Beneficial use of dredged material requires careful coordination between dredging, transportation, treatment, and placement operations. This complex choreography can be costly and without federal match funding, state sponsored dredging projects are increasingly at risk. Small, but significant projects to maintain navigation channels for secondary ports and/or recreational waterways often feel this pinch acutely. In Maryland, the Department of Natural Resources (DNR) is responsible for these types of projects. Like other underfunded state agencies, they do not have the resources to implement all of the dredging projects under their purview. Federal funding is typically allocated for projects that maintain the Baltimore Harbor and Chesapeake Bay approach channels, which support maritime commerce at the Port of Baltimore. As such, in an effort to find cost savings, DNR is exploring opportunities to align their dredging and restoration projects. This abstract presents the methods and outcomes of the geospatial model and suitability analysis that DNR commissioned for two high priority focus areas in the Chesapeake Bay region. The model and analysis utilize a compound index system to assign weights to dredging and beneficial use parameter including geomorphology, cost, environmental services, and climate adaptation services. Each of these parameters is tailored to specific agency priorities and policies, which are assigned flexibly and can be modified as regulations and legislation change. Model and analysis outputs are thus qualitative and quantitative reflecting the physical and political parameters of a given project. The integrated approach to cost savings presented here through combined dredging and restoration efforts may offer precedents for other state agencies and operators interested in planning and evaluating cost savings opportunities in their own dredging and restoration programs.

**Keywords:** GIS modeling, dredged sediment, beneficial use suitability, Chesapeake Bay, landscape architecture

**INTRODUCTION**

This paper presents the results of a geospatial information system (GIS) suitability analysis tool developed to identify and prioritize locations for beneficial use of sediment in two areas of the Chesapeake Bay. The tool was developed for the Maryland Department of Natural Resources (DNR) who oversees small scale dredging projects in the Bay for the state of Maryland. These projects face constant funding and permitting constraints and are typically situated in coastal communities that not only rely on navigation channels but also face challenges stemming from wetlands loss, nuisance and catastrophic flooding stemming from subsidence, sea level rise, and climate change. All of these problems are defined in part by sediment. Often in Bay communities it is simply a critical resource out of place. This suggests that a better spatial understanding of the problem may provide a useful way to synthesize the policies and the best available science to produce better outcomes in accordance with local values and needs.

The tool adapts concepts from established technical and conceptual approaches from landscape architecture, engineering, and coastal science and planning including regional sediment management, suitability analysis, and earlier tools created by the state of Maryland such as the Maryland Coastal Risk Assessment, habitat for critical species, and shoreline inventory data. These elements are spatialized and related using methods explained below in order to provide information useful for localizing dredging projects. Often the spatial distance and time considerations (spawning seasons versus navigation needs, for instance) is a significant barrier to regional sediment management and beneficial reuse projects. This tool will provide some help with that, at least in the spatial dimension.

Environmental, infrastructural, social, and dredging inputs are weighted as parameters that can be adjusted based on priorities or values that may emerge through other avenues, such as through discussion with communities, budget

---

1 Partner and Research Director, Mahan Rykiel Associates, 3300 Clipper Mill Road, Suite 200, Baltimore, Maryland 21211, (410) 235.6001, ihametz@mahahrykiel.com

2 Assistant Professor, Cornell University Department of Landscape Architecture, 440 Kennedy Hall, Ithaca, NY 14853, brd63@cornell.edu.
considerations, or political priorities. The model then does not presume to give any answers, but to provide values-driven analysis that can compliment other critical factors for beneficial reuse and dredging projects including local knowledge and political will. We present these preliminary results and the methodology for discussion among the professional and academic community. In the future, if the tool works it will suggest zones, areas of focus, to consider for beneficial use projects based on four predetermined values: landform, dredge proximity, beneficial use, and coastal risk (explained in greater detail below).

These highlighted areas might then be used as a kind of analytical point of departure to considering actual projects as one layer in a decision-making process that includes local knowledge and political will as well as specific geotechnical and field measures as the range of sites is further narrowed. If this seems too modest a hope, then keep in mind that it is a significant step from having to try and make sense of the myriad existing and competing tools according to a given priority set, or having to survey the 6,945 miles of Bay coast in Maryland in person.

