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Lessons Learned in Regional Sediment Management: The Mobile District Demonstration Program; Technical Program Implementation

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PURPOSE. The goal of the US Army Corps of Engineers Mobile Districts (CESAM) Regional Sediment Management (RSM) technical program was to develop and apply tools to allow CESAM to evaluate coastal processes, quantify sediment transport, and understand sediment transport patterns and pathways at regional scales as well as at project scales. A lesson learned is that successful implementation of RSM requires application of engineering tools appropriate for regional management and analysis. Regional engineering tools include the sediment budget, numerical models, and a Geographic Information System (GIS). Each tool requires contemporary and historical data sets for input and analysis. Ideally, continuous synoptic surveys are available on a regional scale. The sediment budget is the primary tool for regional management because it provides an understanding of the sediment transport patterns and pathways, and beach and bathymetry changes over the region. Through the sediment budget, regional impacts resulting from proposed project modifications can be predicted. Development of the regional sediment budget is directly linked to data management and analysis within the GIS, and sediment transport rates derived from numerical modeling. Because data collection and numerical model applications are historically obtained and applied on a project-by-project basis, difficulties can be encountered in developing a regional sediment budget. This Coastal and Hydraulics Engineering Technical Note (CHETN) documents the lessons learned from the RSM technical program implementation by the US Army Corps of Engineers Mobile District, Mobile, AL.

The CESAM RSM demonstration region extends approximately 600 km from the St. Marks River, FL (eastern boundary), to the Pearl River, MS (western boundary) (Figure 1). To aid in the management of such a large region, the domain was divided into 11 sub-regions based on geography, geology, and/or sediment transport patterns.

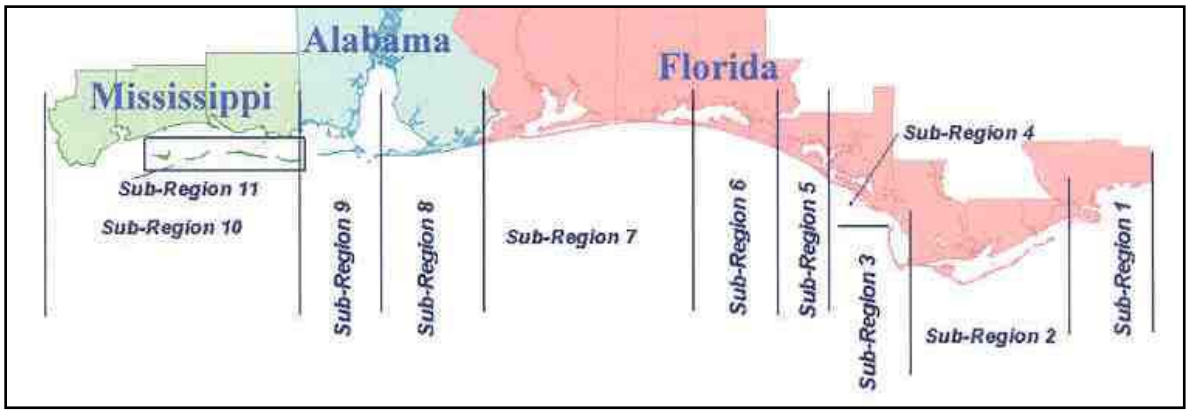

Figure 1. Northern Gulf of Mexico Regional Sediment Management domain.

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TECHNICAL PROGRAM APPROACH.

Interagency Coordination. A successful RSM program requires coordination and communication with all agencies having an interest in the RSM domain. A Technical Working Group (TWG) was established to provide guidance in developing and implementing the program, and to enhance sharing of information and data. The TWG includes representatives from Federal, State, and local governing agencies, and from academia in Florida and Alabama.

Technical Process. The technical program followed the process outlined in Figure 2. The process began by developing a preliminary regional sediment budget based on a thorough literature review. This initial sediment budget quantified the knowns and qualified the unknowns relative to sediment transport over the region. CESAM then developed a program to improve our knowledge through field data collection and application of numerical models. Information gained provided data to refine the sediment budget. It was quickly realized that a data management and GIS tool would be necessary to manage, visualize, and perform analysis of information and data over the large domain. The GIS also provides a means to share information and data with organizations and agencies having an interest in the domain. This comprehensive suite of engineering tools improves ones ability to assess coastal process on a regional scale; manage, analyze, and visualize data; evaluate sediment management practices; develop new procedures to improve sediment management; and evaluate impacts of modified sediment management practices (Lillycrop and Wozencraft 2003b).

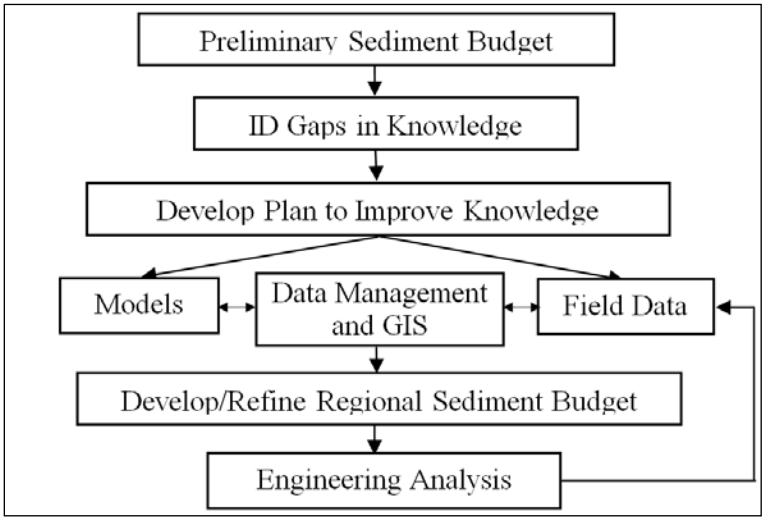

Figure 2. CESAM process to implement Regional Sediment Management.

