An Overview of the Concept of Regional Sediment Management

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Abstract: In this article we described the concept of "regional sediment management" (RSM), and identified opportunities for and impediments to implementing regional approaches to sediment management, and also summarized the background information and applications of RSM. Furthermore, we considered the needs of RSM studies and, suggested the framework for developing RSM strategies, and described the specific studies for the Xiamen region.

Keywords: RSM; resource; coastal zone; dredging

Introduction

In this article we described the concept of "Regional Sediment Management" (RSM), its background and application within the coastal engineering concept, and issues associated with its implementation in the future.

The need for RSM is based on the recognition of the regional implications of dredging and other activities in the littoral zone, as well as the appreciation for sand as a resource as much as water which is a resource experiencing competing demands, along with both quantity and quality issues. RSM is an approach to managing projects involving sand and other sediments that incorporates many of the principles of integrated watershed (including riverine system) resources management, applying them primarily in the context of coastal watersheds. It also supports many of the recommendations on improving the dredged materials management. Examining RSM implementation through demonstration efforts can provide lessons not only on improved business practices, techniques and tools necessary for managing resources on a regional scale, but also in terms of roles and relationships important to the integrated water resources management.

1 History of RSM

RSM originated in the notion of coordinating dredging activities in the coastal zone for the purpose of retaining sand in the littoral system in the interest of promoting more balanced, natural system processes, and reducing project costs. In 1994, the U. S. Coastal Engineering Research Board (CERB) was tasked

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with developing future directions for civil works coastal engineering and supporting R&D (research and development). Recommendations from the CERB task force included, among other things, adopting a “system approach to coastal sediment management”.

As a result, a working group on the sediment resources management was formed to develop implementation recommendations.

The concept of RSM was later introduced at the U S. Marine Transportation System National Conference in 1998 [1]. The theme for the 67th CERB (1998) was “Regional Sediment Management,” and the CERB reexamined the concept along with the proposal for an RSM demonstration project within the Mobile District. Recommendations for pursuing RSM were made by the CERB at its 1997 meeting. The CERB recommended taking a “system approach to effective sediment resource management”, noting that:

(1) Current cost-benefit analysis and engineering considerations treated navigational concerns of coastal engineering separately from the associated impacts of down drift beaches, with the result that it was often more expensive, and less acceptable to repair the down drift beaches than it would have been to maintain the original natural flow of sand.

(2) The challenges of projects in bays and harbors make a systems approach essential to managing sediment in an environmentally sensitive manner.

(3) Benefits of taking this system approach could include enhanced public participation and agency collaboration in planning and management, and reduced adverse impacts on the nearshore system.

(4) Costs (first costs and long-term maintenance costs) could be reduced over both the short and long terms.

2 Implications of dredging

Particularly navigation jetty and navigation-channel projects along the riverine system or boundaries between riverine- littoral marine systems are generally old, having been constructed without knowledge of potential regional impacts and contemporary needs and values associated with the resource management. Advances in understanding of coastal sediment processes, and observation of impacts from earlier projects reveal a number of regional impacts associated with navigation projects. Large jetties, deep channels, and sand management practices that obstruct or otherwise prevent the natural movement of sand along the coast can be detrimental to beaches and other aspects of coastal systems. These effects can extend miles from the project and across many regional boundaries.

Main implications of dredging without considering “Operation and Management” (O&M) under the RSM concept are the changes or effects of the sediment budget -which is an accounting of the sources and sinks (or gains and losses) of littoral material in a defined area- and impacts on the natural environment or the ecosystem in the vicinities, even in the coastal region. From the coastal engineering point of view, main causes and effects of this type of dredging are outlined below.

2.1 Creation of new depositional environment and changes of bottom sediment composition

Deepening of the bottom and increasing of the slope increase the sedimentation rates in the dredged areas. The diagram in Fig. 1 shows how the quality of the sediment changes with depth. The red curve is the bottom profile, running from land at the 10 m height on the left, to a depth of -45 m, on the right. The colored areas show the relative composition (0 - 100 %) of the sea sand. Close to the coast, the sand consists mainly of fine sand, which is capable of being moved by wind, thus forming part of the dune system. Fine sand also moves easily in the water, and up a steep dredged slope. It is also easily moved away from the coast. Further out, the sand is mainly of medium size, easily moved by waves. Then an area comes of mainly coarse sand, which is not easily moved by waves from the coastal zone, and is left behind at the coast, while its finer sand component was winnowed out by the wave action toward deeper waters. Then suddenly, the composition changes to fine sand and a substantial amount of mud comes in. This is the area where even large waves cannot move the sand towards the coast, and the mud is soaked up by the fine sand. Deeper still where the waves are very seldom felt, the mud can settle out on top. Eventually, the bottom of the dredged areas becomes entirely muddy.

