TECHNICAL LESSONS LEARNED FOR REGIONAL SEDIMENT MANAGEMENT

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Abstract: The US Army Corps of Engineers, Mobile District (SAM) has recently completed a three-year Regional Sediment Management Demonstration (RSM) program that was initiated in October 1999. Engineering tools were applied to gain a better understanding of the coastal processes and sediment transport patterns over the SAM RSM region. Because field data collection, numerical models, sediment budgets, and Geographic Information Systems (GIS) are historically applied on a project-by-project basis, difficulties were encountered in assimilating data and applying typically project level tools on a regional scale. Specific difficulties encountered include: numerical simulations over a region greater than 300-miles, reconciling and merging surveys with varying formats and coverages for analysis and model input, obtaining historical data, accounting for gaps between datasets, incorporating and comparing model results, and managing field and numerical data over a large region. Lessons learned from the SAM RSM program are that successful implementation of RSM requires regional datasets and engineering tools appropriate for regional management and analysis. This paper discusses lessons learned and recommendations in applying project level engineering tools on a regional scale for RSM implementation.

INTRODUCTION

In September 2002, the US Army Engineer District, Mobile (CESAM) completed a 3-year demonstration program to evaluate the implementation of Regional Sediment Management (RSM) within the US Army Corps of Engineers (USACE). The purpose of RSM is to take a regional approach to project management, and therefore sediment management, rather than managing projects on an individual basis. With the completion of the demonstration program, CESAM is now in the process of putting RSM into practice.

The CESAM RSM demonstration region is bounded by the St. Marks River, FL, to the east and the Pearl River, MS, to the west (Figure 1). The region extends approximately 375-miles including the Mississippi barrier islands. To ease the management of this large domain, the region is divided into eleven sub-regions based on geography or geology and/or littoral cells. The sub-regions in the Florida Panhandle are coincident with the sub-regions

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defined by the Florida Department of Environmental Protection (FDEP). The region includes three states, Florida, Alabama, and Mississippi, 13 coastal counties, and four congressional districts.

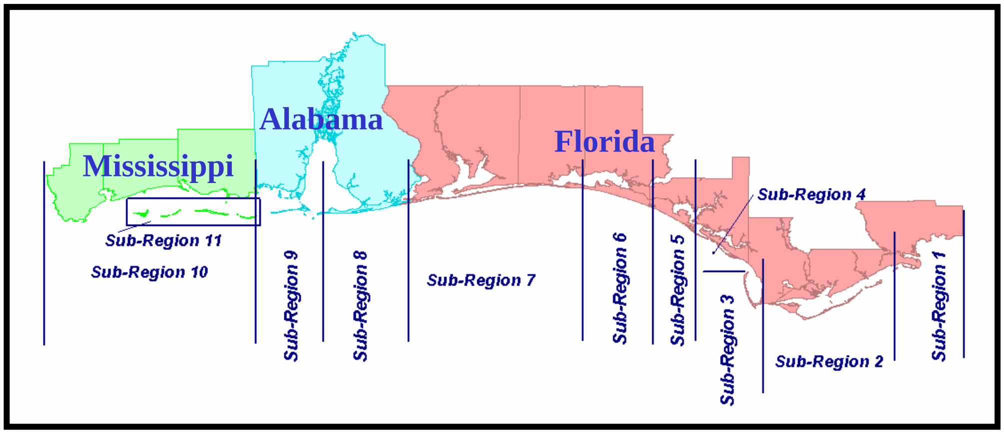

Figure 1. Northern Gulf of Mexico Regional Sediment Management domain

Engineering tools were applied to gain a better understanding of the coastal processes and sediment transport over the RSM domain. Because field data collection, numerical models, sediment budgets, and Geographic Information Systems (GIS) are historically applied on a project-by-project basis, difficulties were encountered in applying typically project level tools on a regional scale. This paper discusses the technical lessons learned and makes recommendations for applying project level engineering tools for RSM.