Engineering Tools. The following engineering tools were identified as necessary for RSM implementation:

- a regional sediment budget, including micro-budgets at sub-regional and project levels
- numerical models to evaluate hydrodynamic conditions, sediment transport, and shoreline change at regional, sub-regional, and project scales
- a data management tool for managing and storing historic and new data, and a tool for performing analysis of data and model results, to allow sharing of information and data.

The following data are necessary to perform regional coastal processes management:

- hydrodynamic and meteorological data (waves, water-levels, currents, winds, and storm data)
- historic bathymetric, topographic, and shoreline data
- regional, continuous, current, and synoptic bathymetric and topographic surveys
- geo-referenced ortho-rectified aerial photography and/or satellite imagery.

TECHNICAL PROGRAM IMPLEMENTATION.

Preliminary Regional Sediment Budget. A key element for successful RSM is the regional sediment budget. The sediment budget assists in identifying longshore sediment transport rates, sediment transport patterns and pathways, and areas of erosion and accretion; and in understanding the reasons for, and magnitude of, beach and bathymetry change over the region. Through the sediment budget, regional impacts resulting from proposed modifications to sediment and project management can be predicted. A preliminary or conceptual regional sediment budget was created based on available historical information and using the Sediment Budget Analysis System (SBAS) (Rosati and Kraus 1999) (Figure 3). The conceptual budget quantified the knowns and qualified the unknowns relative to sediment transport over the region. The sediment budget provided direction for the program by identifying regions where data collection, information, and policy are needed (primarily Alabama and Mississippi).

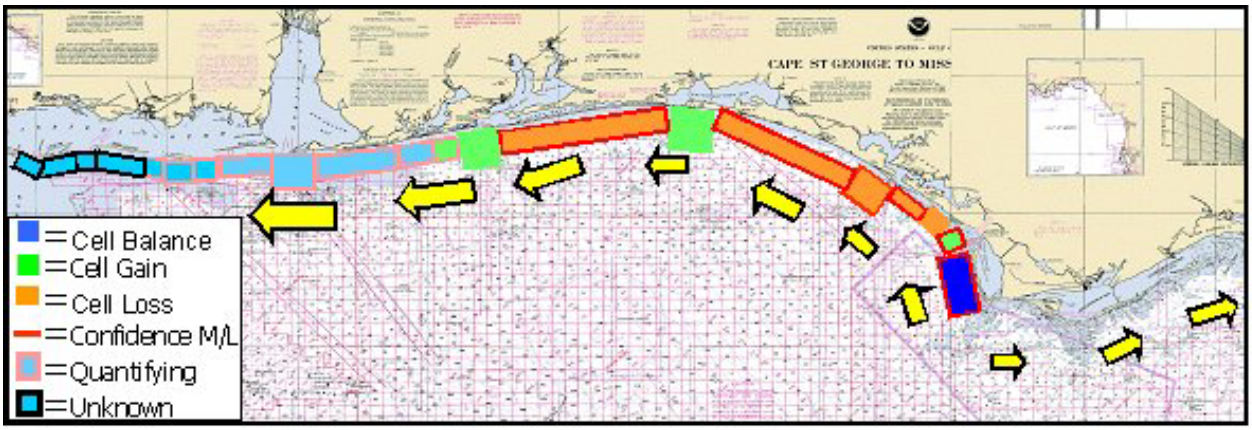

Figure 3. Preliminary regional sediment budget.

Field Data Collection. A field data collection program was implemented to acquire data for areas lacking information. In 2000, data collection efforts focused along the Alabama shoreline and included geo-referenced aerial photography, beach profiles, and the first survey of the entire Mobile Pass ebb shoal since the early 1900s. Geo-referenced aerial photography was also collected along the Mississippi barrier islands. Regional hydrographic surveys were also collected over the Florida Panhandle to Perdido Pass, AL, using the Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) System (Guenther and Lillycrop 2002). Funds from District coastal projects were leveraged to collect project level surveys, SHOALS surveys, and aerial photography for incorporation in the RSM GIS.

During the Demonstration Program, 1 year of wave, water-level, and current data were collected at Pascagoula, MS, through the Pascagoula River Harbor Dredged Material Management Plan feasibility study. Wave and water-level data are currently collected at Perdido Pass, AL, to correlate the forcing functions with sand transport at an RSM sand bypassing initiative designed to improve sediment management at this site.

Baseline Dataset. A baseline data set (Figure 4) was developed to define the RSM existing 2000 conditions for the numerical models and the sediment budget. Because collection of required bathymetric, topographic, and aerial data over the entire region for a given year is not economically feasible, the regional baseline data set consists of a compilation of bathymetric and topographic data, beach profile data, and aerial photography over a given time period. The regional baseline data set is based on 1998 and1999 aerial photography and the National Imagery and Mapping Agency (NIMA) digital nautical chart data, which is a compilation of data over many years. The NIMA nautical chart data were augmented with the following 1997 and 2000 surveys: (1) SHOALS hydrographic and topographic surveys, (2) CESAM conventional project surveys, and (3) beach profiles from the Florida Department of Environmental Protection (FLDEP) and CESAM. The baseline was created through manipulation of these data sets using the SHOALS Toolbox (Wozencraft et al. 2002).

