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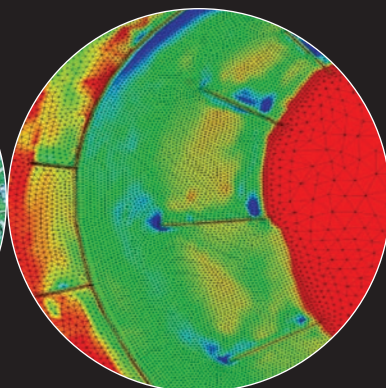
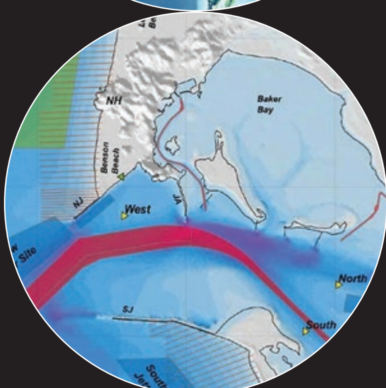
Navigation Channel Sedimentation Solutions





Navigation Channel Sedimentation Task Committee

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Navigation Channel Sedimentation Solutions

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DEDICATION

This manual is dedicated to Bruce L. McCartney, P.E., BC.NE, M.ASCE. Bruce has been a major force in the development of modern navigation engineering practice throughout his careers in the US Coast Guard and US Army Corps of Engineers and decades of active ASCE/COPRI Waterways Committee and Navigation Engineering Subcommittee membership. He wrote and guided half a dozen ASCE manuals on navigation engineering and contributed to scores of conferences and journal papers. His advocacy led to the discipline being recognized as a Board Certified Engineering Specialty by the Academy of Coastal, Ocean, Port, and Navigation Engineers. ASCE recognized Mr. McCartney's accomplishments with its prestigious Hans Einstein Award in 2013. His colleagues in navigation engineering cherish him as a friend, mentor, and continuing source of knowledge and inspiring ideas.

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EXECUTIVE SUMMARY

INTRODUCTION

This manual of practice describes navigation channel sedimentation, lists solutions to sedimentation problems in those channels, and recommends best practices for predicting navigation channel sedimentation responses—sediment deposition to, and erosion of, the channel bed plus surrounding bed and banks—resulting from those solutions.

Navigation is an integral part of the global and US economy, contributing more than $500 billion to the US gross domestic product. The United States spends more than $2 billion annually on dredging, mostly on navigation channel maintenance. Yet, without dredging or other solutions, a lack of adequate navigation channel depth impedes commerce and creates hazardous conditions for vessels. These impacts provide ample motivation to manage sedimentation processes in navigation channels.

Managing waterway sedimentation processes requires making sedimentation response predictions before new channels are constructed or existing channels are modified to reduce dredging needs. Presently available up-to-date critical review or categorization for evaluating navigation channel sedimentation solutions and prediction practices is extremely limited. This manual is intended to fill that gap through

1. Overview of channel sedimentation processes,
2. Discussion of navigation channels' classifications and typical sedimentation issues,
3. Solutions/remedies to channel sedimentation problems with sustainability concepts,
4. Channel sedimentation predictions methods
   a. Field observations
   b. Desktop analyses

   c. Physical (scale) models
   d. Numerical models
   e. Uncertainty in predictions from these methods,
5. Recommendations for best practices in using the prediction methods, and
6. Glossary of terms and acronyms.

Sedimentation

Reliable solutions to, and accurate predictions of, navigation channel sedimentation require a thorough knowledge of sediment transport processes, including the hydrologic and hydraulic forces driving those processes. Broadly speaking, the principal external forces of interest are water, wind, and gravity. In riverine locations, gravity is the dominant external energy force, and the hydrodynamic equations need only to translate that force into flow velocity and boundary shear. The computation is often uncomplicated by variations in fluid densities or wind energy. In coastal locations, wind and tides may be the dominant external energy forces of interest. However, the water properties of density and temperature may vary in the vertical and horizontal directions.

Also broadly speaking, sediment transport in rivers, lakes, estuaries, and coastal settings involves the advection and diffusion of sediment originating from freshwater and/or marine sources, and the bed-water exchange processes of erosion and deposition. Transport is a function of the physical forcings acting upon the sediment, including the fluid forces of barotropic flow (water density a function of pressure only), baroclinic circulation (water density a function of pressure, temperature, and constituent concentrations), freshwater flow, waves, and winds. In addition to impacting transport directly, some of these forcings may also have secondary effects via nonlinear interactions with the others. Anthropogenic activities, primarily vessel traffic, can also directly impact sediment transport through vessel wakes and propwash.

