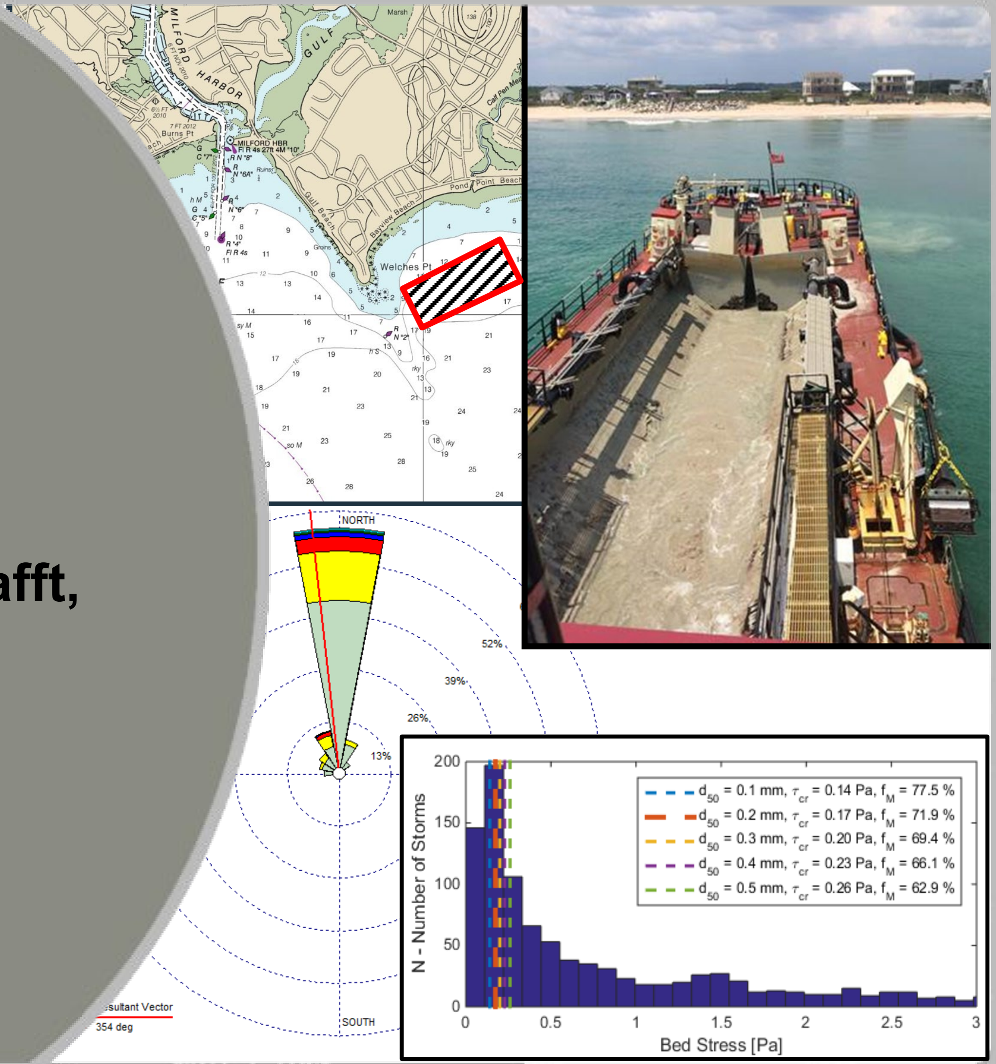
UPDATES TO THE SEDIMENT MOBILITY TOOL



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CIRP Technical Discussion
Feb. 22, 2022

US Army Corps of Engineers®

COASTAL & HYDRAULICS LABORATORY

DISCOVER / DEVELOP / DELIVER

Outline

- Story of the Development of the SMT
- What is the Sediment Mobility Tool?
- How Does it Work?
- Demonstration
- What are its Limitations?
- What's the Next Step for Nearshore Nourishment Research?

Storyline

2014 – ERDC Hosts a Nearshore Berm Workshop and District practitioners request a rapid tool to estimate

- Whether Sediment Placed in the Nearshore Will Move?
- Where is it Likely to Go?

2015 – Tool Creation

- Matlab Script was created to address the need
- Script was tested at Milford, CT with a reimbursable project

2016 – Web Application Development

- Matlab Scripts were given to OP-J to convert to Python for Web Application
- Python Scripts were tested at several sites to verify matching results to the Matlab Scripts

Storyline (cont.)

