ENGINEERING TOOLS FOR REGIONAL SEDIMENT MANAGEMENT

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Abstract: The US Army Engineer District, Mobile (CESAM) has recently completed a three-year Regional Sediment Management (RSM) Demonstration program that was initiated in October 1999. Lessons learned from the CESAM RSM program are that successful implementation of RSM requires application of engineering tools appropriate for regional management and analysis. These regional engineering tools include the sediment budget, numerical models, and a Geographic Information System (GIS). Each tool requires regional and historical data sets for input and analysis. The sediment budget is the primary tool for regional management because the sediment budget 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 project modifications can be identified. 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 were encountered in developing the regional sediment budget. Specific difficulties encountered include: reconciling different survey methods and formats, merging varying coverages within an area, accounting for gaps between datasets, incorporating and comparing model results, and managing field and numerical data over a large region. This paper discusses the application of regional engineering tools and lessons learned in the development of the CESAM regional sediment budget.

INTRODUCTION

In September 2002, the US Army Engineer District, Mobile (CESAM) completed a 3-year demonstration program to evaluate implementation of the Regional Sediment Management (RSM) philosophy within the US Army Corps of Engineers (USACE). CESAM is now in the process of implementing RSM into everyday practice. The goal of the RSM demonstration and future RSM implementation is to change the focus from project specific management to taking a regional approach to project management. Therefore, sediments would be managed as a regional scale resource rather than a localized project resource.

The CESAM RSM demonstration region extends approximately 600-kilometers from the St. Marks River, FL (eastern boundary of CESAM), to the Pearl River, MS (western boundary of CESAM), Figure 1. The region is divided into eleven sub-regions based on geography or geology and/or sediment transport patterns. The sub-regions in the Florida Panhandle are coincident with the sub-regions defined by the Florida Department of Environmental Protection (FLDEP).

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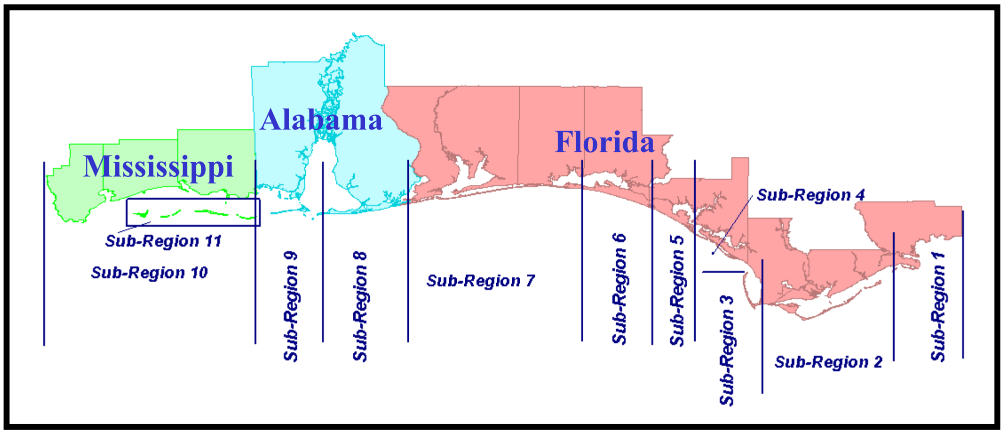


Figure 1. Northern Gulf of Mexico Regional Sediment Management domain

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 followed the process outlined in Figure 2. The process began by developing a preliminary 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 would provide data to refine the sediment budget. 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 region. The comprehensive suite of engineering tools improves our ability to assess coastal process on a regional scale (600-kilometers), manage and analyze data, evaluate sediment management practices and develop new procedures to improve sediment management, and evaluate impacts of modified sediment management practices.

