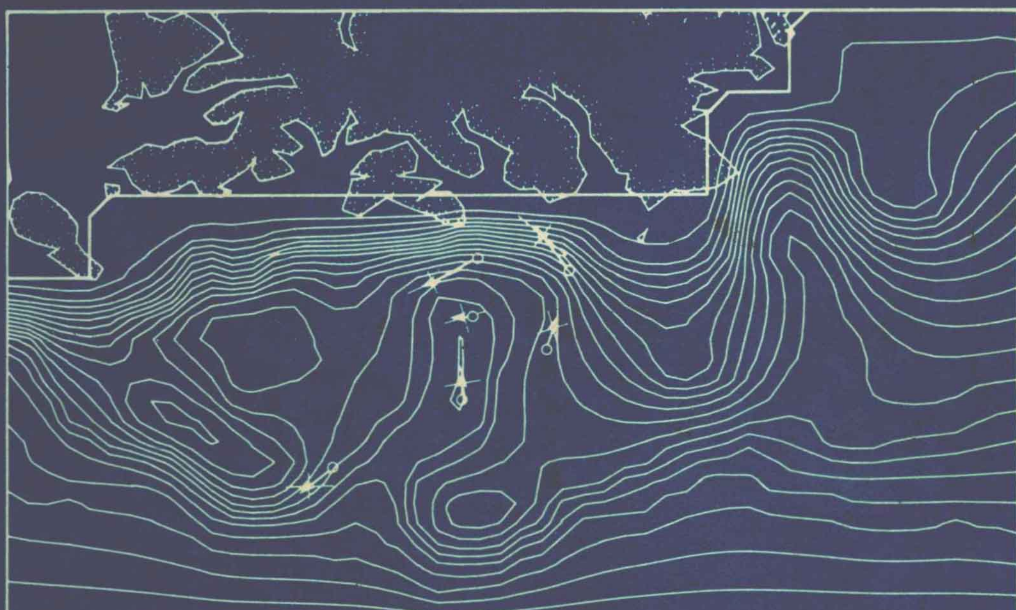
NEARSHORE SEDIMENT TRANSPORT



Edited by Richard J. Seymour

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PREFACE

This book represents the efforts of over a hundred individuals who planned and executed the NSTS field experiments, analyzed the billions of data points, and distilled their findings and insights into the summaries found here. Because these experiments were of a scope that will seldom, if ever, be duplicated, and because the program brought together many of the foremost field experimentalists in this country, we all felt from the beginning that it was important to preserve the outcome. This was done in two ways. First, the raw data were made available to any interested investigator within 18 months of the completion of each experiment. Secondly, both the methodology of the experiments and the findings from them were codified in the form of a monograph. This book is that result.

I have had the occasion recently (Sediments '87 Proceedings, Vol. 1, pp. 642-651) to assess the NSTS performance. I found that we made giant strides in our understanding of the surf zone hydrodynamics -- far more than our fondest expectations at the beginning. We were able to do less than we had hoped about the response of the sediment, largely because of a limited ability to measure it at a point. As I reported in the Sediments '87 assessment, we established a new state of the art in measurement techniques and we demonstrated the effectiveness of large, multi-investigator, instrument-intensive experiments for studying nearshore processes.

There are also a number of others who deserve credit for this volume: certainly the reviewers who labored diligently and anonymously to insure the quality of each chapter, David Duane of the Office of Sea Grant who performed the referee function on those sections to which I contributed, and finally -- the only truly indispensable contributor -- Martha Rognon. Ms. Rognon maintained our communications with the publisher and with the large number of contributors with characteristic efficiency and good humour. She designed the book, selected the typefaces, arranged the graphics and set the type (electronically) for the entire volume. It is clear to all of us who were gently guided and cajoled into their final output that we would never have produced this book without her.

Richard Seymour
La Jolla, California

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INTRODUCTION

David B. Duane
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Models for predicting the transport of sediment along straight coastlines in general use in the mid-1970's were derived empirically from sparse measurement of both the forcing function (waves and currents) and the response function (sediment motions). In addition to the unsatisfactory nature of the basic measurements upon which they were based, the models were deficient because they failed to employ such potentially significant factors as wind stress, sediment size, bottom slope and spatial variations in waves and currents, including the effects of rip currents.

