Integrating Water Quality and Coastal Resources into Marine Spatial Planning in the Chesapeake and Atlantic Coastal Bays

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SUMMARY

The Chesapeake and Atlantic Coastal Bays are vital components of Maryland's culture, economy, and coastal ecosystems. These waters offer diverse habitats that support fish, waterfowl and invertebrate species, as well as a plethora of aquatic plant life. Unfortunately, human activities often place stress on these systems through water quality and habitat degradation. To improve the health of Maryland's estuarine systems, water quality goals were developed for the Chesapeake Bay through a Total Maximum Daily Load (TMDL) framework. Natural filter projects offer a means of reducing nitrogen, phosphorus, and sediment inputs into the Chesapeake Bay to help meet these goals.

Through a Coastal Zone Management Fellowship, the State has taken steps to identify opportunities for natural filter projects and prioritize sites that will best improve water quality. Riparian buffers, wetlands, and living shorelines are of interest because their implementation can be counted towards the TMDL water quality goals. These filters also represent one-time, cost-effective investments for the duration or life-span of each practice.

Priority riparian buffer and wetland restoration sites were identified following an extensive literature review, expert elicitation process, and spatial analysis. State-wide data were consolidated and analyzed through a geographic information system (GIS) to develop county-wide targeting maps for Maryland's coastal zone. Prioritization methods were tested at pilot subwatersheds along the eastern shore, western shore, and coastal bays. The identification of priority restoration sites represents one vital tool in the state's restoration toolbox. These data can be used to narrow site selection, support funding decisions, or strengthen screening activities for natural filter projects. In addition to water quality parameters, broader DNR restoration and conservation priorities were identified to support site screening. Climate change was highlighted within this process to select for sites that will maintain long-term benefits.

In addition to natural filters at the land-water interface, shellfish aquaculture represents a novel in-situ natural filter. Through filtration and nutrient processing, shellfish aquaculture can contribute to water quality goals and coastal zone enhancement. Therefore, a targeting model was developed for bottom, cage, and floating cultures of Maryland's eastern oyster (*Crassostrea virginica*). Identification of potential oyster aquaculture areas may assist in water quality improvement by aiding aquaculture expansion efforts. This is one of many steps Maryland has taken to explore the use of oyster aquaculture as a best management practice to improve water quality.

By addressing aquaculture, natural filter targeting, and climate change, this report highlights the integration of water quality into Maryland's coastal and marine spatial planning (CMSP) and restoration efforts. CMSP supports the analysis of current and future use conflicts within Maryland's coastal zone. Marylanders rely on coastal waters for many commercial and recreational uses in addition to conservation and restoration activities. Furthermore, climate impacts such as sea level rise may impact future activities, including the placement of oyster aquaculture or restoration sites. An understanding of both current human use areas (i.e. boating, fishing, or recreational use areas) and potential natural filter locations will help Maryland evaluate conflicts and select project sites that will support the long-term Chesapeake TMDL goals.

Riparian buffer, wetland restoration, oyster aquaculture, and other data products are available online. See the *Resources* section for more information.

INTRODUCTION

The Chesapeake and Atlantic Coastal Bays are vital components of Maryland's culture, economy, and coastal ecosystems. These water bodies offer diverse habitats that support fisheries, spawning areas, waterfowl, invertebrate species, and aquatic plant life. Our coastal waters are also essential to recreational activities such as swimming, fishing and kayaking, among other uses. Despite the significance of Maryland's coastal environment, stress is continually placed on these resources through rising coastal populations, rampant land use change, and development – all consequences of human activities. About 17 million people inhabit the Chesapeake watershed and these populations amplify nutrient and sediment loading. Nitrogen (N), phosphorus (P), and sediment (TSS) are three major pollutants that impact fisheries, food-web dynamics, community health, and recreational opportunities.

As nutrients enter the water column, eutrophication can become rampant, leading to reduced water clarity, hypoxia, and reduced seagrass cover.[1] To safeguard the natural resources impacted by these pollutants, Maryland has invested in water quality monitoring, restoration, and nutrient reduction policies.

TAKING ACTION THROUGH POLICY

In 2009, President Obama signed an Executive Order calling for shared federal leadership to ensure restoration and protection of the Chesapeake Bay's habitats and living resources.[2] In response to this Executive Order, the Environmental Protection Agency (EPA) developed the 2010 Chesapeake Bay TMDL, which outlines water quality goals through a pollution cap or diet.[3] As defined in the Clean Water Act, TMDL goals set pollution limits that enable receiving surface waters to meet their water quality designation. Standards are determined based on dissolved oxygen, water clarity/underwater bay grass cover, and chlorophyll a levels. Alongside a pollution cap, EPA also required Bay jurisdictions to provide "reasonable assurance of implementation." This was achieved through the development of Watershed Implementation Plans (WIPs), which outline the actions necessary to meet TMDL requirements by 2025. Many best management practices exist to reduce pollution from various sectors across 92 impaired watersheds and 7 jurisdictions.

The Chesapeake TMDL addresses both point and nonpoint source pollution. While point sources are easily monitored and controlled (i.e. wastewater treatment plants, industrial facilities, and National Pollutant Discharge Elimination System sites), nonpoint sources are more ambiguous. They do not discharge at specific locations and are more difficult to intercept. Examples include agricultural run-off (i.e. fertilizer), animal feeding operations, on-site treatment systems or septic tanks, stormwater run-off, degraded streams or shorelines, and atmospheric deposition (i.e. air pollution).

Maryland's pollution cap consists of 41.17 million lbs N, 2.81 million pounds P, and 1,350 million lbs TSS per year.[4] To reach this goal, the State has initiated a number of funding, targeting, and tracking

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1 Boesch, D.F., R.B. Brinsfield, and R.E. Magnien. 2001. Chesapeake Bay Eutrophication: Scientific Understanding, Ecosystem Restoration, and Challenges for Agriculture. *J. Environ. Qual.* 30: 303 – 320.
2 The White House. 2009. Executive Order.
http://executiveorder.chesapeakebay.net/EO/file.axd?file=2009%2f8%2fChesapeake+Executive+Order.pdf
3 EPA. 2010. Chesapeake Bay TMDL. Website http://www.epa.gov/reg3wapd/tmdl/ChesapeakeBay/tmdlexec.html
4 Maryland Department of Environment. 2012. Phase II Watershed Implementation Plan. Website
http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Pages/FINAL_PhaseII_WIPDocument_Main.aspx

mechanisms to support water quality projects. The Chesapeake and Atlantic Coastal Bays Trust Fund,[5] Maryland Assessment Scenario Tool,[6] and Chesapeake*Stat*[7] are among these tools. Moving forward, these efforts can be strengthened through a spatial planning approach.

Coastal and marine spatial planning (CMSP) is defined as a comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process based on sound science. This process supports the analysis of current and anticipated uses of ocean, coastal, and Great Lakes areas.[8] Maryland's Coastal Zone Management Act FY 2011–2015 §309 Assessment and Strategy outlines several program goals, including the integration of CMSP into State and local management plans, programs and authorities while establishing the means to preserve existing and future water-dependent uses.[9] By considering water quality within Maryland's CMSP framework, DNR can proactively meet coastal management, restoration, conservation and human use goals.

One means of meeting State water quality goals is through natural filter best management practices (BMPs). Natural filters are natural approaches that treat surface, subsurface and groundwater over lengthy practice lifespans. By identifying and targeting BMP locations, Maryland can successfully contribute to water quality improvement efforts while identifying future use conflicts with high priority BMP sites.

NATURAL FILTERS FOCUS

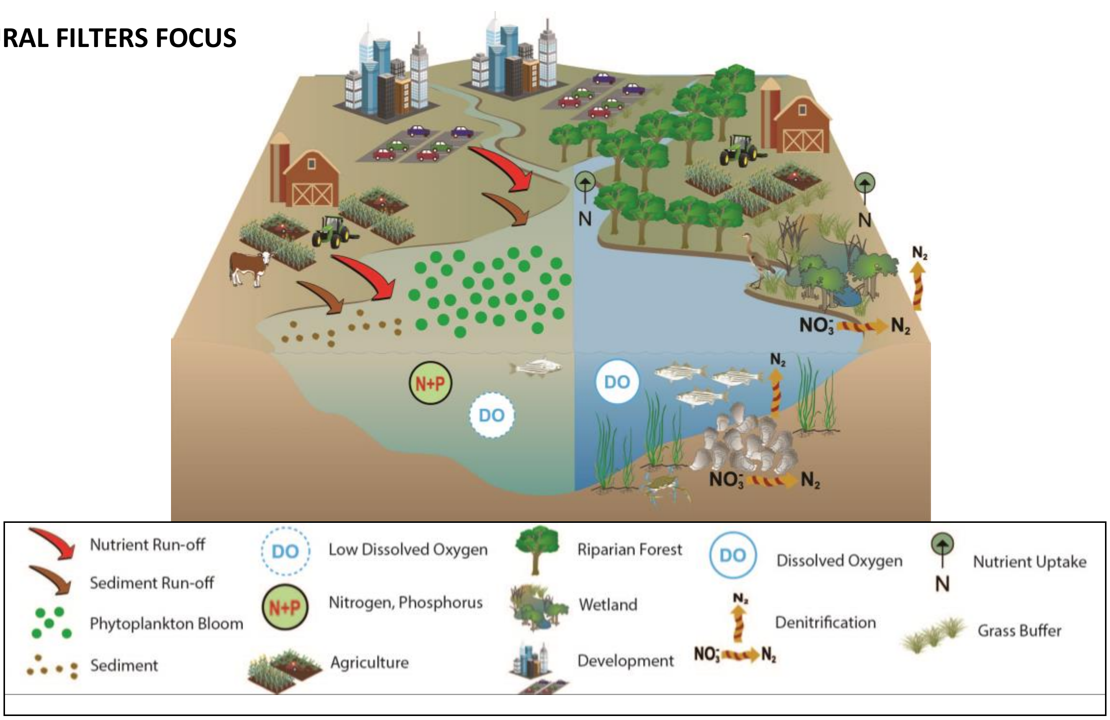

Figure 1. Natural filters represent vital best management practices because their natural components 1) intercept nutrient and sediment loads, 2) create adequate conditions for denitrification, 3) provide wildlife habitat, and 4) enhance coastal resiliency.

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5 Chesapeake and Atlantic Coastal Bays Trust Fund. Website http://www.dnr.maryland.gov/ccs/funding/trust_fund.asp
6 Maryland Assessment Scenario Tool. Website http://www.mastonline.org/
7 Chesapeake*Stat*. Website http://stat.chesapeakebay.net/
8 The White House Council on Environmental Quality. 2010. Final Recommendations of The Interagency Ocean Policy Task Force. http://www.whitehouse.gov/files/documents/OPTF_FinalRecs.pdf
9 §309 Assessment and Strategy. 2011 – 2015. http://www.dnr.state.md.us/ccs/pdfs/MD309AS_2011-15.pdf

Natural filters represent one solution to our water quality and non-point source pollution problems. These practices rely on natural habitat elements to slow or intercept surface, subsurface and ground water. Riparian forests, riparian grass buffers, wetlands, living shorelines, and reforested upland areas all fall under the natural filter category. Through interception, these natural habitat elements filter pollutants and provide opportunities for nutrient processing (Figure 1).

Although many agricultural, forest, septic, urban, and wastewater BMPs exist, natural filter practices are preferred. These practices are unique in that they represent a one-time, cost-effective investment for water quality improvement while also providing wildlife habitat, migration, and coastal resiliency benefits.

A focus on natural filters not only improves water quality, but also addresses the State's overall restoration goals. Maryland has lost 45-65% of its original wetlands and over half of its original forests. These lands were historically cleared and filled for development purposes, or drained for agricultural practices. The State has set ambitious restoration goals to rectify these downward trends. In support of the 2013 two-year milestones, Maryland restored 646 acres of wetlands on agricultural lands, planted 1,069 acres of forest buffers on agricultural and urban land, and planted 2,308 acres of grass buffers. Natural filter practices support these broader restoration goals, which serve as overall indicators of Maryland's ecological health and well-being.

In addition to the land-based practices discussed above, shellfish represent an in-situ natural filter practice that can remove pollutants post-loading (Figure 2).

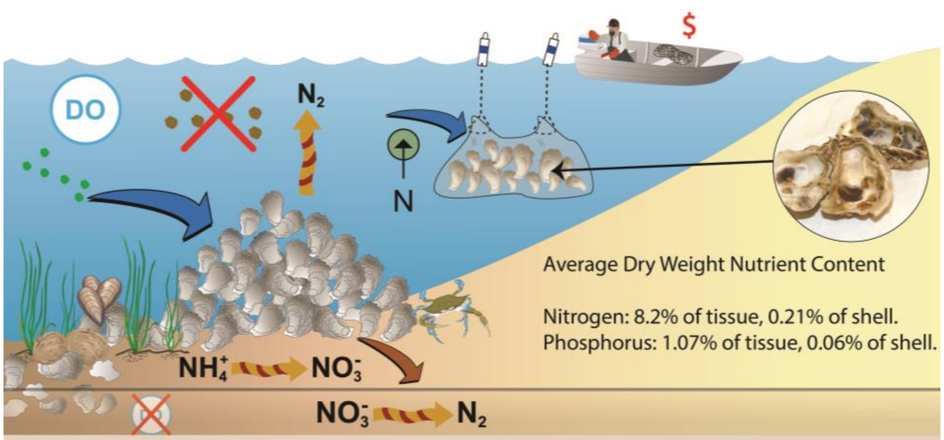

Figure 2. Natural reef and aquaculture oysters act as in-situ natural filters to reduce nitrogen, phosphorus, and sediment levels in the water column. 1) Oysters assimilate nitrogen and phosphorus into their shells and tissue when consuming phytoplankton and organic matter. 2) Waste containing un-processed nutrients is released as biodeposits and slowly buried. 3) Denitrification may occur within the reef environment under suitable conditions. 4) Oyster reefs can reduce sediment re-suspension. 5) Oyster reefs attract filter feeders and macrofauna, which also assimilate nutrients and support the reef structure.

Historically, TMDL goals have been met or pursued through land-based and top-down practices. Waste water treatment plants, riparian buffers, and other approved BMPs have addressed water quality before nutrients enter the water column. Bottom-up approaches, however, can remove pollution within the aquatic system through assimilation and even denitrifcation processes.[10, 11] Maryland's eastern oyster (*Crassostrea virginica*) represents just such an approach to in-situ nutrient removal.

