ADVANCEMENT OF TECHNOLOGIES FOR PRACTICING REGIONAL SEDIMENT MANAGEMENT

LINDA LILLYCROP[1], JULIE DEAN ROSATI[2], JENNIFER M. WOZENCRAFT[3], ROSE DOPSOVIC[4]

1. *U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 1100 Wayne Ave Suite 1225, Silver Spring, MD 20910, USA. Linda.S.Lillycrop@usace.army.mil.*
2. *U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 109 Saint Joseph Street, Mobile, AL 36628, USA. Julie.D.Rosati@usace.army.mil.*
3. *U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 7225 Stennis Airport Road, Kiln, MS, 39556-8003, USA. Jennifer.M.Wozencraft@usace.army.mil.*
4. *U.S. Army Engineer District, Mobile,109 Saint Joseph Street, Mobile, AL 36628, USA. Rose.Dopsovic@usace.army.mil.*

Abstract: The US Army Corps of Engineers (USACE) initiated the Regional Sediment Management (RSM) program in October 1999 to evaluate the implementation of regional approaches to sediment and project management within the USACE. The RSM Program has flourished from a single USACE District evaluation to a national paradigm shift which progresses the USACE from project scale management to regional management for both coastal and inland systems. Advancements in technologies in the areas of data collection, management, and analysis; numerical modeling; web-based tools; and communications have positioned the USACE to more efficiently and effectively implement regional approaches to improve our understanding of regional processes, share information and data, collaborate, and therefore improve decision making in the management of our sediments and projects. This paper discusses the methodology for implementing RSM, with an emphasis on advancements in technologies that have improved the USACE's ability to implement regional approaches.

Introduction

The U.S. Army Corps of Engineers (USACE) has historically managed sediments and projects on a project by-project basis rather than managing the region which encompasses individual projects. This approach may have lead to unanticipated consequences since natural sediment transport processes at a regional scale may perform differently than at local scales. Therefore, sediment management actions implemented within the boundaries of project, jurisdictional, or state scales may have resulted in induced erosion or sedimentation on adjacent areas, inefficient planning for dredged material management, and missed opportunities to more cost-effectively manage sediment resources.

To address these concerns, the USACE initiated the Regional Sediment Management (RSM) Program in 1999. RSM is systems based approach implemented collaboratively with other federal, state, and local agencies. The purpose of the program is to improve the management of sediments and projects on a regional scale, manage sediments as a regional scale resource, and implement adaptive management strategies across multiple projects which support sustainable navigation and dredging, flood and storm damage reduction, and environmental practices which increase benefits while reducing costs. RSM is also means to involve stakeholders to leverage resources, share technology and data, identify needs and opportunities, and develop solutions to improve the management of sediments. The main focus is to better understand the region through integration of regional data and application of tools which improve our knowledge of the region, understand and share demands for sediment, and identify and implement adaptive management strategies. For example, within the navigation mission area, RSM seeks to streamline dredging projects, improve placement of dredged sediment, minimize re-handling of dredged sediment, and improve channel reliability. The adaptive management strategies are developed and implemented through application of the best available science and engineering practices and use of policies which permit regional approaches. Benefits of the RSM approach are improved partnerships with stakeholders, improved regional sediment and project management, improved environmental stewardship, and reduced lifecycle costs.

Because USACE projects were historically managed on a project by project basis, data collection, data management, numerical models, and tools were developed for application at the project level. To transition from project specific to regional capabilities, the RSM program, in conjunction with other programs and efforts, has enhanced, or developed as needed, technologies appropriate for regional evaluation in order to improve decision making and management at regional scales (Wozencraft et al., 2001).

This paper discusses the RSM approach with an emphasis on developments that have occurred since the USACE initial implementation of RSM. Advancements in regional data collection, data management, development of regional sediment budgets, and numerical modeling are reviewed. This paper concludes with a case study of utilizing adaptive management approaches for implementing RSM.