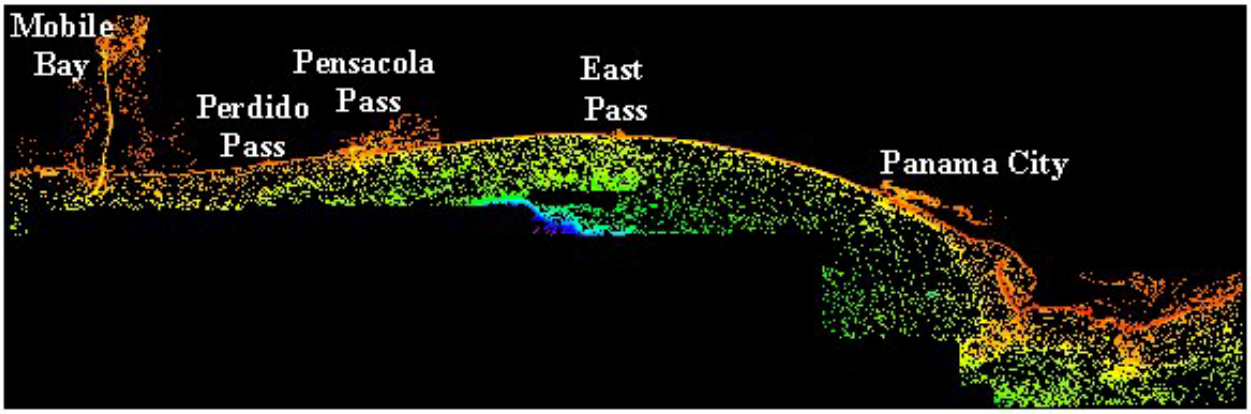

Figure 4. RSM baseline dataset.

Numerical Model Application. To refine the preliminary sediment budget, CESAM coordinated with the US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory, to apply a suite of hydrodynamic models to the RSM region. The modeling efforts provided an understanding of regional coastal processes including wave transformation, sediment transport, shoreline change, tidal circulation, and water-level fluctuations. The models were then focused at the sub-regional and project scales to refine the sediment budget and begin evaluation of proposed project modifications to improve sediment management.

Wave transformation. The Wave Information Study (WIS) (Hubertz and Brooks 1989) 1976-1995 offshore wave hindcast data for the Gulf of Mexico were transformed over the shallow-water bathymetry to develop a nearshore breaking wave climate using the steady-state spectral wave model STWAVE (Smith et al. 1999). STWAVE was not applied along the eastern Apalachee Bay area due to the shallow marsh areas. Because wind-wave information is not

available in the Mississippi Sound, wave transformation to the Mississippi mainland was not conducted. Figure 5 shows the grid system representing sub-regions 4-9. The model requires a 180-deg half-plane grid, and simulates wave transformation perpendicular to the direction of wave crests. Because of the curvature of the shoreline and sizeable distance of the RSM domain, the model required separate grids over various reaches of shoreline with each simulated independently. The resulting breaking wave climate was used to develop potential longshore sediment transport rates.

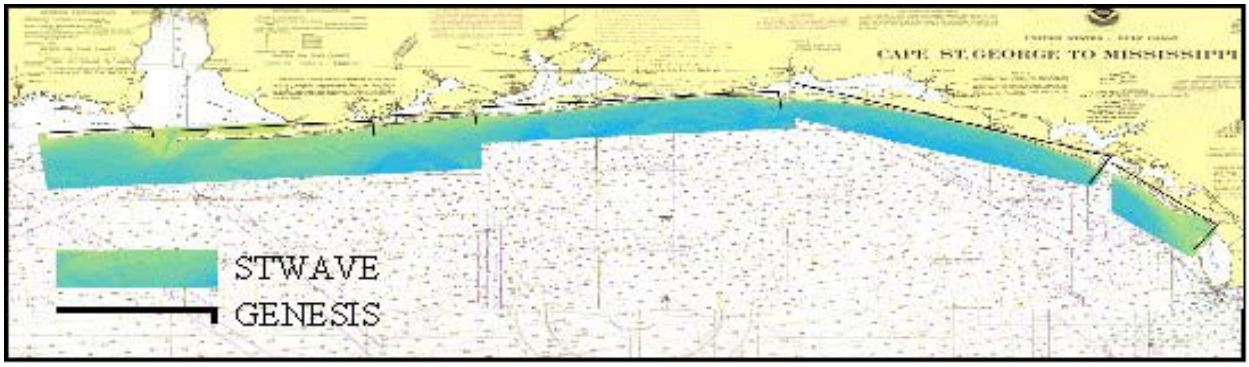

Figure 5. STWAVE and GENESIS grid systems.

Longshore sediment transport and shoreline change. The GENEralized Model for SImulating Shoreline Change (GENESIS) (Hanson and Kraus 1989) was used to develop potential net longshore sediment transport rates based on the breaking wave climate resulting from the STWAVE simulations. GENESIS was configured for the RSM sub-regions, and available historical shoreline position data and coastal processes information were applied to calibrate and verify the model. Due to the curvature of the shoreline, the GENESIS model also required separate grids over various reaches of shoreline with each simulated independently. Figure 5 shows the GENESIS grid system developed for the RSM sub-regions 4-9. The resulting potential longshore sediment transport magnitudes and directions were imported to the RSM GIS (Figure 6) and used in development of the regional sediment budget.

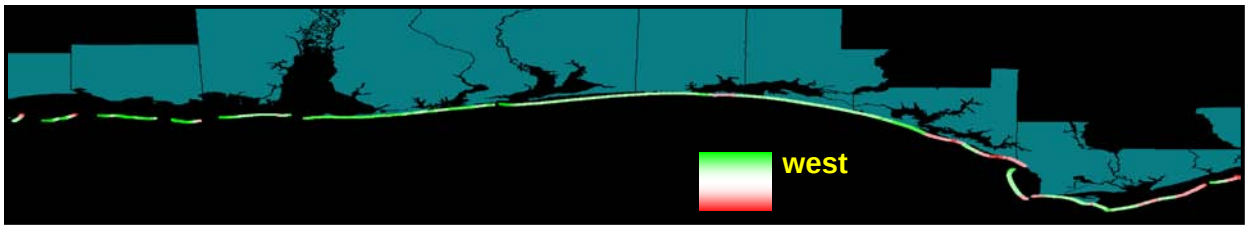

Figure 6. GENESIS potential longshore sediment transport rates imported to the RSM GIS.

