of project fill remaining after one year was done. Figure 25b shows a decrease in fill retention with increasing highest wave activity but again projects with similar highest wave activity (i.e. Captiva vs. Stump Pass, Port Canaveral vs. Delray Beach, and Ocean City vs. Indialantic/Melbourne Beach) still show a variation in fill remaining. In each set of projects the major varying factor is the amount of fill placed but those projects associated with an inlet jetty or groin field (Ocean City) structures retained more fill than the non-inlet or unstablized-inlet projects.

Dean (1983) states, that sand is transported from the ends of the nourished area and a short beach nourishment project would lose a greater percentage of fill much more rapidly than the longer projects. Longer projects, with more fill placed along the project dimensions should have a longer distance for littoral drift to transport the fill out of the project area. Figure 26 plots the project length vs. the percent of fill remaining after one year. In examining the plot there appears to be a general trend between the two factors, however, in observing the project lengths between 3 to 5 kilometers there is a wide range of percent fill remaining. This range suggests that project length may not be the only factor in retention rates.

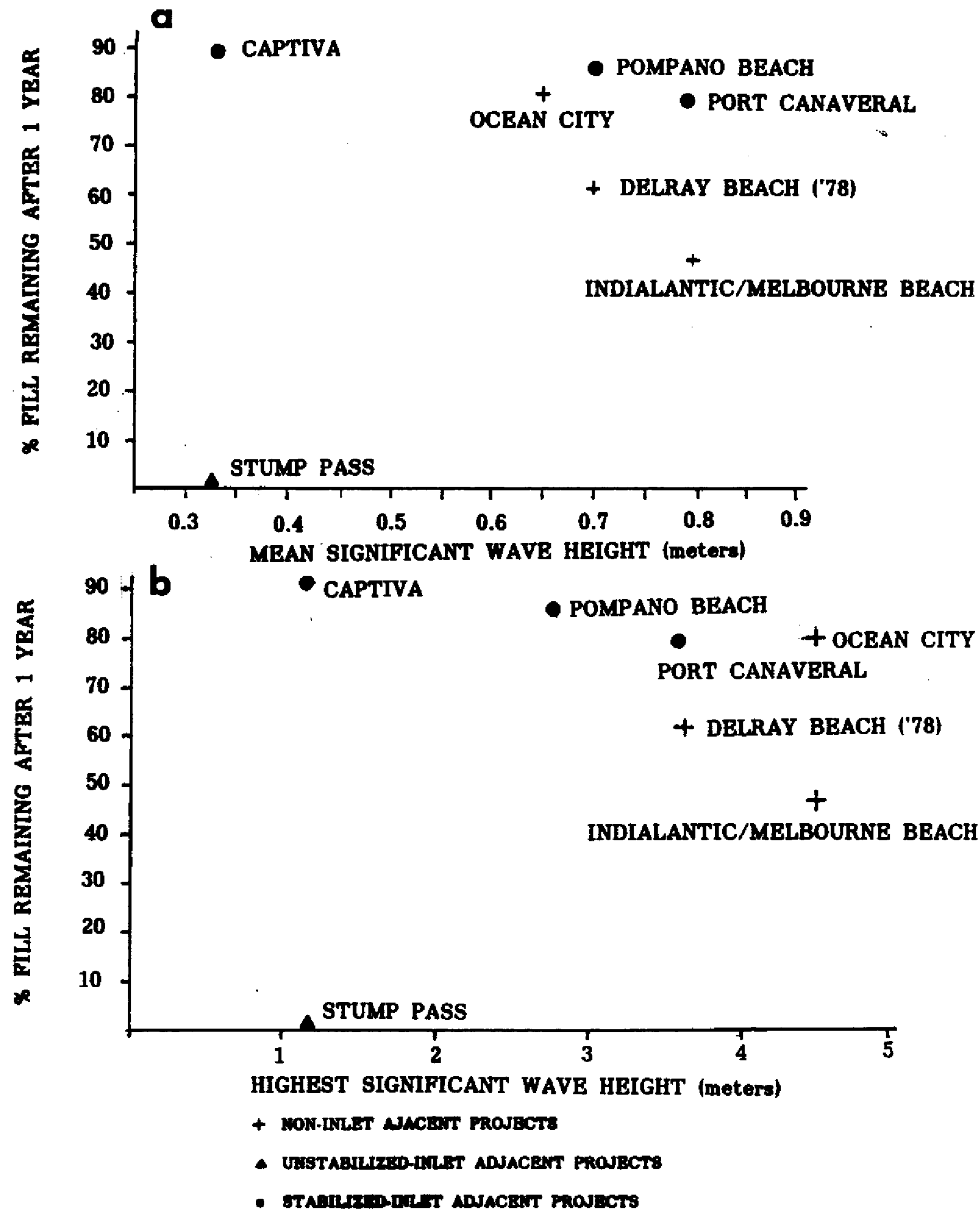


Figure 25. Plot of percent of fill remaining one year after fill placement vs. a) mean significant wave height and b) highest significant wave height for study projects (After Hoel, in press).

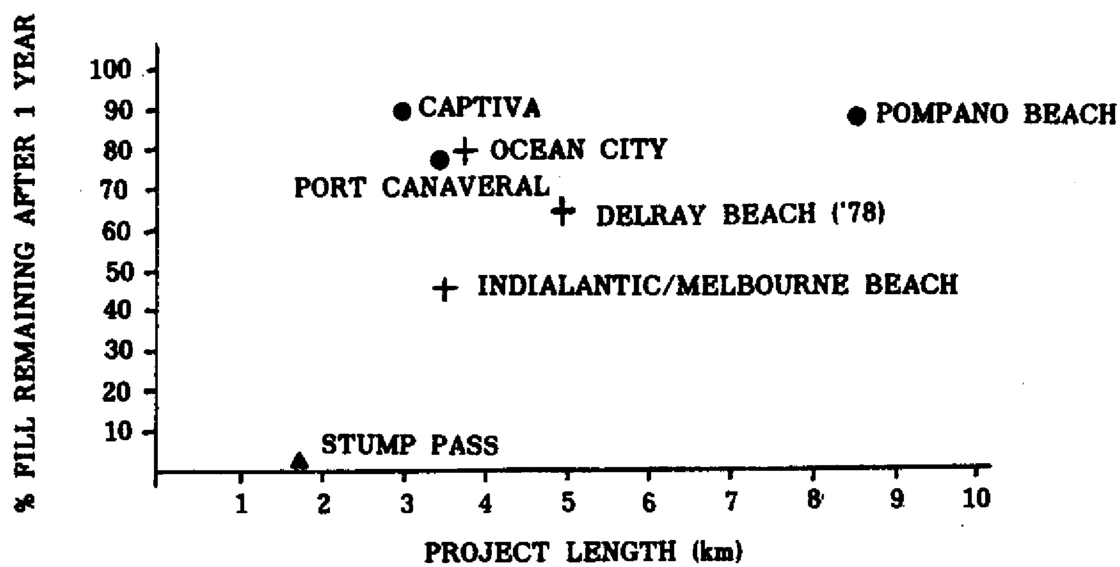


Figure 26. Plot of project length vs. percent of fill remaining one year after fill placement for study projects (After Hoel, in press).

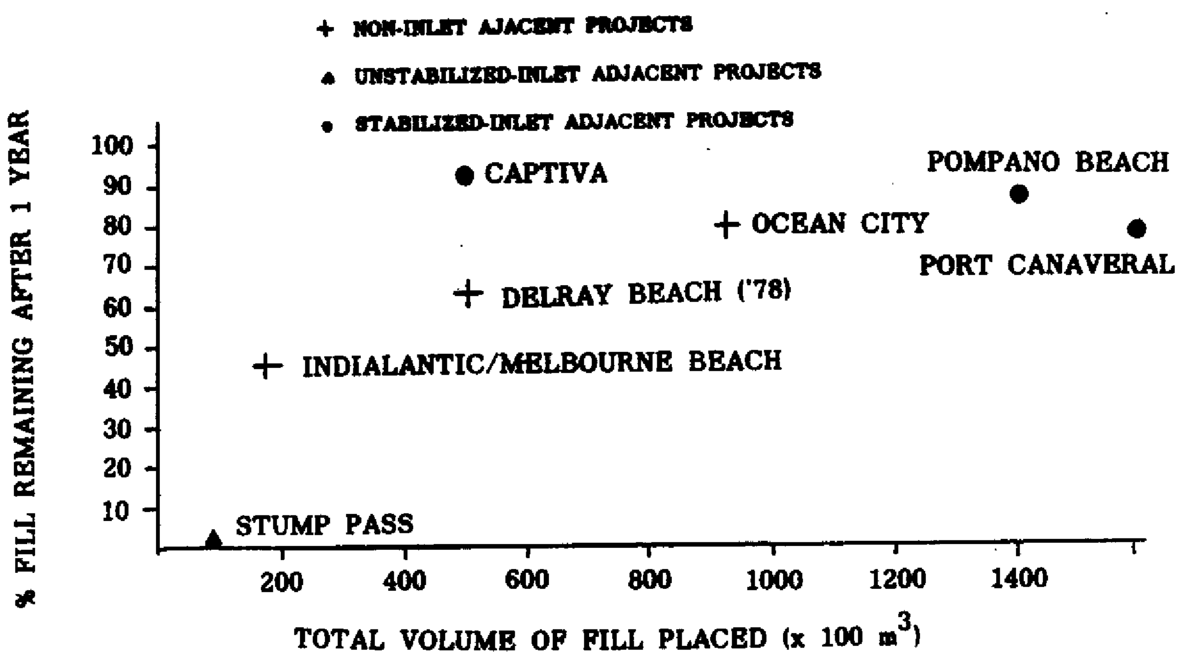


Figure 27. Plot of total volume of fill placed vs. percent of fill remaining one year after fill placement for study projects (After Hoel, in press).

Upon further study of projects in the 3 to 5 km length zone (Hoel, in press), it became apparent that the amount of fill placed varied greatly between projects and may be an important variable. Figure 27 plots the total fill placed vs. percent of fill remaining after one year. A trend appears between the two factors which indicates that the amount of fill placed is proportional to the amount of fill remaining after one year, based on the data from these seven projects. It is believed that just the total amount of fill placed is not a true indication of the fill density on a unit length of the project. For example, a project which placed 1.0 million cubic meters of fill over 2 kilometers would not be the same as a similar volume of fill placed over a 8 kilometer project. To carry this a step further and to normalize each project with respect to length, the density of fill (the total volume placed per unit length of the project) was calculated and plotted in figure 28. This figure indicates that the volume of the fill density placed over the project length is very important in the "success" based on percent of fill retained after one year.

After plotting the project data a curve which best represented the points was fit to the data. Using a curve fitting program the following curve was obtained:

$$Y = 100 - 786.95\ X^{-0.68} \qquad (4)$$

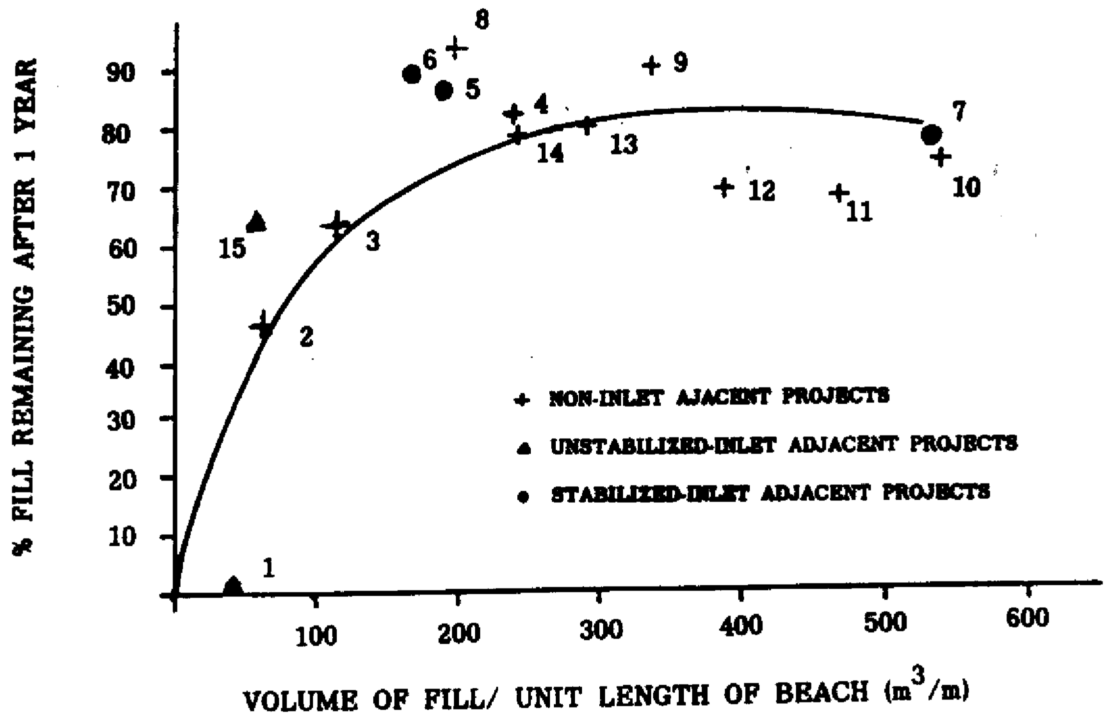
Where: Y is the estimated % of fill remaining after one year and
X is the volume of fill placed /length of project in m^3/m.

This curve has a coefficient of correlation of 0.758 and a standard error of estimate of 0.568. Additional fill retention data from Ocean City, N.J. in 1952 (Watts, 1956); Cape Hatteras, N.C. in 1973 (Fisher and Felder, 1976; Walton, 1977); Hollywood/ Hallandale in 1980 (Suboceanic Consultants, 1980); Virginia Key, Fl. in 1965, Treasure Island, FL. in 1969 and Carolina Beach, N.C. in 1973 (Walton, 1977; Hobson, 1981); and Jupiter Island, Fl. in 1974 and Delray Beach, FL. in 1973 (Walton, 1977; Campbell and Spadoni, 1982) were plotted and compared favorably. From this graph a minimum of 150 m^3/m of fill volume is needed for a 1 year retention rate of greater than 65%.

An equation was also devised to calculate the effect that the combination of the important parameters of grain size, length of project, and wave height have on a nourishment project (Hoel, in press). In the next section it will be suggested that the success of a beach nourishment project closely depends upon the similarity of borrow and native sediments. To evaluate this similarity, the grain-size distribution of the native beach and the prospective borrow material needs to be known. This difference in mean grain size was divided by the sorting of the native beach from a relationship obtained from James (1975) and Hobson (1977). The project lengths were multiplied in the equation due to its decided effects on the nourishment, and the mean significant wave heights were divided into the equation because of the erosive effects on the projects. The equation is:

$$Z = \frac{\mu_b - \mu_n}{\sigma_n} \left[\frac{L}{H} \right] \qquad (5)$$

where: μ_b = mean grain size of borrow
μ_n = mean grain size of native beach
σ_n = sorting of native beach



STUDY PROJECTS

1. Stump Pass
2. Indialantic/Melbourne Beach
3. Delray Beach (1978)
4. Ocean City, N.J.
5. Pompano Beach
6. Captiva
7. Port Canaveral
8. Hollywood/Hallandale

OTHER PROJECTS

9. Jupiter Island (1974)
10. Ocean City (1952)
11. Carolina Beach, N.C. (1965)
12. Cape Hatteras, N.C. (1973)
13. Delray Beach (1973
14. Treasure Island (1969)
15. Virginia Key (1965)

Figure 28. Plot of volume of fill placed per unit length of beach vs. percent of fill remaining one year after fill placement for projects used in this study and additional projects with their year of completion as reported in the literature (After Hoel, in press).

