Development of High-Resolution Sediment Grain Size and Non-Cohesive Sediment Erodibility Maps for the Lower Severn River

Midshipman 1/C Kellyanne M. Hurst and Midshipman 1/C Emily G. Ranzau, USN, Class of 2018

Advisor(s): Dr. Joseph P. Smith, Instructor Andrew Keppel, Mr. Luis Rodriguez, and Instructor Alex Davies

Abstract

Previous research by *Darragh (2016)* used sidescan sonar survey data and grain size analysis of sediment samples collected in December 2015 to develop a high-resolution sediment grain-size distribution map of the lower Severn River, MD. This study builds upon this work and incorporates more precise sediment size analysis and data from additional sediment samples. A multiple linear regression model was applied to predict backscatter amplitude as a function of grain size and a proxy for bottom roughness. The model was used to estimate sediment grain size from sidescan survey data and generate a more accurate, high-resolution sediment grain-size distribution map of the lower Severn River. Acoustic Doppler Current Profiler (ADCP) measurements were collected from the Severn to investigate the potential for the current field to initiate motion of bottom sediments. Areas where the maximum estimated shear velocity at the bottom exceeded a grain-size specific critical value for the initiation of motion for non-cohesive sediment were displayed as a first-order erodibility map for the lower Severn River. The approach demonstrated in this study may have applicability in other low-energy coastal systems.

Study Area and Methods

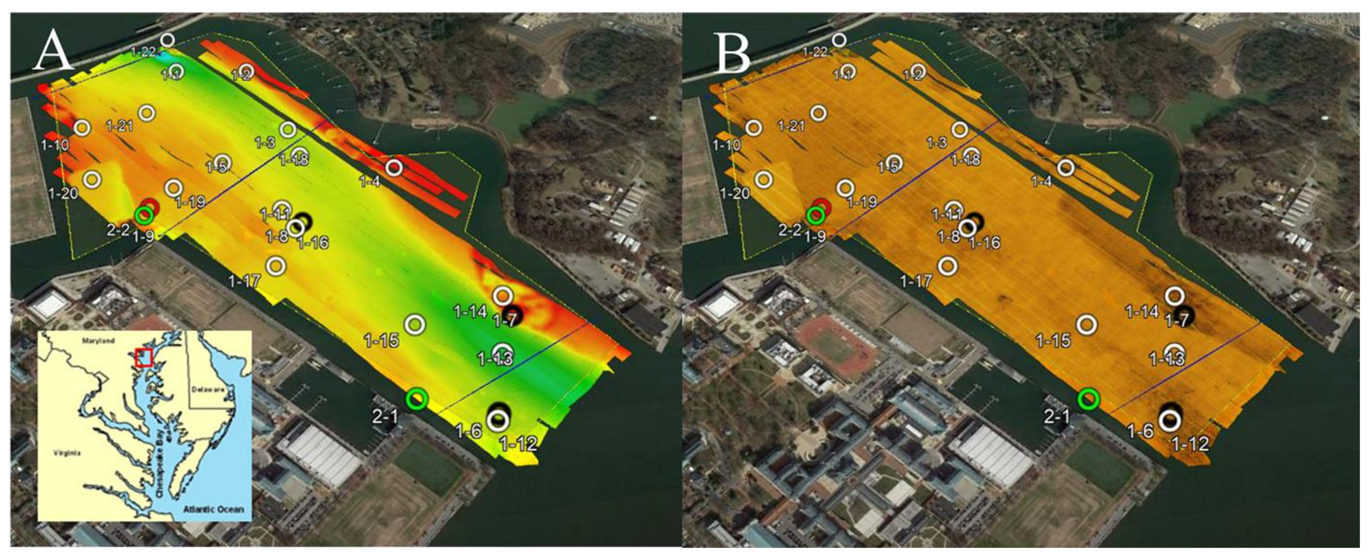

Figure 1. View of the lower Severn River showing locations for sediment collection (2015 white circles; 2018 green circles; black circles not used) and 2018 ADCP transects (blue lines) over (**A**) bathymetry and (**B**) backscatter amplitude collected by an EdgeTech 6205 Swath Bathymetry and Sidescan Sonar system from the R/V *Daiber* (University of Delaware) on 02 December 2015 (modified from *Darragh, 2016*).