Bioremediation, or the use of "living organisms to remove or detoxify pollutants within a given environment," is not a new concept.[12] Pilot projects in New York, Maryland, and Virginia have tested the ability of algal turf scrubbers to remove nutrients and carbon from polluted waters.[13] Maryland has also experimented with floating wetlands, most notably within the Baltimore Harbor.[14] The most common organisms used to reduce nutrients, however, are bivalve mollusks.[12, 15] A recent report by the Chesapeake Bay Scientific and Technical Advisory Committee (STAC) addresses the use of oysters as natural filters, both within a natural reef and aquaculture environment. While oysters improve water quality via many pathways, insufficient information is available to quantify denitrification or sediment trapping within and under the reef structure.

Although not currently an approved BMP, aquacultured oysters represent a bottom-up approach to improve water quality while providing fisheries habitat and an economic benefit. As more information becomes available, we can quantify the full benefits of these native invertebrates.

TARGETING NATURAL FILTER PRACTICES

In August 2012, a NOAA Coastal Management Fellow joined Maryland DNR Chesapeake and Coastal Service to assist in integrating water quality and coastal resources into the state's CMSP efforts. This work involved the siting of natural filter opportunities in terrestrial and aquatic environments in order to advance water quality goals identified for the Chesapeake Bay TMDL. During the fall of 2012, the fellow completed a literature review and expert interviews to identify landscape, hydrologic, soil, and/or aquatic characteristics that would identify riparian buffer, wetland restoration, living shoreline, and oyster aquaculture opportunities. Coastal Restoration[16] and Oyster Aquaculture[17] advisory groups were formed and met as needed between 2013 and 2014 to provide expertise during targeting exercises. Geographic Information System (GIS) models were developed to streamline the targeting process and create targeting outputs for natural filter BMPs. These kinds of spatial data are crucial in the development of any CMSP framework.

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10 Wilcox, W. 2009. Shellfish as a Means to Reduce Nitrogen Impacts in Coastal Waters. Technical Report. University of Massachusetts Boston. 5 p.

11 Stephenson, K. and L. and Shabman. 2011. The Use of Nutrient Assimilation Services in Water Quality Credit Trading Programs. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA. Working Paper No. 2011-01.

12 Gifford, S., R.H. Dunstan, W. O'Connor, C.E. Koller, and G.R. MacFarlane. 2007. Aquatic zooremediation: deploying animals to remediate contaminated aquatic environments. *Trends in Biotechnology* 25(2): 60 – 65.

13 Wheeler, T. 2012. Algae "scrubber" tackles harbor pollution: Scientists pursue "ecological engineering" for cleaning the Chesapeake, producing fuel. *The Baltimore Sun*. Website http://articles.baltimoresun.com/2012-04-29/features/bal-bmg-algae-scrubber-tackles-harbor-pollution-20120424_1_algae-bloom-algal-turf-scrubber-harbor-pollution [Accessed 5 September 2012].

14 Hopkins, J.S. 2010. 'Floating wetlands' find a home in Baltimore's Inner Harbor. Website http://articles.baltimoresun.com/2010-08-08/news/bs-md-floating-wetlands-20100808_1_manmade-wetlands-fells-point-living-classrooms

15 Rice, M.A. 2001. Environmental Impacts of Shellfish Aquaculture: Filter Feeding to Control Eutrophication *In* Marine Aquaculture and the Environment: A meeting for Stakeholders in the Northeast. Cape Cod Press, Falmouth, Massachusetts, p. 77 – 86.

16 MD DNR Chesapeake and Coastal Service, Office of Sustainability, and Forest Service; Natural Resources Conservation Service; Maryland Department of the Environment; and US Forest Service.

17 MD DNR Chesapeake and Coastal Service and Fisheries Service; US Army Corps of Engineers; Chesapeake Bay Program; and University of Maryland.

A stakeholder-driven spatial analysis was also completed to explore potential use conflicts with natural filter practices. Understanding how and where stakeholders use state waters will foster informed planning and decision-making in our coastal zone. To engage stakeholders in discussions about alternative coastal and marine uses, a pilot workshop was held in January 2014. MD DNR staff utilized participatory GIS (pGIS) technology and facilitation techniques to capture recreational use data and elicit feedback on community needs and concerns in the Choptank River – a tributary that has been selected for intensive oyster restoration, habitat protection, and federal focus through the NOAA Habitat Blueprint Initiative.[18] The results of this analysis showcase how valued industries may conflict or coexist with alternative coastal uses.

COASTAL RESTORATION TARGETING

Two accepted natural filter practices were chosen for this targeting exercise – riparian buffers and wetlands (Figure 3). If implemented correctly, both practices offer hydrologic, filtration, shoreline stabilization, coastal resiliency, and habitat benefits.

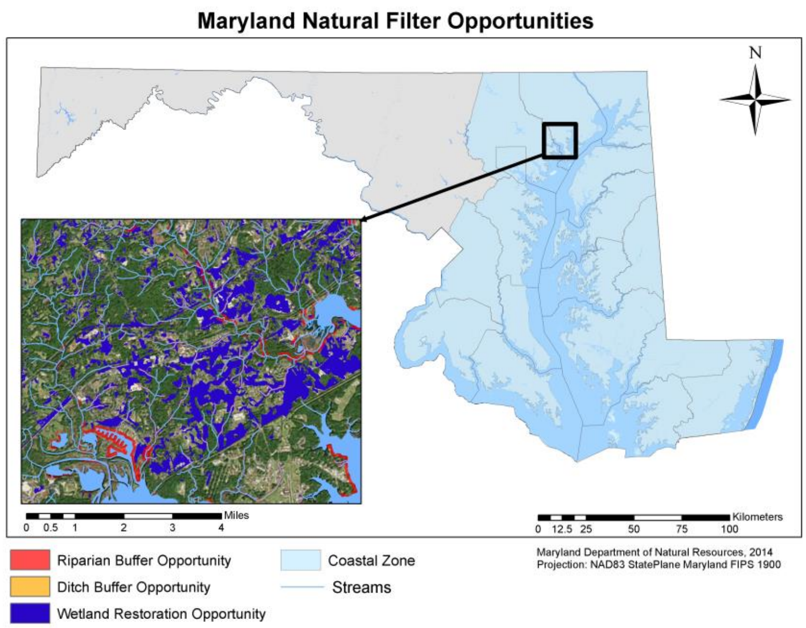

Figure 3. Riparian buffer, ditch buffer, and wetland restoration opportunities were identified in Maryland's Coastal Zone.

Riparian Buffers

Riparian buffers are areas of vegetation adjacent to a body of water that filter, trap, or convert nutrients, contaminants, and sediments. By delaying, absorbing and purifying runoff, riparian buffers reduce nonpoint source pollutants while providing habitat, recreational, and aesthetic opportunities.[19,20]

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18 NOAA Habitat Blueprint. Website http://www.habitat.noaa.gov/habitatblueprint/

19 Xiang, W. 1996. GIS-based riparian buffer analysis: injecting geographic information into landscape planning. *Landscape and Urban Planning* 34: I - 10.

20 Polyakov, V., A. Fares, and M.H. Ryder. 2005. Precision riparian buffers for the control of nonpoint source pollutant loading into surface water: A review. *Environ. Rev.* 13: 129 – 144.

These practices can reduce nutrients at varying levels depending on site specific conditions. While buffer width usually ranges from 35 to 100 feet, wider buffers are often encouraged because width has been positively correlated with nutrient uptake.[21, 22, 23]

Forest and grass buffers are two common practices that can be placed on agricultural, developing, or urban landscapes to reduce nutrient and sediment pollution. Because both BMPs perform well at reducing sediments and treating run-off, neither was differentiated in this targeting exercise. Forest buffers, however, are encouraged where possible since they out-compete grasses in nitrogen removal and offer more habitat and coastal resiliency benefits than their grass counterparts.

Nutrient removal estimates have been calculated for riparian buffers ranging in size and percent watershed cover.[24, 25] The multitude of parameters considered within these GIS models demonstrates the complexities of buffer effectiveness. Maturity, saturation, hydrology, soil type, topography, hydrogeomorphic regions, flow convergence, ground flow patterns, infiltration rate, vegetation cover, degree of fragmentation, length, and width all contribute to a buffer's ability to improve water quality.[20, 26, 27] These site-specific factors can be highlighted during prioritization to target riparian buffers in areas conducive to enhanced filtration.

Wetland Restoration

Wetland restoration is defined as the act of "returning natural/historic functions to a *former* wetland," which leads to an increase in overall wetland acres.[28] Wetlands consist of a variety of hydrophytic vegetation, or plants that grow in water or hydric soils[29] periodically covered by water.[30] Over 1,500 species of plants can be found in Maryland's wetlands and these plants further sedimentation and phosphorus uptake by slowing water velocity. As water velocity is reduced, particles attach and settle, thus decreasing turbidity in nearby waters and allowing for soil sorption. Nitrogen removal also takes place via plant and microbial uptake, as well as nitrification-denitrification reactions.

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21 Mander, U., V. Kuusemets, K. Lohmus, and T. Mauring. 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. *Ecological Engineering* 8: 299 – 324.
22 Vought, L.B.-M., J. Dahl, C.L. Pedersen, and J.O. Lacoursière. 1994. Nutrient Retention in Riparian Ecotones. *Ambio* 23(6): 342 – 348.
23 Todd, A.H. 2002. Nutrient Load Removal Efficiencies for Riparian Buffers and Wetland Restoration. Forestry Workgroup, Chesapeake Bay Program, Annapolis, MD.
24 Weller, D.E., T.E. Jordan, and D.L. Correll. 1998. Heuristic Models for Material Discharge from Landscapes with Riparian Buffers. *Ecological Applications* 8(4): 1156 – 1169.
25 Perry, C.D., G. Vellidis, R. Lowrance, and D.L. Thomas. 1999. Watershed-scale water quality impacts of riparian forest management. *Journal of Water Resources Planning and Management* 125(3): 117 – 125.
26 Fischer, R.A. and J.C. Fischenich. 2000. Design Recommendations for Riparian Corridors and Vegetated Buffer Strips. US Army Engineer Research and Development Center. ERDC TN-EMRRP-SR-24.
27 Tomer, M.D., M.G. Dosskey, M.R. Burkart, M.J. Helmers, and D.E. Eisenhauer. 2008. Methods to prioritize placement of riparian buffers for improved water quality. *Biological Systems Engineering: Papers and Publications.* Paper 3. Access at http://digitalcommons.unl.edu/biosysengfacpub/3
28 Jordan, T., T.W. Simpson, and S.E. Weammert. 2009. Wetland Restoration and Wetland Creation Best Management Practices (Agricultural): Definition and nutrient and sediment reduction effectiveness estimates for use in the phase 5.0 of the Chesapeake Bay Program watershed model *In* Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed: Final Report. December 2009, University of Maryland Mid-Atlantic Water Program, p. 599 – 660.
29 Hydric soils are wet soils with low oxygen content. These soils are inundated or wet long enough to become anaerobic and are often fine in texture.
30 Tiner, R.W. and D.G. Burke. 1995. Wetlands of Maryland. U.S. Fish and Wildlife Service, Ecological Services, Region 5, Hadley, MA and Maryland Department of Natural Resources, Annapolis, MD. Cooperative publication. 193 pp. plus Appendices.

When identifying potential wetland restoration sites, hydrology, soil type and land use are highly important factors.[31, 32] The area must be inundated or partially inundated for a significant portion of the growing season and hydric soils must be present. Former wetlands, ponds, open/unbuilt lands, agricultural lands, and disturbed areas (e.g. sand or gravel mines, drained forests, or drained agricultural land) are all appropriate for wetland restoration.[33] Areas with moderate to steep slopes, infrastructure that might flood, rare/endangered species/habitat, and lands with forest or wetland cover may not be suitable. Overall, survivability is highly dependent on one factor – water. How water interacts with the soil and land cover at any given site will affect wetland conditions. Wetland efficiency often depends on the timing, duration, and magnitude of flow, as well as wetland size.[11] Wetlands with steady water flow improve water quality to a greater extent than wetlands with concentrated or intermittent flows, and larger wetlands often have longer retention times that allow for maximum nutrient removal. Thus, hydrology, soil, and drainage characteristics can be used to prioritize potential wetland restoration sites.

Practice Efficiency

Riparian buffer and wetland restoration BMPs are approved non-point source practices that can be used by counties to meet Maryland's TMDL goals. Furthermore, these practices are often implemented by DNR's Habitat Restoration and Conservation Division. The Chesapeake Bay Program has estimated nutrient removal efficiencies for these practices to track progress towards nitrogen, phosphorus, and sediment removal as projects are implemented (Table 1).

Table 1. Natural filter pollution reduction efficiencies differ by region and land use change

Best Management Practice	Pollution Reduction Range (%)					
	TN Ag	TN Urban	TP Ag	TP Urban	TSS Ag	TSS Urban
Riparian Forest Buffer	19 – 65	25	30 – 45	50	40 – 60	50
Riparian Grass Buffer	13 – 46	N/A	30 – 45	N/A	40 – 60	N/A
Wetland Restoration	7 – 25	20	12 – 50	45	4 – 15	60

Efficiency values often differ between pollutants because nitrogen and phosphorus traverse through the environment via different pathways. Phosphorus can travel in surface water, subsurface flow, or groundwater, but often binds to soil particles before transport.[34] Therefore, its transport depends heavily on soil type, slope, rainfall, and vegetation cover. Phosphorus removal relies on infiltration, plant consumption, dilution, and transformation as it is transported aboveground.[20] Nitrogen, on the other hand, often travels in the form of nitrate, leaching from soils into groundwater flow.[1] Nitrogen removal relies on plant uptake, microbial immobilization,[35] and bacterial denitrification.[20] Because these pollutants are transported and processed in different fashions, some BMP sites may be more efficient at

31 Maryland Environthon. 2006. Resource Packet and Study Guide: Wetlands Management. Access at http://www.dnr.state.md.us/education/envirothon/Wetland%20Management.pdf

32 Maryland Department of the Environment (MDE). Wetlands Restoration Guidebook. Nontidal Wetlands Division, Baltimore, MD. Access at http://www.mde.state.md.us/assets/document/wetlandswaterways/restore.pdf

33 Maryland Department of the Environment. 2012. Water programs. What is Restoration? Website http://www.mde.state.md.us/programs/Water/WetlandsandWaterways/AboutWetlands/Pages/Programs/WaterPrograms/Wetlands_Waterways/about_wetlands/sites.aspx

34 Kobell, R. 2012. Phosphorus Index score will tell MD farmers where, how to apply fertilizer. *Chesapeake Bay Journal* October 2012 issue. Access at http://www.bayjournal.com/article/phosphorus_index_score_will_tell_md_farmers_where_how_to_apply_fertilizer

35 Microbial immobilization is the dissimilatory reduction of $NO3^-$ to $NH4^+$ that occurs under anaerobic conditions.

removing one pollutant than another. The range of suitable soil types and slopes is relatively wide for riparian buffer practices. Thus, multiple suitability models must be used to identify nitrogen, phosphorus, and sediment removal hotspots.

