COASTAL INLET NAVIGATION RESEARCH IN THE U.S. ARMY CORPS OF ENGINEERS

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Abstract

The navigation mission of the U.S. Army Corps of Engineers (USACE) was established in 1824 to provide safe, reliable, and efficient waterborne transportation systems. Today the USACE manages over 40,000 km of coastal and inland navigation channels, dredging 174 Million cubic meters of sediment costing $1,322 Million in 2011. The Coastal Inlets Research Program (CIRP) advances the state of knowledge and engineering technology to improve management of coastal inlets, navigation channels, navigation structures, and adjacent beaches. This paper discusses CIRP advances in modeling coastal inlets and adjacent beaches, estimating navigation channel shoaling, and regional sediment management through placement of mixed-sized sediment in the nearshore. Challenges facing the USACE are discussed, including increased channel shoaling with New Panamax channel dimensions and uncertainty in future climate change.

Key words: coastal inlets, navigation, channel shoaling, numerical modeling, morphology change

1. Introduction

The first mission of the U.S. Army Corps of Engineers (USACE) was established in 1824 and authorized the USACE to improve navigation for channels and ports serving the Missisippi and Ohio Rivers. The USACE's mission has expanded since then to include Operations and Maintenance (O&M) of over 40,000 km (25,000 miles) of commercially navigable channels, including coastal, intercoastal waterways, and inland channels, ports, and harbors. In Fiscal Year (FY) 2011, a total of 805 and 1,342 Million metric tons of domestic and foreign commodities, respectively, transited these channels (USACE Navigation Data Center (NDC), 2012). In order to maintain navigable depths, sediment that shoals in channels must be dredged and placed outside the channel footprint. In FY2011, approximately 174 Million cu meters of sediment was dredged at a cost of $1,322 Million. Of this total, roughly 84% was for channel maintenance to achieve the authorized depth and width, and 8% was for channel improvements, so-called "New Work" dredging, which includes channel deepening, widening, and lengthening. The remaining 8% was for post-hurricane and emergency dredging (USACE NDC, 2013a).

Historically, O&M and New Work dredging volumes have declined but the budget (adjusted for inflation) for O&M and New Work dredging has been relatively constant, increasing only 0.58% per year from 1963-2011 (Figure 1). Navigation channels have continued to be improved to accomodate larger vessels, greater transit speeds, and to be competitive with adjacent ports and harbors. Ports and harbors are planning for additional deepening and widening to accomodate New Panamax vessels that require up to 18.3 m transit depth. In the U.S., New York, NY, Baltimore, MD, Norfolk, VA, Savannah, GA, Jacksonville and Miami, FL, and Houston, TX have completed or are in the process of channel and infrastructure improvements to accomodate these larger vessels (Allen, 2012; Hilarkski, 2013). Many Pacific ports have sufficient depth.

Channel improvements increase the sediment trapping capacity of the channel, resulting in greater channel shoaling and O&M requirements. However the improved channel will be able to accomodate a greater number of vessels with larger tonnages, thus increasing commerce and services at the port or harbor of interest. With budgets limited in the foreseeable future, the USACE is focused on maintaining deep-draft channels that provide on average at least 10 Million tons (9.1 Million tonnes) of cargo per year as averaged from 2001-2005, which the USACE calls the "Top 59."