The economic impact of sediment transport in the nearshore regime is enormous. The costs for coastal dredging and shoreline protection can be measured in billions of dollars on a world scale. The need for improved predictive tools appeared to be universally accepted. The historical approach of research in the coastal zone, where one or two investigators working in the field obtained a few single point measurements over a limited time span, had proven inadequate for the development of satisfactory transport equations. A different approach was needed. It became apparent that several researchers working together in a coordinated series of field experiments over a span of several years using large arrays of instruments were required to make a substantial contribution to solving these problems.

Several events and factors converged in the mid-1970's to make that alternative possible. The National Sea Grant College Program, which by 1975 had achieved a good measure of success in building an organized network of Sea Grant institutions, desired to utilize the multi-institutional network to address a research objective with a major national significance and impact. The U.S. Congress amended the Sea Grant Act in 1976 to include national projects. The first of 15 candidate research areas for funding as national projects was:

> *the development and the experimental verification of hydrodynamic laws governing the transport of marine sediments in the flow fields occurring in coastal waters.*

Advances in materials and electronics made possible, or likely, improved instruments for measuring forcing and response functions in the nearshore. An *ad hoc* group, convened by Richard J. Seymour of the Scripps Institution of Oceanography, met at the Fifteenth Coastal Engineering Conference (Honolulu, 1976) to plan a large scale and coordinated set of experiments leading to improved understanding of sediment transport in the nearshore. With considerable effort, a plan was drawn and submitted to the Office of Sea Grant (OSG). In 1977 OSG reviewed, accepted, and began funding that proposal which became the Nearshore Sediment Transport Study (NSTS).

The major objective of the NSTS program was to produce improved engineering models for predicting the motion of sediment along straight coastlines under the action of waves and currents in the nearshore zone and which could be simply employed (without recourse to large computers) and which would depend upon a few measurements or observations readily obtainable at reasonable costs.

Management of a technically complex program and the effective coordination of a large diverse group of investigators required the creation of a management concept substantially different from existing Sea Grant programs. The program employed a two-tier management structure (Figure 1). The National Sea Grant College Program Director appointed an advisory group referred to as the NSTS Review Group (Table 1A). This group, all experienced in field investigation of nearshore processes, reviewed proposals and made funding recommendations to the Director of Sea Grant, formulated overall program direction and reviewed the progress of the investigators. A second tier group, known as the NSTS Steering Committee, was formed of the senior investigators (Table 1B). The Chairman of this group functioned as the Project Manager and was an *ex officio* member of the Review Group. The Steering Committee formulated details of the project program, planned and executed cooperative field programs and conducted workshops to promulgate the findings of the study to the coastal engineering community.

To accomplish the NSTS objectives, it was agreed from the earliest planning sessions that the program must contain characteristics which set it apart from prior efforts. The most important of these attributes were that:

(1) it was to be a broad-based program with many investigators from a large number of institutions. It was an attempt to bring together many experienced practitioners to plan and execute a

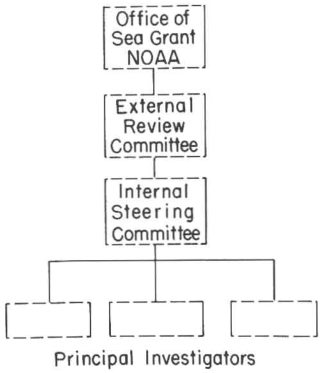

Figure 1. NSTS Program Management.

series of major field experiments which would vastly exceed the capabilities of a single investigator.

(2) it was to be a field-oriented program. Laboratory or numerical modeling were not foreseen as significant elements of the project.

(3) field experiments must attempt to measure, simultaneously, the details of both the velocity field within the surf zone and the sediment response to those velocities. This was recognition of the fact that there are significant spatial variations in sediment transport within the nearshore regime and that the ability to understand and predict these variations is a prerequisite to developing a universally applicable engineering model.

(4) measurements were to encompass a large number of parameters that were potentially significant to a predictive model.

