EFFECTS OF MARINE SAND EXPLOITATION ON COASTAL EROSION AND DEVELOPMENT OF RATIONAL SAND PRODUCTION CRITERIA

By

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ABSTRACT

Mining of sand from natural deposits, including beaches, yields an inexpensive source of sand for construction or industrial uses. Parts of the Turkish Black Sea coast, north of Istanbul, are frequently mined for sand. This resource extraction may result in negative impacts on adjacent coastal areas, particularly since there is a strong incentive to extract sand from shallow nearshore or beach areas in order to reduce mining costs. Extraction from shallow areas may modify nearshore wave conditions, affect erosion and deposition rates, and alter benthic habitats and nearshore circulation. The goals of the project described in this proposal are to quantify the influences of sand mining on nearshore waves and currents, assess the magnitude of any mining-related erosion, and establish guidelines for acceptable mining rates and locations. Conclusions will be based on numerical model results, with validation of some aspects of the modeling via field data from the Turkish Black Sea coast. Project results will be site-specific, but the methodology could be applied at any coastal site that features primarily non-cohesive sediments.

INTRODUCTION

Sand is a primary component of concrete. A typical concrete mixture consists of 30 to 35 percent sand and 45 to 50 percent gravel. Growth in the construction industry, particularly in the Istanbul area, has increased the demand for concrete aggregates in recent decades. As the land-based aggregate sources diminish, marine sand reserves become increasingly attractive for exploitation.

Another popular use of marine sand is the reconstruction of beaches to combat coastal erosion. This technique involves dredging beach-quality (coarse) sand and dumping it either in the foreshore (beach fill) or nearshore (profile nourishment) regions, depending on the hydrodynamic and morphodynamic conditions of the site (Dean et al. 1995). In the coastal states of the U.S.A., beach and nearshore nourishment projects are almost uniformly favored over classical coastal protection techniques that employ hard structures such as seawalls, groins and breakwaters. In many locations, hard structures are now prohibited.

Extraction of marine sands for construction industry supply must be planned carefully to avoid habitat disruption and the creation or worsening of erosion problems. Unlike beach nourishment, extraction for construction purposes represents a net loss from the littoral system. Unplanned excavation can lead to severe erosion problems arising from either the net loss of sand itself, or via creation of erosional "hot spots" resulting from the focusing of wave energy on specific points along a shoreline. These points can be identified using traditional beach surveys or predicted using numerical models of wave transformation (Work and Otay 1996).

Regardless of the final destination of marine sand, topographic changes caused by underwater dredge holes have immediate effects on nearshore waves and currents. These hydrodynamic changes can rapidly lead to local perturbations in the ambient littoral transport patterns and eventually changes in the shoreline morphology. Nearshore dredging conducted without proper investigation of local

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morphologic conditions may cause significant and lasting physical and environmental damage to the coast. The resulting damage may appear in the form of economic losses such as loss of natural resources and tourism revenues, but it may also represent irrecoverable ecological losses.

New technologies in the marine industry have made offshore dredging operations economically more attractive. Especially in countries with large coastal resources and limited land-based sand reserves, marine aggregates constitute up to 25% of the total production of natural aggregates (Charlier and Charlier, 1992). In Japan and Great Britain, which produce two-thirds of the world's marine aggregates, offshore sand and gravel mining have already become a 200 million USD industry.

Following the structural damage of the August 17th, 1999, Marmara, and November 12th, 1999, Düzce earthquakes, the northwestern parts of Turkey, including the Istanbul Metropolitan area, have been undergoing major reconstruction. Knowing that the majority of buildings in the earthquake area use reinforced concrete as the primary construction material, the demand for concrete aggregates and particularly for construction-quality sand has rapidly grown beyond the existing capacity of land-based sand production facilities. Problems associated with the quality and the cost of finding new land-based sand sources have forced producers to look for marine sand alternatives. Today, a growing pressure, led by the concrete industry, is being exercised on local authorities and the government to issue permits for marine sand production within one mile of shore.