Sidescan sonar backscatter amplitude and bathymetry data collected using an EdgeTech 6205 Swath Bathymetry and (multi-phase) Sidescan Sonar system from the *R/V Daiber* (University of Delaware) during a survey on the lower Severn River on 02 December 2015 was re-analyzed in this study (**Fig. 1**). Sediment grab samples collected from 18 sites in 2015 and 2 additional sites on 05 March 2018 were analyzed for grain size (6 size classes) using dry mechanical sieving (**Fig. 2A**; USGS, *Poppe et al., 2000*). Particle size data from a CILAS Laser Particle Size Analyzer (Reed, A., U.S. Naval Research Laboratory-Stennis Space Center) was used to better define the particle size spectra for the 2015 samples. Geo-referenced backscatter amplitude values from the 2015 survey were averaged and the standard deviation of the depth was estimated as a proxy for bottom roughness over a 10 m^2 area corresponding to the area of uncertainty for sediment collection. On 05 March 2018, three Teledyne RiverRay ADCP transects were performed to measure the current field in the lower Severn River (**Fig. 2A**).

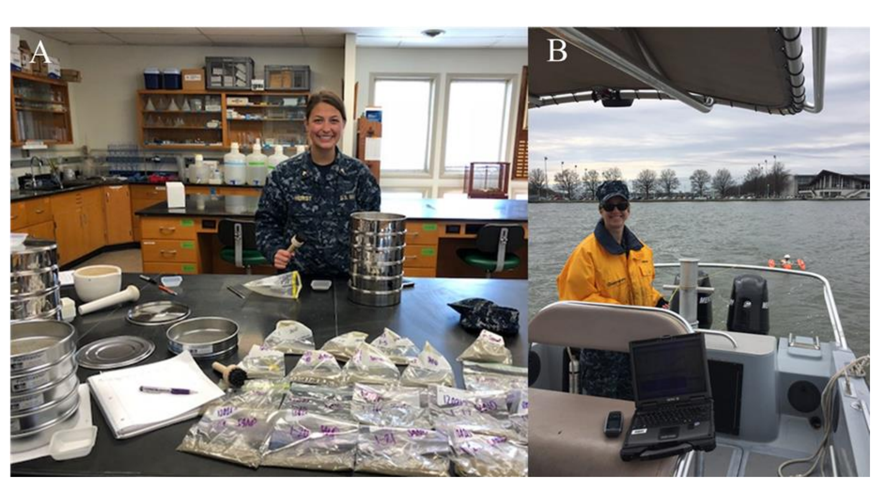

Figure 2. (**A**) MIDN 1/C Hurst in Hendrix Oceanography Lab using sediment sieves to perform grain size analysis on sediment samples and (**B**) MIDN 1/C Ranzau on the lower Severn River towing the River Ray ACDP.