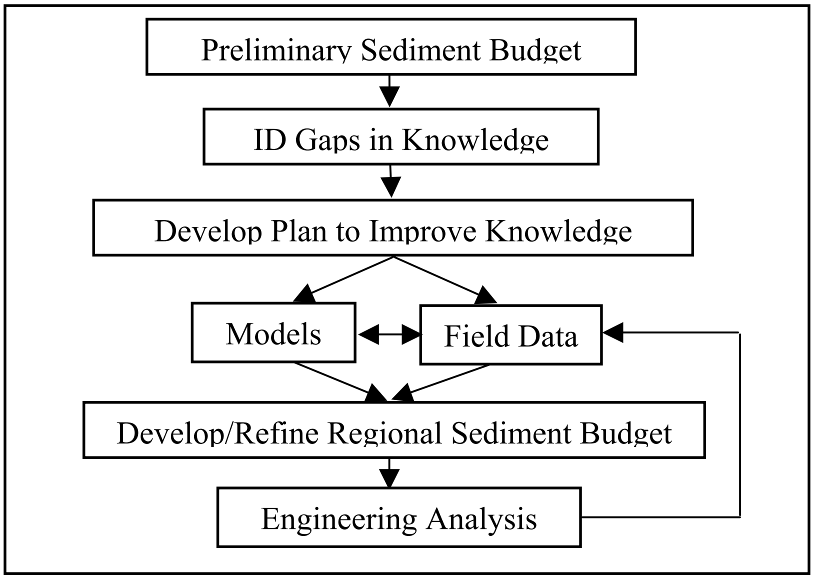


Figure 2. CESAM process to implement Regional Sediment Management

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 new 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), 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 that Florida has a robust coastal program, and Alabama and Mississippi are lacking in data.

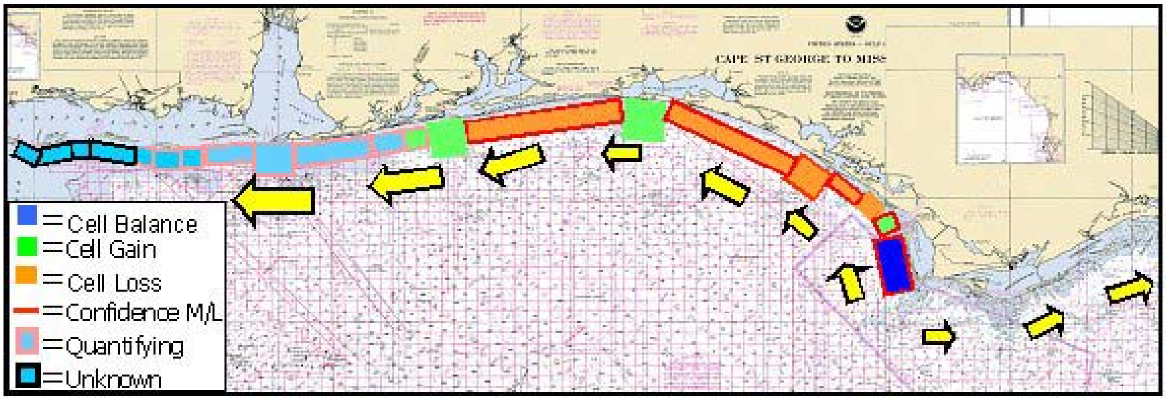


Figure 3. Conceptual regional sediment budget

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, 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).

Difficulties encountered in creating the baseline dataset include: patch-working a compilation of surveys with different coverages, using different datums, and collected in 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 over the region; and data gaps or areas which 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.