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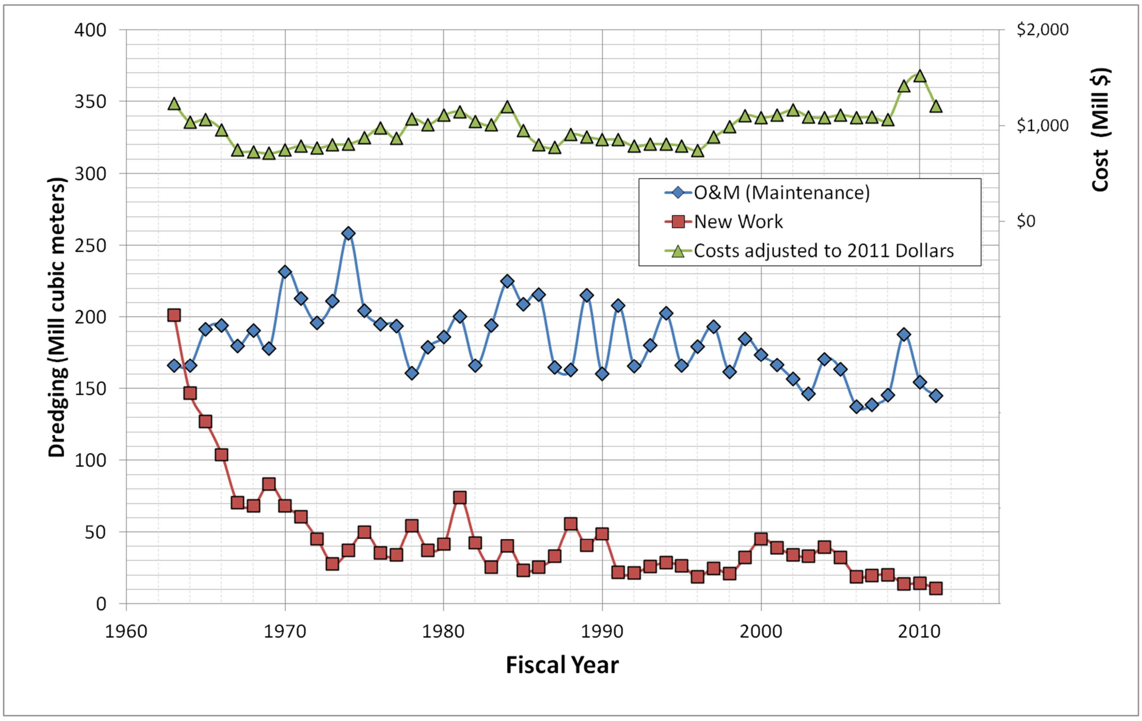

Figure 1. O&M and New Work dredging volumes and associated costs (adjusted to 2011 dollars; 2005-2011 data include Hurricane Katrina supplemental; 2009-2011 data include American Recovery and Reinvestment Act (ARRA) funds) (Data from USACE NDC, 2013a)

The USACE is entrusted with management of 1,067 coastal navigation projects (USACE, 2012). Future challenges include: limited funding dedicated to dredging and the likely increase in O&M dredging required following channel improvements in preparation for the deeper New Panamax ships, aging coastal navigation infrastructure, and a need to keep more sediment in the littoral system to reduce beach erosion. The Coastal Inlets Research Program (CIRP) is a research and development program of the USACE with the mission to advance the state of knowledge and engineering technology for coastal inlets, navigation channels, navigation structures, and adjacent beaches. In the following sections, we describe each of the challenges facing the USACE in more detail and discuss research that is being conducted in CIRP to address these challenges.

2. Influence of Channel Improvements on Shoaling

2.1. *Problem*

Improving channels for navigation typically involves deepening, and can also include widening and lengthening offshore to a common depth. These improvements increase the O&M dredging requirements because of the larger channel footprint, resulting in greater trapping capacity. For estuaries with cohesive sediment, the increased dimensions may also move the saline wedge further into the estuary, changing the patterns and possibly the magnitude of fine sediment flocculation. To illustrate, Figure 2 shows the cumulative history of O&M dredging for a deep-draft channel, Kings Bay Entrance Channel, Georgia (Figure 2a) and a shallow-draft channel, Siuslaw River Entrance, Oregon (Figure 2b). The slope of the cumulative dredging history provides the average annual dredging requirement, and documents how increasing the depth and width of the navigation channel increases the trapping capacity of each Entrance. In 1987, jetty spurs were added to the Siuslaw River Entrance jetties which effectively diverted alongshore transport away from the navigation channel, reinforcing the importance of well-designed and maintained structures in reducing annual dredging requirements.

With the limited O&M dredging budget shown in Figure 1, the anticipated increase in O&M dredging requirements associated with the New Panamax channel depths means that shallow-draft channels most likely will not be regularly maintained, and dredging of deep-draft channels must be prioritized.