2017 – Web App Expanded

- SMT was applied to NACCS data and results are displayed as a layer
- Uncertainty associated with SMT was quantified at Vilano Beach, FL

2018 – SMT User’s Manual was Published

2019 – Identification and Development of New Features

- Nearshore Placement Workshop
- New features are developed in Matlab at tested for various project sites

2020 – Web Application Addition of New Features

- Matlab Scripts were given to OP-J to convert to Python for Web Application
  - Modifications and additions to Matlab scripts are clearly commented

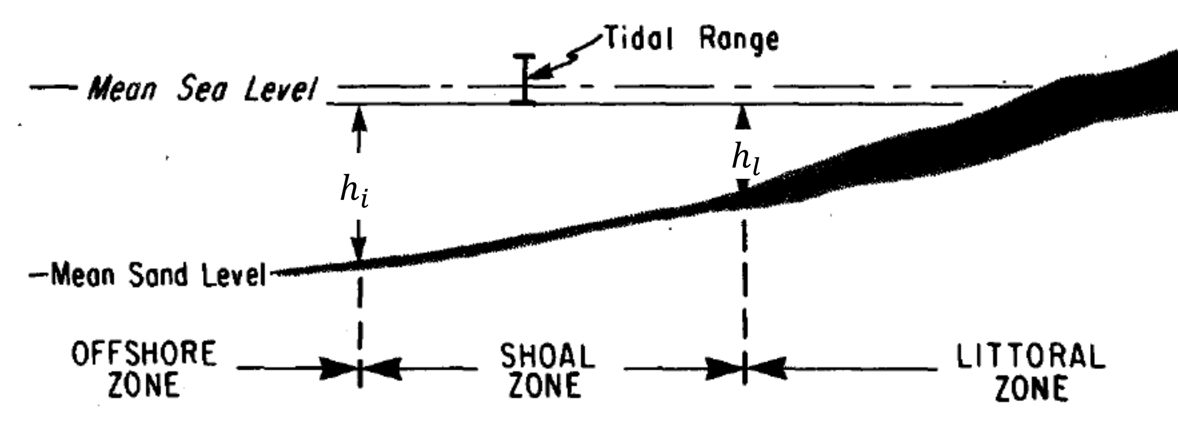
2021 – Operational Web Application with New Features

What is the Sediment Mobility Tool

- Scoping level tool
- Web Application
- Answers:
  - Will sediment placed in the nearshore move?
  - Where is likely to go?
  - New: How does my proposed placement compare to other historical projects?
  - New: What is the seasonality impact on mobility?
  - New: How quickly will a bar/mound deflate?

How Does it Work?

Depth of Closure



(Hallermeier, 1983)

Hallermeier Inner: $h_l = 2.28H_e - 68.5(\frac{H_e^2}{gT_e^2})$

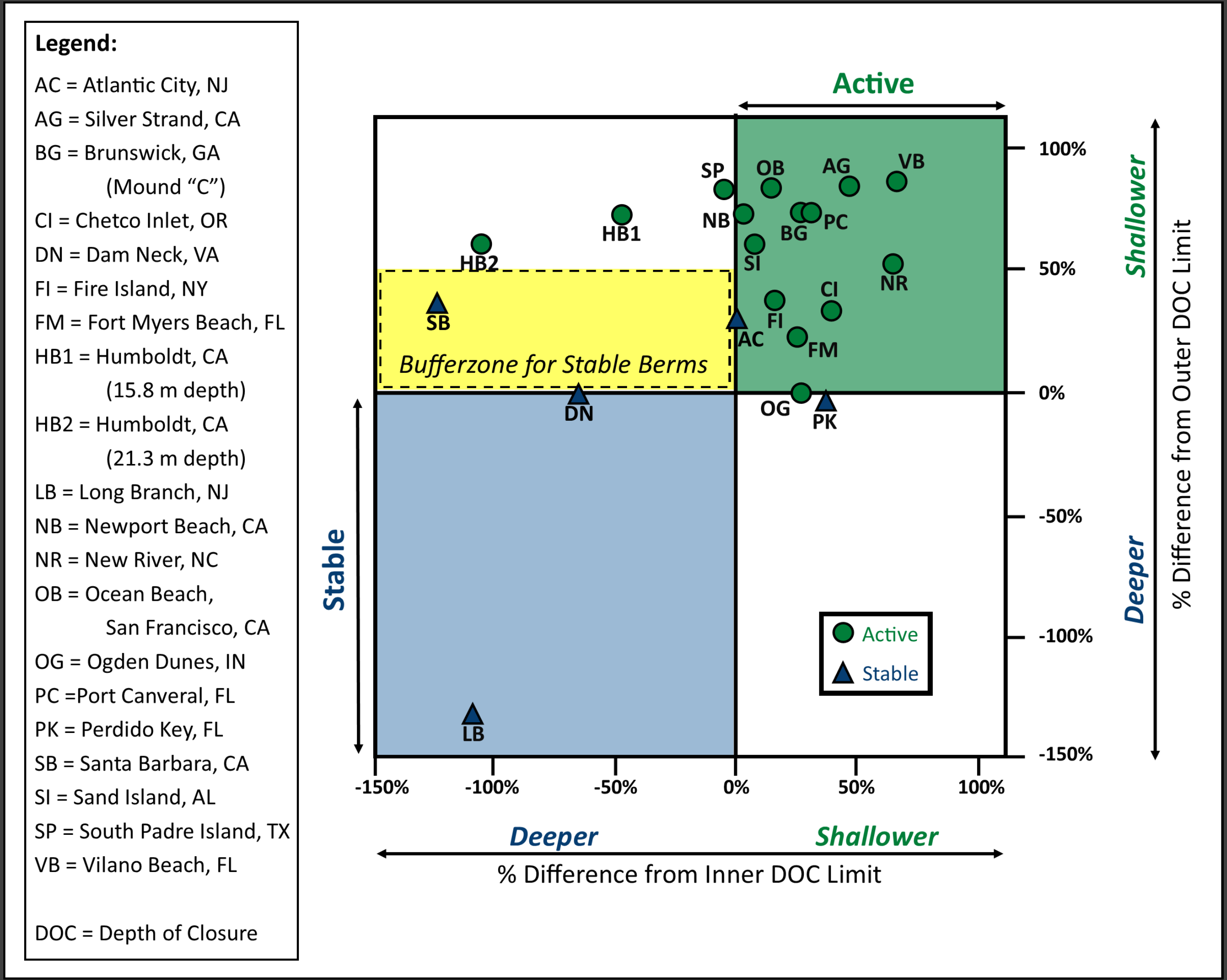
Hallermeier Inner Simplified: $h_l = 2\bar{H}_s + 11\sigma_s$

