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Coastal Engineering Prospect Course Held in Vicksburg

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Introduction and Overview

A revised "Coastal Engineering Prospect Course" was conducted by the U.S. Army Engineer Research and Development Center (ERDC) at the Waterways Experiment Station in Vicksburg, MS, between January 29 and February 7. This 8-day training course was developed around the new Coastal Engineering Manual (CEM), which is replacing the venerable *Shore Protection Manual* (1984). The Coastal Engineering course was attended by 16 engineers from Corps District offices, two civil/ocean engineers from the U.S. Coast Guard, and two engineers from the Ohio State Department of Natural Resources.

This was the second offering of a new prospect course that combined topics previously covered in two separate 1-week courses. The expanded duration of the new Coastal Engineering course allowed a coordinated and comprehensive in-depth technical study of nearly all aspects of coastal engineering covered in the new CEM. The course was aimed at engineers involved in coastal engineering design, project construction, project management, and operations and maintenance. (A companion 5-day course, titled "Coastal Project Planning," provides a less technical overview of coastal engineering issues for planners and managers who oversee coastal projects and must understand issues faced by coastal engineers.)

Course Topics

One key objective in developing the new Coastal Engineering prospect course was assuring a logical arrangement of related topics separated into half-day instruction modules. Many of the half-day modules are comprehensive enough to be presented as stand-alone sessions. A chronological listing of the course modules and the associated instruction topics is given in the table. The modularity of the instruction topics provides flexibility in presenting the prospect course in the future because some modules can be moved around in the schedule to accommodate class needs and instructor availability.

Excursions and Tours

Classroom lectures and design exercises were complemented with excursions to the laboratory model facilities and to the ship simulator located at WES. At the ship simulator, Principal Investigator Dennis Webb explained the operation of the computer-driven simulator, then students were given an opportunity to steer a large vessel as it navigated a harbor.

The laboratory tour was led by Dennis Markle, and it featured stops at the Los Angeles/Long Beach Harbor model, the testing facility for the Rapidly Installed Breakwater, the Barber's Point Harbor model, a flume study of breakwater stability, and the longshore sediment transport facility.

Technology Transfer Fair

Throughout the course students were introduced to various computer-based tools developed by CHL and made available for Corps use. The informal Technology Transfer Fair, held on the final morning of the short course, provided the students an opportunity to gain hands-on experience with most of the PC-based software demonstrated earlier in the course. Experts were on hand to instruct students on program usage, to give guidance on program applicability for various problems,

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Figure 1. Attendees of the FY 2002 "Coastal Engineering Prospect Course"
From left to right - First Row: Lynn Robinson (Galveston District), John McManus (Galveston District), Gail Stewart (Galveston District), Alex Bantigue (Los Angeles District), Justin Reinhart (Ohio DNR), Mark Geib (New England District). Second Row: Matt Miller (Jacksonville District), Jay Clement (New England District), Alain Balmaceda (U.S. Coast Guard, Oakland), John Watkins (Ohio DNR), Jennifer Wozencraft (Mobile District), Clay Gottschalck (New Orleans District), Paul Bellocq (New Orleans District). Third Row: Andrew Benziger (Chicago District), Chris Katzenmiller (Chicago District), Chris Mack (Charleston District), Bill Mullen (New England District), Steven Hughes (ERDC). Fourth Row: James Few (Galveston District), Andrew Morang (ERDC), Felipe de las Pozas (U.S. Coast Guard, Miami), Keith Ayers (Los Angeles District)

and to answer questions about how to obtain and install the programs. Students moved around the room to the various computers according to their interests and needs. In addition to learning more about available computer tools, they established contacts with the CHL engineers and scientists who are responsible for assuring the programs meet the needs of the field. This will promote a two-way information exchange between the program developers and the end-users which will be mutually beneficial.

Summary

The 20 engineers in the FY2002 edition of the Coastal Engineering prospect course distinguished themselves by their enthusiasm, attentiveness, and practical engineering slant they brought to the prospect course. A tremendous amount of technical material was presented over the 8 days of the Coastal Engineering course, and the students took home an equally large amount of engineering guidance that will serve them in their careers. The Corps Districts should be rightly proud of the high quality of these young engineers that will become the future technical leaders in the field of coastal engineering.

Next Offering of the Coastal Engineering Prospect Course

The "Coastal Engineering Prospect Course" is scheduled for presentation at 2-year intervals with the next course being offered in winter of FY2004. For further information about this prospect course, contact Dr. Steven Hughes at e-mail address: *Steven.A.Hughes@erdc.usace.army.mil*. (See the adjacent box for details about specialized onsite CEM short courses.)

Instruction Modules in Coastal Engineering Prospect Course

Day 1: Overview of Coastal Hydrodynamics

Morning Module: Introduction to Coastal Engineering and Water Waves
Course Preliminaries, Pre-Test
Introduction to Coastal Engineering
Project Development
Waves and Wave Theories

Afternoon Module: Long Wave Processes
Wave Prediction and Transformation for Engineering Design
Water Levels and Long Waves
Harbor Hydrodynamics
Shore Protection

Day 2: Project Planning

Morning Module: Elements of Project Planning
Geological Setting and Diversities
Overview of Sediment Transport
Site Characterization

An additional benefit of modular course design used in the "Coastal Engineering Prospect Course" (and also in the "Coastal Project Planning Course") is that CHL can easily develop and present customized short courses at District offices. Such a short course would consist of a subset of the modules listed in the table that are of specific interest to a particular District. For example, a District could design a 2-day course that focuses on beach fills and shoreline change. In addition to Corps staff, the District might want to invite engineers from state and local jurisdictions and AE firms. This would be a cost-effective way to provide needed specialized training to those engineers who will most directly benefit.

For more information about onsite CEM-related short courses, contact Dr. Steven Hughes at e-mail address: *Steven.A.Hughes@erdc.usace.army.mil*.

Afternoon Module: Functional Design Issues
Hydrodynamics for Design
Navigation and Design Issues
Environmental/Restoration
Navigation at Entrances (Ship Simulator Tour)

Figure 2. Robert Carver describes Los Angeles/Long Beach Harbor model

Figure 3. The tour continued with an overview of a flume study of breakwater stability

Day 3: Design of Sloping-Front Structures

Morning Module: Fundamentals of Design
Structure Types and Failure Modes
Wave Runup and Overtopping
Wave Transmission and Reflection
Rubble-Mound Structure Stability

Afternoon Module: Maintenance, Monitoring, Repair and Rehabilitation of Structures
Incorporating Risk into Design
Maintenance and Monitoring of Structures
Evaluation of Coastal Structures
Repair and Rehabilitation of Structures

Day 4: Design of Vertical-Front Structures

Morning Module: Fundamentals of Design
Wave Runup, Overtopping, Transmission, Reflection
Toe Stability / Filter Layer Design
Forces on Vertical Structures
Concrete Armor Units

Afternoon Module: Foundations, Scour, and Construction Materials
Materials in Coastal Design
Coastal Structure Foundations
Forces on Vertical Piles
Scour and Scour Protection

Day 5: Beach Fills and Shoreline Change

Morning Module: Engineering Problems and Design of Beach Fills
Sediment Transport Processes in the Coastal Zone
Introduction to Beach Nourishment Design
Design of Beach-Fill Cross Section
Beach-Fill Planform Design Considerations

Afternoon Module: Example Applications
Construction and Monitoring of Beach Fills
Sediment Budget Analysis
Beach-Fill Design Example
Dune Design Example

Day 6: Inlet Engineering

Morning Module: Tools for Inlet Engineering
Inlet Processes
Inlets Online
Sediment Budgets at Inlets
Waves and Currents at Inlets

Afternoon Module: Inlet Example Applications
Field Measurements at Inlets
Sediment Budget Example
Tidal Circulation Example
Simple Process Estimators

Day 7: Project Maintenance and Review of Design Tools

Morning Module: Dredging and Sand Bypassing
Dredging Fundamentals
Coastal Aspects of Dredging
Sand Bypassing Issues
Jet Scour at Inlets

Afternoon Module: Overview of Design Tools
Physical Modeling
Tour of Physical Model Areas
Overview of Available Automated Tools

Day 8: Technology Transfer

Morning: Technology Transfer Fair

Figure 4. Technology Transfer Fair provided students with information on computer-based tools developed by CHL

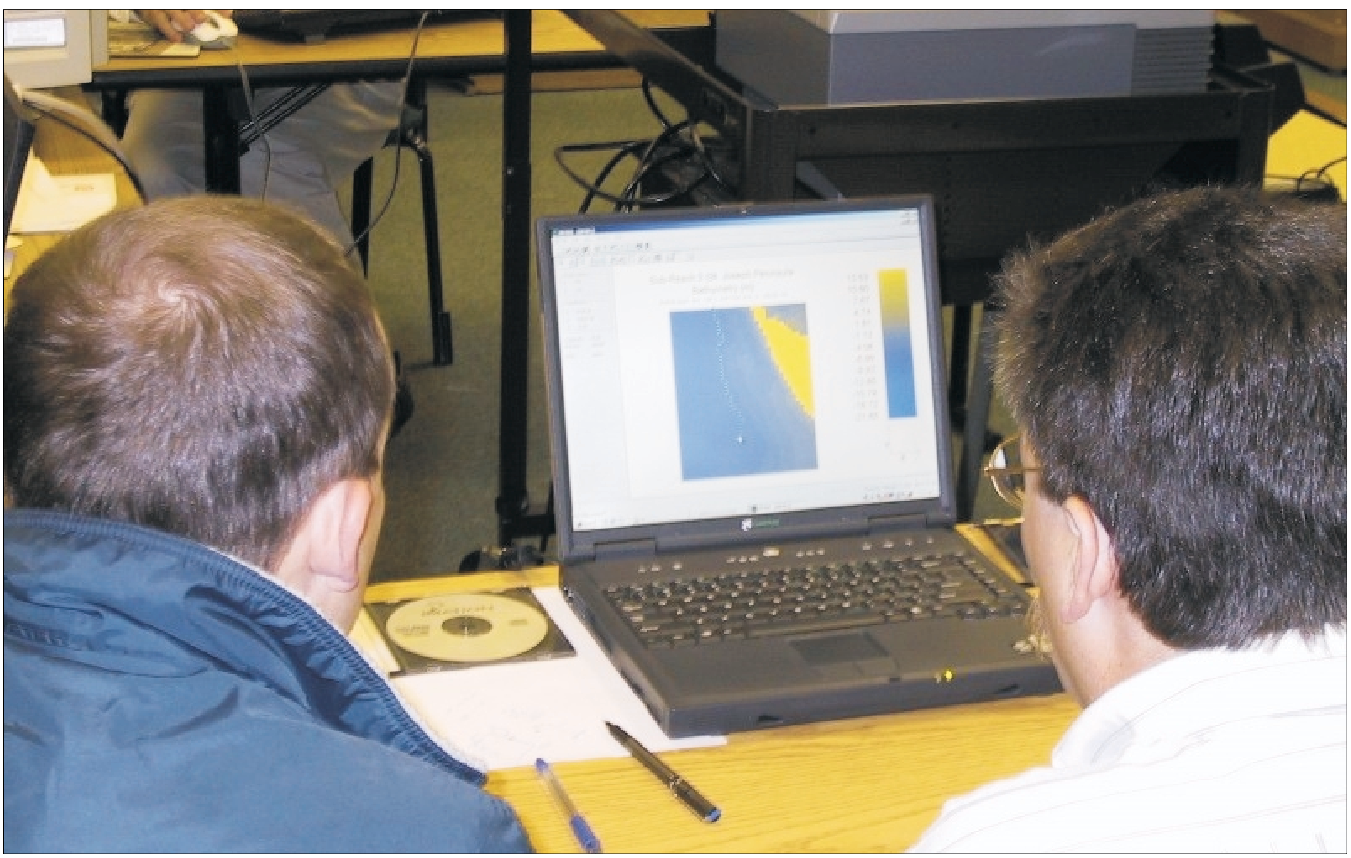

Figure 5. Technology Transfer Fair gave the students hands-on experience with PC-based software demonstrated in the course

Typhoon Overtopping of Berm Frequency Analysis, Apra Harbor, Guam

Edward F. Thompson[1] **and Lincoln C. Gayagas**[2]

This article describes the procedures and results of a typhoon overtopping-frequency analysis for a vulnerable section of the commercial port road along Cabras Island, Apra Harbor, U.S. territory of Guam. The study was a challenging application of present numerical modeling technology to an innovative project design. This article was extracted from Thompson and Gayagas (2001).

Introduction

Apra Harbor, Guam's commercial port, is located on the west side of the island. The harbor is well protected by a combination of natural features and Glass Breakwater, a long man-made breakwater connecting into Cabras Island on the shoreward end (Figure 1). Cabras Island is a narrow east-west oriented island that not only affords protection to the harbor but also accommodates many of the commercial port facilities.

The port access road runs along the north side of Cabras Island. The container yard occupies most of the west-central part of Cabras Island. In this area, the road is protected from the sea by a low recurved concrete seawall fronted by a rubble-strewn beach. Subaerial beach width ranges from 30 m (100 ft) to 70 m (230 ft) along the vulnerable area. A coral reef extends seaward a distance of about 100 m (300 ft). During storms, waves can run up the beach, overtop the seawall, and cause disruption and damage to the road and port facilities.

The U.S. Army Engineer District, Honolulu, and U.S. Army Engineer Division, Pacific Ocean, have developed a project design to reduce vulnerability of the road and container yard to overtopping and flooding (Pacific Ocean Division 1995). The project involves construction of an armored, low-crested berm in the ocean beach profile along a 957-m (3140-ft) stretch of coastline (Figure 2). The U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), recently conducted numerical model studies to assist the Honolulu District in evaluating the expected performance of this innovative project design. Studies included modeling selected historical storms and several hypothetical variations of actual storms, calculating overtopping rates during each modeled storm, and evaluating the protection from overtopping and flooding afforded by both existing and with-project conditions.

Storm Selection

Guam's low-latitude location is favorable for tropical storm and typhoon formation and passage. The island often experiences typhoon impacts and occasionally a typhoon passes directly over the island. Typhoons usually approach Guam from the east or southeast and turn more toward the north, typically after passing the island.

Typhoon track data covering the years 1945-97 were obtained from the U.S. Navy's Joint Typhoon Warning Center (JTWC). Track data are given at 6-hr intervals, including latitude and longitude of the storm eye (with 0.1-deg precision) and maximum sustained 1-min mean surface wind. Available information about storm impacts on Guam was also gathered and reviewed to insure the storm selection process included all important historical storm events.

Only typhoons which passed within a 322-km (200-mile) square box centered on the islands of Rota and Guam and had wind speeds of 64 knots (typhoon strength) or greater within the box were considered. From these typhoons, a representative storm set was selected for modeling. The set included all historical storms with the eye passing within the immediate vicinity of Guam and a representative sample of storms for other typical travel paths relative to Guam. For example, Typhoon Omar (August 1992) approached Guam from the east-southeast and passed directly over the island (Figure 3).

The impact of a typhoon on the study area can be strongly affected by typhoon track. Historical data provide a valuable record, but storms with small variations in the historical tracks would have been equally likely. For analysis of extremes, it is important to capture small variations in the most damaging storms which would have caused them to be more damaging to the study area. After analysis of the effect of small track shifts in extreme historical typhoons, two hypothetical storms were added to the model storm set, giving a total of 30 storms.

Typhoons selected for modeling should be fairly representative of storm track statistics for the full set of

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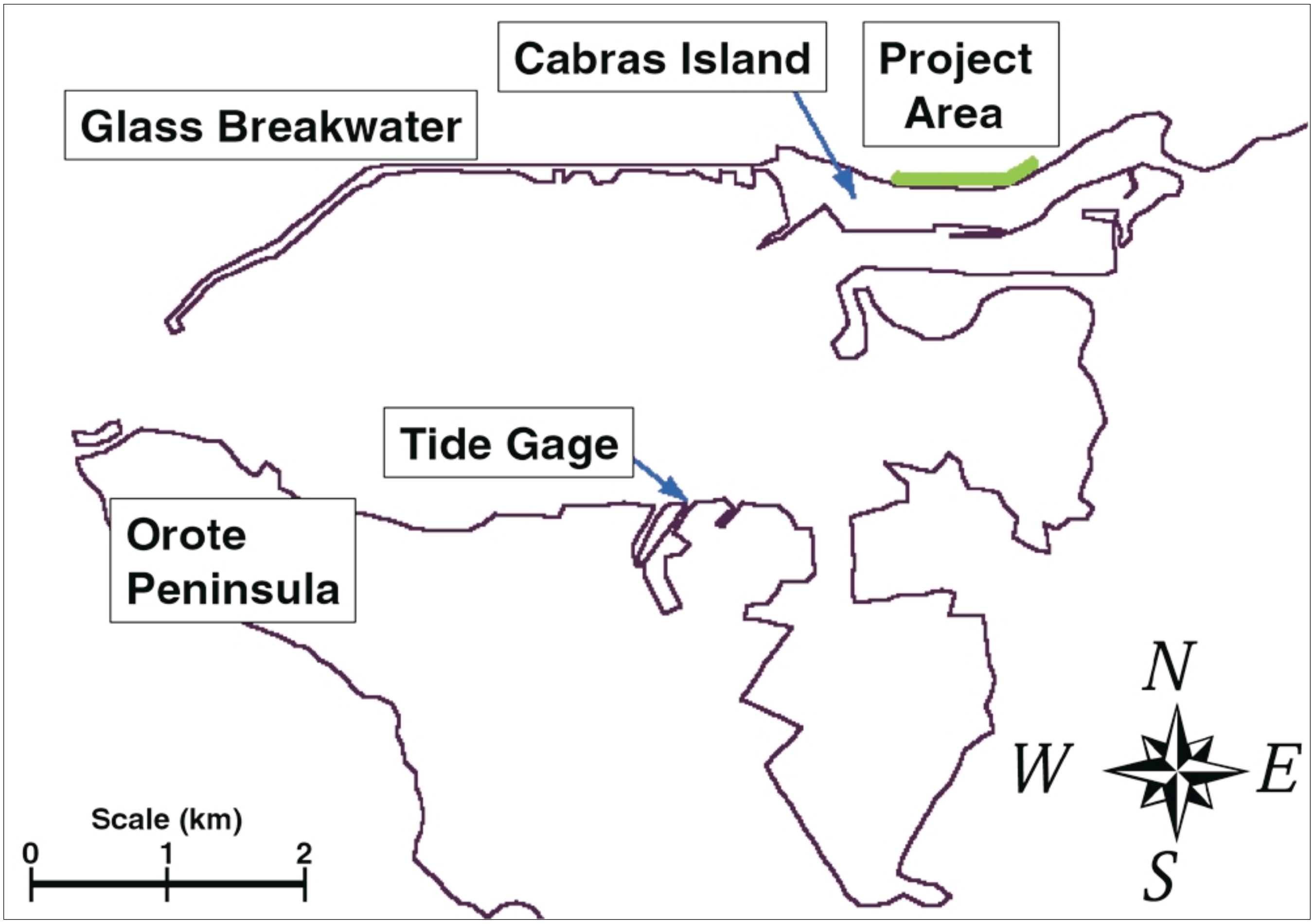