The RSM Approach

The RSM approach, Figure 1, is an iterative process which requires adaptive management. The process begins by evaluating the region and identifying solutions or actions to improve how sediment is managed. Actions are implemented and monitored to evaluate the performance of the action. If the action performs as planned, the action is incorporated as standard practice. If the action does not perform as planned, the action is revised and the improved action is implemented. Again, the action is monitored and performance evaluated. This iterative process continues until a balance between efficient performance and the project constraints are reached. The flow chart shown in Figure 2 and the steps outlined below describe in more detail the effort involved to implement the RSM approach.

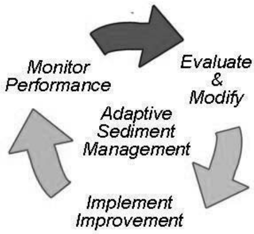

Fig. 1. Regional Sediment Management approach

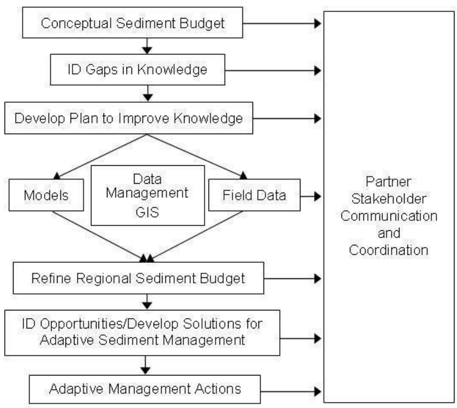

Fig. 2. Steps for implementing Regional Sediment Management approach

Step 1: Understand the Region

The first step in the RSM process is to develop a conceptual regional sediment budget. A sediment budget is the primary tool for RSM because it identifies the sediment sources and sinks, or gains and losses, engineering activities, the sediment transport pathways, and the beach and bathymetry changes over the region. Information and data needed to develop a conceptual sediment budget is obtained through a literature review of studies, projects, and other available information. The conceptual sediment budget also provides an understanding of the gaps in information, or areas lacking in information and data, therefore providing a focus for moving forward in better understanding the region.

Step 2: Collaborate; Establish Partnerships

The key to a successful RSM program is the communication, coordination, and involvement of partners and stakeholders who have an interest in improving the management of sediments within the region. Reaching out to partners in developing the conceptual sediment budget can lead to a wealth of additional information, data, and knowledge. Partners help in identifying sediment related problems, work to identify solutions, and ultimately help make decisions to better manage the region. A lesson learned is to bring partners and stakeholders into the program early to initiate communication and to begin to develop an understanding of the needs and opportunities of all participants (Lillycrop et al., 2003). Bringing together several organizations to collaborate on the management of a region can be initially difficult because every organization has a different need or goal depending on their mission. By communicating, working together, and a willingness to compromise for the advancement of the region, solutions can be developed and implemented which meet the many needs of a region. Coordination and communication is accomplished through regional meetings, workshops, conference calls, webinars, and sub-groups assigned to work through specific challenges.

Step 3: Develop a Plan to Improve Knowledge

Through the conceptual regional sediment budget, the gaps in knowledge, information, and data are identified, as well as a general understanding of the sediment needs and challenges over the region. Through communication with partners and stakeholders, a strategy is developed to fill the gaps and refine the conceptual sediment budget. In developing the strategy to improve regional knowledge, a lesson learned is that successful implementation of RSM requires application of engineering tools appropriate for regional management and analysis. Regional engineering tools include: 1) the regional sediment budget including micro-budgets at sub-regional and project levels; 2) numerical models to evaluate hydrodynamic conditions, sediment transport, and shoreline change at regional, sub-regional, and project scales; and 3) a data management and Geographic Information System (GIS) for managing and storing historic and new data, performing analysis of data and model results, and sharing of information and data. Each tool requires contemporary and historical data sets for input and analysis. Data collection should support filling data gaps in order to provide comprehensive regional datasets. Ideally, continuous synoptic surveys are available on a regional scale. Through this effort to refine the conceptual regional sediment budget, our knowledge of the hydrodynamic and sediment transport processes occurring over the region is greatly improved (Lillycrop et al., 2003).

