Sustainable Sediment Management for Navigation

William H. McAnally, Ph.D., P.E., D.NE, F.ASCE
and
Thomas J. Pokrefke, MSCE, P.E., D.NE, M.ASCE

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Navigation Engineering Sub-Committee
Waterways Committee
Coasts, Oceans, Ports, and Rivers Institute (COPRI)

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Presenters

- William H. McAnally, Ph.D., P.E. D.NE, F.ASCE

  Professor Emeritus, Mississippi State University.
  Engineer, Dynamic Solutions, LLC
  Water Resources Engineering
  whmcanally@gmail.com

- Thomas J. Pokrefke, MSCE, P.E., D.NE, M.ASCE

  Partner, Computational Hydraulics and Transport
  River Engineer and Physical Riverine Modeling
  tompo39@gmail.com

Sustainable Sediment Management for Navigation

- Objective: Examine methods for sustainable sediment management in ports and navigation channels which satisfy engineering principles and ethical standards.
- Sustainability is a set of environmental, economic and social conditions applicable to engineering activities … in which all of society has the capacity and the opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or the availability of natural, economic and social resources. (COPRI Policy Statement 1)
- Sustainable sediment management includes sound engineering methods of treating, preventing, and adapting to sedimentation in ports and channels while minimizing energy expenditures and environmental effects.
- Webinar is part of a series by the Waterways Navigation Engineering Committees of COPRI. (See Slide 56)

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Topics

- Overview (Bill)
- Sediment Basics Review
- Management Methods
- Evaluating Management Methods
- Examples
- Q&A
- Resources

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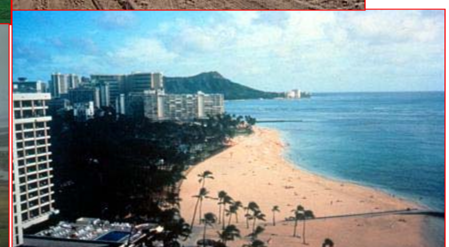
Sediment is valuable

Supplies construction material

Creates farmland

Creates & nourishes marshes



Provides recreational beaches

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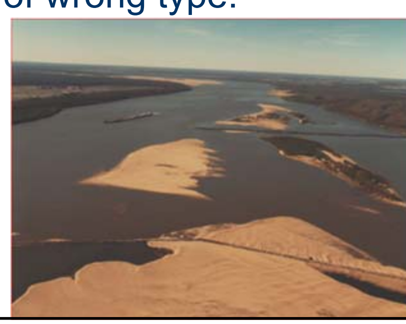
Managing sediment is vital …

It can create environmental and economic problems:

- Too much sediment clogs channels
- Too little sediment starves beaches and marshes
- Sediment in wrong place or of wrong type:
  - Limits navigation
  - Damages equipment
  - Smothers habitat
  - Hurts tourism



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Overview: Engineering Principles*

- Safe
- Effective
- Efficient
- Cost effective
- Reliable
- Robust
- Sustainable
- Societal Goals
- Aesthetic
- Secure
- *Resilient*

Rooted in Codes of Ethics

ASCE Canon 1: Engineers shall hold paramount the *safety, health and welfare of the public* and shall strive to comply with the principles of *sustainable development* in the performance of their professional duties.

ASCE Canon 4: Engineers shall act in professional matters for each employer or client as *faithful agents* or trustees, and shall avoid conflicts of interest.

*ASCE Manual 116

Topics

- Overview
- Basics Review (Tom)
- Management Methods
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Some Sediment Basics

- Sediment Behavior depends on:
  - Size and weight – gravel, sand, silt, and clay
  - Flow – velocity, turbulence, and stresses
- Size (cohesion) changes behavior

Size µm	Classification	Cohesion
40 - 62	Coarse silt	Practically cohesionless
20 - 40	Medium to coarse silt	Cohesion increasingly important with decreasing size
2 - 20	Coarse clay to medium silt	Cohesion important
< 2	Very fine clay to medium clay	Cohesion very important

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Sediment Basics: Cohesion

- Sediment cohesion refers to the property of small particles to attract and bond to each other.
- Cohesion is negligible at sand sizes and larger, but begins to have an effect in the silt sizes and gets stronger as sizes diminish.
- Clay-size individual grains are very small — a bundle of 10^6 of them could be smaller than a human hair — and they will not settle, even in still water.
- Physico-chemical molecular attraction/repulsion forces dominate the behavior of small particles. When cohesive grains come into contact, those forces cause them to flocculate – join together into aggregates or "flocs".
- Flocs --aggregates of thousands or millions of individual grains — may settle or may break apart.
- Mixtures tend to behave as if cohesive.

