Forestry and Land Use Sector Modeling

Evaluating Maryland’s natural carbon sequestration potential

This appendix to Maryland's Climate Pollution Reduction Plan (2023) combines three separate reports on Maryland’s natural carbon sequestration potential.

List of Sections

Potential Pathways for Growing the Forest Carbon Sink

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Summary

A set of new modeling scenarios for growing the state's forest carbon sink thru 2031 and 2045 was developed in consultation with DNR and MDE using the state's new remote sensing based forest carbon monitoring system (MDE 2022a, 2022b and 2023). In total, three versions of four scenarios were evaluated. Each scenario considered the potential afforestation/reforestation of a specified area of land, ranging from 12,000-400,000 acres. The "Full" statewide potential for afforestation/reforestation was included as an upper bound only for context. For each scenario, the afforestation/reforestation area was evenly phased in annually throughout its respective planting period, and the associated statewide total forest carbon sequestration rate was quantified.

Method

The carbon sink potential of afforestation/reforestation hinges on several factors, including the area planted, its geographical location, timing, and associated environmental conditions. Here, we estimated the net forest carbon removal rate using the state's new remote sensing based forest carbon monitoring system. More specifically, we used the Ecosystem Demography (ED) model (Hurtt et al. 1998, Moorcroft et al. 2001). The latest version of ED (v3) has been globally calibrated, validated, and incorporated into NASA's Carbon Monitoring System (Hurtt et al. 2019, Ma et al. 2021, 2022 and 2023). Inputs to the model for Maryland included air temperature, precipitation, air humidity from NASA Daymet and MERRA2 reanalysis datasets (Thornton et al. 2016, Gelaro et al. 2017), CO_2 concentration from NOAA CarbonTracker, soil hydraulic properties (Chaney et al. 2016). Using this model and inputs, geospatial estimates of potential future carbon sequestration rate as a function of time were quantified for each scenario.

For each scenario, three methodological versions were explored, each differing in the complexity of underlying modeling assumptions.

- Version 1 used a constant carbon sequestration rate for each unit of planting area, both spatially and temporally.
- Version 2 used variable carbon sequestration rate over time accounting for the effects of forest aging.
- Version 3 used variable carbon sequestration rate over space and time accounting for both spatial differences in potential growth rates and temporal effects of forest aging. This version utilized spatial maps of feasible plantable areas to be considered and resulted in a range of values representing different options for the phasing of planting locations over time.

For Version 3, a map delineating feasible plantable areas was employed in the modeling analyses. This map was generated by combining the NASA CMS 30m high-resolution tree canopy cover map with the USGS NLCD land cover map. In this map, plantable areas are the non-tree fraction of 30 m grids that are categorized as developed-open spaced, pasture, and cropland in NLCD land cover data (Figure 1).