PROCESS

The technical goal of the program was to apply and develop tools to allow CESAM to evaluate coastal processes and manage sediments at regional scales as well as project scales. To meet this goal, CESAM developed the process outlined in Figure 2. The primary tool to meet this goal is the regional sediment budget. Therefore, the process began by developing a preliminary or conceptual sediment budget based on available historical data and information. This initial sediment budget quantified the knowns and qualified the unknowns relative to sediment transport over the region. With this information, CESAM developed a program to improve our knowledge through application of numerical models and field data collection in support of the numerical models. Information gained would provide data to refine the sediment budget and improve our knowledge of the regional coastal processes. It was quickly realized that a data management and GIS tool would be necessary to manage and perform analysis of information and data over such a large domain. The comprehensive suite of engineering tools improves our ability to assess coastal process on a regional scale (375-miles), manage and analyze data, evaluate sediment management practices, develop new procedures to improve sediment management, and evaluate impacts of modified sediment management practices.

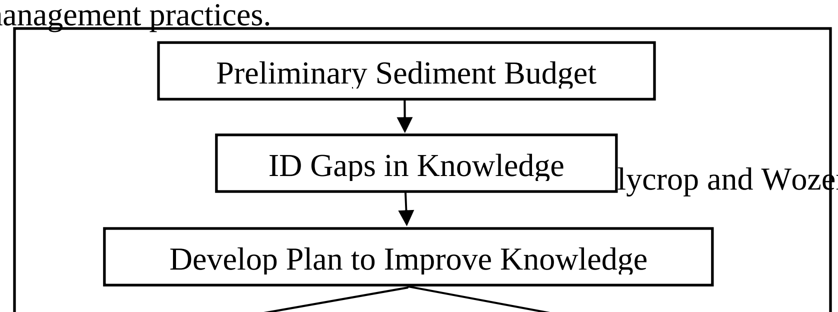

Figure 2. CESAM process to implement Regional Sediment Management

ENGINEERING TOOLS

Through the RSM program, the following engineering tools were identified as necessary for successful RSM and are described in this paper:

- 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 and analysis tool for managing and storing historic and contemporary data and a tool for performing analysis of data and model results. The tool will allow sharing of information internally and externally.

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

- Hydrodynamic and meteorological data including waves, currents, water-levels, winds, and storm data.
- Historic bathymetric, topographic, and shoreline data.
- Regional, continuous, and synoptic bathymetric and topographic surveys. 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.
- Aerial photography and/or satellite imagery collected annually and/or coincident with bathymetric and topographic surveys. All imagery must be georeferenced and ideally ortho-rectified.

Conceptual Regional Sediment Budget

A key element for success of RSM is the regional sediment budget. The sediment budget assists in identifying longshore sediment transport rates, sediment patterns and pathways, areas of erosion and accretion, and understanding beach and bathymetry change over the region. Through the sediment budget, regional impacts resulting from modifications to sediment and project management can be identified. A preliminary or conceptual regional sediment budget was created based on available historical information and utilizing the Sediment Budget Analysis System (SBAS) (Rosati and Kraus, 1999a). 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 that Florida has a robust coastal program, and Alabama and Mississippi are lacking in data.

Baseline Dataset

Prior to the RSM program, in-house hydrographic data were primarily available at the project level (navigation channels) and no data were available along the coasts between projects, Figure 3. A baseline data set 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 compilation of data from many years. The NIMA nautical chart data were augmented with the following surveys collected between 1997 and 2000: Scanning Hydrographic Operational Airborne Lidar System (SHOALS) (Guenther and Lillycrop, 2002) hydrographic and topographic surveys; CESAM conventional project surveys; FLDEP and CESAM beach profiles. The baseline was created through data manipulation using the SHOALS Toolbox (Wozencraft, et al 2002).