The sources, transport, and eventual sinks of sediment represent a complex interplay of long- and short-term processes that must be understood to predict future behavior. In general, prediction of sedimentation in navigation channels involves shorter-term processes on the order of seasonal to annual timescales that deliver sediment from source areas to the channel. Nevertheless, longer-term processes must be considered in projects designed for 50-year-life spans and most often employed for far longer periods.

Sediment can be classified as cohesive or noncohesive. Cohesive sediment behavior is affected by interparticulate attractive forces that cause them to aggregate into flocs containing hundreds to millions of individual mineral grains. Cohesive sediments are generally comprised of clay-sized (< 2 μm) and silt-sized (< 62 μm) particles. High-concentration cohesive sediment suspensions may exhibit non-Newtonian behavior when in a fluid-like state. Noncohesive sediments are sand and gravel-sized material (> 62 μm) plus coarse silts where the particles exert only weight, friction, and impact forces on one another. Overall, noncohesive sediment transport properties are much better understood than cohesive sediment properties because of the difficulty of quantitatively predicting the role of interparticulate forces in cohesive sediment.

Moving water, whether because of river flow, tides, or waves, exerts a shear stress on the sediment bed. The shear stress, if large enough, may mobilize or erode sediment from the sediment bed and suspend it into the water column. Advection moves suspended sediment according to the local water velocity, whereas turbulent diffusion spreads sediment at rates dependent on concentration gradients and turbulence. Further, sediment (both noncohesive and cohesive) may also be transported as bedload—moving in proximity to, and in frequent contact with, the bed. When sediments move into lower-energy regions where turbulence and stresses are not high enough to keep them moving, the sediment settles and deposits.

Navigation Channels

Navigation channels can be categorized by depth: shallow-draft and deep-draft channels with 14 or 15 ft of navigable depth as the most commonly used dividing line. In the United States, shallow-draft channels typically provide 9 to 12 ft of depth and are found in the inland waterway network, the Gulf and Atlantic Intracoastal Waterways, and small ports nationwide. Portions of the Gulf Intracoastal Waterway have an authorized depth of 16 ft but are still considered shallow-draft channels. Deep-draft channels offer navigable depths of 18 to 50 ft and more.

Navigation channel sedimentation problems are most often deposition or excessive erosion. Natural water depths are often too shallow to allow safe navigation and dredging them to provide sufficient depth creates an imbalance in the relationship between sediment supply and sediment transport capacity, resulting in deposition. Excessive sediment erosion becomes a problem when channel banks, nearby land, structures, or buried utilities are threatened.

The alignment and configuration (e.g., depth, slope, width) of a navigation channel affects sediment transport in several ways. In general, a deep trench channel cut into a natural alluvial plain or coastal morphology will disrupt the movement of sediment because of reduced current speed and/or wave effects in the deeper water of the channel. A channel aligned with the direction of dominant sediment transport may experience less deposition than one perpendicular to the transport direction. Thus, a channel following the thalweg of a natural waterway will tend to experience less deposition than a channel that crosses the main transport path.

Channels approaching and passing through riverine navigation locks often present sedimentation challenges, because the pooled water on the upstream side (upper pool) provides a quiet water environment suitable for deposition. The downstream side (lower pool or tailwater) of the dam may be subject to erosion. Harbors, ports, docks, terminals, and marinas plus their connecting channels, anchorages, and turning basins experience the same sedimentation issues as navigation channels plus some unique problems related to their configuration.

Sedimentation Solutions

The variety of channel environments and sedimentation processes prevents a one-size-fits-all solution to deposition and erosion problems. Solutions to sedimentation problems may take many forms, ranging from nonstructural to structural to dredging. A useful classification system consists of three categories and seven strategies:

1. Prevention
   (a) Keep sediment in place.
   (b) Keep sediment out.
   (c) Keep sediment moving.
2. Treatment
   (a) Keep sediment navigable.
   (b) Dredge and remove sediment.
   (c) Dredge and place sediment.
3. Accommodation—Adapt to sedimentation regime.

Examples within each of these categories provide an organized approach to selecting from a variety of appropriate solutions as described in Case Studies.