L – Project length in meters
H – Mean significant wave height in project area in meters

By plotting the difference in calculated and actual percents of fill remaining after one year from figure 28 and equation 4 against this "Z" factor, a line was fitted to the points using linear regression. It may be noted that only four projects had sufficient data to make the comparison. Figure 29 shows the line represented by the equation;

$$\text{error } \% = -0.0035\ Z + 5096 \qquad (6)$$

with a coefficient of correlation of 0.91. By calculating a "Z" factor and using figure 28 and 29, one can calculate the range in which a proposed project's fill retention results might be. This type of approach is still in the early stages of development. To judge the accuracy of the curve in figure 28 for a particular project more data needs to be made available to "fine tune" the results. Further research is needed in order to obtain a more reliable prediction of fill retention.

Sediment Redistribution Monitoring

This section explains the important considerations that have surfaced in the collection and analysis of the sediment data from beach nourishment and inlet sand bypass projects. The correct analysis of sediment data is important to the design engineer and regulatory official in obtaining the following information about the project:

1) The suitability of borrow area sand for erosion control projects,
2) The native beach sand grain size distribution on beaches in need of renourishment and any seasonal variations in the native grain size distribution,
3) The rate and process of resorting of fill material after placement on the project beach,
4) Assessment of long-term sediment characteristics and the need for renourishment.

The purpose of this research was to provide a better understanding of the behavior of sediment textural characteristics after a beach has been artificially nourished to allow insight to post-nourishment fill behavior. This was done by investigating the change in grain-size distributions through time at the selected beach nourishment projects. Composite samples were used to remove beach sediment variability and allow a comparison of fill behavior in the onshore and offshore areas. The mean grain size and sorting were determined from sediment analysis of the native beach before and after nourishment and borrow area material. This information was then applied to beach-fill models to determine the suitability of the borrow material for that particular beach. The suitability calculated from each model was then compared with actual post-project fill behavior. Recommendations and guidelines for the sediment monitoring of future beach nourishment projects were developed and provide specifications for sediment information required to adequately monitor and document a project.

Sampling design and laboratory analysis considerations

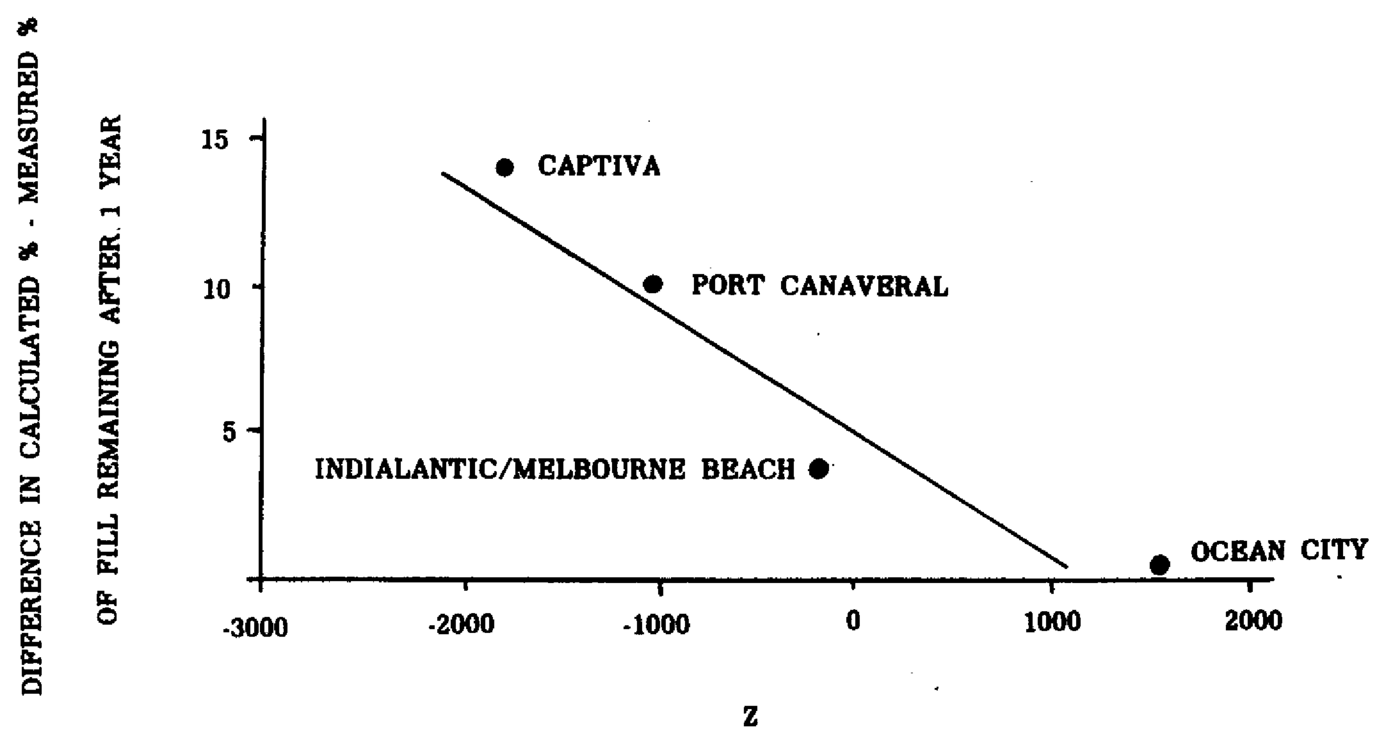


Figure 29. Plot of "Z" factor utilizing borrow and native grain size; wave height; and project length vs. the difference in calculated and actual percent of fill remaining one year after fill placement for four of the study projects with sufficient data (Hoel, in press).

To evaluate a beach for nourishment, one must be able to obtain representative native beach and borrow sediment samples. The question of what is a representative sample arises. The beach can be divided into three general zones: 1) backshore, extending from the dune to berm crest (high tide); 2) foreshore, extending from high tide to low tide; and 3) offshore, extending seaward of low tide to seaward of the breaker zone. There are noticeable differences in the grain size distribution as one proceeds from the dune base, across the beach and continues offshore as described by Bascom (1959). The coarsest grains are usually found in an area just seaward of the backwash/surf interaction zone, an area of much turbulence. The summer berm crest area also contains significant coarse material due to runup sediment transport dynamics. Finer material is found in the dune area owing predominantly to wind transport processes. From the mean low water area sediments become finer with increasing distance seaward of the breaker zone. This general size distribution is variable on any given beach depending on the frequency of occurrence of storms and season of the year (Sonu, 1972). Hobson (1977) states that sediment grain-size characteristics for a beach can vary 1) perpendicular to the beach through varied energy zones, 2) parallel to the beach through any one energy zone, 3) at depth within the sediments and 4) seasonally due to changing meteorological conditions. The borrow area grain size distribution may also vary with location and depth due to the varied energy levels encountered during deposition. Sediment sampling of control areas both adjacent to the fill placement and the borrow area should also be included to assess natural seasonal variation in grain size distributions in the project area and any influence of fill material on downdrift control areas.

No general consensus exists on the technique of sampling beach sands. It is generally accepted to sample a thin layer of surface sample at each sample location. This will obtain sediment deposited in recent tidal cycles. Sampling should also take place at the same time in the tidal cycle (preferably lowtide) to insure collection at the same dynamic stage each time.

Until recently (Leadon, 1984; Stauble et. al., 1984a), no particular method of selecting areas to obtain representative sediment samples of either the native beach or borrow have been identified. Analysis of the project data indicates that location of sediment sampling is critical to give a true picture of the native beach sediment characteristics and post-nourishment fill redistribution. A variety of sampling designs were used in the projects with little standardization in location, number and frequency of sampling (Table 3). A minimal requirement for inclusion of the project's sediment data in this study was data on the native beach, borrow area and a reasonable interval of post-nourishment monitoring sediment samples. Most monitoring reports used fixed distances from a benchmark, or fixed elevations about NGVD for collection of samples independent of the dynamic coastal processes. The most complete picture of sediment redistribution was obtained when sediment samples were collected at the monitoring profiles and the controls, with a time interval of collection and reporting corresponding to the profile sampling as follows:

Sample Collection Interval:	Data Included in Report:
Pre-Nourishment	Pre-Construction
As-built	Post-Construction
3, 6, 9, 12 Month	1st Year
18, 24 Month	2nd Year
36 Month	3rd Year

Special post storm surveys of profiles and sediment would be useful, if logistics and economics allow.

It was found that choosing sampling sites along the profile based on hydrodynamic zonation on the beach (ie. area of maximum runup, mid-tide area and mean low tide area) gives the best representative picture of grain size distribution (Stauble et. al., 1984b). After analysis of several native beach grain-size distributions, Bascom (1959) has suggested using a midtide sample as an accurate way of representing native beach material. Lenhoff (1979) noted that on the beach there are two distinct grain-size populations separated by the midtide line. He suggested that a combination of samples from the upper and lower foreshores are needed to be representative of the beach. These zones change over the course of any study depending on tide, wave and profile shape parameters.

When determining the grain size distribution of the native beach, Hobson (1977) found that by combining samples from across the beach and nearby offshore areas, the variability in grain-size is reduced. He suggests the technique of composite samples to give representative sample statistics of both the variable native beach and borrow area sands. He identified two types: 1) the physical composite and 2) the mathematical composite. The physical composite is constructed by mixing parts of actual samples and then doing a single size analysis. This is done by obtaining homogenous sample splits of equal weight to form the composite sample. The major benefit of this technique is that it greatly reduces laboratory time. The mathematical composite is constructed from data generated after the individual samples have been analyzed. The percentage of sediment in each size class of the different samples is then added together and an average is calculated. This method preserves information on individual samples for later use and allows for investigations of the various combinations of composites. Because of this, mathematical composites were used in this study on five projects with adequate sediment sample data (Indialantic/Melbourne Beach, Delray Beach, Hollywood/Hallandale, Captiva and Ocean City, N.J.).

A mathematical composite was constructed from data generated after the individual samples have been analyzed either from graphic representation in project monitoring reports or actual field collection. The field samples were all sieved at either 1/2 or 1/4 phi intervals. Standardization of sediment data analysis considerations are reviewed by Stauble et. al. (1984a) and Leadon (1984) and deal with the methods of grain size distribution analysis, statistical analysis and data presentation since there are several noncompatible techniques in common use that make project cross comparisons difficult. Several types of composite samples were examined to determine which of these samples eliminated the variability and provided the best comparison of behavior over time. The grain size distribution of these composite samples will vary depending on the location of the included samples. Two basic types of composites were chosen after an examination of various combinations of samples available from each project, the intertidal composite and the profile composite:

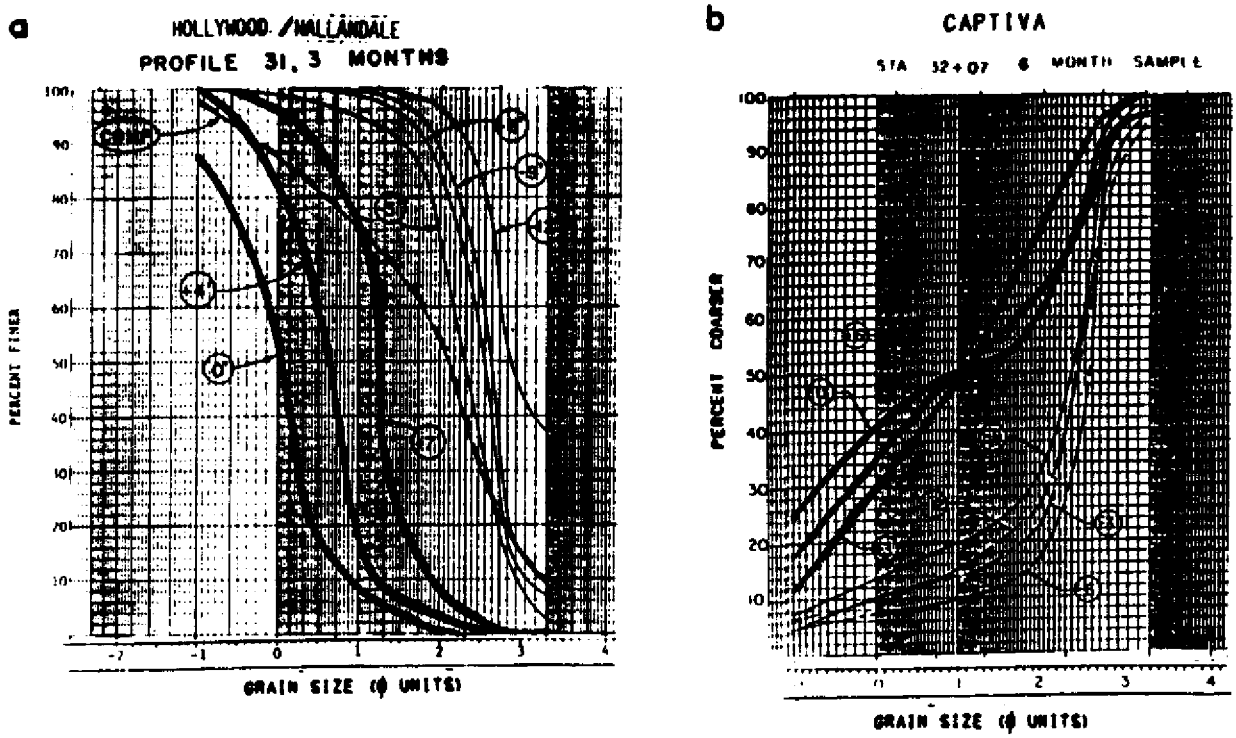
1) The intertidal composites consist of samples from within the intertidal zone, (Figure 4) between mean hightide to mean lowtide, collected around the time of lowtide. This composite gave a good picture of the beach-fill behavior since this is the area of fill placement and of the subsequent reworking.
2) The profile composites consist of intertidal samples plus samples collected seaward of the swash zone to approximately a 12 foot depth. This is a common type of composite used on most past projects.

The native beach

Ideally, borrow material should have a grain size distribution congruent only with the intertidal samples where the fill is to be placed. The inclusion of offshore samples, however, results in a skewness to the finer grain-sizes and may not provide a true representative picture of the hydrodynamic effects on the native beach in the area of fill placement. The standard practice of using the profile composite of the native sediment (including both intertidal and nearshore samples) and comparing that to the borrow sample, usually gives a good match in grain size distributions and sediment statistics, most notably the mean and sorting values used in fill factor models (Table 6). This may be a false picture of fill compatability since most borrow areas have finer material owing to their low energy environment and will compare favorably with the finer offshore component of the native beach. Construction of a composite of only the intertidal samples, which usually showed a poorer match, gave a better picture of a borrow sediment that is usually deficient in the medium to coarse sand range, with an excess of fine material.

An examination of the various project data shows a distinct difference in grain size distributions landward and seaward of the low tide area (Figure 30). Sediment collected from the intertidal area (where most fill was placed on the projects examined) was found to be most representative of native beach material and gave a better picture of fill redistribution after placement (Stauble, et. al., 1983b). Samples collected seaward of the low tide zone exhibited a distinctly different grain size distribution, tending to be composed of finer, better sorted material. This offshore area post-fill sediment grain size redistribution behaved differently from the intertidal area (Figure 31) in that the offshore sediments remained fined grained with little change in the mean and sorting. The intertidal composites, however, changed their mean and sorting as the coastal processes resorted the sediment and changed the profile shape. At the present time, the difference between the native and borrow mean and sorting values calculated from analysis of grain size distributions is used in calculation of fill factors and the renourishment factor. From the data analyzed in this study, it was found that excess fine-grained material in the borrow was quickly winnowed away and transported offshore and/or downdrift of the nourished area. The standard practice of including the finer grained nearshore sediment samples into native beach composites appears to give a false picture on which to compute suitability of borrow material.