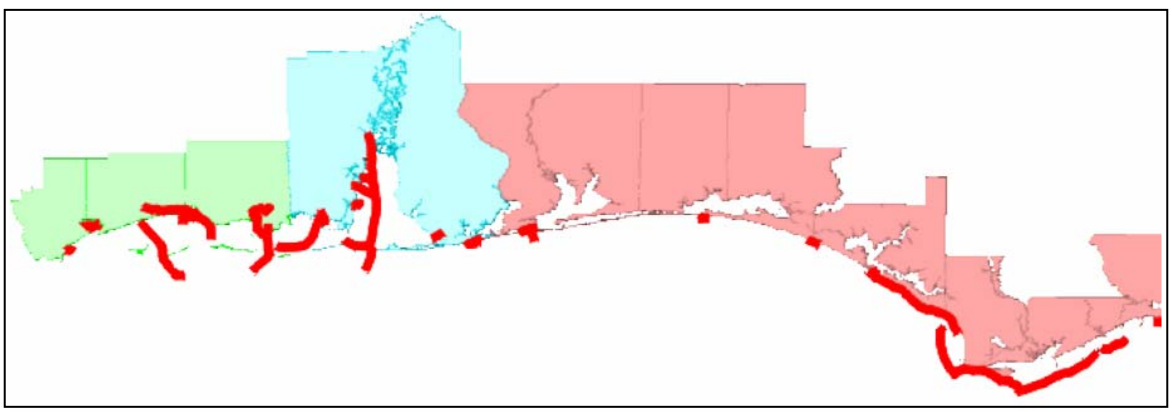

Figure 3. Available in-house data prior to RSM program

Difficulties encountered in creating the baseline dataset include: patch-working a compilation of surveys with various coverages, data sets with inconsistent coordinate systems and datums, surveys collected at different time frames; working with surveys collected through various survey methods (profiles, single-beam, multi-beam, SHOALS) resulting in variable data point densities; converting data to common tidal and geodetic datums; and data gaps or areas which lack data. Examples of the necessary dataset patch working to create the baseline data set are provided in Figures 4 and 5. 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.