Site Identification

The above efficiency values allow Maryland to calculate the contribution of each BMP towards our water quality goals. Identifying opportunities for implementation, then, becomes the next step in meeting the Chesapeake TMDL. To that end, suitability models were developed to identify general and priority BMP opportunities. General opportunities are defined as all areas where a practice could be implemented with success, regardless of its cost or efficiency. Priority opportunities are defined as nutrient removal hotspots where landscape, soil, and hydrology characteristics suggest enhanced nutrient removal potential.

Prior to model development, available land use/land cover, soil, hydrology, and elevation data were collected for review. A complete listing of data used in this model can be found in **Appendix A**. Suitability parameters were identified through a literature review and outreach to local experts (Table 2). All parameters were finalized following review by an Advisory Committee and discussions with the Watershed Resources Registry Technical Advisory Committee[36] over the course of 2013 - 2014.

Table 2. General Model Parameters by BMP

Parameter	Riparian Buffer	Wetland Restoration
Land Use	Exclude forest, open water, and non-Palustrine wetlands	Exclude forest, wetland, and open water
Hydrology	≤ 300 feet from streams of order > 3 ≤ 100 feet from headwaters (stream order ≤ 3) ≤ 35 feet from ditches	N/A
Soil	N/A	Potential wetland soil landscape (hydric/poorly and very poorly drained soils)

Suitability models were built within ArcMap 10.0 Model Builder to identify general riparian buffer and wetland restoration opportunities within Maryland's coastal zone. All data were converted to 10 x 10 meter rasters and projected to NAD_1983_StatePlane_Maryland_FIPS_1900 prior to analysis. The Reclassify and Raster Calculator tools were used to overlap model parameters and remove sites considered unsuitable for restoration (See **Appendix B** for detailed results). Intermediate and final outputs were snapped to 10-meter National Elevation data within the processing environment. All opportunities can be visualized on Maryland's Coastal Atlas mapper.[37]

36 Watershed Resources Registry. Website http://watershedresourcesregistry.com/overview.html
37 MD DNR Coastal Atlas Mapper. Website http://gisapps.dnr.state.md.us/coastalatlas/iMap-master/basicviewer/index.html

Site Prioritization

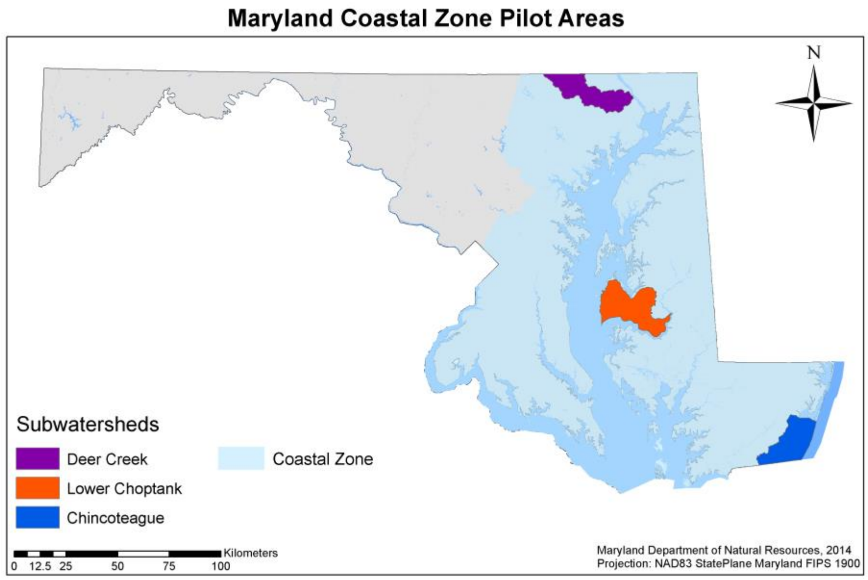

Figure 4. Three pilot areas were selected to develop priority models that identify natural filter opportunities with the potential for enhanced nutrient removal.

Following development of the general models, priority models were developed to identify nutrient removal hotspots. The Chesapeake Bay watershed is large and complex, spanning six states and encompassing about 150 major rivers and streams. To develop a data-intensive model in a timely fashion, three pilot areas were chosen across the state's coastal zone (Figure 4, Table 3). These demonstration areas provide examples of how a GIS model can be employed to prioritize sites for natural filter implementation or allocate funding. Because baseline toolboxes were developed in the analysis of these pilot areas, prioritization can be expanded in the future to encompass larger regions, such as the Choptank Complex or the Maryland Coastal Zone.

Table 3. Natural Filter Pilot Areas

Pilot Area	County	Shore	HUC8 Subwatershed	Area (acres)
Deer Creek	Harford	Eastern	2120202	86,021
Lower Choptank	Talbot	Western	2130403	117,754
Chincoteague	Worcester	Coastal Bays	2130106	89,297

Because differences exist in how nitrogen, phosphorus, and sediment are transported and cycled through the coastal environment, the Advisory Group analyzed nitrogen removal separately from phosphorus and sediment removal for riparian practices. A set of prioritization parameters were chosen for identifying priority restoration sites following an extensive literature review and expert interviews. These parameters were designed to select for restoration sites with greater potential for water quality improvement. Parameters were chosen in relation to interception, nutrient processing, and survivability of each natural filter practice.

The priority models were also built within ArcMap 10.0 Model Builder. All data were converted to 10 x 10 meter rasters and projected to NAD_1983_StatePlane_Maryland_FIPS_1900 prior to analysis. The Reclassify, Raster Calculator, and Weighted Sum tools were used to overlap model parameters, remove sites considered unsuitable for restoration, calculate a suitability score, and weight parameters related to nutrient source and transport. Intermediate and final outputs were snapped to 10-meter National Elevation data within the processing environment. The final targeting methodologies (Tables 4 – 5) were approved following a sensitivity analysis. Parameters related to nutrient source and transport were weighted within the riparian buffer models to target the most impaired waters. Suitable areas were classified into 3 suitability tiers – low, medium, and high – by pilot area (See **Appendix B** for detailed results). The final model outputs consisted of priority tiers for 1) riparian buffer nitrogen removal, 2) riparian buffer phosphorus and sediment removal, and 3) wetland restoration.

Sensitivity Analysis

During model development, sensitivity analyses were conducted to determine the impacts of each parameter to the model outputs. Many soil, hydrologic, and landscape parameters can be applied within a GIS framework to identify suitable restoration sites. Thus, parameters that are directly related may overlap. Because site suitability is determined spatially, overlapping data may lead to artificially elevated suitability scores. Parameters with the potential to overlap were identified by the Advisory Group and the Weighted Sum prioritization model was run with and without each parameter to determine how each parameter impacted the model results. The following suitability tiers were used to identify the highest priority areas:

- Low (bottom 60% of suitable area)
- Medium (mid 30% of suitable area)
- High (top 10% of suitable area)

The percent change in the above tiers was compared between model runs and parameters with little or equal impacts were removed. Parameters could be removed under 2 cases:

1) Low model sensitivity for a parameter (i.e. < 10% change in pixel count for the priority tiers when the parameter is removed). Because Maryland's western and eastern shores differ in topology, hydrology, and soil characteristics, sensitivity analyses were conducted for pilot areas on both shores. If the model parameter displayed sensitivity in any one pilot area, then it was retained.
2) Related parameters display similar levels of sensitivity across pilots. If this occurred, then one parameter could be removed from the associated model. Due to the landscape differences mentioned above, this case did not occur.

Table 4. Riparian Buffer Model Parameters

Riparian Buffer Site Selection Matrix Goal: Identify suitable riparian buffer BMP sites			
Parameter	**Score**	**Weight**	**Model**
Land Use	Pasture/Crop/Agriculture/Low Density Residential (+4) Urban/Barren/Transportation (+2) Palustrine wetlands (0) Exclude: Open water, forest, and all other wetlands	1	N, P
Proximity to Headwaters	Stream order ≤ 3, within 100-foot buffer (+2) Stream order 3 - 6, within 300-foot buffer (+1) Stream Order > 6, within 300-foot buffer (0) Exclude: Areas outside 300 and 100-foot buffers	1	N, P
Proximiy to water source	0 - 35 feet (+3) 35 - 100 feet (+2) 100 - 300 feet (+1) Exclude: none	1	N, P
Floodplain	Within 100 year floodplain (+2) Within 500 year floodplain (+1) Exclude: none	1	N, P
Hydrogeomorphic Region	Score on linear scale based on Bay Program efficiency values.	1	N, P
Downslope of Agriculture (nutrient source)	Natural Breaks Jenks % of flow passing through any one cell. Class 1 = Higher percentage of pilot area's run-off. Class 1 (+3) Class 2 (+2) Class 3 (+1) Exclude: none	2	N, P
Drainage Class	Very poorly drained (+2) Poorly drained (+2) Somewhat poorly drained (+1) All other soils (0) Exclude: none	1	N
Slope	1 - 5% (+2) 5 - 10% (+3) 10 - 15% (+1) 0 or > 15% (0) Exclude: none	1	N
Slope + High transport Areas	Identify high slope areas as designated below and areas connected to these slope categories. > 20% (+3) 15 - 20% (+2) 10 - 15% (+1) 0 - 10% (0) Exclude: none	2	P
Erodible Soils (K Factor)	Natural Breaks Jenks of K Factor. Class 1 = higher value Class 1 (+3) Class 2 (+2) Class 3 (+1) Exclude: none	1	P

N denotes "Nitrogen Targeting Model."
P denotes "Phosphorus and Sediment Targeting Model."

Table 5. Wetland Restoration Model Parameters

Wetland Restoration Site Selection Matrix Goal: Identify suitable wetland restoration BMP sites	
Parameter	**Score**
Land Use	Pasture/Crop/Agriculture (+2) Urban/Barren/Transportation (0) Exclude: Open water, forest, and wetlands
Wetland Lanscape	Exclude soils outside "potential wetland landscape" gSSURGO data Very Poorly Drained (+2) Poorly Drained (+2) Somewhat Poorly Drained (+1) Moderately Well Drained (0) Exclude: none
Proximity to water source	0 - 50 feet (+3) 50 - 100 feet (+2) 100 - 200 feet (+1) Exclude: none
Wetland size : Drainage area Ratio	For sites ≥ 1/4 acre. Natural Breaks Jenks of Ratio. Class 1 = larger wetland area Class 1 (+3) Class 2 (+2) Class 3 (+1) Exclude: none
Floodplain	Within 100 year floodplain (+2) Within 500 year floodplain (+1) Exclude: none
Hydrogeomorphic Region	Score on linear scale based on Bay Program efficiency values.
Headwater Connection	Potential restoration site intersects headwaters (stream order ≤ 3) Connected (+2) Exclude: none

INTEGRATING BROADER STATE GOALS INTO RESTORATION TARGETING

Water quality remains a major concern throughout the Chesapeake Bay watershed. Nevertheless, other priorities exist when conserving and managing Maryland's natural resources. To that end, the identification of broader State restoration and conservation priorities will aid in BMP site selection and the refinement of targeting metrics. Restoration potential, water quality improvement, conservation value, and ecological value are considered to varying degrees during BMP site selection to ensure that Maryland invests in sites with long lifespans and ecosystem-wide benefits. Furthermore, the State is working to integrate climate factors into targeting and prioritization. By identifying potential setbacks, concerns, conflicts, and climate impacts, practitioners can better prepare for project implementation.

A screening document was developed to help practitioners evaluate potential BMP sites beyond water quality considerations. This document represents baseline considerations that can be supplemented or condensed as needed. The number of factors considered during site evaluation should be tailored by users based on their objectives and needs. To learn more about the screening process and available screening data, see **Appendix C and D**.

Restoration in a Changing Climate

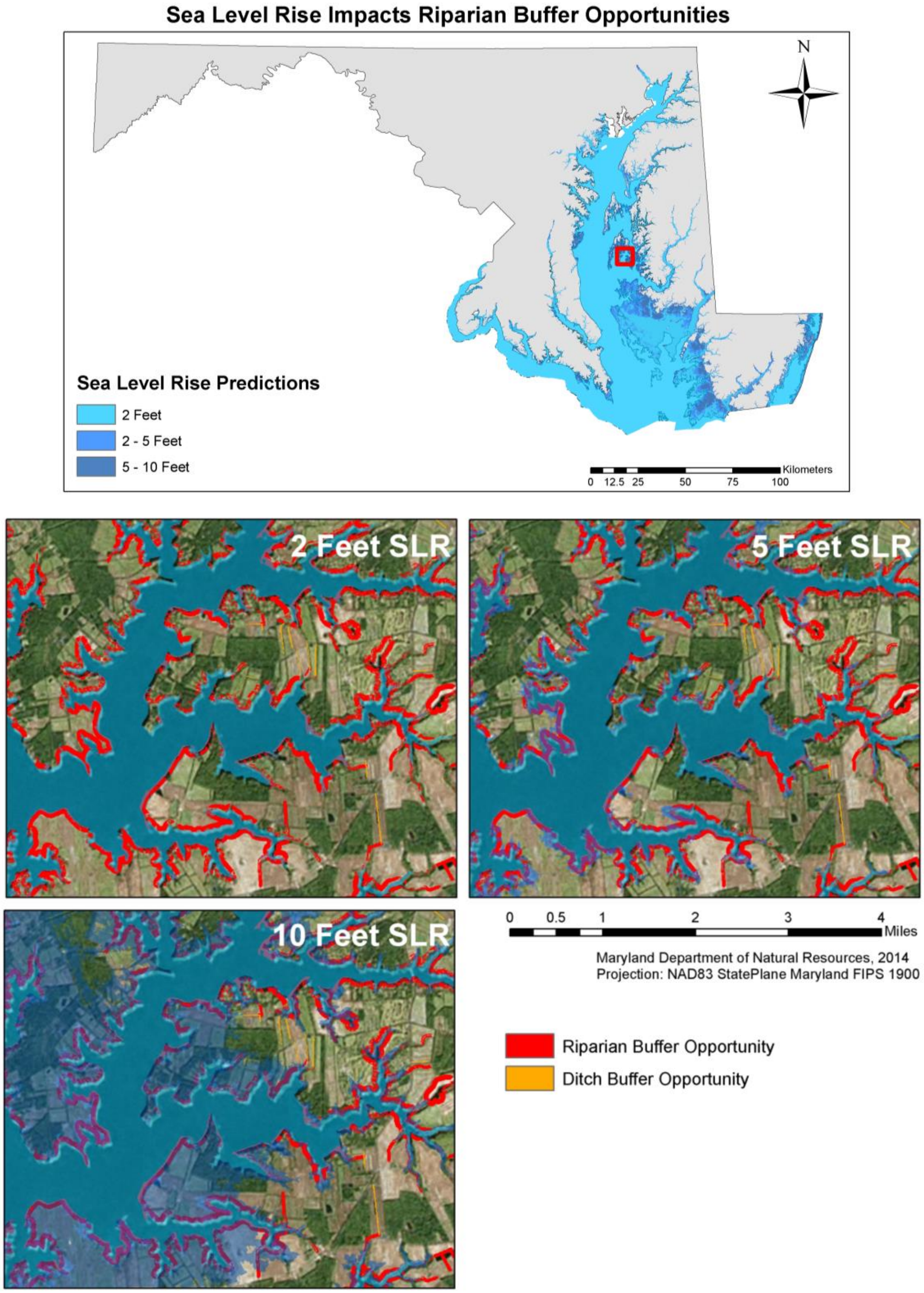

Figure 5. Climate change impacts such as sea level rise, saltwater intrusion, rising temperatures, and changes in precipitation patterns will impact the restoration practices implemented today and in the future. Sea Level Rise data were derived from high-resolution topographic data (LiDAR) to identify vulnerable areas in Maryland's coastal zone. Data are available on MD iMAP.