The projects were analyzed for borrow/native sediment compatability to study their response to fill redistribution and compatability with the fill models. A native-borrow comparison plot of the projects is shown in Figure 14 along with nine possible native-to-borrow relationships. A native-borrow plot in the center of the graph (area 5) would represent a borrow material very similar to the native material as characterized by their mean and sorting values. The data used is all intertidal composites, except for Delray Beach where only project composite data (includes offshore samples along with intertidal samples) were available. Indialantic/Melbourne Beach had borrow material with a similar mean grain-size but was more poorly sorted (area 2). Delray Beach had much finer borrow material whose sorting was slightly poorer (area 3 or 6). The borrow at Captiva Island was almost identical to the native beach (area 5). At Ocean City, NJ, the borrow was slightly finer and better sorted than the native beach. When comparing native and borrow materials, there was more variation in the sorting values than there was in the mean grain-size.



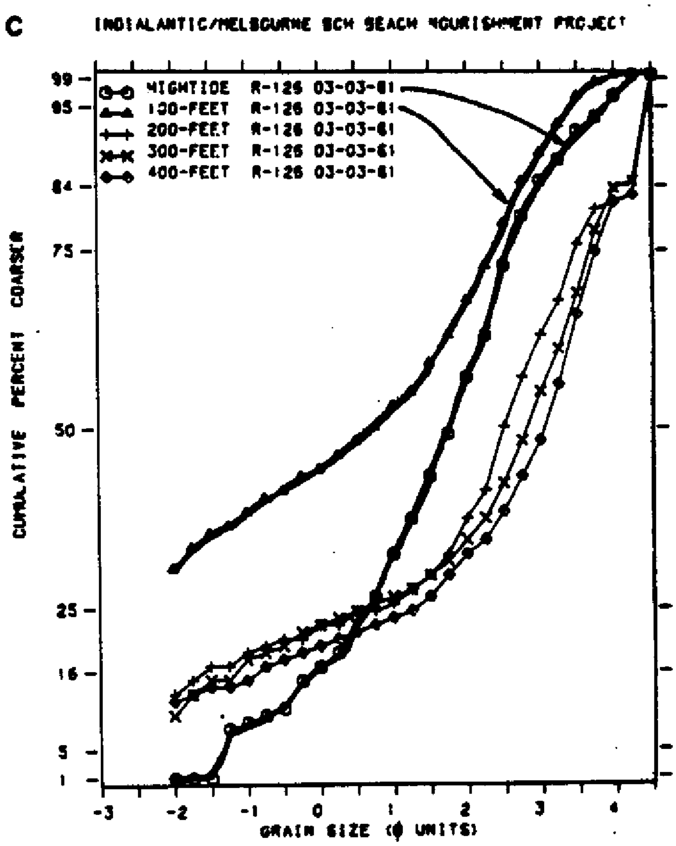


Figure 30. Plots from projects showing difference in grain size distributions of sediment samples collected landward (thick lines) and seaward (thin lines) of the low tide area after fill placement at a) Hollywood/Hallandale project, 3 months after fill placement, (numbers are sediment sample location elevations in feet about NGVD) including the profile composite (COMP) giving a false picture of the fill grain size distributions that falls somewhere between the two sediment zones (after Suboceanic Consultants, 1980); b) Captiva project, 6 months after fill placement (numbers are sediment sample location elevations in feet about NGVD) after Tackney and Associates (1982); and c) Indialantic/Melbourne Beach project, 3 months after fill placement (numbers are sediment sample location elevations in feet seaward of high tide samples) after Stauble et. al. (1983a).

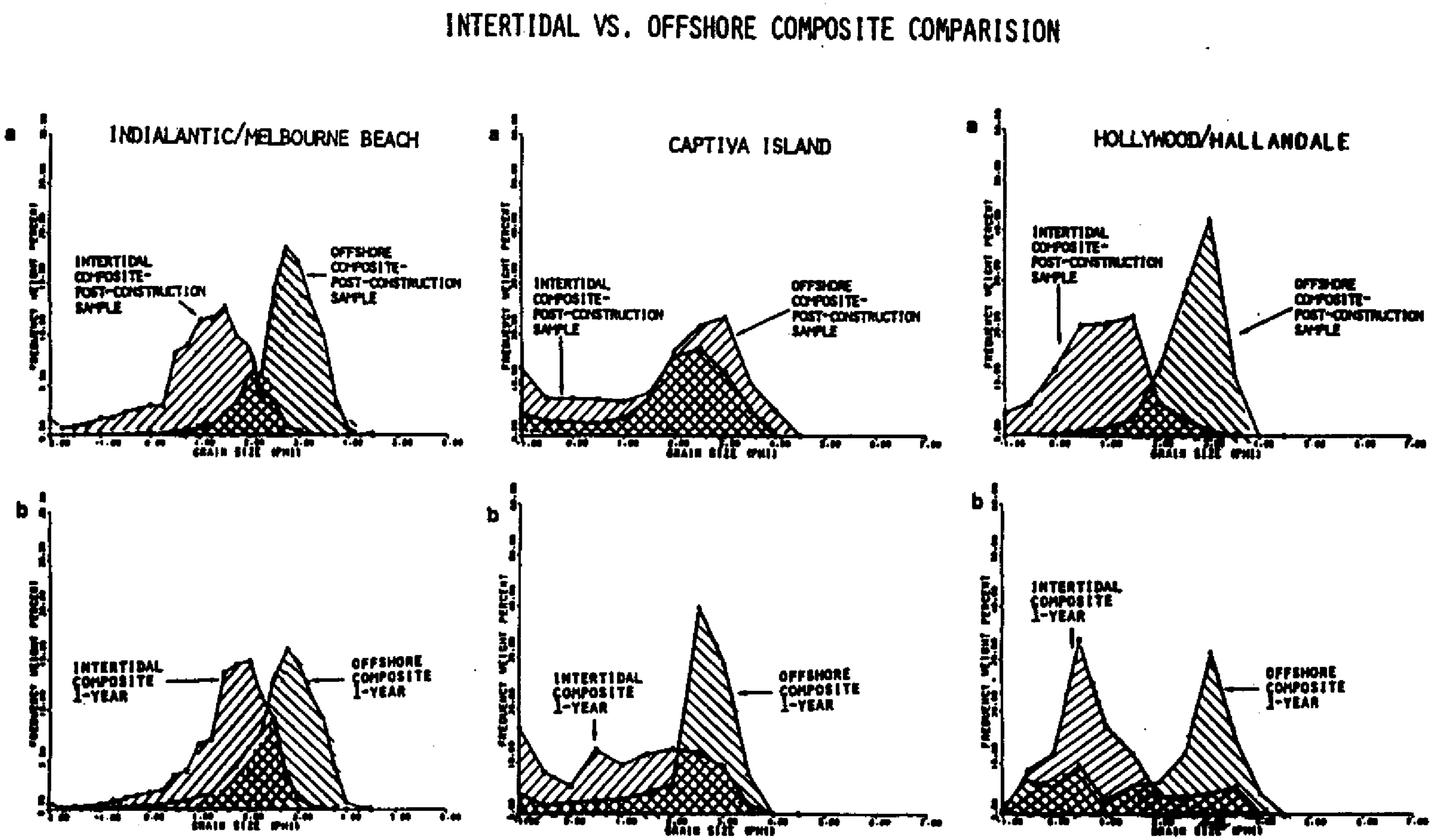


Figure 31. Comparison of intertidal vs. offshore composite grain size distribution frequency curves from the Indialantic/Melbourne Beach, Captiva and Hollywood/Hallandale projects a) shortly after fill placement and b) one year after fill placement. The intertidal sample composites show the greatest resorting (from Stauble, et. al., 1984b).

Figure 32a compares the intertidal project composite with the borrow material. The borrow for Indialantic/Melbourne Beach contained excess coarse shell material (-2.0 to 1.0 phi), excess fine-grained material (2.5 to 4.5 phi) but was significantly deficient in the 1.0 to 2.5 phi, medium sand range. The native mean was 1.62 phi and exhibited a sorting of 0.72 phi, while the borrow had a mean of 1.59 phi and a sorting of 1.61 phi. Though the mean grain-size was similar, the borrow material was more poorly sorted and significantly bi-modal. This emphasizes the importance of looking at the entire grain size distribution when determining the suitability of a borrow material for a beach, and not just using the mean and sorting values alone. Figure 32b compares the profile project composite with the borrow material for Indialantic/ Melbourne Beach. As can be clearly seen, there appears to be a closer match between borrow and native than that of the intertidal composite. This is due to the inclusion of the finer offshore samples which increases the sorting of the native sediment.

The borrow for Delray Beach, FL contained a large excess of fine-grained material (2.0 to 4.5 phi) and is deficient in the larger sand-sized fraction (-1.0 to 2.0 phi). The native beach (profile composite only data available) had a mean and sorting of 1.02 phi and 0.57 phi respectively. The borrow material had a mean and sorting of 2.27 phi and 0.67 phi respectively. This is an extremely large difference in mean grain-size, but the sorting was very similar (Figure 33). Large losses of the fine-grained sediments were seen initially.

No information was available on the borrow material used at Hollywood/Hallandale.

The borrow material for the Captiva Island contained excess coarse shell material (-1.0 to 1.0 phi) and was deficient in sand from 1.0 to 4.5 phi. The native beach had a profile project composite mean and sorting value of 1.53 phi and 1.63 phi respectively. The borrow material had values of 1.20 phi and 1.72 phi respectively, reflecting the excess shell material (Figure 34).

The samples at Ocean City, NJ consisted of intertidal samples only. The native-borrow comparison for Ocean City, NJ (Figure 35), shows very well sorted samples with the borrow material having a lower percentage in the 2.5 to 3.0 phi range and excess sand in the 3.25 to 4.5 phi range. The excess fine material in the borrow is due to its estuarine origin. The native mean and sorting was 2.55 phi and 0.58 phi respectively. The borrow material had a mean of 2.72 phi and a sorting of 0.50 phi. Some of this excess fine material was immediately transported offshore during placement by hydraulic dredge.

Post-construction redistribution characteristics

Fill sediment will resort and reshape itself on the profile due to the coastal processes at work after fill placement. It is important to monitor changes in the grain size distribution as wave activity resorts the fill that is not in equilibrium with its new environment. Characteristically, due to different energy conditions in the borrow area, fill sediment will usually have excess coarse and fine material, different sorting characteristics and possibly different mineral content. In past projects, excess coarse shell material and fine silt and clay material, not normally found on ocean beaches, have been present in the fill. From the data analyzed, it was found that excess fine-grained material in the borrow was quickly winnowed away and transported offshore and/or downdrift of the nourished area soon after fill placement.

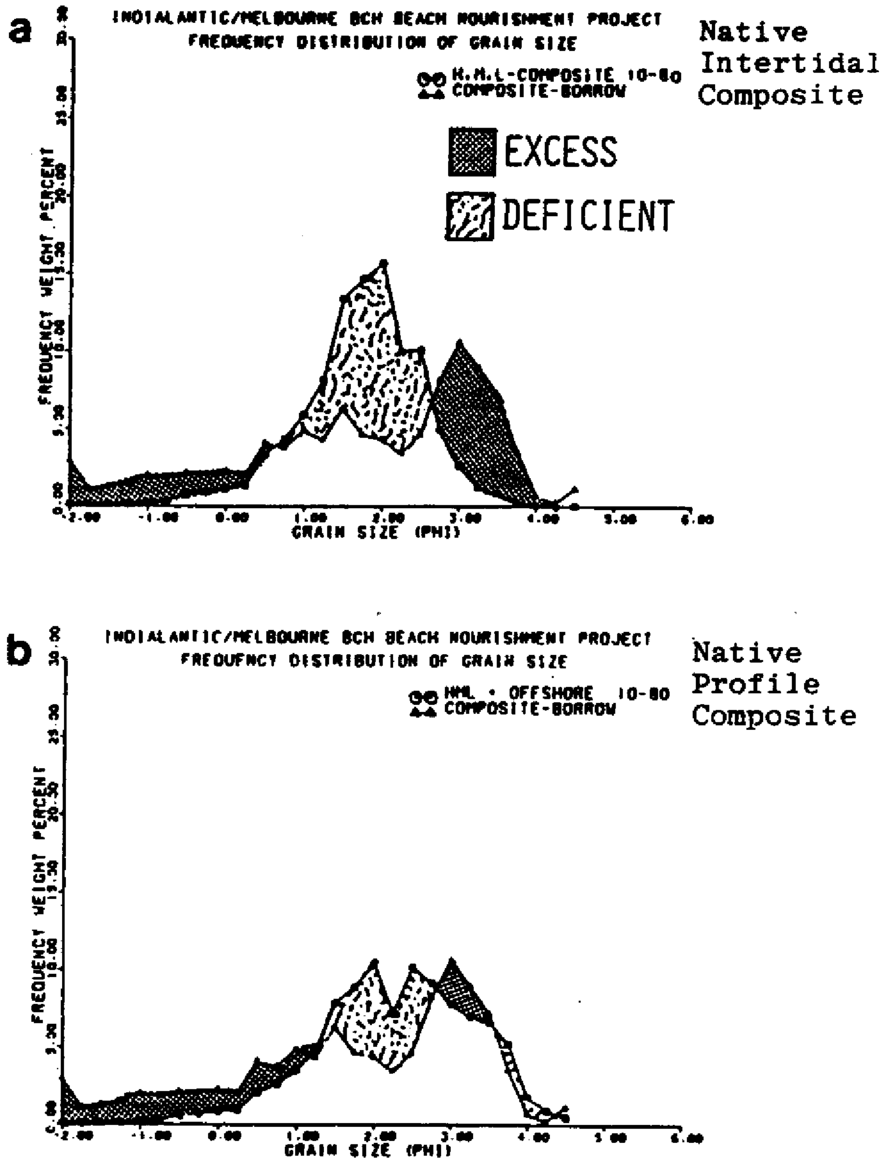


Figure 32. Comparison of the grain size frequency distribution of a) the native project intertidal composite vs. the borrow and b) the native project profile composite vs. the borrow sediment for the Indialantic/Melbourne Beach project. (After Blake, 1984)