Figure 1. Location map, Apra Harbor, Guam

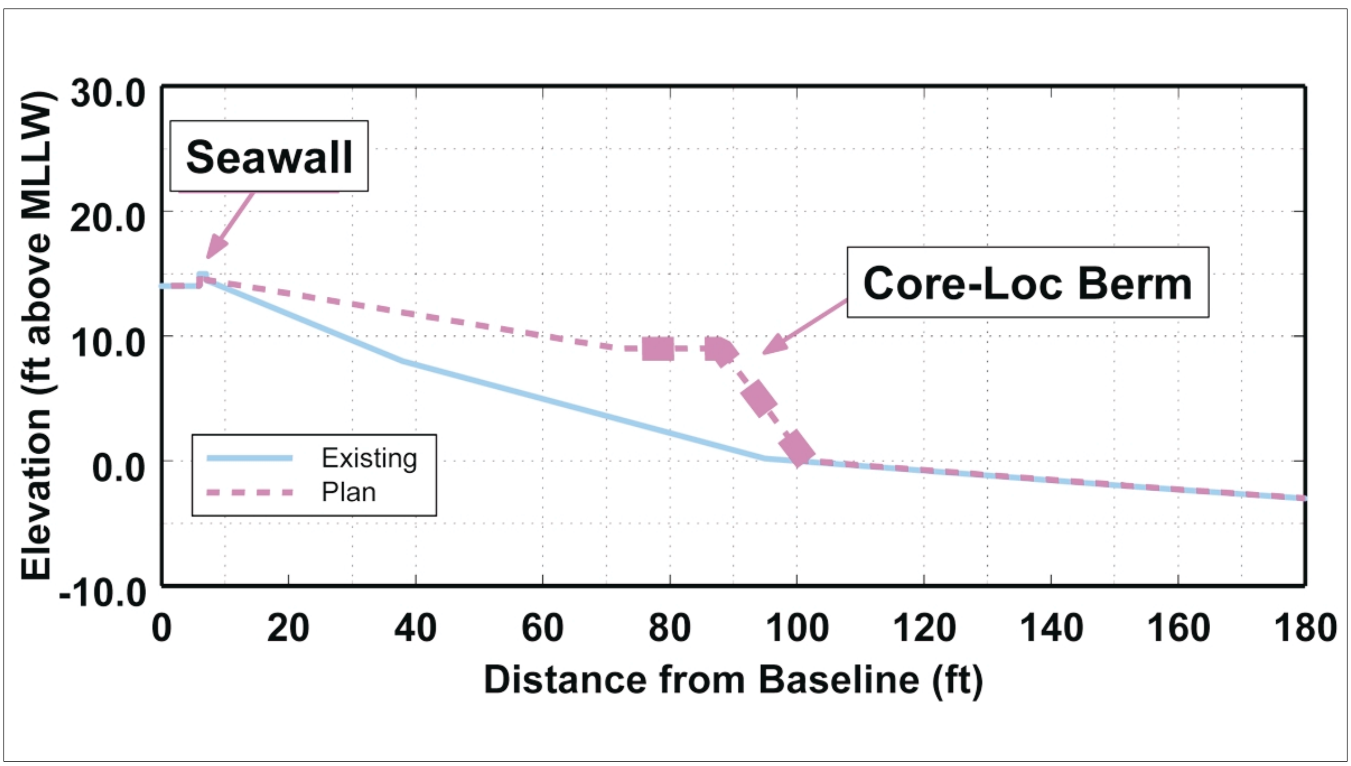

Figure 2. Example of existing and plan profiles (To convert feet to meters, multiply by 0.3048)

typhoons passing into the box around Guam. Typhoons were classified according to their travel direction (Table 1). Storms selected for modeling are considered sufficiently representative of the full set of storms.

Modeling Approach, Offshore

Calculation of typhoon stage-frequency and overtopping relationships for Cabras Island requires application of several standard CHL numerical models and many additional processing steps. First, a Planetary Boundary Layer (PBL) wind model simulates the time-history of typhoon-induced surface wind and atmospheric pressure fields for each selected storm during its general proximity to the study area (Cardone, Greenwood, and Greenwood 1992). The PBL model operates on a nested grid system centered on the storm eye. Storm tracks and maximum sustained 1-min mean surface winds were obtained from the JTWC database. Central pressure was calculated from maximum wind speed using the relationship developed by Atkinson and Holliday (1977), based on data from Guam. Radius to maximum winds was approximated by application of relationships developed in a generalized numerical model study of storm characteristics (Jelesnianski and Taylor 1973). Wind velocities produced by the PBL model represent an averaging time of 30-60 min, which is appropriate for wave and storm surge modeling (Thompson and Cardone 1996).

The time-history of wind information serves as input to both a long-wave hydrodynamic model ADCIRC and a wind wave model WISWAVE. The ADCIRC model

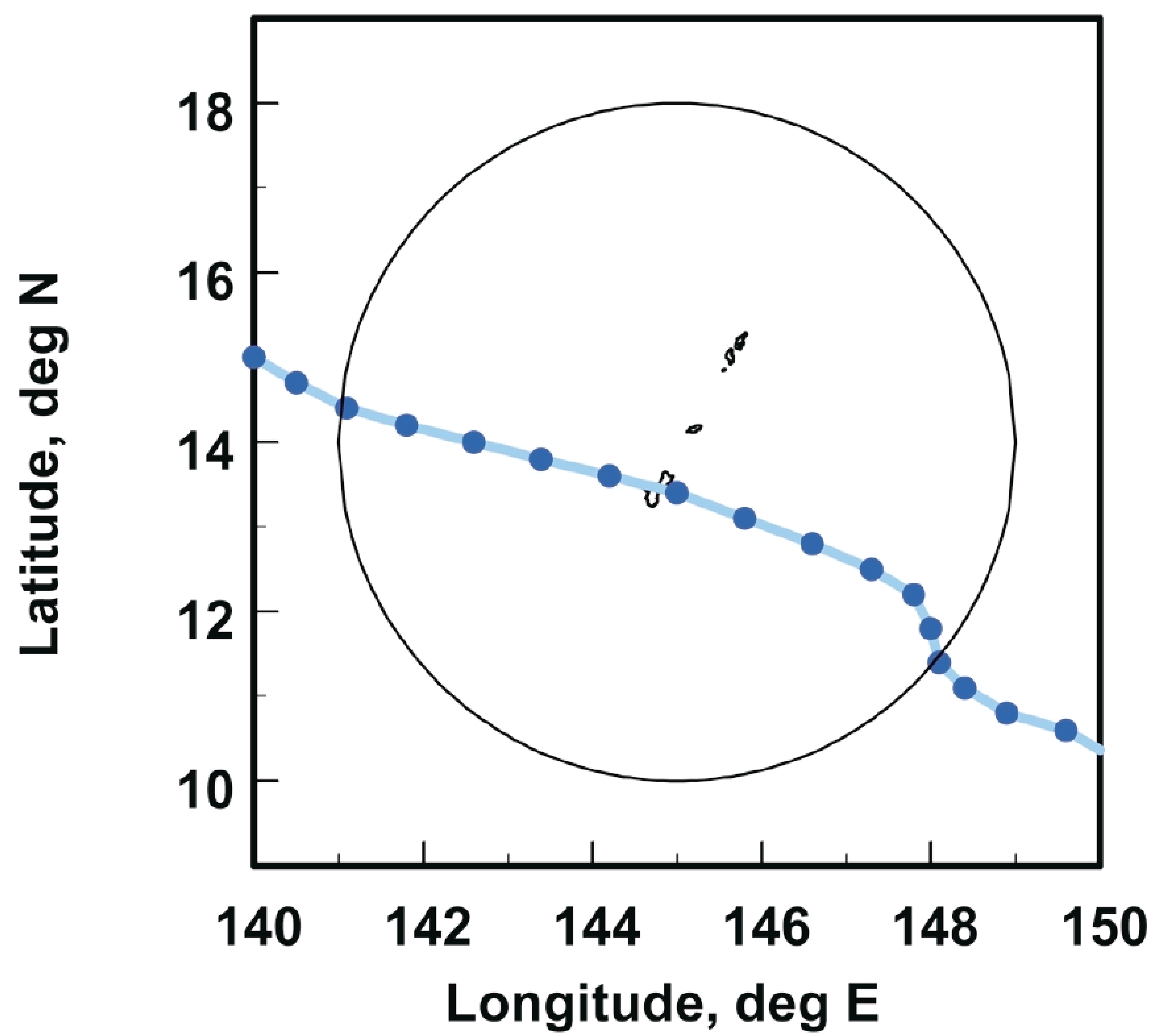

Figure 3. Typhoon Omar track across Guam

Table 1. Statistics of Typhoon Travel Direction				
	Full Set of Storms		Storms Selected for Modeling	
Travel Direction	Number of Storms	Percent	Number of Storms	Percent
Moving toward west	75	65	18	60
Moving toward north	27	23	8	27
Moving toward west and then north	11	9	3	10
Moving toward east	3	3	1	3
Total	**116**	**100**	**30**	**100**

(Luettich, Westerink, and Scheffner 1992; Westerink et al. 1992) provides a refined time-history of typhoon-induced water levels at the study location for each storm. The computational grid developed for this study is circular with 8-deg (900-km) diam and center at long. 145°E and lat. 14°N. The islands of Guam and Rota are located in the central region of the grid. The grid boundary is shown as a circle in Figure 3. Grid resolution is coarser in the open regions with increasing resolution toward the shore, reaching node spacing of about 50 m in the project area. The grid contains 15,301 elements and 8,410 nodes. Reefs, shallow areas, and embayments are finely resolved in and near the study area so that the hydrodynamics can be accurately calculated in these regions. Although astronomical tides were simulated for calibration, they were not included in routine storm simulations, as discussed later.

The WISWAVE model (Hubertz 1992; Resio and Perrie 1989) provides a time-history of deepwater wave parameters in the general vicinity of Apra Harbor. This model is a second-generation directional spectral wave model in which spectral wave computations are based on the integration of energy over the discrete frequency spectrum. The grid was an 8-deg square with constant spacing of 0.083 deg. The islands of Guam and Rota were specified as land in the grid for accurate calculation of wave sheltering and refraction. Wind forcing for the wave model was calculated by application of the PBL model, as discussed previously. Wind speed and direction were calculated for each point on the wave grid at 1-hr intervals.

Deepwater waves produced by WISWAVE were transformed to the study area by application of the nearshore wave transformation model WAVTRAN (Jensen 1983; Gravens et al. 1991). The WAVTRAN model calculates transformation of directional wave spectra during propagation from one depth to another shallower depth, taking into account bottom contour orientation and wave sheltering. Bottom contours are assumed to be straight and parallel. Waves were transformed to 10-m depth or, in cases where waves would be breaking in that depth, the approximate nearshore depth at which breaking would begin.

Modeling Approach, Nearshore

The time-history of transformed wave parameters is subsequently matched with nearshore water level information from ADCIRC and used to calculate a time-history of wave ponding over the reef and nearshore setup, runup, and overtopping. Storm surge levels were typically quite small, never greater than 1 m, and did not need to be included in wave processes outside the reef.

Astronomical tide range is also small in the study area, 0.7 m (2.4 ft) between mean higher high water (mhhw) and mean lower low water (mllw). The shape of the tidal time series is asymmetrical, such that high tides rise little above mean sea level (msl), while lower low tides can drop precipitously below the msl (Figure 4). Thus, tide levels are characteristically in a narrow 0.4-m (1.3-ft) range between msl and mhw most of the time. Astronomical tide was included in the study as a single level, mhw, a representative, but not extreme, high tide level.

Water level in the reef lagoon was estimated as a combination of storm surge, tide, and wave-induced ponding. The increase in water level due to ponding was estimated from empirical relationships developed by Seelig (1983) in laboratory experiments with a fringing reef configuration typical of Guam. In this formulation, ponding is related to deepwater significant wave height, wave period, and water depth over the reef crest. For given incident wave and water level conditions, the estimated ponding is a fixed value with no time-varying surf beat behavior.

Significant wave height in the reef lagoon was estimated as 0.4 times the local water depth, as indicated in previous fringing reef investigations (e.g., Smith 1993). During an intense local typhoon, depth over the reef can exceed 3.0 m (10 ft), giving nearshore significant wave heights of over 1.2 m (4 ft).

Waves that have propagated across the reef lagoon encounter the nearshore slope approaching the seawall. Again, they break and cause a local increase in water level. This contribution to water level, referred to as wave setup, is not included in the ponding calculation. It is calculated with traditional relationships for wave setup on a sloping beach, with significant wave height and water depth in the reef lagoon serving as incident wave

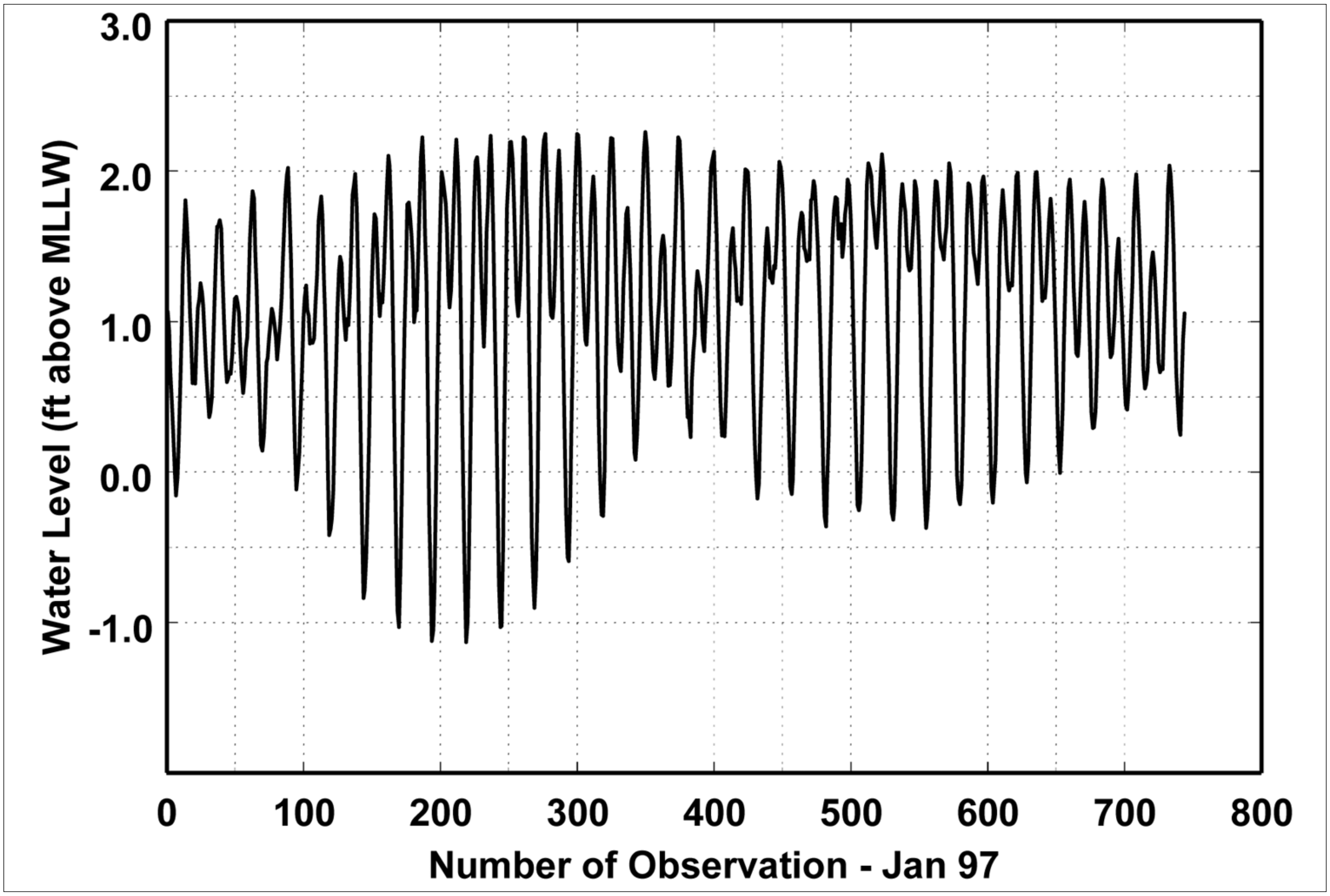

Figure 4. Tide gage data, Apra Harbor, Guam, January 1997

height and depth of wave breaking (*Shore Protection Manual* 1984).

Breaking waves at the shore intermittently push water up the beach, creating wave runup. For both existing and plan nearshore profiles in the project area, runup during an intense typhoon can reach the seawall crest and continue over the top of the seawall. This wave overtopping can create problems along the commercial port road due to flooding, debris, and damage to the road surface. It can also cause flooding in the Apra Harbor container yard. Wave overtopping rate was calculated with the methodolgy developed by van der Meer and Janssen (1994). Reduction factors used in the calculation were determined to fit this application and produce overtopping rates consistent with qualitative observations of storm damage in the project area, as discussed in the following section.

Implementation of Overtopping Method

The methodology used to estimate overtopping rates includes four reduction factors to represent a variety of physical factors which can reduce overtopping. Implementation of these reduction factors requires a calibration/validation process to insure that the methodology is giving a reasonable representation of the project area.

Three historical typhoons which caused damage to the commercial port road in the study area are considered in the Feasibility Report (POD 1995). Typhoon Roy (January 1988) and Typhoon Koryn (January 1990) were reported to cause significant overtopping of the seawall and washing of rubble and debris onto the road. Typhoon Omar (August 1992) caused similar damage but to a lesser extent due to rapidly changing conditions as the eye passed almost directly over the study area.