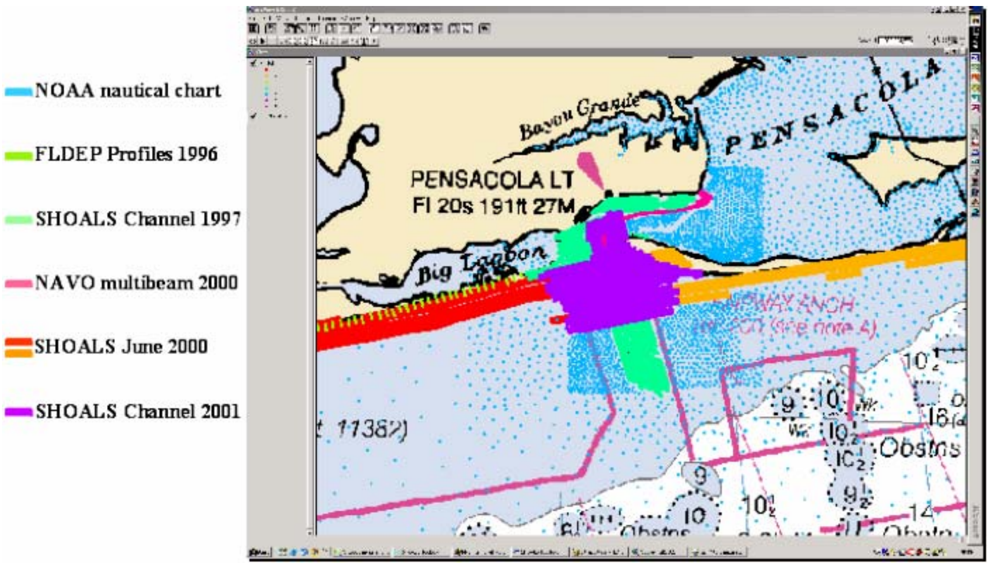

Figure 4. Patch working of various data sets at Pensacola Pass, FL

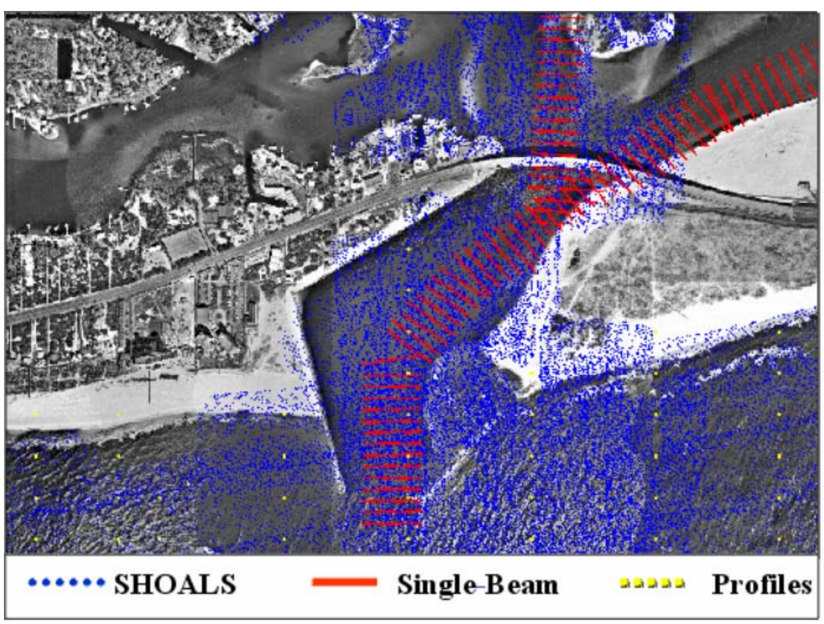

Figure 5. Variable data point densities due to various survey methods

Aerial photography and satellite imagery were obtained or collected as part of the baseline dataset. Unlike maps, which portray the physical and cultural landscape with generalized symbols and colors, aerial photography reveals the terrain as it exists in nature. All buildings, bridges, roads, coastal structures, shorelines, offshore features, sediment plumes, and vegetation types are depicted as they were at the time of photography. These images show detail that no map can depict, and provide an overlay to enhance hydrographic data, identify coastal phenomena, and supplement map information. Aerial photography is, therefore, extremely useful both for specific site evaluation, for regional analysis, as well as for historical perspectives. In the future, hyper-spectral imagery will be obtained to map submerged and floating aquatic vegetation, identify major wetland plan communities, and identify major upland land cover types.

In obtaining, organizing, and coordinating imagery, it became apparent that more than one agency collected data over the same area, at various resolutions, and at times, in the same time frame. In some cases the imagery was flown controlled, therefore providing georeferenced and/or ortho-rectified imagery, in others cases it was not. Through the RSM program, CESAM is working to eliminate duplication of efforts and increase data sharing among the various agencies in the CESAM RSM region, and to obtain imagery that can be directly imported to the GIS.

Numerical Models

To refine the sediment budget, CESAM coordinated with the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory to apply a suite of hydrodynamic models to the RSM region. The modeling efforts provided an understanding of the 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. The models, sediment budget, and field data will be used in the future to evaluate project modifications to improve sediment management.

Wave Transformation. The Wave Information Study (WIS) (Hubertz and Brooks, 1989) 1976-1995 offshore 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). The grid system representing sub-regions 4-9 is show in Figure 6. The model requires a 180-degree half-plane grid and simulates wave transformation perpendicular to the direction of wave crests. Because of the curvature of the shoreline and sizeable breadth 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 discussed in the next section.