Climate change remains an increasingly important consideration within restoration and conservation initiatives because of its potential to minimize the benefits of completed and planned projects (Figure 5). Many indicators of climate change exist and can be evaluated at local, regional, and global scales to provide a best guess of future climate scenarios. The EPA recently released a report of 26 indicators often used to track the trends and impacts of climate change.[38] NOAA has also identified climate impacts of concern, including changes in relative sea level rise, air and water temperature, air and ocean chemistry, precipitation patterns, storm intensity and frequency, and species ranges.[39] Changes in temperature, precipitation, relative sea level rise, and storm events are expected in Maryland and can be predicted to some degree.[40]

Over the next century, Maryland expects increased winter-spring precipitation and runoff, warmer air and water temperatures, and relative sea level rise of at least 3.7 feet.[41, 42] Inundation and saltwater intrusion will increasingly alter the current coastal landscape, and these impacts will undoubtedly affect the success and efficiency of restoration practices along the land-water interface. Growth, survival, vegetation stabilization, marsh structure, and species composition will be impacted by a changing climate. Additional stress is predicted as increased precipitation leads to alterations in the quantity, timing, and delivery of nutrients and sediment.[43] Hydrology changes will most likely impact plant uptake, nutrient processing, and overall nutrient cycling.

In order to proactively address climate concerns, DNR's Habitat Restoration and Conservation Division has documented how DNR promotes resiliency through habitat restoration projects in the white paper *Building Resilience through Habitat Restoration*. This report first identifies how DNR addresses climate change within current practices, and then discusses future opportunities for integrating climate into the site selection, design, implementation, and monitoring process. The outlined climate change recommendations serve as a foundation for how climate can be incorporated into restoration decisions and practices. Available climate change data, water quality/quantity and nutrient loading models, and additional resources are also addressed. **Appendix E** provides an overview of DNR's restoration process and how climate change may impact business as usual.

OYSTER AQUACULTURE OPPORTUNITIES

Scientists and managers alike have long examined the ability of eastern oysters (*Crassostrea virginica*) to filter Chesapeake Bay waters and serve as an indirect nutrient sink. Three-inch adult oysters can filter 30 – 50 gallons of water per day,[44] and the Chesapeake Bay's historic oyster population may have filtered

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38 Environmental Protection Agency. 2012. Climate Change Indicators in the United States, 2012. EPA 430-R-12-004 Report. Website www.epa.gov/climatechange/indicators
39 Wieting, D. et al. 2010. Programmatic Framework for Considering Climate Change Impacts in Coastal Habitat Restoration, Land Acquisition, and Facility Development Investments. NOAA Coastal Strategy Report.
40 Maryland Smart Green & Growing. Climate Change Maryland. Website http://climatechange.maryland.gov/science/
41 Boesch, D.F. and the Scientific and Technical Working Group. 2008. Chapter 2: Comprehensive Assessment of Climate Change Impacts in Maryland *In* Climate Action Plan. Maryland Commission on Climate Change.
42 Boesch, D.F., L.P. Atkinson, W.C. Boicourt, J.D. Boon, D.R. Cahoon, R.A. Dalrymple, T. Ezer, B.P. Horton, Z.P. Johnson, R.E. Kopp, M. Li, R.H. Moss, A. Parris, C.K. Sommerfield. 2013. Updating Maryland's Sea-level Rise Projections. Special Report of the Scientific and Technical Working Group to the Maryland Climate Change Commission, 22 pp. University of Maryland Center for Environmental Science, Cambridge, MD.
43 Scavia, D., J.C. Field, D.F. Boesch, R.W. Buddemeier, V.Burkett, D.R. Cayan, M. Fogarty, M.A. Harwell, R.W. Howarth, C. Mason, D.J. Reed, T.C. Royer, A.H. Sallenger, and J.G. Titus. 2002. Climate Change Impacts on U.S. Coastal and Marine Ecosystems. *Estuaries* 25(2): 149 – 164.
44 Golen, R.F. 2007. Incorporating Shellfish Bed Restoration into a Nitrogen TMDL Implementation Plan. Proceedings of the Water Environment Federation TMDL: 1056 – 1068.

the Bay's entire volume in just three days time.[45] Sitting at less than 1% of historic levels, today's population does the same feat in about one year. This documented population decline has been attributed to many factors including harvesting, disease, and water quality (Figure 6).

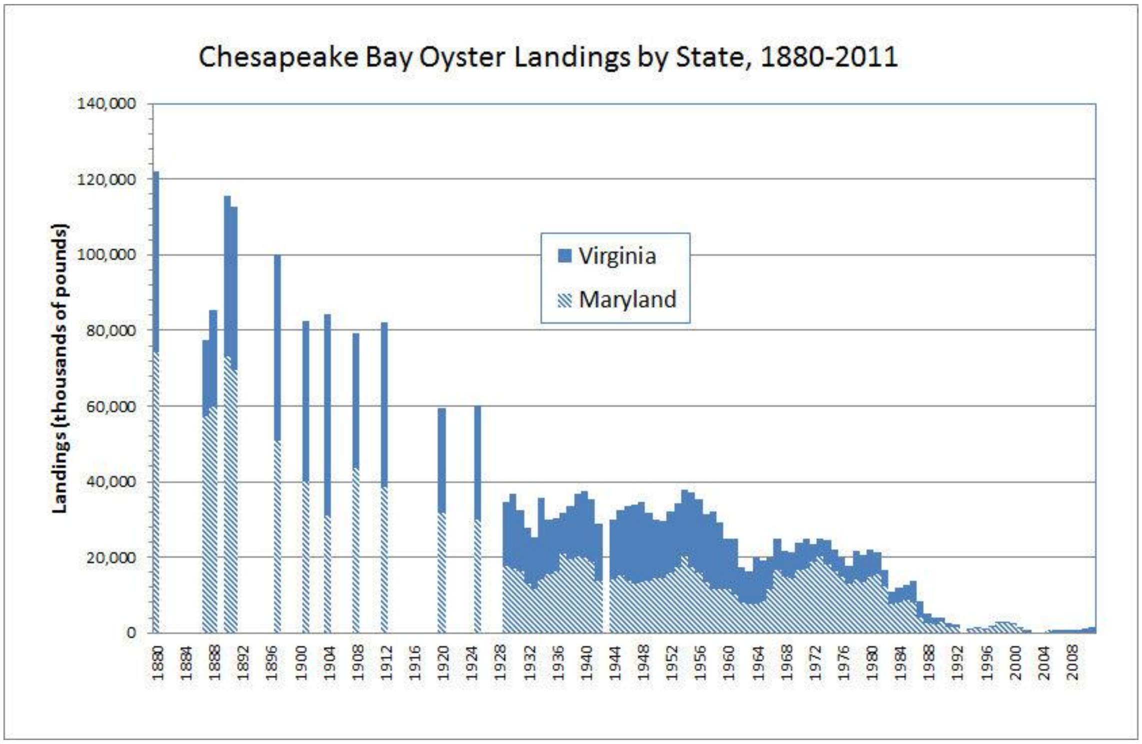

Figure 6. NOAA Chesapeake Bay Office, Chesapeake Bay oyster landings. Species declines beginning in 1949 an 1959 from Dermo and MSX diseases, respectively.

Aquaculture represents a harvesting practice that increases filtration capabilities without impacting sensitive natural populations. Aquaculture practices include on-bottom spat-on-shell, on-bottom cage, and off-bottom floating cultures (Table 6).

Table 6. Maryland Oyster Aquaculture Practices

Aquaculture Practice	**Description**	**Benefit**
Bottom / Spat-on-shell	A historic method of placing oyster shells on the bottom and allowing the reef to naturally attract larvae.	Less maintenance and cost.
Caged	Cages of oysters are placed about 1 foot off the bottom.	Cages provide a reduced predation risk for the brood.
Floating	PVC frames and/or floats are used to grow oysters within the upper portion of the water column.	Floating cultures are less susceptible to hypoxia threats and often grow more quickly, allowing aquaculturists to stay one step ahead of disease.

45 Newell. R.I.E. 1988. Ecological changes in the Chesapeake Bay: Are they the result of overharvesting the American oyster, *Cassostrea virginica*? Understanding the Estuary: Advances in Chesapeake Bay Research. Proceedings of a Conference. 29-31 March 1988. Baltimore, Maryland. Chesapeake Research Consortium Publication 129. CBP/TRS 24/88.

Although limited information currently exists on the full filtration benefits of Maryland's eastern oyster, a few benefits have been quantified by the scientific community.[46] Namely, the percent nitrogen and phosphorus assimilated into oyster shell and tissue. These estimated values are applicable to nutrient removal reporting only if the oyster is not returned to the water column. Oyster aquaculture may also enhance denitrification and increase the movement of organic nitrogen compounds from the water column to bottom sediments via feeding and biodeposition. Although important, these processes are not yet fully understood.

Despite data limitations, oysters are an up-and-coming in-situ practice for nutrient removal. Widespread interest exists for using shellfish to improve water quality, as demonstrated by the growth of oysters in the Baltimore Harbor to do that very activity.[47] The Maryland Department of Agriculture has listed oyster aquaculture as a potential credit-generating BMP for use in the state's nutrient trading program, and the State is currently investigating the use of intensive oyster aquaculture as an official BMP towards the Chesapeake TMDL goals. As additional research is conducted, oyster reefs and broader oyster aquaculture practices could very well be accepted as official BMPs.

To support future BMP implementation, oyster aquaculture opportunities were investigated through a natural filter targeting and mapping effort. The methodology described below was designed to assist industry and resource managers and others in planning and applying for shellfish aquaculture leases or similar projects. Targeting exercises consider water quality and potential conflicts with recreational uses, commercial uses and environmentally sensitive areas. The opportunities identified for bottom, cage, and floating practices are meant to help users make more informed decisions regarding the siting of shellfish aquaculture, but do not guarantee that an aquaculture lease will be issued or that any one site will be productive. Site visits and coordination with the DNR Fisheries Service is required prior to leasing activities.

46 STAC Factsheet: Oyster Nutrient Reduction Potential. Website http://www.chesapeake.org/pubs/321_Luckenbach2014.pdf
47 Healthy Harbor. Website http://healthyharborbaltimore.org/how-to-get-involved/healthy-harbor-news/40

Site Identification

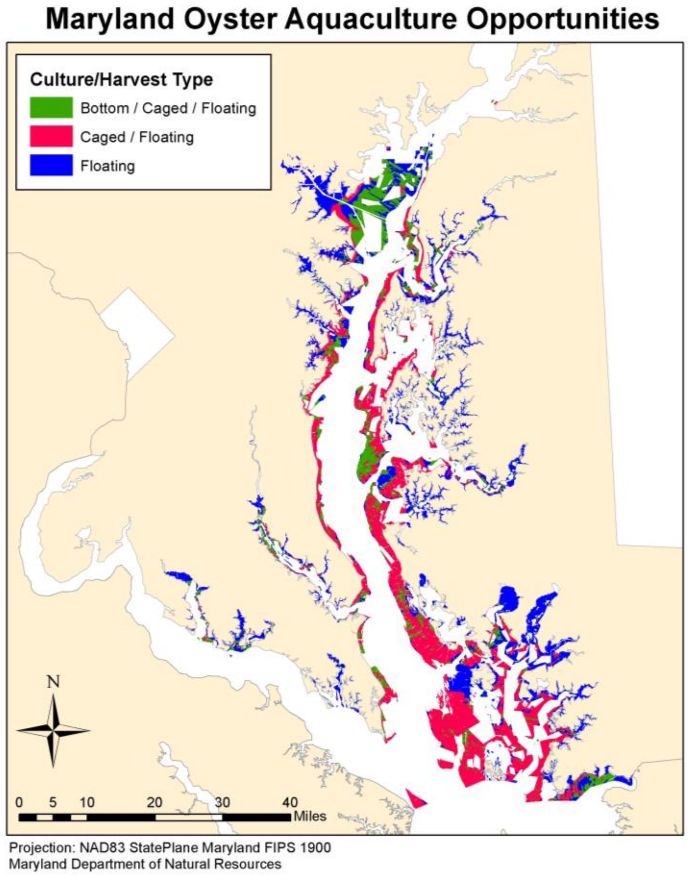

Figure 7. Aquaculture opportunities based on environmental conditions and policy constraints. Opportunities differ by culture type.

The availability of oyster habitat and the opportunity for oyster aquaculture (Figure 7) are two different, albeit related, concepts. Oyster health and growth depend on many factors, including substrate availability, minimal algal bloom occurrences, and water quality (e.g. DO, salinity, temperature, turbidity, etc.). Many estimates of environmental requirements exist for long-term reef development, but short term oyster growth for aquaculture purposes is another matter. While oyster restoration requires hard bottom and stable water quality for growth and reproduction, floating and caged aquaculture do not require such strict benthic conditions. A number of policy restrictions also exist that limit oyster aquaculture opportunities (Table 7) where restoration opportunities may still exist. Many of these policy restrictions are not depicted spatially (Table 8).

Because environmental constraints may differ between culture types, suitability models were developed for bottom, cage, and floating aquaculture practices. Bottom cultures are the most prevalent type of aquaculture in Maryland waters, but caged and floating cultures are also present and growing, particularly in Virginia's adjacent Chesapeake waters. Prior to model development, available water quality, benthic, fishery, and policy data were collected for review. Environmental suitability parameters for bottom, cage, and floating cultures were identified through a literature review and outreach to local experts (Table 9). Policy parameters were identified through DNR's Shellfish Aquaculture Siting Tool[48] and a review of the permit application and allocation process (Table 7 – 8). All parameters were finalized following review by an Advisory Group over the course of 2013 – 2014. A complete listing of environmental and policy data used in this project can be found in **Appendix F**.