The GENESIS model was further applied to improve maintenance dredging and placement operations at Perdido Pass, AL (Gravens 2003). An examination of the efficiency and effectiveness of past dredging and placement activities was conducted to estimate the minimum discharge distance that will prevent reintroduction of bypassed sediments into the inlet. The resulting modifications are being implemented and monitored. These new dredged material placement practices are intended to improve the overall sand bypassing efficiency at Perdido Pass by placing dredged sediments further west (downdrift) of the Pass.

Water levels and circulation. The two-dimensional formulation of the ADvanced CIRCulation (ADCIRC) long-wave hydrodynamic model (Luettich et al. 1992) for simulating water surface fluctuations and tidal currents was applied over the RSM region. To ensure appropriate boundary conditions, the grid encompassed the entire Gulf of Mexico with refined resolution to resolve the RSM region at the project level (Figure 7). Bathymetry specified in the model was obtained from the NIMA digital nautical charts, National Ocean Service navigation charts, and SHOALS surveys.

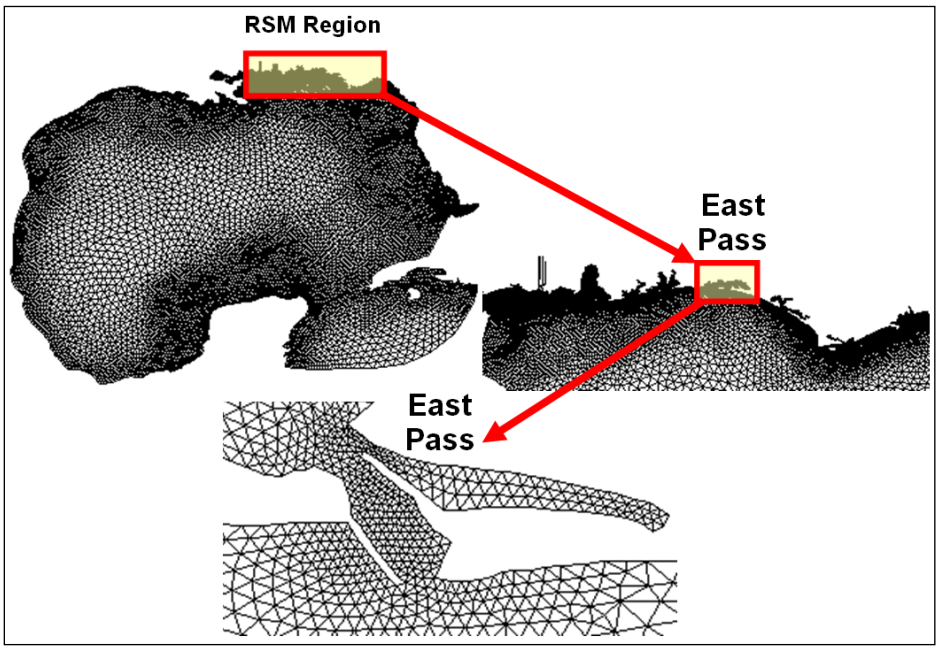

Figure 7. ADCIRC circulation model regional grid.

The ADCIRC model characterized tidal circulation patterns and water-level fluctuations both regionally and at project scales. The circulation magnitudes and patterns provided insight to understanding sediment transport patterns and pathways, and erosion and accretion occurring along the shoreline and at project sites. The calibrated model will be used for future applications to develop and evaluate proposed modifications to management practices, and to evaluate storm impacts to existing conditions.

Regional Sediment Budget. The regional sediment budget is the primary tool for regional management because the sediment budget provides the key to all data and analysis performed for the region. These data and analyses were compiled into a sediment budget using the Sediment Budget Analysis System for ArcView© (SBAS-A) GIS extension (Dopsovic et al. 2002). The SBAS-A GIS Extension was coded to exactly match the standalone version created by the ERDC Coastal Inlets Research Program. Files created using both the stand-alone version and the GIS extension are compatible with both interfaces.

For the Demonstration Program, the regional sediment budget was created using hydrographic surveys, regional numerical models, and dredging and placement records. Each of these data sets is accessible through the RSM GIS. First, the region was divided into sediment budget "cells." Cell divisions were placed at county and state lines, and based on morphological features like

ebb and flood shoals, inlet throat, and adjacent beach. The seaward boundary of the cells was the 30-ft contour, designated by RSM engineers as the probable depth of closure for the region (Lillycrop and Wozencraft 2003b).

Next, potential sediment transport rates were determined for the shore-perpendicular boundaries of each cell. The potential sediment transport rates were extracted from the GENESIS model results and incorporated as point data in the GIS. Each point is associated with a 20-year average eastward and westward transport rate. The point data lying within the boundaries of each cell were averaged to determine an overall transport rate for each cell. Figure 8 shows the resulting transport rates over the region. The cells are color-coded based on the cell volume change as: purple (sediment gain), yellow (sediment loss), or green (sediment balance, or in the case shown in Figure 8, that no transport rates were estimated for the cell).