Results

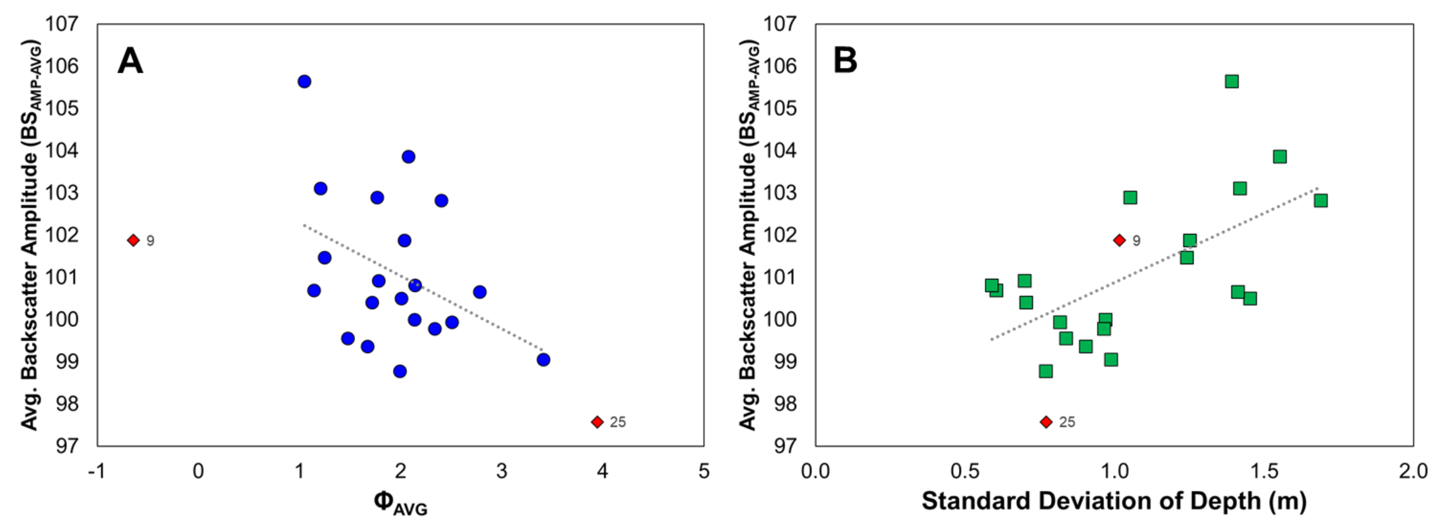

Figure 3. Averaged backscatter amplitude (BS$_{AMP-AVG}$) plotted as a function of: (**A**) measured average phi (ϕ_{AVG}) values in sediment samples and (**B**) the standard deviation of depth (m) over a 10 m^2 area (STDEV$_{DEPTH}$). The dashed line indicates the linear regression fit to the data. Note: sample 9 was omitted due to a gravel fraction of >75% by weight and 25 was omitted because of an error in recording sampling location.

Figure 3 A and **B** show averaged backscatter amplitude (BS$_{AMP-AVG}$) over a 10 m^2 area plotted as a function of measured average phi (ϕ_{AVG}) values ($\phi = -\log_2(d_{50}$ in mm); d_{50} is median particle diameter) in sediment samples and the standard deviation of depth (m) over the 10 m^2 area (STDEV$_{DEPTH}$). Previous research by others (*Collier and Brown, 2005*) has shown that backscatter amplitude is largely a function of bottom type and roughness. The STDEV$_{DEPTH}$ was estimated as a proxy for bottom roughness. There was no clear simple linear relationship between BS$_{AMP-AVG}$ and ϕ_{AVG} or STDEV$_{DEPTH}$. A multiple linear regression was applied (MS Excel) to predict BS$_{AMP-AVG}$ as a function of ϕ_{AVG} and STDEV$_{DEPTH}$. This assumes that ϕ_{AVG} and STDEV$_{DEPTH}$ are independent variables which can be problematic. But for low-energy systems with low sediment supply like the Severn River, this assumption may be valid. Results of the multiple linear regression model fit are shown below:

$$BS_{AMP-AVG} = -1.382 \times \Phi_{AVG} + 3.443 \times STDEV_{DEPTH} + 100.116$$

$$P-Value_{BS_{AMP-AVG}} = 0.009$$
$$P-Value_{STDEV_{DEPTH}} < 0.001$$
$$P-Value_{Intercept} < 0.001$$

The P-values for the multiple linear regression fit to BS$_{AMP-AVG}$ as a function of ϕ_{AVG} and STDEV$_{DEPTH}$ suggest a highly significant fit for the model. This modeled relationship was used to re-analyze the 2015 survey data (MATLAB R2017a) to relate measured BS$_{AMP-AVG}$ and STDEV$_{DEPTH}$ to ϕ, enabling the development of an updated, high-resolution contour map for sediment grain size. **Figure 4A** shows the sediment grain size map developed by *Darragh (2016)* and the map created in this study (**Fig. 4B**). The map developed in this study better represents the distribution of sandy silts found in the lower Severn River but still slightly overestimates grain size.