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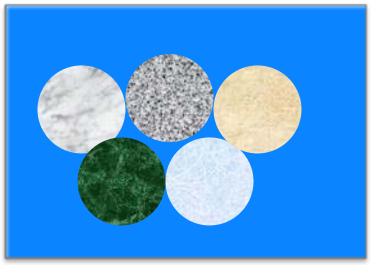
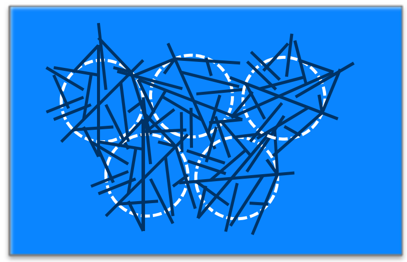
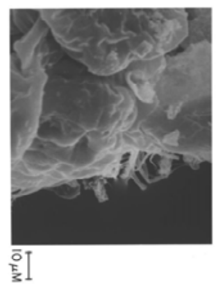
Effect of Cohesion on Incipient Motion

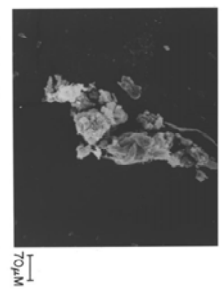


Non-cohesive



Cohesive





Courtesy sixfootsix.com

Load – Transport Rate

- Sediment Transport Classifications – Total Load

Table 7-2
Explanation of Total Load

Mode of Transport	Availability in Streambed	Method of Measurement
Suspended	Wash	Measured
Bed	Bed Material	Unmeasured

Source: SEDIMENTATION INVESTIGATIONS OF RIVERS AND RESERVOIRS, EM 1110-2-4000, U.S. Army Corps of Engineers

Live Stable Channels

Sediment Supply (Load) = Sediment Transport Capacity

Note: Non-cohesive sediment only

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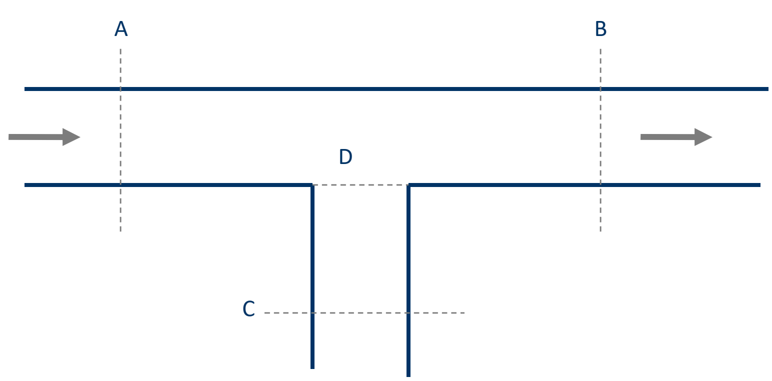
Depositional Channels

If Depositable Sediment Supply (Load) > Sediment Transport Capacity

Deposition Occurs



Note: Non-cohesive sediment only

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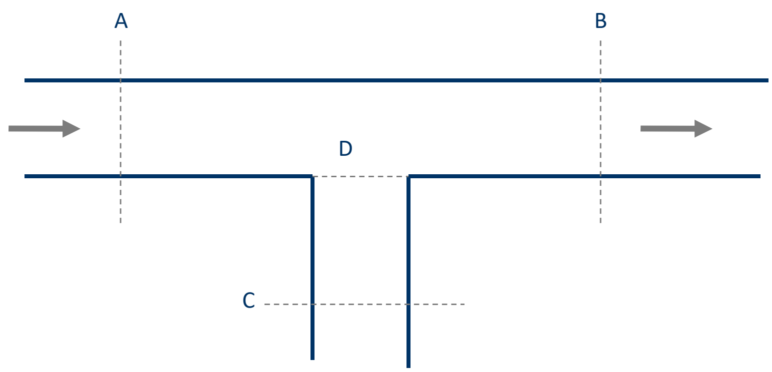
Erosional Channels

- If Sediment Supply (Load) < Sediment Transport Capacity

Erosion Occurs <u>if Bed is Mobile</u>



Note: Non-cohesive sediment only

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Navigation Channel Basics

- Objectives:
  - Stable or self-scouring channel of adequate width and depth through the full range of flows to permit continuous navigation.
  - Currents not adverse to safe navigation
- Example: If modifications such as river training structures are required, keep the degree of contraction to a minimum so that during high flows velocities are not too high for safe navigation.
- Example: Channel alignment may require adjustment to allow design vessel passage. These adjustments can be bendway cutoffs or bend radius modifications. Major cutoffs may be necessary; however, should be minimized.
- Excessive deposition is the most common navigation problem.
- Erosion is a problem when channels meander or banks fail.