**Regional Sediment Management**

Regional sediment management (RSM) remains an ongoing effort put forward by the USACE to take a systems approach to best management practices to produce more efficient and effective use of sediments in coastal, estuarine, and inland environments.

**Origins**

Begun in 2000, the program currently claims participation of 29 districts, the Engineer Research and Development Center, the Institute for Water Resources, and the Hydraulic Engineering Center. In a basic way the RSM program has aimed to link dredge navigation projects to beneficial reuse projects based on the simple but important observation that sediment is a resource.

**Problems and successes**

It remains common to have navigational projects producing dredged material that has to be permitted and disposed of in the same area that a different dredging project is producing material for beach nourishment, wetlands creation, or infrastructure purposes. The RSM program sought to close this gap which originated in part from difficulties in timing characteristics. Navigation channels need to be dredged on time for commerce but sediment for nourishment and habitat creation often have specific windows. Other typical complications include differences in funding streams and jurisdictional communication, difference in sediment characteristics, and volumes of material in specific projects.

Nonetheless, significant successes have been achieved across a range of scales and project types and while the order of magnitude remains small, this is perhaps more related to the limits of beneficial use efforts rather than the concept itself. In addition several important projects have been implemented by the Baltimore District, including some in the Chesapeake Bay that demonstrate the potential of the approach. This concept seems even more promising at the state scale. These projects tend to be small in volume and with little funding but with fewer complications related to state jurisdictions and the potential for easier communication among agencies.

In Maryland, both the US Army Corp of Engineers (USACE) and the Maryland Department of Natural Resources (MDNR) oversee dredging operations. USACE projects are larger in scale and geographically concentrated around major port infrastructure. Sediment from these dredging projects is primarily placed in centralized containment facilities called Dredged Material Containment Facilities (DMCF’s). MDNR projects on the other hand, are smaller in scale and are geographically distributed across the state. The pattern of decentralized dredging that typifies MDNR’s program suggests that financial and environmental benefits may be achieved by better aligning the agencies dredging, placement, and restoration projects through the beneficial use of dredge material.

---


The distribution of MDNR dredging operations varies considerably across counties in Maryland. In more densely populated areas like Baltimore and Anne Arundel counties MDNR is responsible for approximately 50 dredging programs. In less heavily populated areas like Somerset County, MDNR only oversees 1 dredging project.

**Suitability Analysis**

Suitability analysis using GIS is an analysis to determine the suitability of a particular area to meet the needs of or in accordance with the values of users or stakeholders. The practice grew out ecological inventory methods pioneered in the 1960s by the landscape architect Ian McHarg and has been applied to a wide variety of land based questions related to things such as crop production, urban development, habitat restoration or conservation, and infrastructure. It has not been commonly applied in a systematic way to beneficial use projects but it offers a promising extension of conventional methods due to its ability to parameterize landscape values and quickly synthesize and weight large datasets that take into account many of the complex issues that define coastal landscapes. While comprehensive and analytical, the quantification of landscape values can exclude critical characteristics, such as those whose operational scale is below the fidelity of the model, as well as qualities, due to their unquantifiable nature. In part because this it is important to note that this tool cannot replace other forms of local knowledge, expert judgement, and political will but augments them with analysis.

The analysis is a multi-parameter geospatial framework that includes primary parameters which are weighted and adjustable (Figure 1). These parameters were mutually identified by the project team and MDNR to maximize the financial, environmental, and social benefits of aligning dredging with beneficial use. The model parameters are Landform, Dredge Proximity, Beneficial Use, and Coastal Risk. The parameters were conceived as adjustable with the understanding that on any given project or during a certain year or administration particular priorities might be emphasized or certain project types might be more possible. The weighted nature of the parameters allows for this to be accounted for in a basic way. Nested within each of these parameters are datasets and assessment tools that were identified as important by MDNR and the project team. Care was taken to make sure that datasets were properly revalued or reclassified when necessary so that they could relate to one another, and to make sure that data was utilized in multiple parameters only when appropriate.