Hallermeier Outer: $h_i = (\bar{H}_s - 0.3\sigma_s)\,\bar{T}_s(\frac{g}{5000d})^{0.5}$

Birkemeier Inner: $h_l = 1.75H_e - 57.9(\frac{H_e^2}{gT_e^2})$

Birkemeier Inner Simplified: $h_l = 1.57H_e$

How Does it Work?
Comparison with Historical Projects



NEW:

- Updated Hands And Allison (1991) Chart
- 20 Project sites
- Kept H&A DoC values for projects before 1990 because d_{50} could not be located
- Used WIS for monitoring period for projects after 1990
- Additional details see McFall et al. (2021)

How Does it Work?

Wave Theories

Frequency of Mobility:

- Linear Wave Theory (Bed Shear Stress)
  - Soulsby (1997)
- Stream Function Wave Theory (Near-bed Velocity)
  - Ahrens and Hands (1998)

How Does it Work?
Linear Wave Theory

Critical Shear Stress

$$D_* = d_{50}\left(\frac{g\left(\rho_s/\rho - 1\right)}{\nu^2}\right)^{1/3}$$

$$\theta_{cr} = \frac{0.30}{1 + 1.2\,D_*} + 0.055[1 - \exp(-0.020\,D_*)]$$

$$\tau_{cr} = \theta_{cr}\, g\,(\rho_s - \rho)\, d_{50}$$

Current-Induced Shear Stress

$$\tau_c = \rho\left(\frac{\bar{U}\,\kappa}{\ln\left(\frac{z}{z_0}\right)}\right)^2$$

Wave-Induced Shear Stress

$$\tau_w = \frac{1}{2}\,\rho\, f_w U_w^2$$

Maximum Shear Stress

$$\tau_m = \tau_c\left[1 + 1.2\left(\frac{\tau_w}{\tau_c + \tau_w}\right)^{3.2}\right]$$

$$\tau_{max} = [(\tau_m + \tau_w\cos\phi)^2 + (\tau_w \sin\phi)^2]^{1/2}$$

How Does it Work?

Stream Function Wave Theory

Critical Near-Bottom Velocity

$$u_{cr} = \sqrt{8\, g\, \gamma\, d_{50}} \qquad d_{50} \leq 2.0\, mm$$

$$u_{cr} = [0.46\, \gamma g\, T^{1/4} (\pi d_{50})^{3/4}]^{4/7} \qquad d_{50} > 2.0\, mm$$

