User's Guide for the Sediment Mobility Tool Web Application

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PURPOSE: This U.S. Army Corps of Engineers (USACE) Regional Sediment Management Technical Note (RSM-TN) describes how to use the interactive Sediment Mobility Tool (SMT) web application to quickly assess prospective nearshore placement sites of dredged sediment for scoping-level engineering studies.

INTRODUCTION: As part of regional sediment management, dredged sediment is commonly placed in the nearshore for beneficial use. A simple web application has been created that can rapidly produce a preliminary assessment of sediment mobility at prospective nearshore placement sites. This web application is ideal for preliminary or reconnaissance engineering studies to evaluate the potential mobility of sediment grain sizes and volumes placed in the nearshore and for comparison between multiple placement sites. This user's guide is intended to describe the function and steps to use the web application. Currently, the web application can be found on the Navigation Portal (<http://navigation.usace.army.mil>) under the Sediment & Ecosystem Management tab. Additional details about the sediment mobility calculations are detailed in the Coastal and Hydraulics Engineering Technical Note (CHETN) *Evaluating Sediment Mobility for Siting Nearshore Berms* by McFall et al. (2016), and the depth of closure calculations are detailed in the CHETN *Calculating Depth of Closure Using WIS Hindcast Data* by Brutsché et al. (2016).

WEB APPLICATION INPUT: The web application is intended to be an intuitive interface to apply the SMT and to easily view a calculated depth of closure for the entire U.S. coastline. A screenshot of the web application is shown in Figure 1.

To evaluate a potential nearshore placement site, the SMT transforms offshore wave hindcast data from the nearest Wave Information Study station (WIS) (Hubertz 1992) to the nearshore placement site and calculates the depth of closure, frequency with which placed sediment will be mobilized, cross-shore sediment migration direction, and axis of wave-dominated sediment transport. The SMT web application calculates these items by prompting the user with the following steps:

Step 1. Zoom-in to the nearshore study site.

Step 2. Draw the approximate orientation of the shoreline in front of the nearshore study site as shown in Figure 2. The shoreline should be a single line segment, and the second point has to be double-clicked by the user.

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Figure 1. View of the SMT web application. The dots along the coastline represent the calculated depth of closure, with red, yellow, and green indicating shallower to deeper depths, respectively. The color of the dots provides an intuitive method to quickly assess the depth of closure for specific locations relative to the entire U.S. coastline. The depth of closure values calculated for individual years can be viewed using the layers button in the top right-hand corner of the map.

Figure 2. The shoreline near the nearshore study site is drawn by the user.

Step 3. Select the approximate nearshore study site to investigate. This can be done by selecting the place on the map or by inserting the latitude and longitude coordinates (Figure 3). The approximate study site location is needed to locate the closest WIS station and calculate the shoreline angle.

Figure 3. The user-input parameters in the web application.

Step 4. Click the “Find WIS/Calculate Angle” button. This will initiate the query to locate the closest WIS station for wave conditions and calculate the shoreline angle. This step generally takes less than a minute.

Step 5. Input the required parameters for the proposed nearshore placement. The user must input the median grain size of the dredged material (d_{50}), nearshore placement depth, longshore current 1 meter (~3 feet) above the bed, water temperature, and salinity. The nearshore placement depth is local water depth prior to sediment placement. The placement depth, current, and temperature can be toggled between metric and imperial units.

Step 6. Click the “Submit” button. After approximately 2 minutes, a results table will appear with tabs to display the wave characteristics, depth of closure, sediment mobility, cross-shore migration direction, and wave rose at the nearshore study site (Figures 4–8). These results can be easily changed between metric and imperial units using the button at the top of the results table.

Figure 4. The wave characteristics at the investigated nearshore study site.

Figure 5. The calculated DoC using several empirical equations.

Figure 6. Histograms of the calculated maximum (a) bed shear stress and (b) near-bottom velocity. The critical thresholds for the respective median grain sizes are noted with the vertical dashed lines. N is the number of waves during the 10-year period in each bin.

Figure 7. Cross-shore sediment migration direction using the method described by Larson and Kraus (1992).

Figure 8. Wave rose at the nearshore study site showing wave direction and zero-moment wave height, H_{m0} .

RESULTS

Wave Characteristics. The web application downloads the WIS wave conditions from the WIS server and transforms the waves to the nearshore study site. The waves are transformed using the conservation of energy flux and Snell's Law. The commonly used wave characteristics are displayed in a table as shown in Figure 4. These wave characteristics include the average zero-moment wave height, H_{m0} , effective wave height, H_e , the largest 10% of the zero-moment wave heights, $H_{0.1}$, standard deviation of the zero-moment wave height, σ , peak wave period, T_p , and effective wave period, T_e .