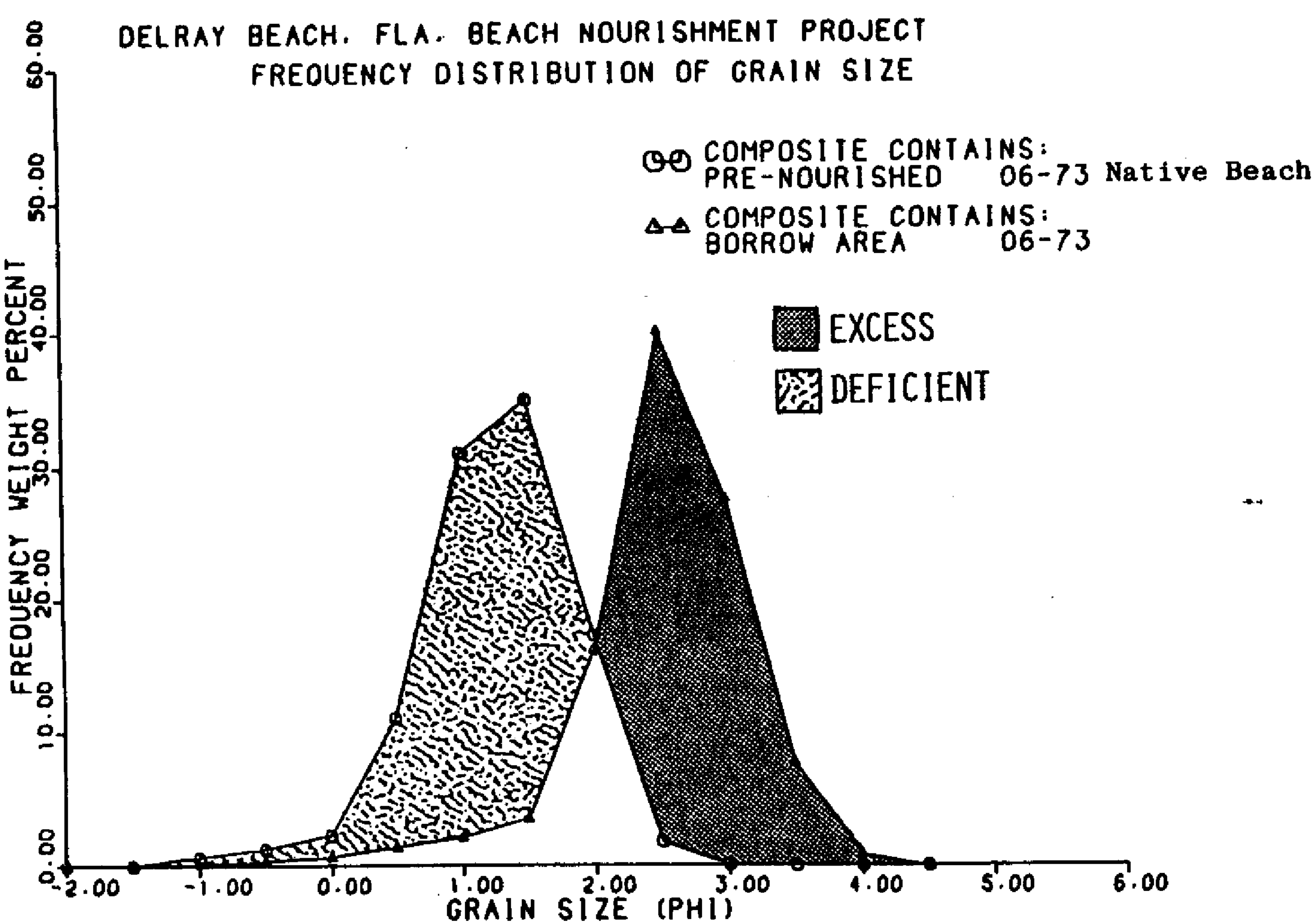


Figure 33. Comparison of the grain size frequency distribution of the native project profile composite vs. the borrow sediment for the Delray Beach project. (Data from Strock and Associates, 1979). (After Blake, 1984)

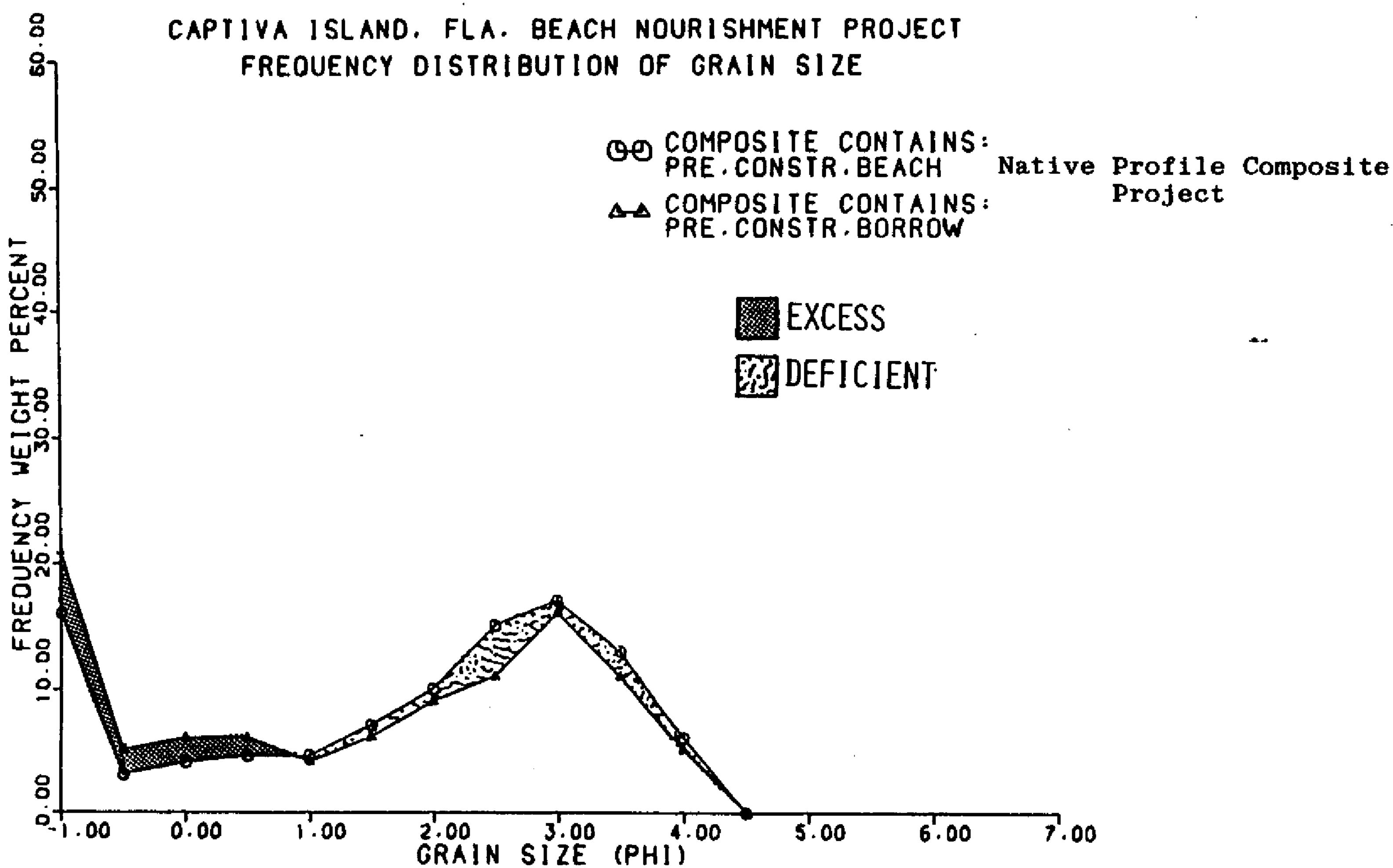


Figure 34. Comparison of the grain size frequency distribution of the native project profile composite vs. the borrow sediment for the Captiva project. (Data from Tackney and Associates, 1982). (After Blake, 1984)

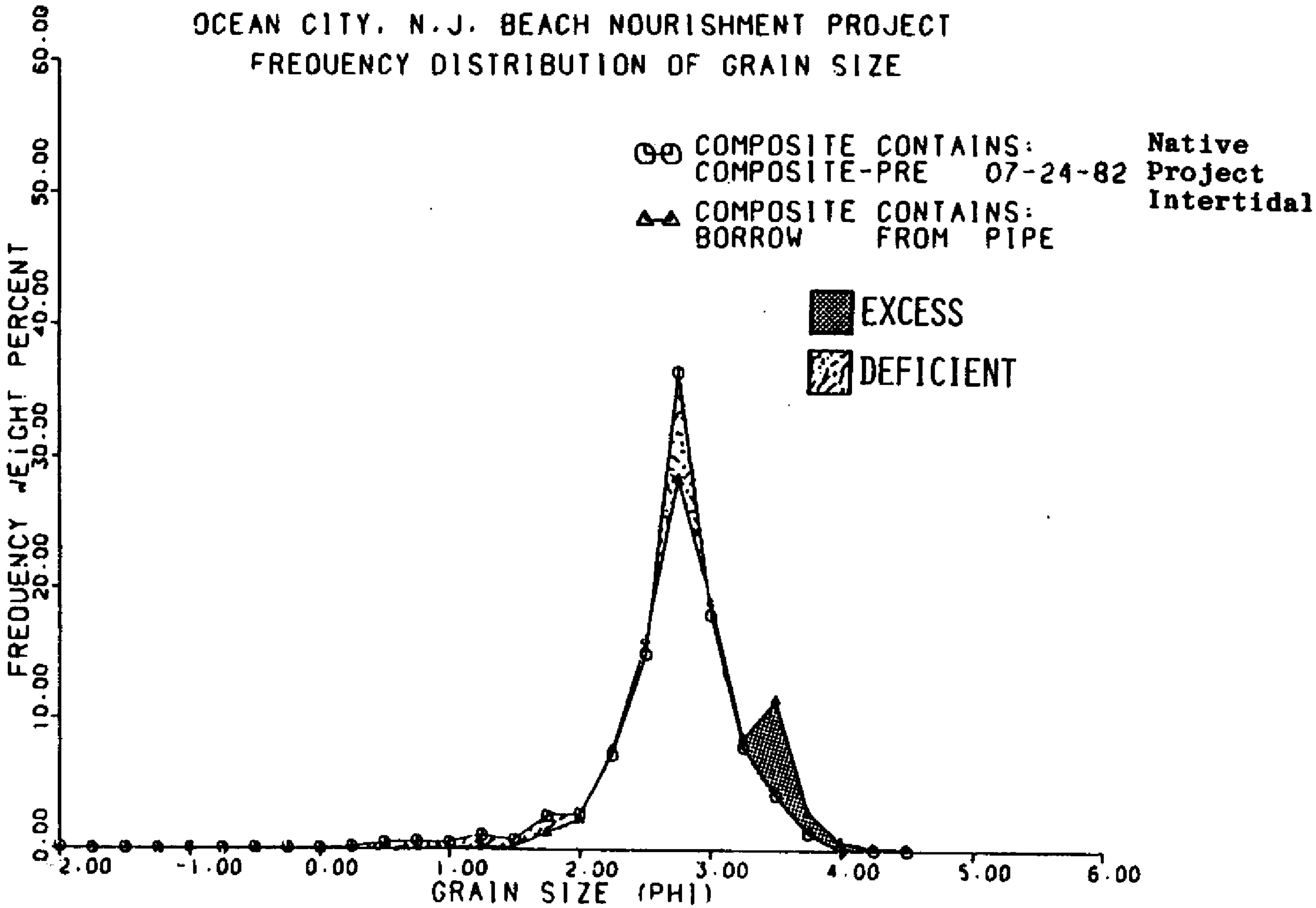


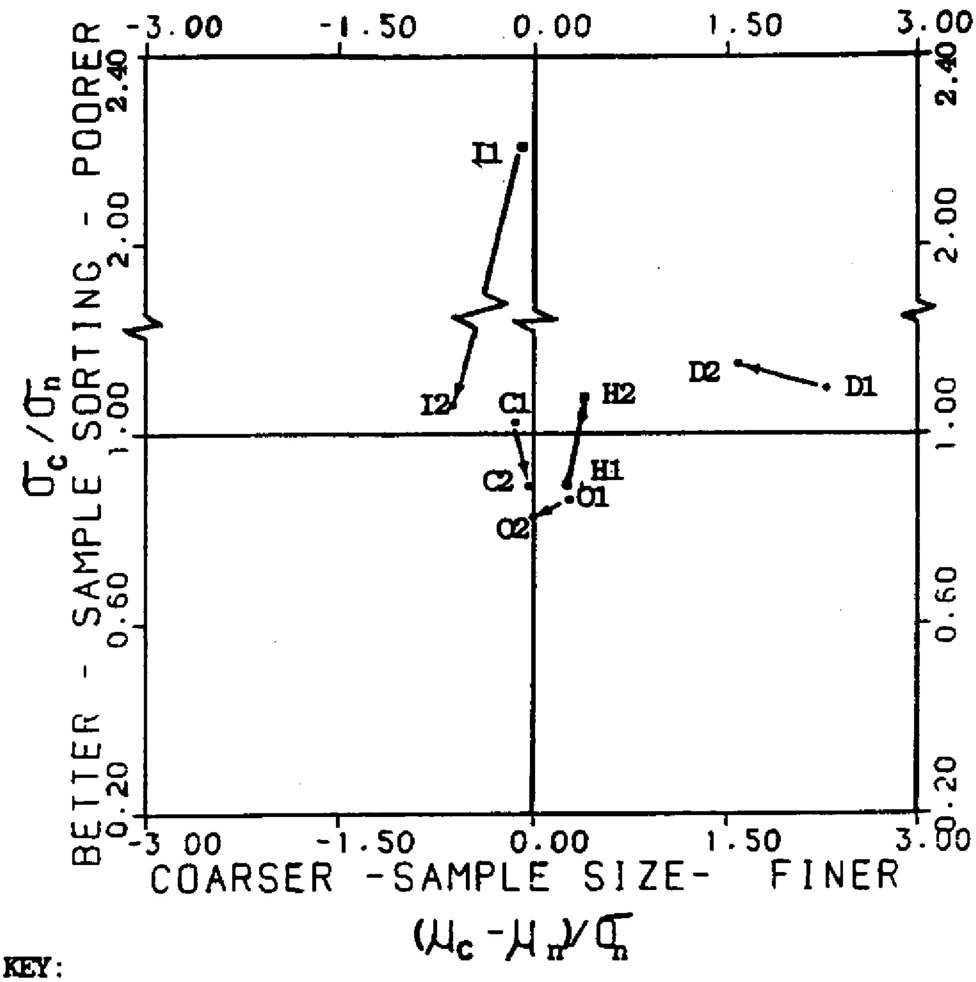
Figure 35. Comparison of the grain size frequency distribution of a) the native project intertidal composite vs. the borrow sediment for the Ocean City, N.J. project. (After Blake, 1984)

The response of the grain-size at each beach following nourishment is shown in Figure 36. The first point for each location is a comparison of the native beach with the borrow material. The second point is a comparison of the native beach with the beach one year later (8 years for Delray Beach). Choosing a one year sample reduces seasonal variations and allows inter project comparisons. A point moving towards the center of the graph would indicate that the beach was returning to the native beach conditions. Sorting at Indialantic/Melbourne Beach returned almost native conditions one year after the poorly sorted borrow was placed. At Delray Beach, the beach eight years after nourishment was much finer than the native beach. Captiva Island and Ocean City became better sorted with time, while their means remained similar.

An examination of long term grain size characteristics of the fill material has lead to a complex picture of project grain size redistribution. The projects used in this study exhibited a wide range of native-to-borrow grain size distributions and coastal wave energy distributions. A method was developed, using a "post-nourishment fill estimate", based on volume of fill stabilized over a year or longer and the changes in grain size distribution over time, to graph fill behavior.

The inclusion of the safety factor, G, seems to predict more accurate fill factors than the Adjusted fill factors alone. Our findings indicate that safety factor calculations should be shifted to the fine limit of native sediment, which was 3 phi (0.125 mm) for the projects studied, not the 4 phi (0.0625 mm) limit suggested by Hobson (1977). Figures 37 - 41 depicts the grain-size excesses and deficiencies in the borrow material as compared to the native beach at the top half of each figure and actual gains and losses one year later (8 years later for Delray Beach) at the bottom of each figure. If there was excess fine material in the borrow, the intersecting grain-size is shown by the dashed line. In the lower half of each figure, the solid line indicates the 3 phi grain-size at which the G values were calculated. The grain-size at which actual losses of fines occurred (if any) are shown with the crossed line. The 3 phi cut off point was used for the ease of obtaining percent sand at that point. Use of the 3 phi cut off point for calculating G and actual losses correlate well at Indialantic/Melbourne Beach (Figure 37), Captiva Island (Figure 38) and Ocean City (Figure 39). For the projects that had a reasonably good match between borrow and native or borrow that was for the most part slightly finer than native in areas of moderate to high wave energy the 3 phi adjustment gave a reasonable prediction of fill behavior.