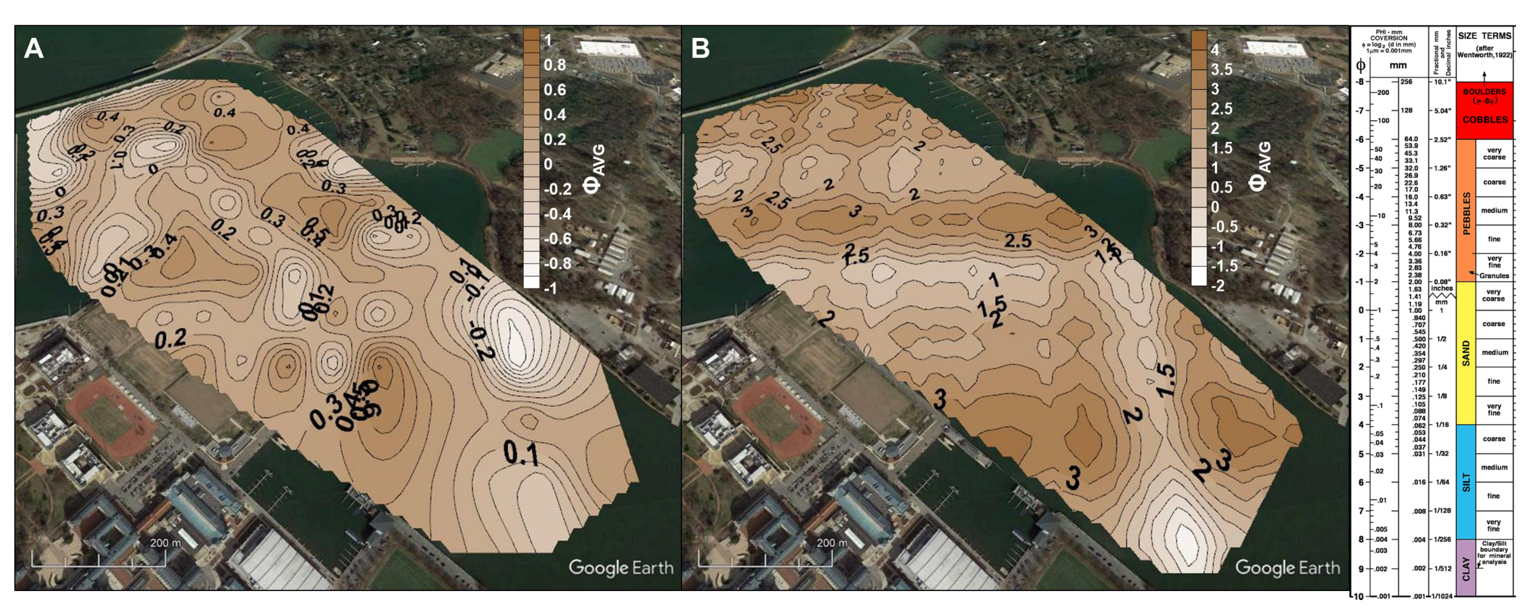

Figure 4. High-resolution contour maps of grain size (ϕ) developed by: (**A**) the simple linear regression model fit of BS$_{AMP-AVG}$ as a function of ϕ_{AVG} used by *Darragh (2016)* and (**B**) a multiple linear regression fit to BS$_{AMP-AVG}$ as a function of ϕ_{AVG} and STDEV$_{DEPTH}$ used in this study. Note: the Udden-Wentworth Scale (USGS) is shown to the right of the figures as a reference.