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Topics

- Overview
- Sediment Basics Review
- Management Methods (Bill)
- Evaluating Management Methods
- Examples
- Q&A
- Resources

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A General Solution Taxonomy for In-Channel Problems

CATEGORY	STRATEGY	EXAMPLES
Prevention	KSP – Keep Sediment in Place	Erosion control on land and/or bed and banks
	KSO – Keep Sediment Out	Sediment Traps, Gates and Dikes, Channel Separations
	KSM – Keep Sediment Moving	Training Structures, Agitation, Flocculation Reduction, Manipulate Flows
Treatment	KSN – Keep Sediment Navigable	Nautical Depth Definition, Aerobic Agitation
	DRS – Dredge and Remove Sediment	Placement in confined disposal facilities or offshore, Permanent beneficial uses
	DPS – Dredge and Place Sediment	Bypass sediment (KSM), Temporary beneficial uses
Accommodation	Adapt to Sediment Regime	Water level timing, Flexible infrastructure, Lightering, Offshore terminals

Adapted from: Pokrefke, T. J., McCartney, B. L., Cox, M. D., Ellis, S. W., Gordon, D. C., McAnally, W. H., & Pinkard, F. 2013. Inland Navigation: Channel Training Works. *Manuals and Reports on Engineering Practice No. 124*. ASCE.
See also *Minimising Siltation in Harbours*, PIANC Report 102, 2009. PIANC.

Prevention: KSP

Keep Sediment in Place

Control Land Erosion

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Prevention: KSP

Keep Sediment in Place

- Control Bank Erosion

Photos courtesy of Corps of Engineers

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Prevention: KSO

Keep Sediment Out

- Separate channels from sources
- Sediment Traps

Port of Antwerp

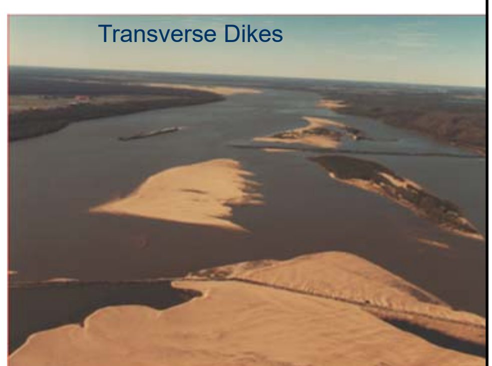
Mission Bay, San Diego

Savannah River

Prevention: KSM

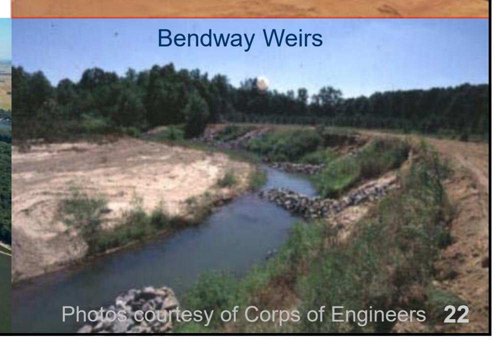
Keep sediment moving

- Training Dikes
  - Transverse
  - Longitudinal
  - Bendway weirs
  - etc.



Transverse Dikes

Parallel and Chevron Dikes



Bendway Weirs

Photos courtesy of Corps of Engineers

Prevention: KSM

Keep Sediment Moving

- Sand Bypassing

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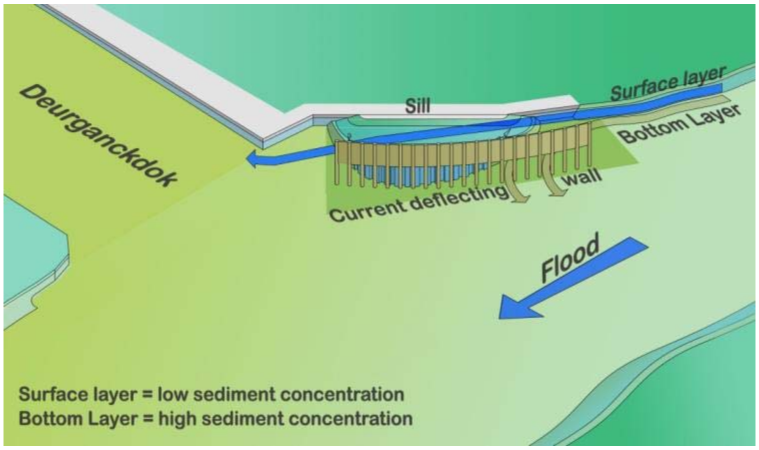
Prevention: KSM