Table 7. Shellfish Aquaculture Spatial Policy Targeting Parameters

Requirement	**Data Source**
Outside 5 year Submerged Aquatic Vegetation (SAV) zone	DNR; VIMS
Outside 6 year DNR/Oyster Recovery Partnership Planting Area	DNR
Outside 150' buffer of Public Shellfish Fishery Area	DNR
Outside 150' buffer from Harvest Reserve Area	DNR
Outside 150' buffer from active pound net sites	DNR
Outside 150' buffer from historic (Yates) bars if within a sanctuary	DNR
Outside Protected Lands	DNR
Outside 150' buffer of federal navigation channels	DNR
Outside 50' buffer of shoreline	SHA
Outside Maryland Artificial Reef Initiative Sites	DNR
Cultural/Historical resources absent	DNR
Outside Potomac River Mainstem	DNR
Outside marina buffers*****	MDE; DNR

*** Spatial data not yet available**

48 Maryland Shellfish Aquaculture Siting Tool. Website http://dnrweb.dnr.state.md.us/fisheries/aquatool/aquatool.asp

Table 8. Shellfish Aquaculture Policy Considerations

Consider	Data Source	Notes
Oyster Sanctuary Status	DNR	Check oyster lease acreage in sanctuary (cannot be > 10% of sanctuary acreage). Leases must be compatible with restoration.
Waterfowl Concentration Area	DNR	Wildlife and Heritage Services Review required.
Sensitive Species Project Review Area	DNR	Wildlife and Heritage Services Review required.
Wetlands of Special State Concern (WSSC)	DNR	Wildlife and Heritage Services Review required.
Cultural/Historical resources absent	DNR	Requires review by Maryland Historical Trust.
250' buffer of federal navigation buoys	DNR	Evaluated at the federal level by the Army Corps of Engineers and the Coast Guard. Case-by-case.
Bathymetry < 25 feet	DNR	No depth requirements exist but deeper areas may have access and DO issues. Most leases occur nearshore within easy access.
Blind spots (500 yard buffer)	DNR	Conditional. Only one activity can occur at a time. Potential gear conflict with hunting activities. These locations change annually and so were not included in the static policy constraints used in the model.
Near working waterfront infrastructure/access	DNR	Maintenance/Cost Factor
Not conflicting with alternative recreation uses or stakeholder groups: crabbers, gillnetters, recreational boaters/fishermen, upland property owners, etc.	DNR	Further review required

Table 9. Oyster Aquaculture Targeting Parameters

Parameter	Parameter Range	Preferred Value	Aquaculture Type
Dissolved Oxygen	Exclude if ≤ 2mg/L average bottom in any summer month at least 5 of the last 10 years (2002 - 2011, June - August).	≥ 4 mg/L summer average bottom	B, C
	N/A	N/A	F
Salinity	> 5 ppt average bottom (2001 - 2011, April - October)	8 - 12 ppt	B, C
	> 5 ppt average bottom (2001 - 2011, April - October)	8 - 25 ppt	F, triploid
Temperature	Exclude if average bottom is > 29°C in any summer month (June - August).	N/A	B, C
	Exclude if average surface is > 29°C in any summer month (June - August).	N/A	F
Bacteria	Approved, Conditional, and Restricted Harvest Areas	Non-conditional Approved Harvest Areas	B, C, F
Substrate	Hard, Firm, Mixed, Gravel, Sand-Mud Complex, Unclassified	Hard/shell > mixed > gravel > sand-mud complex/unclassified	B
	Hard, Firm, Mixed, Gravel, Sand, Sand-Mud Complex, Unclassified	Hard/shell, mixed, sand, gravel	C
	All	N/A	F

***B = Bottom culture/spat-on-shell**
***C = Off-bottom culture/caged**
***F = Column/floating culture**

Suitability models were built within ArcMap 10.0 Model Builder to identify all oyster aquaculture opportunities within Maryland's Chesapeake Bay by culture type. All data were converted to 10 x 10 meter rasters and projected to NAD_1983_StatePlane_Maryland_FIPS_1900 prior to analysis. The Reclassify and Raster Calculator tools were used to overlap model parameters and remove sites considered unsuitable for aquaculture (See **Appendix G** for detailed results). All opportunities can be visualized on Maryland's ArcGIS Online platform.[49]

Site Prioritization

After identifying oyster aquaculture opportunities within Maryland's Chesapeake waters, priority models were developed to identify regions where conditions may support enhanced oyster growth and filtration (Figure 8). Many factors can be used to predict where aquaculture might flourish. Salinity, for example, is a major predictor for disease presence and growth.[50, 51, 52] Exposure to the protozoan pathogens *Perkinsus marinus* (Dermo) and *Haplosporidium nelsoni* (MSX) is less likely in waters with low to moderate salinity. Dissolved oxygen, salinity, temperature, pH, substrate, flow, food availability, seston, bacteria levels, and harmful algal blooms were identified as environmental factors that can

49 ArcGIS Online. 2014. Oyster Aquaculture Opportunities Map. Website http://bit.ly/Uao6ch
50 Fulford, R.S., D.L. Breitburg, R.I.E. Newell, W. M. Kemp, M. Luckenbach. 2007. Effects of oyster population restoration strategies on phytoplankton biomass in Chesapeake Bay: a flexible modeling approach. *Marine Ecology Progress Series* 336: 43 – 61.
51 Loosanoff, V.L. 1965 The American or eastern oyster. United States Department of Interior Circular 205: 1 – 36.
52 Galtsoff, P.S. 1964. The eastern oyster: Crassostrea virginica Gmelin. *Fishery Bulletin*, 64: 1 – 480.

impact oyster growth, filtration, and survival. When selecting priority parameter ranges, only parameters with widespread scientific agreement within published literature were integrated into the GIS models. Because the documented optimal ranges for flow, chlorophyll and seston were inconsistent, these factors were removed from consideration. Therefore, only dissolved oxygen, salinity, bacteria, and substrate were considered to identify priority locations (See Table 9, Preferred Values). The final environmental and policy factors address disease, mortality, ability to harvest, and maintenance cost. As more information becomes available, this model can be adapted to prioritize areas that enhance denitrification and nutrient assimilation.

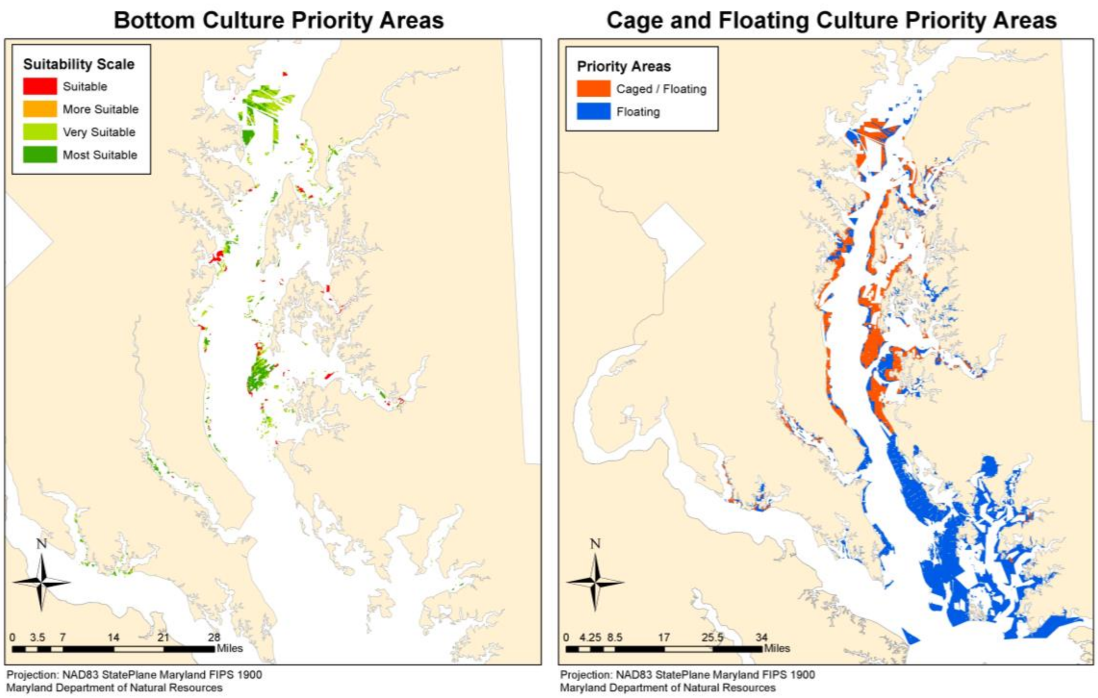

Figure 8. Priority areas were designated by limiting the range of dissolved oxygen and salinity levels while eliminating conditional harvest areas. Bottom culture sites were prioritized using bottom substrate data. Cage culture sites were limited with bottom substrate data. These areas can be further refined by considering flow, chlorophyll, or seston ranges.

These models were built off of the general oyster targeting models (See **Appendix G** for detailed results). All opportunities can be visualized on Maryland's ArcGIS Online platform.[49]

IDENTIFYING COASTAL AND MARINE SPATIAL CONFLICTS

Addressing spatial use conflicts remains one vital component of CMSP. Furthermore, understanding how and where stakeholders use State waters will foster informed planning and decision-making in our coastal zone. To address both stakeholder uses and spatial conflicts, many methods of stakeholder engagement and mapping have been utilized by coastal planners, natural resource managers, researchers, and communities. Participatory GIS (pGIS) represents one form of stakeholder engagement that involves stakeholders in discussions about alternative coastal and marine uses through a GIS mapping process. Maryland has successfully utilized interactive mapping software in conjunction with projected wall maps to explain the extent of human use activities using a visual medium.

A 2-day pilot workshop was held in January 2014 to collect information on recreational activities in the Choptank River (Figure 9). MD DNR staff utilized pGIS technology[53] and facilitation techniques to capture spatial data and elicit feedback on community needs and concerns in the Choptank River and surrounding counties. This tributary has been selected for intensive oyster restoration, habitat protection, and a number of other projects including bottom surveys, access planning, NOAA's Habitat Blueprint Initiative, and Maryland's Working Waterfront Initiative.[54] Exploring recreational use areas will inform future restoration, planning, and data collection efforts because these data characterize stakeholder activities and needs.

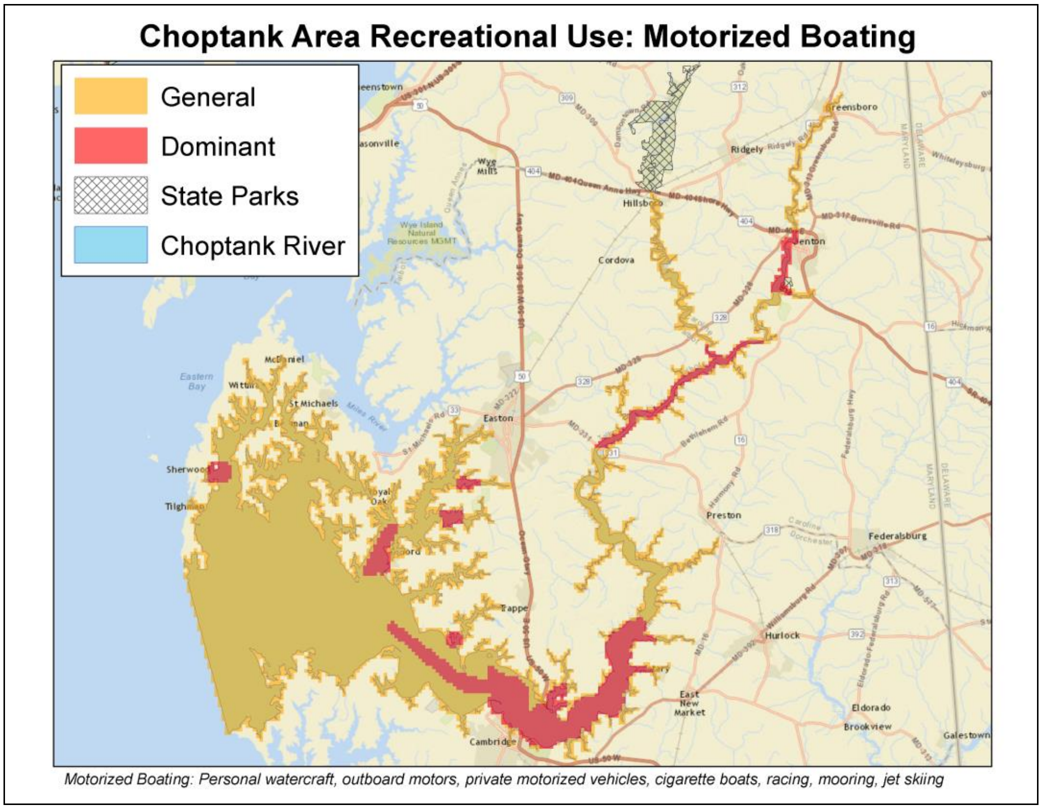

Figure 9. The Choptank River is a heavily used tributary with a variety of conflicting commercial and recreational uses. The River and surrounding shore span 3 counties that contain State Parks, Wildlife Management Areas and State Forest Lands. A system of trails and fishery areas provide communities with access to the natural resources that support commercial and recreational uses. The Choptank is also home to oyster sanctuaries, public shellfish fishery grounds and historic oyster reef sites. Increasing restoration, recreational, and commercial activities may yield future conflicts. Understanding where those conflicts may arise will help local and State planners visualize the future coastal and marine landscape.

The Choptank River pGIS workshop was modeled after participatory workshops held by CCS in Western Maryland and along the State's Atlantic and coastal waters. As Maryland's first Chesapeake Bay focused workshop, this effort will inform future data collection efforts in the coastal zone. Spatial information was collected for 23 recreational uses relating to guided/charter recreation, recreational fishing and hunting, and general recreation (See **Appendix H** for categories and definitions). Participants mapped general[55] and dominant[56] use footprints for each activity and were asked to identify intensity, seasonality, and timing information along with spatial location.

53 Wireless eBeam technology allows users to draw on a projected electronic wall map with an electronic pen. Their drawings are directly captured in editable ArcGIS geodatabases.

54 MD DNR Working Waterfronts Initiative. Website http://www.dnr.state.md.us/ccs/workingwaterfronts.asp

55 The general use footprint includes all areas in which the use is *known to occur with some regularity* (over the past 3-5 years), regardless of its frequency or intensity.

56 The dominant use footprint includes *areas routinely used by most users most of the time*, whether the activity occurs year-round or seasonally.

Overall, 35 stakeholders participated from a variety of sectors including enforcement, boating, recreation, tourism, commercial fishing, aquaculture, resource management, and local government. Additional stakeholders reviewed the workshop results, which can be viewed on Maryland's ArcGIS Online platform.[57] Although Maryland waters are regularly utilized for recreational purposes, spatial data on these uses are limited. The visualization and understanding of recreational use areas and intensity levels will help planners identify spatial conflicts in our coastal waters while considering how recreation relates to other coastal activities and needs such as land acquisition, public access, and aquaculture expansion.