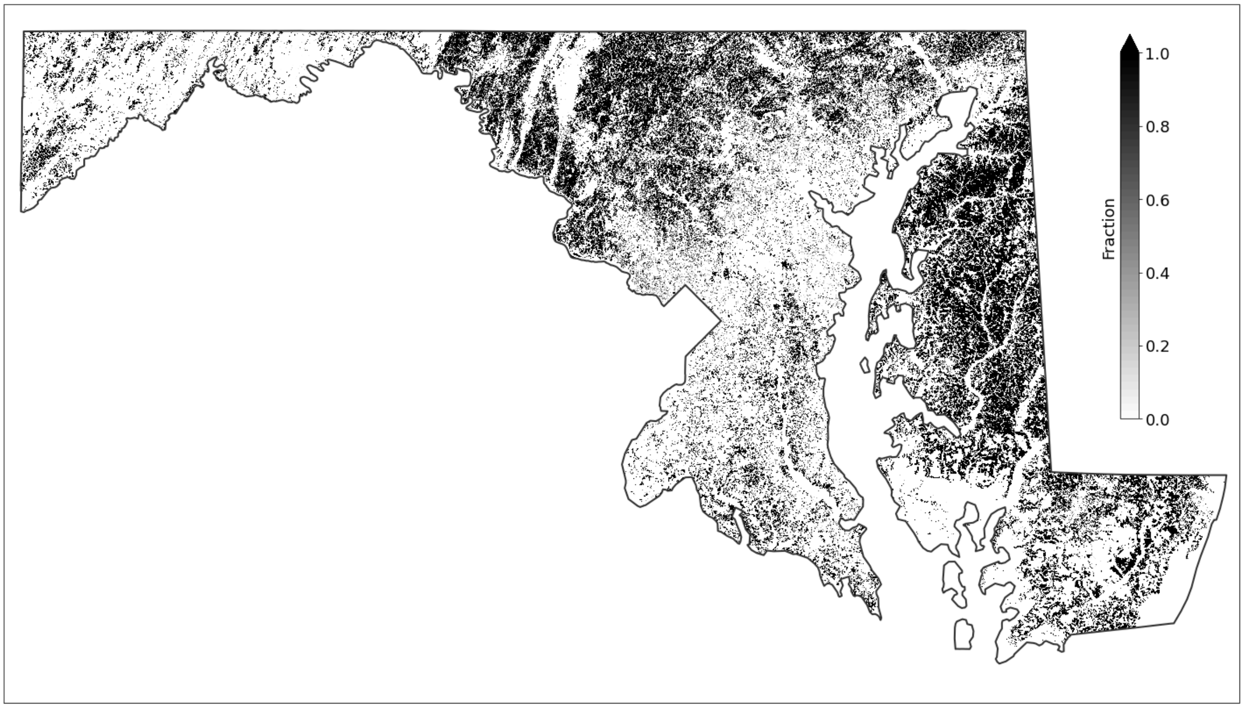

Figure 1. A map of feasible plantable area derived by combining NASA CMS 30m tree canopy cover and USGS NLCD land cover.

Results

The state of Maryland has potential to store additional carbon in forests through afforestation/reforestation activities thru 2031, 2045, and beyond. Table 1 provides a summary of the afforestation/reforestation scenarios considered and their and corresponding estimates of their projected statewide carbon removal in 2031 and 2045 specifically. Figures 2-4 provide quantitative estimates for each scenario annually 2021-2100.

Annual forest carbon sequestration on land ranged from 0.013 - 0.501 MMT CO_2e/yr in 2031, and 0.-1.995 MMT CO_2e/yr in 2045, across all scenarios and model versions (Table 1). The 5M Tree scenario resulted in an estimated 12,000 acres planted and corresponding 0.015-0.051 MMT CO_2e/yr in 2031, and 0.039-0.067 MMT CO_2e/yr in 2045, depending on model version. The 100K scenario resulted in an estimated 100,000 acres planted and corresponding 0.042-0.127 MMT CO_2e/yr in 2031 and 0.370-0.422 MMT CO_2e/yr in 2045. The 200K scenario resulted in an estimated 200,000 acres planted and corresponding 0.013-0.264 MMT CO_2e/yr in 2031, and 0.118-1.017 MMT CO_2e/yr in 2045. The 400K scenario resulted in an estimated 400,000 acres planted and corresponding 0.031-0.501 MMT CO_2e/yr in 2031, and 0.291-1.995 MMT CO_2e/yr in 2045. For context, the full statewide potential was estimated to be 0.048-0.725 in 2031 and 0.474-2.797 MMT CO_2e/yr in 2045.