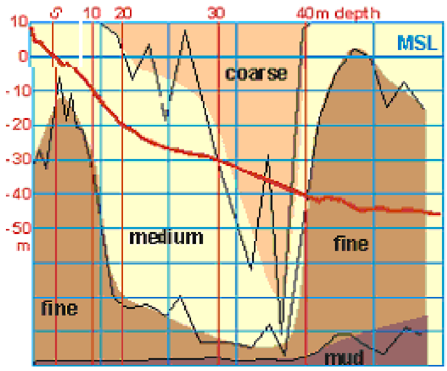

Fig.1 Relationship between sediment types vs. depth

2.2 Changes of current velocities for erosion/accretion, sedimentation and transport

The diagram in Fig.2 depicts the relationships between water velocity and grain size with relevance to erosion/accretion, transport and sedimentation. It defines the behavior of sediment in water, under the influence of currents and waves. Notice that the scales span an enormous range of four decades! Vertically, from bottom to top, the grain size increases, and colored bands have been drawn to mark clay, silt, sand, granules and pebbles. The straight line is the theoretical drag, as defined by Stokes' equation, which excludes turbulence. The two curves left and right of it have been derived from actual measurements. Water velocity needs to exceed the right-hand curve before the cohesive (packed-together) material begins to move. It is interesting to note that silt and clay, once settled as a 'cake', are hard to dislodge. The left-hand curve shows at which velocities particles settle out. Again silt and clay need extremely tranquil conditions before doing so. For the coarse material, the erosion and sedimentation curves follow the theoretical straight line. The diagram shows that pebbles can be moved only by strong wave action, or by fast flowing currents. In order to form beaches, the grains must be moved easily but also stay put - two conflicting properties. Sand from about 0.2 mm to boulders of 100 mm or larger (the area between the straight ends), would do this. Silt and clay, however, would not. Boulder beaches form only on very exposed shores, whereas beaches of fine sand form on more sheltered shores. Mud flats, on the other hand, form only at the most sheltered places inside enclosed harbors. Furthermore, particularly in the navigational channels and jetties while causing the deposition of muddy material, combination of changes of natural current velocities due to sudden slope variations with the turbulence created by vessels' propellers export the sand to the less deep areas will not only alter the coastline configurations, but also create shoals and bars, and increase the deposition of mud within the harbor.

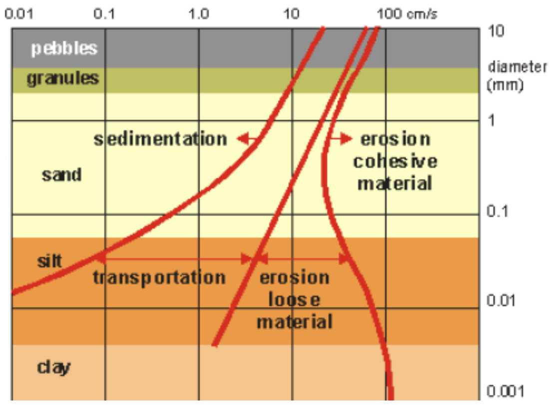

Fig.2 The relationship between erosion/accretion, transport and sedimentation due to changes in current velocities and particle size

2.3 Environmental consequences of dredging

This type of local or project-specific scale dredging will have negative impacts on the environment or the overall ecosystem. A main effect of dredging is stirring. For instance, skimming the bottom 30 cm daily will cause an area of 1 km^2 disturbed by the stirring.

As it is illustrated in Fig.3, firstly, this will cause a direct habitat disturbance to bottom living communities. Secondly, during the dredging, a plume of silt will develop, both over the bottom and near the surface. It will pollute the sea water for some time, and promote plankton blooms from the released nutrients. Poisons such as heavy metals and hydrogen sulphate, locked up over time within the sea soil, are released again. This will cause either death of some of the bottom fauna, or alteration within the bottom living communities on the one hand, and transportation of polluted plumes by currents, waves or tidal actions to elsewhere on the other.