Prediction Methods

Channel sedimentation responses to proposed solutions can be predicted by numerous methods grouped into four general approaches: field observations, desktop analyses, physical models, and numerical models. These approaches vary in terms of data requirements, complexity, reliability, applicability, cost, and time requirements. They should be applied with full recognition of their strengths and weaknesses and the user's skill in applying them.

Field observations provide insight into the physical processes of sedimentation and data for desktop analyses, physical modeling, and numerical modeling. Basic data collected for sedimentation studies include standard time-varying morphologic, hydrodynamic, sediment, and water-quality measurements. Rates of channel deposition and erosion can be estimated by hydrographic/bathymetric surveys analysis, densiometric surveys analysis, dredging records, sediment sample dating, and test pits.

Desktop approaches represent the simplest methods for estimating sedimentation rates and can be applied relatively efficiently. Most desktop methods are empirical in nature, relying on field observations to predict future sedimentation rates. Their benefits of speed and low cost arise from assumed simplifications to physics and geometry and those same simplifications often produce lesser reliability than more rigorous modeling approaches.

Physical models are scale models constructed according to scientific scaling principles for geometric, kinematic, and dynamic similarity. They require considerable expertise, typically gained through long experience. Therefore, most sediment transport modeling is now performed using numerical modeling.

Process-based numerical methods for estimating navigation channel sedimentation rates solve differential and algebraic equations representing the physical forcings and transport processes relevant to sedimentation. Numerical sedimentation models of waterways consist of two principal parts—a modeling program that solves the appropriate equations and a digital representation of the waterway to be modeled. The digital representation of a waterway includes inputs such as a mesh that defines the physical boundaries of the waterway and initial elevations of the bed, banks, structures, and overbanks; some combination of water, sediment, and sometimes constituent inflows, outflows, and water levels at the water boundaries; bed and inflowing sediment characteristics; other pertinent driving forces; and parameters required by the computer program equations. The number of spatial dimensions—zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), or three-dimensional (3D)—constitutes a primary classification for numerical model program capabilities and applications. More spatial dimensions result in more equations to solve and that generally requires more computer time and storage space.

All quantitative predictions of natural systems, including sedimentation, have inherent uncertainty resulting from errors in the inability to know future conditions, understanding and measurement of the physical and biological processes, and approximations and simplifications of the prediction method. Engineering decisions must be made despite these uncertainties, using the best available information with a full appreciation of the uncertainty bounds on that information. Therefore, modelers are responsible for quantifying uncertainty in their results and reporting them alongside model results.

Best Practices

Channel sedimentation problems are best solved through a methodical, step-by-step approach:

1. Problem Definition—including a written set of objectives, products, and schedule with quality expectations; definition of project and process boundaries; inventory of available data; and a Conceptual Site Model of sedimentation processes.
2. Design Approach—including progressing from simplest to more rigorous solution methods, selecting appropriate tools based on objectives, time and space scales, and available resources.
3. Tools Application—using best professional practices as detailed in this manual.
4. Interpreting and Reporting—using engineering judgement, not simply relaying raw numbers, to provide interpreted findings, including uncertainty bounds and limitations that may influence decision-making.

Managing a sedimentation study includes ensuring that the aforementioned steps are followed conscientiously, that client and team communications (including written progress reports) are frequent and candid, and that a rigorous quality assurance/quality control process is followed.

CHAPTER 1
INTRODUCTION

PURPOSE

This manual describes navigation channel sedimentation, lists solutions to sedimentation problems in those channels, and recommends best practices for predicting navigation channel sedimentation responses—sediment deposition to, and erosion of, the channel bed plus surrounding bed and banks—resulting from those solutions.

SCOPE

Vanoni (1975) defines sedimentation as follows:

> Sedimentation embodies the processes of erosion, entrainment, transportation, deposition and the compaction of sediment. These are natural processes that have been active throughout geological times and have shaped the present topographic and bathymetry dimensions of our earth.

The manual focuses on sedimentation in navigation channels within rivers, canals, lakes, estuaries, and coastal waterways that allow commercial waterborne transport of people and goods and recreational use. Most, but not all, navigation channels are designated as such by government or other authorities. Ports, terminals, and anchorages located on or adjacent to these navigation channels experience the same sedimentation processes as channels. Solution procedures recommended for channels may apply to those navigation facilities as well. Overall