The correlation was not as good at Delray Beach (Figure 40) which had such a large grain-size difference between the borrow and native and resulted in a significant long term change in the grain size distribution on that beach over the eight years of the study. If enough fill volume is placed on a beach it may alter the grain size distribution on a permanent basis as in the case of Delray beach. There is some indication that Ocean City also has undergone a change in the sediment grain size distribution to an extremely well sorted beach due to the large volume of finer, more well sorted bay sediment pumped onto the beach on an almost constant basis since the 1950's. No borrow information was available for Hollywood/Hallandale, but analysis using sediment collected three months after fill placement showed that the native material contained coarser material than the borrow that replaced it even though the borrow was composed of medium sand. From three months to one year later, the beach gained a significant amount of fine material not found in either the native or borrow sediment (Figure 41). It appears from this limited data set, that sediment grain size



KEY:

I1= Indialantic/Melbourne Beach- Native Intertidal vs. Borrow
I2= Indialantic/Melbourne Beach- Native Intertidal vs. 1-Year

D1= Delray Beach- Native Intertidal vs. Borrow
D2= Delray Beach- Native Intertidal vs. 8-Year Intertidal

C1= Captiva Island- Native Profile vs. Borrow
C2= Captiva Island- Native Profile vs. 1-Year Profile

O1= Ocean City, NJ- Native Intertidal vs. Borrow
O2= Ocean City, NJ- Native Intertidal vs. 1-Year Intertidal

H1= Hollywood/Hallandale - Native Intertidal vs. 3 Mo.
H2= Hollywood/Hallandale - Native Intertidal vs. 1-Year

Figure 36. Comparison of response of the native vs. borrow to native vs. 1 year after placement sediment grain size data from study projects. (After Blake, 1984)

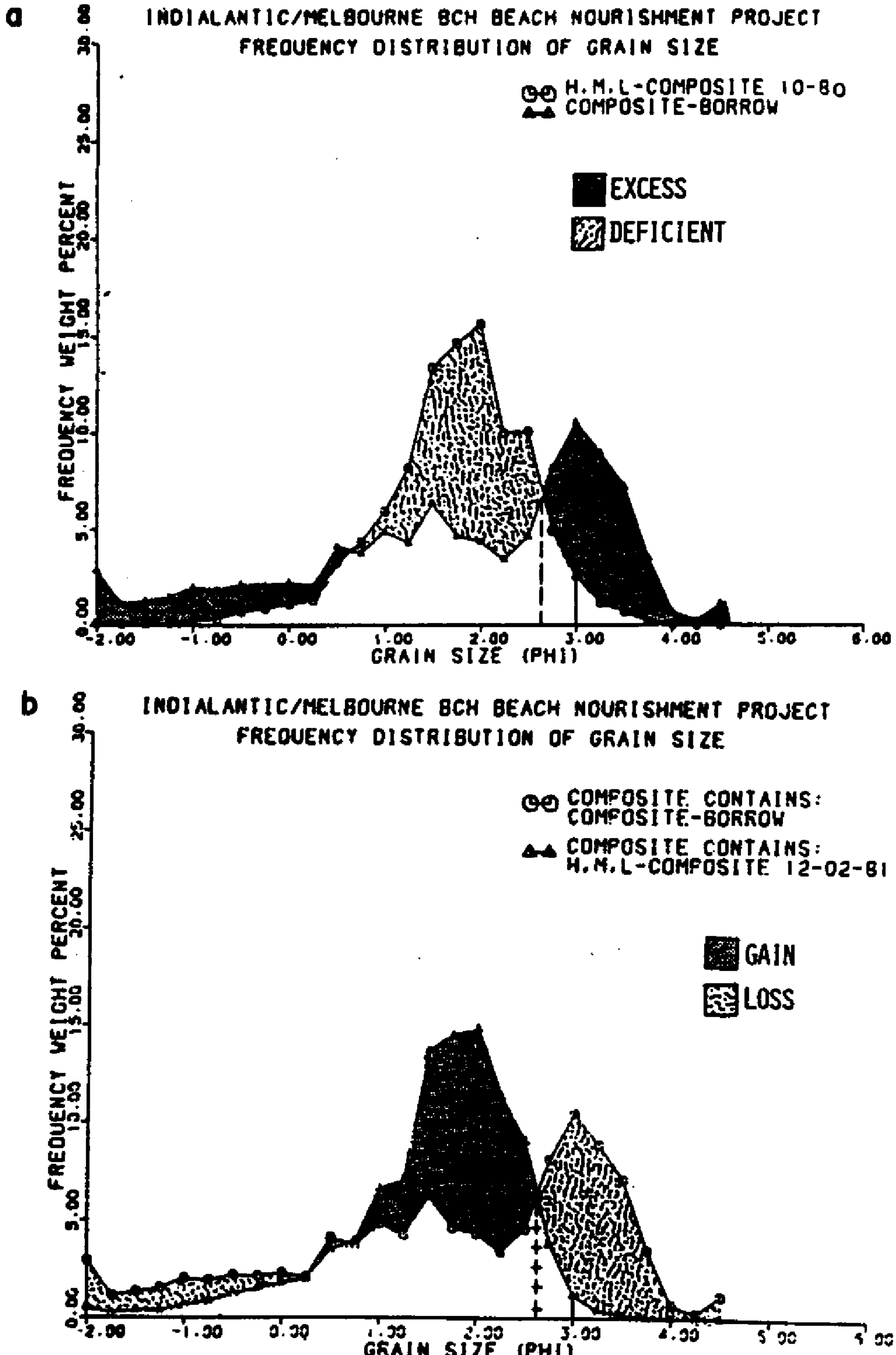


Figure 37. Grain size frequency distribution of a) borrow vs. native intertidal composite indicating the 3 phi safety factor (G) cut off (solid line) and the actual excess fine material (dotted line) and b) borrow vs. 1 year intertidal composite indicating the 3 phi safety factor and actual loss of fine material (+ line) for the Indialantic/Melbourne Beach project. (After Blake, 1984)

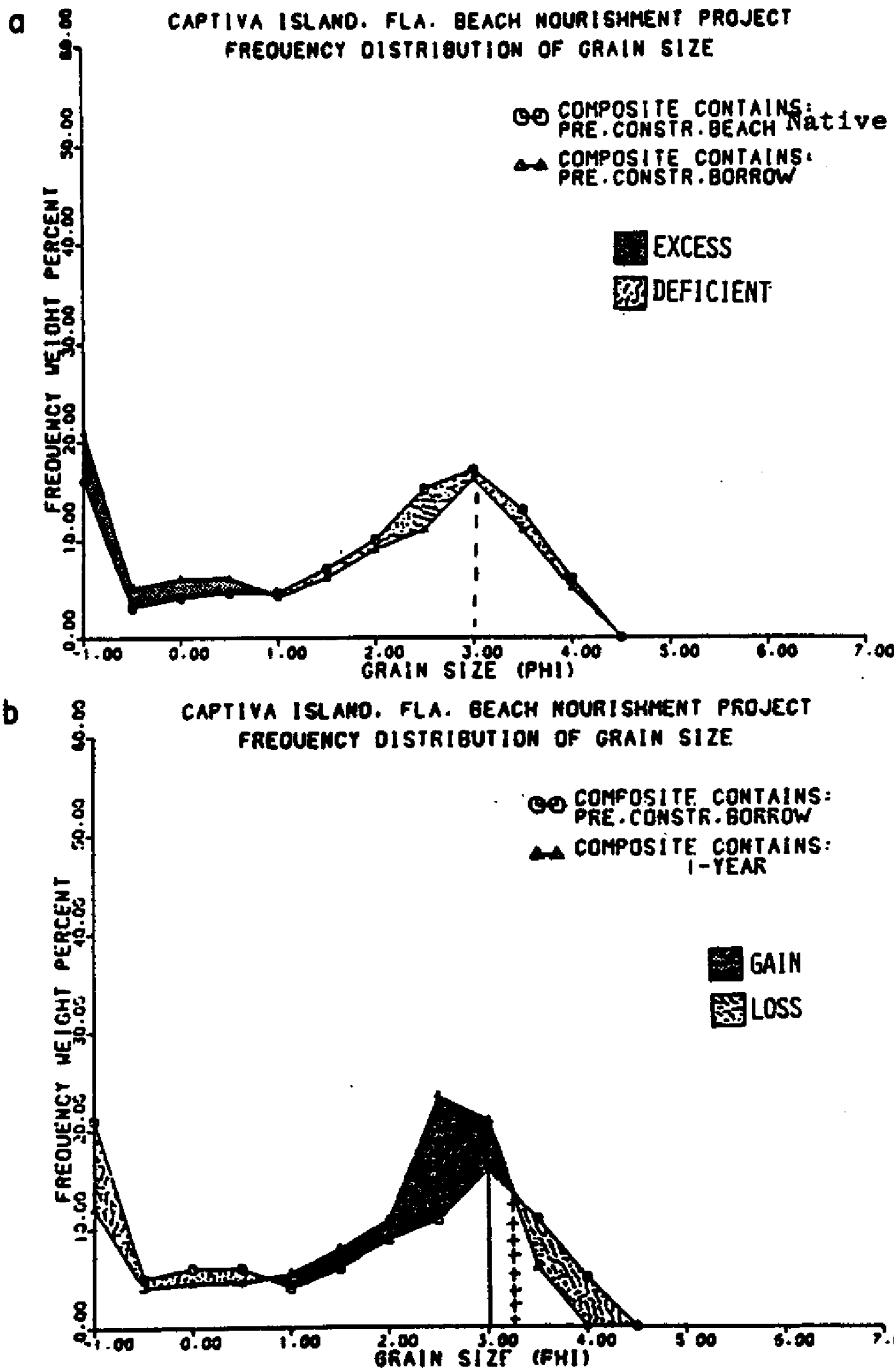


Figure 38. Grain size frequency distribution of a) borrow vs. native project composite indicating the 3 phi safety factor (G) cut off (solid line) and the actual excess fine material (dotted line) and b) borrow vs. 1 year project composite indicating the 3 phi safety factor and actual loss of fine material (+ line) for the Captiva project (data from Tackney and Associates, 1982; 1983a). (After Blake, 1984)

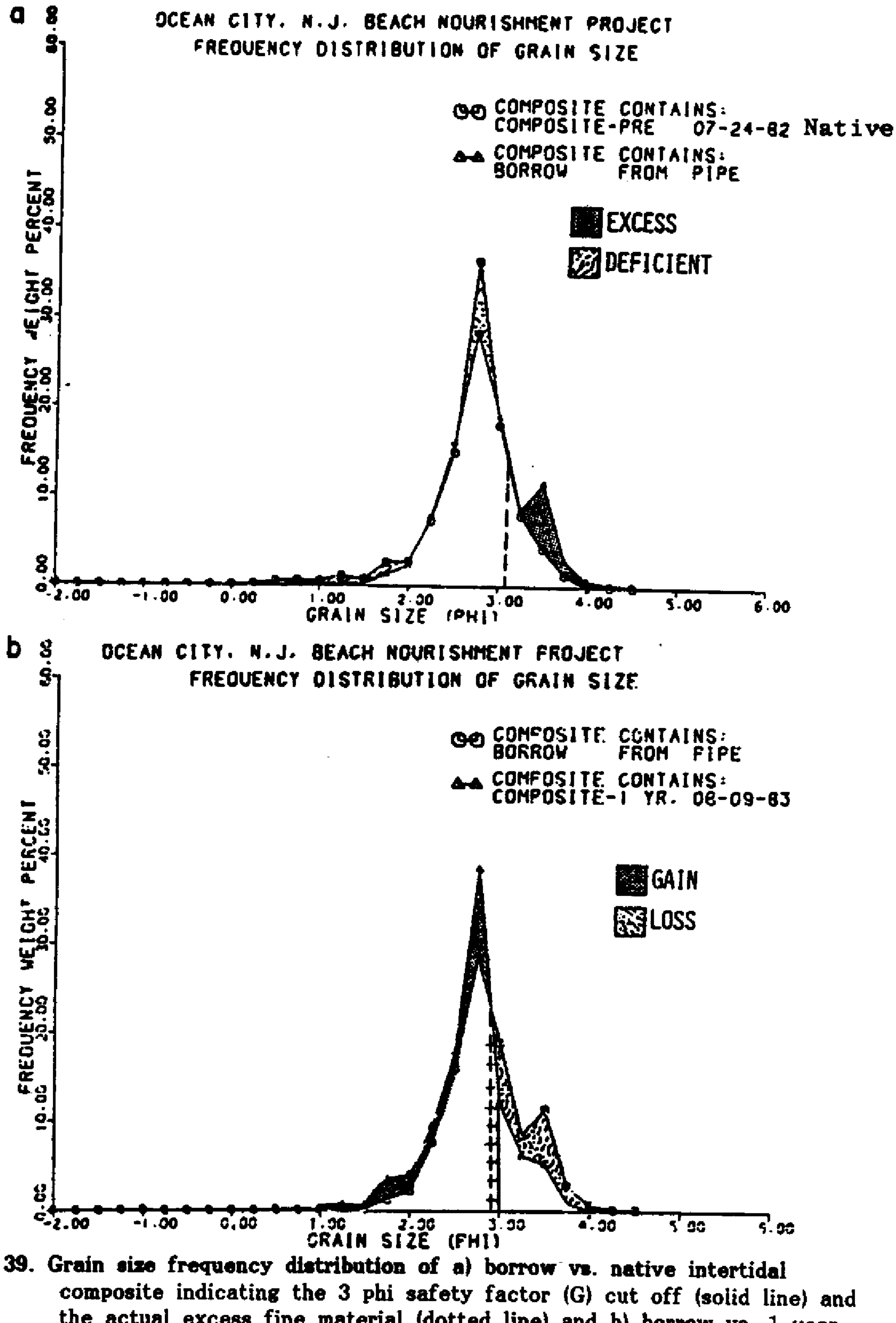


Figure 39. Grain size frequency distribution of a) borrow vs. native intertidal composite indicating the 3 phi safety factor (G) cut off (solid line) and the actual excess fine material (dotted line) and b) borrow vs. 1 year intertidal composite indicating the 3 phi sarety factor and actual loss of fine material (+ line) for the Ocean City, N.J. project. (After Blake, 1984)