Near-Bottom Wave-Induced Velocity

$$u_{\max\, crest} = \left(\frac{H}{T}\right)\left(\frac{h}{L_o}\right)^{-0.579} \exp\left[0.289 - 0.491\left(\frac{H}{h}\right) - 2.97\left(\frac{h}{L_o}\right)\right]$$

$$u_{\max\, trough} = -\left(\frac{H}{T}\right) \exp\left[1.966 - 6.70\left(\frac{h}{L_o}\right) - 1.73\left(\frac{H}{h}\right) + 5.58\left(\frac{H}{L_o}\right)\right]$$

$$u_{max} = \max(|u_{\max\, crest}|, |u_{\max\, trough}|)$$

How Does it Work?
Cross-shore Sediment Transport

Dean Number:

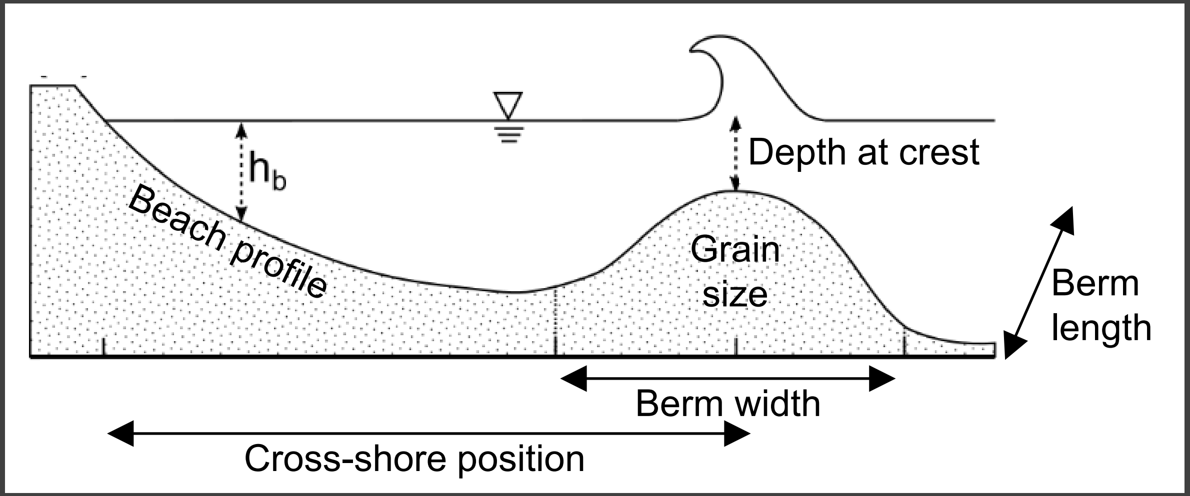
$$D = \frac{H_0}{\omega\, T}$$

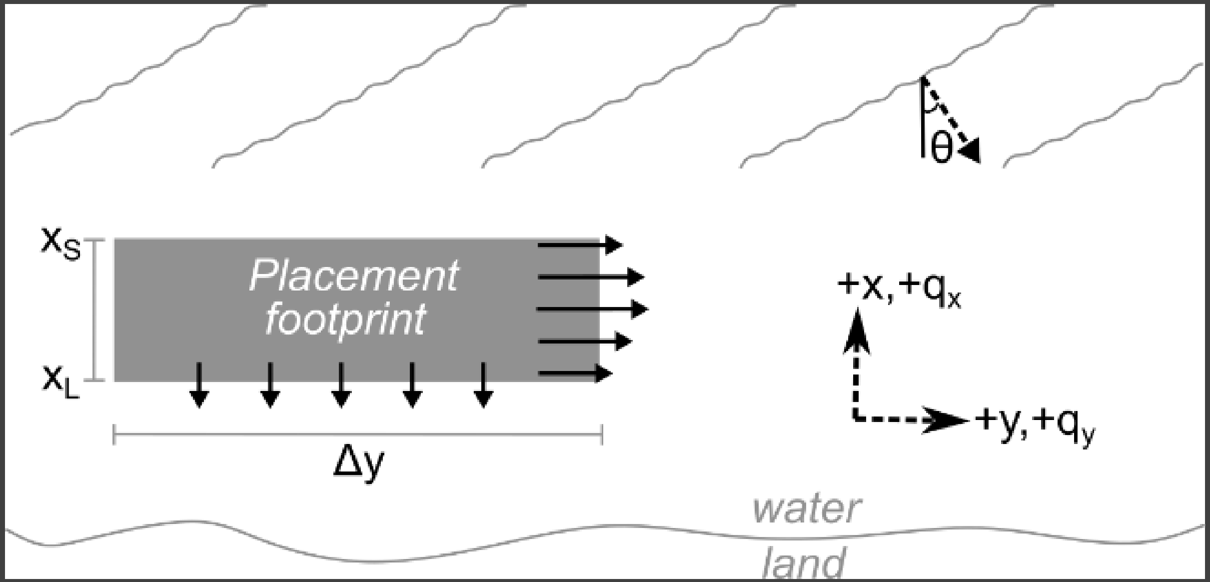
> 7.2, Offshore Migration

< 7.2, Onshore Migration ***(Larson & Kraus, 1992)***

How Does it Work?
Bar/Mound Deflation

- Longshore and cross-shore transport are treated as independent (orthogonal) processes which can be calculated separately and superimposed.
- Nearshore berm “deflation” is defined as the transport of sediment away from the original placement footprint.
- Assume that sediment is exclusively sediment source(no “reinflation”).
- Berm geometry (cross-shore position, length, depth at crest, *etc.*) are assumed constant in time.
- Wave conditions vary with Δt=1 hour.
- Technique from Bain et al. (2021)