Keep Sediment Moving

- Current Deflecting Wall with entrance flow control



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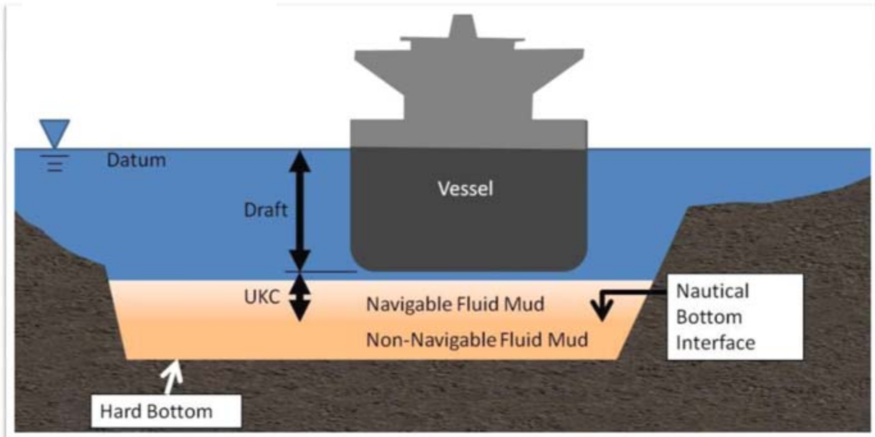
Treatment: KSN
Keep Sediment Navigable: Nautical Depth

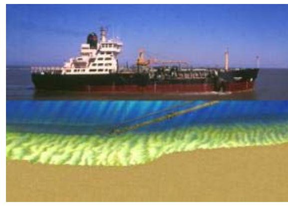
- Nautical Depth = Distance from water surface to a given suspension rheological parameter value which limits the ability of vessels to safely navigate.



Nautical Depth: A Well-Studied Solution

Treatment: DRS — Dredging and Disposal

- Open water disposal
  - Dispersive Sites
  - Retentive Sites
- Confined Disposal
  - Aquatic Sites
  - Land Sites
- Sustainable?



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Treatment: DPS — Dredging and Placement

- AKA: Beneficial Uses
- Aquatic Sites
  - Marsh and Mudflat Building
  - Habitat Creation
- Land Sites
  - Island Creation
  - Beach Nourishment
  - Brownfields Restoration
- Sustainability?
- See Dredging Fundamentals Webinar

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Accommodation

- Nautical Depth (Passive)
- Offshore Terminals
- Lightering
  - Lighter on Board (LASH)
  - Offloading


Photo: U.S. Navy

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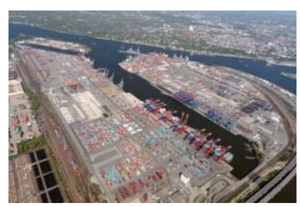
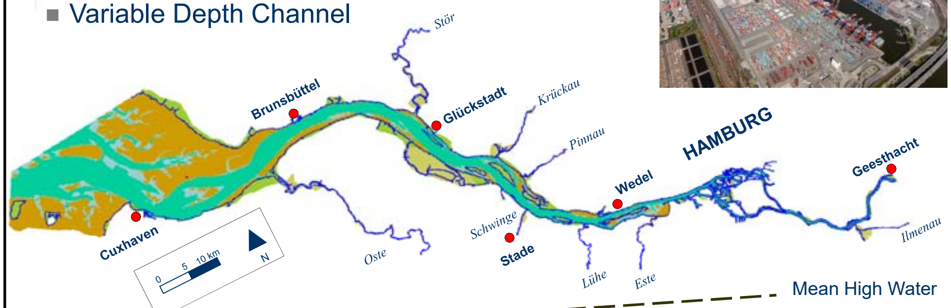
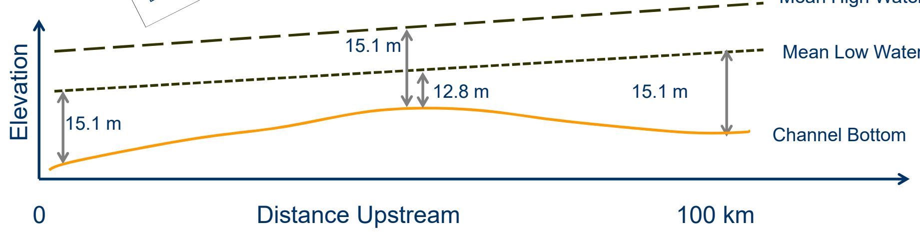
Accommodation 2

- Variable Depth Channel







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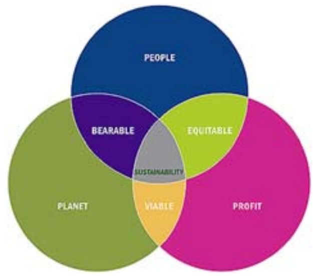
Sustainable or Not?