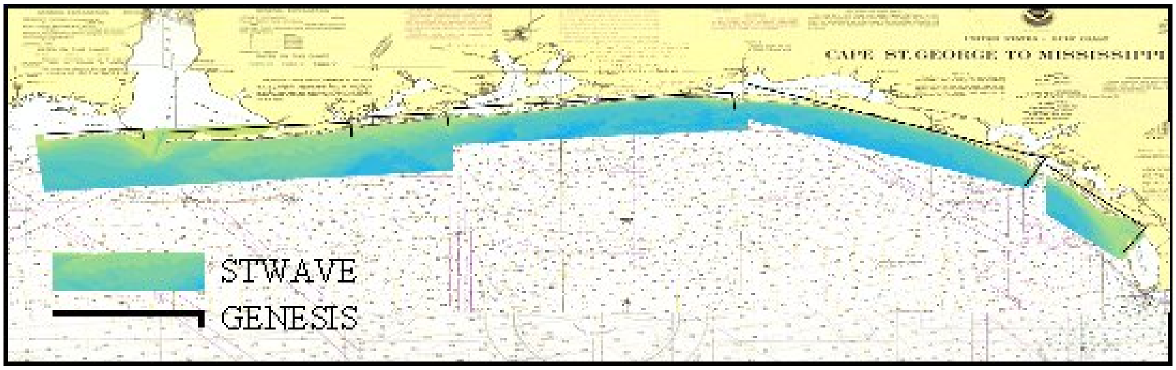

Figure 6. STWAVE and GENESIS grid systems

Several limitations were encountered in applying STWAVE over the RSM region. STWAVE was not applied along eastern Apalachee Bay due to shallow marsh areas, which reduced WIS data accuracy. Because wind-wave information is not available in the Mississippi Sound, wave transformation to the MS mainland was not conducted. The main limitation where STWAVE was applied was the lack of historical data for specifying boundary conditions, representing accurate bathymetry in the grids, and 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. The GENEralized Model for SImulating Shoreline Change (GENESIS) (Hanson and Kraus, 1989) was utilized to develop potential net longshore sediment transport rates based on the breaking wave climate results of 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. The GENSIS grid system developed for the RSM sub-regions 4-9 is shown in Figure 6. 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, as describe in the Sediment Budget section of this paper.

The GENSIS model was further applied to improve maintenance dredging and placement operations at Perdido Pass, AL. An examination of the efficiency and effectiveness of past dredging and placement activities was conducted to estimate the minimum downdrift 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.

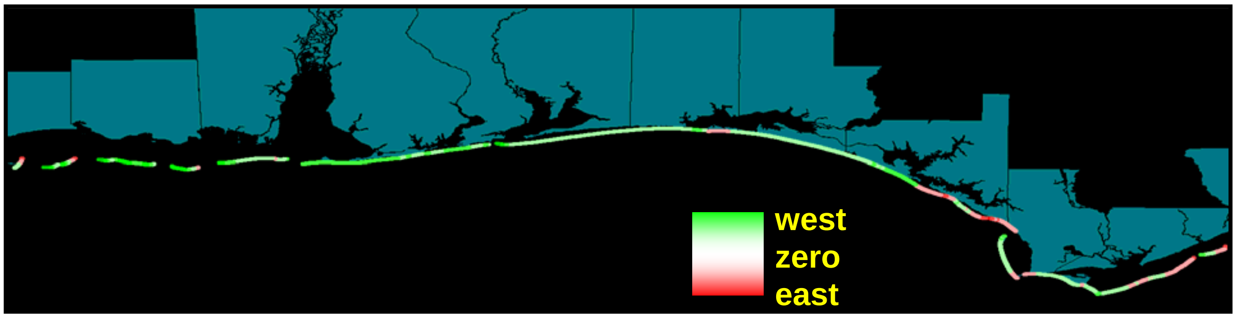

Figure 6. GENESIS potential longshore sediment transport rates imported to RSM GIS

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 in order 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 improve model use for RSM.

Water-level 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 and at project levels (Figure 7). Bathymetry specified in the model were obtained from the National Imagery and Mapping Agency digital nautical charts, National Ocean Service navigation charts, and SHOALS (Guenther and Lillycrop, 2002) surveys.

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 modifications to management practices and estimate storm impact to existing conditions.

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 are not representative of existing channel and shoal area conditions. The 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 Supercomputer capabilities.