Step 4: Collect or Obtain Regional Data

Effective implementation of RSM practices requires regional datasets for developing sediment budgets, application of numerical models, and to analyze and understand the morphologic changes along the shoreline resulting from offshore forcing. The following data are necessary to perform regional coastal processes management: 1) hydrodynamic and meteorological data: waves, water-levels, currents, winds, and storm data; 2) historic bathymetric, topographic, and shoreline data; 3) regional, continuous, current, and synoptic bathymetric and topographic surveys; 4) georeferenced/ortho-rectified aerial photography and/or satellite imagery; and 5) historical dredging information and data (Lillycrop et al., 2003).

When the RSM program initiated, data were typically collected on a project specific basis. This required significant manipulation of project level survey and mapping data to create regional baseline datasets. Hydrodynamic data were also collected at the project level resulting in sporadic datasets across the region which did not provide for comprehensive regional forcing. Data collection in this manner was inefficient and expensive, labor intensive for regional use and analysis, and did not foster coordination in data collection and sharing.

Survey and Mapping Data

As part of the first RSM demonstration in the USACE Mobile District, which encompassed 350 km of Gulf of Mexico shoreline from the west end of Dauphin Island, AL, east to Apalachicola Bay, FL, a regional baseline dataset was assembled for refinement of the conceptual regional sediment budget and for application of numerical models to better understand the coastal processes within the region.

Data available in this area included beach profile, singlebeam and multibeam project condition surveys, nautical chart bathymetry, and Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) (Lillycrop et al., 1996) bathymetric lidar). Creating the baseline dataset required merging the compilation of surveys with different coverages, collected in different time frames, and with variable data point densities. The datasets across the region were also collected at different vertical datums; therefore merging them together required interpolation using a vertical datum transformation surface (McClung, 2000). Figure 3 illustrates the different project level datasets available at Pensacola Pass, FL. Much time and effort was expended in data manipulation to merge the datasets together. The SHOALS data were captured at individual navigation and dredging projects to support USACE activities, and along the entire Florida panhandle in an early demonstration of the airborne lidar mapping capability for the provision of regional datasets for the Florida Department of Environmental Protection (Watters and Wiggins, 1999), Figure 4.

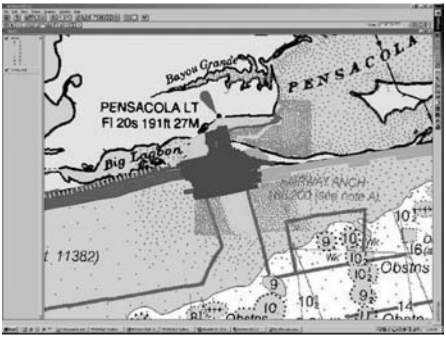

Fig 3. Multiple project level datasets collected at Pensacola, Pass, FL

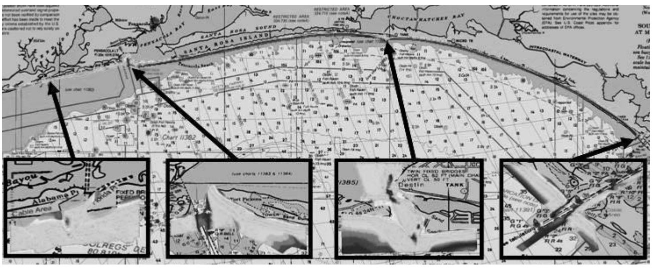

Fig 4. Initial SHOALS survey across the Florida Panhandle

Repeat regional data sets are necessary for quantifying the topographic and bathymetric volume changes integral to the creation of meaningful sediment budgets and to understand the morphologic changes resulting from various forcing. Recognizing this need, data collection technologies have emerged to enhance coverage (ie. jet skis and all terrain vehicles). Data collection efforts have expanded beyond project boundaries and often combine multiple projects.

In 2004, Headquarters USACE established the National Coastal Mapping Program (NCMP) for the provision of high-resolution, high-accuracy, regional, reoccurring elevation and imagery data. NCMP is executed by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) using its Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system (Wozencraft and

Millar, 2006) and similar capability is available in industry. NCMP elevation and imagery data are collected using bathymetric lidar for depth measurements (shoreline to 1000m offshore), topographic lidar (shoreline to 500 m onshore), high-resolution aerial photography, and high spectral resolution hyperspectral imagery. This 1500 m swath is designed to capture physical and environmental characteristics along the U.S. sandy shoreline from the dunes to depth of closure.