The same three storms were used in this study to help calibrate overtopping rate calculations to be consistent with documented experience. An overtopping rate time series was computed for each of the three calibration storms acting on the existing profiles. The berm reduction factor was determined as recommended by van der Meer and Janssen (1994). Since most existing profiles do not have a berm, this factor affected only a small number of profiles. The reduction factor for influence of a shallow foreshore was initially set equal to 1. The reef presence suggests that a value less than 1 could be more appropriate, but behavior of waves over a reef during intense typhoon winds is not well documented. The reduction factor for influence of roughness was initially set equal to 1. The presence of rubble on the shore suggests that a value less than 1 may be applicable, but the overall roughness impact of the rubble is unknown. The reduction factor for influence of angle of wave attack was set equal to 1. This value is appropriate since the long-period waves characteristic of intense typhoons can be expected to approach nearly perpendicular to shore.

Calculated maximum overtopping rates for each storm were compared with qualitative damage reports along the commercial port road and published information about dangerous overtopping rates on roadways (e.g., CIRIA/CUR 1991). It was concluded that reduction factors for influence of shallow foreshore and roughness should be set equal to 1 for all applications with existing profiles.

For plan profiles, the reduction factor for influence of shallow foreshore was set equal to 1, as with existing profiles. However, the reduction factor for influence of roughness will be affected by the planned addition of Core-Loc armor units to the nearshore profile. A roughness factor of 0.6 was taken for the Core-Loc portion of the profile. The section of nearshore profile one significant wave height above and below the still-water level (swl) was used to determine the reduction factor for influence of roughness. Using a linear weighting, factors of 0.6 for Core-Loc slope and 1.0 for other parts of the profile were combined to give the overall reduction factor, which varied with swl and significant wave height during the course of each typhoon.

Development of Overtopping Relationships

Wave setup and overtopping rates were computed along 15 transects within the study area. Transects were specified by elevation profiles surveyed and provided by the Honolulu District. Plan profiles were also provided. The project stations modeled are at 61-m (200-ft) intervals, beginning with sta 00+00 and ending with sta 28+00. Maximum overtopping rate is extracted for each nearshore profile in each storm.

The Empirical Simulation Technique (EST) (Scheffner et al. 1999) was applied to get overtopping-frequency relationships based on historical storm parameters and calculated maximum overtopping rates. Overtopping-frequency values and their standard deviations were derived for 5, 10, 25, 50, and 100-year return periods. Maximum overtopping rates with 100-year return period illustrate variability along the coast (Figure 5). Most profiles have overtopping rates of about 0.065 m^3/sec/m (0.7 cfs per ft) for existing conditions and 0.009 m^3/m (0.1 cfs per ft) for plan profiles. Existing Profiles 6 and 28 have reduced overtopping rates which are more like the plan overtopping rates, a consequence of the natural berm present on these existing profiles.

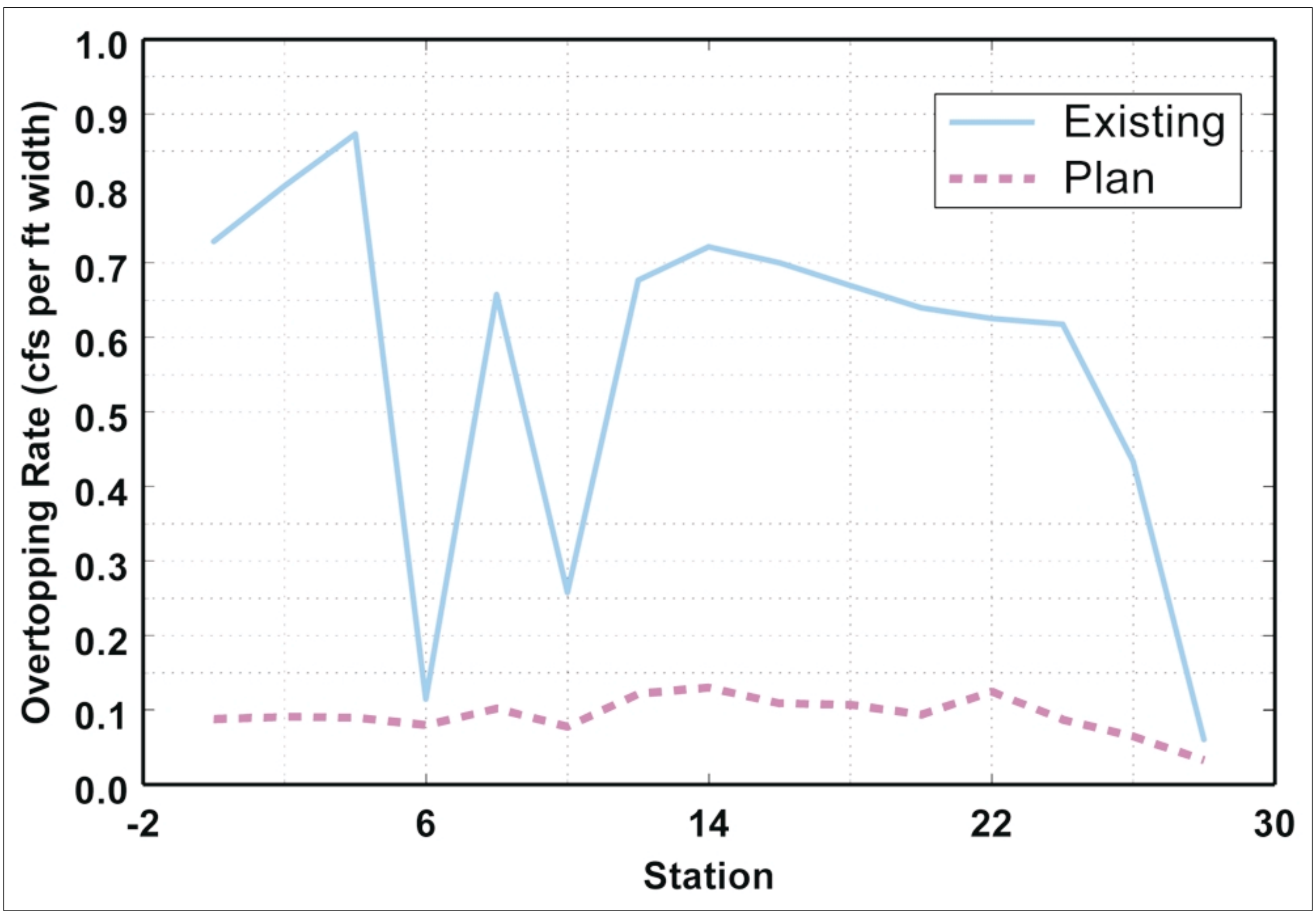

Figure 5. Station overtopping rates, 100-year return period (To convert cubic feet per second to cubic meters per second, multiply by 0.02831685)

Maximum overtopping rates for the full project length can be obtained from the profile results. Profile overtopping rates are given as m^3/m (cfs per ft) of width. Since profiles are at 61-m (200-ft) intervals, each profile overtopping rate can be multiplied by that spacing to give total overtopping rate along the section of coast represented by the profile. The first and last profiles are considered to represent an 82-m (270-ft) width so that the full project length is included. Total overtopping rates along the project area are summarized in Table 2 and Figure 6. The proposed project has a strong impact on reducing overtopping rates.

Conclusions

Numerical modeling of typhoon winds, waves, storm surge, and nearshore processes can be used to estimate wave overtopping rates along the Commercial Port Road, Guam, due to historical storm events. The EST methodology can be used to predict overtopping rate versus return period for extreme events. By modeling both existing nearshore profiles and proposed changes, impacts of the proposed project on protection of the road and commercial port facilities can be evaluated. Model results indicate that the proposed low-crested

Table 2. Maximum Overtopping Rates Along Project Length

Return Period, year	Maximum Overtopping Rate, m^3/sec (cfs)	
	Existing	Plan
2	0.0 (0.0)	0.0 (0.0)
5	1.03 (36.4)	0.0 (0.0)
10	8.15 (287.7)	0.86 (30.5)
25	25.19 (889.4)	3.11 (110.0)
50	36.68 (1295.4)	5.17 (182.4)
75	45.65 (1612.1)	7.15 (252.6)
100	50.19 (1772.3)	8.18 (288.7)

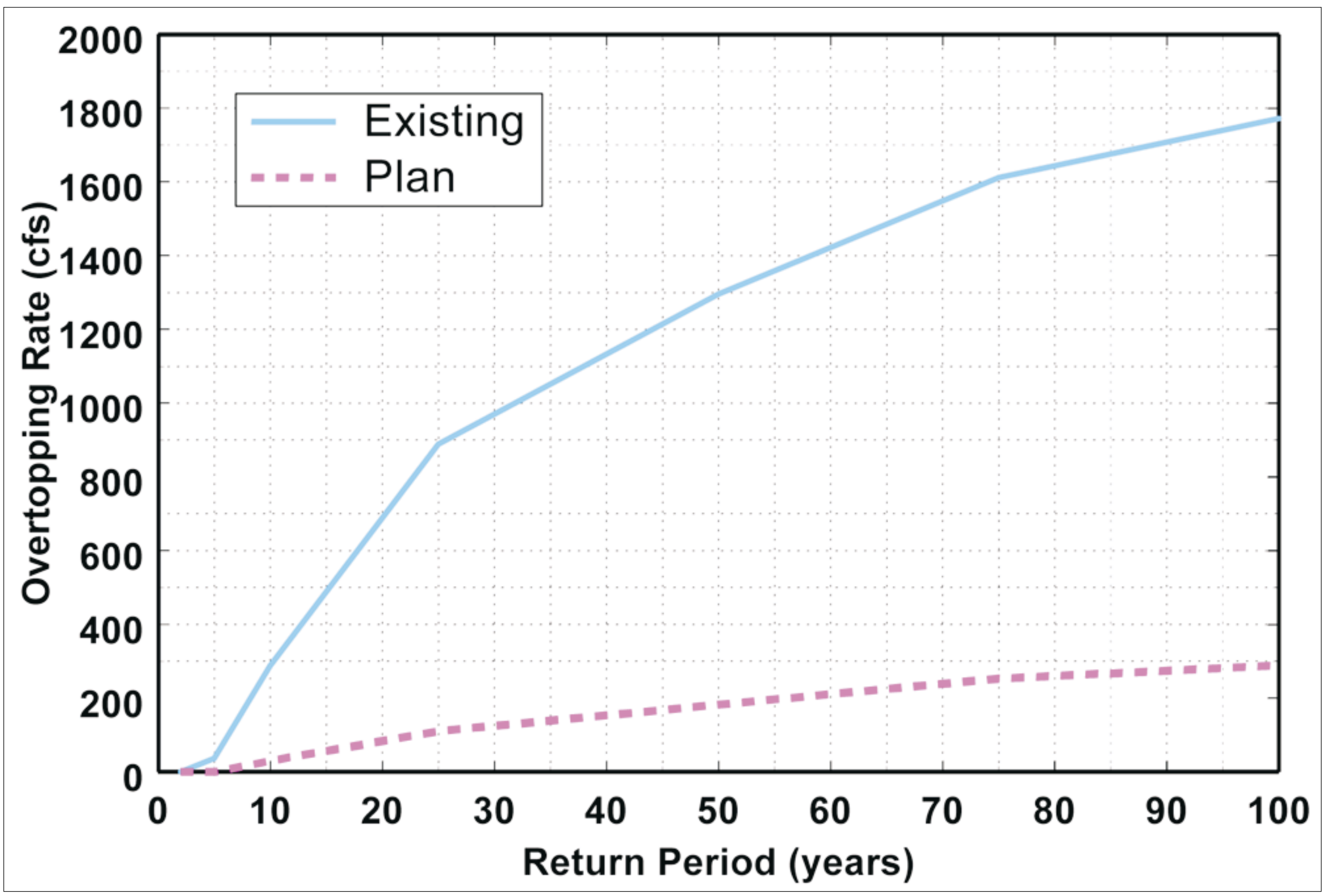

Figure 6. Total overtopping rate along project length

berm to be built in the nearshore profile will significantly reduce the vulnerability of the road and port facilities to damage due to wave overtopping.

Acknowledgements

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from work at the U.S. Army Engineer Research and Development Center, supported by the Honolulu District. The technical report pertaining to this study (Thompson and Scheffner 2002) is available on the internet in .pdf format at *http://chl.wes.army.mil/reportlinks.htm*.

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Regional Sediment Management (RSM) Demonstration Program

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This article describes the U.S. Army Corps of Engineer's National Regional Sediment Management (RSM) Demonstration Program, which was implemented in Fiscal Year (FY) 2000. Sediment management at the regional scale is discussed, followed by sections on each of the six demonstration projects underway in FY01, and regional economics and benefits of RSM. This article was extracted from Rosati et al. (2001).

Introduction

RSM refers to the effective utilization of littoral, estuarine, and riverine sediment resources in an environmentally effective and economical manner. RSM procedures are directed at maintaining or enhancing the natural exchange of sediment within the boundaries of a physical system. RSM changes the focus of engineering activities within the coastal, estuarine, and riverine systems from the local, or project-specific scale, to a broader scale that is defined by the natural sediment processes and may include the entire watershed. Implementation of RSM recognizes that the physical system and embedded ecosystems are modified and respond beyond the formal dimensions and time frames of individual projects. The larger spatial and longer temporal perspectives of RSM, as well as the broad range of disciplines with a stake in RSM projects, require partnerships with and co-leadership of RSM initiatives by the stakeholders. Decisions concerning the timing and scope of projects that move or utilize sediment must be made within an understanding of the regional system. The National Demonstration Program has initially been focused on coastal sediment management, although RSM encompasses the entire watershed.

Figure 1 illustrates a hypothetical example of two regions within a coastal watershed. Features are shown that provide a source of sediment (rivers and eroding headlands), and are a sink to sediment (sandy beaches, inlet/harbor entrance, and bay). Ideally, regions are defined by the large-scale sediment transport patterns as shown in Figure 1, although in practical application, other factors influence regional boundaries, such as political delineation, ecosystems, and economics.

An example of project-level sediment management in a coastal setting might be maintenance dredging of an inlet, with offshore placement of the mixed sand and silt material (the least cost, most economically defensible alternative) despite an eroding adjacent beach. However, regional sediment management would consider the watershed in the problem, and perhaps place the dredged material in a nearshore berm offshore of the eroding beach. The intent is that beach-quality material would ultimately move onshore (or at least provide wave dissipation) and reduce erosion of the beach. If nearshore placement increased the cost of the project, it may be justified by considering the additional economic and/or environmental benefits of providing storm protection for the eroding beach. Alternatively, state and local partners might share the additional cost.

The Corps has a unique role in the implementation of RSM. The mission areas of the Corps include navigation, environmental restoration, storm damage reduction, and flood reduction. In particular, the mission area ensuring the navigability of our nation's waterways involves removing, transporting, and placing sediment, and in some cases providing material that is utilized to support the other mission areas. In planning, designing, and executing RSM, the Corps works towards consensus with state and local partners.

At the 60th Coastal Engineer Research Board (CERB) meeting in 1994, the CERB president tasked the Board with developing future directions that the Corps and the coastal engineering research and development program should take. A task force was formed, and recommended among other things that the Corps adopt a "systems approach to coastal sediment management." As a result, a Working Group on Sediment Resource Management was formed to develop an implementation plan for the initiative. Corps Headquarters introduced the concept of RSM at the Marine Transportation System National Conference held in Airlie, VA, in November 1998. The 67th CERB meeting held in 1998 was themed "Regional Sediment Management," and later CERB meetings entertained a proposal for a RSM demonstration within the U.S. Army Engineer District, Mobile. The Mobile District was the first District with a RSM demonstration plan that received Congressional support. Funding for the National Demonstration Program began with this demonstration in October 1999. Separately, the grassroots movement for RSM grew with Corps Districts pursuing RSM initiatives with

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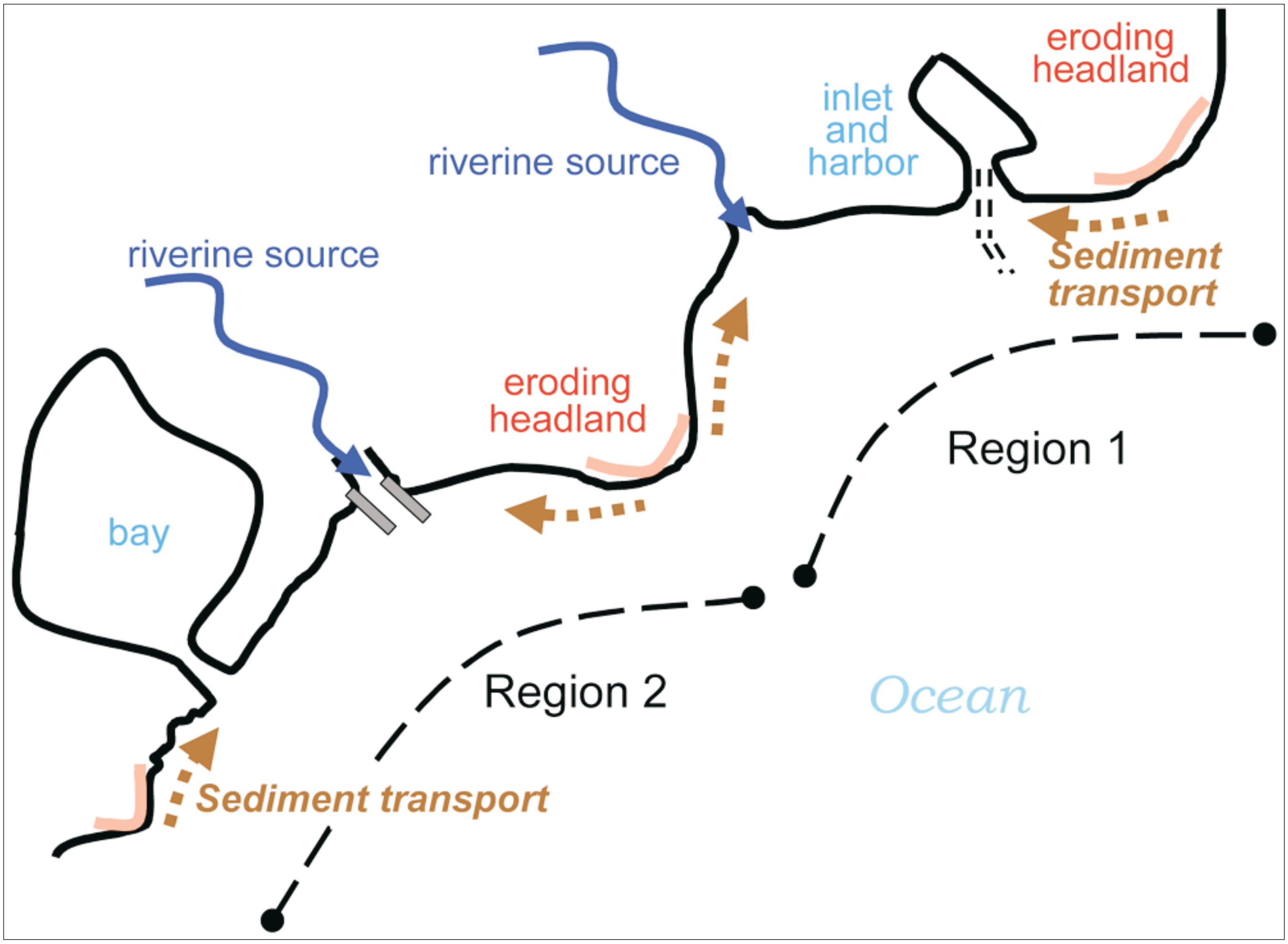

Figure 1. Example of regions for a hypothetical coastal setting

state and local partnerships. In late 2000, the National RSM Demonstration Program expanded to include five additional demonstration sites in the U.S. These six sites are discussed subsequently.