Sand manufacturers in Istanbul claim that the yearly average demand for construction sand in Istanbul is approximately 10 million tons (Istanbul Batı Yakası Kumcular Kooperatifi, 1999). On the other hand, legally permitted areas for marine sand extraction can meet only 60% of the total demand on the Western coast and only 40% on the Eastern coast of Istanbul. The remaining sand is produced either from illegal sources or through nearshore coal mining operations by extracting the sandy upper layer of the sea bottom through suction pumps. In Ağaçlı-Akpınar region on the Black Sea coast, it is reported that part of the sand extracted from nearshore coal mines is deposited on the beach causing an ecologic threat to the coastal environment (Figure 1). Currently, the only permitted area in Istanbul for marine sand extraction is the Podima region, on the Black Sea coast, approximately 2 km offshore and 50 km West of the Straight of Istanbul.

Figure 1. Coastline deformation due to coal mining operations on the Black Sea Coast of Istanbul (Courtesy of Istanbul Batı Yakası Kumcular Kooperatifi, 1999)

Disregarding all environmental, ecologic and aesthetic damages resulting from coastal erosion, the corresponding economic losses alone can render offshore dredging infeasible. A simple cost calculation based on assumptions of current market values shows that the value of one square meter of beachfront property is equivalent to the value of sand produced from an offshore dredge hole of 400 m^2 surface area and 1 m depth. In other words, a 400-m^2-dredge hole should cause less than 1 m^2 of beach erosion in order to make this operation economically feasible, if no other factors are considered.

As this example clearly demonstrates, the physical processes relating the offshore dredging and the nearshore morphodynamics are essential elements of proper design and planning. Without the influence of regulatory bodies, these connections may not be investigated, since the owner of the sand mining operation may not have any concern for coastal property values.

PROJECT DESCRIPTION

Within the scope of this project, it is proposed to examine the physical impact of marine sand exploitation on shoreline morphology. The main focus of the study will be the interaction between incoming waves and sediment transport processes driven by local and temporal perturbations in the wave and current fields. To study the underlying physics of this problem, computer models will be used to simulate the existing nearshore environment controlled by waves, wave-driven currents, and sediment transport processes. The necessary input bathymetry, forces due to wind, wave, and currents, boundary and initial conditions will be obtained through field measurements, where possible, and through existing knowledge in the form of literature, charts or published data for the study area.

PREVIOUS RELATED WORK

In many coastal countries, including the United States, nearshore borrow pits are frequently used to provide sand for beach nourishment. The U.S. Minerals Management Service has sponsored projects intended to identify such sources (e.g. Hobbs 1991, Davies et al. 1993, Katuna et al. 1993, Van Dolah et al. 1993, Finkl et al. 1997, Gayes et al. 1998, Van Dolah et al. 1998), and others to assess the physical and environmental impacts of the dredging on nearshore areas (e.g. Hurme and Pullen 1988, Rosen 1993, Drucker et al. 1995, Stone and Xu 1996, Kenny and Rees 1996, Maa and Hobbs 1998, Hobbs et al. 1998). Several investigators have studied the problem from the economic standpoint (Beachler and Campbell 1984, Weggel 1986, Townend and Fleming 1991, Charlier and Charlier 1992, Dobkowski 1998). Sand is now widely recognized as a valuable and finite resource that should not be moved or removed without considering the possible negative impacts of the transfer.

Although the ultimate use of the sand may differ from the problem addressed here, the nature of the problem addressed in this proposal is the same as that considered by the projects cited above. In fact, the dredging off the Black Sea coast of Istanbul is even more critically sensitive to borrow pit location and size, because of the fact that the extracted sand is being removed from the littoral system.