Depth of Closure. The next tab on the results table is the depth of closure (DoC), which summarize the DoC calculated using five different methods. The different methods provide the user with a range of DoC values. The real-time calculation using the SMT allows the user to determine the DoC with the most up-to-date information from the WIS, as compared to the static layers that are also available on the tool. According to Hallermeier (1978, 1981b), the DoC has both an inner and outer limit. The inner limit marks the seaward extent of the littoral zone (h_l) where the bed experiences extreme activity caused by waves breaking and their related currents. The outer limit (h_o) denotes the limit of the shoal zone where waves will cause little sediment transport (Hallermeier 1981b). The inner limit is appropriate for shoreline response and beach nourishment projects (Dean 2002). The DoC is calculated with the entire time span of wave hindcast data downloaded from the WIS station. The “Hallermeier Inner” DoC is calculated using the equation given by Hallermeier (1978) as

$$h_l = 2.28H_e - 68.5\left(\frac{H_e^2}{gT_e^2}\right) \quad (1)$$

where H_e is the effective wave height, or wave conditions that exceeded only 12 hours out of a single year (or the top 0.137% of waves in a year), T_e is the associated wave period, and g is the gravitational constant. The “Hallermeier Inner Simplified” DoC is calculated as

$$h_l = 2\bar{H}_s + 11\sigma_s \quad (2)$$

where $\bar{H}_s$ is the annual mean significant wave height and σ_s is the associated standard deviation of the significant wave height. The “Hallermeier Outer” DoC is calculated as

$$h_o = (\bar{H}_s - 0.3\sigma_s) \bar{T}_s \left(\frac{g}{5000d}\right)^{0.5} \quad (3)$$

where $\bar{T}_s$ is the average period associated with average significant wave height and d_{50} is the median sediment grain size.

Birkemeier (1985) evaluated Hallermeier’s relationship for the inner depth of closure using bathymetric surveys from the U.S. Army Corps of Engineers (USACE) Field Research Facility in Duck, NC. The “Birkemeier” DoC is calculated as

$$h_l = 1.75H_e - 57.9\left(\frac{H_e^2}{gT_e^2}\right) \quad (4)$$

and the “Birkemeier Simplified” DoC is calculated as

$$h_l = 1.57H_e \quad (5)$$

Results from each of these equations are displayed in the results table as shown in Figure 5. Brutsché et al. (2016) provide additional details about the depth of closure calculations.

Mobility – τ and u . Two methods are used to estimate the sediment mobility. The first method analyzes the bed shear stress using linear wave theory, and the second method analyzes the near-bottom velocity using nonlinear stream function wave theory, which generally produces larger velocities than linear wave theory. Both methods are applied to 10 years (1/1/1990–1/1/2000) of WIS wave hindcast data. Additional details about these two methods are described by McFall et al. (2016).

The first method uses the critical shear stress estimated from Shields diagram following a procedure given by Soulsby (1997), and Soulsby and Whitehouse (1997) as

$$\tau_{cr} = \theta_{cr} g (\rho_s - \rho) d_{50} \quad (6)$$

where τ_{cr} is the critical shear stress, θ_{cr} is the Shields parameter, ρ_s is the sediment density, and ρ is the water density. The critical shear stress is the threshold stress for which the sediment can be expected to be dislodged from the seabed for all greater shear stresses.

The bottom shear stress is calculated using a method described by Soulsby (1997) for currents and waves. Form shear stress, in which the shape of bedform features causes shear stress, is not included in the calculations. The maximum shear stress, τ_{max} , from the waves and currents is calculated as

$$\tau_m = \tau_c \left[1 + 1.2 \left(\frac{\tau_w}{\tau_c + \tau_w} \right)^{3.2} \right] \quad (7)$$

and

$$\tau_{max} = [(\tau_m + \tau_w \cos \phi)^2 + (\tau_w \sin \phi)^2]^{1/2} \quad (8)$$

where τ_m is the mean bed shear stress, τ_c is the current-induced shear stress, τ_w is the wave-induced shear stress, and ϕ is the angle between the wave and current directions. The legend in Figure 6(a) shows the median grain size, critical shear stress τ_{cr} , frequency of mobility during the 10-year period, f_M , and mean mobility score which is given as

$$M = \left(\frac{\tau_{max} - \tau_{cr}}{\tau_{cr}} \right) \quad (9)$$

The frequency of mobility and mean mobility score apply to the specified median grain size diameter. Sediments with smaller grain size diameters will be mobilized more frequently. The mean mobility score allows the user another way to analyze the predictive sediment mobility by quickly assessing how much the maximum bottom stress exceeds the critical stress on average and can be particularly useful when comparing sites with similar frequencies of mobility. The mean mobility score can be negative in sites where the average maximum bottom stress is less than the critical bottom stress. Sites with mobility scores less than 1 should generally experience little mobility.