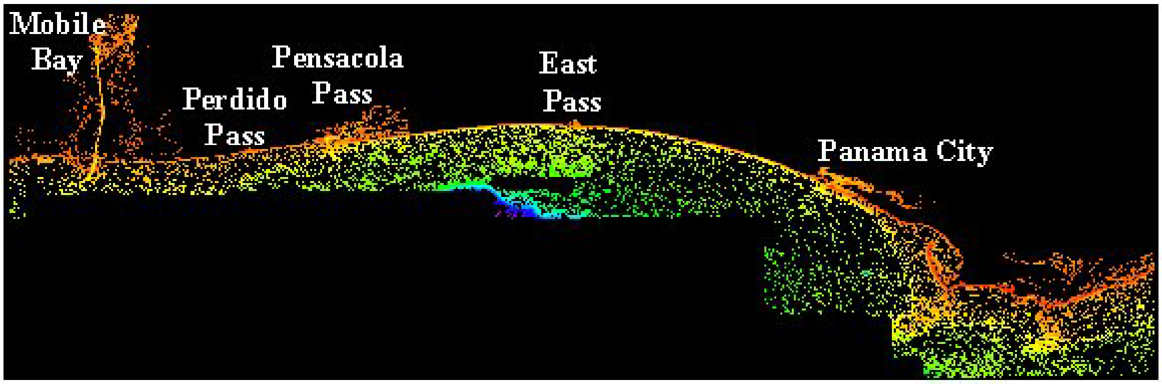


Figure 4. RSM Baseline Dataset

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 and begin evaluation of 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). STWAVE was not applied along the eastern Apalachee Bay area 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 Mississippi mainland was not conducted. The grid system representing sub-regions 4-9 is show in Figure 5. 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 discussed in the next section.

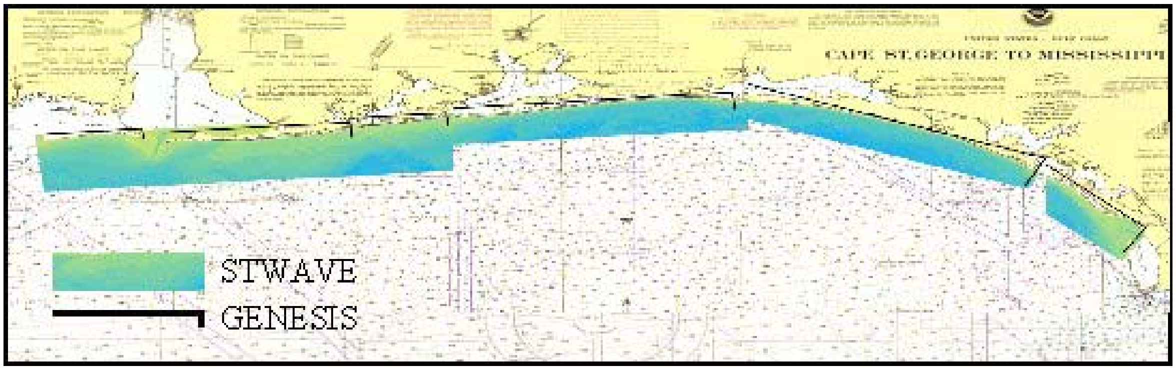


Figure 5. STWAVE and GENESIS grid systems.

Several limitations were encountered in applying STWAVE over the RSM region. The main limitation was the lack of historical data for specifying boundary conditions, representing accurate bathymetry in the grids, and for regional model calibration and verification. Data at East Pass and St. Andrew Bay Entrance, Florida 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 course 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 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. The GENSIS grid system developed for the RSM sub-regions

4-9 is shown in Figure 5. 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.

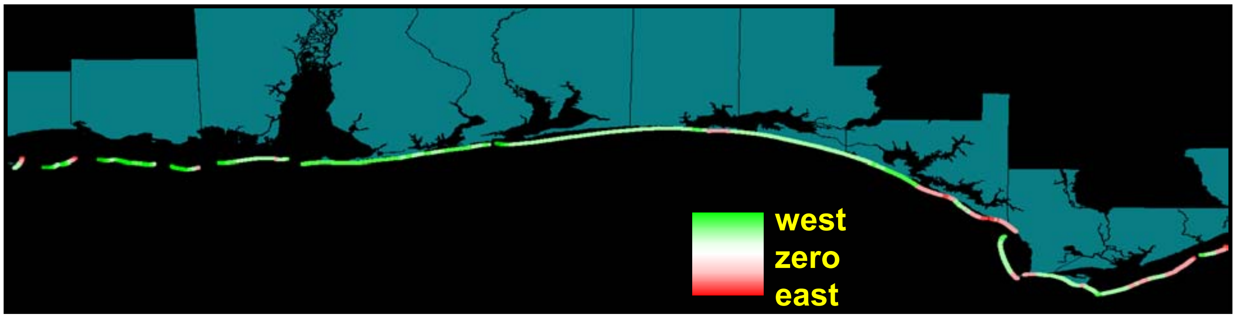


Figure 6. GENESIS potential longshore sediment transport rates imported to the RSM GIS

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 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.