A physical modeling study of the problem is not feasible because of the scale of the problem and the size of the model that would be required to overcome scaling effects. Previous investigators have used numerical models to simulate wave propagation across bathymetric grids representing the existing and hypothetically modified bathymetries (e.g. Stone and Xu 1996, Maa and Hobbs 1998, Hobbs et al. 1998). Wave conditions can then be compared in the lee of the dredged region to determine the influence of the dredge hole on wave conditions. As a sufficiently long wave data set is typically not available for the site, wave hindcast data are often employed to drive the model (e.g. Brooks and Brandon 1995).

Validation of the resulting numerical model predictions is not a simple task, because of a low signal to noise ratio at many sites, the large space and time scales involved, and the fact that it is not possible to collect data for both scenarios (with and without borrow pit). Most investigations have been performed as feasibility studies.

A variety of numerical models are available for description of wave transformation across arbitrary bathymetry. A mild bottom slope is often assumed (e.g. Kirby and Özkan 1994). Shoaling, refraction, and wave breaking typically dominate, with diffraction generally exerting a secondary influence. Both monochromatic and spectral models are available; the latter requiring more sophisticated input (directional wave energy spectra) but providing added realism (Kirby and Özkan 1994, Ris et al.

1999). Spectral models may either operate in the frequency domain, and describe how wave energy spectra are altered as the waves propagate across the bathymetric grid, or may model the transformation of individual waves, which are then superimposed at each point of interest to describe local energy spectra.

PROJECT METHODOLOGY

The impacts of sand mining on nearshore regions will be assessed using numerical modeling tools. The project described here involves application of an existing numerical model for wave transformation (REFDIF/S, Kirby and Özkan 1994) and shoreline change (Work and Dean 1995, Güngördü and Otay 1997) to assess the impacts of different dredging scenarios on nearshore coastal processes. Project methodology is briefly summarized as follows:

1) Assimilate available data for input to the models. This includes:
    a. Initial shoreline planform (measured on-site).
    b. Bathymetry (inferred from available nautical charts).
    c. Input wave conditions (from available hindcast and wind data).
    d. Information about past dredging locations and rates (to establish dredging scenarios).
2) Perform baseline model runs with pre-dredging bathymetry. This involves using the numerical wave transformation model to propagate a directional spectrum of waves across the bathymetry to determine nearshore (breaking) wave conditions, and using these values to calculate longshore sediment transport rates. Longshore gradients in longshore sediment transport rates will then reflect predicted areas of erosion or deposition and rates of shoreline change.
3) Assess importance of wave-current interaction on erosion/deposition trends. A simplified ad-hoc velocity field will be put into the model and its influence on results (predicted erosion/deposition areas) tested.
4) Construct various dredging scenarios and run tests using each case.
5) Compare dredged vs. non-dredged scenarios and make recommendations on locations, configurations and maximum rates of dredging for sand mining purposes.
6) Collect field data for validation of the predictive techniques described above. This involves three one-month deployments of an available wave and current meter at the site and biannual measurements of shoreline position within the project area to document initial conditions and shoreline change.

Site Description

The project site is located at Gümüşdere Beach, approximately 10 km west of the northern entrance of the Straight of Istanbul (Figure 2). There are several reasons for the site selection. Firstly, and most importantly, it is a major area near Istanbul that has been serving as a source of marine sands. Secondly, it is logistically convenient, since Boğaziçi University has a nearby campus with access to the Black Sea. Storage and office space will be provided by the university to facilitate the field measurements described below.

Complete verification of the model results is not feasible without an expensive, long-term field campaign. Instead, limited field measurements are included for verification of the project methodology. Measurements of shoreline position will be made within the area of interest to validate predictions of the locations of erosion and deposition areas.