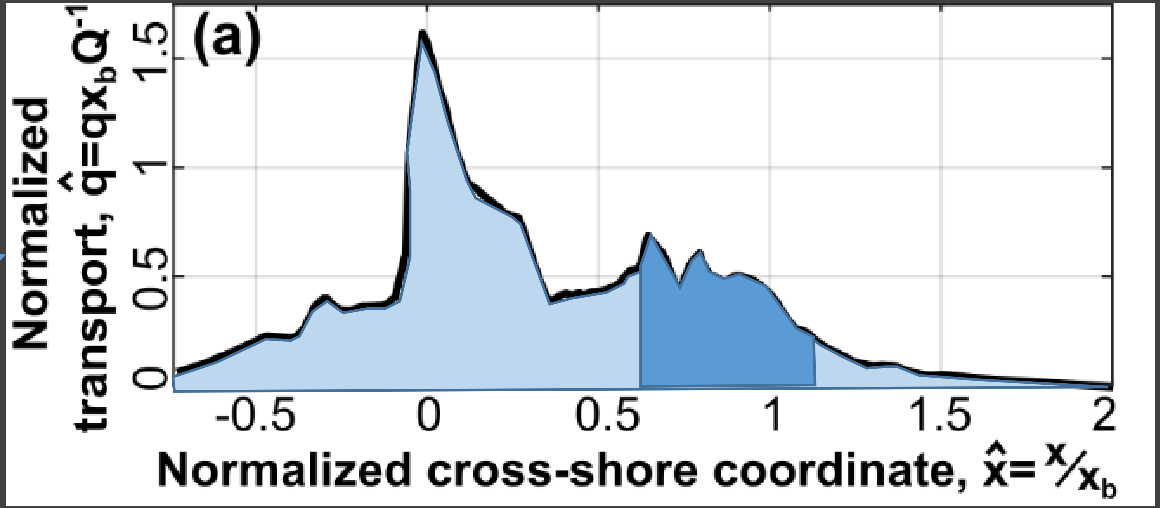
How Does it Work?
Bar/Mound Deflation

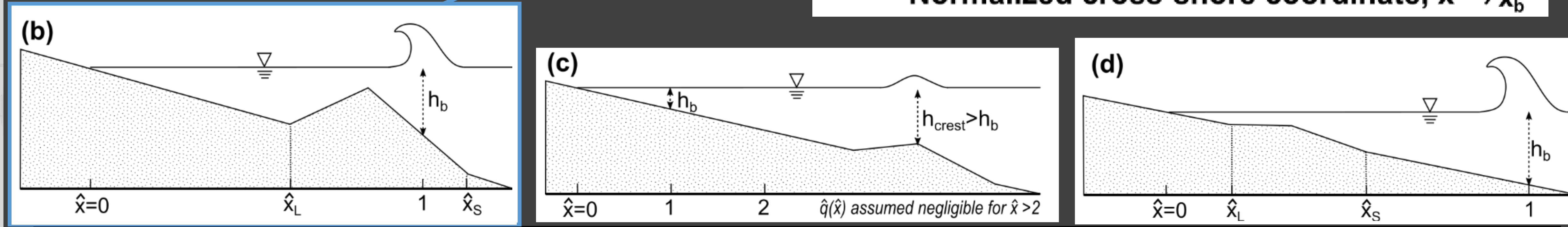
Total Longshore Transport

$$\frac{Q_y T_p}{H_b^3} = \frac{3x10^{-4}}{(1-a)} \frac{\rho_w}{\rho_s - \rho_w} \left(\frac{H_b}{L_0}\right)^{-0.9} \sin^{0.5}(2\theta_b)$$

Shaeri et al (2020)

Fraction of Longshore Transport





How Does it Work?
Bar/Mound Deflation

Cross-shore Transport:

Based on Dronkers (2016)

m=beach profile slope

Critical velocity scaling term (no transport if peak orbital velocity is less than critical velocity)

$$Q_{\text{cross}} = \left|\alpha\left[\underbrace{\lambda m\langle|u_w|^3\rangle}_{\text{down-slope transport due to gravity}} - \underbrace{\langle|u_w|^2 u_w\rangle\overbrace{(1-\kappa)}}_{\text{wave velocity-driven transport}}\right]\right| \cdot \cos(\theta_{\text{crest}})\,\Delta y$$

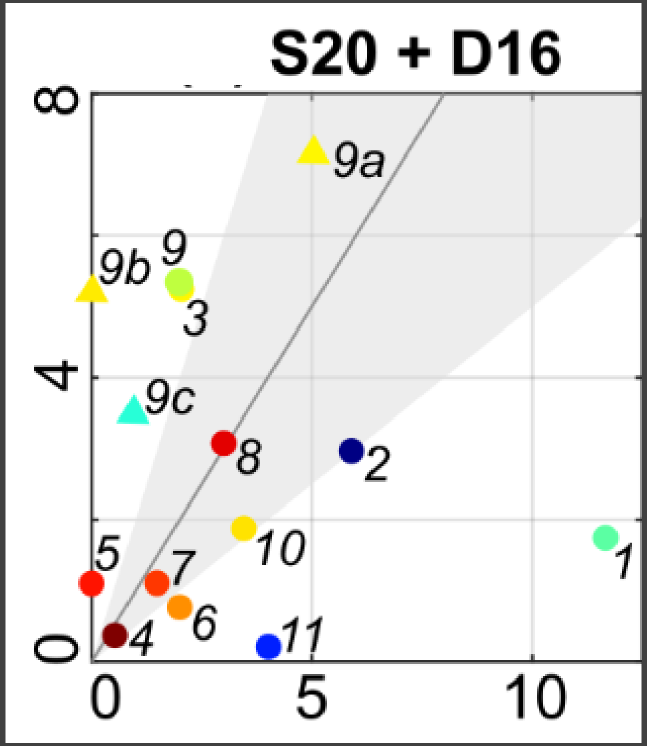
down-slope transport due to gravity

wave velocity-driven transport

Near-bed velocity determined using stream-function wave theory

How Does it Work?
Bar/Mound Deflation

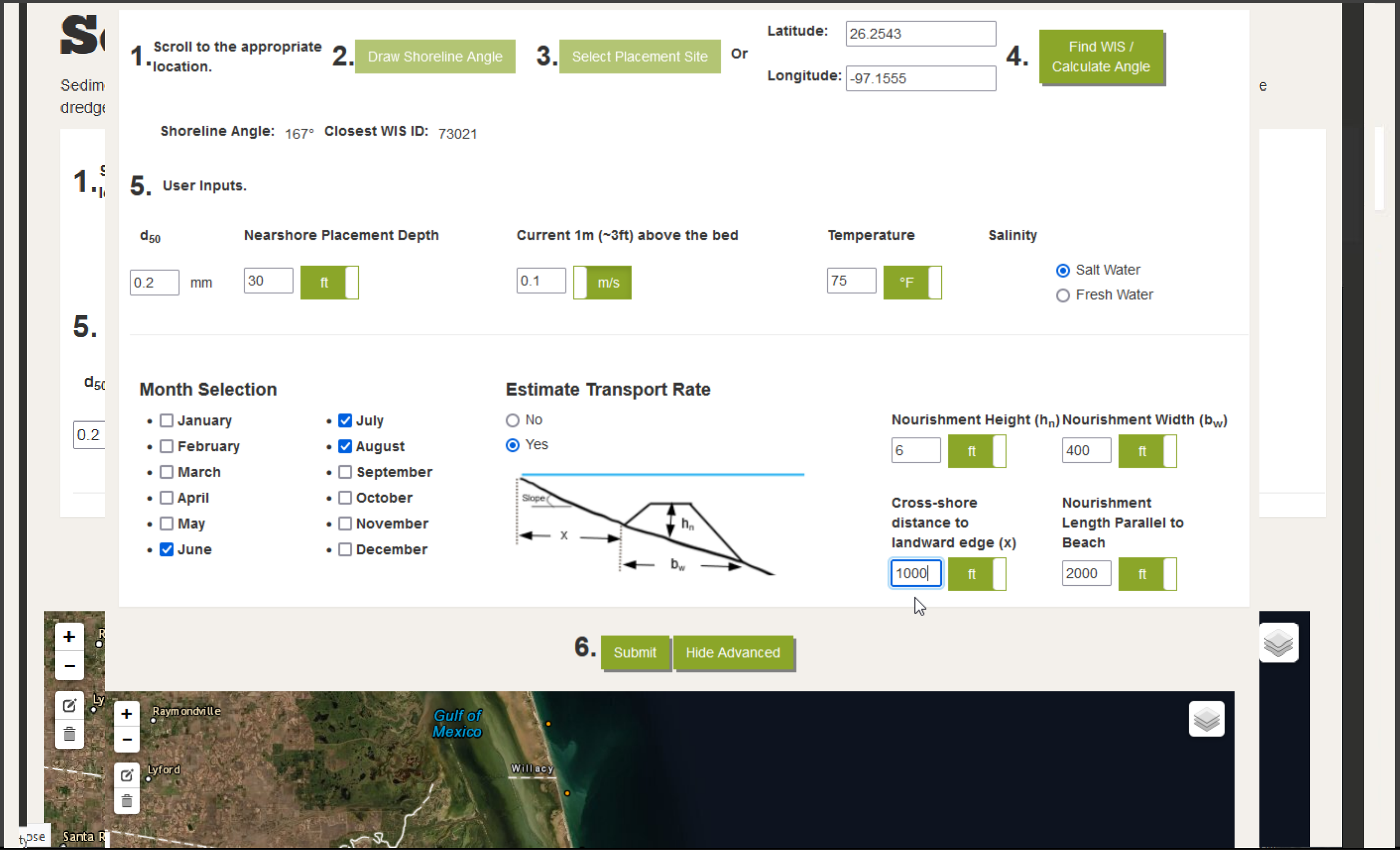
Combined Longshore and Cross-shore Transport