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 in 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 evaluate storm impacts 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 is 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 a Supercomputer.

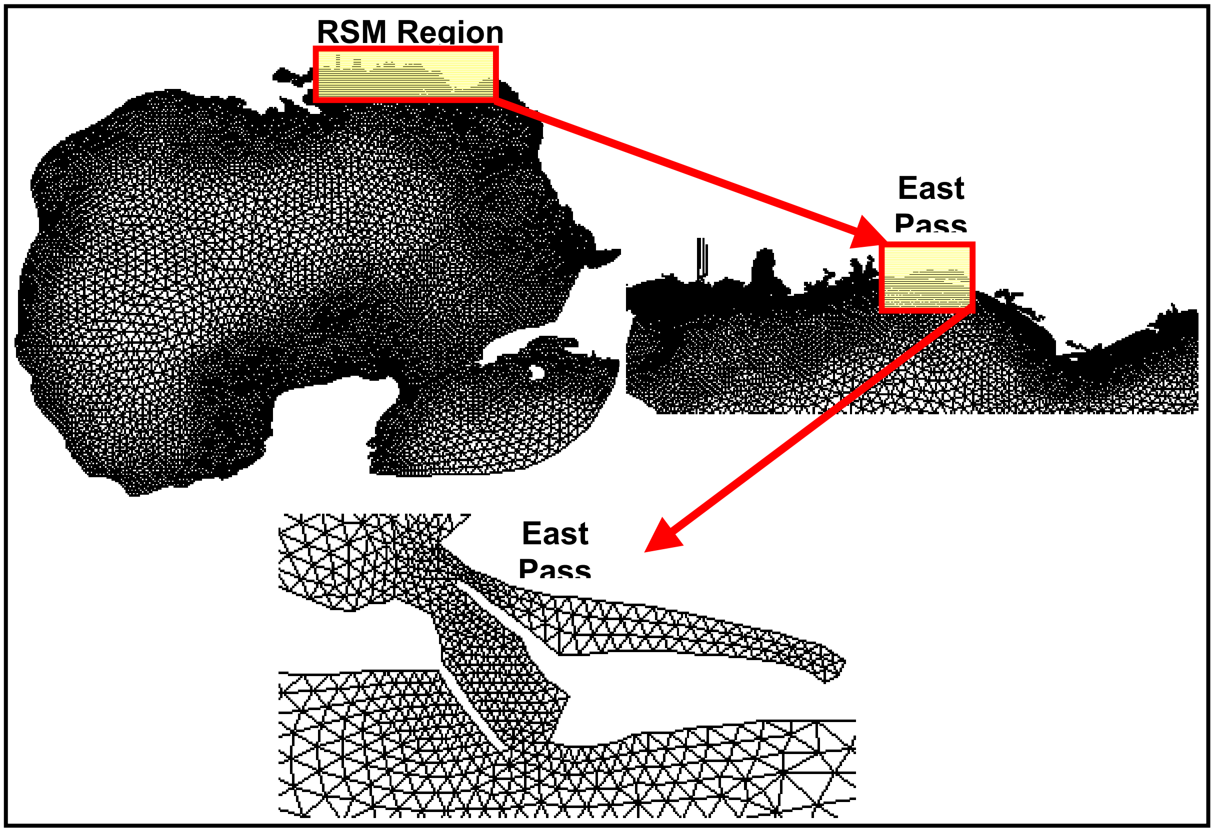


Figure 7. ADCIRC circulation model regional grid

Surface Modeling System

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. SMS enhances the capability to implement RSM through data manipulation for development of the sediment budget as well as model application. Future application of the RSM models will be conducted at CESAM through the SMS interface.

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 the 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. RSM tools within the GIS are discussed in the following section.

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 Spatial Data Branch of CESAM 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 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.