(5) the final predictive model was to be two-dimensional. That is, it would predict cross-shore movement as well as longshore movement of sediment.

As originally envisioned, NSTS was to be a four-year program with three, possibly four, major field experiments conducted at the rate of one per year. The first was to be a sort of proof of concept; the second and third a Pacific and Atlantic coast experiment, and a fourth in the Great Lakes or Gulf Coast. In actuality, because of the unforeseen effects of both severe fiscal inflation on a fixed budget and the magnitude of the effort required to analyze the enormous data base produced, only two major field experiments (Torrey Pines and Santa Barbara in California), and a limited scope validation experiment (Rudee Inlet, Virginia) were completed. The latter experiment and the final two years of analyses and report preparation were accomplished with the fiscal support of the U.S. Army Corps of Engineers, the U.S. Geological Survey, the Office of Naval

Table 1. Participants in the Two-Tier Management Structure for the Nearshore Sediment Transport Study

A. Review Group

	TERM
Mr. Arthur G. Alexiou, Office of Sea Grant	1977-82
Dr. James R. Allen, National Park Service	1981-82
Dr. David B. Duane, Office of Sea Grant, Chairman	1977-82
Dr. William R. James, U.S. Geological Survey	1977-79
Dr. Stephen P. Leatherman, National Park Service	1980-81
Dr. Bernard J. LeMehaute, Tetra Tech and University of Miami	1977-82
Dr. John C. Ludwick, Jr., Old Dominion University	1977-82
Dr. Alexander Malahoff, National Ocean Survey, NOAA	1977-82
Dr. Ned A. Ostenso, National Sea Grant Program	1977-82
Dr. Asbury H. Sallenger, Jr., U.S. Geological Survey	1977-82
Mr. Rudolph P. Savage, Coastal Engineering Research Center	1981-82
Mr. Thorndike Saville, Jr., Coastal Engineering Research Center	1977-81
Dr. James J. Saylor, Great Lakes Environmental Lab, NOAA	1977-82
Dr. Richard J. Seymour, Ex Officio	1977-82

B. Steering Committee

Dr. Richard J. Seymour Chairman/NSTS Project Manager	Scripps Institution of Oceanography
Professor Robert G. Dean	University of Delaware
Professor Douglas L. Inman & Director, Center for Coastal Studies	Scripps Institution of Oceanography
Professor Edward B. Thornton	Naval Postgraduate School

Research, and the U.S. National Park Service in addition to the Sea Grant funding. A substantial portion of the costs of editing and setting type for this volume were provided by a grant from the Foundation for Ocean Research, San Diego, California.

Despite the reduction from the planned level of effort, almost all of the basic program objectives were met. To understand the scope of NSTS, consider that the research was carried out at one time or another by ten principal investigators from five different universities or institutes and two government agencies; and, three significant field experiments were performed on two coasts. At peak activity, as many as 60 individuals and more than 100 instruments were involved simultaneously in field experiments. To apprise the community of progress in the program, four workshops were held. Available to the community, at cost of reproduction, for use in continued research are reports of the experiments and all of the data recorded on magnetic tape. (Inquiries should be directed to National Oceanographic Data Center, User Services Branch, NOAA/NESDIS E/OC21, Washington, D.C. 20235, telephone: (202) 673-5549). NSTS was funded from appropriations over a period of five fiscal years at a total of approximately 4 million dollars; a portion of a sixth year was required for the preparation of this final report.

This book is the culminating effort of NSTS. Its purpose is to bring together under one cover, the major aspects of the coordinated research, and by reference to previously prepared papers, to be the principle source document for NSTS. Of perhaps equal importance, this compilation provides a comprehensive review of the state of the art in measuring, analyzing and predicting surf zone dynamics and the resulting transport of sediment and may therefore serve as a valuable reference for students, researchers and coastal engineers.

Chapter 1

THE NSTS FIELD EXPERIMENT SITES

A. Torrey Pines Experiment

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Torrey Pines Beach is part of the Torrey Pines State Preserve located along the coast between the communities of La Jolla and Del Mar, San Diego County, in the southern part of California. The coast is relatively straight with nearly north-south trending beaches backed by 90 m high wave-cut sea cliffs. The 2 km long section of beach selected for the experimental site is 6 km north of Point La Jolla headland and 3 km north of the head of Scripps branch of La Jolla Submarine Canyon (Figure 1A-1).