Average error magnitude = 72%

Demonstration

https://navigation.usace.army.mil/SEM/SedimentMobility



Demonstration

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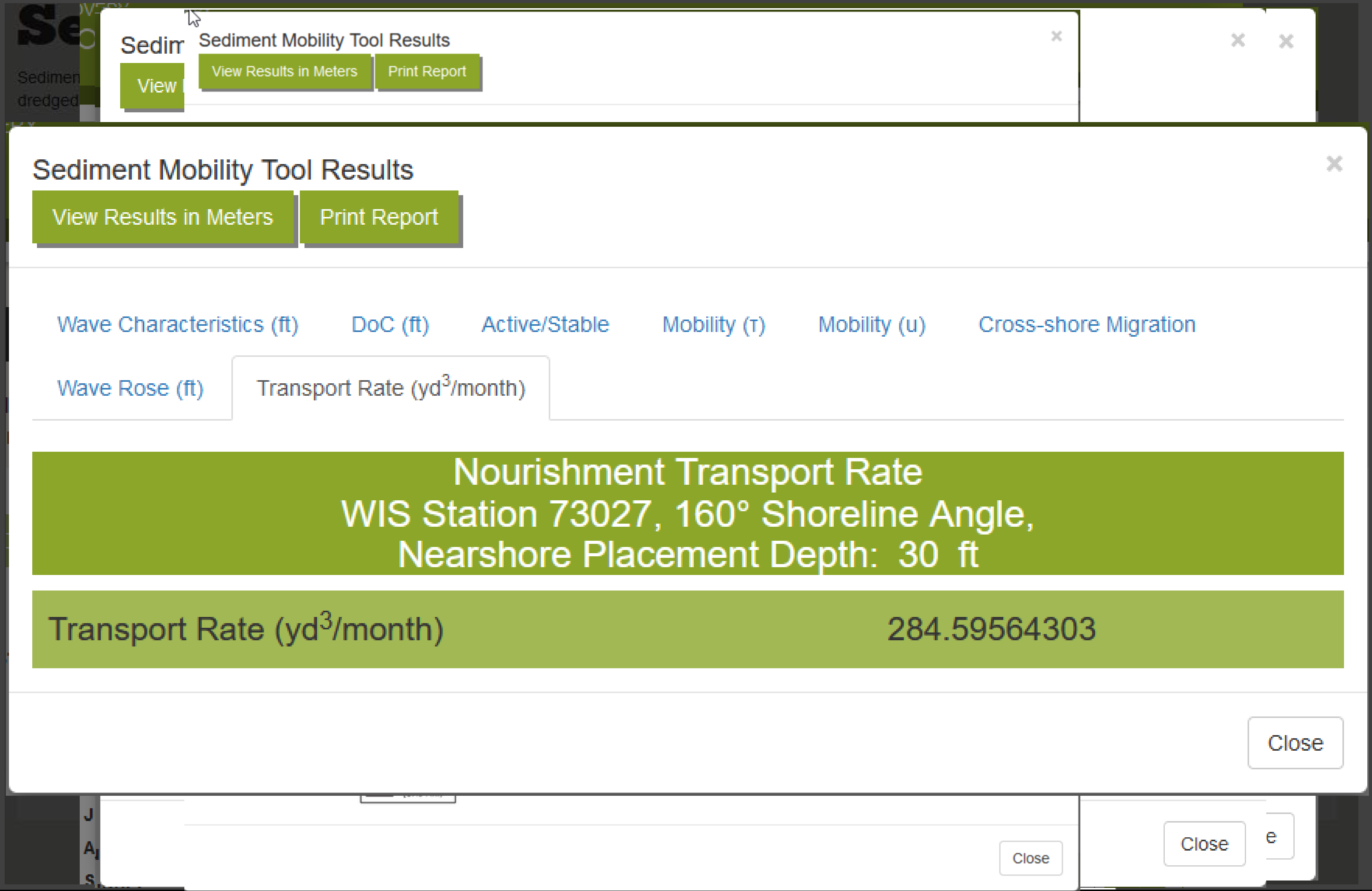