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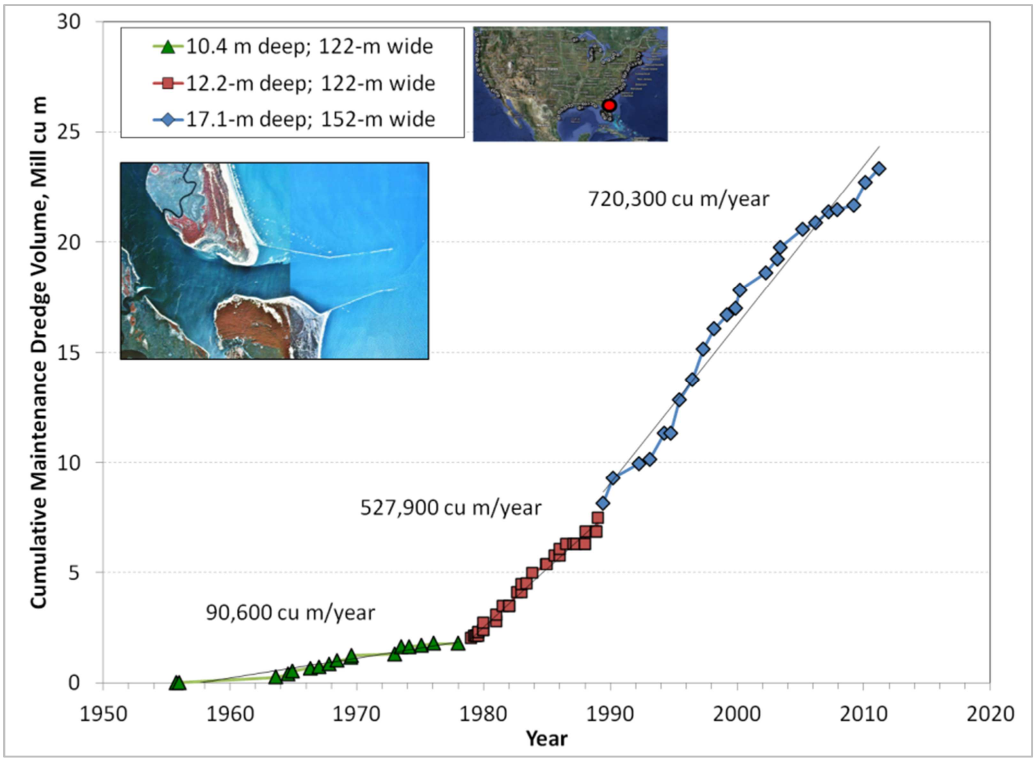

a. Kings Bay Entrance Channel, GA, deep-draft channel

b. Siuslaw River Entrance, OR, shallow-draft channel

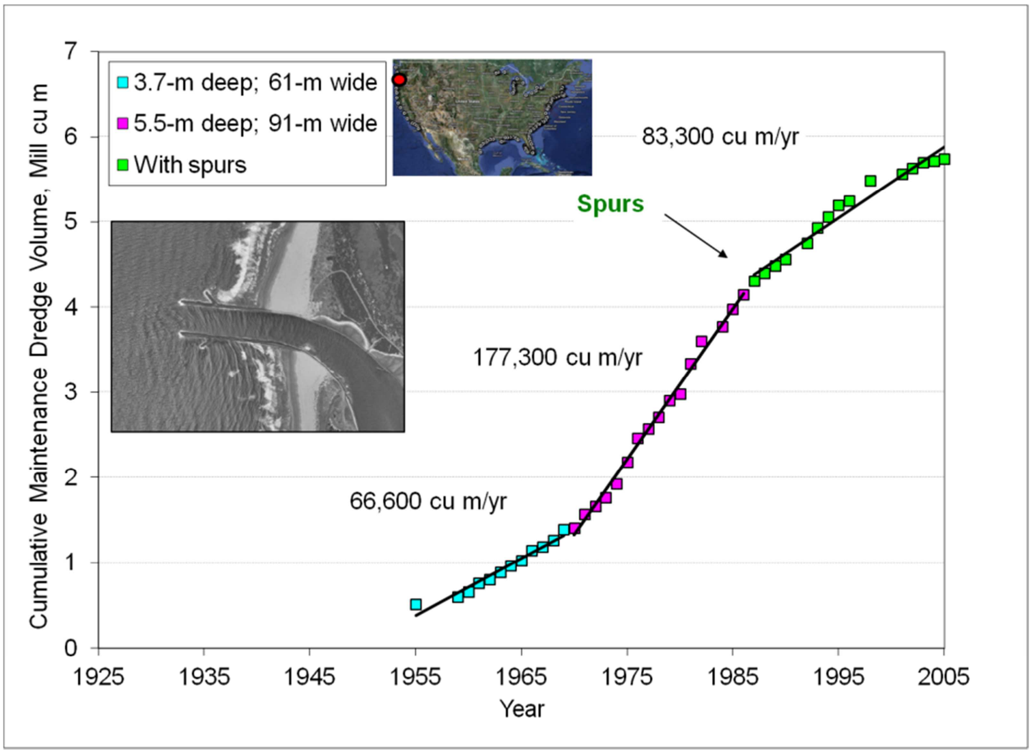

Figure 2. (a, b) Examples of inlet navigation channel increase in maintenance dredging with deepening and widening, and (b) how well-designed and maintained structures can reduce dredging

which deep-draft channels provide the greatest economic benefits for the nation with a transparent, reproducible method that justifies dredging expenditures has been a challenge addressed by the CIRP. Two products are discussed herein: the Channel Portfolio Tool (CPT) and the Coastal Modeling System (CMS).