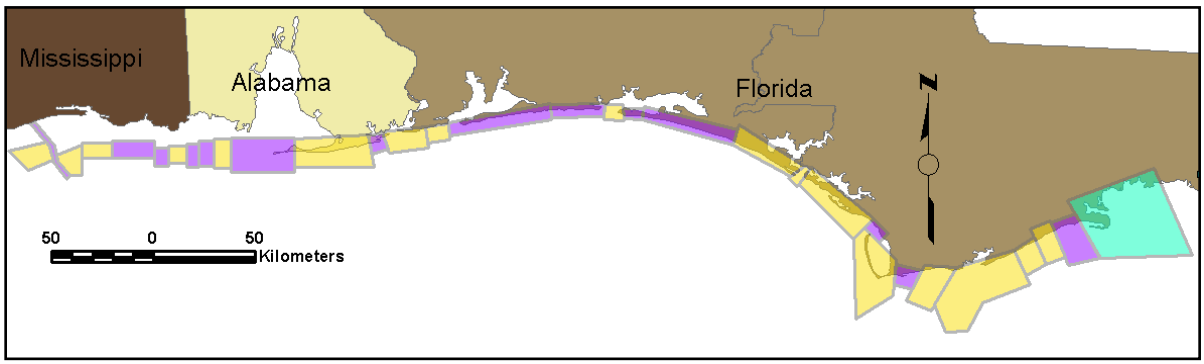

Figure 8. Results of transport rates applied to sediment budget cells. Purple indicates a gain of sediment. Yellow indicates a loss of sediment. Green indicates no gain or loss, or no data.

For this formulation of the regional sediment budget, volume computations between successive data sets were performed using the SHOALS Toolbox. Volumes were computed within each cell. Where data coverage was not available over the entire cell area, an uncertainty was applied based on the average height difference in the cell, and on the area of coverage lapse. Volumes between SHOALS data sets were computed using Triangulated Irregular Network (TINs), while the average-end-area method was used between FLDEP profiles and SHOALS data sets. The computed volumes were annualized; i.e., the volume change computed was normalized by the number of years between surveys, resulting in a number with units of cu yd per year.

Finally, the dredging and placement quantities were input for the appropriate cells. Because dredging records are maintained by CESAM Area Offices in non-digital format, a database was created for data access within the RSM GIS. The dredging and placement quantities were annualized values expressed as cu yd per year.

Figure 9 shows an example of the SBAS-A data entry window for both volume computations and dredging and placement quantities. An uncertainty may be associated with each of these values. The user also has access to transport rate values in this window. Figure 9 also provides the sediment budget representing 7 years of data in the vicinity of East Pass, FL. Some reasonable assumptions may be used to balance the sediment budget. However, additional data collection is required to validate these assumptions, especially regarding sediment exchange between the upland and submerged beach.

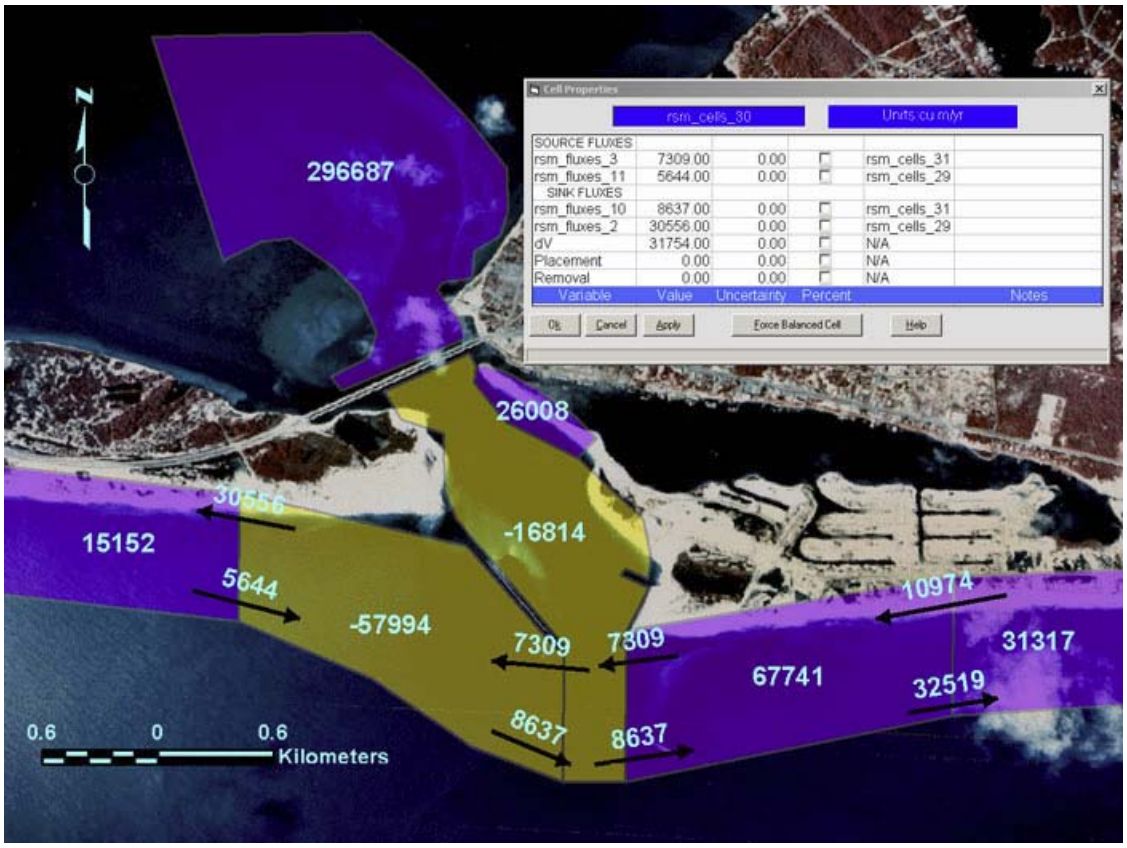

Figure 9. Transport rates and residuals for East Pass sediment budget cells.