USACE RSM Demonstration Projects

The Corps National RSM Demonstration Program was started largely through the CERB initiative together with strong Congressional support from several coastal and Great Lakes states. The 5-year program is designed to run through Fiscal Year 2003.

The goals of the RSM program are as follows:

- To improve sediment management practice within the Corps (as necessary).
- To highlight and document unique elements of RSM and provide guidance for future implementation of specific RSM actions as appropriate.
- To foster state and local partnerships for RSM, resulting in a unified vision, cost-sharing, and co-leadership of RSM actions.
- To engage cross-mission objectives of the Corps. (More projects will be designed and constructed with the deliberate intent to achieve cross-mission benefits, e.g., storm protection, navigation, and environmental restoration.)
- To define environmental and economic benefits for RSM.
- To improve decision-support technology for RSM. (Conceptual, analytical, and numerical models will have been adapted and improved to support RSM.)

Towards these goals, RSM demonstrations within the Corps are presently being conducted in the Districts and Divisions shown in Figure 2. The following section highlights only a part of each demonstration project, and is intended to describe how each demonstration is working towards the goals of the program.

Mobile District: The Mobile District's demonstration project covers 2,164.56 km (345 miles) of shoreline, extending from the St. Mark's River, FL, in the east through the Pearl River, MS, in the west. As such, the demonstration involves the coastal, estuarine, environmental, and geological agencies from three states, their county offices, and other Federal agencies. At the start

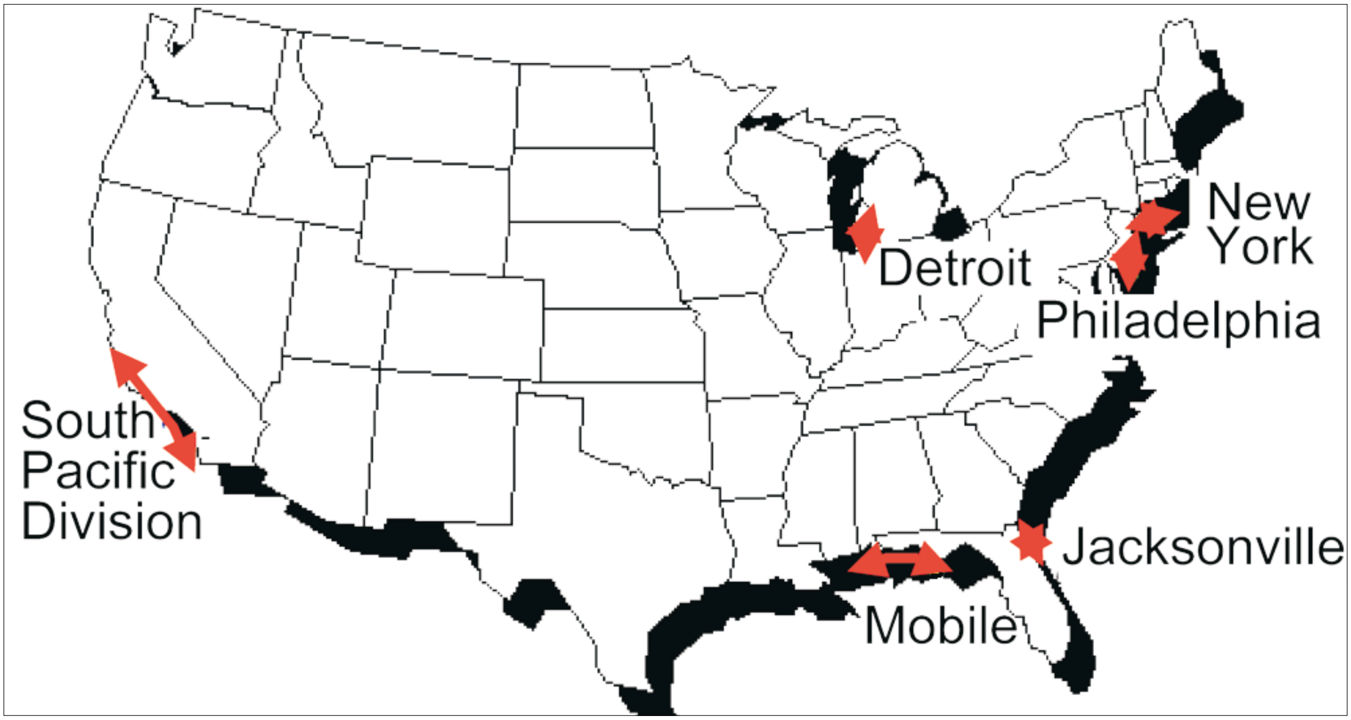

Figure 2. Districts and Divisions having Fiscal Year 2001 RSM Demonstration Projects

of the demonstration in October 1999, historical data sets for the region were vastly different (Lillycrop and Parson 2000; Lillycrop et al. 2000). Data were unavailable for large portions of the region. A primary goal, then, was to establish a baseline data set (bathymetry, shoreline position, and profiles) within a Geographic Information System (GIS), which is ongoing (Wozencraft et al. 2001). Partnerships have been formed and several subinitiatives of the RSM demonstration are being appropriately directed by partnering (non-Corps) agencies.

The Mobile District is working towards the vision of the program by changing operation and maintenance practices at three sites. At Perdido and East Pass Inlets, disposal sites for dredged material have been selected that minimize rehandling of material. The third initiative presently under consideration involves the disposal sites for dredged sediment along the Apalachicola River, located near the eastern boundary of the region. Disposal sites along the river are full, and the RSM demonstration project is considering the cost and benefits of bringing this sediment to the coast for beach nourishment and/or environmental enhancement. For more detail about the Mobile District's RSM demonstration project, the reader is directed to the Web site for the demonstration project *http://gis.sam.usace.army.mil/Projects/RSM/*.

Jacksonville District: The Jacksonville District formally began its National demonstration project in January 2001 for the northeast coast of Florida, although they had initiated state and local partnerships and cost-sharing with the state, conducted four regional workshops, and began three initiatives prior to receiving formal demonstration funding (e.g., see Schmidt and Scwichtenberg 2000). RSM investigations in this region were accomplished under a Section 22 agreement between the U.S. Army Engineer District, Jacksonville, and the Florida Department of Environmental Protection (FDEP), Office of Beaches and Coastal Systems (OBCS). Section 22 of the Water Resources Development Act of 1974 (Public Law 93-251), as amended, authorizes the Secretary of the Army, acting through the Chief of Engineers, to assist the states in the preparation of comprehensive plans for the development, utilization, and conservation of water and related land resources. The agreement facilitated RSM practices in the Sea Islands and St. John's Beaches subregions of the Northeast Atlantic Coast region as defined by the OBCS. As so defined, the limits of these subregions extend from the northern Nassau County line through Duval County to the southern St. Johns County line.

The Jacksonville District provided technical assistance to the OBCS in coordinating RSM activities in the two subregions. An RSM Web site (*http://rsm.saj.usace.army.mil*) has been developed as part of the agreement to facilitate coordination with other Federal and non-Federal agencies as well as the public.

RSM strives to enhance the planning, construction, operation and maintenance (O&M) of navigation, shore protection, and environmental restoration projects while protecting natural resources. The Corps and the FDEP recognize that there are other agencies, entities, and nongovernmental organizations that are also integral to RSM initiatives and have solicited their input. Workshops concerning RSM in northeast Florida were held in St. Johns, Duval, and Nassau counties. During these workshops the Federal, state and local perspectives were presented and opportunities for RSM were identified. Potential Demonstration Projects (PDPs) were identified as cost-effective and innovative regional approaches. A fourth workshop involving all of the regional interests focused on implementation of PDPs in northeast Florida.

Six specific PDPs identified during initial workshop efforts included the following: (a) stabilize south end of Amelia Island, (b) bypass sand at St. Marys entrance, (c) backpass and bypass sand at Ft. George and St. Johns River entrances, (d) bypass sand at St. Augustine Inlet, (e) offloading disposal areas, and (f) demonstrate innovative technologies. The offloading disposal areas PDP involve placing beach quality sand from upland disposal areas onto the beach. As part of maintenance operations for the Intracoastal Waterway, dredged material is routinely placed into designated upland disposal areas. Much of the material is either originally beach quality or is rendered so during the sorting process of the dredging operation. Once a large enough volume of suitable material is placed in a disposal area, it becomes economically feasible to offload it onto an adjacent beach to restore capacity in the existing disposal area in lieu of establishing another site.

The purpose of the fourth workshop was to identify and brainstorm actions required to implement demonstration projects under the framework of the Corps missions and the Strategic Beach Management Plan. The workshop included several overview presentations intended to provide baseline information upon which the group discussions were based. The discussions themselves were intended to elicit comments and suggestions from various stakeholders regarding the PDPs, as well as to obtain specific information requisite to the implementation of the PDPs. Specific recommendations were generated for each PDP that addressed engineering, economic, environmental and policy issues. Participants identified specific economic and environmental benefits as well, and these benefits were similar across all six PDPs. Economic benefits include reduction in future renourishment and O&M costs, enhanced recreational usage and increased protection for upland development. Environmental benefits of these PDPs include maintenance of nesting habitats for turtles and shore birds, re-establishment and stabilization of dune systems, increased viability of local species (e.g., beach mouse populations) and overall improvement to public lands. Based upon the final comments of the workshop sponsors, the workshop provided useful information and recommendations for the Corps and the FDEP to prioritize the RSM demonstration projects. The priority PDPs were identified as "stabilize south end of Amelia Island" and "backpass and bypass sand at Ft. George and St. Johns River entrances."

The southern tip of South Amelia Island presently experiences chronic erosion. The FDEP Strategic Beach Management Plan identified a 4.98-km (3.1-mile) segment of critical erosion along the ocean shoreline of South Amelia Island that needs renourishment. The plan also recommends a feasibility study of shore protection structures. The influences of the 1994 beach-fill borrow pit on wave refraction and action of the existing groins on transport processes will be evaluated. Short-term efforts to implement the "stabilize south end of Amelia Island" PDP have recently been completed through a multiagency (USACE, FDEP, Florida Inland Navigation District, South Amelia Island Shoreline Stabilization Association and others) cooperative RSM initiative. This initiative resulted in the placement of approximately 252,303.1 cu m (330,000 cu yd) of beach quality material from O&M dredging of the Atlantic Intracoastal Waterway (Figure 3) and construction of geotextile shoreline stabilization tubes. Ultimately, the goal of the PDP is to establish long-term solutions to the erosion problems on the south part of the island.

The "backpass and bypass sand at Ft. George and St. Johns River entrances" PDP involves the backpassing of beach quality material onto Little Talbot Island and bypassing material across the entrance to the Duval County beaches. The PDP also strives to identify the optimum location for placement of the bypass material. The FDEP Strategic Beach Management Plan has identified a 16.09-km (10-mile) segment of critical erosion that extends from the St. Johns River entrance south to the Duval-St. Johns County line. The plan also calls for continued beach nourishment in Duval County and further study of the St. Johns River entrance. The Jacksonville District has identified several sources for beach renourishment including Buck Island and the Jacksonville Harbor deepening project. In addition, three alternative borrow sites have been identified in and around Ft. George Inlet (northernmost inlet shown in Figure 4). These include the extensive ebb shoal system, the flood shoal north of the State Road A1A bridge, and the shoal that forms just south of the north jetty at the southern tip of Wards Bank. Another purpose of this PDP involves backpassing of sand to persistent erosion areas located on the south end of Little Talbot Island (northern island in Figure 4).

Concrete riprap shore protection provided by the Florida Department of Transportation effectively stabilizes a segment of the north bank of the Ft. George Inlet channel in the vicinity of the eastern end of the State Road A1A bridge. However, the channel remains free to shift northward over its eastern segment. This process has led to the continued erosion of the southeastern corner of Little Talbot Island along with a northward growth of Wards Bank. In turn, the inlet channel has changed its former east-west orientation, and has increased in length. As a result of the ensuing shoreline recession, state park facilities on Little Talbot Island have been compromised. Several of the potential borrow sites for the St. Johns River bypass operations could also serve as backpassing sources for the southern tip of Little Talbot Island.

Funds provided by the Corps National program along with matching state funds will be used to investigate various alternatives for implementation of these PDPs. The scope of work for this investigation involves applying Diagnostic Modeling System (DMS) (Kraus 2000) tools and methodologies to examine the sediment transport mechanisms related to each PDP. Additionally,

Figure 3. South Amelia Island O&M disposal area (January 25, 2001). Approximately 252,300 cu m (330,000 cu yd) of beach-quality sand was placed as part of this multiagency initiative

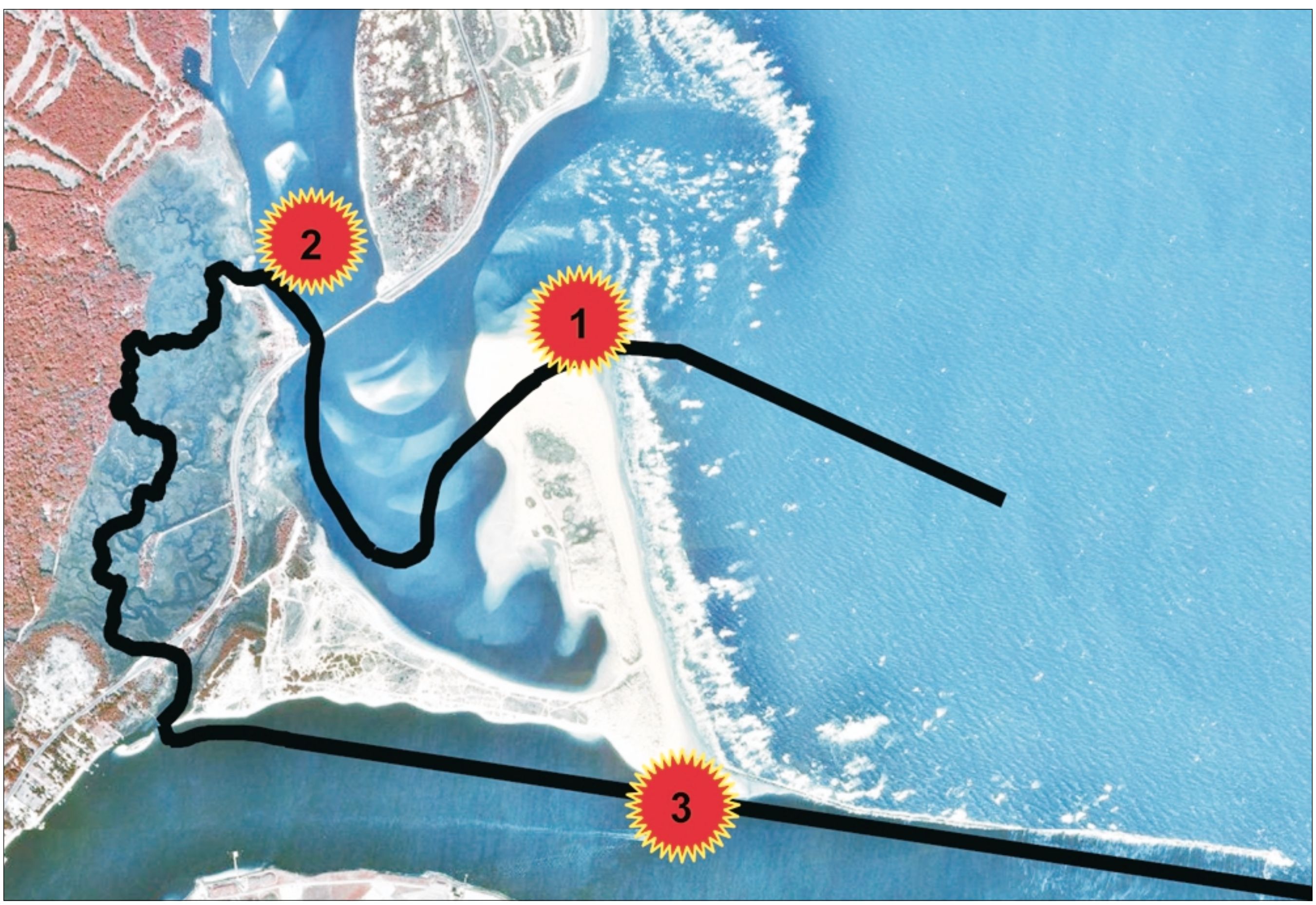

Figure 4. Three proposed borrow areas identified for the "backpass and bypass sand at Ft. George and St. Johns River entrances" potential demonstration project

the DMS will identify existing sources of beach compatible material for erosion control. For more information about DMS, see *http://www.Taylorengineering.com/DMShome/DMSDefault.htm*. The scope of work for the investigation of these two PDPs includes the following:

- Compile and collect survey data
- Identify existing sources of beach placement material
- Model existing conditions and alternative plans
- Evaluate alternatives effectiveness and impacts
- Report results

Work will begin by conducting a hydrographic and high-water survey of each PDP vicinity, Nassau Sound and Ft. George Inlet, and by amassing recent available hydrographic and shoreline data. These data will be used in conjunction with an existing community model grid developed by the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC) to refine the two regions of interest. The survey data will provide high-resolution, subregion detail not included in the existing grid. Next, suitable validation data for the wave and current models will be located for the study area. ADvanced CIRCulation model (ADCIRC) and STeady-state spectral WAVE model (STWAVE) will provide simulations of representative wave and tidal conditions and bathymetric controls on the nearshore wave pattern. Specifically, wave and current modeling will be linked through the steering module being developed under the Coastal Inlets Research Program (CIRP). The steering module provides interaction between ADCIRC and STWAVE giving a more accurate representation of the wave and current climates. The existing conditions model will provide the baseline conditions at the south end of Amelia Island. Applying the DMS in conjunction with the previously-described modeling will identify the areas of problematic shoaling and impacts of shoal mining. Specifically, for the Amelia Island PDP, DMS results will be used to assess the effectiveness of implementing stabilization alternatives. For the Ft. George and St. Johns River entrances, DMS will evaluate the impacts of mining Ft. George ebb shoal, flood shoal, and the shoal within the jetties south of Wards Bank. Wave modeling will also aid in both identifying the location of the transport node downdrift of the St. Johns River entrance and determining nominal locations for potential nearshore or onshore placement of dredged material.