2.2. *Channel Portfolio Tool (CPT)*

The CIRP has developed the Channel Portfolio Tool (CPT), a web-based application which facilitates queries of the USACE's extensive tonnage database from the Waterborne Commerce Statistics Center. The CPT can be used to relate the losses in channel depths due to periodic sedimentation at a given navigation project to the vessels and commodities that have historically utilized that project at the shoaled depths. In this way, the CPT ties O&M dredging requirements to the economic activity supported by maintained navigable waterways, and it also provides a consistent method to justify allocation of limited O&M funds. A reduction in allowable draft at one USACE project could disrupt vessel operations elsewhere within the regional system since waterborne cargo typically transits multiple ports and waterways while en route. The CPT can be applied to quantify these system-level disruptions if one channel in the transportation network is passed over for dredging in a particular year (Mitchell, 2009).

Figure 3 shows a draft-utilization profile for the Corpus Christi Ship Channel, a deep-draft navigation channel in southern Texas. The chart shows the 5-year (2006-2010) average annual tonnage amounts at each 1-ft increment of vessel draft, with color-coding to show commodity types. The Corpus Christi navigation project is maintained so as to accommodate vessels drafting up to 45 ft, but the majority of all tonnage moving through the project will utilize depths less than this. Per Figure 3, more than 10 Million tons (9.1 Million tonnes) per year move on barges at the 8-10 ft (2.4-3 m) draft ranges, due to the Corpus Christi project's connection with the Gulf Intracoastal Waterway. Likewise, roughly 15 Million tons (13.7 Million tonnes) transit on vessels utilizing the deepest 5 ft (1.5 m) of project depth, indicating that typical annual rates of sedimentation in navigation channels will only directly disrupt a portion of the total tonnage. CPT's ability to shift the tabulation of tonnage to the deepest, shoal-vulnerable depths within all navigation projects allows for a more objective, realistic assessment of critical dredging needs USACE-wide, and helps ensure that limited dredging funds are allocated efficiently.

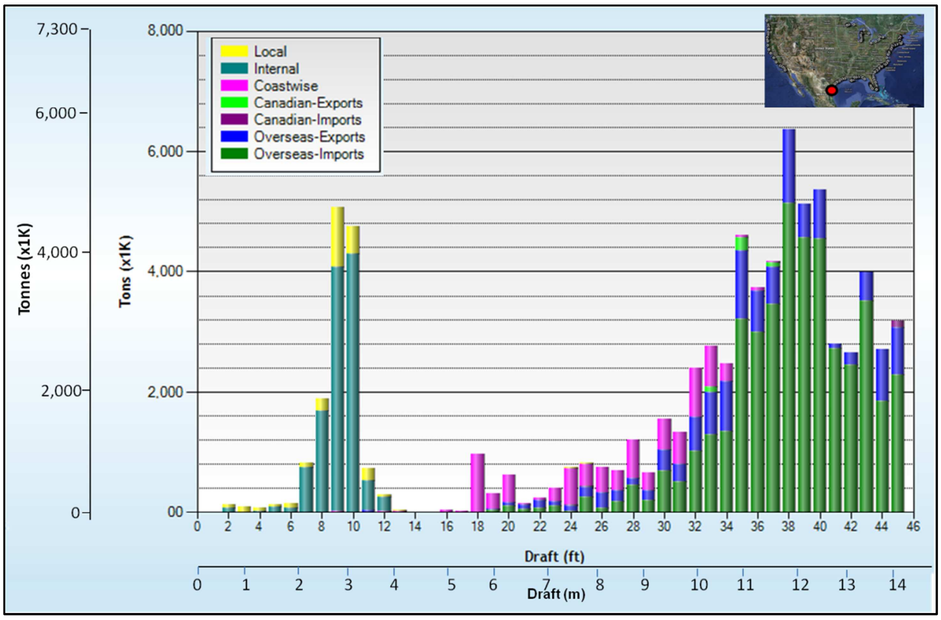

Figure 3. Local, import, and export tonnage for 2008 in Corpus Christi Channel, Texas as a function of depth