Once all data sets were compiled, the relevant pieces of information were input into the SBAS-A GIS Extension. Each piece of data is related to a particular location within the region, designated as a "cell" of the sediment budget. These cells were drawn as polygon features in the GIS using a set of nautical charts and municipal boundaries for reference. First, cell divisions were placed at county and state lines. At inlets, cells were drawn based on morphological features: ebb and flood shoals, inlet throat, and adjacent beaches. The seaward boundary of the boxes was the 30-foot contour, designated by RSM engineers as the probable depth of closure for the region. An example of the cells drawn for East Pass, Florida, is shown in Figure 8.

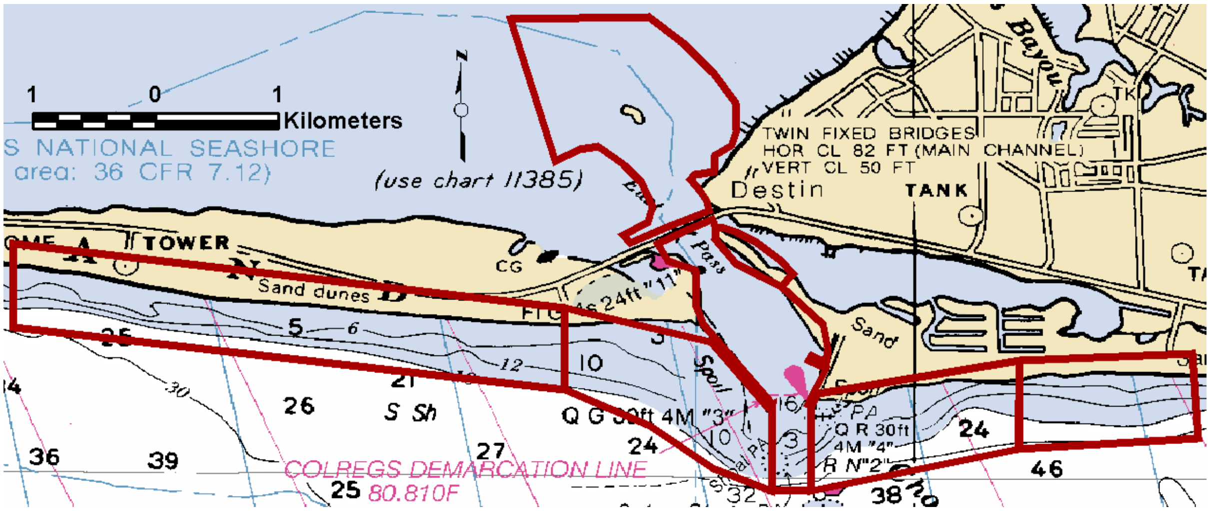
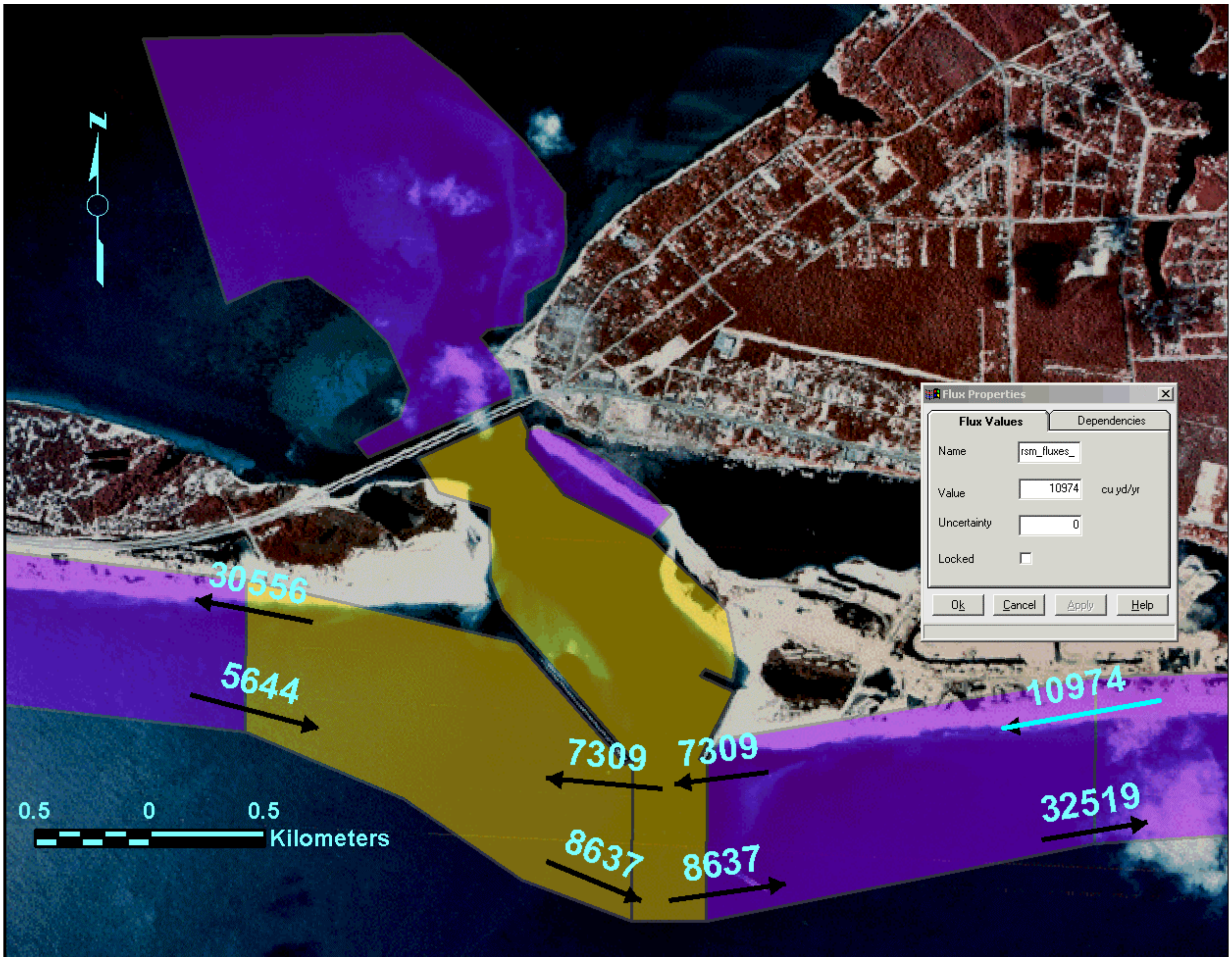