Furthermore, during the offshore disposing of dredged material suspended load with contaminated materials will be generated by the surface dust plume. Some of this contaminated suspended load will be carried by the transporting agents (current, wave, tide) to the nearshore areas. This would cause pollution of the beaches and nearshore waters.

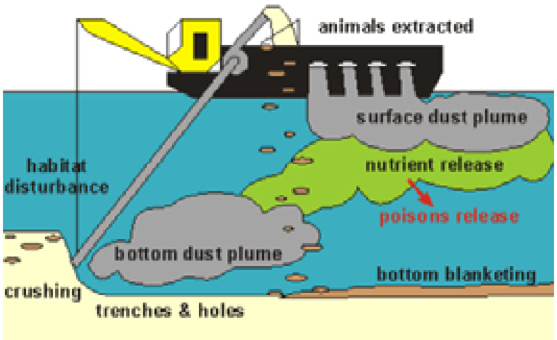

Fig.3 Environmental consequences of dredging

2.4 Overall/combined effects of the local or project-specific dredging

The overall or combined negative effects and its consequences of local or project-specific dredging in the navigation channels or jetties off the riverine system are given below.

(1) Rapid sediment transport toward the newly dredged sites, and its accumulation and settling.

(2) Increase of both erosion in the coastal headlands, and offshore shoaling and nearshore bar formation.

(3) Physical, chemical, and biological changes by disturbing the sea bottom.

(4) From an ecological perspective, bottom fauna could suffer permanently from disturbance.

(5)Increase of the pollution stress in the coastal zone and coastal areas.

(6) As it is proven elsewhere, increase of the dredging costs (first costs and long-term maintenance costs) year by year.

For instance, in the USA the yearly average for total dredging for the 10-year period 1992-2001 was $641 million, to dredge an average of 269 million cubic yards. The average total dredging cost for the last three years was $834 million. The average O&M dredging under the RSM plan for the same three-year period is about $559 million and 228 million cubic yards. That means, the three year cost of the dredging under local or project-specific works are $281 million more than the RSM planned dredging. (These figures are in real dollars, not adjusted for inflation.) Source: Annual Continuing Analysis of Dredging Data; US Corps of Engineers, 2003.

3 Current concept of regional sediment

Regional sediment management (RSM) is a “system-based approach” that seeks to solve sediment-related problems by designing solutions that fit within the context of a regional strategy.

(1) RSM involves making local project decisions in the context of the sediment system and forecasting the long-range implications of management actions.

(2) RSM recognizes that sediment management actions have potential economic and ecological implications beyond a given site, beyond originally intended effects, and over long time scales (decades or more).

(3) RSM is the integrated management of littoral, estuarine, and riverine sediments to achieve balanced and sustainable solutions to satisfy the sediment-related needs. This approach provides opportunities to achieve greater effectiveness and efficiency.

As it was mentioned earlier, the concept of RSM originated in the notion of coordinating dredging activities in the coastal zone for the purposes of retaining sand in the littoral system in order to foster more balanced, natural system processes, and reduce project costs. RSM applies a system perspective to problem solving, managing sand as a regional resource, and integrating the portfolio of coastal engineering programs and projects related to the sediment in a given region. It is intended to advance application of sustainability principles, by

(1) Recommending approaches that can reasonably accommodate multiple objectives,

(2) Promoting consideration of the competing demands for sediment resources (ecological and socio-economic),

(3) Recognizing "sediment as a resource", RSM involves maintaining or promoting the natural exchange of sediment within the boundaries of the physical natural system,

(4) Identifying sand and sediment processes as important components of coastal and riverine systems that are integral to economic and environmental vitality,

(5) Considering effects beyond the immediate timeframe, and

(6) Achieving acceptable tradeoffs and cost efficiencies.

Concurrently, RSM involves recognizing the multiple, often competing demands for sediment in a region, and that the systems involved are often modified by multiple factors.

RSM is intended to integrate planning, engineering and operations activities within coastal, estuarine, and riverine systems, and broaden the problem solving perspective from a local or project-specific scale, to an expanded scale defined by natural sediment processes. It recognizes that the physical system and associated ecological system are modified and respond beyond the limited dimensions and time frames of individual projects. The larger spatial and longer temporal perspectives of RSM require the integration of a broad range of disciplines along with collaborative partnerships among stakeholders.