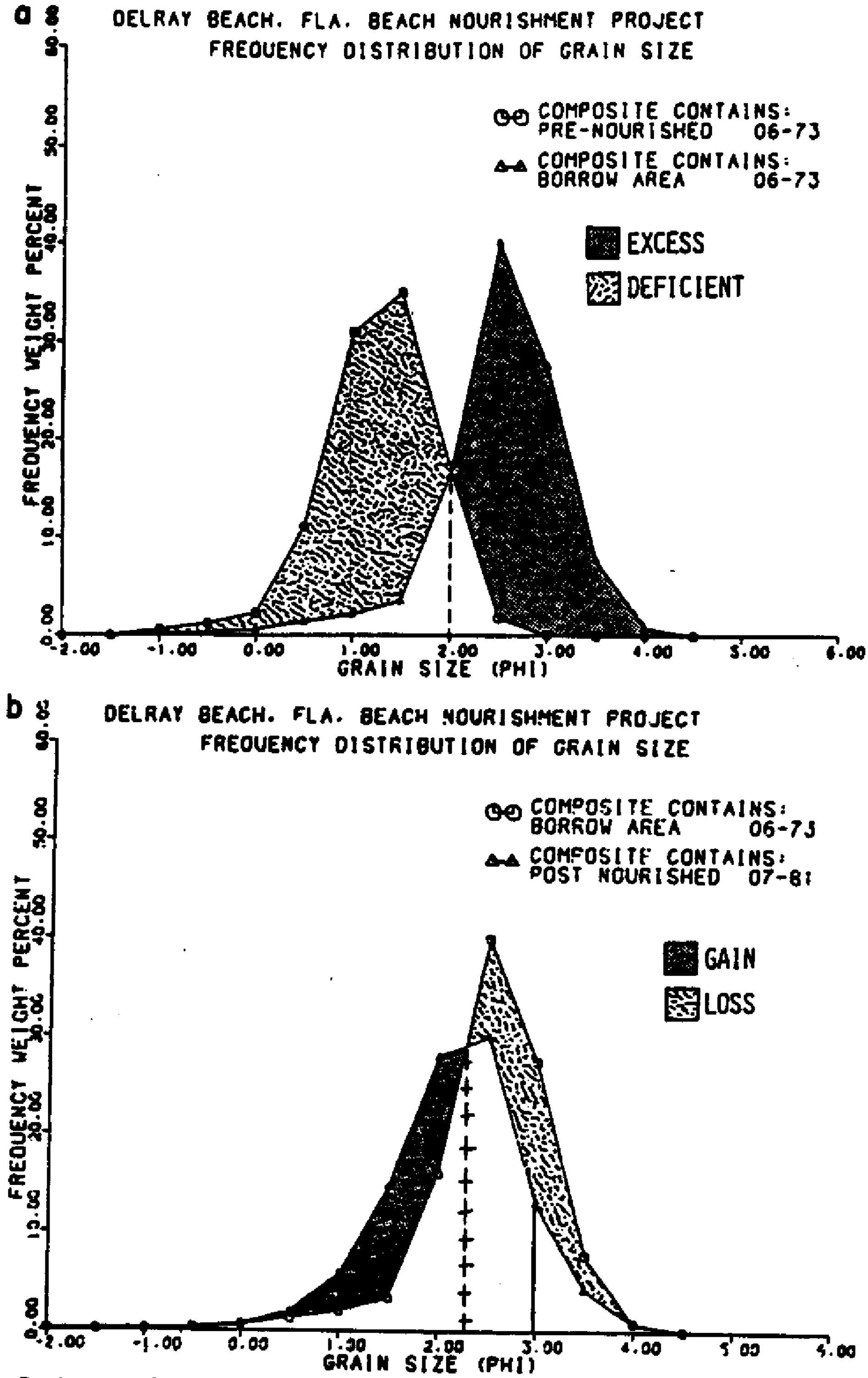


Figure 40. Grain size frequency distribution of a) borrow vs. native project composite indicating the 3 phi safety factor (G) cut off (solid line) and the actual excess fine material (dotted line) and b) borrow vs. 8 year project composite indicating the 3 phi sarety factor and actual loss of fine material (+ line) for the Delray Beach project (data from Strock and Associates, 1976; 1981b). (After Blake, 1984)

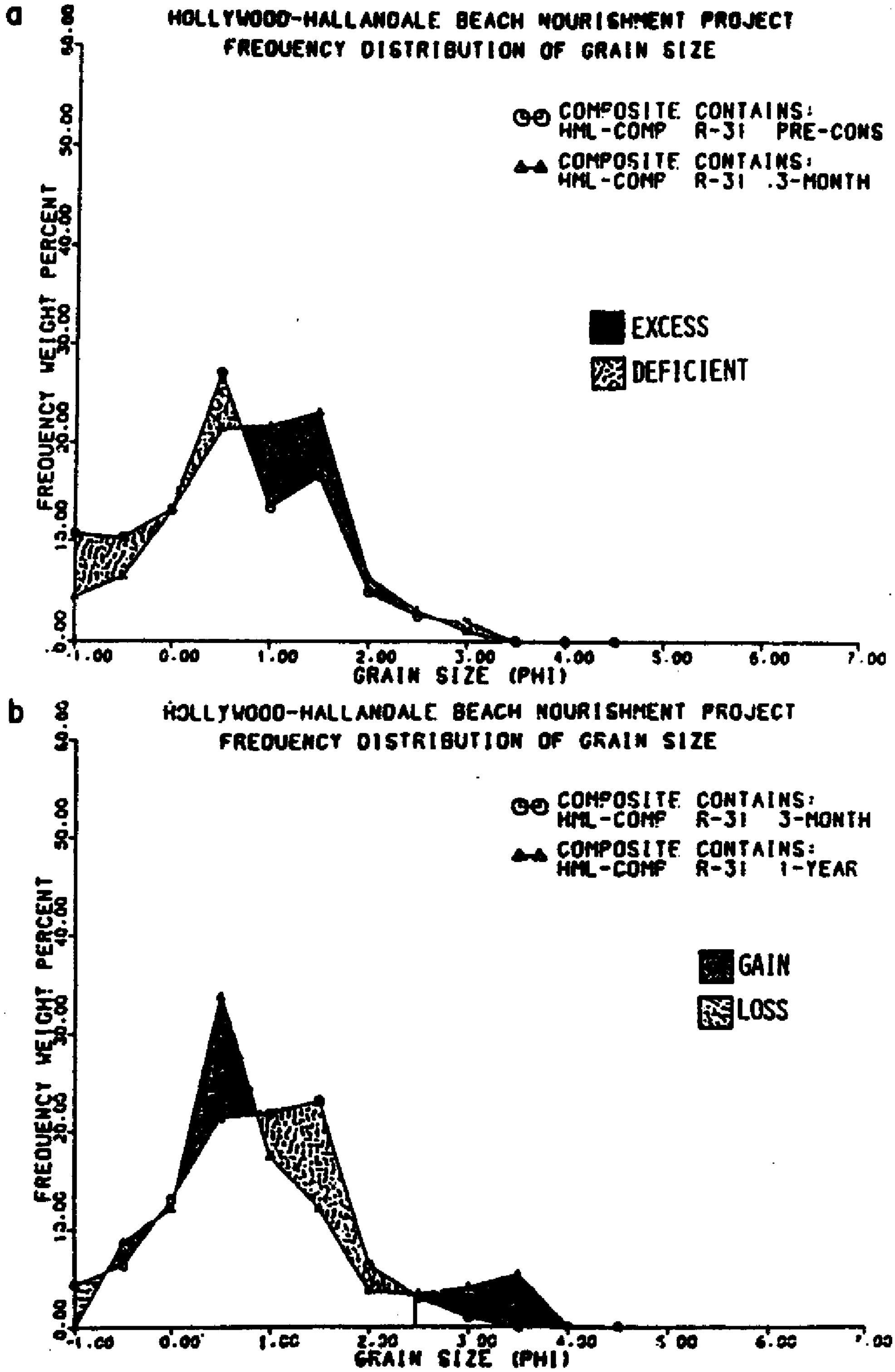


Figure 41. Grain size frequency distribution of a) 3 month vs. native intertidal composite indicating the 3 phi safety factor (G) cut off (solid line) and the actual excess fine material (dotted line) and b) 3 month vs. 1 year intertidal composite indicating the 3 phi sarety factor and actual loss of fine material (+ line) for the Hollywood/Hallandale project (data from Suboceanics, 1980; 1981). (After Blake, 1984)

redistributions play an important roll in stability of a beach fill project and more importance should be placed on the collection of adequate data in future projects, not only of the pre-construction native and borrow sediment but post-construction samples as well.

Littoral Environmental Monitoring Specifications

Supplementary data relating the littoral forces and other environmental parameters should be included to give a better understanding of fill behavior. The first pre-nourishment report of both beach nourishment and inlet sand bypass projects should include:

1) a brief description of the project and if applicable a description of the inlet,
2) a history of previous erosion control projects effecting the present project area,
3) a description of historical structural improvements to the shoreline and associated inlet, and
4) a brief summary of coastal processes occurring in the project area.

This coastal processes summary should include (if data is available) wave period, height; angle of predominant wave approach, tide range, wind direction velocity and measure of direction and quantity of longshore drift. For inlet projects, information on tidal inlet dynamics and morphology should also be included.

Historic shoreline trends

Where available a history of shoreline movement and erosion rates for the project beach in a beach nourishment project and in addition beaches on both sides of the inlet in a sand bypass project should be included in the report depending on their availability. A base map, utilizing optically corrected aerial photographs could be useful for basic project location information. In the State of Florida, the DNR erosion control line base maps would be readily available for this purpose. They contain information on benchmark location and coastal construction control line position, as well as dune line and high tide line position at time of photograph. The project profile lines and sediment sampling locations could be superimposed.

The wave climate

The wave data used in the study was obtained from U.S. Army Corp of Engineers Atlantic Coast Hindcast Data for Shallow-Water Significant Wave Information (Jensen, 1983). When available, wave data from the University of Florida wave gauges were used to calculate the yearly mean significant wave height for project location. This data proved useful to evaluate the behavior and response of the beach profiles after nourishment. The wide range of projects and locations provided a range in the physical parameters. Collection of this type of data either on hindcasting or real time from the nearest operating wave guage was not included in any of the reviewed reports. It is usually difficult to obtain real time wave conditions except at a few selected locations along the U.S. coast but an attempt at identifying the projects wave climate will allow for the continuation of the development of empirical relationships for the project response and establish recommendations for future project design.

Use of L.E.O. data

The U.S. Army, Corps of Engineers (Schneider, 1981) has developed a program for collecting important coastal processes data with minimal data gathering equipment called the Littoral Environmental Observations program (LEO). A form has been developed to accompany the collection of data to facilitate data recording and analysis. It would be advantageous to establish this program on a daily basis during construction and for at least the first year of monitoring. The construction personnel could be trained to record the data during project construction and interested local observers could follow up during the monitoring period. The important physical data to be recorded on the form are:

1. Wave period, breaker height, breaker angles and breaker type
2. Wind direction and velocity
3. Longshore current direction and velocity and the occurrence and spacing of rip currents.
4. Beach characteristics such as foreshore slope and occurrence of beach cusps

The ability to identify storm events during construction and monitoring is enhanced by the L.E.O. program. Storm events should be identified and a frequency of occurrance should be included for each monitoring report period even if the L.E.O. program is not used.

Aerial photography analysis

Aerial photography (if available) and ground photography during construction and monitoring can serve as useful documentation of the project conditions. Analysis of historical shoreline trends and project effects on a large alongshore scale can be easily documented with the use of aerial photography and may reduce the number of costly ground surveys needed. The shoreline changes of the complete project, including the control areas as well as other erosion control structures associated with the project shoreline can be viewed as one unit (see Figure 2 for an example of this technique used on the Port Canaveral project). Short term monitoring of construction and first year monitoring can benefit from this type of analysis, especially on large scale projects. The use of aerial photography is especially useful on long term monitoring where it may be difficult to reestablish older profile locations, but landmarks are readily identified and can be correlated on the photography (Hushla, 1982, and Stauble, et. al. 1983). This allows for a better understanding of the entire project behavior with sufficient spatial and temporal detail. Any rhythmic shoreline topographic changes as the fill establishes an equilibrium profile with the existing wave conditions can be documented as was observed in the Indialantic/Melbourne beach project (Figure 42). The effects on adjacent shorelines as longshore reorientation of fill material occurs thru time as well as effects of other coastal erosion structures on the movement of the fill can be readily documented.

Inlet dynamics

On inlet sand bypass projects, supplementary data on inlet dynamics and morphology should be taken. Inlet hydraulics and stability data such as wave activity, tidal range, tidal type, and tidal prism/cross sectional area data would also be useful. The

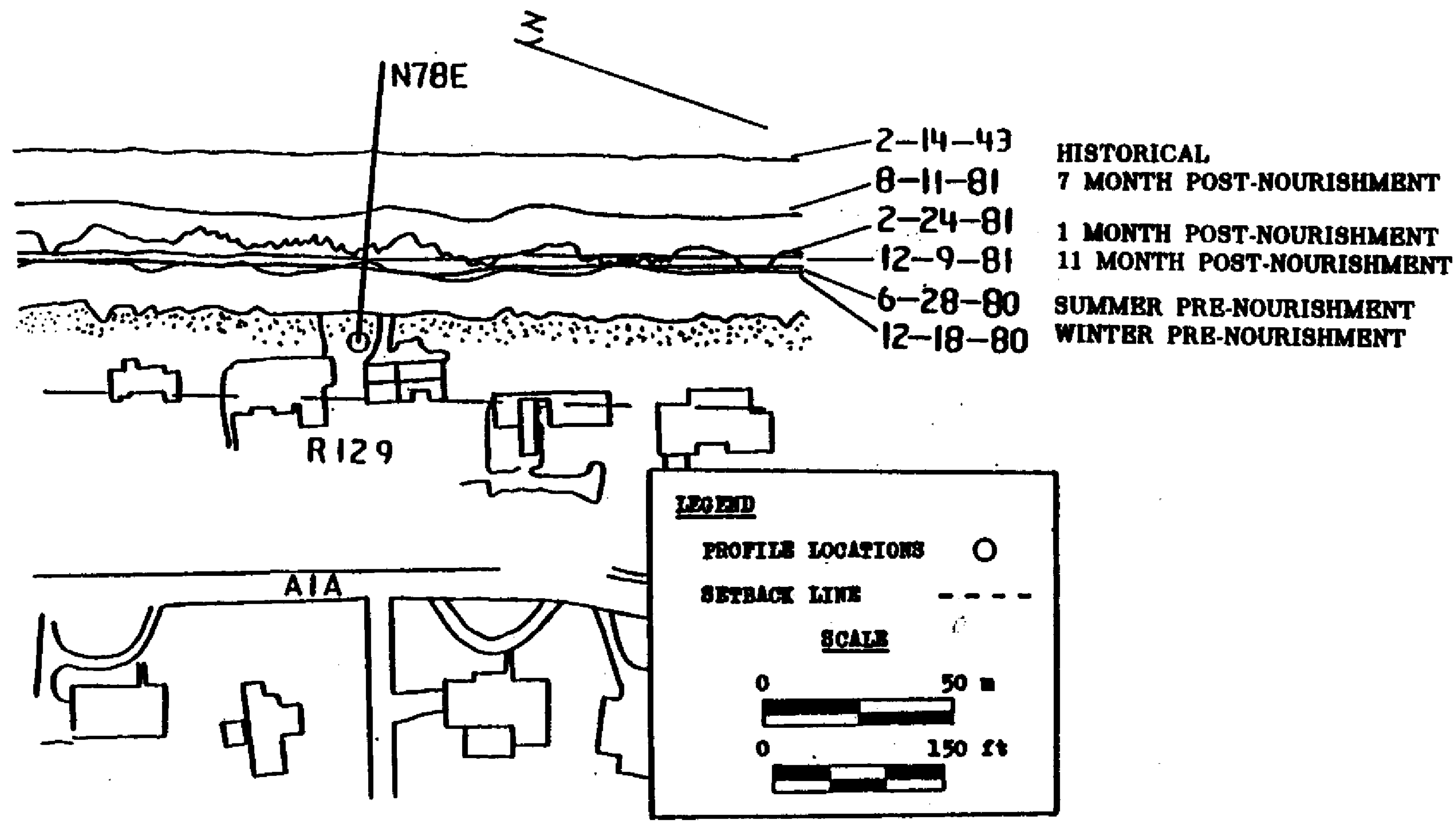


Figure 42. Baseline map of mean high water line positions from aerial photography at site R129, in the mid portion of the Indialantic/Melbourne Beach project showing the shoreline variation from historical, pre- and post-construction and 1 year after fill placement. (After Hushla, 1982)

dredging of tidal inlets are usually for maintenance of the navigation channel and/or a source for downdrift beach restoration. This dredging operation may affect the stability of the inlet and it's shoals and monitoring of this stability can prove important to the projects success. Leadon (1984) lists recommendations on the type and accuracy of monitoring measurements that relate to the inlet hydraulics and stability. These measurements would supply data to calculate inlet stability based on accepted stability relationships as found in numerous publications on tidal inlet dynamics (i.e. O'Brien and Dean, 1972; Mehta, 1975; Jarrett, 1976; Brunn, 1978 and others).