DMS results will summarize sediment inputs, outputs, and available shoreline and channel response information generated or developed in the overall summary in a Sediment Budget Analysis System (SBAS) application (Rosati and Kraus 1999, 2001). The coastal issues previously described are readily summarized and explored in a conceptual sediment budget that can be made quantitative through incorporation of magnitudes and directions of longshore and cross-shore transport, volume change on the beaches, and engineering actions. Applicable results of the proposed studies, such as potential transport rates and directions, will be compiled in SBAS and transferred to study sponsors. The SBAS will contain both macro and individual preliminary budgets for initiation of an RSM approach to the study areas. It is understood that the sediment budgets are preliminary in that potential rates and inferences will form the basis of the SBAS input, not specific data collection and analysis (such as shoreline change, nearshore bathymetry change) that would require a separate and dedicated effort. The SBAS will also include metadata explaining the budget formulation.

The brainstorming and coordination provided through the workshop series and products derived from the DMS modeling efforts are being utilized by the Corps and FDEP to efficiently and effectively implement RSM demonstration projects in northeast Florida.

Philadelphia District: The Philadelphia demonstration extends approximately 209.21 km (130 miles) from Sandy Hook in the north (located in the New York District), to Cape May (mouth of the Delaware Bay) in the south. A suite of wave, current, and sediment transport models will be applied to the region to characterize the longshore and cross-shore transport rates, as well as the regional sediment budget. The RSM demonstration involves moving sand from an accreting beach northeast (updrift) of Cape May Inlet to the eroding southwest (downdrift) side of the inlet. Accretion along the updrift beach is believed to be caused primarily by the construction of jetties at Cape May Inlet in 1911, and it has resulted in at least two problems: (a) storm water outfalls that do not drain because of beach accretion, and (b) excessive beach widths that make recreational beach user access to the water problematic. Nourishment of the downdrift shoreline has been obtained from an offshore borrow site, but that site has an insufficient reserve of material for future nourishment needs (approximately 200,116.4 cu yd (153,000 cu m/year)).[1] Through application of the numerical models, and possibly a pilot implementation study, the RSM demonstration will evaluate two means of moving the sand: (a) a continuous mechanical bypass system, and (b) trucking material as required.

New York District: The New York District has two initiatives within the National RSM Demonstration Program: (a) backpassing of sand at Jones Inlet, NY, and (b) creation of an artificial overwash fan using dredged material proposed for Seabright, NJ.[2] The first initiative will explore the benefits of removing an attachment bulge in the shoreline downdrift (west) of Jones Inlet, located on Long Island. This attachment zone formed as

1 McCormick, J., Chasten, M., and Lucas, S. (2001). "National Regional Sediment Management Demonstration Program—Proposal for the New Jersey Coast," unpublished memorandum submitted to ERDC Coastal and Hydraulics Laboratory, Vicksburg, MS.

2 Rahoy, D., and Bocamazo, L. M. (2001). "Regional sediment management demonstration project," internal proposals submitted to National Regional Demonstration Program.

the ebb tidal shoal reached a size that it began bypassing sediment to the adjacent beach. It is hypothesized that the attachment zone is now acting as a barrier to eastward-directed sand transport. Directly to the east of the attachment zone, and west of the inlet, the beach is severely eroded. The demonstration project will place sand scraped from the attachment zone into the severely eroded beach. In addition to providing an immediate source of sand for this area, it is believed that removing the attachment zone will allow east-moving sand to nourish the severely eroding region, at least until the ebb tidal shoal re-establishes the bypassing bridge. This demonstration project has the potential for national applicability, because many inlets in the United States share the same downdrift signature of Jones Inlet (Kraus and Galgano (in preparation).

The second demonstration, creation of an overwash fan, attempts to restore this type of habitat on these populated barrier islands. On an undeveloped barrier island, storms with elevated wave and water levels will overwash the island and move sand into the bay. This material forms an "overwash fan," and provides habitat for specific endangered species. The infrastructure of these barrier islands prohibits this process from occurring on a regular basis. The success of an artificial overwash fan will be evaluated as an alternative for dredged material disposal, and, if successful, guidance for construction will be developed.

Detroit District: The Great Lakes provide a unique setting for RSM. Beach quality sediment available to nourish eroding beaches is scarce. The clay bluffs can erode rapidly when unprotected by a sandy beach and nearshore profile. As part of the National RSM Demonstration Project, the Detroit District is striving to develop a sand placement schedule and warning system for protecting the fragile bluffs. Also under the demonstration, they are exploring the feasibility of implementing a "sand bank" policy in which proponents of new private shore protection projects would have the option to pay into a trust fund dedicated to financing larger scale beach nourishment projects.[1] Alternatively, individual sand placements would be required to mitigate for coastal structures that prevent sand from entering the littoral system.

South Pacific Division (San Francisco, Sacramento, and Los Angeles Districts): The South Pacific Division began partnerships with the state, counties, and various grassroots agencies with a goal to develop a statewide plan in FY 00, prior to formal funding. Regional studies have been conducted in Southern California since the 1980s. Funds from the National Demonstration Project are being used to finalize the statewide RSM plan, as well as explore the feasibility of moving material trapped behind dams on rivers feeding the coast to the coastline. Ownership of this material has long been a topic of discussion and debate in California (O'Brien 1936; Magoon and Edge 1998). Reservoirs on many rivers in southern California have reached sediment capacity, and some have degraded to such an extent that the infrastructure must be repaired, replaced, or removed. Several options have been discussed: (a) remove the dams and allow riverine transport processes to move the material, (b) excavate and truck the material to the coast, and (c) pump the material via pipeline. The RSM demonstration is evaluating the cost, benefits, and time required for each of these options.[2]

Benefits

The role of the economist in RSM is to help the study team identify the best Federal investment options for operating and maintaining coastal projects, both at given sites (local and regional systems) and at the program level (nationwide). One goal of coastal RSM is to keep sediment in the littoral system. It is not feasible to return all littoral sand to active transport system at once, so the best opportunities for managing sand need to be identified for priority implementation. This question addresses the fundamental economic problem: how do we put our scarce resources to their best uses?

Sources: Benefits from RSM are derived from several different sources. The first is better information, specifically better knowledge about the physical makeup and processes in the coastal zone. By better understanding the problem and its causes, more efficient management approaches can be identified. RSM also generates benefits through better technology. New techniques, and refinement of older techniques, can lead to better-designed management actions. RSM also brings a broader view of how to best manage sand. It incorporates a systems view of projects, rather than treating projects in isolation, taking advantage of previously unidentified synergistic effects. The categories of benefits considered under RSM are also broadened in comparison to status quo management, so more desirable purposes can be achieved. Finally, RSM builds stronger partnerships among coastal and watershed stakeholders leading to a wide range of potential benefits in improving business processes, sharing data, expanding the Corps and its partners' effectiveness, and greater cooperation among parties.

Economic Framework for RSM: Historically, projects within the Corps have been optimized by the least-cost means of delivering the desired performance and benefits. Frequently this local project policy resulted in actions that removed sediment from the littoral system, through upland, isolated, or offshore placement. Additionally, each site or project was treated in isolation, rather than as part of an integrated watershed system.

1 Ross, P., Thieme, S., and Selegan, J. (2001). "National Regional Sediment Management Demonstration Program—Proposal for Ludington, Michigan, to Michigan City, Indiana," unpublished memorandum submitted to ERDC Coastal and Hydraulics Laboratory, Vicksburg, MS.

2 Domurat, G., and Sloan, R. (2001). "National Regional Sediment Management Demonstration Program—Proposal for State of California," unpublished memorandum submitted to ERDC Coastal and Hydraulics Laboratory, Vicksburg, MS.

Offsite and unintended effects were not generally recognized nor considered.

Under RSM, the economic effects of evaluating alternative sediment management activities can be considered under two “tracks”: (a) cost savings, and (b) best management of resources. Cost savings can most easily be thought of as achieving the same results or benefits from a project through more efficient methods. Cost savings are realized by identifying production efficiencies, such as combining dredging actions, or by minimizing sediment rehandling, such as adjacent dredging and beach nourishment projects. Better management of sediment resources can be achieved by expanding the scope of beneficial effects considered for alternative approaches to project operations and maintenance. It recognizes the value of sediment as a resource. For example, keeping sediment in the system may be slightly more expensive than disposing material offshore, but it may reduce costs at an eroding beach, thereby realizing overall net benefits by not requiring an erosion control or beach-fill project. Another possibility is that dredged material can be put to a beneficial use, rather than be placed in a disposal area that may or may not have storage costs.

A range of anticipated benefit categories is shown in the following tabulation, organized by the system of four “accounts” established in the Principles and Guidelines (U.S. Water Resources Council 1983):

- **National Economic Development**
  - Storm Damage Reduction
    - Commercial, residential structures
    - Undeveloped land
    - Infrastructure
  - Recreation
    - Domestic
    - International tourism attraction
  - Navigation
    - Better performing projects
    - Reduced operation and maintenance outlays
- **Environmental Quality**
  - Ecosystem Protection and Restoration
    - Beach habitats, dunes, freshwater wetlands
    - Endangered species
  - Aesthetics
  - Cultural Resources
- **Regional Economic Development**
  - Income
  - Employment
  - Tax Receipts
- **Other Social Effects**
  - Urban and Community Impacts
  - Life, Health, Safety
  - Environmental Justice

Note that policy, authorization, and appropriation laws give different benefit categories different priority under various circumstances, but all are potentially important in making RSM investment decisions.

The Six-Step Planning Process: The Corps typically employs a six-step process to take plans from conceptualization to implementation. These steps and a review of RSM activities that relate to these six steps are as follows:

- *Specify problems and opportunities:* Expand the scope of the problems and opportunities to other resource categories, and expand the scope of space and time considerations.
- *Inventory and forecast conditions:* Inventory categories of interest such as buildings, development, or significant environmental resources.
- *Formulate alternative plans:* Assess the efficiencies of approaches, including different methods, temporal and spatial scales for approaching the problem.
- *Evaluate consequences of alternative plans:* Note that it may be difficult to distinguish between with and without project conditions and to evaluate incremental impacts.
- *Compare alternative plans:* Measures of success must be able to distinguish between plans.
- *Select recommended plan:* Criteria will differ depending on authorities, partnerships, and plans incorporating issues concerning the entire watershed.

Priorities for RSM Demonstration Studies: Benefits of RSM actions can be realized in reduced costs, increased revenues, and new benefits. They can be realized in the short term, as well as over the long term. Demonstration proposals that highlighted management actions to realize cost savings in the short term received highest priority within the RSM program. While all benefits across these variables are important, those actions demonstrating short-term cost savings will rapidly show the best of what RSM can achieve. Actions providing other benefits have been included in the demonstration program to round out the range of experience that can be captured under the program.

Specific Beneficial Activities from RSM Demonstration Projects: The proposed RSM actions include a fairly wide range of measures that will be beneficially employed. These actions can be grouped into categories, even at this early stage of conceptualization. The first broad area can be described as accretion/erosion management. In these cases, the natural flow of sediment may be disrupted. Measures to balance the sediment movement include various means of bypassing and/or backpassing sediment artificially, as well as restoring natural flows that have been impeded. Both accretion and erosion can be problematic, with too much sand clogging channels, storm water outflow systems, etc., and erosion threatening property, sensitive environmental habitat, or infrastructure.

Environmental or ecosystem restoration is another category of activity present in the initial demonstrations. Reinforcing natural berms that protect freshwater lakes or wetlands from saltwater intrusion is one example. Placing sediment behind an island to mimic historic natural overwash and sediment dynamics (early successional habitat for colonial and nesting shorebirds) is another. There are a number of threatened and endangered species in the areas of the demonstration studies that should benefit from restored habitat under RSM.

Demonstration studies are also identifying new efficiencies in dredging for existing coastal projects. These efficiencies may result from scheduling maintenance for adjacent projects to share costs; from better understanding sediment flows to avoid rehandling; and by employing more refined technologies, such as pinpoint dredging systems.

Recognizing sediment as a valuable resource (and expensive liability, depending on circumstances) accounts for another area where savings are foreseen. Dredged material may be put to beneficial uses rather than dumped or placed in disposal areas. This results in positive benefits where the material is wisely used, and may be less expensive than finding other beach quality material. Additionally, there are savings that result from reduced costs in disposal areas, which can be especially important as existing areas reach capacity. Sediments trapped behind dams starve beaches of material that would be expensive to replace, and accumulation reduces both the volume and effectiveness of the dams' original purposes. Stockpiling sand for emergency recovery from major storms is also being considered to reduce recovery costs and improve readiness to alleviate the emergency.

Improved Processes and Partnerships: The approach taken to implement RSM involves substantial participation across levels and agencies of government. Participants in the Mobile District RSM Demonstration Project have identified a number of important intangible benefits of working together that will ultimately lead to wiser sand and coastal management, which have been divided by related category in the following tabulation:

- **Overarching Program Goals**
  Wider beaches, more protection, less maintenance
  Keep sand in the littoral zone
  Keeping sand in the system as a beneficial use of dredged material
- **Aligned Actions Across Agencies**
  Identifying programs that are working at cross-purposes (e.g., trucking sand away from an area that needs sand)
  Opportunities to align programs at the Federal, state, and local levels
- **Improved Understanding of Physical Processes**
  Sediment budget will identify areas of erosion/accretion to assist in modifying sediment management practices
  Better models and understanding of the physical system will lead to better decisions
- **Business Process Efficiency**
  Baseline data to make future feasibility studies faster and cheaper
  Building a common database for all agencies to use
  Solving datum problems, which are currently costly to fix, but more costly to ignore if errors lead to bad or inefficient decisions
- **Stakeholder Collaboration**
  Improved communication between Federal, state, and local governments (and presumably nongovernmental organizations, too)
  RSM is a catalyst for realizing the importance of managing the coastal resources
  Understanding where the various states are in terms of coastal management and policies
- **Preparedness**
  Identifying future problem areas, and acting now (expected concentrations in population growth, related development, recreational use)
  Identification of where data collection is needed

Goals for National RSM Economic Assessment: The economics tasks for Fiscal Year 2001 include establishing the framework described in this paper and applying it to each of the demonstration projects. Efforts will focus on sharing measurement approaches and broadened concepts of benefits attributable to RSM. In Fiscal Year 2002, the scope of the analysis will widen to attempt to sum up the potential for RSM actions if undertaken on the demonstration districts as a whole. In Fiscal Year 2003, the scope will increase to assessing the potential of implementing RSM nationwide.

Conclusions

The intent of the National Regional Sediment Management Demonstration Program within the Corps is to improve the management of coastal sediment resources, with consideration of the watershed (from the riverheads, through the estuaries, to the coasts). The program has been designed to accomplish this goal by minimizing the interruption of natural sediment transport processes or by enhancing these processes to maximize environmental and economic benefits. Implementation of RSM, both from the grassroots level prior to implementation of the national program, and during the past year of the National Demonstration Program has resulted in partnerships between the Corps, state, local, and other Federal offices, some of which are cost-sharing RSM projects. The result of state and Corps RSM initiatives will be improved methods for managing sediment within our nation's waterways, with advances in conceptual, analytical, and numerical models, field measurement techniques, and implementation within GIS frameworks to support regional studies.

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Corps of Engineers Dredged Material Fate Models

James Clausner,[1] Joseph Gailani,[1] Allen Teeter,[1] Paul Schroeder,[2] Steven Bratos,[3] and Billy Johnson[3]

Since the 1970s, the U.S. Army Corps of Engineers has developed or refined a series of numerical models that predict the fate of dredged material. These models address concerns on environmental impacts related to dredging and placement of dredged material. These models include the Short-Term Fate of dredged material (STFATE), the Multiple Dump Fate of dredged material (MDFATE), the Long-Term Fate of dredged material (LTFATE), the Suspended Sediment FATE of dredged material (SSFATE), and the Pipeline Discharge Fate of dredged material (PDFATE). Included in this article are descriptions of the models, a brief history of model development, descriptions of model applications, input, output, availability, and brief descriptions of recent improvements to the algorithms. Also discussed are planned improvements in model usability and current plans for distribution. This article was extracted from Clausner et al. (2001).

Introduction

The fate of dredged material placed in aquatic environments is a major concern to the groups that dredge and place dredged material (primarily the U.S. Army Corps of Engineers and major port authorities), and to the agencies that regulate and oversee dredging and dredged material placement (EPA and the states). In recent years an increasing number of environmental groups and the general public are also expressing concerns over the fate of dredged material. Dredging and aquatic disposal practices that in the past were considered routine are in many cases receiving considerable scrutiny. The Corps' ability to continue providing safe navigation via low cost dredging practices requires being able to accurately predict the fate of dredged material placed in aquatic environments. Similarly, the Corps' ability to implement innovative dredging and placement practices is even more dependent on the ability to predict the fate of the dredged material.

In response to concerns about impacts of aquatic placement of dredged material, a number of numerical models that predict the fate of dredged material have been developed. These models span the range of processes that cause dredged material to be resuspended or transported (i.e., plumes resulting from the dredging process itself, water column plumes and the dredged material mounds created during placement of dredged material into aquatic placement sites), and the potential for the dredged material mounds to erode due to currents and waves. Model development has been funded primarily by the Corps and conducted primarily by the U.S. Army Engineer Research and Development Center (ERDC) at the Waterways Experiment Station (WES).

Major episodes of dredged material FATE models (hereafter referred to as FATE models) development and refinement have occurred during the Corps' Dredged Material Research Program (DMRP) in the 1970s; the Dredging Research Program (DRP) in the late 1980s and early 1990s; and is continuing under the Dredging Operations and Environmental Research (DOER) Program that started in 1997 and is still ongoing. In addition, the Corps' Dredging Operations Technical Support (DOTS) program has funded technical transfer and related work for FATE models, e.g., graphical user interfaces (GUIs), user manuals, training courses, etc.