---


777 Elevation data, for instance, is prevalent in the parameters and had to be accounted for so that it could inform parameters without being counted unduly.
CHESAPEAKE BAY BENEFICIAL USE SUITABILITY MODEL

The Beneficial Use Suitability Model was prepared by Mahan Rykiel Associates (MRA) in collaboration with Professor Brian Davis of Cornell University & the Dredge Research Collaborative (hereafter ‘the Team’) to assist the Maryland Department of Natural Resources (MDNR) in aligning their dredging and restoration projects for environmental and economic benefits. MDNR goals for the study included modeling and identifying potential beneficial use project sites to populate their ‘Beneficial Use: Identifying Locations for Dredge (BUILD)’ mapping tool and developing preliminary design strategies for beneficial use project opportunities.

The sites and strategies that were documented propose uses for dredged material authorized by The Dredged Material Management Act of 2001 and Maryland Department of the Environment (MDE) Innovative Reuse and Beneficial Use of Dredged Material Guidance Document (2017). These sites and strategies also recognize dredged material as a resource with significant potential; a position reinforced by the 2017 Waste Reduction/Resource Recovery Plan Executive Order (01.01.2017.13), which states “Whereas, Through source reduction, reuse, and recycling, Maryland can extend existing disposal capacity, reduce the need to construct new or expanded solid waste disposal facilities, conserve natural resources, including water and energy, increase the innovative reuse and beneficial use of dredged material, and support a productive economy through recovery of valuable resources.”

In the research the team collaborated closely with MDNR to identify sites and design strategies intended to beneficially use dredged material in ways that provide co-benefits (economic, environmental, and social) to the State and its citizens. Design strategies were developed and categorized along a continuum from natural/nature-based techniques to structural techniques and then organized according to common shoreline typologies including beaches, marsh/wetlands, and open water. The feasibility of specific beneficial use project opportunities identified in this report must be evaluated and designed on a case-by-case basis to ensure that they are aligned with the most up-to-date Geotechnical, survey, permit, operations, and stakeholder data.
In addition to documenting project deliverables, this report and the final presentation also serve as interdisciplinary outreach tools for collaboration on beneficial use across public, private, and non-profit sectors. Expository and analytical diagrams, quantitative model outputs, qualitative site analysis, and descriptive text are provided to show the co-benefits of beneficial use projects, as well as to ameliorate public acceptance limitations that currently exist through compelling graphic communication. The MDNR identified two focus areas for the beneficial use suitability model (Figure 2). These areas include Kent Narrows in Queen Anne’s County and the Lower Wicomico River that straddles Wicomico County and Somerset County.

![Figure 2. Context image. The model was set up and run to focus on two specific areas within the Chesapeake Bay as identified by Maryland DNR; Kent Narrows and the Lower Wicomico River.](image)

Kent Narrows

Kent Narrows is a waterway used by marine vessels to travel from the Chester River to the Eastern Bay. It was selected as a focus area by MDNR for this study because of its dredging frequency and its lack of a permanent placement site for dredged sediment. The Kent Narrows focus area is situated in Queen Anne’s County on the eastern shore of the Chesapeake Bay. The navigation channel has a federally authorized depth of 7’ and an authorized width of 75’. According to MDNR records, the channel is typically dredged every 5 years and yields approximately 25,000 cubic yards (CY) of sediment per dredging cycle. It was last dredged in 2007 with an estimated sediment yield of 25,031 cubic yards. Current dredging operations at Kent Narrows are supported by the MDNR Waterways Improvement Fund and the agency has implemented shoreline enhancements that beneficially utilize dredged material at both the Chesapeake Bay Environmental Center and Ferry Point Park.

Model outputs

To identify potential beneficial use opportunity sites in the Kent Narrows area, the team ran the suitability model with different prioritization values for each of the model parameters (e.g. Balanced = Landform 25%, Dredge Proximity 25%, Beneficial Use 25%, and Coastal Risk 25%). MDNR elected to prioritize the final model output according to the following valuation: Landform 10%, Dredge Proximity 35%, Beneficial Use 35%, and Coastal Risk 20% (Figure...
3). Sites with the highest suitability for beneficial use projects are shown in dark green while the lowest suitability sites are shown in dark red (Figure 4).

Figure 3. Model output showing the most suitable possible sites in the Kent Narrows area based on the value parameters identified by Maryland DNR.

Figure 4. Suitability model outputs for the Kent Narrows study area, maximizing for individual parameters and, on the far left, showing the chosen integrated values.