- All principles (Slide 7) sustained for life of project.
- Triple Bottom Line
  - Social
  - Economic
  - Environment



- How do we measure it? Envision Rating System

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ENVISION Sustainability Rating Index

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I S I

- Envision™ provides a holistic framework for evaluating and rating the community, environmental, and economic benefits of all types and sizes of infrastructure projects. It evaluates, grades, and gives recognition to infrastructure projects that use transformational, collaborative approaches to assess the sustainability indicators over the course of the project's life cycle.
- Envision™ has 60 sustainability criteria, called credits, divided into five sections: *Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Risk.*
- Website: http://www.sustainableinfrastructure.org

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Topics

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- Evaluating Management Methods (Tom)
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Warning:

There are many simple, easy-to-understand, and wrong solutions to sediment problems.

David Beidenharn

Constructing a management plan without careful evaluation for the site is a recipe for failure.

Evaluating Management Methods by Site

- Field Investigations
- Laboratory Investigations
- Desk Analyses
- Numerical Analyses

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Field Investigation

- Uses the prototype as the model
  - Example: Dike Length - Nearby sites show the contraction width capable of transporting the sediment load.
  - Example: Follow-the thalweg - Hydrographic surveys may show a desired channel alignment within the existing project limits.
  - Example: Trial solutions - Test pits can indicate deposition rates
- Provides data for desktop analyses.
  - Example: Calculate sediment load.
  - Example: Identify sediment character and sources.
- Provides data for model validation.

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Laboratory Investigation

- Complex and numerous issues need to be addressed when designing navigation channels, so a model study is often necessary.
- Lab model methods available
  - Flume and Basin experiments
  - Physical (scale) movable-bed models
  - Hydraulic Sediment Response Model

More Info: Inland Navigation: Channel Training Works. *Manuals and Reports on Engineering Practice No. 124*. ASCE.

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Desk Analyses Procedures

- Review previous studies and literature
- Review maintenance dredging records and talk with users of the project. (Warning: "footprint" prediction method is unreliable.)
- Analyze hydrographic surveys over time
  - Evaluate previous improvements
  - Identify morphological trends
- Compute characteristic flows and sediment loads.
- When linked to the field investigation, helps determine:
  - Construction materials breakdown or deterioration
  - Slope undercutting
  - Unusual scour patterns
  - Overall changes in the project
  - Accumulation of debris

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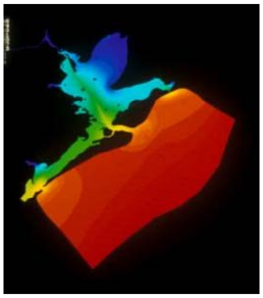
Numerical Analyses

- Apply numerical techniques such as iteration to solve simplified versions of complex equations of motion.
- A range of numerical models for navigation project sediment issues.
  - HEC-RAS
  - HEC-6T
  - ADH
  - EFDC
  - Others



More Info: See Hydraulic Modeling. *Manuals and Reports on Engineering Practice No. 97*. ASCE.

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Keys to Sustainable Sedimentation Solutions

- Understand basic sediment processes and use them to manage – e.g., “Working with Nature”
- See the big picture – Systems Engineering e.g., “Regional Sediment Management”
- Prepare for tradeoffs – cost, effectiveness, sustainability, etc.
- Calculate the Full Life-cycle Costs and Benefits
  - Economic costs and benefits
  - Environmental costs and benefits
  - Social effects
  - Direct and Secondary Effects
- Manage Adaptively after careful analysis, but not by Trial and Error

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Examples: Missouri River (Tom)

- Site: Missouri River channel extends from Sioux City, Iowa to its confluence with the Mississippi River just north of St. Louis, Missouri. The navigation channel is 300-ft wide with a minimum depth of 9 ft.
- Problem: River carries large amounts of fine-grained sediments, and pile dikes and dike systems are very effective in accumulating sediment within the dike fields.
- Solution Process/Method: Channel designed using timber pile dikes and revetments since it was believed that these types of structures provided the most economical and practical method to keep the large sediment load moving downriver.

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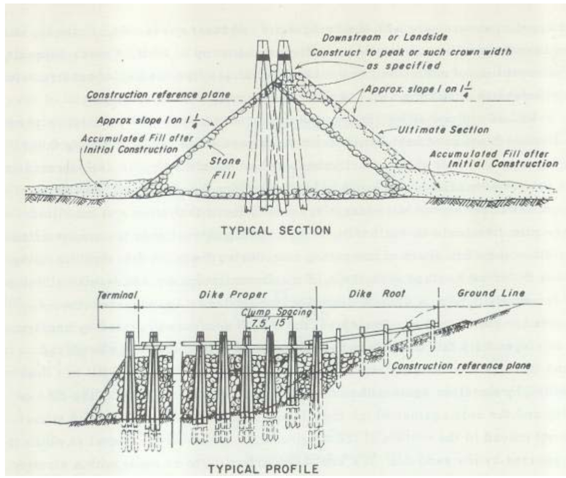
Missouri River Example (cont.)