Perhaps the most significant information gained from the regional sediment budget is the identification of those areas where more data collection is required. For most of the region, except the inlets and shore protection projects, there is little or no data for volumetric computations. In Figure 10, the cells shown in red are those cells where insufficient data exist to make volumetric computations to balance the sediment budget.

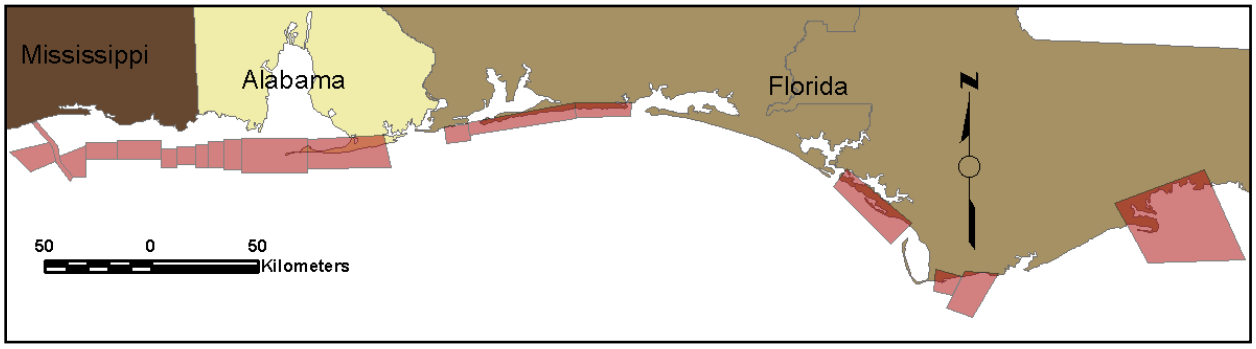

Figure 10. Sediment budget cells with insufficient data for volume comparisons.

RSM Data Management and Geographic Information System.

Overview. The CESAM Operations Division, Spatial Data Branch, created the RSM GIS to address the data management and data analysis requirements of the RSM Demonstration

Program. The resulting GIS provides an interface to contemporary and historic hydrographic, topographic, photogrammetric, and geotechnical data, as well as dredging records over the RSM domain. Custom applications were designed to facilitate engineering analyses, primarily development of the regional sediment budget. The RSM GIS serves as the link between engineering analyses and regional numerical models. To date, development of the RSM GIS has included: (1) input of spatial data for the RSM region, (2) use of built-in GIS applications to enhance data manipulation and display, and (3) creation of custom applications to extend the utility of GIS for RSM specific goals. The primary functions of the RSM GIS are: (1) data management, (2) dredging management, (3) sediment budget analysis, (4) environmental information management, and (5) impact evaluation.

Definition. The RSM initiative is a prime example of how a GIS can be used as a powerful tool in spatial data analysis. By enabling coastal engineers and managers direct access to all spatial datasets across the entire study area, the RSM GIS allows each stakeholder to make educated decisions regarding sediment transport and structure design. More than just a simple data viewer, this decision support GIS empowers all users to analyze numerous datasets in a variety of scenarios using advanced computer models embedded in the GIS to make well-informed decisions on future management practices. To develop such a comprehensive GIS, CESAM cooperated with numerous Federal, state, and local agencies. Synchronization of data collection efforts of each organization allowed data and resources to be acquired and deposited into one spatial data repository referenced by the RSM GIS. To access this massive database of coastal information, all datasets and associated metadata have been integrated into an internet-based mapping system using Environmental Systems Research Institute's (ESRI) ArcIMS (Internet Map Server). ArcIMS allows data distribution and analysis of all collected datasets, such as imagery, hydrologic surveys, and basemap data in a user-friendly interface accessible via a web browser and Internet connection.

Architecture. Using existing US Army Corps of Engineers geospatial data standards, the Spatial Data Branch originally designed the RSM GIS for use and development within ESRI's ArcView© 3.x environment. All custom applications and datasets were initially deposited into a file-based architecture residing on a central Windows 2000 server. Custom applications were wrapped into extensions and referenced via a standard RSM project file. The project file (*.apr) contained references to all necessary links, including extensions and databases.

Two Access databases were incorporated into the RSM GIS. The most robust database existed as an index for each dataset imported into the information system (see below). Each dataset was categorized by a sub-region and data type, and then denoted with layer description and metadata. The other database was created for use as the document manager. This enabled multiple documents to be retrieved via the GIS interface. The extensions, all written in ESRI's proprietary language Avenue, used information contained in these databases to create user-friendly interfaces.

In 2002, ESRI changed the fundamental platform for design from Avenue to Visual Basic and upgraded versions of the standard GIS package from ArcView© 3.x technology to ArcGIS 8. This change forced CESAM to recode all applications to the new environment. During this migration process, all feature datasets were formatted with the approved attribution of the Spatial Data Standards and imported into a spatially referenced Structured Query Language (SQL) geodatabase running ArcSDE (Spatial Data Engine). This conversion significantly increased

performance of data retrieval and processing of RSM datasets and allowed for significantly more applications to be created, such as the 3D Bathymetric Viewer, Volume Change Calculator, and Bathymetric Profile Generator (Figure 11).

In addition to the standard desktop GIS product, the RSM GIS was also made available in an Internet version. This new technology of IMS allows individuals and organizations to create maps, integrate information, visualize scenarios, and present powerful ideas interactively on the Intranet or Internet. Specifically, this RSM ArcIMS allows the user direct access to coastal information and includes the capability to zoom in/out, turn on/off specific map features, perform queries, calculate area, and print maps at several selected scales.