Figure 2. Project Locator Map

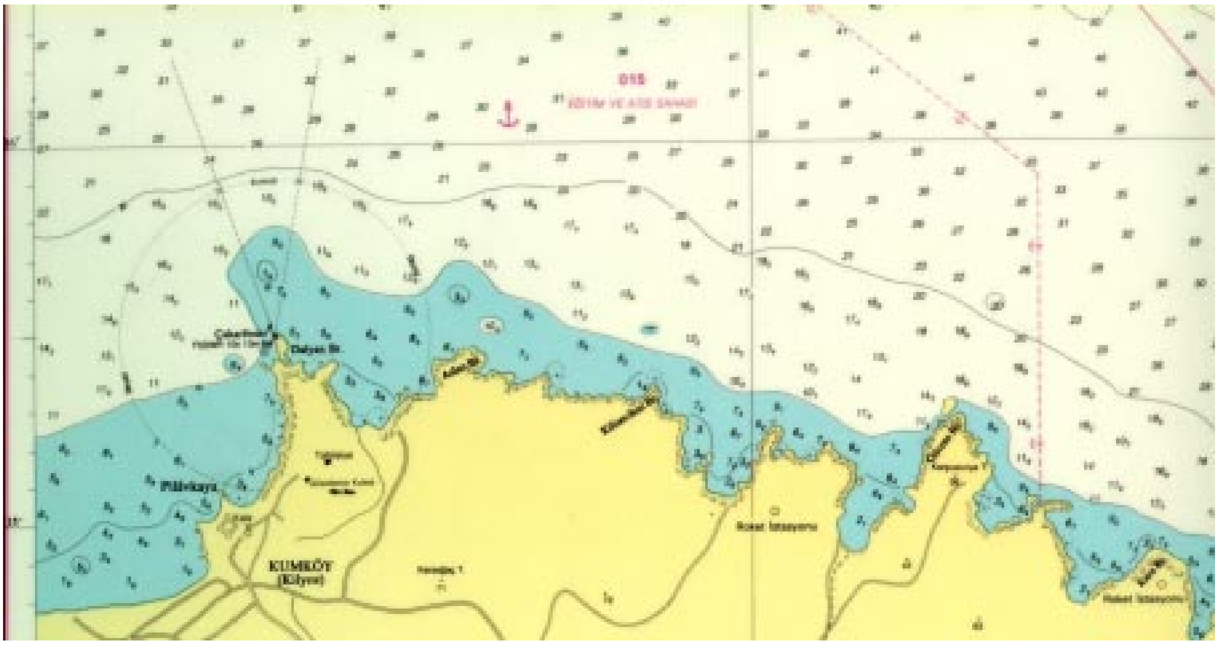

Figure 3. Nautical Chart of Kilyos Area

Field Data Collection

The field data collection efforts fulfill three primary project needs:

1) Short-term (months) measurements of wave conditions will be used to validate the wave data used to drive the wave transformation model. Simultaneous measurements of currents (from the same instrument) will indicate the importance of and temporal variability of mean currents at the site. Collecting data during one winter and two summer months will provide an indication of both inter-annual and seasonal variability.
2) Shoreline position data will establish seasonal and longer-term beach changes that will reveal the validity of the predictions that result from the modeling component of the project.
3) A weather station will report wind speed and direction at the site for the duration of the project. Existing wind data, collected elsewhere, will be used to estimate wave conditions to serve as input to the wave and shoreline change models. The new data set will be used to validate the existing data.

Each data set is addressed below:

Wave And Current Measurements

A state-of-the-art, three-dimensional acoustic current meter is already available for project use through other funding. This device measures three components of velocity (two horizontal, one vertical) at a point, and pressure, allowing computation of a directional energy spectrum. The 3D Wave Current Meter by Falmouth Scientific combines an acoustic current meter with a micro-machined silicon pressure sensor. This enables measurement of wave direction and spectrum as well as tide and wave height with a single instrument. The Acoustic 3D-Wave utilizes a silicon resonate pressure sensor and a large internal memory for burst sampling. The device rests on the seafloor in a tripod, which will be purchased via new funds (Figure 4). Instrument specifications are provided in Tables 1 and 2.