A series of products are generated for immediate use by geographic information systems (GIS) and analysis tools. Seamless Digital Elevation Models (DEMs) (Figure 5a) that include bathymetric and topographic elevation data are produced in first-return and bare-earth format. The first return format includes buildings and trees for quantification of vegetation metrics and assessment of coastal infrastructure while the bare-earth removes these features for use in numerical models. A vector shoreline indicates shoreline position at the time of survey. Aerial photo mosaics (Figure 5c) are used for processing the lidar and are valuable in interpreting the elevation data and assessing coastal infrastructure. Hyperspectral image mosaics are combined with the DEMs to create a basic land cover classification that identifies bare ground, buildings, roads, and vegetated areas. The hyperspectral mosaics are available for further analysis like vegetation mapping: invasive species, wetlands, and submerged aquatic vegetation. Images of laser reflectance (Figure 5b) can be used alone or in combination with the hyperspectral imagery to discriminate different seafloor types. Habitat delineation is possible using a combination of the geomorphology described by the lidar data and the environmental characteristics described by the hyperspectral imagery.

NCMP began its second circuit of the U.S coastline in 2009 with mapping the Gulf and East Coasts, initiating a new set of products for quantifying change in the coastal zone. A comparison of DEMs will quantify volume changes and changes in coastal infrastructure and vegetation. A comparison of shoreline position will quantify shoreline change. Comparing vegetation and seafloor classifications and habitat delineations will enumerate gain or loss of these valuable resources.

Hydrodynamic Data

Historically, waves and current data were collected at the project level on an ad hoc basis. This resulted in datasets with significant gaps across a region, data collected over different time periods, and a one-year duration was considered long term. Data collection in this manner was inefficient and expensive, labor intensive for regional use and long-term analysis, and did not foster coordination in data collection and sharing.

Over the last ten years, national programs and interagency collaboration (i.e., the US Integrated Ocean Observing System) has resulted in efforts to coordinate and share resources in the collection of data, reduce duplication of efforts, standardize procedures and formats, and provide continuous long-term datasets.

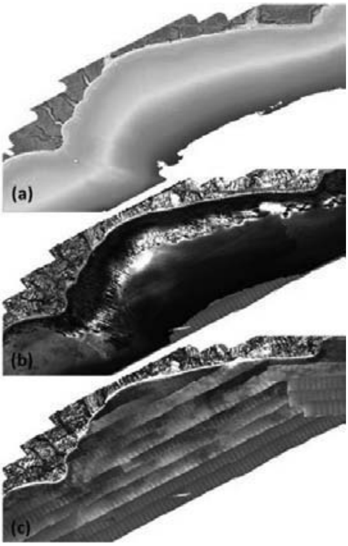

Fig 5. USACE NCMP standard products: (a) seamless bathymetric/topographic DEM, (b) laser reflectance image, (c) aerial photo mosaic.

Step 5: Data Management, Analysis, and Visualization

Early in the RSM program it was recognized that moving from project level to regional datasets requires a data management system to adequately manage, analyze, archive, and share the large volume of data acquired across the region. The system would require a standardized architecture to maximize the sharing of data and applications across various organizations, and eliminate duplication. The result was the eCoastal enterprise GIS for RSM which provided an interface to hydrographic, topographic, photogrammetric, and historic dredge material data as well as custom applications designed to facilitate engineering analyses. The eCoastal GIS serves as the link between data management, engineering analyses, regional numerical models, and stakeholders (Wozencraft et. al., 2001). 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.

Initially eCoastal was available to ESRI ArcView 3.x software users; however, online mapping capability made available early in the RSM program provided access to all users through Microsoft (MS) Internet Explorer. With the development of Internet Map Server (IMS) technology, eCoastal began distributing data to all users. Since 2006, eCoastal has incorporated live data feeds from existing enterprise data sources. These sources were distributed in a web mapping service (WMS) format which allows data retrieval directly from the data steward, rather than referencing a potentially outdated copy of the data. This technique eliminates locate data storage and minimizes duplication. In 2008, eCoastal migrated to ArcGIS services for more efficient data distribution. In 2009, a MS Silverlight mapping application was created and geospatial capabilities are now distributed to a much larger audience. With increased speed, users are migrating to online map viewers to obtain geospatial information.