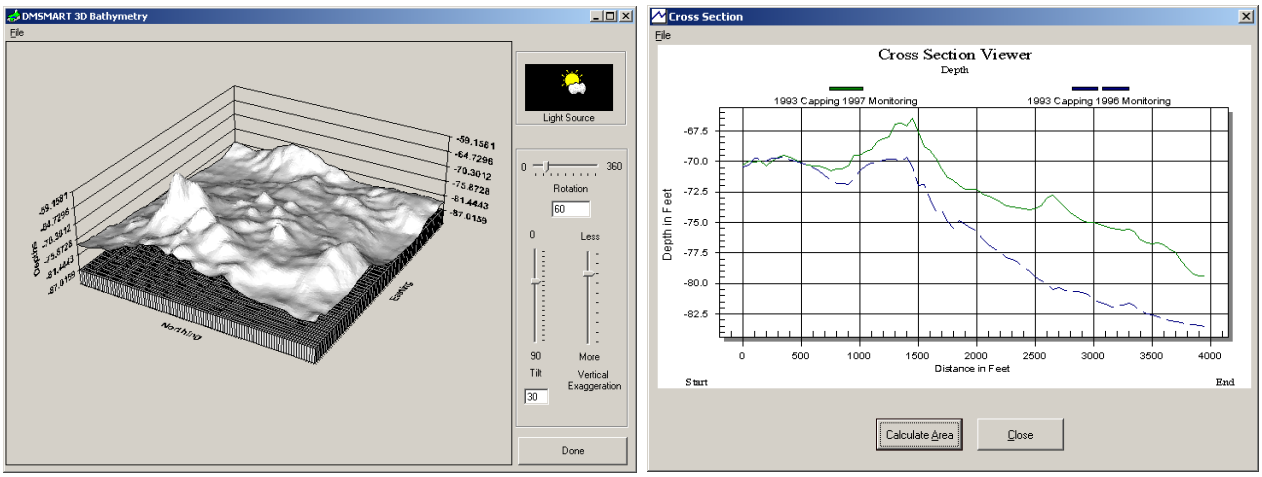

Figure 11. GIS applications: 3D Bathymetric Viewer, and Volume Change Indicator.

The initial interface screen includes a map of the entire project with a window that allows the user to query based on a specific geographic feature, quad sheet name, species, etc. The map service includes over one hundred layers in a single mapping project. Therefore, each layer is granted a visible zoom extent. Once the user has zoomed in/out, the table of contents will expand/shrink to include all available layers for that zoom scale. Twelve ArcIMS map services have been created for use in the online mapping environment (one for each sub-region of the RSM program, and one overview service). As in the desktop version, each sub-region holds high-resolution datasets including precise imagery and bathymetric surveys (Figure 12). Users have the ability for online analysis and map production 24 hr a day and 7 days a week.

LESSONS LEARNED. Lessons learned from the CESAM RSM program include the fact that successful implementation of RSM requires application of engineering tools appropriate for regional management and analysis. The primary tool is the regional sediment budget, with a suite of engineering tools to manage and refine the sediment budget. These engineering tools are further applied to evaluate and improve present sediment management practices over the region. Enhancements to the tools and models will improve USACE ability to implement RSM. Management and visualization of the data were accomplished through the RSM GIS. Data manipulation, analysis, and sediment budget development were accomplished through application of SMS, SHOALS Toolbox, RSM GIS, and SBAS-A. The key to regional sediment budget development and numerical model application is in the quality and quantity of historica and contemporary data sets for input and analysis. Continuous synoptic surveys of entire regions,

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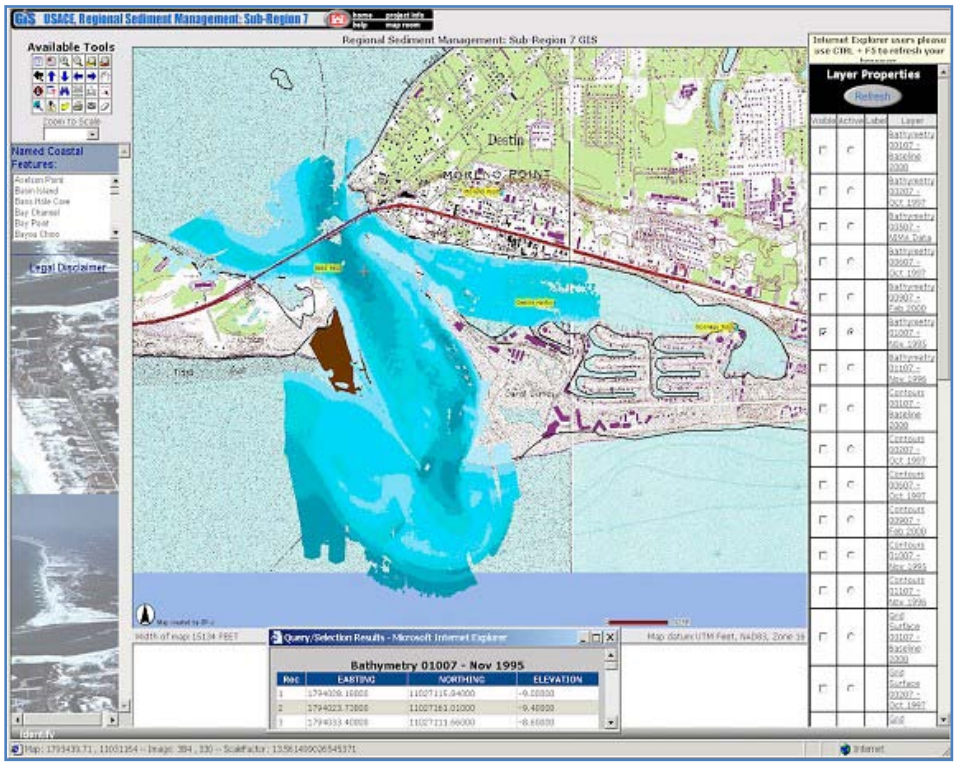

Figure 12. RSM GIS ArcIMS view of East Pass, FL.

collected annually or semi-annually, will eliminate present difficulties and reduce error by less manipulation of elevation data in the effort to quantify, understand, and manage sediments regionally (Lillycrop and Wozencraft 2003a).