- Solution Chosen: : Timber pile dikes were used to direct the river flow as well as control the river while the timber pile revetments stabilized the bank lines were necessary. Cutoffs and channel realignments were also included in the Missouri River master plan.
- Sustainability evaluation: Initially the timber pile dikes constructed on the Missouri River were single pile in line using treated piles. As the project evolved and sediment accumulated within dike fields stone was placed in some of the timber pile dikes to control flow through the dikes and manage the sediment within the dike fields. This also provided a long-term stability to the dikes as the timbers deteriorated. As the navigation channel became established and developed on the Missouri River, the actual approach to dike construction was modified to work with the channel that was forming. The timber pile dike design was changed to a stone-filled timber pile dike design.

Missouri River Example (cont.)

- It was found that using stone-filled timber pile dikes was a cost effective method that provided a structure with a longer life. It was determined that this type of structure provided savings by allowing the stone to be placed at a steeper slope within the timber piles than an all-stone dike where the natural angle of repose of the stone would determine the side slopes.
- The construction procedure became (1) Untreated piles for the dike are driven, (2) Stone is placed around the piling to the desired elevation or above, (3) Later, following deposition against the dike, stone is added in the dike on the top and side where fill occurred. Therefore, the additional stone does not extend to the original pile dike base, but only to the bed elevation of the deposition
- Following is a drawing of the Missouri River pile dike details, a location map of a study reach, and 4 photographs of the channel development in the study reach with pile dikes over time.

Missouri River Example (cont.)



Missouri River stone-fill timber pile dike details

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Missouri River Example (cont.)

- Map showing location of the Rock Bluff Bend Reach on the Missouri River. Reach is located approximately 28 miles downstream of Omaha, Nebraska and 20 miles upstream of Nebraska City, Nebraska.

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Missouri River Example (cont.)

Rock Bluff Bend, Missouri River with Timber Pile Dikes, March 1935 (USACE, Omaha District)

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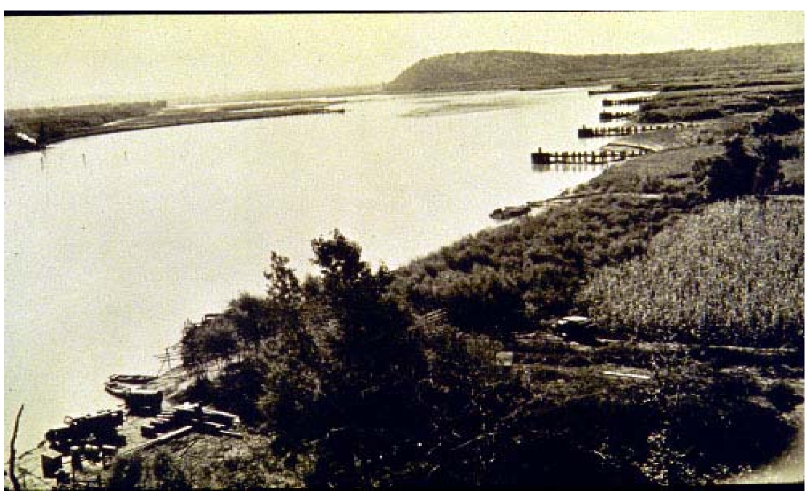
Missouri River Example (cont.)



Rock Bluff Bend, Missouri River with Timber Pile Dikes October 1939 (USACE, Omaha District)

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Missouri River Example (cont.)

Rock Bluff Bend, Missouri River, 1956 (USACE, Omaha District)

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Missouri River Example (cont.)

Rock Bluff Bend, Missouri River with Timber Pile Dikes, March 1983 (USACE, Omaha District)

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Missouri River Example (cont.)

Rock Bluff Bend, Missouri River with Timber Pile Dikes, October 2006 (USACE, Omaha District)

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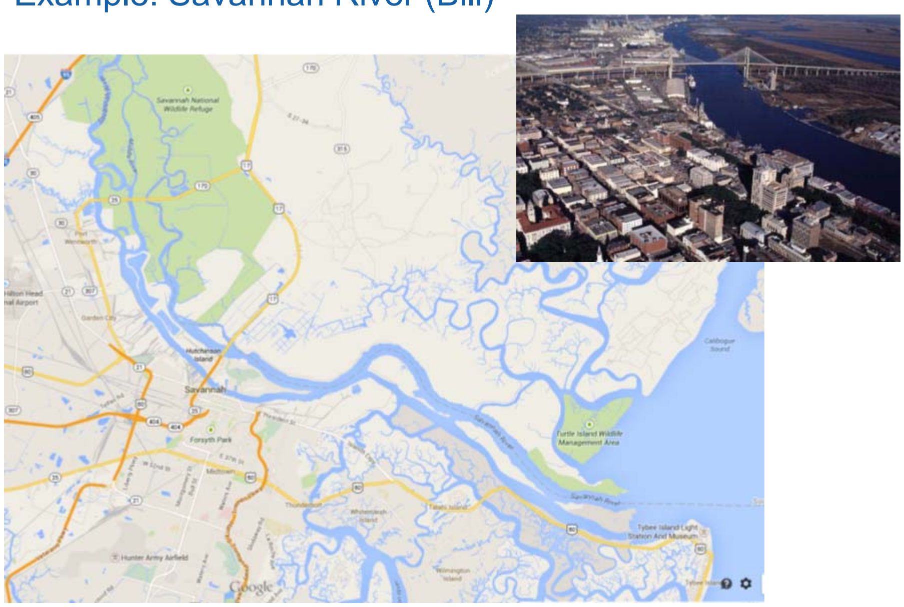
Example: Savannah River (Bill)