Scenario Name	Area (x1000 acres)	Planting Period	2031			2045		
			v1	v2	v3	v1	v2	v3
5M Trees[1]	12	2021-2030	-0.048	-0.031	[-0.051, -0.015]	-0.048	-0.057	[-0.067, -0.039]
100K[2]	100	2024-2045	-0.127	-0.056	[-0.101, -0.042]	-0.382	-0.367	[-0.422, -0.370]
200k[2]	200	2024-2045	-0.255	-0.112	[-0.264, -0.013]	-0.764	-0.735	[-1.017, -0.118]
400k[2]	400	2024-2045	-0.509	-0.225	[-0.501, -0.031]	-1.527	-1.469	[-1.995, -0.291]
Full[2]	1992	2024-2100	-0.725	-0.320	[-0.688, -0.048]	-2.174	-2.091	[-2.797, -0.474]

Table 1. Summary of planting scenarios considered in modeling analysis, including planting areas (thousand acres), planting period, and annual carbon sequestration (MMT CO2e/yr) (vegetation + soil) in the years of 2031 and 2045. The 'Full' case includes all available land and is provided only as an upper bound for context. Units for annual carbon sequestration are negative for atmosphere reference. [1] 5 Million Tree initiative [2] Total acres of planting area.

Over the entire interval 2021-2100, model estimates of annual forest carbon sequestration potential increased with scenario of planted area and time up to 2045 when additional planting was assumed to be completed, and either held constant or was projected to decline thereafter due to consideration of tree aging (Figures 2-4).

Figure 2 presents the model results assuming constant carbon sequestration rate for each unit of planting area, both spatially and temporally (Version 1). Scenarios of annual forest carbon sequestration in this case peak in 2045, when new planting is assumed to be complete, and held constant thereafter due to assumption of constant sequestration rate. Estimates of statewide potential continue to increase linearly as planting is assumed to continue thru end of century.