The final suitability model output for Kent Narrows represents a composite analysis of the four weighted suitability parameters. Alternative outputs (i.e. beneficial use opportunity sites) could be generated by adjusting the weighted
value of the parameters. This functionality is built into the model to provide MDNR the flexibility to adjust its priorities for other focus areas or adapt its priorities in response to specific political, social, economic, or environmental circumstances.

**Concept case**

The team developed concept cases to demonstrate how the model might be used to identify promising sites for a range of alternatives. To align beneficial use design strategies with the opportunity sites identified by the suitability model, the team categorized the strategies along a continuum of natural & nature-based to structured. Natural/nature-based strategies primarily utilize sediment and plant material, whereas structured strategies include additional building material like cement, stone, etc. In addition we categorized the strategies according to common coastal landscape conditions. These landscapes include marshes, beaches, and open water sites. Beneficial use design strategies may be applicable to more than one of landscape.

To support implementation of beneficial use design strategies, the team researched successful regional and international precedents (Figure 5). These examples of beneficial use highlight the value of sediment in habitat restoration, coastal resiliency, and public landscapes.

![Figure 5. Strategies for beneficial use for regional conditions.](image)

Using a integrated analysis with weighted values assigned to each of the suitability model’s four parameters (e.g. Landform 10%, Dredge Proximity 35%, Beneficial Use 35%, and Coastal Risk 20%), the team identified three high value opportunity sites within the Kent Narrows focus area. The opportunity sites include Eastern Neck North, Chesapeake Bay Environmental Center, and Crab Alley Neck North. These sites represent landscapes most suitable for beneficial use projects within the focus area.

To confirm the potential value of the Eastern Neck North site identified using the suitability model for beneficial use, the team overlaid the model output pixels onto satellite imagery of the site. This composite drawing synthesizes the quantitative dimensions of the suitability model with the qualitative dimensions of the site’s landscape character. To evaluate specific beneficial use design strategies that might be appropriate for the Eastern Neck North site, the team analyzed its coastal landscapes, adjacent land uses, and accessibility. The Eastern Neck North site’s shoreline includes beaches, breakwaters, and wetlands, while the upland portion of the site includes agricultural land.
Utilizing insight from both the quantitative and qualitative analysis of the Eastern Neck North site, the team identified potential beneficial use design strategies for each of the site’s landscape typologies (Figure 6). Beach strategies include beach nourishment; marsh/wetland strategies include thin layer placement, wetland buffers, and living shorelines; and open water strategies include soft sea wall defenses and confined aquatic disposal (Note: Field studies and detailed site investigations are necessary to confirm appropriate beneficial use strategies and project potential).

![Figure 6. Eastern Neck North beneficial use design strategies and model composite](image)

**Lower Wicomico**

The Lower Wicomico River is part of the federal navigation channel that leads to the Port of Salisbury on the Eastern Shore. It was selected as a focus area by MDNR for this study because of its dredging frequency and its lack of a permanent placement site for dredged sediment. The Lower Wicomico River focus area is situated between Wicomico County and Somerset County on the eastern shore of the Chesapeake Bay. The navigation channel has an authorized depth of 14’ and an authorized width of 150’. According to MDNR records, the channel is typically dredged every 4 years and yields approximately 125,000 cubic yards (CY) of sediment per dredging cycle. It was last dredged in 2013 with an estimated sediment yield of 124,687 cubic yards. Current dredging operations in the Lower Wicomico River are supported by the USACE and in 2014 USACE implemented a marsh restoration project in the Ellis Bay Wildlife Management Area (WMA). Historical photographs suggest that previous placement sites in the Ellis Bay WMA were concentrated on the northern banks of the Lower Wicomico River.

**Model results**

To identify potential beneficial use opportunity sites in the Lower Wicomico River area, the team ran the suitability model with different prioritization values for each of the model parameters (e.g. Balanced = Landform 25%, Dredge Proximity 25%, Beneficial Use 25%, and Coastal Risk 25%). MDNR elected to prioritize the final model output according to the following valuation: Landform 10%, Dredge Proximity 35%, Beneficial Use 35%, and Coastal Risk 20% (Figure 7). Sites with the highest suitability for beneficial use projects are shown in dark green while the lowest suitability sites are shown in dark red.