Custom tools and applications were developed which link geospatial and tabular/business database information to visualize patterns, relationships, and trends in data. Data retrieval tools enabled access to datasets distributed among many projects or throughout many USACE Districts. Analytical tools designed for LIDAR datasets empowered engineers to compute volume differences, view cut/fill of erosion and accretion areas, cut cross-sections, and view data in 3D.

eCoastal products and capabilities are combined with data analysis tools to understand and analyze more data in less time and provide a mechanism to convert data into useful information in a cost-effective and timely manner. The approach is modular so that each tool can operate independently or in conjunction with others. This design allows for the incorporation of new technologies and capabilities as new requirements are identified. Key to improving the analysis process is reducing the effort to import information. New techniques automatically extract results for input to databases, GIS, data visualization, and other tools.

The ten year evolution of eCoastal has resulted in a library of lessons learned. The primary obstacles involved data integration, data manipulation, and data storage. The enterprise GIS effort has reduced extensive data manipulation by establishing new procedures to ensure surveys are delivered in the RSM projection of choice with associated metadata files.

Step 6: Regional Numerical Models

After an understanding and quantification of the regional sediment pathways and magnitudes has been developed through data analysis and formulation of the regional sediment budget, numerical models are often applied. Numerical modeling can give insights to understand storm and seasonal processes that are averaged in the longer historical analysis, and applications can assess the implications of proposed engineering activities on the local project area as well as cumulative changes of the proposed projects (and possibly other projects) in the littoral system.

An ideal RSM modeling study would include regional circulation (tide, wind, river flow, and salinity), wave (incorporating wave runup, reflection, transmission, and overtopping at structures), sediment transport (cohesive and non-cohesive), and morphology change models that encompass the littoral system with sufficient resolution both at the regional and local project scales. Such a modeling system is calibrated and validated with field measurements and applied to evaluate how future sediment management practices may affect the regional system over years to decades. Environmental concerns such as water quality in bays, changes to circulation patterns, and sediment transport deposition over critical habitat would also be culled from model simulations. Because littoral systems can encompass large areas and require long time periods to evolve, such a modeling study as described is generally too intensive to be practical for most studies.

However, accommodations can be made to streamline modeling applications and address regional modeling needs. Nested grids with finer resolution can be used in conjunction with larger regional models at coarse resolution to speed up calculations and still give the detailed information near the project or in critical areas. Intensive, detailed calculations can be conducted for relatively short time periods for a local area and report a time series of boundary conditions. Then simpler methods such as regional shoreline change or river transport models can use the boundary conditions as forcing for an application at regional scale. Once numerical models are established for an area, they can be updated through time with new data and applied to evaluate alternatives for adaptive management.

Step 7: Analyze Data and Revise Regional Sediment Budget

Evaluating the success of previous RSM activities and relative merits of proposed alternatives requires assessment of historical data including shoreline and bathymetric volume change, analysis of engineering activities, and formulation of a regional sediment budget. Key to the RSM approach is the need to evaluate data and improved strategies on a regional spatial scale that is commensurate with the littoral sediment transport system over longer temporal scales that range from years to multiple decades. Two new analysis tools are discussed here: the Regional Morphology Analysis Package (RMAP) and the Sediment Budget Analysis System (SBAS). Both are free and readily available for download (CIRP, 2010).

RMAP is a PC-based software package for analysis of beach profile, river cross-section, and shoreline position data within a georeferenced framework (Morang et al., 2009). Beach profiles can be overlain with equilibrium, modified equilibrium, interpolated (based on other data), and plane sloping profiles. Volume changes between shorelines, cross-sections, and profiles can be calculated. Georeferenced data can be plotted with aerial photography to illustrate coverages and trends.