Demonstration

https://navigation.usace.army.mil/SEM/SedimentMobility

Nourishment Transport Rate:

Sediment Migration (1980-2013) WIS Station 73027, 160° Shoreline Angle, Nearshore Placement Depth: 30.00 ft	
Transport Rate	**284.60 yd^3/year**

The nourishment transport rate is the rate at which placed sediment is calculated to leave the placement footprint, and is calculated using the Bain et al. (2021) technique.

Uncertainty Associated with the Tool:

McFall et al. (2020) quantified the epistemic uncertainty associated with the sediment mobility of the tool using a case study at Vilano Beach, Florida. The confidence intervals were calculated for the frequency of mobility that encompassed the epistemic uncertainties associated with each step of the SMT, which included the offshore hindcast wave conditions, wave transformation to the nearshore, critical thresholds for sediment motion, maximum bed shear stress, and maximum near-bottom velocity. The median grain size's frequency of mobility was calculated using linear wave theory as 94.8%, with 95% confidence limits of 85.4% and 99.4%, respectively. Using stream function wave theory, the median grain size was estimated to be mobilized by 98.5% of the waves with 95% confidence limits of 97.2% and 99.2%. The smaller confidence interval for the stream function theory method is likely due to the high frequency of mobility and physical restriction that the frequency of mobility cannot exceed 100%. The uncertainty associated with the wave transformation from offshore to the nearshore is case dependent and varies with local bathymetry, but the case study uncertainty and confidence intervals provide a qualitative understanding of the potential uncertainty at other sites.

References:

Brutsché, K. E., J. Rosati III, C. E. Pollock, and B. C. McFall. 2016. *Calculating depth of closure using WIS hindcast data*. ERDC/CHL CHETN-VI-45. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Hands, E. B., and M. C. Allison. 1991. *Mound migration in deeper water and methods of categorizing active and stable depths.*. In Coastal Sediments '91, edited by N. C. Kraus, K. J. Gingerich, and D. L. Kriebel, 1985–1991. Reston, VA: ASCE.

Larson, M. and Kraus, N. C. 1992. *Analysis of cross-shore movement of natural longshore bars and material placed to create longshore bars.* Technical Report DRP-92-5. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

McFall, B. C., K. E. Brutsché, A. M. Priestas, D. R. Krafft. 2021. *Evaluation Techniques for the Beneficial Use of Dredged Sediment Placed in the Nearshore.* Journal of Waterway, Port, Coastal, and Ocean Engineering. doi: 10.1061/(ASCE)WW.1943-5460.0000648.

McFall, B. C., V. M. Gonzalez, N. C. Nadal-Caraballo, K. E. Brutsché. 2020. *Uncertainty Associated with the Sediment Mobility Tool.* ERDC/CHL CHETN-IV-122. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

McFall, B. C., S. J. Smith, C. E. Pollock, J. Rosati, III, and K. E. Brutsché. 2016. *Evaluating sediment mobility for siting nearshore berms.* ERDC/CHL CHETN-IV-108. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

What are its Limitations?

Only to be used on:

- **Non-cohesive sediment**
- **Exposed Shoreline with Direct Line to WIS Station (not in estuaries or bays, not sheltered behind islands)**

Does not include tidal currents or water level changes

REMEMBER: THIS IS A SCOPING TOOL!

Summary and Next Step

The SMT has been upgraded to include:

- **Comparison with Historical Projects**
- **Month Selection**
- **Transport Rate**

Future: Creation of a Nearshore Nourishment Website to include:

1. **Historical projects:** Locations of projects on an interactive map with basic project details and links to publications on each project
2. **Planning Tools:** Summary of available planning tools, links to access them, and links to user's guides for the tools
3. **Technical Documents:** Links to technical documents
4. **Current and Best Practices:** Abstracts and links to documents that explicitly address the practices of nearshore nourishment projects