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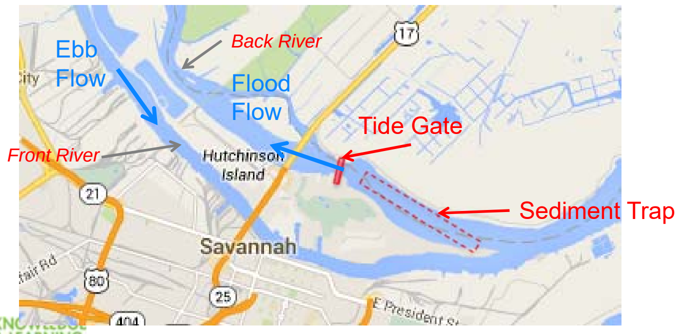
Savannah (cont)

- Problem: Rate of sedimentation increased with deepening. Excessive sedimentation in port area of Front River. Dredging activities blocked vessels. Disposal space was limited.
- Solution:
  - Tide gate located in Back River to allow flow in flood direction only
  - Sediment trap located in Back River to capture turbidity maximum
  - Middle River (upstream) cut to allow ebb flows to flush Front River



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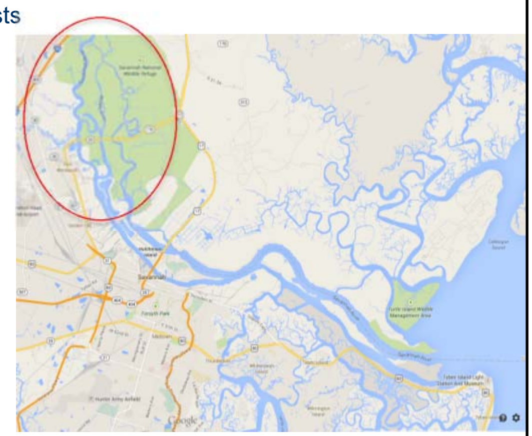
Savannah (cont)

- Results
  - Total dredging reduced by ~50%
  - Dredging cost per cu yd reduced by ~50%
  - 75% net savings in dredging costs
  - Improved navigation access
- But,
  - Salinity increased in refuge
  - Public perception faulted project
  - Tide gate removed
  - Dredging increased



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Q&A

- Questions/Comments/Corrections?

Fundamentals of Navigation Engineering Series - Planning, Design, Dredging and Sustainability

- Navigation Engineering: Understanding the Basics
- Intro to Navigation Channel Design
- River Information Services: Basics of RIS and US Implementation
- Dredging Fundamentals
- Navigation Engineering: Challenges of Sustainability and Resilience
- Sustainable Sediment Management for Navigation Projects

http://mylearning.asce.org/diweb/catalog/item/id/1028838/q/c=79&q=navigation&t=2125

Information Sources: Navigation

- ASCE Manuals
  - 50: Small Craft Harbors
  - 94: Inland Navigation
  - 97: Hydraulic Modeling
  - 107: Ship Channels
  - 116: Navigation Engineering & Ethics
  - 124: Inland Navigation Channel Training Works
- ASCE Journals
- Transportation Research Board Reports
- Corps of Engineers Manuals
  - Shallow Draft
  - Deep Draft
  - & more
- PIANC Reports
  - WG6: Sustainable Inland Waterways
  - 102: Minimising Harbour Siltation
  - 106: Innovations in Lock Design
  - & more
- Navy Manuals

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Information Sources: Sustainability & Sedimentation

- ASCE Journals
  - Waterways
  - Hydraulics
  - Environmental
- ASCE Manuals
  - 110: Sedimentation Engrng
  - 124: Inland Navigation Channel Training Works
- Corps of Engineers Manuals
  - 4000 – Sedimentation Invstgtns
  - 1607 – Tidal Hydraulics
  - 5025 – Dredging
- PIANC Reports
  - WG6 – Sustainable Inland Watwys
  - 102 – Minimising Harbour Siltation
  - 107 – Sustainable Waterways
  - 136 – Sustainable Maritime Nav
  - 150 – Sustainable Ports

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Navigation Engineering Certification

The Academy of Coastal , Ocean, Ports, and Navigation Engineering recognizes those individuals who have excelled in one or more of the sub-disciplines of COPRI, including Navigation Engineering.