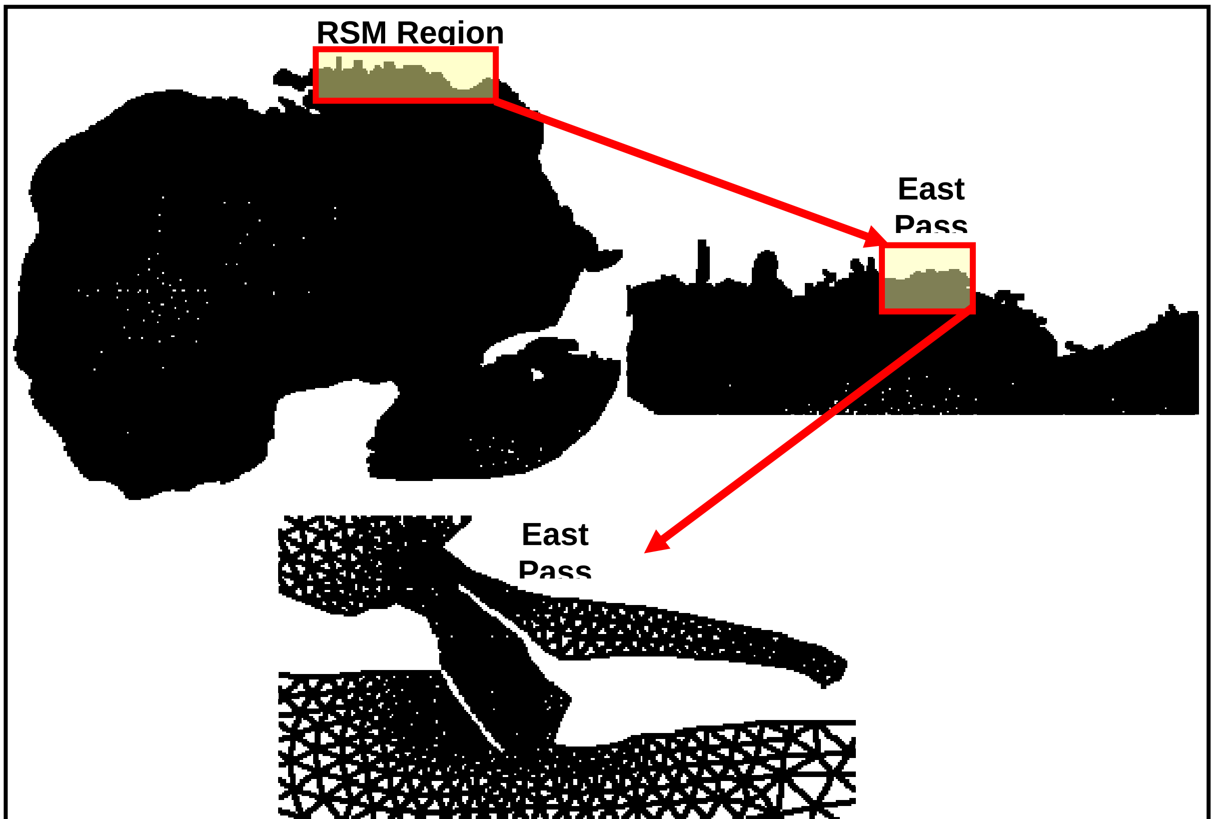

Figure 7. ADCIRC circulation model regional grid

Surface Modeling System and SHOALS Toolbox

The Surface Modeling System (SMS) (Gravens 1991) is a pre- and post processor for surface water modeling and analysis. SMS includes two- and three-dimensional finite element and finite difference models, and one-dimensional backwater modeling tools. Interfaces were specifically designed to facilitate utilization of several numerical models, which include STWAVE and ADCIRC. The SHOALS Toolbox (Wozencraft, et al 2002), a standalone module of SMS provides the capability to analyze, visualize, and manipulate hydrographic data collected from a variety of survey methods. The baseline dataset and sediment budget calculations were conducted through the SHOALS Toolbox. SMS and the SHOALS Toolbox enhance the capability to implement RSM through data manipulation in support of the sediment budget, to evaluate bathymetric change, and for model application.

Regional Geographic Information System

A regional GIS was developed to manage, analyze, share, and view historic and newly collected data, as well as numerical model results. These data will be crucial to evaluating potential O&M decisions affecting RSM. For example, information such as beach profiles, navigation project surveys, aerial photos and dredging records comprise the historic data for comparison with baseline data established in 2000. These data will be instrumental in calibrating and verifying the sediment budget. A key component of the RSM program is partnering with State and local governments. To maximize the sharing of data and eliminate duplication, this GIS forms the backbone for standardizing formats and producing easily accessible information. The GIS also provides a means to maintain "institutional" knowledge over the region.

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 anlysis were compiled into a sediment budget using the Sediment Budget Analysis System for ArcView (SBAS-A) GIS extension (Dopsovic et al, 2002). The CESAM Spatial Data Branch coded the SBAS-A GIS extension to exactly match the stand-alone version created by the Coastal Inlets Research Program. Files created using both the stand-alone version and the GIS extension are compatible with both interfaces.

Input to the SBAS-A extension includes volume computations between successive hydrographic surveys, model output, and dredging and placement records. Each of these data sets is accessible through the RSM GIS. The bathymetric and topographic survey data are managed through the GIS, and volume computations can be computed in the GIS as well. Model output is contained within GIS shapefiles. The dredging and placement volumes are accessible through a database that interfaces with the GIS.