Biological monitoring information

If biological monitoring is required by other agencies, a brief summary should be included as to nature and extent in the physical monitoring report. Normally biological monitoring of the borrow and fill areas is reported in a separate report (if required) and no record is included with the physical monitoring. In order to keep a complete record on all aspects of a project, especially the relationship between fill sediment and important organisms in both the borrow area and the beach nourishment area, a reference to all studies on a specific project should be provided. Recent concerns about burial tolerances of certain organisms has prompted the Florida Department of Environmental Regulation to limit the sediment acceptable for placement as beach fill at the Sebastian Inlet sand bypass project to sediment greater than the 100 mesh sieve (2.75 phi or 0.149 mm) irregardless of the physical suitability of finer grain sizes. While finer than the 2.75 phi sediment is found on the native beach during the summer months and would normally be included in fill factor calculations on fill suitability, the biological concerns have required close examination of the borrow to avoid placement of this biologically non suitable fine material. This biologically determined 2.75 phi cut off is close to the 3 phi safety factor value found in this study and it is suggested, that since material smaller than 3 phi is usually winnowed out, that the biological requirement be moved to the 120 mesh seive (3 phi) to be consistant with physical processes. For further considerations on biological monitoring see part I of this study by Nelson.

Erosion control structure information

Supplementary information on existing and additional erosion control structures and dune maintenance or construction associated with the project should also be included in monitoring reports. This will allow for complete evaluation of project behavior and the effects of the use of multiple erosion control options in the project. The construction, maintenance and/or vegetation of: dunes, storm protection berms (as included in the Miami Beach project), revetments or seawalls and terminal groins or jetties are but a few of the additional structural components that are included in the total nourishment or bypass project. These structures may significantly influence the performance of any project and their relationship with the project needs to be documented.

Recommendations

The recommended guidelines developed from this study should provide new insight for design and permitting of future projects. In the economic context, guidelines which reduce the permitting period would help to substantially diminish the rate of increase in project cost, as well as decrease the chance that a project needed for storm protection might be delayed until it is too late.

Performance Monitoring Standards

A Project Monitoring Standardization System was designed along with this study to support the following DNR functions:

a) Systematic evaluation of project applications
b) Assurance of project design compliance at completion
c) Systematic evaluation of project performances
d) Maintenance of monitoring data base of all state funded beach nourishment and inlet sand bypass projects.
e) Development of special studies or reports on status or achievements of the state beach erosion control program.

Suggested formats and time schedules were developed for interim and final report submission (Stauble et. al., 1984b) and developed into standard monitoring and reporting formats (Leadon, 1984). This system was designed to be a companion to a project management system that tracts the fiscal accountability of the project. These two reports develop monitoring standards guidelines of specific tasks, formats, data analysis and presentation that will be required on state funded projects. Leadon (1984) contains specific data sheets and procedures to standardize data collection and presentation.

This study has examined several beach nourishment and sand bypass projects and found that there is no systematic procedure for monitoring such projects. An enormous effort was undertaken to take the reported data and develop a systematic approach to better understand beach nourishment project behavior. Much data has been lost in the past that would be of great value in developing models of fill and borrow area area behavior. Regulatory officials have been handicapped by little information on which to assess environmental impact. Project delays and increased cost have been the rule rather than the exception in an attempt to establish the projects impact and protect sensitive environmental areas.

A review of the components of the monitoring process have been divided into the borrow area and the fill placement area. In summary, each area has specific concerns that need to be monitored.

Borrow Area

It is recommended that borrow area information be required on all projects, to prevent unsuitable fill material being placed in the nourishment area, to identify the impact of turbidity on borrow and fill area organisms, to limit undue damage to the ecology of the borrow area or adjacent bottom habitats and to assess the reuse of the borrow area for future projects. In addition, this system will provide a data base of behavior of borrow areas in general. The degree of suitability is related most importantly to grain-size distribution and volume of acceptable sediment in the borrow area. The relationship of the borrow vs. native grain size is an important factor in the retention rate of fill not to be overlooked. Economic factors such as proximity of the borrow site to the project location and transfer costs also play an important role in determining which borrow site is most suitable for the individual project.

Fill Placement Area

The following guidelines on monitoring of the fill placement are based on previous investigations and from the review of the projects in this study. They should be applied in monitoring and design of a nourishment project to insure success.

1) A detailed pre-construction survey of the project location should include a series of pre-nourished profiles noting any trends, and/or dominant coastal processes. After investigation of previous projects it may be noted different processes or a combination of processes were influential on each project. Some examples are: littoral drift was prevalent at the Port Canaveral project with the jetty sheltering the northern portion, at Pompano there was littoral drift but no sheltering from a jetty. Captiva had a reversal in the littoral drift which carried the fill north and south along the project. In Ocean City, the on-offshore migration of fill segmented by groins caused 10% of the fill to be "lost" and then "regained". The Stump Pass project was greatly affected by the migration of the adjacent inlet. The nourishment at Indialantic/Melbourne Beach was influenced by the southern drift, which, due to construction during an active winter storm season, enhanced the removal alongshore of much of the material. Each individual project was unique due to coastal processes and it is important to understand these processes prior to design of a project to obtain optimum distribution and retention time after placement. Fill placed at the updrift portion of the project with significant downdrift sediment transport allow for a "nature assisted" distribution of the fill over the project and to the downdrift beaches, therefore increasing retention time of fill.

2) In this study it appears volume density of fill placed was the dominant factor in the fill retention rate of the project. In the design of a nourishment project it is not feasible to place a volume density of less than approximately 150 cubic meters/linear meter of beach. This was based on the results of this study of volume of fill per unit length of beach and its relationship to the percent of fill remaining after one year (figure 28). In the projects where volumes were placed below the minimum, the retention rates were not within acceptable limits to provide adequate storm protection to adjacent property. This may be observed at Indialantic/Melbourne Beach and Stump Pass. Both of these projects had lost a major portion of the fill three years after construction.

The placement of fill material acts to increase the berm elevation, beach width, and foreshore slope in most of the projects reviewed, thereby placing the profiles in disequilibrium for a period of time after placement. This resulted in formation of a scarp and rapid cut back of the artificial berm. Much of the material which eroded from the berm was observed to have been deposited offshore. It is optimum to design the nourished profiles with a grade that will give a gradual transition in foreshore slope after initial offshore adjustment of the fill by coastal processes. This initial design should take into account the offshore and downdrift transport of fill material as being advantageous to alleviating the erosion problem in the area of nourishment. The public usually identifies the rapid cut back of the fill and readjustment in the offshore area as a failure of the project. The non-equilibrium placement of fill is necessitated by the mechanics of fill placement. The wave activity will then resort the fill and reshape the profile into a more natural shape over time. These initial readjustments also give additional beach protection.

3) After the design of the project is completed, it is important to establish and initiate a comprehensive monitoring program. A poor or incomplete monitoring program will not measure the actual changes in volume over the majority of fill.

Profiling for the project, at a minimum, should include a pre-nourished survey, as well as the "as built" profile at time of the placement of fill. Note, it is important to profile immediately after fill placement at each profile location, not after completion of the entire project, which is most often the case. This was proven at Indialantic/Melbourne with the comparison of the total volume change after completion of the project to the total volume change after the completion of fill on each individual zone. The volume change after completion of the project did not take into account the loss of fill up to that point. After nourishment, the monitoring should include repeated profiling on a quarterly basis for a period of at least one year after construction, then subsequently twice a year for the second year period and once each year thereafter for the design life of the project. This allows for documentation of the initial rapid readjustment and later stabilization of the fill. The profile locations should be representitive of a zone, spaced at intervals to cover the entire length of the project. Adjacent control profiles need to be establish to give a complete understanding of the migration of the fill. All of the profiles need to be referenced to an established ground truthing system like the Department of Natural Resources Benchmark's. In any project the actual amount of fill placed must be calculated using the pre-nourished and as built profile and compared with subsequent profiles in order to more accurately calculate the amount of fill retained.

During this study it was noted very few projects had complete or adequate monitoring. Most planners and managers consider short and long term monitoring a luxury, which is consequently excluded from most projects. However, a thorough pre-nourishment survey, proper design of the project and monitoring after construction will allow an increase in understanding of the behavior of fill placement and subsequent rearrangement and improve the effectiveness of future projects.

Other Recommendations

From the study on grain size information from the selected projects it can be concluded that:

1. Composite samples are needed to remove the variability in sediment distribution across a beach and in a borrow area. Intertidal composite sample statistics of the native beach are more suitable for use in the models. Of the projects studied, offshore sediments include fine sizes and changed little in their grain size distribution over the project life. Fill was placed in the intertidal area in all projects studied and this area had the greatest redistribution of sediment grain sizes.

2. The Adjusted Shore Protection Manual method (recommended in the majority of cases by U.S. Army, 1984), gave the best calculation of actual fill behavior, provided a safety factor (G) was used. A safety factor of 3.0 Phi has been found to

give the best results for the projects studied.

3. Fill factor models commonly use only the sediment mean and standard deviation values. The sample mean and sorting alone are not sufficient to describe the variability of the native, borrow and post-fill sediment behavior because natural sediment distributions are not normally distributed as assumed in the models. Frequency distribution plots provide the best means of showing the differences between the native and borrow grain sizes over the entire sediment distribution.

4. Renourishment Factor calculations using computed delta values (James, 1975) gave the best match to actual fill behavior.

5. Standardization of collection, analysis and presentation of beach nourishment sediment data is needed for better understanding of project behavior.

Compatibility of the borrow material is but one of the factors to be considered in project planning, along with fill placement techniques, knowledge of coastal processes and interaction with other coastal structures. More projects with adequate data need to be examined and a standard data collection and reporting system established. Clearly a systematic approach to project performance monitoring is advantageous to effectively manage the important and large scale coastal erosion control program such as the one proposed in the state of Florida by the Governor's Task Force (Florida Dept. of Natural Resources, 1985).

The guidelines developed in this report are designed to provide a systematic approach to the multi-phase planning, implementation and regulation of state funded erosion control projects. A summary schematic of the beach nourishment or sand bypass project process is given in figure 43. It is important that the initial permit application processing be done in conjunction with the basic pre-project monitoring procedures. In addition, adequate monitoring of both the biological and physical parameters must occur with the construction and post-construction periods to most efficiently assess the project performance and environmental impact (Stauble and Nelson, 1984).

While specifically designed for beach restoration and nourishment and inlet sand bypass and transfer projects, the guidelines have the capability to be expanded to be useful for "hard" coastal erosion structural construction concerns as well as "soft" dune management programs. All erosion control nourishment projects can now be uniformily administered with a standard approach. An added benefit is the capability to generate baseline project behavior data and insures a systematic approach to document project performance. By developing such a data collection and analysis system on every project, an excellent data base will be generated. The design engineer, regulatory official and project planner will have access to heretofore nonexistent information, on which to base future project design and industry standards. Within project and cross project comparisons and summary data could be easily generated. This systematic study of the entire project history from prenourishment background data, borrow area information and long-term project performance would provide a better understanding of the behavior of these erosion control projects and their influence on adjacent shorelines. In the long run, this will reduce both the high cost and permit delays, by supplying required data to make regulatory and engineering decisions. We

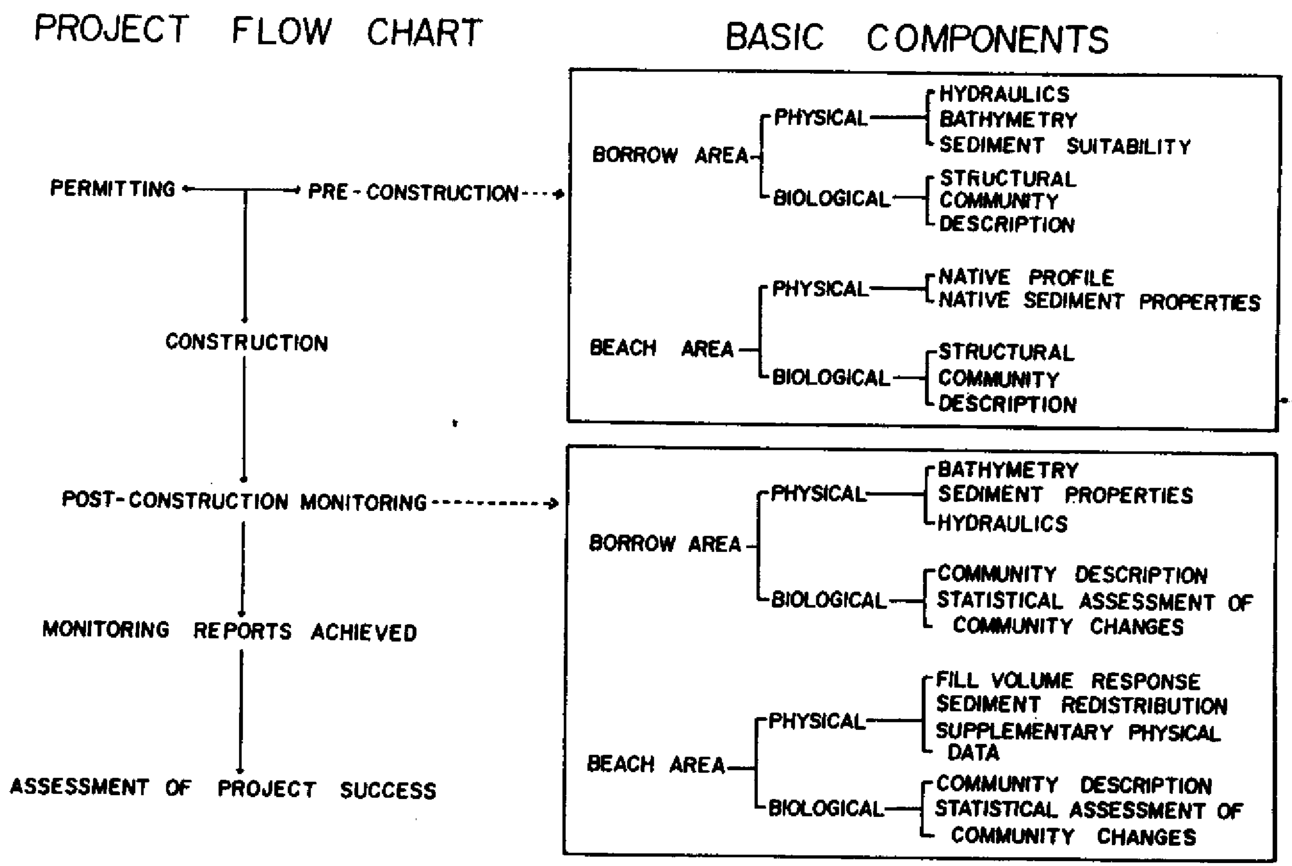


Figure 43. Schematic flow chart detailing the necessary components of the physical and biological monitoring and evaluation for beach nourishment and sand bypass projects (Stauble and Nelson, 1984).

will then have a better basis for understanding fill behavior and development of new predictive methods for project success.

REFERENCES

Allison, H., 1981. Expeditious regimes of artificial beach nourishment or dredging. Coastal Engineering, Vol. 5, pp. 311-330.

Bascom, W.N., 1959. The relationship between sand size and beach face slope. Am. Geophysical Union Trans., Vol. 32, No. 6, pp. 866-874.