By calculating the sediment mobility using a second method, a range of predicted mobility is provided. The critical near-bottom velocity, u_{cr} , as given by Ahrens and Hands (1998), is based on research by Hallermeier (1980) and Komar and Miller (1974) and is given as

$$u_{cr} = \sqrt{8 g \gamma d_{50}} \quad \text{for } d_{50} \leq 2.0 \text{ mm} \quad (10)$$

and

$$u_{cr} = [0.46 \gamma g T^{1/4} (\pi d_{50})^{3/4}]^{4/7} \quad \text{for } d_{50} > 2.0 \text{ mm} \quad (11)$$

where T is the wave period and γ is defined as $\gamma = (\rho_s - \rho)/\rho$. Ahrens and Hands (1998) used Dean's (1974) stream function wave theory table (SFWT) to derive the following equations for the near-bottom wave induced velocity based on stream function wave theory for the wave crest, $u_{\max crest}$, and trough, $u_{\max trough}$, as

$$u_{\max crest} = \left(\frac{H}{T}\right) \left(\frac{h}{L_0}\right)^{-0.579} \exp \left[0.289 - 0.491 \left(\frac{H}{h}\right) - 2.97 \left(\frac{h}{L_0}\right) \right] \quad (12)$$

and

$$u_{\max trough} = -\left(\frac{H}{T}\right) \exp \left[1.966 - 6.70 \left(\frac{h}{L_0}\right) - 1.73 \left(\frac{H}{h}\right) + 5.58 \left(\frac{h}{L_0}\right) \right] \quad (13)$$

where h is the water depth, H is the wave height in the placement site, and L_0 is the offshore wave length given by $L_0 = (g T^2)/2\pi$. The maximum near-bottom velocity was taken as $u_{\max} = \max(|u_{\max crest}|, |u_{\max trough}|)$. The mean mobility score, M_u using the near-bottom velocity is calculated as

$$M_u = \left(\frac{u_{\max} - u_{cr}}{u_{cr}} \right) \quad (14)$$

Histograms using both methods to estimate the sediment mobility are shown in Figure 6. The critical threshold to initiate sediment movement for the different median grain sizes is noted with the colored vertical dashed lines. Waves to the right of the colored dashed lines are large enough to mobilize the sediment. For this example, the median grain size of 0.26 millimeters (mm) is estimated to be mobilized by 58% to 88% of the waves. Finer sediments are expected to be mobilized more frequently than coarser sediment, as expected.

Cross-shore Sediment Migration. To predict the cross-shore sediment migration of nearshore berms constructed of dredged sediment, Larson and Kraus (1992) hypothesized that nearshore berm behavior should be similar to natural sand bars and studied the onshore and offshore migration of the offshore bar in Duck, NC, from 1981 to 1989. The dimensionless Dean number is generally used to determine bar migration and is given as

$$D = \frac{H_0}{\omega T} \quad (15)$$

where H_0 is the offshore wave height, ω is the sediment fall speed, and T is the wave period. Dean number, D , values greater than 7.2 were found to induce erosive, offshore bar migration, and values less than 7.2 resulted in accretionary, onshore bar migration. The sediment fall speed is dependent on the grain size diameter and was calculated with the equations derived by Hallermeier (1981a). The Dean number is calculated for each wave record, and the predicted sediment migration results for several grain sizes, including the user-defined d_{50} of 0.26 mm, are shown in Figure 7. The predicted cross-shore migration directions for a range of grain sizes are shown for the user to have an improved understanding of the expected cross-shore sediment sorting. Finer sediments tend to be transported offshore, and coarser sediments tend to migrate onshore.

Wave Rose. A wave rose is used to estimate the wave-dominated axis of onshore and offshore sediment migration. The wave rose shows the transformed wave conditions in the nearshore study site and is shown in Figure 8.

Report. A report can be easily generated to document the input parameters and results from the web application by clicking the “Print Report” button. A multipage report is generated with a description of the tool, map of the area applied, input parameters, and the results. This report can be used to document different runs of the SMT to easily compare potential nearshore placement sites. The first page of the five-page report is shown in Figure 9.

Figure 9. First page of the SMT web application report.

SUMMARY: The SMT web application allows users to quickly assess sediment mobility at a nearshore site. This web application uses readily available WIS data to calculate the wave characteristics, depth of closure, sediment mobility, cross-shore sediment migration direction, and axis of wave-dominated sediment transport at the nearshore study site. This tool is intended to be used for placement of non-cohesive sediment on straight, open coast lines and not to be used near inlets, in estuaries, or on the lee side of barrier islands. This scoping level tool can be used in large projects as a preliminary step to narrow the number of nearshore placement site choices for further evaluation. For smaller projects that do not warrant an in-depth study, this tool can aid in gaining knowledge that will help to address stakeholders' and resource agencies' concerns.

FUTURE DEVELOPMENT: The web application can be extended to include the storm wave conditions from the Coastal Hazards System (CHS) which contains storm wave and current conditions from the North Atlantic Coast Comprehensive Study (NACCS) (Cialone et al. 2015; Nadal-Caraballo et al. 2015; USACE 2015). CHS is a coastal storm hazard data storage and mining system that stores the NACCS comprehensive, high-fidelity storm response computer modeling results from 1,050 synthetic tropical storms that can be added to the web application as a static layer to improve the understanding of sediment mobility under storm wave conditions.

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