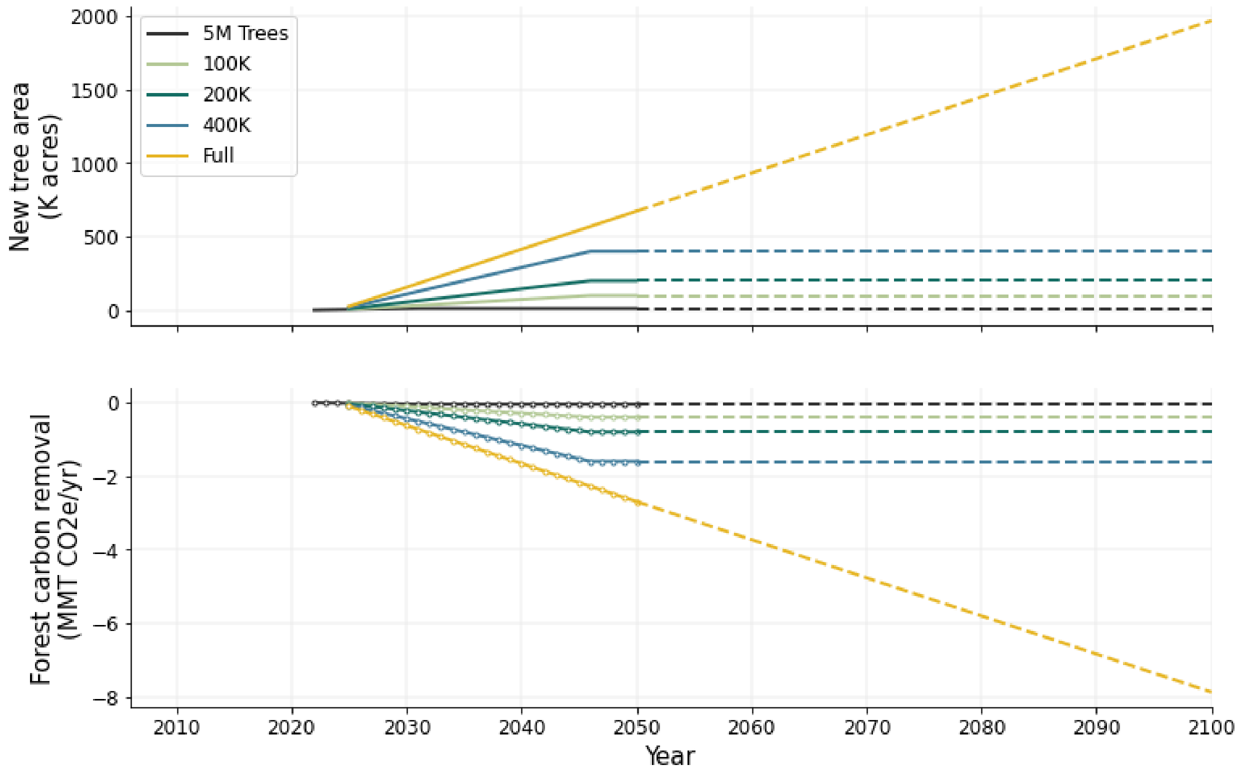

Figure 2. Planting scenarios and corresponding estimates of forest carbon removal- Version 1. (Top panel) Scenarios for new tree area. (Bottom panel) Forest carbon removal. Units for annual carbon sequestration are negative for atmosphere reference.

Figure 3 presents the model results assuming variable carbon sequestration rate over time accounting for the effects of forest aging (version 2). Scenarios of annual forest carbon sequestration potential peak somewhat after 2045, when new planting is assumed to be complete due to delayed maturity, and decline thereafter due to aging. Estimates of statewide potential carbon sequestration continue to increase non-linearly as planting is assumed to continue thru end of century and the effects of aging slow net carbon uptake.

Figure 3. Planting scenarios and corresponding estimates of forest carbon removal- Version 3. (Top panel) Scenarios for new tree area. (Bottom panel) Forest carbon removal. Units for annual carbon sequestration are negative for atmosphere reference.

Figure 4 presents the model results assuming variable carbon sequestration rate over space and time accounting for both spatial differences in potential growth rates and temporal effects of forest aging (Version 3). Like Version 2, model estimates of annual forest carbon sequestration potential peak somewhat after 2045 when new planting is assumed to be complete due to delayed maturity, and decline thereafter due to aging. Estimates of statewide potential carbon sequestration continue to increase non-linearly as planting is assumed to continue thru end of century and the effects of aging slow net carbon uptake. Different options for the phasing of planting locations over space and time resulting in large uncertainties of projected annual carbon sequestration rates.