The Torrey Pines Beach site was selected for its straight coastline and gently sloping offshore bathymetry, and because of the previous studies of beach profile changes (e.g., Nordstrom and Inman, 1975; Winant *et al.*, 1975) and their relation to wave climate (e.g., Pawka *et al.*, 1976). The shelf here is approximately 3 to 4 km wide and slopes at about 1 in 50 to 1 in 100 out to the shelf break at a depth of about 100 m. In water depths of 20 m and less, the wave-cut shelf in this area is overlain by 1 to 5 m of sandy sediment (Moore, 1960; Inman and Bagnold, 1963).

The beach is near the southern end of the Oceanside Littoral Cell, a sedimentation compartment containing sources, transportation paths and sediment sinks, which extends for 84 km from the rocky headland at Dana Point (Figure 1A-2) to the heads of Scripps Submarine Canyon. The principal sources of sediment for the cell are the rivers, which periodically supplied large quantities of sandy material to the coast. The sand is transported along the coast by waves and currents until it is intercepted by Scripps Submarine Canyon, which diverts and channels the flow of sand into the adjacent submarine basin (Chamberlain, 1964; Inman, 1980; Inman, 1982).

The sediments on the beach and shelf are predominantly fine quartz sand with minor amounts of feldspars and heavy minerals. Light minerals, those with a specific gravity of less than about 2.85, usually comprise 90% of the beach sample, while heavy minerals total about 10%. Of the light minerals

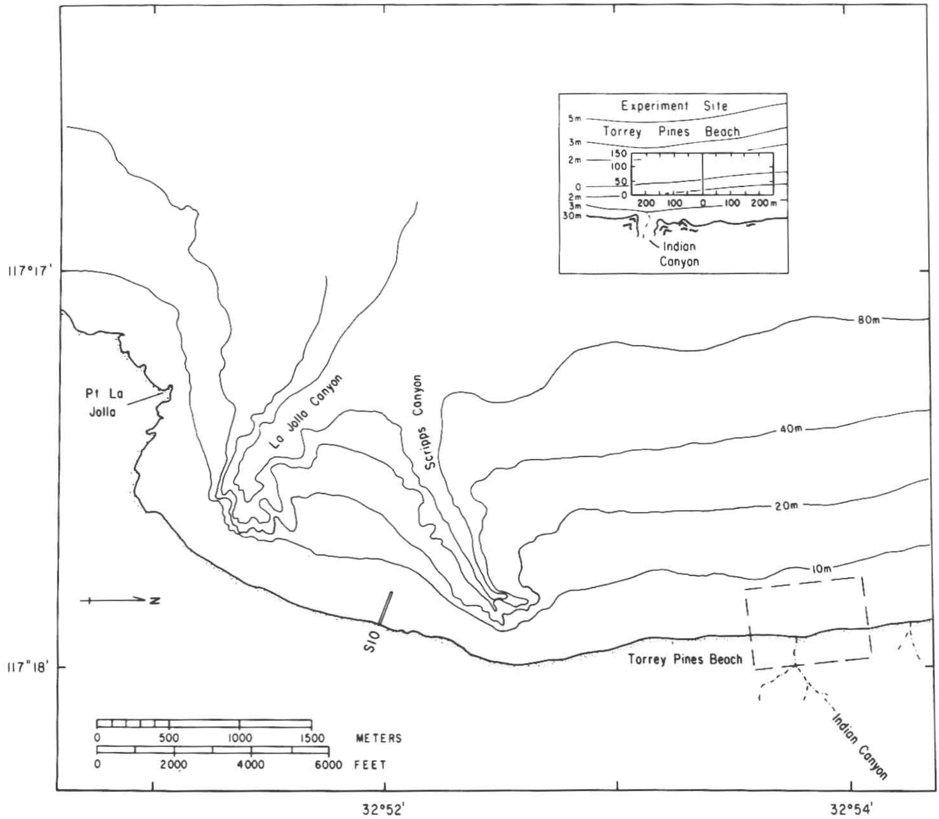

Figure 1A-1. Location and survey grid for the Torrey Pines Beach site.