Recreation and Public Access

Local governments and resource managers can draw on the pGIS recreational use datasets during annual county recreation planning or during the 5-year Maryland Preservation, Parks & Recreation Plan update. These plans guide land conservation and recreational development priorities and outline land use activities and opportunities from a county and system-wide perspective, respectively. The incorporation of stakeholder-derived data will allow these planning efforts to further integrate local input.

An understanding of current recreational areas can also inform future public access locations and water trail planning. In fact, many of the pGIS workshop participants used public access sites as a starting point during mapping exercises. Public access sites and water trails provide opportunities for residents to recreate on Bay waters and utilize the State's natural resources. These sites are essential since about 95% of Maryland's shoreline is privately owned. As uses in the Bay have expanded and changed over time, the public has called for additional public access sites. Maryland is committed to identifying current public access opportunities and future needs. The 2013 Chesapeake Bay Watershed Public Access Plan recommends actions for increasing Bay access by more than 20% by 2025. Because recreational use data represents a snapshot of how stakeholders use Chesapeake waters, these data can inform where future public access sites are needed or may be most beneficial to residents.

Recreation and Oyster Aquaculture

Oyster restoration and aquaculture expansion have been identified as priorities for the Chesapeake Bay. To increase Maryland's oyster population from its current state – which rests at less than 1% of the historic population – the state has invested in artificial reefs and sanctuaries. Additionally, Maryland is preparing for aquaculture expansion, as evidenced by the development of the 2010 Oyster Restoration and Aquaculture Development Plan. This plan has led to several data collection and planning efforts, including the development of an online siting tool, public shellfish fishery maps, and aquaculture enterprise zones (i.e. pre-approved aquaculture lease areas). Chesapeake Bay oyster sanctuaries were also expanded and regulations were updated to encourage aquaculture leasing.

Maryland's Coastal Zone Management Act FY 2011 – 2015 §309 Assessment and Strategy commits to the evaluation and siting of public and private aquaculture facilities in the coastal zone through a marine spatial planning approach. Aquaculture has been identified as a priority for water quality improvement and an alternative pathway for oyster harvest. Because leases require specific conditions for long-term

57 ArcGIS Online. 2014. Choptank River Recreational Use Map. Website http://bit.ly/UarsMj

success, siting could greatly benefit from a CMSP approach.[58] Limited suitable waters may overlap with or impact alternative uses such as recreation, wild fisheries, or transportation (Figure 10). By identifying recreational use areas within the vicinity of potential lease sites, managers can investigate conflicting or compatible uses to share with future lease applicants. Although not all of the identified recreational uses in the Choptank are incompatible with oyster aquaculture, some negative interactions may be prevented through a transparent and proactive planning approach.

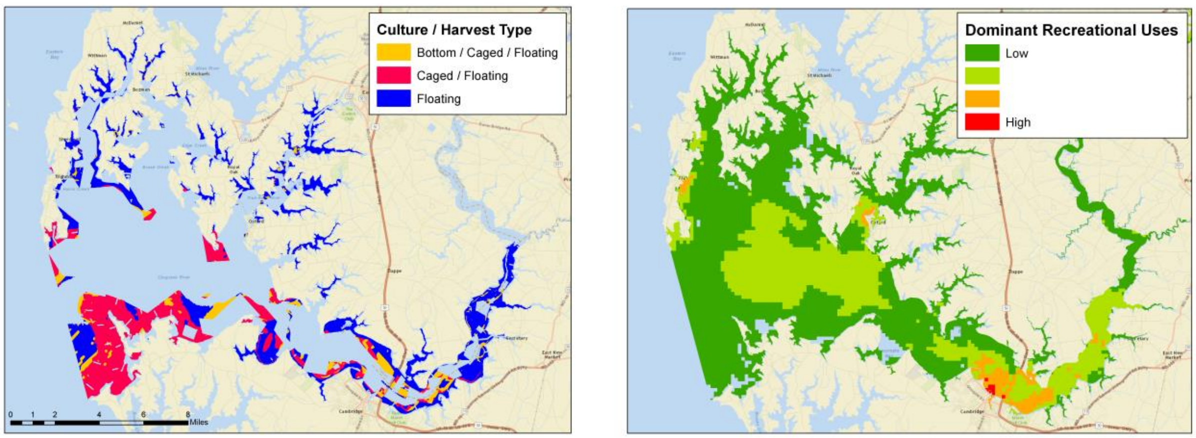

Figure 10. A Choptank River spatial use comparison demonstrates potential use conflicts between dominant recreation areas and future aquaculture activities. Because some recreational activities may be compatible with aquaculture, careful forethought is required before lease approval or dismissal.

MARINE SPATIAL PLANNING OUTCOMES AND RECOMMENDATIONS

A coastal and marine spatial planning approach will help Maryland meet the Chesapeake TMDL water quality goals. Spatial planning allows Maryland DNR to target high priority lands for natural filter practices, consider climate change impacts to potential restoration sites, and investigate spatial use conflicts. Full knowledge of current and anticipated uses will aid coastal planners when making decisions about future projects and funding initiatives to support restoration goals and community needs.

County and subwatershed-level natural filter targeting models were developed using the best available science and a collaborative inter- and intra-agency approach. As new information becomes available, Maryland DNR will update and refine the targeting results. Model outputs are only as relevant as the data inputs. Moving forward, the following approaches can be used to leverage CMSP within state-wide restoration and water quality improvement efforts.

1. Methodologies and models have been developed to identify natural filter opportunities in Maryland's coastal zone. Pilot areas in Harford, Talbot, and Worcester counties were analyzed for natural filter prioritization and high priority "nutrient removal hotspots" were identified. Drawing on these tools and results, identify priority riparian buffer and wetland restoration locations throughout Maryland's Coastal Zone or in priority watersheds. Update the model parameters and data inputs as needed.

58 The Nature Conservancy. 2011. Coastal and Marine Spatial Planning in Maryland's Chesapeake Bay: Driving forces and potential applications. Internal report, 46 pp.

2. Continue engaging the NOAA Chesapeake Bay Office, Chesapeake Bay Program Scientific and Technical Advisory Committee, and University of Maryland and Virginia Institute of Marine Science researchers in discussions regarding in-situ nutrient removal. As scientists quantify the nutrient removal capabilities of oysters via assimilation and denitrification, oyster aquaculture and/or reef development may be used or expanded as a best management practice to meet the Chesapeake TMDL. As more information becomes available on environmental conditions conducive for enhanced nutrient removal or oyster growth, update the oyster aquaculture targeting models appropriately. Factors such as oyster spatfall predictions,[59] chlorophyll, or flow can be used to target aquaculture practices.

3. Investigate climate change impacts to natural filter efficiencies through climate change vulnerability assessments, long-term monitoring, and/or support of scientific research. Integrate climate change into restoration decisions through targeting, design, and implementation practices. Target restoration locations where the practices will 1) provide enhanced water quality benefits over the long term, and/or 2) provide additional coastal resiliency benefits to surrounding communities and targeted ecological areas. The MD DNR 2014 white paper on *Building Resilience through Habitat Restoration* outlines guidance for these efforts. Continue collaborating with the Habitat Restoration and Conservation Division to integrate climate change into planning and implementation as outlined by the 2014 white paper.

4. Expand participatory GIS exercises beyond the Choptank River region to collect recreational use data throughout Maryland's Chesapeake Bay. Begin in tributaries with high aquaculture coverage or where the State expects a demand for future aquaculture leasing. Workshops should also be driven by public interest in access locations and county interest in collecting recreational use data for planning or tourism purposes. Utilize online marine spatial planning tools, such as ArcGIS Online[60] or SeaSketch,[61] to obtain feedback from additional stakeholders and to refine recreational use data every 5 years, or as needed. As data are refined, analyze changes over time to identify community needs and/or trends.

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59 Maryland Sea Grant. Analyzing 70 Years of Oyster Monitoring Data to Help Guide Oyster Restoration in Maryland. Website http://www.mdsg.umd.edu/research-projects/2011/rfish-100a
60 Arc GIS Online. Maryland Website http://maryland.maps.arcgis.com/home/
61 SeaSketch. Website http://www.seasketch.org/home.html

RESOURCES

Maryland Department of Natural Resources: NOAA Fellowship Project and Data

- Fellowship Website
  http://www.dnr.state.md.us/ccs/coastal_fellowship.asp

- Natural Filters Data
  http://bit.ly/1jhYctg

- Oyster Aquaculture Opportunities
  http://bit.ly/1qVq3IU

- Choptank River Participatory Mapping
  http://bit.ly/UarsMj

Maryland Department of Natural Resources: Coastal Atlas
http://www.dnr.state.md.us/ccs/coastalatlas/

Maryland Department of Natural Resources: Climate Change
http://dnr.maryland.gov/dnrnews/infocus/climatechange.asp

Maryland Department of Natural Resources: Habitat Restoration and Conservation
http://www.dnr.state.md.us/ccs/restoration.asp

Maryland Department of Natural Resources: Aquaculture Siting Tool
http://dnrweb.dnr.state.md.us/fisheries/aquatool/aquatool.asp

Chesapeake Bay Watershed Public Access Plan
http://www.baygateways.net/PublicAccess/

Appendix A

Coastal Restoration Assessment and Data Collection

Riparian Buffer Models

Parameter	Data Source(s)	Model	Processing Notes
Land Use Land Cover	2010 Maryland Department of Planning	General	Exclude unsuitable areas; buffer open water
Forest Cover	2007 National Agriculture Imagery Program	General	Exclude forested areas
Wetland Cover	2010 MD Department of Natural Resources / National Wetland Inventory	General	Include Palustrine wetlands; exclude all other wetland areas
Hydrology	2013 University of Maryland Stream Drainage Network; 1:24,000 USGS National Hydrography Dataset; 2006 Eastern Shore Regional GIS Cooperative tax ditches	General	Buffer streams/ditches
Floodplain	FEMA Q3 Floodplains	Priority	Identify 100 and 500 year floodplains
Hydrogeomorphic Regions	2000 USGS Hydrogeomorphic Regions	Priority	Reclassify on linear scale according to Bay program efficiency ratios for nitrogen and phosphorus removal
Elevation	10-meter National Elevation Dataset	Priority	Calculate percent slope; identify areas downslope of agricultural sites; identify high transport areas
Soils	2013 NRCS Soil Survey Geographic Database (SSURGO)	Priority	Identify drainage class and erodible soils

Wetland Restoration Models

Parameter	Data Source(s)	Model	Processing Notes
Land Use Land Cover	2010 Maryland Department of Planning	General	Exclude unsuitable areas; buffer open water
Forest Cover	2007 National Agriculture Imagery Program	General	Exclude forested areas
Wetland Cover	2010 MD Department of Natural Resources / National Wetland Inventory	General	Exclude wetland areas
Hydrology	2013 University of Maryland Stream Drainage Network; 1:24,000 USGS National Hydrography Dataset	Priority	Identify headwaters and adjacent areas
Floodplain	FEMA Q3 Floodplains	Priority	Identify 100 and 500 year floodplains
Hydrogeomorphic Regions	2000 USGS Hydrogeomorphic Regions	Priority	Reclassify on linear scale according to Bay program efficiency ratios for nitrogen and phosphorus removal
Elevation	10-meter National Elevation Dataset	Priority	Identify wetland drainage areas
Soils	2013 Gridded Soil Survey Geographic Database (gSSURGO), Potential wetland soil landscape	Priority	Identify potential wetland soils; identify drainage class and erodible soils

Appendix B

General Model Results: County Riparian Buffer and Wetland Restoration Opportunities

General restoration opportunities were identified by coastal county based on land use/land cover, hydrology, and soil characteristics.

Natural Filter Opportunities

County	BMP Acreage		
	Stream Buffer Opportunities	Ditch Buffer Opportunities	Wetland Restoration Opportunities
Anne Arundel	12,444	0	14,132
Baltimore	13,760	0	27,103
Baltimore City	4,606	0	3,214
Calvert	4,479	0	5,898
Caroline	7,224	1,647	41,689
Cecil	5,383	0	40,205
Charles	4,921	1	38,517
Dorchester	12,298	1,276	73,741
Harford	18,521	48	27,739
Kent	8,361	9	61,142
Prince Georges	17,195	0	26,149
Queen Anne's	11,718	275	58,157
Somerset	3,633	416	37,282
St. Mary's	11,054	12	13,344
Talbot	15,013	183	68,760
Wicomico	4,475	1,493	56,752
Worcester	8,512	3,354	68,556

Priority Model Results: Nutrient Removal Hotspots for Pilot Subwatersheds

Priority restoration opportunities were identified for 3 pilot areas across Maryland's coastal zone. Subwatersheds were selected to capture a range of land use/land cover, slope, and restoration opportunities. Priority areas were selected based on factors related to nutrient source, nutrient transport, and nutrient processing.

Riparian Buffer Priority Areas

County	Subwatershed	MD HUC 8	Nitrogen Removal Acreage			Phosphorus/Sediment Removal Acreage		
			High Tier	Medium Tier	Low Tier	High Tier	Medium Tier	Low Tier
Harford	Deer Creek	2120202	949	2,639	3,970	902	2,230	4,424
Talbot	Lower Choptank	2130403	586	2,424	5,340	928	2,702	4,720
Worcester	Chincoteague	2130106	109	418	675	112	377	712
		Total Acreage:	1,644	5,480	9,985	1,943	5,309	9,856

Wetland Restoration Priority Areas

County	Subwatershed	MD HUC 8	Nutrient Removal Acreage		
			High Tier	Medium Tier	Low Tier
Harford	Deer Creek	2120202	820	2,259	3,278
Talbot	Lower Choptank	2130403	1,866	12,040	16,237
Worcester	Chincoteague	2130106	329	2,134	4,097
		Total Acreage:	3,015	16,432	23,611

Spatial Data are available at MD DNR Coastal Atlas Shorelines Mapper:
http://www.dnr.state.md.us/ccs/coastalatlas/shorelines.asp

NOTE: These opportunities include all lands regardless of roads, major utilities, building footprints, etc.

Appendix C

Maryland's Natural Filter BMP Screen: Integrating broader state restoration and conservation priorities into BMP implementation decisions.

Project targeting, prioritization, and selection are integral parts of DNR's in-house habitat restoration and conservation efforts. A number of GIS-based targeting exercises exist to identify and prioritize areas and/or watersheds where streams, waterways, wetlands, and habitats are degraded and qualify for restoration. The following screening process can be used throughout targeting exercises to 1) identify sites that align with broader DNR programmatic priorities, and 2) flag sites with potential programmatic, ecological, or cultural and historic conflicts. This screen selects for sites with the potential for long life-spans and ecosystem-wide benefits. Because project objectives are site-specific, users may limit the number sites under consideration based on any or all of the below factors. This screen serves as an additional tool to help with decision-making and final site selection.