When confronted with reductions in navigable depths due to periodic shoaling, vessel operators have several options available. They may divert traffic to nearby ports with sufficient depths, engage in lightering operations in which a portion of cargo is off-loaded to reduce vessel draft prior to entering, or they may light-load the vessel at the outset of the voyage such that the sailing draft is less than or equal to the channel limiting depth. In order to better understand and quantity the impacts of light-loading, the CPT can be applied to roll up channel utilization data at a variety of spatial scales. In this way, CPT can estimate the sensitivity of average cargo tonnage per voyage to sailing draft for different types of vessels and traffic (e.g., imports, exports, domestic). This type of analysis is presented for dry bulk imports and exports in Figures 4a and 4b, and for tanker imports and exports in Figures 4c and 4d, based on average annual data from 2006-2010. As expected, deeper-drafting vessels are able to transport higher tonnage per voyage than are vessels transiting at shallower depths. The linear regression trend lines provide an estimate over the vessel draft ranges shown for the average amount of cargo which must be removed from each vessel in order to reduce sailing drafts by 1-ft (0.3 m). The trends are clearly linear with very high correlation coefficients, even though there are many classes of vessels carrying a wide variety of cargo types comprising the data. These types of metrics can be used to provide broad estimates of the average amounts of cargo tonnage that must be left onshore due to shoaling-induced reductions in navigable depth. The analysis can be extended to compute the number of additional voyages required to transport the light-loaded cargo, and ultimately estimates of additional shipping costs can be obtained and directly compared to the O&M dredging expenditures.

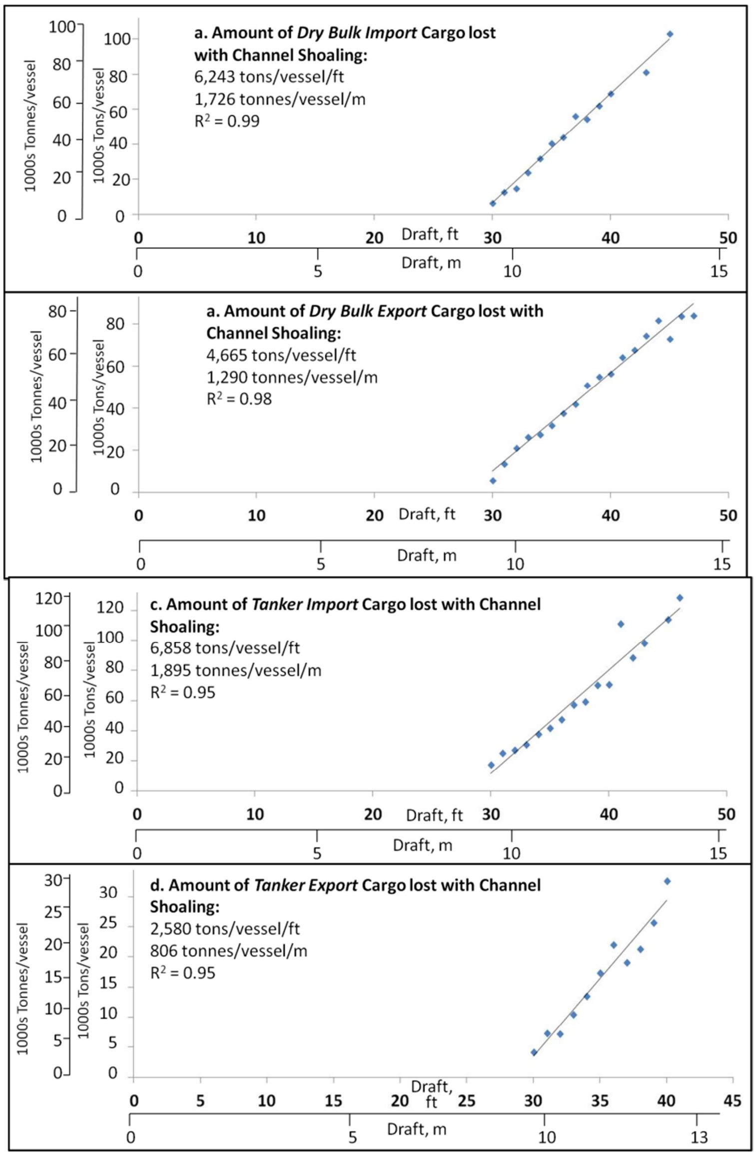

Figure 4. National roll-up showing loss of tonnage with channel shoaling from 2008, (a) Dry Bulk Import Cargo, (b) Dry Bulk Export Cargo, (c) Tanker Import Cargo, (d) Tanker Export Cargo

2.1 Coastal Modeling System

The Coastal Modeling System (CMS) is an integrated suite of numerical models for simulating flow, waves, sediment transport, and morphology change in coastal areas and is intended as a research and engineering tool for desk-top computers (Sanchez et al., 2011a, 2011b; Lin et al., 2011). The CMS was designed to assess coastal navigation channel and structure performance, and sediment management in the vicinity of coastal inlets and adjacent beaches.