Many of the FATE models developed under the DMRP and DRP were intended for use as screening or planning level models. Because the purpose of the models in most cases was for screening and/or planning, in certain cases a number of simplifying assumptions were made, and in other cases detailed modeling of some processes were not included. Low computing power (limited speed and memory) available during development of most of the models resulted in time invariant two-dimensional models (e.g., currents did not vary in time and had limited spatial variation) and a limited number of grids cells. Also, the time and cost required to develop the input and make model runs for fully 3-D models was so great (at that time) as not to be practical for most cases. Another reason for concentrating FATE model development on 2-D models was that 3-D models typically required a level of training and expertise not generally available in Districts.

However, in recent years, Corps Districts have applied the FATE models more frequently (often having ERDC staff apply the FATE models for complicated projects) as responses to concerns from resource agencies. In a significant number of cases, the FATE models are being used for design because there are no other more suitable models readily available that can be applied within a reasonable time frame and cost. These more detailed design applications using the FATE models are highlighting model limitations, and in some

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cases, the lack of a suitable model. For example, one limitation was unacceptable amounts of uncertainty associated with marginal representation of the actual physical processes, e.g., a time varying current (tidal) is needed to accurately model fine grained sediments concentrations in the water column from multiple placement over periods of hours. In other cases, insufficient data on model sensitivity to a range of input variables can be a concern. These limitations are spurring additional model development.

All the models described are designed to operate on personal computers (PCs), using a Microsoft™ operating system. Several of the older models (MDFATE and LTFATE) are presently only available as versions that use the DOS™ operating system; however, STFATE and SSFATE use current Windows™ (95 and newer) operating systems. All the older models are presently being converted to a Windows version. The STFATE, MDFATE, and LTFATE models can be downloaded for free from the Corps' Dredging Operations Technical Support Automated Dredging and Disposal Management System (ADDAMS) Web page *http://www.wes.army.mil/el/elmodels/*. User guides are also available on this Web site, although several of the user guides are in the process of being updated. Some of the newer models are not yet available for general distribution. Specific model availability and status is addressed in the section on that model.

An overview of existing dredged material fate models developed by ERDC follows subsequently. For each model the following information is presented: a short description of what the model does and the applications, a brief history of development, basic input and output, theory and major limitations. Present model availability and plans for improvements are also provided. This article concludes with some overall directions for model improvements and integration.

STFATE

The Short-Term FATE of dredged material model () simulates the behavior of dredged material placed in open water, emphasizing the water column aspects. STFATE models placement of a single load of dredged material from a hopper dredge or dump scow. The model provides screening level estimates of receiving water concentrations of suspended sediment and dissolved conservative constituents and the deposition of material on the bottom. STFATE can be used in evaluating water column effects of open-water disposal of dredged material in accordance with Section 103 of the Marine Protection, Research, and Sanctuary Act and Section 404(b)(1) of the Clean Water Act.

STFATE estimates receiving water concentrations of suspended solids, dredged material fluid and suspended phases, and dissolved contaminants as a function of time and location and compares contaminant concentrations with water quality standards. STFATE also estimates mixing zone requirements for discrete discharges to meet water quality standards. The volume of suspended solids deposited on the bottom as a function of time and location and the thickness of deposition is also estimated by STFATE. With this array of capabilities, STFATE can be used for site designation and sizing studies, to determine if a dredged material plume may impact resources of concern, or to address other water quality issues.

Field evaluations by Bokuniewicz et al. (1978) and laboratory tests by Johnson et al. (1993) have shown that the placement of dredged material from hopper dredges and bottom dump scows generally follows a three-step process: (a) convective descent during which the material falls under the influence of gravity, (b) dynamic collapse, occurring when the descending cloud or jet either impacts the bottom or arrives at a level of neutral buoyancy, in which case the descent is retarded and horizontal spreading dominates, and (c) passive transport-dispersion, commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation. Figure 1 illustrates these phases.

The convective descent phase models the release of dredged material from the vessel. During the convective descent phase, in almost every case the vast majority of the dredged materials falls in a dense jet directly to the bottom with minor losses to the water column. Important considerations included in the model are initial momentum (i.e., injection velocity and mass), density differences between the dredged material cloud and surrounding water column, entrainment of surrounding water into the descending jet, and stripping off of fine sediments from the main jet into the surrounding water column. The model simulates the convective descent phase as a series of individual hemispherical clouds. The use of separate clouds allows simulation of a moving disposal vessel.

The dynamic collapse begins when the disposal cloud either impacts bottom or arrives at a level of neutral buoyancy where descent is retarded and horizontal spreading dominates by density, kinetic energy, entrainment, and friction. Bottom collapse in STFATE is computed from a conservation of energy concept. When the cloud strikes the bottom, it possesses a certain amount of potential energy that can be computed since the mass of the cloud and the location of its centroid are known. In addition, the kinetic energy of the impacting cloud can be computed since its velocity and mass are known. Thus, the total energy of the cloud at the moment of impact is known. This energy is then available to drive the resulting bottom collapse or surge.

At most disposal sites, the convective descent and dynamic collapse phases only last on the order of a few minutes. When the rate of spreading of the collapsing cloud becomes less than an estimated rate of spreading due to turbulent diffusion, the collapse phase is terminated and the "longer" term transport-diffusion phase is initiated. In this phase, material in suspension is transported and diffused by the ambient current while undergoing settling. Any nonsediment constituents being

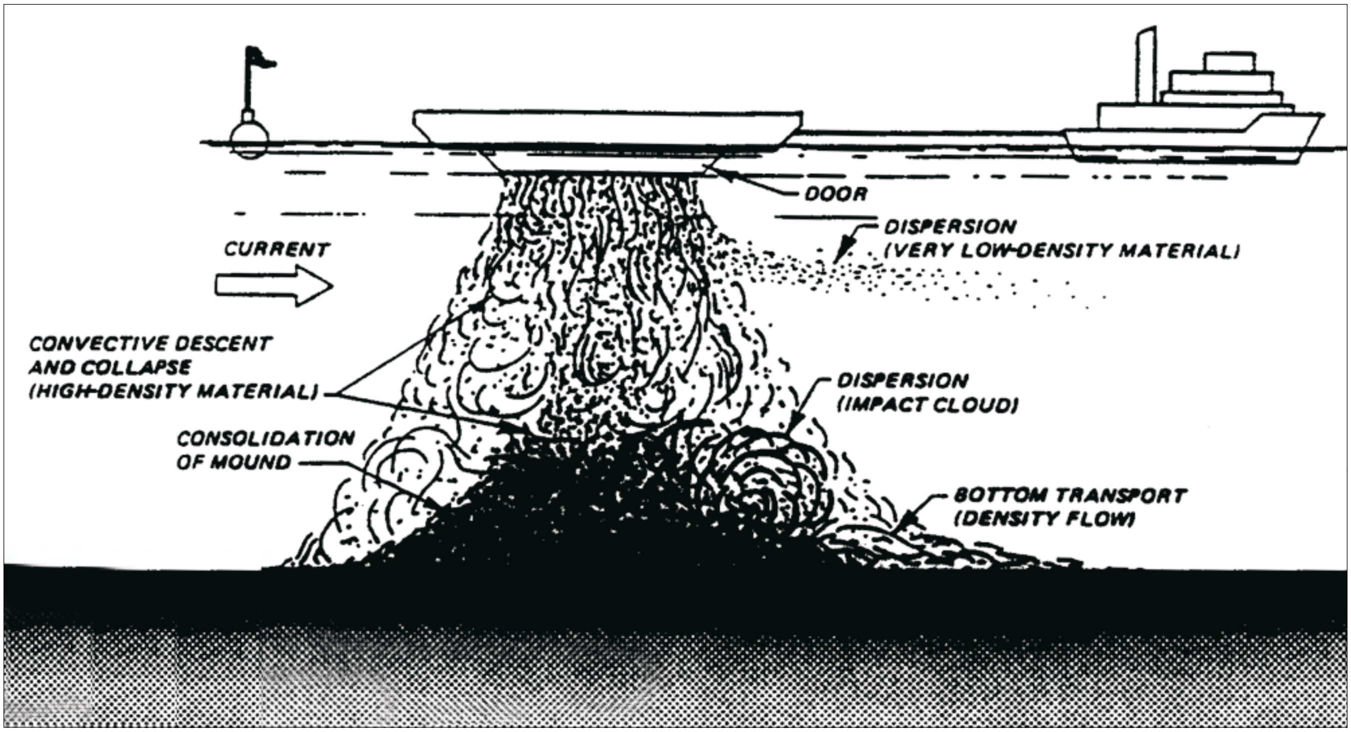

Figure 1. Processes modeled in STFATE

modeled are also transported and diffused. During the passive transport-diffusion phase, material transport and spreading are determined by ambient currents and turbulence rather than by the dynamics of disposal operation. The disposal clouds are transported by the velocity at the centroid of the cloud while experiencing both vertical and horizontal turbulent diffusion. Suspended sediment concentrations in the clouds are assumed to have a Gaussian distribution. Solids are allowed to settle by discrete settling or flocculent settling.

Model development in this area was initiated in the early 1970s with the work of Koh and Chang (1973) and was continued with developments by Brandsma and Divoky (1976) and Johnson (1990). However, deficiencies remained in the model. Research in the DRP which resulted in the STFATE model, was directed at removing many of these deficiencies, e.g., inadequate representation of disposal from hopper dredges, the inability to represent the nonhomogeneity of disposal material, the inability to model disposals at dispersive sites, the inadequate representation of the bottom collapse phase, and the inability to model disposal over bottom mounds. Basic concepts employed in STFATE are presented in the following paragraphs. Details can be found in Johnson and Fong (1993).

The previous discussion for the transport-diffusion of solids also applies to the disposed fluid with its dissolved constituents. The constituents are assumed to be conservative with no further adsorption on or desorption from the solids in the water column or those deposited on the bottom. Computing the resultant time-history of constituent concentration provides information on the dilution that can be expected over a period of time at the disposal site and enables the computation of mixing zones in water column evaluations.

Required STFATE input includes data on the disposal site, water quality, modeling parameters, description of the dredged material, and information on the disposal vessel. Disposal site data includes depth (actual bathymetry or a flat or uniformly sloping bottom), current velocity, and water density, roughness, and slope. Water quality data required are: elutriate concentration, water quality standards, and background concentration of chemical constituents of concern. Modeling parameters that must be entered are: coefficients (e.g., drag), grid output parameters, time-step, and simulation duration. The model provides default values of the coefficients. Dredged material description data includes: solids fractions, void ratio, specific gravity, and fall velocity. The dredged material can be modeled as consisting of up to four components from five possible choices (gravel, sand, silt, clay, and clumps). The disposal operation description includes volume, discharge vessel dimensions, disposal duration, and vessel velocity.

STFATE has several options for output, these include: time-history of descent and collapse phases; contaminant and solids concentrations as a function of location, depth, and time; volume and thickness of deposition as a function of location and time; graphics of maximum contaminant concentration, concentration contours, and deposition thickness.

One limitation of STFATE concerns its ability to accept and employ only simplified forms of ambient currents in its computations. Although several options exist, in each case the current is assumed to be time invariant (i.e., it is assumed to be constant over the time period that STFATE is normally applied, typically 2-4 hr). Options for the specification of ambient currents include a vertical profile for a constant depth water body and vertically averaged currents for a variable bathymetry application. In this case, STFATE will modify the vertically averaged velocities to match a log profile, if instructed to do so. Other limitations include: (a) STFATE does not accurately model the bottom dynamic collapse phase over bathymetry with significant bottom slopes, e.g., 2 deg or more. A fully three-dimensional model that can more accurately simulate bottom surges moving over variable bathymetry is being developed under the DOER Program. (b) No erosion of bottom sediments by the bottom surge is allowed in STFATE, and once sediment is deposited on the bottom it is assumed to remain there. (c) If the disposal operation is represented by several convecting clouds, more accurate water column results are computed, but the spreading of the bottom surge may be underestimated since STFATE does not model the interaction of multiple clouds collapsing on the bottom. (d) Suspended sediment concentrations are computed based on assuming the sediment takes a Gaussian distribution. In regions of high velocity shear, this assumption is likely violated. A DOS version of STFATE and an older user guide are available on the DOTS/ADDAMS Web site. A Windows 95, 98, 2000 version and an improved windows-based GUI are presently under development.

At this time, there are no specific plans to enhance algorithms. The ability to easily make a series of STFATE runs with different currents that represent normal tidal variations (e.g., slack, midtide, full flood, and ebb, etc.) has been developed in some specialized versions and is under consideration for general distribution. Smith and Wood (2001) describes a specialized version of STFATE developed to allow ADCP current data to be read in every 3 hr during a series of STFATE simulations. Inclusion of this capability into the widely available version of STFATE is also under consideration.

STFATE is routinely used to determine water quality compliance. Smith and Wood (2001) describes a comprehensive study where STFATE as used as part of the EIS process to investigate the impacts of barge size, barge load, and dredged material composition on the ability to meet water quality criteria. STFATE was used as part of a study of the Contained Aquatic Disposal (CAD) pits option in a Dredged Material Management Plan (DMMP) for New York Harbor (Chu et al. 1998).

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MDFATE

MDFATE predicts the geometry (height, side slope, and footprint) of dredged material mounds created by multiple placements of dredged material from hopper dredges or dump scows over time periods of weeks to months. MDFATE uses modified versions of STFATE and LTFATE to simulate multiple disposal events at one site to predict mound building and can be used to determine if navigation hazards are created, to examine site capacity and mound stability, to design capping operations, and to conduct long-term site planning. MDFATE was developed under the DRP (Hales 1995). MDFATE was formerly known as Open Water Disposal Area Management Simulation (ODAMS) program (Moritz and Randall 1995).

The primary uses of MDFATE are to predict mound geometry for the following applications related to open-water site management. MDFATE can be used to predict mound height to insure a minimum depth for navigation is not exceeded, perhaps by assisting in determining optimum placement locations. Related to this application is the use of MDFATE to determine how a change in dredged material or equipment will impact mound elevations. Perhaps the ultimate uses of MDFATE are to investigate long-term site capacity in relation to management of existing sites or designation of new site. Moritz (1997) provides a good description of MDFATE for this type of application. MDFATE has also been used in conjunction of capping projects. This often involves using MDFATE to predict the elevation and extent of the contaminated material mound to insure the mound does not exceed a specific elevation or extend beyond the disposal site boundary. The MDFATE capping option can also be used to predict the cap thickness for sandy caps placed by spreading (cracked hull and direct pumpout).

In MDFATE, the suspended solids and conservative tracer portions of STFATE are removed so the modified STFATE submodel within MDFATE models the convective descent, dynamic collapse, sedimentation and passive diffusion processes. The LTFATE model, described in detail in the following section, combines hydrodynamics (waves, currents, and tides) and sediment transport algorithms to predict the stability of dredged material mounds. The modified LTFATE submodel in MDFATE accounts for noncohesive sediment transport and noncohesive avalanching (once the dredged material slope reaches a given critical angle, it avalanches to a new, more stable angle). In addition to being able to model the high-density jet from a conventional bottom dump, MDFATE also has a capping module that simulates the slow release of material from a barge/hopper so it may spread evenly on the bottom with a minimum amount of momentum imparted to the primary mound (i.e., the particles are assumed to fall at the individual particle settling velocities).

MDFATE may be roughly categorized into three primary components: grid generation, model execution, and postprocessing. The initial step in executing MDFATE and the foundation of the model is generation of the gridded version of site bathymetry. Subsequent to grid generation, MDFATE execution consists of running the STFATE and LTFATE submodels, which provide information to update the grid with a revised bathymetry that reflects changes resulting from placements and/or erosion. Postprocessing consists of various plotting routines to present model results.

Much of the model input for MDFATE is nearly identical to STFATE. For the disposal site, MDFATE requires bathymetry (actual bathymetry can be imported or a flat or uniformly sloped bottom can be generated), residual currents and water density. Depth-averaged currents are the only option for current simulations, however, the direction can be changed once during the simulation to reflect a seasonal change. To improve the simulated mound configuration, waves and tides can be input. A constant wave period and direction can be input in addition to a wave time series. Also synthetic wave time series can be generated using statistics from the Wave Information Studies (WIS) data. Tidal currents can also be simulated using tidal constituents from the Advanced Circulation Model (ADCIRC). MDFATE has a number of placement scenario options including: at a point, along a line, grid points, or an ASCII file of random placements. Like STFATE, the placement vessel characteristics (length, beam, light and loaded draft, velocity) and sediment characteristics (grain size distribution, volume fraction, as deposited void ratio) must be included. Like STFATE, MDFATE can simulate the fate of material stripped from the descending jet. To fully define the placement scenario, the volume of each load, total volume placed, number of loads per day, and starting month and year are required.

The primary output from MDFATE is the final bathymetry that shows the results of the simulated mound placement. Within MDFATE, the initial bathymetry and final bathymetry grids can be subtracted to produce a bathymetry difference map. In addition, the volume change resulting from the placement operations are computed along with the maximum potential volume that would have resulted if all the dredged material released from the dredge reached the bottom inside the grid representing the disposal site. Cross sections can also be displayed. In addition to the graphic data, tabular data listing the input variables and placement locations are also produced. A sample of MDFATE output produced by the new graphical user interface (GUI) now being developed is shown in Figure 2.