A. **Restoration Potential:** *Identify restoration potential to ensure selected sites will survive over the long term. We aim to provide water quality and habitat benefits throughout the project's life-span, whether the project is used for a set timeframe or indefinitely. Select for sites with the greatest recovery potential.*

1. Are the land use, hydrology, and/or soil characteristics appropriate for the selected project?

    a. Within opportunities identified by the general natural filter BMP targeting model [62] or the Watershed Resources Registry.[63]

    b. Outside the GIS-identified opportunities but restoration potential confirmed by field visit/s (i.e. on-site evaluation of land use, hydrology, and/or soil characteristics).

2. Does the site fall within priority watersheds?

    a. Within a Biological Restoration Initiative Watershed. These watersheds contain biologically impaired waters with high potential for removal from Maryland's 303(d) list of impaired streams.[64] +1

3. Do plans for adjacent or upstream future land use/development complement the project's success?

    a. No adjacent or upstream land use change is anticipated. +1

B. **Water Quality Improvement:** *To improve the health of Maryland's estuarine systems, water quality goals were developed through a Total Maximum Daily Load (TMDL) framework. Natural filter projects offer a means of reducing nitrogen, phosphorus, and sediment loads into the Chesapeake Bay. To help meet water quality goals, identify restoration sites that will best reduce nutrient loading.*

1. Are the land use, landscape, hydrology, soil, and elevation characteristics appropriate for enhanced nutrient removal?

    a. Within opportunities identified by the priority natural filter BMP targeting model.

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62 Maryland Department of Natural Resources. Water Quality and Climate Change. Website http://bit.ly/1jhYctg
63 Watershed Resources Registry. Website http://watershedresourcesregistry.com/home.html
64 Maryland Department of the Environment. Biological Restoration Initiative. Website http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Pages/programs/waterprograms/tmdl/implementation.aspx#bioresti ni

1. Low Priority +2
2. Medium Priority +3
3. High Priority +4

b. Within high nutrient loading watersheds.
   1. Trust Fund Priority Watershed – Medium +1
   2. Trust Fund Priority Watershed – High +1.5

C. **Conservation Value:** *The State protects and/or manages land for recreational, cultural, environmental, and scenic purposes through the Program Open Space, Rural Legacy, and Maryland Environmental Trust programs. Restoring land within these protected landscapes will enhance their value while planning for future habitat and species migration needs and increasing coastal resiliency.*

1. Does the site fall within protected lands?

   a. Within agricultural or conservation easements, or state owned/managed protected lands. +1

D. **Ecological Value:** *Maryland has developed a number of data layers to target management efforts in areas of high ecological value. Restoring water quality, habitat, and natural landscapes within or adjacent to these areas will enhance overall watershed health while aiding future habitat and species migration.*

1. Does the site fall within or adjacent to targeted or protected areas?

   a. Within Greenprint Targeted Ecological Areas (TEAs).[65] +3
   b. Adjacent to TEAs. +1.5
   c. Adjacent to easements, state owned/managed protected lands, previously restored sites, or historic/cultural sites. +1.5
   d. Outside TEAs, but within or adjacent to Green Infrastructure.[66] +1
   e. Outside TEAs, but within stronghold watersheds. +1
   f. Outside TEAs, but within or adjacent to wildlife/rare species habitat. +1
   g. Outside TEAs, but within High Priority Blue Infrastructure watersheds. +1
   h. Outside TEAs, but within High Priority Forest Watershed (≥ 30). +1
   i. Within a Tier II watershed.[67] These watersheds exceed minimum water quality standards. +1

2. Does the site fall within targeted watersheds for fisheries habitat restoration?

   a. Within a watershed containing 5 – 15% impervious surface. Recovery potential becomes marginal at > 15% +2

E. **Climate Change:** *Over the next century, Maryland expects increased winter-spring precipitation and runoff, warmer air and water temperatures, and relative sea level rise of at least 3.7 feet.[68] Projected impacts are based on the best available science for the Mid-Atlantic Region. As sea level rises, inundation and saltwater intrusion*

65 Maryland Smart, Green & Growing. Greenprint. Website http://www.greenprint.maryland.gov/faq.asp
66 Maryland Merlin Metadata. Green Infrastructure Hubs and Corridors. Website http://www.mdmerlin.net/metadata/brief/GIhub_corridor.html
67 Maryland Department of the Environment. Tier II High Quality Waters Maps. Website http://www.mde.state.md.us/programs/Water/TMDL/Water%20Quality%20Standards/Pages/HighQualityWatersMap.aspx
68 Boesch, D.F. et al. 2008. Comprehensive Assessment of Climate Change Impacts in Maryland. Maryland Commission on Climate Change.; Boesch, D.F., L.P. Atkinson, W.C. Boicourt, J.D. Boon, D.R. Cahoon, R.A. Dalrymple, T. Ezer, B.P. Horton, Z.P. Johnson, R.E. Kopp, M. Li, R.H. Moss, A. Parris, C.K. Sommerfield. 2013. Updating Maryland's Sea-level Rise Projections. Special Report of the Scientific and Technical Working Group to the Maryland Climate Change Commission, 22 pp. University of Maryland Center for Environmental Science, Cambridge, MD

will alter the current coastal landscape. Restoration efforts should not be prioritized in areas at risk of permanent inundation. Maryland has identified potential wetland migration areas based on sea level rise projections for 2050 and 2100.[69] *By conducting restoration activities within or adjacent to these areas, Maryland will facilitate future wetland and habitat migration while increasing wetland connectivity.*

1. Is the site resilient to climate change?
   a. > 2 foot elevation. +1
   b. < 2 foot elevation with room for migration. +0.5
   c. Within a wetland migration area. +2
   d. Adjacent to a wetland migration area. +1

F. **Potential Conflicts and Concerns:** *Sites with potential programmatic, ecological, or historic conflicts should be flagged for more in-depth review before proceeding. If one or more of these factors are applicable, then project design or construction may be impacted.*

1. Is the site within a sensitive species project review area?[70]
   These areas may contain habitats of special interest (i.e. bog turtles, tiger beetles, state plants, etc.) that could be impacted by restoration activities.

2. Does the site fall within a wellhead protection area (WHPA)?
   Excavation and construction may impact the natural infiltration capability or soils within WHPAs by reducing the depth to water table. While construction may impact natural soil infiltration, restoration within WHPAs can also improve well water quality if restoration occurs at sites that were previously pollutant sources – such as agricultural lands – or if the restoration site draws groundwater for additional filtration before entering wells.

3. Is the site adjacent to submerged aquatic vegetation (SAV), potential SAV habitat, shellfish, oyster beds, wetlands, or beach dune habitat?
   Construction activities may impact sensitive environments.

4. Does the site contain cultural or historic components?
   Projects should avoid, reduce, or mitigate adverse effects to historic and/or cultural sites.

5. Does the site fall within 0-2 feet of sea level?
   These areas may be at risk of permanent inundation if conditions are not conducive for migration.

6. Does the site have potential barriers to habitat migration, such as hardened shorelines, bare bank cover, steep bank height, high erosion rates, or impervious surfaces?
   Migration potential is an essential component for any project to ensure long-term benefits.

G. **Outreach Needs:** *Sites within privately owned lands may require a strategic outreach plan.*

1. Does the site fall outside of federal, state, or county owned lands?

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69 Papiez, C. 2012. Coastal Land Conservation in Maryland: Targeting Tools and Techniques for Sea Level Rise Adaptation and Response.
70 Sensitive Species Project Review Areas represents the general locations of documented rare, threatened and endangered species. This data layer contains buffered polygons and does not delineate or strictly represent habitats of threatened and endangered species. The data layer incorporates various types of regulated areas under the Critical Area Criteria and other areas of concern statewide, including: Natural Heritage Areas, Listed Species Sites, Other or Locally Significant Habitat Areas, Colonial Waterbird Sites, Nontidal Wetlands of Special State Concern, and Geographic Areas of Particular Concern.

Appendix D

Maryland's Companion Data Guide for Restoration Targeting

The following data layers are available on DNR, statewide, or national platforms to aid in site selection.

Theme	Data Layer	Source	Description	Public Location
Restoration Potential	DNR Natural Filter Targeting	MD DNR	DNR identified general opportunities for riparian buffer and wetland restoration BMPs based on land use/cover, hydrology, and soil conditions.	MD iMAP, Coastal Atlas
	Riparian/Wetland Restoration Potential	Watershed Resources Registry (WRR)	The WRR identifies natural resource areas that are a priority for preservation and restoration. The registry includes suitability analyses for upland, wetland, and riparian preservation/ restoration.	WRR Website
	Priority Areas for Wetland Restoration, Preservation, and Mitigation	MDE	Between 2004 and 2006, MDE released wetland prioritization guidance based on soil, land use/cover, hydrology, water quality, wellhead protection areas, ecologically important areas, zoning, protected lands, and Green Infrastructure.	MDE Wetlands and Waterways Website
	Biological Restoration Initiative Watersheds	MDE	These watersheds contain biologically impaired waters with high potential for removal from Maryland's 303(d) list of impaired streams.	MDE TMDL Implementation Website
Water Quality Improvement	Natural Filter Priorities for Water Quality	MD DNR	DNR developed a priority model to target high priority riparian buffer and wetland restoration sites. High priority sites have a greater potential of reducing nitrogen and/or phosphorus and sediment loads into receiving waters.	MD iMAP, Coastal Atlas
	Trust Fund Priority Watersheds	MD DNR	Priority watersheds for BMP implementation used to reduce nonpoint source pollution were selected using a Water Quality Index and the SPARROW watershed model. Identified watersheds are targeted to achieve the largest reduction of nonpoint nutrient and sediment inputs to receiving waters.	DNR Chesapeake and Atlantic Coastal Bays Trust Fund Website
Conservation Value	Agricultural Easements	MDA	These easements restrict development on prime farmland and woodland.	MD iMAP
	Conservation Easements	MD DNR	These easements protect MD land by restricting the future uses of a landowner's property.	MD iMAP
	State owned/managed protected lands	MD DNR	State-owned property	MD iMAP
Ecological Value	Targeted Ecological Areas	MD DNR	Lands and watersheds of high ecological value that have been identified as conservation priorities.	MD iMAP
	Green Infrastructure	MD DNR	Maryland's remaining hubs and corridors of forests and wetlands.	MD iMAP, Coastal Atlas
	Stronghold Watersheds	MD DNR	Watersheds that support high fish, amphibian, reptile and mussel biodiversity.	Internal
	Wildlife/Rare Species Habitat (BioNet)	MD DNR	Areas that support rare, threatened, and endangered species; rare and high quality plant and animal communities; species of Greatest Conservation Need; wildlife concentrations; and important habitats needed for wildlife migration and movements related to climate change.	Internal
	Blue Infrastructure	MD DNR	High quality coastal habitat, critical natural resources and associated human uses in tidal waters and near-shore areas.	Coastal Atlas
	Priority Forest Watersheds	MD DNR	Forest watersheds that are the most effective at reducing pollution and preserving water quality.	DNR Watershed-based Forest Management and Restoration Website
	Tier II Watersheds	MDE	Watersheds that support high quality streams under regulatory anti-degradation protection.	MDE Tier II High Quality Waters Map Website
	Percent Impervious Surface	National Land Cover Database	Estimated percent impervious cover over 30-meter grids.	Digital Coast

Theme	Data Layer	Source	Description	Public Location
Climate Change	Sea Level Rise Wetland Adaptation Areas	MD DNR	Potential wetland migration areas based on projections from the Sea Level Affecting Marshes Model (SLAMM). These areas are likely to be important future wetland habitats.	MD iMAP, Coastal Atlas
	Sea Level Rise Inundation Areas	MD DNR	Inundation risk areas based on 2050 and 2100 sea level rise projections. Inundation zones include 0 - 2 feet, 2 - 5 feet, and 5 - 10 feet.	MD iMAP, Coastal Atlas
Other	Sensitive Species Project Review Area	MD DNR	General locations of documented rare, threatened and endangered species.	MD iMAP
	Wellhead Protection Area	MDE	Areas surrounding a well where management is needed to protect public drinking water supplies.	Internal
	Submerged Aquatic Vegetation (SAV)	MD DNR	SAV coverage by year.	MD iMAP, Coastal Atlas
	Shellfish Habitat	MD DNR	General shellfish habitat, reserves, sanctuaries, and bars.	MD iMAP, Coastal Atlas
	Current Wetland Cover	NWI; MD DNR	Wetland Coverage	MD iMAP, Coastal Atlas
	Cultural/Historic Sites	MHT	Sites of historic and/or cultural significance.	Internal, National Register of Historic Places

CLIMATE CONSIDERATIONS FOR HABITAT RESTORATION

HABITAT RESTORATION IN A CHANGING CLIMATE

The Maryland Department of Natural Resources Chesapeake and Coastal Service (CCS) provides the science, financing, and technical services that State and local partners need to meet their water quality and habitat restoration goals. CCS's Habitat Restoration and Conservation Division works with federal, state, and local partners to apply innovative best management practices that reduce harmful run-off, increase coastal resiliency, and provide wildlife habitat through restoration, creation, and enhancement of riparian and stream systems. With increasing climate change concerns, CCS is adjusting restoration and conservation efforts to incorporate climate into decision-making.

Maryland's Changing Climate

Over the next century, Maryland expects increased winter-spring precipitation and run-off, warmer air and water temperatures, and relative sea level rise of at least 3.7 feet. One hundred years of data confirms that Maryland is warming on average by 1.8°F and by as much as 3.6°F in the winter. Wetter conditions have become prevalent in March and September, while July and August have become drier. These trends will impact the success and efficiency of restoration practices along our dynamic coast.

Habitat restoration guidance in a changing climate

- Build coastal resiliency through living shoreline implementation, invasive species management, or vegetation selection for future climate conditions.
- Employ a landscape approach to restoration and conservation. Maintain green corridors, protect against fragmentation, and facilitate habitat migration.
- Maintain, identify, and protect new marsh migration corridors.
- Create habitat mosaics that may be more resilient to climate change impacts, such as sea level rise.
- Reconnect streams with their floodplains to reduce the flashiness of storm flows, improve water quality, and increase habitat benefits.
- Understand interactions between climate change and other stressors that impact ecosystems, such as development or landscape change.
- Incorporate uncertainty into project planning and design by planning for multiple climate scenarios.
- Target areas that will be sustainable under future conditions.
- Consider slope and site elevation in planning and design to aid in vegetation migration and mitigate the immediate impacts of sea level rise.
- Monitor, review, and revise projects as needed. Acquire baseline data, such as water and surface elevations or vegetation transects.