Here we discuss an application to Grays Harbor, Washington, a deep-draft navigation channel on the Pacific Northwest (Figure 5a). Growth of the Damon Point Spit inside the Grays Harbor estuary began to extend south towards the navigation channel by the 1970s-80s (Figure 5b; Li et al., 2012). Subsequent elongation of the spit caused the channel thalweg to migrate to the southeast. The CMS was applied to understand how potential future growth of the spit and possible breaching would modify channel infilling and

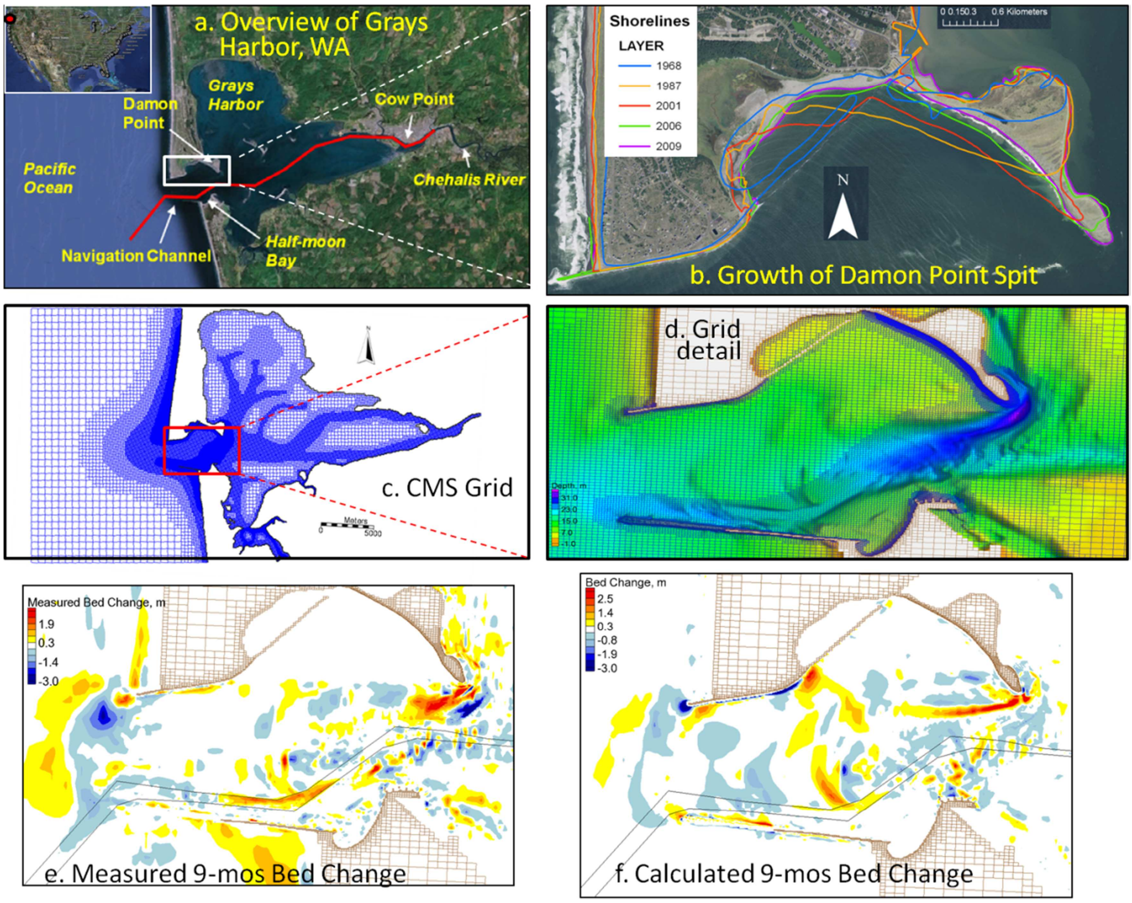

Figure 5. Application of the Coastal Modeling System to Grays Harbor, Washington, USA (Li et al., 2013)

navigability of the waterway. A telescoping grid was developed for the application which covered 25 km alongshore and 20 km cross-shore, with refinement near the north and south jetties, Half Moon Bay, Damon Point, and tidal channels within the estuary (Figures 5c and 5d). Model validation was conducted for two simulation periods: hydrodynamics were validated using data from a 30-day field campaign; and morphology change was validated using a 9-month simulation period corresponding to a post-dredging to pre-dredging morphologic period (Figures 5d and 5e). Variable grain sizes were simulated with CMS ranging from fine sand (0.15 mm) in the ocean to coarse sand (2 mm) at Damon Point. Once validated, the CMS was applied for three hypothetical cases: a breach in the Damon Point spit, moderate spit growth of 68 m, and large spit growth of 200 m. The numerical modeling demonstrated that changes in spit morphology will not have a significant influence on channel infilling within the next 1-5 years for all three hypothetical cases (Li et al., 2013). Longer-term morphology change is an active area of research within CIRP.