Discussion

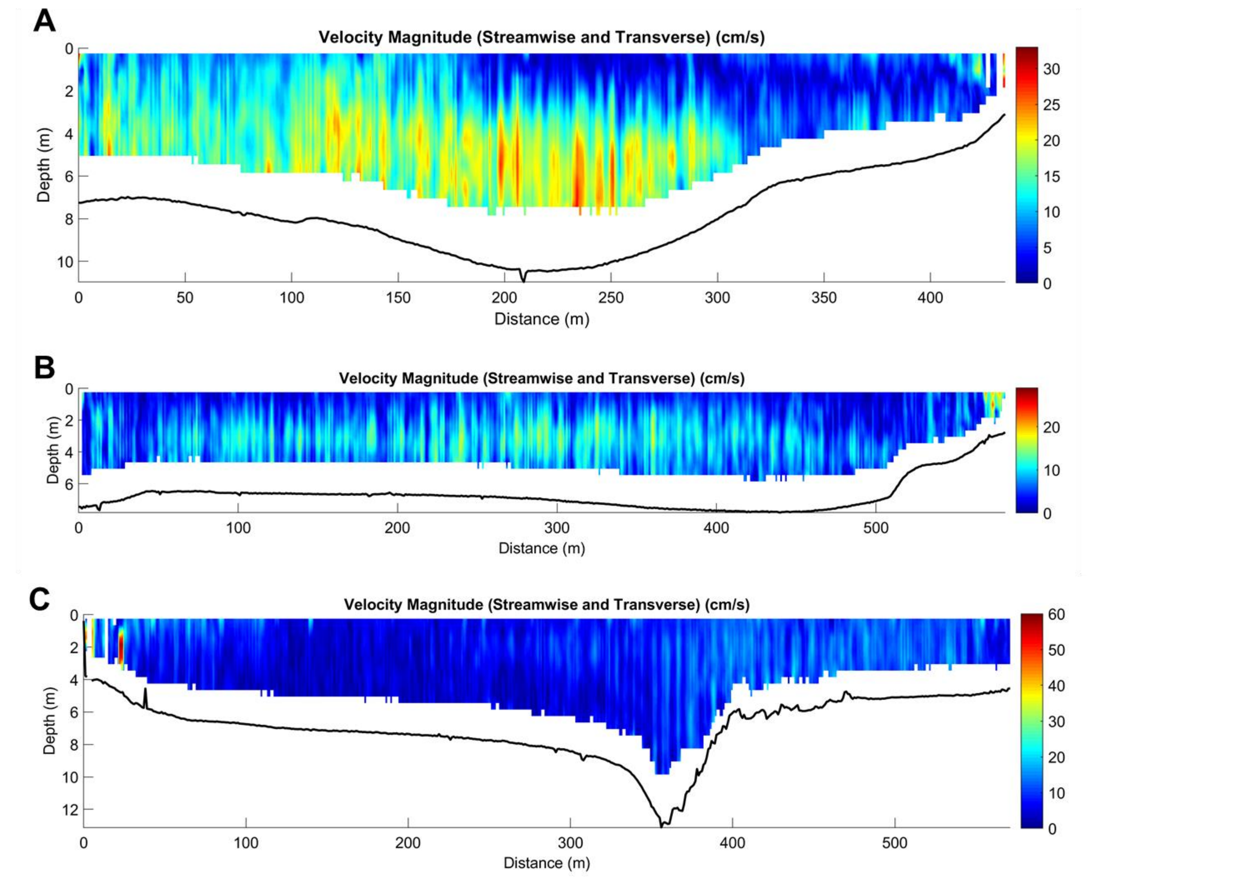

Figure 5. Streamwise and transverse velocity magnitude (cm/s) measured by the RiverRay ADCP on 05 March 2018 in the: (**A**) easternmost transect near the mouth of the Severn River; (**B**) middle transect, and; (**C**) westernmost transect near the U.S. Naval Academy (USNA) Bridge. Note differences in scale for each transect. Cross channel contours were processed using USGS Velocity Mapping Toolbox v4.08.