EXISTING PRACTICES PROVIDE A VALUE ADDED BENEFIT FOR REDUCING CLIMATE RISK

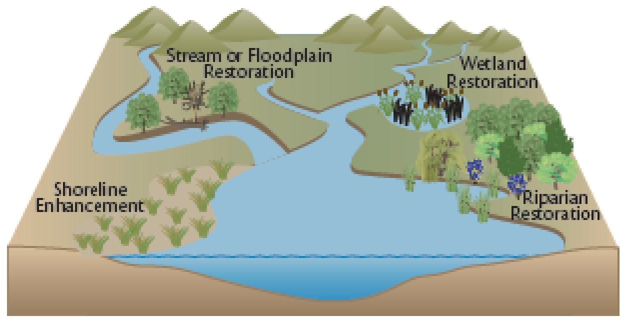
Management Practice	Nutrient Benefit	Climate Resilience Benefit				
		Temperature Reduction	Storm Buffer	Drought Buffer	Sea Level Rise Buffer	Wildlife Corridor
Stream Restoration	●	◖	◖			●
Forest Buffer	●	●	●			●
Wetlands	●		●	●	●	●
Shoreline Erosion Control	●		●		●	
Vegetated Open Channel	●		●			

* Practices designated with a ◖ potentially buffer against climate impacts and could be enhanced through modifications suggested in this document.

ADDRESSING CLIMATE CHANGE WITHIN RESTORATION PROJECTS

Adaptive management supports restoration and enhancement activities

CCS conducts in-house restoration projects to address coastal resiliency, water quality, and wildlife habitat. Technical and financial assistance is also provided to federal, state, county and municipal governments. A general project implementation process directs most activities related to shoreline, riparian, stream, floodplain, wetland, and aquatic enhancement and restoration. Throughout project planning and implementation, an adaptive management framework is used to consider and respond to climate impacts.



Key Project Steps	Climate Considerations
Project Targeting & Prioritization	Targeting and prioritization can identify restoration sites at most risk to climate change impacts, or highlight where restoration may enhance coastal resiliency. Sea level rise, migration potential, and other climate factors are considered during site selection.
Site Analysis	Sea level rise data are referenced and considered in living shoreline and other tidally-influenced restoration projects. Site-specific factors, such as elevation or floodplain presence, are noted during field visits to predict future conditions, inform resilient project designs, and ensure long-term project success.
Design	Design criteria can address climate impacts and improve project resilience. Criteria include species selection, hydrologic and floodplain connectivity, infiltration, and the maximization of wetland areas. These criteria address species diversity and natural succession, on-site water storage capacity, and stormflow flashiness. CCS can alter designs to handle precipitation events or hydrology fluctuations.
Environmental Review	Reviewers consider sea level rise and other climate factors for projects with long expected life spans. Projects involving sensitive species and habitats, such as coldwater streams, are addressed during project review because climate impacts may significantly alter these sites.
Project Construction	CCS addresses changing environmental conditions during project construction as needed by reacting to high intensity rain events, seches, tropical storms, or other weather events that impact construction progress and timing. As the climate becomes less predictable, CCS will continue utilizing adaptive management techniques within project planning and construction.
Monitoring	Monitoring and adaptive management allow CCS to address climate change during current and future restoration projects by providing for perpetual design improvements. If the vegetation or structural stability of a project is threatened, then actions can be taken to ensure long-term project success.

CLIMATE TOOLS AND RESOURCES

The following data are freely available on CCS's online data viewing platform - The Coastal Atlas (http://dnr.maryland.gov/ccs/coastalatlas/) - and can be used to consider climate change throughout project planning and implementation.

1. Sea Level Rise Vulnerability: These vulnerability layers display 2, 5, and 10-feet inundation risk zones.
2. Sea Level Affecting Marshes Model (SLAMM): SLAMM predicts future shoreline modifications and wetland change for 16 various wetland classifications.
3. Erosion Vulnerability Assessment Tool (EVA): EVA is a shoreline planning tool developed to identify shorelines with historic patterns of instability, as well as shorelines that support natural, social, or economic resources.
4. Storm Surge Risk: The US Army Corps of Engineers completed two hurricane evacuation studies for the eastern and western shores of Maryland. Storm surge areas were developed using the Sea, Level, and Overland Surges from Hurricanes (SLOSH) model.

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Appendix F

Oyster Aquaculture Assessment and Data Collection

Oyster Aquaculture Environmental Model Parameters

Parameter	Data Source(s)	General Range	Preferred Range	Culture	Processing Notes
Dissolved Oxygen	2002 - 2011 Chesapeake Bay Program Interpolated Dissolved Oxygen (mg/L)	> 2mg/L average bottom DO in any summer month at least 6 of the last 10 years (2002 - 2011, June - August).	≥ 4 mg/L summer average bottom DO	B, C, F	Adult oysters are resilient to low DO over short periods. Because daily data are not available at the Bay-wide scale, average monthly interpolated values were used to identify hypoxic zones. Zones were excluded if they contained ≤ 2 mg/L average bottom DO in any summer month (June - August) at least 5 of the last 10 years. Current lease locations were compared to these data to ensure that the parameter range wasn't too strict.
Salinity	2002 - 2011 Chesapeake Bay Program Interpolated Salinity (ppt)	> 5 ppt average bottom salinity (April - October)	8 - 12 ppt average	B, C	Preferred ranges indicate conditions with reduced disease threat and normal to optimal growth during the growing season. Aquaculture is feasible at all salinities greater than 5 ppt, but preferences depend on market demand and disease management.
			8 - 25 ppt average	F, triploid	Because floating and triploid cultures grow faster, disease risk is reduced and a wider salinity range is possible.
Temperature	2002 - 2011 Chesapeake Bay Program Interpolated Temperature (°C)	≤ 29°C bottom temperature in any summer month (June - August)	N/A	B, C	Warmer temperatures yield higher filtration rates and optimal growth, but high temperatures also correlate to low DO waters. Temperature is not limiting for oyster survival unless coupled with low DO, salinity and other factors that cause mortality or disease. Therefore, no preferred values exist for temperature. Temperature may play a larger role in as climate change impacts our coastal waters.
		≤ 29°C surface temperature in any summer month (June - August)	N/A	F	Surface temperature was evaluated for floating cultures.
Bacteria	MDE, July 2013	Approved, Conditional, and Restricted Harvest Areas	Non-Conditional Approved Harvest Areas	B, C, F	MDE identifies nonshellfish harvest areas, which are unavailable for oyster aquaculture or harvest. Harvest is allowed within approved, conditional, and restricted areas. Conditional Harvest Areas are conditionally open based on bacteria levels. Restricted Harvest Areas are open but require a relay period before shellfish consumption.
Substrate	2013 NOAA Oyster Decision Support Tool	Hard, Firm, Mixed, Gravel, Sand-Mud Complex, Unclassified	Hard/shell > mixed > gravel > sand-mud complex/unclassified	B	While hard bottom requires less maintenance, current MD leases are found on sand, mud, and mixed sand/mud substrate. Unclassified areas may or may not be suitable, so they are included as potential sites at this time.
		Hard, Firm, Mixed, Gravel, Sand, Sand-Mud Complex, Unclassified	Hard/shell, mixed, sand, gravel > other	C	Caged aquaculture is feasible on sand substrate in addition to suitable bottom culture substrate. While cages sink in soft muddy bottom and settle on sandy bottom, they can be designed or modified to work in thin mud or sand.
		All	NA	F	Substrate is not a factor.

Oyster Aquaculture Policy Model Parameters

Requirement	Data Source	Notes
Outside 5 year Submerged Aquatic Vegetation (SAV) zone	DNR; VIMS	Merged 2008 - 2012 SAV layers.
Outside 6 year DNR/Oyster Recovery Partnership Planting Area	DNR	Merged 2006 - 2011 planting areas.
Outside 150' buffer of Public Shellfish Fishery Area (PSFA)	DNR	Buffered PSFAs.
Outside 150' buffer from Harvest Reserve Area	DNR	Buffered harvest reserve areas.
Outside 150' buffer from active pound net sites	DNR	Buffered 2012 pound net locations.
Outside 150' buffer from historic (Yates) bars if within a sanctuary	DNR	Buffered Yates bars that fall within sanctuaries.
Outside Protected Lands	DNR	
Outside 150' buffer of federal navigation channels	DNR	Buffered available navigation channel data. Note that this factor is evaluated at the federal level by the Army Corps of Engineers and the Coast Guard.
Outside 50' buffer of shoreline	SHA	Buffered State Highway Administration shoreline. Aquaculture may be allowed within this zone if permission is granted from the riparian owner. Due to shoreline fluctuations, this factor should be checked manually using field visits or recent satellite imagery.
Outside Maryland Artificial Reef Initiative Sites	DNR	
Cultural/Historical resources absent	DNR	Merged available cultural and historic data (MD Historic Inventory, MHT Archeological Sites, MHT Easements, National Register of Historic Places). These sites were eliminated from the Priority model only. Note that this factor requires review by the Maryland Historical Trust. These sites are not all inclusive and do not necessarily prevent aquaculture. Because most of these sites are land-based. the shoreline buffer exclusion should remove the majority from each model output.
Outside Potomac River Mainstem	DNR	Not currently available for leasing.
Bathymetry < 25 feet.	DNR	No depth requirements exist but deeper areas may have access and DO issues. Most leases occur nearshore within easy access.
Outside marina buffers*****	MDE; DNR	Aquaculture is prohibited around marinas, with the exclusion area dependent on slip number. This data layer is currently under development. Once completed, it can be used to exclude sites from the model output.

*** Spatial data not yet available**

Appendix G

Oyster Aquaculture Targeting Results

Oyster Aquaculture Opportunities*

Culture	**Acreage**	
	General	Priority
Bottom	81,174	38,018
Caged	275,494	313,678
Floating	432,489	224,705

*may overlap

Priority Bottom Culture Opportunities

Priority	**Bottom Substrate**	**Acreage**
Suitable	Sand-mud complex or unclassified	5,051
More Suitable	Gravel	< 1
Very Suitable	Mixed	17,747
Most Suitable	Hard, Shell	15,220

Spatial data are available on Maryland's ArcGIS Online platform:
"Oyster Aquaculture Opportunities" at http://bit.ly/Uao6ch

NOTE: These outputs can be further refined by considering chlorophyll, flow, seston, wave action, spatfall, algal bloom threats, etc. Outputs rely on the best available bottom substrate data.

Appendix H

CHESAPEAKE BAY RECREATIONAL USE LIST
Recreational Use Mapping Project
Pilot Area: Choptank River
Chesapeake College, Wye Mills, MD
January 7 & 8, 2014

Human Use Categories for Coastal Planning

Marylanders use the Chesapeake Bay in many ways. For some uses, reliable data exist and those data layers are viewable on Maryland's Coastal Atlas (dnr.maryland.gov/ccs/coastalatlas/). Two categories of human uses exist where more data are needed: recreational and cultural uses. A technique called Participatory GIS (PGIS) is proving very useful for mapping and collecting data on recreational uses. The tables below outline the types of recreational uses that Chesapeake Bay PGIS workshops will address.

Boating for Hire Uses

Use name	Includes	Appropriate Mapping Scale Min	Max
Guided fishing	Guided (charter) activities related to fishing led by charter vessels	1:250,000	1:500,000
Guided diving/snorkeling	Guided (charter) activities related to recreational dive or snorkel charters	1:100,000	1:250,000
For hire party cruises	Charter activity for cruises	1:250,000	1:500,000
For hire educational cruises	Charter activity for educational cruises	1:250,000	1:500,000
Guided wildlife viewing	Guided (charter) activities focused on wildlife viewing	1:250,000	1:500,000
Guided scenic viewing	Guided (charter) activities focused on scenic or natural area viewing, photography, historic perspective	1:250,000	1:500,000
Charter transport	Charter activity related to transport services, ferry boats, etc	1:250,000	1:500,000
Other			

Recreational Fishing/Hunting Uses

Use name	Includes	Appropriate Mapping Scale Min	Max
Recreational kayak and non-motorized vessel fishing	Any fishing activities from private non-motorized vessels	1:50,000	1:100,000
Recreational fishing from motorized vessels	Any fishing activities from private motorized vessels, including tournaments	1:250,000	1:500,000
Recreational shore fishing	Recreational fishing from beaches, piers	1:50,000	1:100,000
Recreational crabbing	Any crabbing activities from private motorized vessels or piers	1:50,000	1:100,000
Recreational shellfish harvesting	Digging clams, gathering oysters, shellfish diving; excludes shellfish cultivation	1:50,000	1:100,000
Recreational waterfowl hunting	Hunting from shore, from blinds and from boats	1:50,000	1:100,000
Recreational muskrat trapping	Trapping activities from shore and boats	1:50,000	1:100,000
Other			

General Recreational Uses – Non-consumptive

Use name	Includes	Appropriate Mapping Scale Min	Max
Motorized boating	Personal watercraft, outboard motors, private motorized vehicles, cigarette boats, racing, mooring, jet skiing	1:100,000	1:500,000
Paddling	Kayaking, canoeing, rowing, paddle-boarding, outrigger paddling	1:50,000	1:100,000
Sailing	Sailboats, overnight anchoring, mooring, races, regattas	1:250,000	1:500,000
Scuba/snorkeling/diving	Scuba diving, tethered diving, snorkeling, free diving	1:25,000	1:50,000
Shore Use	Islands, marshes, marsh islands, and beach visitation; all non-consumptive uses such as birdwatching, sunbathing, picnicking, beach combing, etc.	1:25,000	1:50,000
Wildlife viewing from non-motorized vessels	Wildlife viewing from kayaks, canoes, or other non-motorized vehicles.	1:25,000	1:50,000
Surface water sports	Wind-surfing, kite-surfing, water skiing	1:25,000	1:50,000
Swimming	Short and long distance surface swimming any distance from shore	1:25,000	1:50,000
Other			

1:25,000 (1 inch = about 0.4 miles) 1:50,000 (1 inch = about 0.8 miles) 1:100,000 (1 inch = about 1.6 miles)
1:250,000 (1 inch = about 4 miles) 1:500,000 (1 inch = about 8 miles) 1:1,000,000 (1 inch = about 16 miles)

Cultural Uses

In a recent statewide recreational use survey, “visiting historical sites” was identified as one of the top two recreational activities. Participants will be asked to help define and describe the relative importance of cultural uses for their region of coast. This information may be used to develop a strategy for collecting cultural use information in the future, or to inform state and county recreation planning.

Use name	Includes	Appropriate Mapping Scale Min	Max
Historic/cultural	Bay areas or views with inherent cultural, traditional, archaeological, religious, spiritual, tribal or historic value	1:250,000	1:500,000
Scenic/natural views	Bay areas or views that provide unique opportunities for photography, historic perspective, visual experience, etc.	1:250,000	1:500,000
Other			

NOTE: These categories may be updated over time as use trends change. Not all of these activities may occur in every tributary.