Bell, F.W. and V.R. Leeworthy, 1984. The economic impact and valuation of Florida's saltwater beaches - some preliminary findings on resident and tourist beach users. Presented at the 28th Annual Meeting of the Florida Shore and Beach Preservation Association, Captiva, Florida.

Bell, F.W. and V.R. Leeworthy, 1986. An economic analysis of the importance of saltwater beaches in Florida. Report No. 82, Florida Sea Grant College, Gainesville, FL, 166 pp.

Blake, W.J., 1983. The response of sediment grain size distributions following beach nourishment: monitoring, prediction, and guidelines for future projects. Unpublished Masters Thesis, Florida Institute of Technology, Melbourne, Florida. 158 pp.

Brunn, P., 1978. Stability of tidal inlets, theory and engineering. Developments in Geotechnical Engineering, Vol. 23, Elsevier Scientific Pub. Co., 506 pp.

Campbell, T.J., Spadoni, R., Beachlier, K., and Morgan, J., 1980. Planning for beach restoration in South Florida. ASCE, Proc. Annual Meeting, Vol. II, pp. 1319-1330.

Campbell, T.J. and R.H. Spadoni, 1982. Beach restoration - an effective way to combat erosion on the Southeast Coast of Florida. Shore and Beach, Vol. 50, No. 1, pp. 11-12.

Coastal Engineering Consultants, Inc., 1981. Stump Pass monitoring report. For Florida Dept. of Natural Resources, Naples, Fl., Series of three blueprint books.

Coastal Engineering Consultants, Inc., 1982. Stump Pass monitoring report II. For Florida Dept. of Natural Resources, Naples, Fl., 10 pp. and appendicies.

Coastal Engineering Consultants, Inc., 1983. Stump Pass monitoring report 1982. For Florida Dept. of Natural Resources, Naples, Fl., 10 pp. and appendicies.

Coastal Engineering Consultants, Inc., 1984. Stump Pass monitoring report IV. For Florida Dept. of Natural Resources, Naples, Fl., 10 pp. and appendicies.

Coastal Planning & Engineering, Inc., 1985. Pompano Beach/Lauderdale-by-the-Sea beach restoration project. 12 month monitoring report. For Broward County Erosion Prevention District, Boca Raton, Fl., 10 pp. and Appendices.

Dalrymple, R.A., 1970. An offshore beach nourishment scheme. Proc. 12th Coastal Engineering Conference, ASCE, Vol. II, pp. 955-966.

Dean, R.G., 1974. Compatibility of borrow material for beach fills. Proc. 14th Coastal Engineering Conference, ASCE, Vol. II, pp. 1319-1330.

Dean, R.G., 1977. Equilibrium beach profiles: U.S. Atlantic and Gulf Coasts. Ocean Engineering Report No. 12, Department of Civil Engineering, Univ. of Delaware, 45 pp.

Dean, R.G., 1983. Principles of beach nourishment. in: CRC Handbook of Coastal Processes and Erosion, P.D. Komar, ed., CRC Press, Boca Raton, Fl., pp. 217-231.

Everts, C.H., A.E. DaWall and M.T. Czerniak, 1974. Behavior of beach fill at Atlantic City, New Jersey. Proc. 14th Coastal Engineering Conference, ASCE, Vol. II, pp. 1370-1387.

F.S.B.P.A., 1981. Sunshine state 1st in erosion control. Shoreline Newsletter, Fla. Shore and Beach Pres. Assoc., Vol. XXIV, No. 1, pp. 5.

Fisher, J.S. and W.N. Felder, 1976. Cape Hatteras beach nourishment. Proc. 15th Coastal Engineering Conference, ASCE, pp. 1512-1529.

Florida Dept. of Natural Resources, 1985. Beach restoration: a state initiative. Division of Beaches and Shores and Restore Our Coast Task Force, Tallahassee, FL., 78 pp. and appendix.

Gabriel, S.R., 1983. Project plans and survey notes, Ocean City, N.J. beach restoration. Div. of Public Works, City of Ocean City, N.J., 4 sheets.

Hallermeier, R.J. 1981. A profile zonation for seasonal sand beaches from wave climate. Coastal Eng., Vol. 4, pp. 253-277.

Hansen, M.E., 1982. Evaluation of beach fill models and the effect of carbonate material on beach fill. Unpublished Masters Thesis, Florida Institute of Technology, Melbourne, FL., 107pp.

Hicks, S.D., H.A. Debaugh and L.E. Hickman, Jr., 1983. Sea level variations for the United States 1855-1980. U.S. Department of Commerce, NOAA, Rockville MD., 170 pp.

Hobson, R.D., 1977. Review of design elements for beach-fill evaluation. TM-77-6, U.S. Army Corps of Eng., Coastal Eng. Research Center, Fort Belvior VA, 51 pp.

Hobson, R.D., 1981. Typical U.S. beach nourishment projects using offshore sand deposits. Beach Nourishment Techniques Report 3, Tech. Rept. H-76-13, U.S. Army, Engineering Waterways Experiment Station, Vicksburg, Ms. 117pp.

Hoel, J.S., in press. Beach profile response after beach nourishment at selected projects in Florida and New Jersey. Unpublished Masters Thesis, Florida Institute of Technology, Melbourne FL., 118 pp. & appendices.

Hoffman, J.S., D. Keyes and J.G. Titus, 1983. Projecting future sea level rise, methodology, estimates to the year 2100 and research needs. U.S. Environmental Protection Agency, Washington, D.C., 2nd. Edition, Revised., 121 pp.

Hunt, S.D., 1980. Port Canaveral Entrance. Glossary of Inlets Report No. 9, Florida Sea Grant College, Gainesville, FL., 50 pp.

Hushla, F.L., 1982. Evaluating the performance of beach nourishment in Brevard County, Florida through the use of aerial photography. Unpublished Masters Thesis, Florida Institute of Technology, Melbourne, FL., 80 pp.

James, W.R., 1974. Beach fill stability and borrow material texture. Proc. 14th Coastal Engineering Conference, ASCE, Vol. II, pp. 1334-1344.

James, W.R., 1975. Techniques in evaluating suitability of borrow material for beach nourishment. TM-60, U.S. Army Corps of Engineers, Coastal Eng. Res. Center, Vicksburg, MS., 81 pp.

Jarrett, J.T., 1976. Tidal prism - inlet area relationships. U.S. Army, Corps of Eng., GITI Rept. No. 3.

Jensen, R.E., 1983. Atlantic coast hindcast, shallow water, significant wave information. WIS Report 9, U.S. Army Engineering Waterways Experiment Station, Vicksberg, MS.

Jones, C.P. and A.J. Mehta, 1980. Inlet sand bypassing systems in Florida. Shore and Beach, Vol. 48, No. 1, pp. 25-34.

Krumbein, W.C., 1957. A method for specification on sand for beach fill evaluation. TM 102, U.S. Army Corps of Engineers, Beach Erosion Board, 43 pp. and appendices.

Krumbein, W.C., and W.R. James, 1965. A lognormal size distribution model for estimating stability for beach fill material. TM-16, U.S. Army Corps of Engineers, Coastal Eng. Res. Center, 17 pp.

Leadon, M.E., 1984. Erosion control/permit monitoring program: monitoring standards and reporting formats. Beaches and Shores Report CZM-84-2, Division of Beaches and Shores, Florida Department of Natural Resources, Tallahassee, FL., 77 pp.

Lenhoff, L., 1979. Beach sediment sampling methods. Council for Scientific and Industrial Research, Report No. 336, National Research Institute for Oceanology, Coastal Engineering and Hydraulics Division, Stellenbosch, South Africa, 75 pp.

Metha, A.J., 1975. Hydraulics of tidal inlets, simple analytic models for the engineer, parts I and II. UFL/COEL-75/019, Univ. of Florida, Dept. of Coastal and Ocn. Eng., Gainesville, Fl.

Nelson, W.G., D.K. Stauble and R.O. Johnson, 1982. Biological monitoring of an offshore borrow area, beach erosion control project, Fort Pierce, Florida. Final Report to the U.S. Army, Corps of Engineers, Jacksonville District, Jacksonville, Fl., 120 pp.

O'Brien, M.P. and R.G. Dean, 1972. Hydraulic and sedimentary stability of coastal inlets. Proc. 13th. Coastal Engineering Conference.

Parson, L.E., 1982. The immediate response of beach profile readjustment of the Indialantic/Melbourne Beach nourishment project. Unpublished Masters Thesis, Florida Institute of Technology, Melbourne, FL., 106 pp.

Schneider, C., 1981. The littoral enviornmental observation (LEO) data collection program. CETA 81-5, U.S. Army Corps of Engineers, Coastal Eng. Res. Center, Vicksburg, MS.

Shemdin, O.H., Brooks, H.K, Ceylanli, Z., Harrel, S.L., 1976. Comprehensive monitoring of a beach restoration project. Proc. 15th Coastal Engineering Conference, pp. 1477-1491.

Shuisky, Y.D. and M.L. Schwartz, 1979. Natural laws in the development of artificial sandy beaches. Shore and Beach, Vol. 47, No. 4, pp. 33-36.

Smith, S.K., 1981, Number of households and average household size in Florida: 1960, 1970 and 1980. Bulletin No. 57, Population Studies, Coll. of Business Administration, Univ. of Florida, Gainesville, FL., 4 pp.

Sonu, C.J., 1972. Bimodal composition and cyclic characteristics of beach sediment in continuously changing profiles. Jour. of Sedimentary Petrology, Vol. 42, No. 4, pp. 852-857.

Spadoni, R.H., N.H. Beumel and T.J. Campbell, 1983. The design and performance of a weir at Boca Raton Inlet, Florida. Proc. Coastal Structures '83, ASCE, Arlington, VA., pp. 884-901.

Stauble, D.K., 1973. Seasonal and storm-related beach changes at Ocean City, New Jersey. Abs., Northeastern Section, 8th Annual Meeting, Geological Society of America, Vol. 5, No. 2, pp. 221-222.

Stauble, D.K., 1982. A detailed study of profile response and sediment textual changes of the Indialantic/Melbourne Beach nourishment project. In Proc., 24th and 25th Annual Meetings of the Florida Shore and Beach Preservation Association, Tallahassee, FL., pp. 197-216.

Stauble, D.K. and W.G. Nelson, 1984. Beach restoration guidelines: prescription for project success. In: The New Threat to Beach Preservation, L. Tate, ed., Florida Shore and Beach Preservation Association, Tallahassee, Fl., pp. 137-155.

Stauble, D.K., M.E. Hansen, R.L. Hushla, and L.E. Parson, 1983a. Biological and physical monitoring of beach erosion control project, Indialantic/Melbourne Beach, Florida. Part 1: physical monitoring. U.S. Army, Corps of Engineers, Jacksonville District, 72. pp.

Stauble, D.K., M.E. Hansen, R.L. Hushla, and L.E. Parson, 1983b. Beach nourishment monitoring, Florida East Coast: Physical engineering aspects and management implications. Proc. of the Third Symposium on Coastal and Ocean Management, ASCE, pp 2512-2526.

Stauble, D.K., J.C. Sainsbury and J.M. Knight, 1984a. Erosion control/permit monitoring program: Beach erosion control project management system and beach nourishment/inlet sand bypass project monitoring system. Beaches and Shores Report CZM-84-1, Division of Beaches and Shores, Florida Department of Natural Resources, Tallahassee, FL.

Stauble, D.K., M. Hansen and W. Blake, 1984b. An assessment of beach nourishment sediment characteristics. Proc. 19th Coastal Engineering Conference, ASCE, pp. 1471-1487.

Strock, A. V. and Assoc. Inc., 1976. Design analysis for maintenance nourishment project, City of Delray Beach, Palm Beach County, Florida. Report to U.S. Army, Corps of Engineers Jacksonville District, Deerfield Beach, Fl., 52 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1979. City of Delray Beach, beach maintenance nourishment project, 12 month follow-up study. Report to City of Delray Beach, Fl., Deerfield Beach, Fl., 18 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1981a. City of Delray Beach, beach maintenance nourishment project, 24 month follow-up study. Report to City of Delray Beach, Fl., Deerfield Beach, Fl., 18 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1981b. City of Delray Beach, beach maintenance nourishment project, 36 month follow-up study. Report to City of Delray Beach, Fl., Deerfield Beach, Fl., 21 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1981c. Boca Raton Inlet and adjacent beaches monitoring study report. For The City of Boca Raton, Fl., Deerfield Beach, Fl., 29 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1981d. Town of Jupiter Island follow up study. Report to Town of Jupiter Island, Fl., Deerfield Beach, Fl., 13 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1982. Boca Raton Inlet, dredge and beach monitoring program, mid-study interm report. For The City of Boca Raton, Fl., Deerfield Beach, Fl., 8 pp. and Appendices.

Strock, A. V. and Assoc. Inc., 1983. Boca Raton Inlet, dredge and beach monitoring program, final report. For The City of Boca Raton, Fl., Deerfield Beach, Fl., 14 pp. and Appendices.

Suboceanic Consultants, Inc., 1979a. Erosion control project monitoring guidelines, Report to Bureau of Beaches and Shores, Florida Department of Natural Resources, Tallahassee, FL., 11 pp.

Suboceanic Consultants, Inc., 1979b. Inlet project monitoring guidelines. Report to Bureau of Beaches and Shores, Florida Department of Natural Resources, Tallahassee, FL., 10 pp.

Suboceanic Consultants, Inc., 1980. Hollywood/Hallandale beach restoration project, six months monitoring report. For Broward County Erosion Prevention District, Naples, Fl., 27 pp.

Suboceanic Consultants, Inc., 1981. Hollywood/Hallandale beach restoration project, one year monitoring report. For Broward County Erosion Prevention District, Naples, Fl., 34 pp.

Tackney and Associates, Inc., 1982. Captiva beach restoration project, six month monitoring report. Naples, Fl., 39 pp.

Tackney and Associates, Inc., 1983a. Captiva beach restoration project, one year monitoring report. Naples, Fl., 41 pp.

Tackney and Associates, Inc., 1983b. Captiva beach restoration project, eighteen month monitoring report. Naples, Fl., 49 pp.

Tanner, W.F., 1960. Florida coastal classification. Trans. Gulf Coast Assoc. of Geol. Soc., Vol. X, pp. 259-266.

Univ. Of Florida, 1976. Report on monitoring of a beach fill south of Canaveral jetties, Brevard County, Florida. Coastal and Oceanographic Engineering Laboratory, Gainesville, FL., 59 pp.

Univ. of Florida, 1982. Florida coastal data network, wave data reports. Coastal and Oceanographic Engineering Department, Gainesville, FL.

Univ. of Florida, 1983. Florida coastal data network, wave data reports. Coastal and Oceanographic Engineering Department, Gainesville, FL.

Univ. of Florida, 1984. Florida coastal data network, wave data reports. Coastal and Oceanographic Engineering Department, Gainesville, FL.

U. S. Army, 1978. Brevard County beach erosion control project, general and detail design memorandum addendum. Corps of Engineers, Jacksonville District, Jacksonville, FL. 43 pp. and Appendicies.

U. S. Army, 1984. Shore protection manual. 4th. ed., Corps of Eng., Coastal Eng. Research Center, Vicksburg, MS., 2 Vols.

Walton, T. L., 1977. Beach nourishment in Florida and on the Lower Atlantic and Gulf Coast. Tech. Paper No. 2, Florida Sea Grant, 64. pp.

Watts, G.M., 1956. Behavior of beach fill at Ocean City, New Jersey. TM 77, Corps. of Engineers, Beach Erosion Board, 33 pp.

Winton, T.C., Chou, I.B., Powell, G.M., Crane, J.D., 1981. Analysis of coastal sediment transport processes from Wrightville Beach to Fort Fisher, North Carolina. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Misc. rep. No. 81-6, 205 pp.