The final suitability model output for Lower Wicomico River represents a composite analysis of the four weighted suitability parameters. Alternative outputs (i.e. beneficial use opportunity sites) could be generated by adjusting the
weighted value of the parameters (Figure 8). This functionality is built into the model to provide MDNR the flexibility to adjust its priorities for other focus areas or adapt its priorities in response to specific political, social, economic, or environmental circumstances.

![Figure 7. prioritized model results for Lower Wicomoco](image1)

![Figure 8. Suitability map output comparing of model results prioritizing different parameters for Lower Wicomoco](image2)

**Concept case**

Using a integrated analysis with weighted values assigned to each of the suitability model’s four parameters (e.g. Landform 10%, Dredge Proximity 35%, Beneficial Use 35%, and Coastal Risk 20%), the team identified three high
value opportunity sites within the Lower Wicomico River focus area. The opportunity sites include Ellis Bay Wildlife Management Area, Clay Island Creek, and Dames Quarter Creek. These sites represent landscapes most suitable for beneficial use projects within the focus area.

To confirm the potential value of the Ellis Bay Wildlife Management Area site identified using the suitability model for beneficial use, the team overlaid the model output pixels onto satellite imagery of the site (Figure 9). This composite drawing synthesizes the quantitative dimensions of the suitability model with the qualitative dimensions of the site’s landscape character. To evaluate specific beneficial use design strategies that might be appropriate for the Ellis Bay Wildlife Management Area site, the team analyzed its coastal landscapes, adjacent land uses, and accessibility. The Ellis Bay Wildlife Management Area site’s shoreline includes previous dredged material placement sites and wetlands, while the upland portion of the site includes agricultural land.

Utilizing insight from both the quantitative and qualitative analysis of the Ellis Bay Wildlife Management Area site, the team identified potential beneficial use design strategies for each of the site’s landscape typologies. Marsh/wetland strategies include thin layer placement, horizontal levees, and hybrid living shorelines; and open water strategies include artificial reef structures and living breakwaters (Note: Field studies and detailed site investigations are necessary to confirm appropriate beneficial use strategies and project potential).

Figure 9. Ellis Bay Wildlife Management Area beneficial use design strategies and model composite

METHODOLOGY

Overview

The suitability model uses an index system to weight each of the four parameter from 1-10. Weights are aggregated to get the overall suitability index. The index values are visualized through a raster color image from red to green. Red represents low suitability, while green represents high suitability. In the raster output of the model, one pixel represents a data sample cell of 50-feet by 50-feet. The data sample cell size was determined through a combination of workflow efficiency and map accuracy.
GIS toolsets were used to develop the beneficial use suitability mode. The fundamental principles underlying each of the toolsets are represented diagrammatically through a matrix of sample cells. The Overlay toolsets comprise Weighted Overlay and Maximum Overlay tools (Figure 10). The Weighted Overlay tool extracts the original values from two or more sources and calculates the weighted average value for the output. The Maximum Overlay tool compares original values from two or more sources and selects the maximum value for the output.

![Figure 10. Overlay toolset showing the difference in weighted overlay and maximum overlay criteria.](image)

The Euclidean Distance Tool is used to calculate the value of a cell based on its distance from a source. In the beneficial use suitability model, all the cell values are inversely related to their distance itself; meaning the lower the distance from the sample cell to the source, the higher the value it is assigned (Figure 11).

![Figure 11. Beneficial use suitability model methods; the overlay distance tool.](image)

The Overlay Distance Tool is a combined tool used for data which have layered values. It includes both the Euclidean Distance tool and Maximum Overlay Tool. For instance, if two data sources are assigned different point values, the Euclidean Distance tool would be used to calculate the distance value and the Maximum Overlay tool would be used to compare the two distance value matrices and assign the maximum number for the final cell value (Figure 12).
Figure 12. Beneficial use suitability model methods; overlay distance tool showing selection method for maximum value.