Figure 4. The 3D Wave Height and Direction Current Meter by Falmouth Scientific Instruments

The instrument will be deployed for three one-month periods: one month during each project summer and one month in winter. This will allow comparison of the waves and currents during the two seasons, indicate annual variability and provide the widest range of wave height, wave period, wind, and current conditions, and increase the likelihood of capturing a storm event.

The device will be deployed and retrieved by divers from a small boat. A handheld global position system (GPS) receiver will be used to locate the position of the instrument. The position of the instrument must be established for two reasons: 1) to locate it within the numerical bathymetry grid for comparison to model results, and 2) more importantly, to find it again when it is time for retrieval.

The acoustic velocity sensor/directional wave gauge will be deployed offshore of the borrow region to provide two types of information:

1) An estimate of the magnitude and direction of the mean currents encountered at the site. This will help indicate the importance of wave-current interaction in the modeling work.
2) Wave data for validation of the data set used to drive the model.

Table 1. Sensor Specifications

	Type	Range	Accuracy	Resolution
Velocity	Acoustic	0-300 cm/s	± 2% of reading, max ± 1 cm/s	0.01 cm/sec
Direction	2 axis fluxgate	0 - 360 ° C	± 2.5 ° C	0.01 ° C
Tilt	2 axis	0 - 45 ° C	± 0.5 ° C	0.01 ° C
Temperature	Platinum	-2 - 35 ° C	± 0.5 ° C	0.01 ° C
Pressure	Resonant Silicon Micro-Machined	0 - 23 m depth (0 - 50 PSIA)	± 0.01% FS	0.4 mm depth

Table 2. Instrument Specifications

Power	+7 – 40 VDC @ 35 mA @ 140 mW
Sample Rate	5 - 6 Hz (Burst)
Vector Average	15 seconds to 1 hour
Burst Sampling	15 seconds to 1 hour
Physical Material	1000 meter pressure rating 316 SS mooring frame
Real Time Clock (RTC)	32.768 KHz ± 12 ppm per year Programmable alarm / sleep functions External switch instrument wake-up

Shoreline Position Data

One of the primary project goals is to assess impacts of bathymetric changes on adjacent shorelines. It is important to have a clear understanding of the existing shoreline change patterns for an area, in order to assess the signal-to-noise ratio when changes are introduced offshore. Measurement of the changes attributable to modified bathymetry can then be made.

A “one-line model” will be used to predict shoreline changes. This involves description of the coast by a single line – the waterline. Thus, monitoring of this single line is the most logical way to obtain a data set for comparison to model results.

Global Positioning System (GPS) is the most efficient tool for collection of shoreline position data, particularly at a site where surveying benchmarks are not readily available. Instrument cost is inversely proportional to rated survey error. An instrument with cm-level accuracy, when used in static mode, with post-processing of carrier phase data, will be employed. This approach yields data of sufficient quality to assess shoreline change rates, yet keeps costs reasonable, compared to mm-level instruments or those employing real-time differential corrections. A high quality GPS base unit located at the Kandilli Observatory and Earthquake Research Institute will provide differential correction to post-process measured GPS signal. Another portable survey quality GPS receiver will also be used to determine the wave/current gauge location.

An initial summer survey will be performed to document the initial condition for shoreline change modeling. Additional surveys will be performed biannually to document long-term and seasonal changes at the shoreline site. It is not known at the present time whether offshore dredging will actually take place at the project site. But the resulting data can be used either to validate the no-dredging or the with-dredging model runs, depending on future events.

Numerical Modeling

The long-term deep water wave height, wave period and direction data will be analyzed to establish a stochastic wave field in the form of probability distributions of the above mentioned wave parameters. At the same time a rectangular bathymetric grid will be generated from relatively deep water up to the existing shoreline across the potential and/or known borrow areas. Using the known or assumed size and thickness of the dredge pits, the original bathymetry will be modified to obtain a natural and a dredged bathymetry.