Figure 8. Sediment budget cells for East Pass, Florida

Sediment transport rates were the first piece of information input into the sediment budget. The transport rates are included in the GIS as point data. These data points were extracted from a NetCDF binary file into an ASCII file. The ASCII data were imported into the GIS. Each point has several transport rates associated with it: an eastward, westward, and net transport rate for each of the twenty years of model run, and an average eastward, westward, and net transport rate over all of those years. The values used in the sediment budget were the latter, or 20-year averages of the transport rate estimates. Each sediment budget cell required an eastward and westward transport rate. The eastward transport rate was obtained by averaging all the eastward transport estimates residing in a cell. Transport rates were estimated at points along the shoreline spaced from 60 to 180 meters apart. The westward transport rate for each cell was determined in the same manner. For this step in the process, transport out of inlet cells was assigned the same value as into the inlet cells. An example of how transport rates are entered into the cells is shown in Figure 9. The user simply draws an arrow indicating the direction of transport, and then accesses the data entry window. In this window, the user can input both the calculated transport rate and an associated estimate of the uncertainty of that value.

The result of applying transport rates over the region is shown in Figure 10. The colors are designated to cells based on the value of the residual, or the amount of volume change in the cell not accounted for by the input values (Rosati and Kraus 1999). In purple cells, the residual is positive. In yellow cells, the residual is negative. Green indicates that the cell is balanced, or in the case of the Figure 10, that no values were entered, because no transport rates were estimated for the cell. Based only on transport rate estimates, the residuals tell us in which boxes we should expect a gain (positive residual) or loss (negative residual) of sand.