Technical Working Group. Throughout the Demonstration Program, TWG meetings were held semi-annually. Scheduling TWG meetings on a more frequent basis and assigning technical tasks to the TWG agencies would enhance coordination, communication, and effectiveness of the TWG.

Baseline Dataset/Field Data Collection. Difficulties encountered in creating the baseline dataset include: (1) patch-working a compilation of surveys with different coverages, referenced to different datums, and collected in different time frames, (2) working with surveys collected through various survey methods (profiles, single-beam, multi-beam, SHOALS) resulting in variable data point densities, (3) converting data to common tidal and geodetic datums over the region, and (4) data gaps or areas that lack data. Continuous synoptic surveys of entire regions will eliminate present difficulties and reduce error by requiring less manipulation of elevation data in the effort to quantify, understand, and manage sediments regionally. Annual surveys will provide the most accurate and comprehensive information; however, as a minimum, surveys should be collected on a 2- to 3-year cycle. A USACE program for the collection of regional surveys is necessary for successful implementation of RSM into USACE practice.

The collection of wave, water-level, and current data is logistically difficult, expensive, and therefore difficult for Districts to justify and obtain. A USACE field data collection program would assist Districts in obtaining necessary hydrodynamic data required to adequately evaluate coastal processes and impacts on regional scales and further focusing at project scales. Further, present wave gages use technology developed possible 10 years ago, and these gages often require expensive repair and maintenance. A USACE program to develop more robust wave gages would reduce gage downtime, deployment costs, and improve data availability.

Wave Transformation. Several limitations were encountered in applying STWAVE over the RSM region. The main limitation was the lack of historical data for specifying boundary conditions, for representing accurate bathymetry in the grids, and for regional model calibration and verification. Data at East Pass and St. Andrew Bay Entrance, FL, are abundant; however, historical data for the remaining projects and areas between the projects is limited or not available. Secondly, input wave characteristics are uniform along the offshore grid boundary. In modeling over large domains, the variation in wave climate and localized storm conditions are not captured. Finally, uniform cell sizes must be maintained. This encumbers regional applications since model execution time is linearly related to the number of grid cells. High-resolution grids are necessary to resolve the complex bathymetry in the nearshore, yet coarse grids can be used offshore where bathymetry is less complex. Model simulations are limited by the combination of large domains and high-resolution grids. Resolutions to these STWAVE limitations are progressing through the development of grid nesting (Smith and Smith 2002). Grid nesting will minimize computational requirements and maximize accuracy.

Longshore Sediment Transport and Shoreline Change. For regional applications, the GENESIS model is limited by boundary conditions at inlets and the shore parallel grid requirement. Enhancements to the model for RSM would include the ability to apply one continuous grid over the large RSM domain. The ability to obtain results at the sub-regional and project levels would continue to be necessary to evaluate project modifications and improve sediment management at localized levels. To import the GENESIS results into the RSM GIS, conversion of the model output from binary NETCDF format to ASCII was required. The ability to obtain GENESIS output in shapefile format would simplify model use for RSM.

Water Levels and Circulation. The ADCIRC model is ideal for RSM since the model requires large domains to adequately represent boundary conditions. However, in the application to the RSM region, difficulties were encountered in obtaining accurate wind and bathymetry data. While tidal constituents from astronomical forcing are accurate, the difficulty was in getting nearshore winds correct over the large domain. Although wind data are measured at airports and National Data Buoy Center C-Man Stations, the measurement increment misses rapid changes in wind direction. As previously stated, bathymetric data are limited over the RSM region. In some areas, the available bathymetric data are very old (i.e., 20 years) and is not representative of existing channel and shoal area conditions. Inaccuracies in the data will result in discrepancies in model simulations. Finally, computer-processing limitations hinder model application for RSM. Although the encompassing grid domain may include low resolution in the offshore and high resolution at project levels, model simulations using a comprehensive grid that resolves all local projects with high-resolution cells requires a supercomputer.

SBAS and SBAS-A. While the SBAS tools are valuable in cataloguing understanding of sediment transport pathways and volumes, additional capability can increase its usefulness. Volumetric computations and dredge placement volumes must be annualized in a separate software package prior to entry into SBAS. A capability to database all volume computations and dredging/placement operations, and to compute an annualized budget for a specified time period, would be more efficient and reduce the bookkeeping required by the current system. Additionally, to evaluate the impact of a dredging operation, the user is required to manually propagate the placement/removal volume through each cell in the region. The capability to establish relationships between cells based on equilibrium theory and automatically propagate the impact through the region, such as is available in the PC-version, would enhance the efficiency of SBAS.

Data Management and GIS. The majority of lessons learned pertain to the initial development and setup of the RSM GIS. The largest obstacles involved data integration, data manipulation, and data storage. Prior to the GIS, there was no mandatory data collection standard for coastal surveys within the Mobile District. This resulted in historical datasets of various projections, datums, units, and file deliverable type. To add to this unfortunate situation, metadata were not available for most historical datasets. Extensive manipulation of data was required to integrate historical datasets into the GIS. As a result of this undertaking, new procedures were implemented to ensure that future surveys would be delivered in the RSM projection of choice with associated metadata files.

With the continued increase of data into the RSM GIS (primarily large ortho-photography and imagery datasets), the overall project increased exponentially in size. This resulted in the continued procurement of data storage devices and, therefore, added a new budgetary requirement for the RSM program.

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