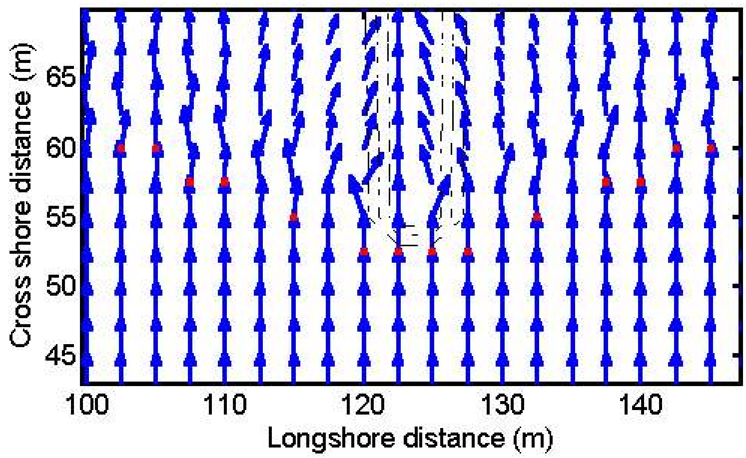

Figure 5. Nearshore wave transformation modeled with REFDIF (Kirby and Özkan, 1994). Arrows indicate waves, dots at arrow heads indicate break points.

A 2D wave propagation model will be run across both the natural and the dredged grids using the computed stochastic wave field (Kirby and Özkan, 1994). The wave model will output transformed wave parameters on every grid point including the breaking points. The two sets of breaking wave parameters for the natural and the dredged bathymetries will then be used as input to a shoreline evolution model (Güngördü and Otay, 1997). As a final output, the effect of the dredge holes on the natural shoreline evolution will be quantified in terms of erosion or deposition rates ands erosional hot spots can be identified along the shore (Work and Otay, 1996).

RESEARCH POTENTIAL

Boğaziçi University has a small but dedicated research group working mainly in coastal engineering. The two primary investigators in the project, Dr. Osman Börekçi and Dr. Emre Otay both have Ph.D. degrees in coastal and oceanographic engineering. Their research interests focus on nearshore hydrodynamics and sediment transport. Recent studies and graduate theses led by this group include analytical and numerical modeling of waves, currents and sediment transport processes.

Two important additions have recently been made to increase the existing research capability of the local team. The computers required for the data analysis and numerical modeling are already made available through a separate funding. These include a Silicon Graphics Octane workstation and three Silicon Graphics 320 workstations with Fortran 90 compilers, a graphics package for 3-D computer visualization and Matlab for data analysis. With limited on-campus laboratory facilities, emphasis is being placed on field experimentation. For this purpose, the Kilyos campus of the University provides an excellent location to study coastal processes at a location close to the main campus (Figure 7). A directional wave gauge with a built-in 3-D acoustic Doppler current meter, pressure and temperature sensors was purchased to be deployed at Kilyos.

Figure 6. Gümüşdere Beach Project Site

Besides the equipment upgrades, the existing man power has been strengthened with the addition of Dr. Paul Work, a Fulbright Scholar from the United States, whose background in field experimentations of coastal engineering would be beneficial for the local research. Dr. Work is in Istanbul for the 1999-2000 academic year during his sabbatical and will return twice during the project lifetime to assist with field data collection and numerical modeling efforts. Proposals for matching funds to cover travel expenses for these visits are in preparation for submission to other sponsors.

The proposed project will provide an opportunity to improve the existing research capability of the Boğaziçi University team, especially in setting up a coastal field station at the Black Sea Coast. In addition to the expected scientific contributions of the proposed study, this project will help to start a field measurement station that would increase our knowledge about our natural environment including our seas and coastlines. Our research group intends to keep the field station active to fill the gap for coastal research through national and international funding in the future.