Because MDFATE is based on STFATE, it suffers from all the STFATE limitations. MDFATE has only one current simulation option, a time invariant depth-averaged current. This becomes particularly important when there is a considerable difference between upper and lower water column (Moritz and Kraus 1999). Geotechnical limitations are also important; the avalanching angle algorithms have limited verification. The algorithms for consolidation of fine-grained sediments are limited. Fine grained mound stability phenomena, e.g., slope failures and bearing capacity are not included in

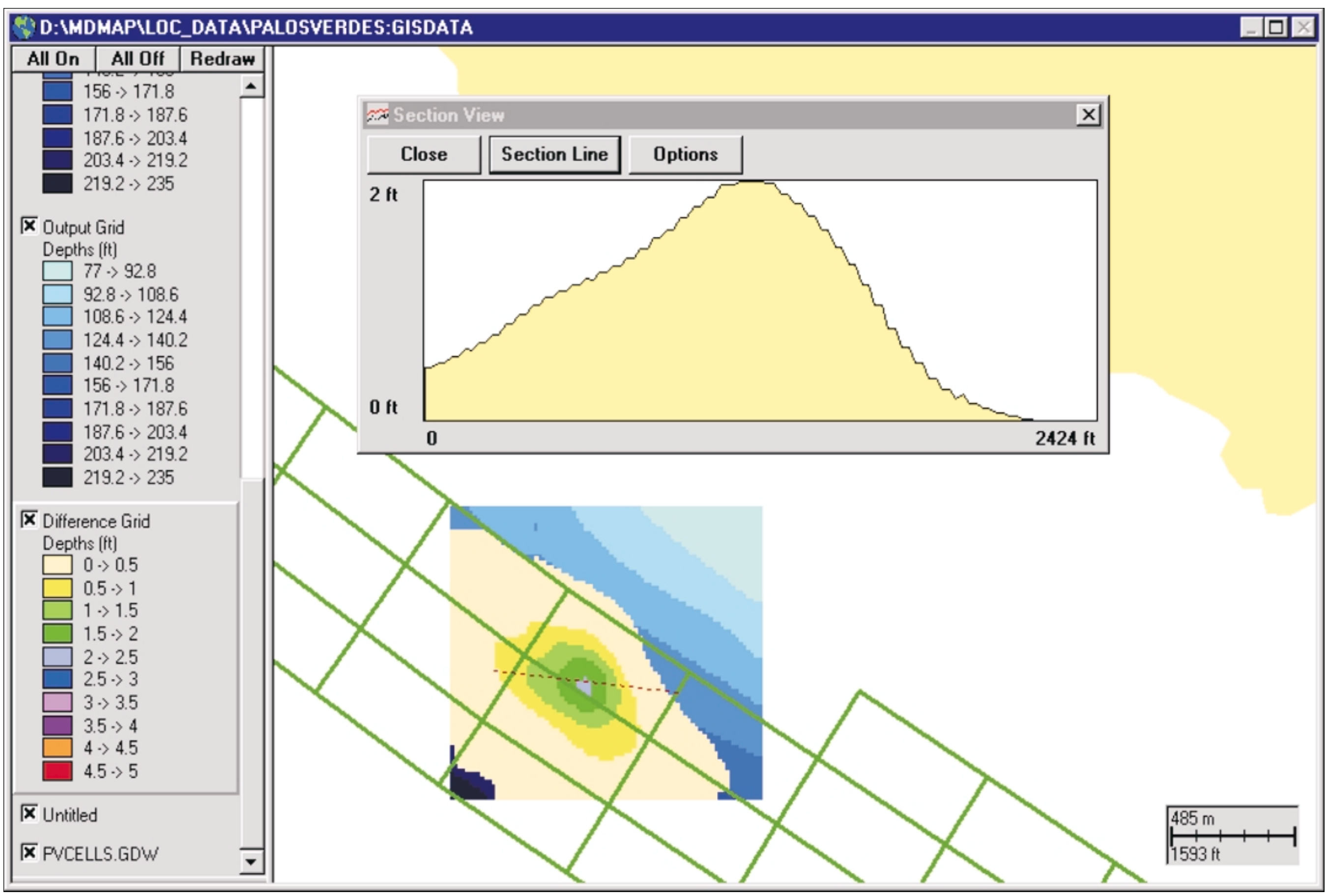

Figure 2. Sample MDFATE output from Palos Verdes Shelf, CA, application

the model. Also the amount of data on geotechnical properties of the dredged material in the disposal vessel prior to placement and on the bottom following placement are quite limited. Good verification data of MDFATE predictions are limited.

MDFATE was used extensively in the design of capping project at the Mud Dump site for New York District (Lillycrop and Clausner 1998). MDFATE was also used during the design of in situ capping project on Palos Verdes Shelf for Los Angeles District (Palermo et al. 1999) and design of capping project in Long Beach Harbor for Los Angeles District (Clausner, Gailani, and Allison 1998).[1] The initial application and model verifications were performed to predict dredged material mound configurations off Cape Fear, NC (Moritz and Randall 1995).

An older version of MDFATE and limited user's guide are downloadable from the ADDAMS Web site *http://www.wes.army.mil/el/elmodels/index.html#addams*. An improved Windows based GUI that has limited GIS capabilities, along with an improved user's manual and applications guide, are now under development under the DOTS program.

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LTFATE

The Long Term FATE of dredged material model (LTFATE), developed under the DRP, predicts dispersion from a dredged material disposal site for time periods ranging from several hours to several years (Scheffner 1996). The model predicts erosion, transport, and local deposition of material. It does not predict the far field deposition of eroded material. The model simulates dispersion for either sand or cohesive (fine) sediment and includes both current and wave forcings. The model is designed to permit multiple layers with different sediment properties for cohesive sediment erosion.

LTFATE is a disposal site management tool for investigating the stability of dredged material mounds. LTFATE can be used to predict mound dispersion for cohesive sediments and mound migration for sand material. The ability to make these types of predictions allow LTFATE to be an integral part of site capacity studies. Specifically, LTFATE can be used predict cap stability during storms and ambient conditions for sand or cohesive caps. This information can then be used to estimate necessary cap thickness for isolation during extreme events and estimate needed cap replenishment due to storm or ambient condition cap dispersion. The LTFATE model was designed for multiple, fast simulations. This permits the user to simulate different locations, mound configurations, storm hydrographs, and sediment types with reasonable CPU allotments. It also allows statistical based simulations such as the Empirical Simulation Technique.

LTFATE is a localized, two-dimensional, finite difference hydrodynamics and sediment transport model. Model inputs include mound bathymetry, sediment characteristics, and a time-history of local hydrodynamic and wave conditions. The model then simulates changing hydrodynamics across the mound and sediment erosion, transport, and deposition. The model can simulate either noncohesive (sand) or cohesive sediment transport.

Noncohesive sediment transport in the most recent version of LTFATE is based on equations developed at Delft Hydraulics Laboratory (van Rijn 1984a, 1984b, 1993). The user specifies three noncohesive grain size class sizes within the coarse sand/silt size range. The model estimates bed-load and suspended-load transport rates for each class of sediment. The three class sizes of sediments permit more realistic simulation of transport, where coarse grain material will armor the bed while finer material is eroded and transported long distances. Prediction of shear stress at each cell on the mound, necessary for estimation of erosion and deposition, is calculated using a combined current/wave shear stress model (Christoffersen and Jonsson 1985). An older, more widely distributed version of the LTFATE model available through the ADDAMS on-line software system includes a simpler, bed-load-only noncohesive sediment transport model. This model was initially formulated by Ackers and White (1973) for current only conditions and modified by Bijker (1971) and Swart (1976) to account for combined current/wave effects. This procedure works fairly well when (a) conditions are current, not wave, dominated, and (b) shear stresses are moderate. The newer version better simulates processes in high energy and wave-dominated conditions.

Recent DOER work in erosion of cohesive sediments has added fine-grain sediment transport algorithms to LTFATE (Gailani 1998). Bottom shear stress is estimated using the Christoffersen and Jonsson (1985) combined current/wave model. Because cohesive sediment bed characteristics will change with depth below the sediment/water interface (i.e., bulk density affects erosion rate), the model includes a layered sediment bed model with user-specified erosion characteristics. For each layer, erosion is estimated using the standard epsilon equation for erosion rate (Ariathurai and Krone 1976). The user-specified input requires that the user obtain some knowledge of the erosion potential of the sediments being modeled. This is a requirement of any cohesive sediment transport model because small changes in sediment properties can result in order of magnitude changes in erosion rate (Jepsen, Roberts, and Lick 1997).

One of the major limitations of LTFATE is that the grid dimensions do not permit analysis of far field fate of

1 Clausner, J. E., Gailani, J. Z., Allison, M. (1998). "MDFATE modeling of contaminated sediment and cap placement in the eastern section of the north Energy Island borrow pit," draft report prepared for the U.S. Army Engineer District, Los Angeles, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

eroded material. For sand this a not a particular problem, but for fine grained sediments, this in some cases can be quite limiting. Another limitation is that cohesive sediment erosion parameter data availability are often limited or difficult and expensive to collect. Storm current and wave data can often be difficult to acquire or validate. LTFATE does not account for bed-load transport of cohesive aggregates or simulate fluid mud movement. At the present time, wave asymmetry is not included, making LTFATE unsuitable for surf zone and very nearshore applications. In addition, LTFATE is two-dimensional. Therefore, the user must use extreme caution when applying it to regions where the water column is stratified. If there is a large vertical region near the bottom where the flow is uniform, then the model can be used, but this near-bottom velocity should be used as the input current, not the vertically averaged velocity. Finally, due the difficultly in acquiring good before and after bathymetry data associated with storms, there is limited verification on actual projects.

Input required by LTFATE includes site bathymetry and mound geometry. The program can use either an idealized mound/CAD cell geometry, imported existing geometry, or imported MDFATE predicted geometry. LTFATE requires boundary forcing functions. These include a time-history of current and water level conditions due to wind, tide, and storms and a time-history of wave conditions (height and period). These boundary forcings can be obtained from field data, storm databases, or far field circulation and wave models. A description of sediment parameters is also required. For sand, the grain size of the particles is needed, while for cohesive sediments, site-specific erosion parameters are required. These data are generally acquired from laboratory or field testing of the site sediments. Avalanching angles for cohesionless sediment are an input available from standard textbooks on sand transport. Finally, the thickness of the sediment layer at each grid cell is required.

LTFATE output consists of time-histories of: bathymetry and change in bathymetry over the entire grid; time-history of vertically averaged sediment concentration over the entire grid; and time-history of bottom shear stress over the entire grid. If desired, the user can specify more frequent time-history of concentration and change in bathymetry at user specified points on the grid.

LTFATE has been applied at a number of projects. LTFATE was part of a site designation study for the proposed Providence River Dredging (Gailani and Smith 2001).[1] LTFATE was also used to assist designating a new disposal site for the Wilmington Harbor, NC, project (Clausner et al. 2000).[2] As part of that study, LTFATE was used to hindcast erosion of an existing mound in the old disposal due to Hurricane Fran. While no actual sediment characteristic data were available, a limited investigation showed reasonable agreement between actual and predicted erosion. Figures 3 and 4 show the results. Figure 3 is the actual erosion, while Figure 4 is the LTFATE predicted erosion. Maximum depth of erosion is represented well in model results. The volume of erosion is overestimated by the LTFATE model, but the comparison is reasonable for predictive and management purposes.

LTFATE has also been used to assist in design of contaminated sediment capping project. LTFATE was used in the design of in situ capping project on Palos Verdes Shelf for Los Angeles District (Palermo et al. 1999) and in design of capping project in Long Beach Harbor for the Los Angeles District (Clausner et al. 1999). LTFATE has also been used for evaluating dredged material mound stability as part of Environmental Impact Statements (EIS). This was done for a site of Cape Fear, NC (Clausner et al. 2000), and for the Providence River Project (Gailani, Sturm, and Wood 2001).

On-line references for LTFATE are available at *http://www.wes.army.mil/el/dots/doer/technote.html*, and include technical notes DOER-N1, N4, and N6.

An older, DOS-based version of and limited user's guide are downloadable from the ADDAMS Web site - *http://www.wes.army.mil/el/elmodels/index.html#addams*. However, this version does not have any of the improvements made under the DOER program and is only recommended as a planning tool for noncohesive sediments in deep water. A more user-friendly version that operates within ESRI's ArcView GIS and incorporates some of the algorithm improvements from the DOER program will be available to Corps offices in early 2002. A new GUI for the most recent version of LTFATE is being considered.

Point of contact for LTFATE is Dr. Joseph Gailani, ERDC Coastal and Hydraulics Laboratory, (601) 634-4851, *gailanj@wes.army.mil*.

SSFATE

A model recently developed under the DOER Program is the Suspended Sediment FATE of dredge material model (). SSFATE is a screening level model that computes suspended sediment concentrations resulting from dredging activities. This is in contrast to STFATE that predicts suspended sediment environmental windows questions, primarily the fate of the dredged material plume over larger scales (up to 10 + km) and over longer times than STFATE, up to several tidal cycles. The modeling system employs a shell-based approach consisting of a color-graphics-menu-driven

1 Gailani, J. Z., and Smith, S. J. (2001). "Dredged material fate modeling of proposed Providence River confined aquatic disposal (CAD) cells and ocean dredged material disposal site (ODMDS)," prepared for U.S. Army Engineer District, New England, (draft) by U.S. Army Engineer Research and Development Center, Vicksburg, MS.

2 Clausner, J. E., Gailani, J. Z., Bratos, S., Thompson, E., Scheffner, N. W., and Allison, M. (2000). "Dredged material fate modeling of the proposed Wilmington Harbor ocean dredged material disposal site (ODMDS)," draft report prepared for the U.S. Army Engineer District, Los Angeles, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

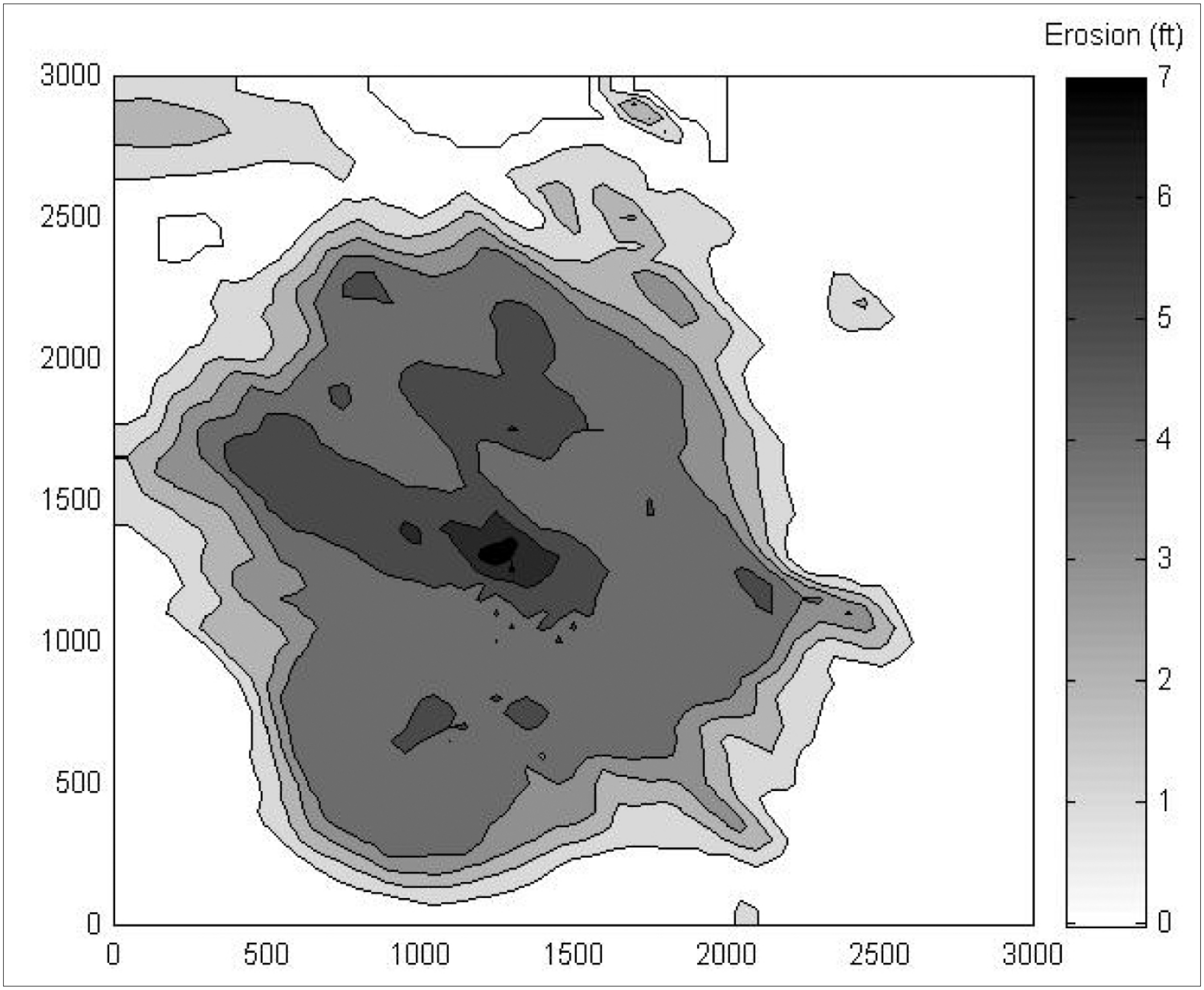

Figure 3. Bathymetry difference map showing erosion of a mound in the Wilmington Harbor, NC, ocean dredged material disposal site due to Hurricane Fran (To convert feet to meters, multiply by 0.3048)

user interface; geographical information system (GIS); environmental data management tools; and gridding software. All of these tools interface with supplied input data and display output from the model, e.g., animation of the suspended sediment plume. SSFATE can be set up to operate at any dredging operation site and includes a series of mapping and analysis tools to facilitate applications. Initial setup for new locations of dredging operations can normally be accomplished in a few hours.

SSFATE was developed in response to the need for tools to assist dredging project managers when confronted by requests for environmental windows. In many cases, decisions regarding environmental windows are based on limited technical information, with potential impacts linked to a host of site- and project-specific factors. For example, navigation dredging operations in different reaches of the same waterway may pose risks to different resources, or potential impacts may vary depending on the type of dredge plant involved.