4 Potential benefits of RSM

These benefits can be realized in terms of cost savings (near-term and long range), improved management and use of sediment resources for a broad range of benefits, as well as in terms of valuable intangible benefits. These benefits can be characterized as "technical," "programmatic," and "institutional".

4.1 Technical Benefits

(1) New engineering techniques to optimize and conserve sediment -Bypassing of beach quality

sand at inlets and implementing regional rather than project scale approaches.

(2) Foundations for future studies and projects in region – The improved process models, data and information management tools will benefit both current and future studies and projects.

(3) Dredged Material Management plans can provide an important vehicle for developing and executing the regional approaches to sediment management, particularly when developed regionally, rather than for individual projects.

4.2 Programmatic Benefits

(1) Process efficiencies

A. Potential reductions in rehandling of material, improved channel efficiency and associated cost savings over the longer term.

B. Increased disposal site capacity and reduced need to acquire new sites.

(2) Environmental

A. Stabilized habitat for listed species

B. Sediment as a resource

C. Potential new sources of desirable sediment.

4.3 Institutional

(1) Stronger partnerships - Partnerships among coastal and watershed stakeholders leading to improved business processes, data sharing, greater cooperation and collaboration among parties.

(2) Better information – Improved understanding of regional sediment processes and the interrelationships of projects and management actions contribute to the improved knowledge about problems, causes and solutions. This in turn contributes to the development of more effective and efficient management approaches.

(3) Identification of institutional obstacles so they can be addressed. – Some issues may be addressable through clarification of policy, or revisions to business practices. Some issues may need to be addressed through multi-agency or other partnership efforts.

5 Examples to RSM works

RSM can be illustrated with a hierarchy of examples:

(1) The simplest involves coordination of dredging activities in the coastal zone for the purpose of establishing regional sediment budgets, reducing project costs and protection or restoring environmental resources. Efforts may involve using the suitable dredged material from an inlet nearshore to feed an eroding beach, rather than disposing of it offshore. Placement of the material near shore could make the material available to the littoral system, potentially enabling natural processes to move it onshore.

(2) Moving beyond an individual project, the “pairing of projects” has the potential to produce economies of scale in planning or construction, along with more effective projects and problem

solving due to the incorporation of system relationships. “Project pairs” can ultimately produce cost savings, and in theory this savings can involve different civil works funding accounts, where the savings is realized at the civil works program level. For example, dredging for inlet or navigation channel maintenance could be linked with a beach nourishment project, where, instead of the dredged material being disposed of off-shore and the sand for beach nourishment being obtained from an off -shore source, the dredged material could be used directly in the beach nourishment projects, assuming the material is suitable.

(3) Examples of broader application would include coordinating all civil works projects and studies related to the sediment in a region – comprehensive studies with dredged material management plans, new projects and potentially regulatory decisions.

At each of these levels benefits may be realized by the improved integration of coastal engineering projects and programs with those of other agencies. RSM has the potential to result in not only significant cost savings through coordination of construction activities, but also development of regional data and information that will enhance regional planning and management capabilities.

6 Suggestions on the framework for developing RSM strategies for Xiamen

A conceptual framework composed of alternative actions, projects, or sediment management practices appropriate for a Xiamen Region (includes the riverine systems, the port, Gulang Yu Island, and the eastern coastal zone and its beaches) for developing RSM strategies, along with management plans is outlined below. Working through this framework will be an iterative process. Information provided at each step advances the knowledge base for decisions and recommendations along the way. Stakeholder and public involvement may vary with each strategy and plan, but is integral to each part of the framework.

6.1 Specifying Sediment-related Problems and Opportunities

(1) Recognition of the Region: Identifying and defining the region by means of region based sediment system, boundaries, sectoral division within the boundaries, and management objectives and issues.

(2) Distinguishing of Sediment Concerns and Needs: In view of erosion, accretion, sediment demands, and structures.

(3) Identifying Public and Private Stakeholders Interests: Includes several of the following: channel maintenance and other works involving dredging, habitat protection or restoration, beach nourishment and renovation, beach and sediment use regulation, bank erosion reduction, sedimentation problem in channels and jetties, and others.

6.2 Listing and Estimating the Conditions

(1) Collecting the available information: Which contributes to the comprehension of historic, present, future sediment conditions, along with associated planning and management implications. It also includes overland transport and sediment transport through riverine systems (rivers, estuaries, etc.), and

mechanism of coastal transport.