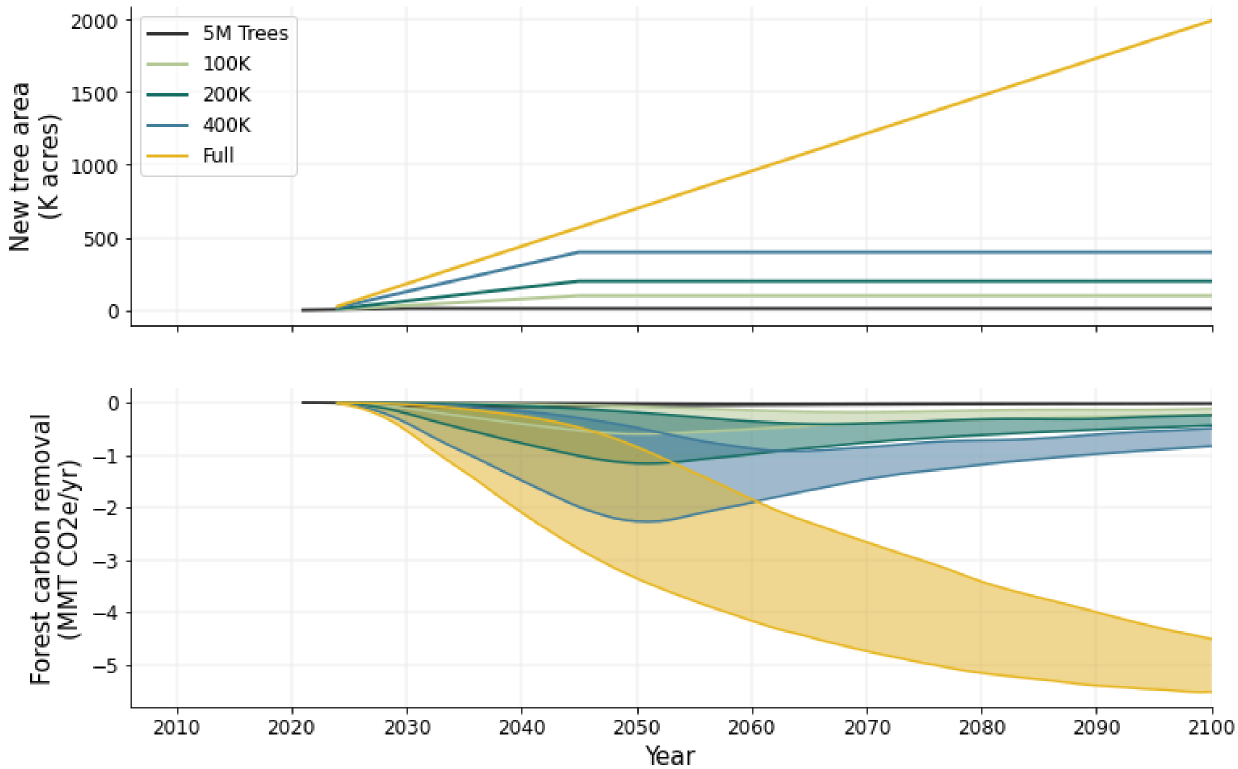

Figure 4. Planting scenarios and corresponding estimates of forest carbon removal- Version 3. (Top panel) Scenarios for new tree area. (Bottom panel) Forest carbon removal. Units for annual carbon sequestration are negative for atmosphere reference.

Acknowledgements

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Quantifying and Growing Maryland's Agricultural Soil Carbon Sink

Maryland Department of the Environment & Maryland Department of Agriculture

Background

Soil carbon refers to the carbon, both organic and inorganic, that exists in soil. This carbon is in flux, with annual net carbon flux being the balance of losses and inputs in any given year. An area that sequesters carbon is known as a carbon sink. Agricultural land use has the potential to both release stored soil carbon, for example when soil is disturbed exposing the stored carbon to oxygen, as well as remove (and sequester) carbon from the atmosphere, for example through photosynthesis in cover crops.

Given commitments to restoring the Chesapeake Bay, Maryland farmers have been building healthier soils for decades through the adoption of best management practices (BMPs). This ongoing investment in our soils reverses historic depletions of soil carbon and helps to meet statewide greenhouse gas (GHG) emissions reduction goals. Maryland has accounted for agricultural soil carbon in its GHG emissions inventory and in current and past GHG emissions reduction plans.

To ensure the additional carbon contributions of Maryland farmers are accurately captured against the broader agricultural soil carbon landscape, the historical and projected estimates of agricultural soil carbon reported in Maryland's Climate Pollution Reduction Plan are based on a new methodology. This new methodology utilizes the United States Department of Agriculture (USDA) and Colorado State University's (CSU) Carbon Management & Emissions Tool, COMET-Farm, a farm-scale GHG accounting tool.

Improved quantification methods were developed through a partnership between Maryland Department of the Environment (MDE), Maryland Department of Agriculture (MDA), U.S. Climate Alliance (USCA), Sierra View Solutions, and Colorado State University. Thanks to a technical assistance grant from the U.S. Climate Alliance (USCA), the partnership was able to integrate state-specific data with COMET-Farm's underlying biogeochemical model to, 1) generate historical annual agricultural soil carbon flux estimates across all cropland, 2) develop a method to quantify annual fluxes for future state inventories, and 3) consider future fluxes under a range of planning scenarios for ongoing implementation of BMPs towards future GHG goals.