Name rsm_fluxes_
Value 10974 cu yd/yr
Uncertainty 0
Locked ☐

Figure 9. Transport rate estimates for East Pass, Florida

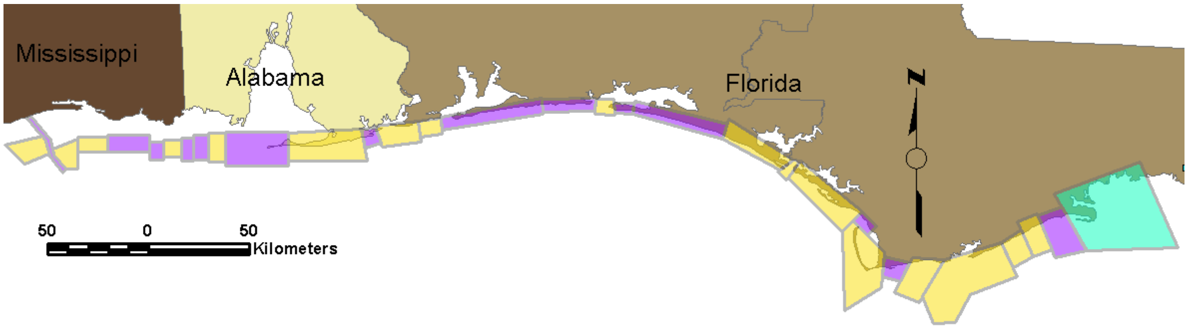
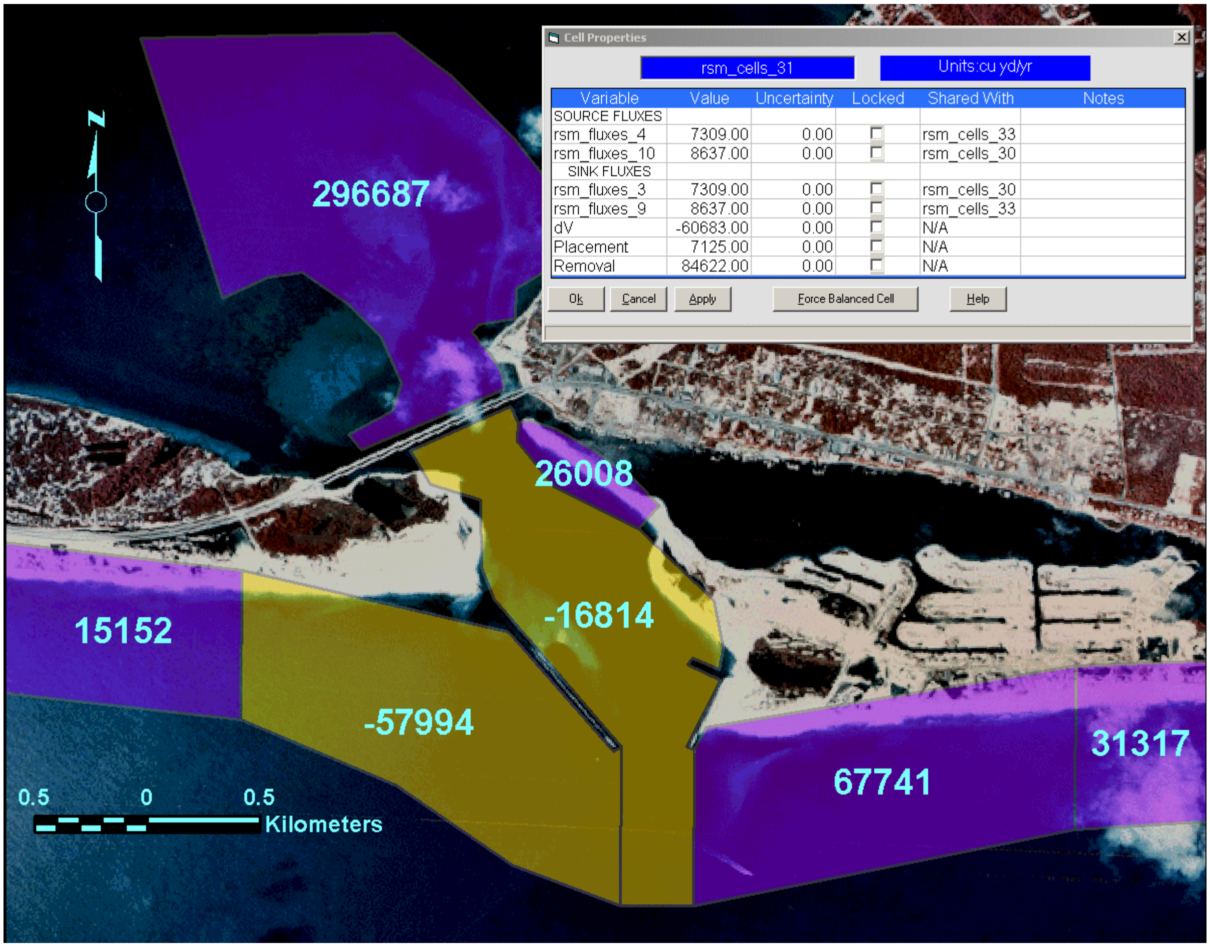