The 20-year averages of eastward, westward, and net sediment transport rate calculated from the numerical models were input into the sediment budget, Figure 8. The littoral cell colors are designated based on the value of the cell residual, or the amount of volume change in the cell not accounted for by the input values (Rosati and Kraus 1999). Purple cells represent a positive residual, yellow cells represent a negative residual, and green cells indicate a cell balance, or in the case of the Figure 8, that no values were entered because no transport rates were estimated for the cell.

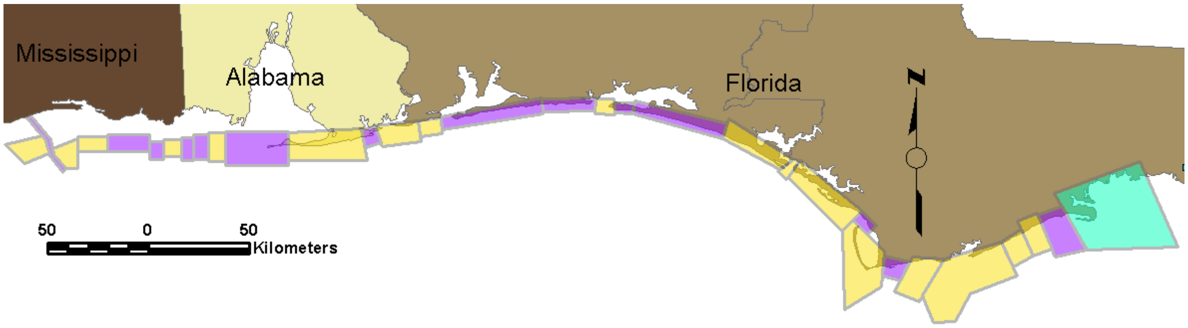

Figure 8. Sediment transport rates applied to sediment budget cells

For this formulation of the regional sediment budget, volume computations between successive data sets were performed using the SHOALS Toolbox (Wozencraft, et al 2002). Volumes were computed within each cell; where data coverage did not account for the entire cell area, an uncertainty was applied based on the average height change in the cell and the area of coverage lapse. Volumes between SHOALS data sets were computed using tins, while the average-end-area method was used between FLDEP profiles and SHOALS data sets. The computed volumes were annualized, resulting in units of cubic yards per year. Finally, dredging and placement volumes were input to appropriate cells. The dredging and placement volumes were also annualized values expressed as cubic yards per year. Those events that preceded the baseline dataset were excluded from the sediment budget.

The information in Figure 9 represents seven years of data at East Pass. With this data, some reasonable assumptions can be made to balance the sediment budget, but more data collection is required to validate these assumptions, especially concerning sediment exchange between the upland and submerged beach.

Perhaps the most important information gained from the creation of 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 with which to make volumetric comparisons. In Figure 10 cells shown in red are those cells where insufficient data exist to make volumetric comparisons in order to balance those cells.