RiverRay ADCP transects of the lower Severn River on 05 March 2018 showed variability in cross channel and along channel velocities with maximum current velocities of ~0.20 cm/s (**Fig. 5 A-C**). The lower Severn River is a tidal tributary and measurements were made over a 2-3 hour period around low tide. The currents shown are only a representative snapshot of the current field of the lower Severn River. A linear fit to a ~20 cm/s average current velocity profile v. ln(z), where z = depth in m above the bottom in the lowest 50% of the water column referenced to the bottom, was used to provide a crude estimate of the shear velocity at the bottom (*Petrie et al., 2010*). This value was then used to evaluate locations in the lower Severn River where the threshold for the initiation of motion of non-cohesive sediment grains of size ϕ was exceeded (**Fig. 6A**). The resultant sediment erodibility map for 05 March 2018 during the time of data collection is shown in **Figure 6B**.

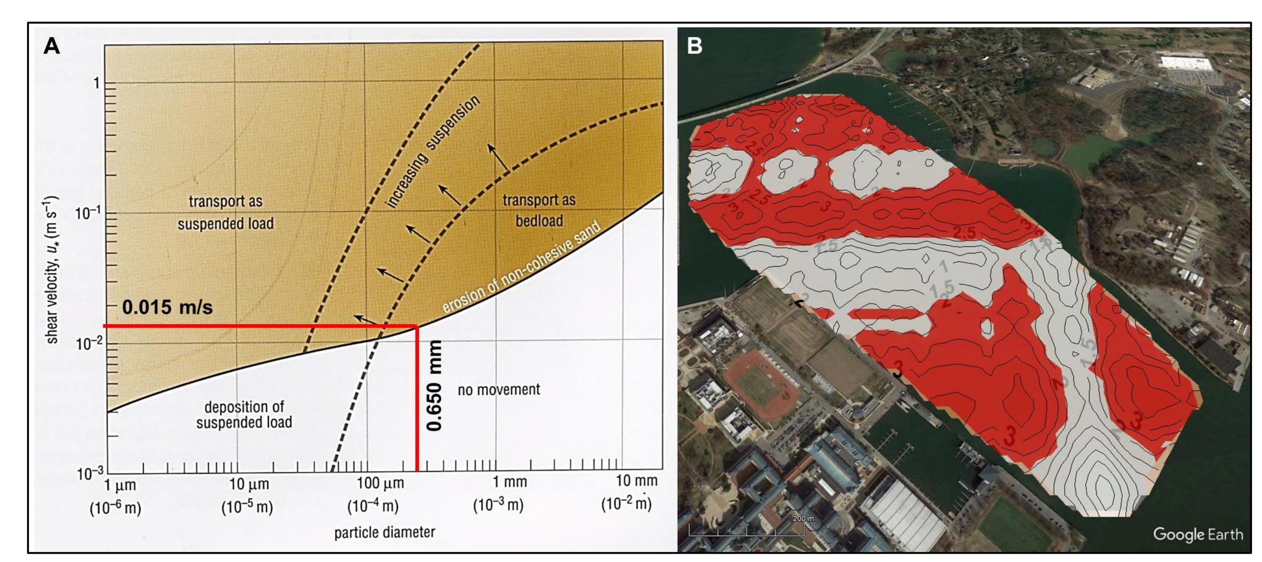

Figure 6. (**A**) An empirically-derived relationship between shear velocity and the threshold for sediment motion (*Open University Team, 2008*) and (**B**) a high-resolution, first-order sediment erodibility map of the lower Severn River for 05 March 2018.

Conclusions

- ***Sidescan sonar and bathymetry data can be used with grain size measurements in sediment samples to develop high-resolution grain size maps in low-energy coastal areas like the lower Severn River***
- ***Current measurements can be used with high-resolution grain size distribution maps to estimate erodibility of non-cohesive sediments***
- ***Future research should include cohesion and evaluate this approach under different forcing conditions in other low-energy coastal systems***

Acknowledgements*: Many thanks to Dr. Art Trembanis, Chief Scientist Ken Haulsee, and the science crew and Captain of the R/V Joanne Daiber (University of Delaware). Also special thanks to CDR William Swick (USN) for his help with USGS VMT v.4.08.*