approximately 88% is quartz, 10% feldspars, and 2% shell fragments and miscellaneous material. Of the total heavy minerals, hornblende comprises an average of 60%. There is a pronounced seasonal variation in the amount of heavy minerals in beach and nearshore samples. During the winter when the beaches are cut back, the heavy mineral content of the beach foreshore samples increases appreciably compared to summer conditions. At the same time, the heavy mineral content of the sands outside of the surf zone is reduced. An explanation for this apparent seasonal migration of heavy minerals is given by the transportation of light minerals from the beach foreshore to deeper water during the winter and back again during the summer (Inman, 1953; Nordstrom and Inman, 1975).

During some winter storms the beach sand is transported offshore and waves actively erode the sea cliffs. However, during the NSTS experiments there was always a cover of sand over the beach, and country rock was not exposed. The

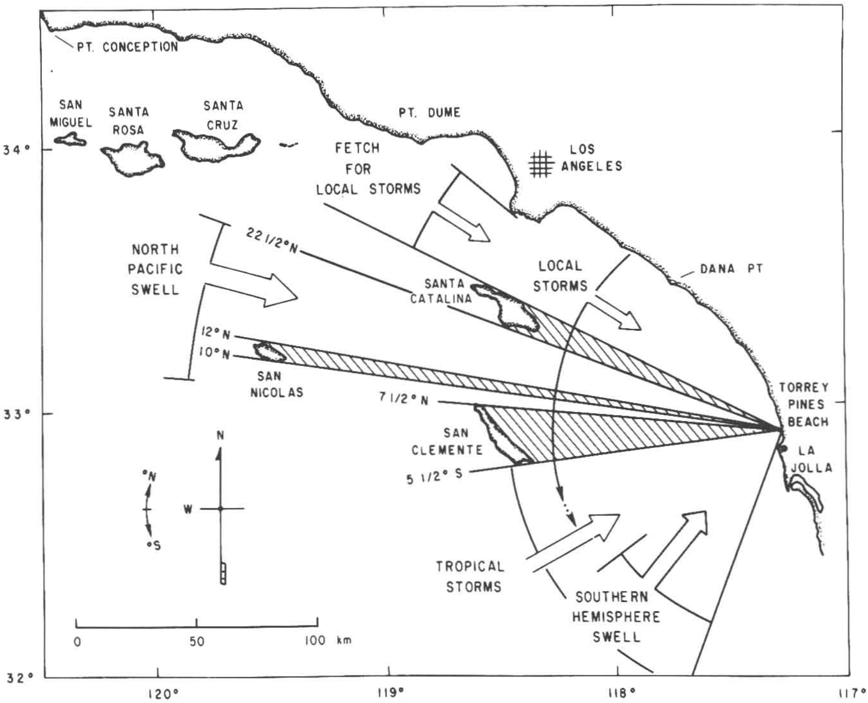

Figure 1A-2. Wave exposure chart for Torrey Pines Beach showing the source and direction.

seasonal cross-shore motion of sediment in the Torrey Pines and La Jolla Shores area has been studied in detail (e.g., Shepard and La Fond, 1940; Inman, 1953; Inman and Rusnak, 1956; Nordstrom and Inman, 1975; Winant *et al.*, 1975; Winant and Aubrey, 1976; Aubrey *et al.*, 1980). These studies show that during summer months when waves are relatively small, sand migrates back to the foreshore, increasing the height and width of the beach berm as well as the beach face slope. Nordstrom and Inman (1975) found that the seasonal migration of beach sand between the beach berm and the offshore portions of the beach profile amounted to 92 cubic meters per meter length of beach.

1A.1 Wave Climate

The Channel Islands, which border the Southern California coast, exert a dominant influence on the wave climate at Torrey Pines Beach. The islands significantly shelter the site from north swell as there is only a narrow (13 degree) window to the Northern Hemispheric generation regions (Figure 1A-2). The wave energy at the site is typically an order of magnitude lower than the