The present analysis is limited to cropland and the primary associated in-field BMPs of cover crops, nutrient management, and tillage. Farmer adoption of edge-of-field practices to reduce soil erosion and nutrient runoff, such as grassed waterways and field borders, are not included in this analysis, nor are pasture-based practices. Agencies hope to improve on the analysis in future years to be inclusive of additional BMPs. Of note, while farmers also adopt many forest related BMPs, such as riparian forest buffers, all tree and forest carbon in Maryland is captured separately through forestry modeling for the inventory and Maryland's Climate Pollution Reduction Plan.

Past work

Maryland's previous GHG emissions reduction plan[1] included an analysis of agricultural soil carbon sequestration potential based on USDA COMET-Planner. COMET-Planner is a tool to evaluate the potential carbon sequestration of conservation practices and was created using COMET-Farm. It employs a fixed baseline condition with individual additions of practices to provide regional-average estimates of the change in emissions from adopting BMPs. Unlike COMET-Farm, COMET-Planner does not consider site-specific conditions and is unable to assess the absence of conservation practices. As such, the prior plan only considered the added benefit of future conservation practice implementation, but lacked an accounting of background or baseline carbon flux of all cropland. The present analysis using COMET-Farm directly, reflects the full landscape of Maryland's cropland, including carbon losses, and provides improved resolution both spatially and temporally.

MDE added agricultural soil carbon estimates to Maryland's GHG inventory in 2022 using the Environmental Protection Agency's (EPA) State Inventory Tool (SIT). The EPA's estimate of national agricultural soil carbon flux is based on several methods including the DayCent model (the same biogeochemical model underlying the COMET-Farm) and management activity data combined with country-level emissions factors. The SIT divides the national-level estimates to states based on predetermined 2015 state proportions. This however does not provide adequate state-level specificity nor does it track actual implementation occurring in Maryland. To this end, the accounting methodology presented in this report will be incorporated into a future iteration of Maryland's GHG inventory.

Methodology

Overview

COMET-Farm is a farm-scale GHG accounting tool developed by the Natural Resource Ecology Laboratory at Colorado State University (CSU) in collaboration with USDA. CSU validates their model with field data collected by USDA and other partners. The tool is location and operation specific, allowing users to input a farm through a web-based user interface. Inputs include field locations, management history, crop and livestock information, conservation practices, and fertilizer and fuel use. Outputs include emissions results for soil carbon, carbon dioxide, nitrous oxide, and methane.

COMET-Farm is commonly described as an entity-scale inventory tool. The most comprehensive and direct use of COMET-Farm in developing a statewide agricultural soil carbon inventory would

[1] The 2030 Greenhouse Gas Emissions Reduction Act (GGRA) Plan, 2021.

be to model each and every farm in the state; however, such a statewide farm-level approach would prove difficult given needs of data availability, staff time, and computing power.

A sample-based county-level approach was developed to combine existing county-level land use and management activity data with the site-specific function of COMET-Farm using a sampling approach similar to how COMET-Planner was developed. COMET-Planner features emission reduction coefficients (ERCs) to estimate the potential benefit of implementing conservation practices. The ERCs are determined by modeling a baseline scenario with iterative addition of practices through COMET-Farm, at sample point locations throughout the nation. The sample location results are averaged regionally, per practice. While COMET-Planner provides an initial estimate for planning purposes, there are downsides to using it for a comprehensive statewide assessment: 1) ERCs are for individual practices so do not consider collective impact with other practices, 2) ERCs are static in time so do not consider soil saturation effects, and 3) while COMET-Planner provides the potential GHG benefit of practice adoption from an assumed baseline scenario, it does not provide an estimate of the GHG flux of the baseline scenario. The present methodology – using COMET-Farm – improves upon these downsides.

The analysis discussed in this report employs a similar sample-based approach with key differences that allow for greater spatial and temporal resolution: 1) Rather than evaluating individual practices, the sample field locations are modeled with a suite of management scenarios or combination of practices representative of varying farm operations in the state; 2) The results of the model runs are maintained as a times series to capture temporal variations; 3) Modeling management scenarios provides a full representation of the net of carbon sequestration and releases (i.e. flux); 4) Results from COMET-Farm are then scaled to all cropland in the state using county-level land use and management practice data.