CONTRIBUTIONS

Project contributions will have two different aspects. The more immediate contribution will be the quantification of the impacts of offshore dredging based on scientific research of nearshore hydrodynamics and sediment transport. With the help of computer models, design criteria will be developed in terms of engineering parameters to ensure proper production of marine sand without impact on adjacent coasts. Project results will be somewhat site-specific, but the methodology could be applied to most coastal sites where sand mining would be considered.

Another contribution will be to the general understanding of the energetic processes of the Western Black Sea coast. Very few measurements of nearshore waves and currents are available along the Black Sea coasts, despite widespread acknowledgement of ecological problems. Within the scope of this project, important aspects of coastal erosion caused by man-made perturbations will be investigated. Therefore, the experimental and computational findings in this project can lead to publishing quality outcomes and produce knowledge on both national (in terms of experimental results) and international (in terms of theoretical findings) levels of applied research.

ADMINISTRATIVE ORGANIZATION

The project will be jointly administered by Dr. Osman Börekçi and Dr. Emre Otay, who are currently affiliated as full-time faculty with the Department of Civil Engineering at Boğaziçi University. The general responsibility of the project will be shared equally. Dr. Börekçi will be leading the numerical modeling aspects of the study while Dr. Otay will be in charge of the field measurements. In addition to the local team, a scientist from Clemson University, South Carolina, USA, Dr. Paul Work, will join the project twice to assist with numerical modeling and field data collection. Dr. Work is currently visiting the Department of Civil Engineering at Boğaziçi University as a Fulbright scholar until July, 2000. His research background is in experimental and numerical studies of coastal sediment transport. He is currently working as the primary investigator on a research project on the nearshore impacts of offshore dredging for beach nourishment, sponsored by the South Carolina Sea Grant Consortium. With his background and research expertise, Dr. Work will be helping the local team with the field and numerical modeling work.

MEASURES OF SUCCESS

- Physics based method of impact assessment of marine sand extraction.
- Data sets describing the winds, waves and shoreline change on the Western Black Sea coast.
- Numerical model results for wave transformation and planform evolution of Gümüşdere Beach.
- Presenting the project in national and international conferences.
- Publications in national and international scientific journals.

WORK SCHEDULE

Job Items	Dates
• Equipment purchase and mobilization. • Establish bathymetric grid from nautical charts. • Test and calibrate wave gauge. • Select wave gauge location. • Collect sediment samples. • Sediment grain size analysis.	Nov, 2000 – May, 2001
• Benchmark set-up on the beach. • Survey shoreline position as initial condition. • Collect bathymetry data to augment nautical chart data. • Install weather station and start data acquisition. • Deploy wave gauge by divers. • Survey the wave gauge location. • Data acquisition: Hydrodynamic pressure and horizontal current velocities for one month. • Retrieve instrument.	Jun-Sep, 2001
• Develop post-dredge bathymetry scenarios for borrow areas. • Spectral analysis of wave data to obtain directional wave parameters and mean flow characteristics. • Develop input wave conditions.	Oct-Dec, 2001
• Deploy wave gauge by divers. • Data acquisition: Hydrodynamic pressure and horizontal current velocities for one month. • Retrieve instrument. • Spectral analysis of wave data to obtain directional wave parameters and mean flow characteristics. • Investigate seasonal variation in wave and current conditions and assess and refine quality of input wave prediction scheme. • Survey shoreline.	Jan-May 2002
• Perform wave and shoreline evolution model runs with existing bathymetry. • Deploy wave gauge by divers. • Data acquisition of hydrodynamic pressure and horizontal current velocities for one month. • Retrieve instrument. • Spectral analysis of wave data to obtain directional wave parameters and mean flow characteristics. • Survey shoreline to document shoreline evolution.	Jun-Sep 2002
• Continue model runs for the wave and shoreline evolution. • Perform wave and shoreline evolution model runs with dredged bathymetry.	Oct-Dec, 2003
• Finish final report. • Prepare journal and conference publications. • Completion of student thesis. • Present the work at a conference. • Survey shoreline.	Jan-May 2003

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