Figure 10. Results of transport rates applied to sediment budget cells. Purple indicates a gain of sediment. Yellow indicates a loss of sediment. Green means no gain or loss, or no data

For this formulation of the regional sediment budget, volume computations between successive data sets were performed using 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, that is, the volume change computed was normalized by the number of years between surveys, resulting in a number with units of cubic yards per year.

The last piece of data entered for each cell is the dredging and placements that have occurred in the cell. Dredging records are kept by the Area Offices of the Mobile District. The records were stored on 3x5 note cards from which a database was created. The RSM GIS accesses this database. The dredging and placement input for each cell are also annualized values expressed as cubic yards per year. Those events in the database that preceded the surveys included in the volume calculation were excluded from the sediment budget.

An example of the data entry window for both volume computations and dredging and placement values is shown in Figure 11. Each of these values may also have an associated uncertainty. Note that the user also has access to transport rate values in this window. Figure 11 also has the residuals calculated in the vicinity of East Pass with all known information included in the sediment budget. The information 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 as regards sediment exchange between the upland and submerged beach.



rsm_cells_31

Units:cu yd/yr

Variable	Value	Uncertainty	Locked	Shared With	Notes
SOURCE FLUXES					
rsm_fluxes_4	7309.00	0.00	☐	rsm_cells_33	
rsm_fluxes_10	8637.00	0.00	☐	rsm_cells_30	
SINK FLUXES					
rsm_fluxes_3	7309.00	0.00	☐	rsm_cells_30	
rsm_fluxes_9	8637.00	0.00	☐	rsm_cells_33	
dV	-60683.00	0.00	☐	N/A	
Placement	7125.00	0.00	☐	N/A	
Removal	84622.00	0.00	☐	N/A	

Figure 11. Residuals for East Pass, Florida

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 12 cells shown in red are those cells where insufficient data exist to make volumetric comparisons in order to balance those cells.

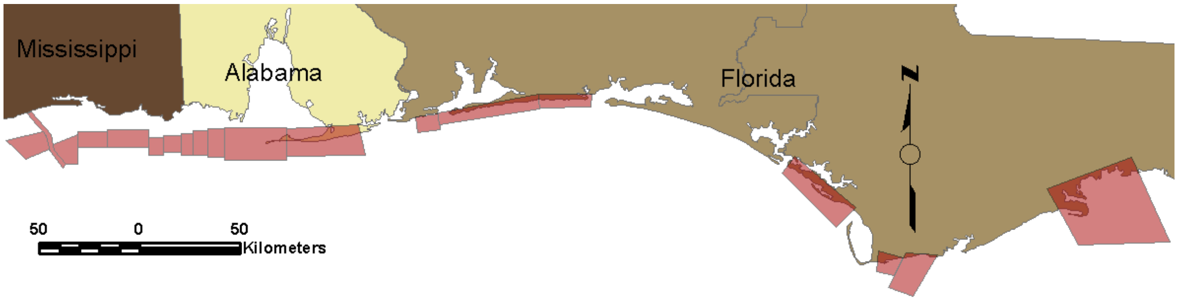


Figure 12. Sediment Budget cells with insufficient data for volume comparisons

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.

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