(2) Identification and Formulation of Alternative RSM Plans: Including various numerical models in order to be utilized to estimate the regional sediment transport, optimize alternative plans, and asses the cumulative impacts of multiple projects within the region.

(3) Evaluation and Comparison of Alternative RSM Plans: Consideration of the following aspects (parameters) of magnitude, location, timing, duration, benefits or disadvantages. Judgment of the effects of tradeoffs, cost-effectiveness of outputs relative to different types of effects and preferences.

(4) Selection and Implementation of RSM Strategy.

7 Conclusion: proposal of the specific studies under the Xiamen RSM plan:

As we mentioned above, we defined the Xiamen Region as Jiulong River, distributaries and headlands, Xiamen Port, Gulang Yu Island, N-S direction navigation channel located at the port which, we assume, has a profound effect on the sediment flow, and the eastern coastline where residents and tourists use these beach areas for recreation, tourism and housing needs. These same beaches also provide habitat for various fauna and flora. Erosion from storms and tides often threatens coastal areas, including material loss of or damage to sandy beaches.

A complex array of variables which are involved in the determination and identification of RSM are given below.

8 Technical program implementation

A key element for the successful regional sediment management is the regional sediment budget. The sediment budget assists in identifying longshore sediment transport rates, sediment transport patterns and pathways, areas of erosion and accretion, and 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 the available historical information and utilizing the Sediment Budget Analysis System (SBAS) (Rosati and Kraus 1999). The conceptual budget quantified the knowns and qualified the unknowns relative to the sediment transport over the region. The sediment budget provided direction to the program by identifying regions where data collection, information, and policy are needed (primarily riverine system). For this purpose, as the first step, the process to implement RSM is illustrated in Figure 4.

8.1 Engineering tools

The following engineering tools are identified as necessary for the regional sediment management:

(1) A regional sediment budget including budgets at subregional and project levels.

(2) Numerical models to evaluate hydrodynamic conditions, sediment transport, and shoreline change at regional, subregional, and project scales.

(3) A data management tool for managing and storing historic and new data, and a tool for performing analysis of data and model results; the tools will allow sharing of information and data.

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

(4) Hydrodynamic and meteorological data: waves, water levels, currents, winds, and storm data.

(5) Historic bathymetric, topographic, and shoreline data.

(6) Regional, continuous, current, and synoptic bathymetric and topographic surveys.

(7) Data acquisition and monitoring, includes field collection of the necessary data, and surveying (data relevant to waves, currents, tides, drifts, longshore currents, etc, and bathymetric, hydrographic surveys)

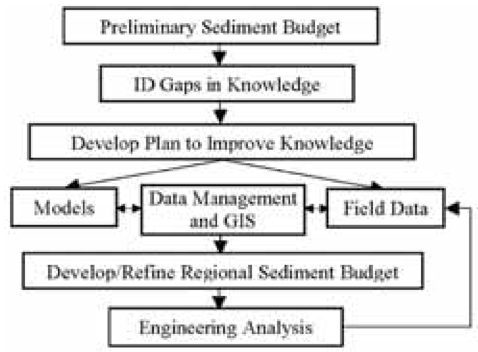

Fig.4 Process to implement RSM

8.2 Numerical model application

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 subregional and project scales to refine the sediment budget and begin evaluation of proposed project modifications to improve sediment management. Related works are:

(1) Wave transformation studies,

(2) Longshore sediment transport and shoreline change

(3) Water levels and circulation / tides and tidal effects

(4) Comparisons between transport rates derived from the available physical data and those computed from the hindcast wave information should be provided.

8.3 Dredged material management

In order to classify the dredged materials for the possibilities of future use and offshore disposal, the following studies should be conducted:

(1) Bulk sediment analysis and identification of their geotechnical, sedimentelogical properties;

(2) Testing and analysis bioaccumulation and toxicity levels of the dredged materials.

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区域沉积物管理概论

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摘 要：就“区域沉积物管理”(简称 RSM) 概念与方法进行了系统论述，以厦门地区为例阐述了 RSM 研究的必要性和重要性，并对如何应用区域沉积管理来处理海岸冲刷、淤积与港口码头建设过程中可能遇到的问题进行了深入浅出的讨论，同时，提出了发展 RSM 的战略构想与框架。

关键词：区域沉积物管理（RSM）；资源；海岸带；疏浚