To learn more about the Academy and certification as a Diplomate, Navigation Engineering, visit: http://www.acopne.org

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Some Useful Web Pages

- COPRI: http://coprinstitute.org/
- Am Assoc. Port Auth.: http://www.aapa-ports.org/
- Inland Rivers Ports & Terminals: http://www.irpt.net/
- Maritime Administration: http://www.marad.dot.gov/
- NOAA Ocean Service: http://oceanservice.noaa.gov/topics/navops/marinenav/
- PIANC USA: http://www.pianc.iwr.usace.army.mil/
- Transportation Research Board: http://www.trb.org/MarineTransportation1/MarineTransportation1.aspx
- USACE Pubs: http://140.194.76.129/publications/
- USACE Navigation Data Center: http://www.ndc.iwr.usace.army.mil/

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Bonus Materials

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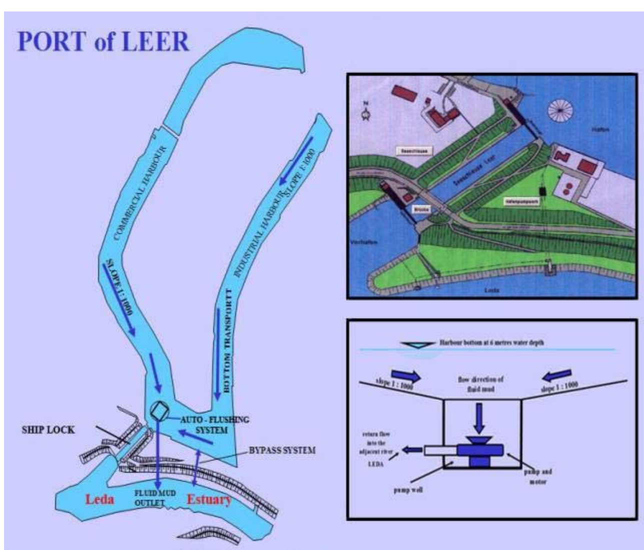
Sediment Trap for Fluid Mud



ASCE | KNOWLEDGE & LEARNING

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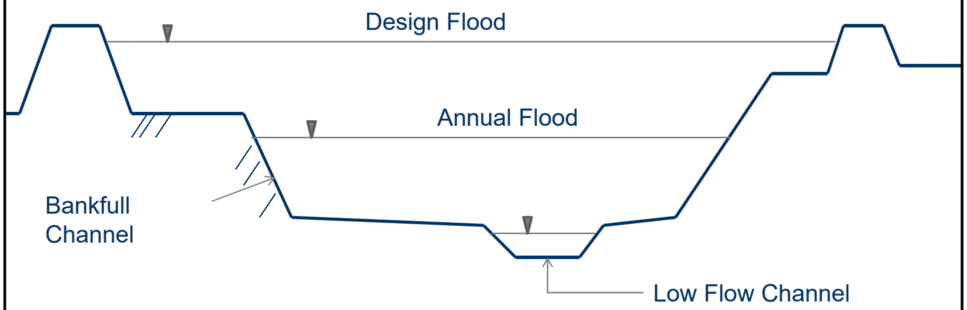
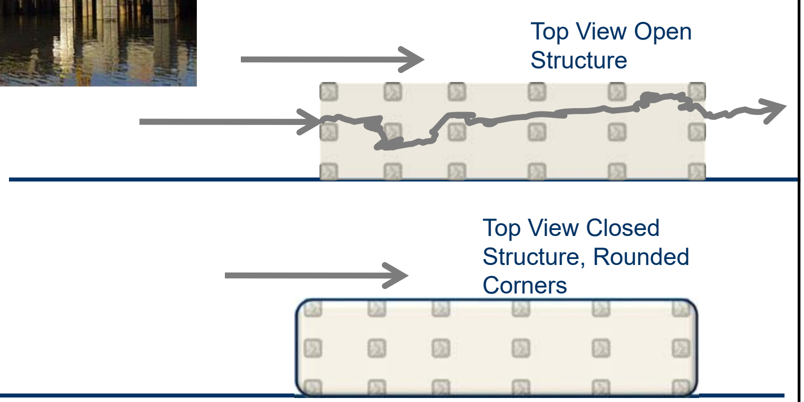
Compound Channel (Elevation View)



Fine Sediment: Flocculation Control (KSM)

Waterfront Structures on Piles



Fine Sediment: Flocculation Control and KSO

Adaptation: Navigation Channels & Ports