3. Aging Coastal Infrastructure

3.1 Problem

Approximately 40-percent of the U.S. breakwaters and jetties were constructed in the 1800s, prior to development of design guidance and armor stability criteria (Hughes, 2011; Pope, 1992). Through time, these structures have experienced damage and deterioration through factors such as storms, impacts from vessels, seismic activity, and settlement of the foundation. Because the aging process is slow and funding for rehabilitation has been limited, repair of these structures has been postponed if the structure is still functioning at an acceptable level. In addition, relative sea level has risen at most sites since construction and reduced the effective height of jetties and breakwaters, decreasing their functionality.

3.2 Coastal Structure Management, Analysis and Ranking Tool (CSMART)

The USACE is developing methods to manage infrastructure with a risk-based, Asset Management framework that assesses the lifecycle of projects within a watershed system. A relative risk index is developed for each asset through an evaluation of the present condition of the asset and the consequences of its failure. The Coastal Structure Management, Analysis and Ranking Tool (CSMART) developed by the CIRP has been adopted as a part of the Asset Management initiative as a way to visualize, report, and rollup Asset Management ratings for the more than 900 coastal structures. The CSMART is similar to CPT in that it relates an asset – in this case, coastal structures – to the goods and services that the asset provides. In addition to commerce and navigation data provided by CPT, CSMART also connects each structure to commercial fishing data, US Coast Guard incident reports, dredging information, first-order structure condition ratings, and USACE project codes relaying whether the structure serves as a harbor of refuge, subsistence harbor, or public transportation terminal (Mitchell, 2010). CSMART can also develop a rating for each structure based on a user-defined weighting. As an example, Table 1 shows CSMART composite ratings for the top 10 structures by applying a user-defined weighting as follows: 40% for commercial tonnage, 40% for structure condition, 10% for commercial fishing, and 5% each for subsistence harbor status and harbor of refuge status.

Table 1 demonstrates how CSMART can compare structures in different projects around the Nation, and provide a transparent, reproducible method to support investment decisions.

4. Need to Keep Sediment in Littoral System

4.1 Problem

For integrity of beaches near coastal navigation channels, it is most advantageous to place dredged sediment such that it is kept within the littoral system through beach, nearshore, and wetland placement. However, if sediment is contaminated, it must be placed in upland facilities or confined offshore, and many states restrict nearshore and beach placement based on the percentage of fines which also reduces the volume that can be placed within the littoral system. In addition, for placement in vicinity of coastal inlets, the the site of the placement ideally will be a sufficient distance from the inlet such that sediment is not rehandled in a future dredging cycle.

Based on data from 2006-2011, an average of 30% of dredged sediment has been placed within the littoral system, with 54% placed either upland, in open water, or confined offshore. The remaining 16% was either mixed placement or undefined (Figure 6). Ideally, all non-contaminated sediments would be placed to either environmentally enhance coastal regions, on adjacent beaches, or within the active littoral zone, to be mobilized and sorted by natural processes. Presently, most U.S. states limit the percentage of fine sediment (silt and clay) that is acceptable for beach and nearshore placement.

Table 1. Sample CSMART composite rankings for top 10 structures (Mitchell 2010).

Coastal Structure(s)	Rank	Score (%)
Galveston Entrance Jetties	1	60.3
Columbia River Mouth Jetties	2	48.1
Fairport Harbor (Ohio) East Breakwater	3	45.5
Tillamook Bay (Oregon) Jetties	4	45.1
Quillayute River, Washington Jetties	5	45.0
Southwest Pass, Louisiana, Jetties	6	45.0
Los Angeles-Long Beach, California Breakwaters	7	44.9
Humboldt Bay, California Jetties	8	40.9
Mission Bay, California Middle Jetty	9	40.7
Lorain Harbor, Ohio, West Breakwater	10	40.7