SSFATE allows screening level estimates of suspended sediment concentrations associated with hopper, cutterhead, and mechanical dredges. The user can readily vary source strengths, sediment characteristic, and currents and visualize the plume created in relation to resources of concern.

can be applied in rivers, lakes, and estuarine systems on a spatial scale of up to tens-of-kilometers. For each location, the user supplies digital data describing the shoreline and the bathymetry. These data can be digitized from an appropriate map, obtained from digital databases, or produced by using an external GIS and then imported into the system. Other input data include:

- *Ambient currents* - These can either be imported from an external numerical hydrodynamic model, drawn graphically using interpolation from field data, or computed internally using information from the NOAA Tides and Currents Tables.
- *Sediment sources* - SSFATE contains algorithms that compute the sediment source strength and

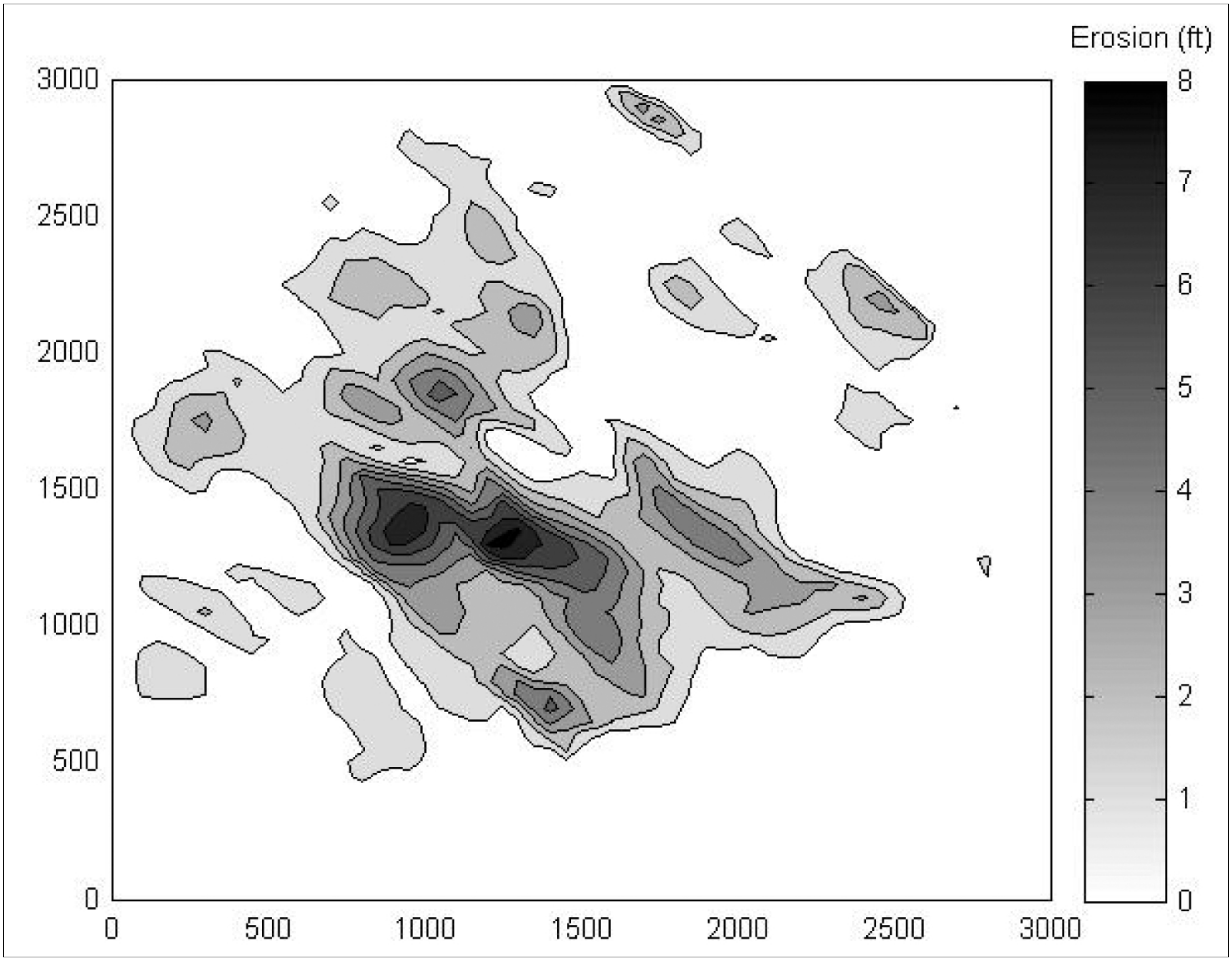

Figure 4. Bathymetry difference map showing erosion predicted by LTFATE of a mound in the Wilmington Harbor, NC, ocean dredged material disposal site due to Hurricane Fran

distribution for hopper, cutterhead, and clamshell dredges. The user can also specify a generic source strength and distribution. Multiple sources and their times of operation can be specified within a location.

- *Sediment characteristics* - Information about the sediment being dredged is required, e.g., the bulk density and the percent of each solids class making up the material to be dredged. Settling velocities for fine-grained sediments are computed internally within SSFATE.
- *Model parameters* - A horizontal diffusion coefficient is either specified or SSFATE will compute it internally. The vertical diffusion coefficient must be specified. In addition, parameters that determine how many particles are released and the level of smoothing employed in the computation of concentration contours are specified.

SSFATE output includes animation of the particles representing each sediment type individually or all the particles together over GIS layers depicting environmentally sensitive areas. Additional outputs are:

- Horizontal and vertical concentration contours of each sediment type or a superposition of all suspended sediment,
- Time series of concentrations available for plotting at each point of the numerical grid,
- Spatial distribution of sediment deposited on the sea bottom,
- Tabular summaries of how much sediment is in suspension, how much has been deposited, and how much has left the numerical grid.

A sample SSFATE output is shown in Figure 5.

SSFATE is based on a computational model that simulates the suspended material as a series of particles. These particles are transported by the ambient currents, dispersed by turbulence, and settled. Dispersion is modeled using a random walk procedure. The model contains algorithms for computing sediment source terms for hopper, cutterhead, and clamshell

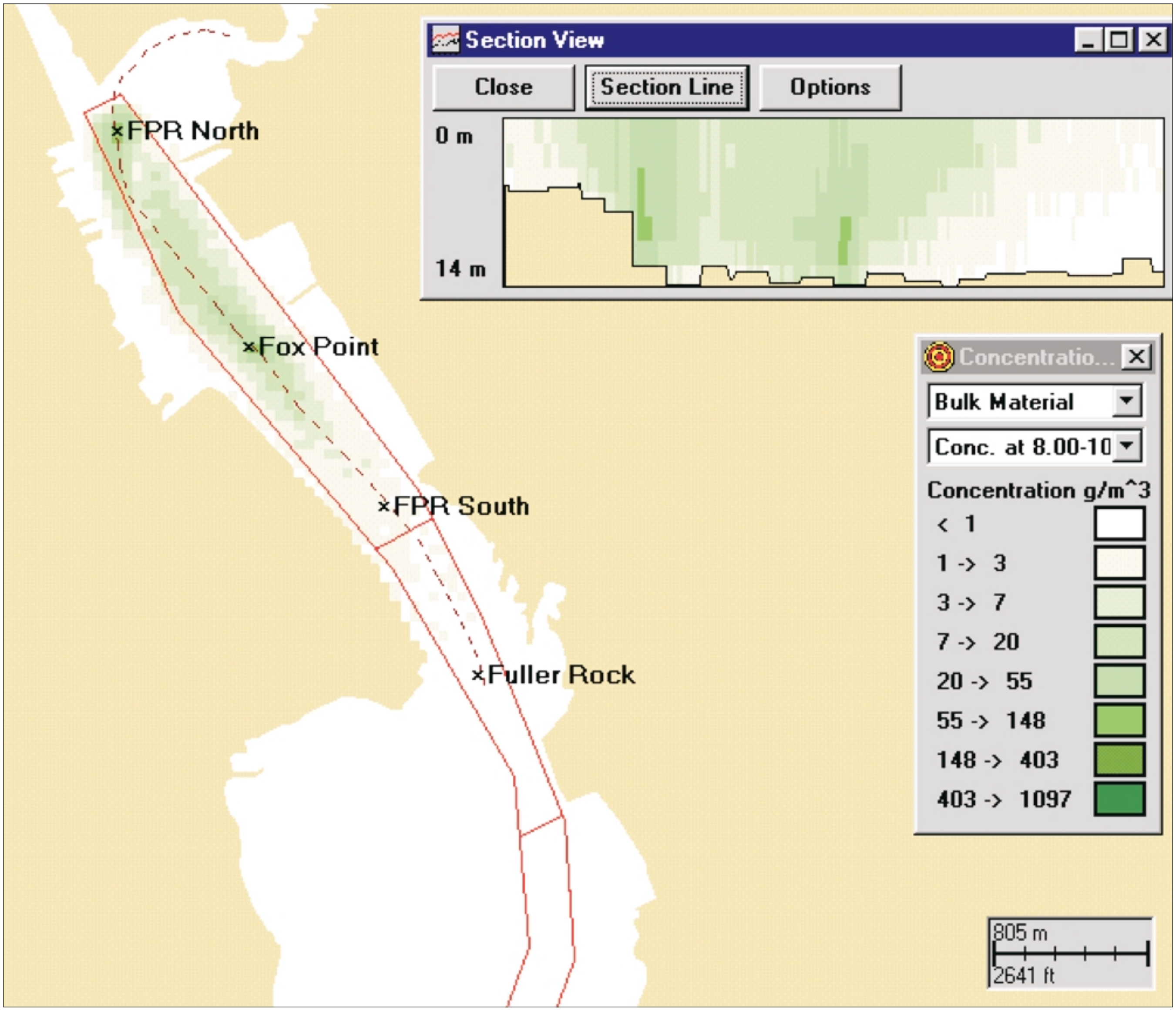

Figure 5. Sample SSFATE output showing plume TSS from a mechanical dredge operating on the Providence River (note that two dredges operating simultaneously are shown)

dredges, as well as a generic source term that allows the user to specify source strength and its vertical distribution.

SSFATE has a number of primary assumptions. Within SSFATE, the suspended sediments are treated as a limited number of particles. The sediment sources are point or vertical line sources and a moving point or vertical line source is also supported. Any overflow from a hopper or clamshell dredge plant is neutrally buoyant. Simulations have a constant vertical diffusion coefficient.

SSFATE assumes a uniform water column, thus the effect of water column stratification on vertical diffusion is not allowed. For shallow, well-mixed estuaries and open coasts, this is not seen as a major problem. SSFATE is limited to vertically-averaged ambient currents. Although three-dimensional ambient currents can be imported, the expected normal use of SSFATE will involve the use of vertically average currents. In addition, if currents are graphically drawn from field data, phasing effects are not modeled. The numerical grids normally constructed for SSFATE simulations are rectangular with maximum dimensions of 100 x 100 grid cells. The number of cells is such that a smooth representation of bathymetry is not always possible. A boundary-fitted grid can be imported, but a smooth representation of bathymetry still is not always possible. A major source of uncertainty is found in the specification of the dredged material source terms. The amount of data upon which the terms are based is quite limited.

The U.S. Army Engineer District, New England, conducted studies to determine whether the use of environmental windows is justified both environmentally and economically for the proposed Providence River and Harbor Maintenance Dredging Project. Modeling of the plumes generated from the dredging process to determine the extent and duration of such plumes using SSFATE was one component of the studies.

Additional developments are underway to add a time-integrated sediment dose computation, which is computed as a concentration time-history for motile and sessile organisms to SSFATE. In addition, a source term representing a fluid mudflow resulting from a pipeline discharge is being added. Considerations are underway to allow a background TSS level to be displayed and used within the computations. Collaboration with HR Wallingford Research Laboratories, United Kingdom, is expected to better define the sediment source terms in SSFATE.

SSFATE and documentation are available from the U.S. Army Engineer Research and Development Center in Vicksburg, MS, to all offices of the U.S. Army Corps of Engineers. Others should contact Applied Science Associates, Inc., in Narragansett, RI.

On-line technical notes describing SSFATE are available at *http://www.wes.army.mil/el/dots/doer/technote.html*, and include technical notes DOER-E6, E10, and E12.

Points of contact for SSFATE are Dr. Douglas Clarke, ERDC Environmental Laboratory, (601) 634-3770, *clarked@wes.army.mil*, and Mr. Eric Anderson, Applied Science Associates, (401) 789-6224, *ela@appsci.com*.

PDFATE

The Pipeline Discharge FATE of dredged material (PDFATE) model predicts the extent and thickness of fluid mud mounds created by placement of pipeline dredging in shallow estuaries. PDFATE is the most recent of the FATE models, a beta version of PDFATE was completed in 2001 under the DOER program.

will be used in managing open-water disposal sites, specifically, shallow (5 m deep or less) estuarine sites where dredged material is placed with a pipeline. PUFFATE can be used to site, size, and manage these types of sites. PDFATE will predict the extent of the dredged material mound created and its thickness as a function of bottom slope, sediment characteristics, and dredge operating characteristics. This information can also be useful in determining disposal losses through entrainment into the water column and whether the mound might impinge on sensitive bottom areas. The spreading fluid mud layer simulated by PUFATE is called underflow.

The PDFATE model conserves mass and momentum and simulates the following processes: bottom friction; entrainment of ambient water into the underflow; deposition of the underflow due to settling; and lateral spreading. Presently under consideration is an option to have PDFATE provide a source term that can be used by SSFATE to predict the fate underflow sediment particles that have been resuspended into the water column by waves.

Most pipeline-discharged material reaches the bed in shallow water shortly after disposal. For example, it has been estimated that 95 to 99 percent of the discharged sediment mass descents to the bottom layers within 30 m of the point of placement. Once near the bed, sediments form fluid mud layers that flow away from the discharge point. The rate and extent of spreading is a function of bottom slope, ambient currents, and the initial injection trajectory. The bottom layer quickly thickens at the point of discharge, depending on the bed slope, and spreads under the influence of gravity.

Empirical evidence suggests that the underflow become laminar after spreading a short distance along a flat bottom. As the fluid mud layer spreads, it becomes less dense due to entrainment while it is turbulent flow. Fluid mud is considered pseudo-plastic with various rheological models used to define its stress relationship over two shear ranges. Teeter (2000) describes the theory used in PDFATE in detail, while Teeter (in preparation) provides details on the PDFATE model.

The PDFATE model requires input for the following items: discharge characteristics including depth and orientation, pipeline discharge rate, duration, and sediment concentration, coefficients relating transition from the pipeline injected slurry into a fluid mud underflow layer, ambient fluid density and current, bottom slope, horizontal step size, and underflow sediment conditions (e.g., settling rate as function of concentration, depositional threshold, yield stress and viscosity coefficients and exponents).

Model output lists the trajectory, travel time, thickness, breadth, and concentration of the underflow. From this information, plots can be generated of the location of the water surface, underflow surface, deposit layer surface, and original bed surface versus distance at a given time from the start of placement. A plan view plot showing the length and width of the deposit can also be created.

Bed slope is assumed to be uniform in the downslope direction. The bed is therefore represented as a planar surface, and this limits the geometric representation of the disposal area.

As previously noted, PDFATE does not predict the water column concentrations of suspended solids for any material that does not descend to the bottom in the initial descending jet. PDFATE does estimate water column sediment concentrations due to material eroded from the underflow layer by waves, but does not have the capability to advect these suspended sediments beyond the area above the deposit. If water quality (i.e., suspended solids concentrations) due to the placement process are a major concern, then the ERDC CDFATE model (*http://www.wes.army.mil/el/elmodels/index.html#addams*) can be used to make those predictions. One limitation of PDFATE is that it cannot use real bathymetry, as described earlier, or produce output in a full 360-deg horizontal mode. Not enough experience has been gained with this model to fully assess other limitations.

Because PDFATE is still under development; it has not yet been applied to a project. Model calibration data were collected during dredging of the estuary at Laguna Madre, TX, in 2000. Plans are to use at least two other sites for model validation. Candidate sites are in Chesapeake Bay, near Norfolk, VA, or at another site in Texas.

A beta version of the model was completed in 2001, along with a draft user manual. A limited distribution version of the model and an improved user's guide are now being considered; however, PDFATE is not yet available for distribution.

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Plans for the FATE Models

Specific plans for FATE model improvements, particularly related to improved capabilities or algorithms were discussed as previously. Additionally, the FATE models are being supplemented by other tools, ranging from simple calculations available over the internet to 3-D tools to address limitations of 2-D models. The ERDC DOER Web page, *http://www.wes.army.mil/el/dots/doer/doer.html,* will soon have these simple tools on-line. The remainder of this section provides details on the overall goal and direction of FATE model development.

Under the Nearshore/Aquatic Placement Focus Area of DOER, the entire suite of FATE models is being examined. While still in formation, the basis for future development and integration will be based on the following principles. The overall goal is to make the models more easily used. This entails a range of improvements. The obvious step of developing Windows-based GUIs has already begun. In the near future, all the GUIs will have some form of GIS included. A goal is to not require a commercial-off-the-shelf (COTS) GUI for the FATE model due to the expense of the COTS GIS. However, the models should produce output compatible with COTS GIS.

Improved project application manuals to accompany the software user's guide are being developed. Project application manuals describe how to apply the model to a real world project and include how to develop input for a specific application, reasonable default values, when more detailed information is needed, sources of more detail information, and example applications.

Ultimately, all the FATE model will be provided with that look and operate similarly. Thus, once a user has had training in one model, he/she can easily use another model. Models that have similar functions may have a single GUI. The models will have a common module(s) for inputting data and common data input structure and standards. This will allow input data to be shared. For example, all the models require input bathymetry, with a common format/standard, the input grid could be used for any of the models. STFATE and MDFATE have nearly identical required input. Once the input file for STFATE has been created, the information will be transferable to an associated MDFATE input file, thus saving considerable time. Output data standards will be developed with similar, if not identical file structures. Thus the output from one model could become input to a second model with little or no modifications required. Similar models may be combined. Another likely improvement will be the ability to run batch jobs over a range of variables to identify sensitivity or find an optimum solution.

Another goal is improved access to and creation of input files, particularly for the more difficult environmental driving forces, waves, currents, and water levels. For example, methods to easily create or access ADCIRC simulations for currents and wave levels are being considered.

Significant time and effort has gone into development of the Surface Water Modeling System () (http://chl.wes.army.mil/sms7/docs/sms70.chm), which houses a number of hydrodynamic models (e.g., ADCIRC and STWAVE (a wave transformation model)). Plans are underway to make the FATE models at least compatible with SMS and perhaps to include some of the FATE models in SMS.

Models are developed to assist engineers and scientists in making a decision about project (e.g., where and when material can be placed in a disposal site to minimize the potential for material to exit the site boundaries or, conversely, at what stages of the tide and how close to the boundary can material be placed and not exceed water quality standards). While the results of a model may be a key component for making this decision, a host of other factors are important. A decision support system attempts to provide the user with as much information as practical to make a decision. Thus the decision support system can identify available models that are appropriate for a given application, locate and acquire data needed to run the model, actually access the model and conduct the simulation, suggest a range of parameters over which to simulate to identify the best solution. A decision support system would be accessed via a personal computer, but use the Internet to actually assist in the decision-making process via some type of framework software. An example of this decision support system concept and supporting framework can be found in the Land Management System (LMS) (*http:://www.denix. Osd.mil/denix/Public/Library/LMS/lms.html*). The ultimate goal will be to have the FATE of dredged material models a part of a larger decision support system specifically designed for dredging and placement.

Summary

Brief discussions of the fate of dredged material models (STFATE, MDFATE, LTFATE, SSFATE, and PDFATE) have been presented. Plans for future model improvements also have been provided. Much of this basic information on the models presented here is or will be available on the Internet as information sheets for these and other related dredged material fate models. The site will be located on the DOTS Web page at *http://www.wes.army.mil/el/elmodels/*.

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Contributions of pertinent information are solicited from all sources and will be considered for publication. Communications are welcomed and should be addressed to the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, ATTN: Dr. Lyndell Z. Hales, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call (601) 634-3207, FAX (601) 634-4253, Internet: Lyndell.Z.Hales@erdc.usace.army.mil

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