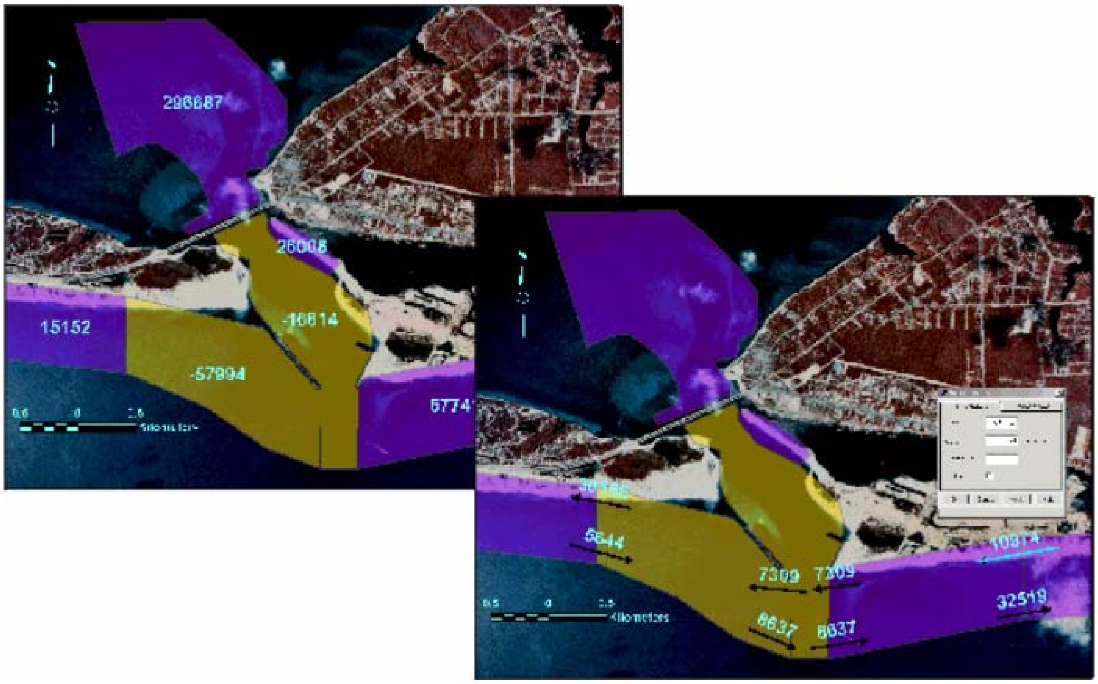

Figure 9. Residuals for East Pass, Florida

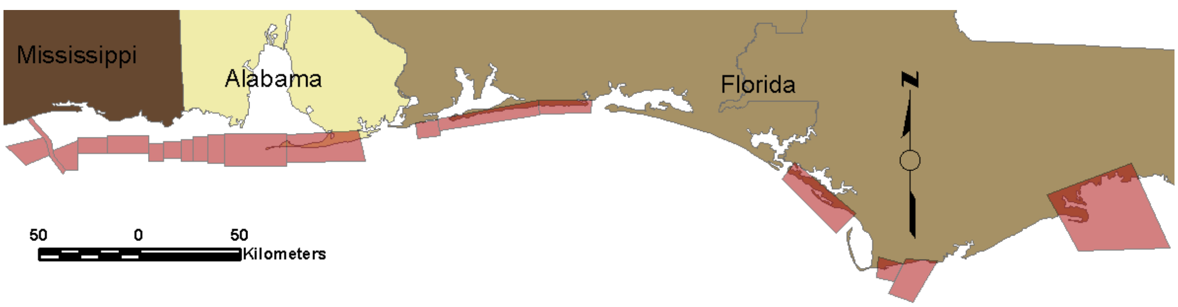

Figure 10. Sediment Budget cells with insufficient data for volume comparisons

While the SBAS tools are valuable in cataloguing our understanding of sediment transport pathways and volumes, additional capability can increase its usefulness. As outlined previously, volumetric computations and dredge placement volumes had to be annualized in a separate software package prior to entry into the SBAS tool. A capability to database all volume computations and dredging/placement operations, and to then compute an annualized budget for a specified time period would be more efficient and reduce some of the bookkeeping required by the current system. Additionally, in simulating a dredging operation to determine its impact on the region, the current system requires the user to input the dredge value and changes the value of the residual for the cell in which the inlet is located. The user is required to propagate the impact on the adjacent cells and through the rest of the region. The SBAS tool should allow the user to establish relationships between cells based on equilibrium theory to automatically propagate the impact through the region.

CONCLUSIONS

Lessons learned from the CESAM RSM program are 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. Potential longshore sediment transport rates were derived applying numerical models (WIS, STWAVE, and GENESIS) on sub-regional scales. To apply these models regionally requires grid nesting and flexibility in the grid orientation with respect to the shoreline to reduce or eliminate grid systems. The ADCIRC model provided a better understanding of circulation and water level fluctuations, and therefore sediment transport patterns and pathways, over the region. The model was effective in using low-resolution grid cells offshore and high-resolution grid cells at the project level; however, computational inefficiencies require a supercomputer to run the model. 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. Improvements to SBAS-A would include the capability to store multiple sets of values for each cell, and the ability to assign relationships between the cells. These model enhancements will improve the USACE ability to implement RSM. The key to regional sediment budget development and numerical model application is in the quality and quantity of historical and contemporary data sets for input and analysis. Continuous synoptic surveys of entire regions, 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.

ACKNOWLEDGEMENTS

The efforts discussed in this paper were performed jointly by the U.S. Army Engineer District, Mobile and the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. The use of trade names does not constitute an endorsement in the use of these products by the U.S. Government. Permission was granted by the Chief of Engineers to publish this paper.

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