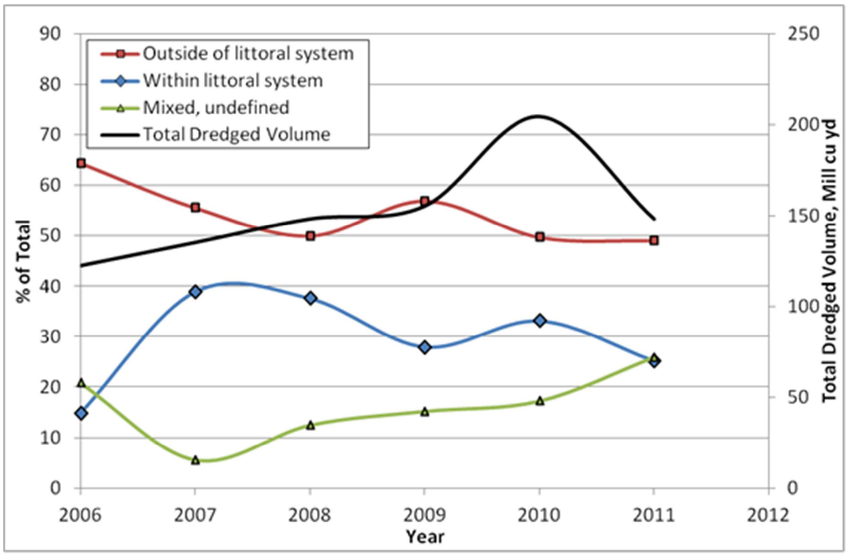

Figure 6. Percentage of total O&M dredged sediment placed within and outside of littoral system (left axis), and total O&M volume (right axis) (Data from USACE NDC, 2013b)

4.2 Research on Placement of Sediment in Nearshore

Regional sediment management (RSM) seeks to keep non-contaminated sediment that is dredged from navigation channels within the active transport system. For mixed-sized sediment that is not beach-quality, nearshore placement is an option that keeps sediment within the littoral system and ideally harnesses natural processes to sort fines sediments offshore and transport sand onshore. These placements are typically less costly and often easier to construct, and are strategically located to use the natural forces within nature to transport the sediments or possibly to serve as a structure that influences the natural processes. The long-term effects of nearshore placements within the littoral zone have not historically been studied in great detail due to their perceived limited impact on beaches or other highly mitigated areas.

Nearshore berms are one means of accomplishing RSM, but there is a lack of guidance for estimating the rate and spatial extent of berm movement, as well as selective sorting of mixed fine and coarse sediment by nearshore processes. Stakeholders have concerns about fine sediment dispersion over sensitive subaqueous habitat such as sea grasses and reefs, and burial of biological and benthic assets. The RSM and CIRP programs have joined efforts to monitor and study several nearshore berm placement sites located in Florida. The goal of this research is to develop improved guidance on nearshore berm placement by building off the detailed studies providing beach and nearshore morphologic change. Results from these studies will provide the necessary background for guidance on design and project performance, and will improve certainty in placement locations under temporal and spatial guidelines to avoid rehandling of sediment that may re-enter the navigation channel.

Figure 7 is a schematic illustrating some of the processes and variables related to nearshore berm research. The left side of Figure 7 shows cross-shore parameters in which Hallermeier's (1981, 1983) depth of closure criteria are utilized to provide a range of placement depths for relative stability. Placement of sediment near the outer depth of closure, d_{outer} , results in relative stability of the berm; placements between d_{outer} and the inner depth of closure, d_{inner}, are more likely to be mobilized under energetic conditions; and berms placed near d_{inner} are likely to be migratory and provide feeder material to the nearshore. Inherent in the analyses are the grain size gradation of the placed sediments and forcing conditions. Alongshore, knowledge of existing regional sediment transport pathways is necessary to understand likely alongshore dispersion and migration and reduce the likelihood of rehandling sediment in the next dredging cycle.

Figure 7. Schematic illustrating cross-shore (left) and alongshore (right) variables and forcing processes related to nearshore berm morphodynamics.

5. Conclusions

The U.S. Army Corps of Engineers' mission to maintain navigable waterways is challenging for several reasons: the breadth of the navigation system which covers 40,000 km of commercially navigable channels and navigation structures; limited funding for maintenance of the channels and rehabilitation of the structures; the age of these navigation structures; and the need to manage dredged sediments in an environmentally-sustainable and cost-effective manner. The Coastal Inlets Research Program (CIRP) was established to develop decision-support products to guide investments within the navigation business line. Four areas of research were discussed herein: the Channel Portfolio Tool (CPT), the Coastal Structures Management, Analysis, and Ranking Tool (CSMART), the Coastal Modeling System (CMS), and nearshore berm research for placement of dredged sediments within the nearshore. Future challenges being addressed by the CIRP include operations research to better manage navigation systems, prioritize structure rehabilitation, and reduce time and cost associated with O&M activities; develop methods to calculate long-term (multiple years to decades) morphologic change at inlets and adjacent beaches; and conduct basic research on the design, siting, and short- and long-term evolution of mixed-type sediments placed in the nearshore.

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