The regional sediment budget represents the long-term, best estimate of sediment transport, engineering activities, and bathymetric and topographic change over a defined period of time (years to decades). As implied by the term “budget”, the sediment budget is intended to balance sources and sinks of sediment with known engineering activities and observed volume change within the region. However, an unbalanced budget can provide information about areas needing additional data to improve understanding or resolve conflicting information. Since inception of RSM practices within the USACE over the past decade, sediment budget visualization and presentation methods have progressed to include free PC-based software and GIS applications that facilitate a standardized format.

Prior to the RSM approach, sediment budgets were prepared in a spreadsheet or by hand and explained and transferred visually with figures. New advancements allow calculations to be conducted at a desk-top, either through a graphical user interface or via a GIS application which streamlines incorporation of GIS volumetric analyses within the sediment budget. The resulting calculated sediment budget can be readily viewed and transferred for review and evaluation. SBAS is free software that standardizes presentation, minimizes arithmetic errors, and streamlines communication of the budget. Erosional cells are typically represented as red and accretional cells as green; or, colors can be toggled to show unbalanced and balanced cells. Cells can be “collapsed” or combined to summarize changes within a particular morphologic regional such as a barrier island or inlet system. Collapsing details of a morphologic regional is useful when zoomed out and viewing a large regional extent. Shoreline and riverbank change data can be imported and visualized adjacent to the sediment budget cells.

Historically, the sediment budget was presented and communicated as shown in Figure 6. With new software developed as a part of the RSM program, sediment budgets have become more detailed and informative, Figure 7.

Step 8: Collaboratively Develop and Implement Adaptive Management Strategies

Case Study: Perdido Pass, Alabama

Perdido Pass, AL, is a federally authorized navigation channel; therefore, the dredged from the navigation channels and placed in various disposal areas (DA)

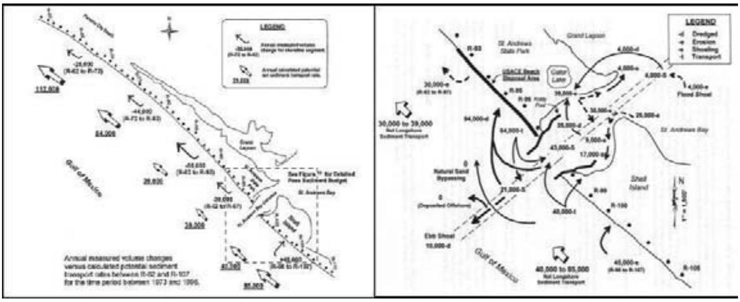

Fig 6. Sediment budget : Panama City Beaches/St Andrew Bay Entrance, FL (Coastal Tech, 2002)

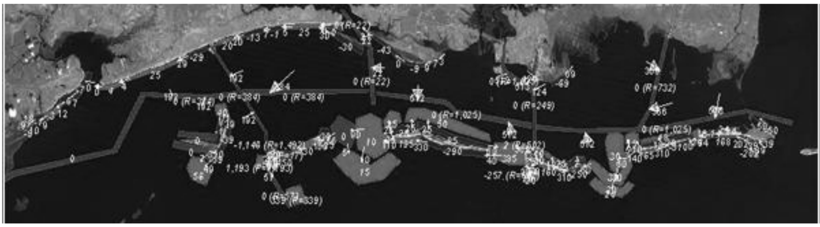

Fig 7. Regional sediment budget for the Mississippi Coast

shown in Figure 8, with much of the sandy material permanently removed or slow to return to the littoral system. Maintenance dredging is conducted on a 2-3 year cycle, and dredging volumes have ranged from 150,000 to 750,000 CY per dredging cycle. The objectives of this initiative were to reduce erosion downdrift thereby enhancing the storm protection along the shoreline, reduce rehandling of material that returns to the pass, and reduce O&M and overall lifecycle costs (Parson and Rees, in publication).