**Parameters**

The Landform Parameter assigns the most valuable sites for dredge placement by identifying a shallow area within a five-foot elevation range from sea level. Ten points are assigned to the +/- half-foot interval and decrease by one point for every half-foot interval thereafter. The closer sample cells are to the sea level, the higher points they are assigned. The map visualization indicates both the highest value locations for beneficial use based on elevation, as well as general slope information through the color gradient. The wider color gradient belt illustrates gentle slopes, while the narrow color gradient belt illustrates steep slopes (Figure 13).
The Dredge Proximity Parameter identifies high value placement areas based on their distance from the dredging the channel to potential beneficial use sites. This serves as a stand in for placement and transportation costs, with closer sites being less costly. Values for this parameter are assigned based on the maximum distance of hydraulic dredging vessel without a booster pump (2 miles) and with a single booster pump (up to 4 miles). Within the 2-4 mile range, point values decrease at one mile intervals. Outside of the four-mile range, points decrease at half-mile intervals, indicating the increased expense of utilizing more than one booster plump for dredged material placement.

The Beneficial Use Parameter identifies high value areas for beneficial use by integrating land ownership, land cover, and habitat and recreational use data (Figure 14). It includes four major sub-values: Protected Land Potential Value, Land Cover Potential Value, Habitat Potential Value, and Waterfront Recreational Potential Value. Each of potential value comprises several raw layers from public data sets. To assign values to the data sets (excluding the protected land potential value, which was ranked without a buffer), boundary areas were identified and a buffer zone was created to establish a value gradient, with the highest value in the center of the boundary. Values decrease by one point every 160 feet based on the 250m (~800 ft) habitat buffer area referenced in Maryland Coastal Resiliency Assessment (a medium value of 6-points is assigned to 800-foot mark from the center with each point decreasing along the 160 foot buffer interval).
The Coastal Risk Parameter identifies high value areas where shoreline improvement projects that beneficially use dredged material may offer enhanced opportunities to mitigate coastal and community risk. In this parameter, the team developed two values, the Shoreline Physical Protection Value and Coastal Community Protection Value. Both values were transformed using base data from the Maryland Coastal Resiliency Assessment.

To develop the Shoreline Physical Protection Value and Coastal Community Protection Value, the Overlay Distance Tool was used to assign values for the beneficial use suitability model. The Shoreline Physical Protection Value is transformed from Shoreline Hazard Index. To do so, an initial shoreline protection value is assigned to the data based on the shoreline hazard index (with the assumption that high risk areas also have high protection values). This new data set is then transformed from point data to area data by assigning an attenuation range of 0.15 miles to each shoreline protection value point using the Euclidean Distance tool. The attenuation range areas are integrated into a final Shoreline Physical Protection Value map through Maximum Overlay tool. The Coastal Community Protection Value is transformed from Community Flood Risk Area. To do so, an initial coastal community protection value is assigned to the data set based on the shoreline hazard index (with the assumption that high risk areas also have high protection values). This new data set is then transformed from point data to area data by assigning an attenuation range of 0.15 miles to each shoreline protection value point using the Euclidean Distance tool. Sample points were then extracted from intermediate map to reclassify the values, which were once again transformed to area data using the Euclidean Distance tool. The final attenuation range data sets were integrated into Coastal Community Protection Value map through Maximum Overlay tool.

**CONCLUSIONS**

While no one of the parameters tends to be sensitive enough to provide useful information, when read all together they do produce an inventory of priority sites that seem plausible based on initial site assessments by the team and historical MDNR projects. This is reasonable given that each parameter is simplified and its fidelity to the original dataset, much less the prototype landscape, is not always high. Currently MDNR is undertaking additional site assessment to verify the initial results of the model. While it is not expected to line up precisely with field assessments initial returns suggests that it may be consistent enough to prove useful as a way of focusing limited agency resources.
In addition, given its emphasis on analysis, it may provide a reasonable way to prioritize among projects that are otherwise equally desirable. Perhaps most importantly, the scale of the spatial resolution can run reliably at a scale that relates to the small dredging volumes that are typically at issue in MDNR projects.

REFERENCES


ACKNOWLEDGEMENTS

We would like to express our appreciation to the Maryland Department of the Environment, in particular Jackie Specht who helped shepherd this project. We would also like to thank Mahan Rykiel interns Jason Wu and David Wu who were incredibly dedicated and tireless, as well as Cornell University MLA student Zeynep Goksel whose work initially showed that this method might be possible for dredge material in nearshore sites. This report was prepared by Department of Natural Resources - Maryland. gov using Federal funds under award number NA16NOS4190170 from NOAA, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA or the U.S. Department of Commerce.

CITATION