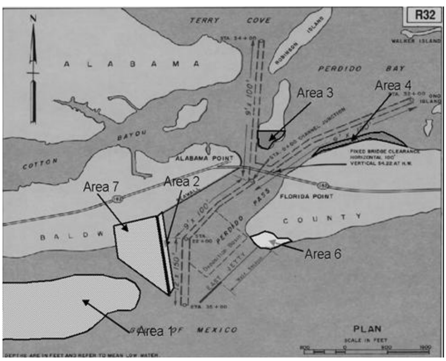

Fig 8. Perdido Pass historical placement options

To improve sand bypassing, it was recommended that DA 1, 3, 4, and 7 no longer be used since these sites permanently remove sediment from the littoral system. An evaluation of the Pass recommended that material be placed downdrift at a distance beyond the influence of the ebb tidal shoal (Gravens, 2003); therefore maximizing sand retention and minimizing sand returning to the navigation channel. To maximum benefits, direct beach placement was recommended. However, some material must be placed in DA 2 and 6 to maintain the structural integrity of the jetties.

Through coordination with Operations, Planning, and Engineering within the Mobile District, the resource agencies, and the project stakeholders and sponsors, the initiative was implemented which removed about 430,000 cy of sand from the navigation channel and placing 400,000 cy on the downdrift beaches west of the Pass. About 30,000 cy was placed at DA 6. The project was monitored to assess the performance of the placement strategy with documented lessons learned.

Benefits of this initiative are more efficient sand bypassing associated with maintenance activities which contribute to alleviating coastal erosion downdrift; a reduction in material which returns to the pass which reduces rehandling; and wider downdrift beaches which increases habitat for sea turtles and shore birds, and augments natural dune creation which is beneficial for dune dwelling organisms and provides greater storm protection. Educating the public through outreach activities improved cooperation from private property owners. This adaptive management strategy has been incorporated as standard practice in the management of sediments at Perdido Pass (Parson and Rees, in publication).

Conclusion

RSM within the USACE has evolved since the initial implementation in 1999. Our technical capabilities have enhanced from the project to regional and national scales, providing the ability to evaluate and implement actions to improve the management of sediments. Collaboration and coordination with partners and stakeholders has advanced RSM as standard practice among many organizations The RSM program continues to flourish in meeting the objectives to improve the management of sediments and projects regionally, manage sediments as a regional resource, and implement adaptive management strategies across multiple projects which support sustainable navigation and dredging, flood and storm damage reduction, and environmental practices which increase benefits while reducing costs.

Acknowledgements

This paper was funded by the Regional Sediment Management Program of the U.S. Army Corps of Engineers. The USACE, Headquarters granted permission to publish this paper.

References

Coastal Inlets Research Program (CIRP). (2010). "U.S. Army Corps of Engineers – CIRP Website, Products and Tools," http://cirp.usace.army.mil/products/index.html.

Coastal Technology Corporation (2002), St. Andrews Bay Entrance Downdrift Influence Assessment, Coastal Technology Corporation, Vero Beach, FL.

Lillycrop, W. J., Parson, L. E., and Irish, J. L. (1996). Development and operation of the SHOALS airborne lidar hydrographic system. SPIE: Laser Remote Sensing of Natural Waters From Theory to Practice. 15: 26-37.

Lillycrop, L.S., Wozencraft, J. M., Hardegree, L. C., Dopsovic, R., and Lillycrop, W. J. (2003). "Lessons Learned in Regional Sediment Management: The Mobile District Demonstration Program Technical Program Implementation," Coastal Engineering Technical Note, CHETN-XIV-13 2003, US Army Engineer Waterways Experiment Station, Vicksburg MS.

Parson, L. E., and Rees, S. I. (in publication). "Northern Gulf of Mexico RSM Demonstration Program Initiatives," ERDC/CHL CHETN-XIV-xx, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Rosati, J. D., Carlson, B. D., Davis, J. E., and Smith, T. D. (2001). "The Corps of Engineers' National Regional Sediment Management Demonstration Program," ERDC/CHL CHETN-XIV-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Watters, T. and Wiggins C. E. (1999). Utilization of remote sensing methods for management of Florida's coastal zone. . *Proceedings, US Hydrographic Conference '99*. Mobile, Alabama, USA.

Wozencraft, J. M., Hardegree, L., Bocamazo, L. M., Rosati, J. D., and Davis, J. E. (2001). "Tools for RSM," ERDC/CHL CHETN-XIV-2, U.S. Army Engineer Research and Development Center, Vicksburg, MS.