Details and key concepts

The COMET-Farm Application Program Interface (API) was used to model a set of sample fields across the state under a range of management scenarios. Each sample field is a point location with an area of 5 acres. Sample field locations were selected to reflect a range of soil conditions. Figure 1 shows a map of the 69 sample field locations (3 locations each in 23 counties) used in the COMET-Farm API and the geographic regions used in defining region-specific management scenarios that are discussed in detail later.

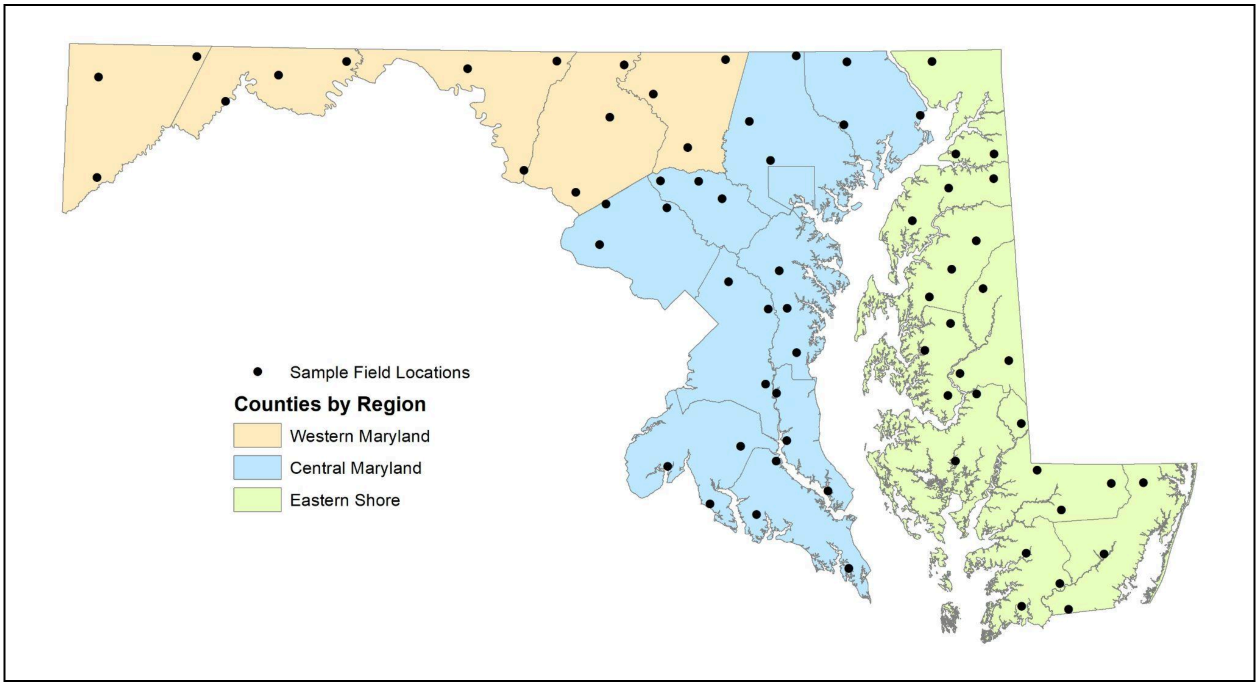

Figure 1: Map of sample field locations and county regions

To understand the methodology in greater detail it is first necessary to understand and differentiate several key terms and concepts.

Management Practice

Management practice refers to conservation and cropland management techniques that aim to conserve soil, improve soil health, and protect water quality among other benefits including sequestering carbon. The practices evaluated in this analysis include the cropland management practices identified in the 2030 GGRA Plan. Land use change practices, such as riparian forest buffers, are excluded from this analysis to avoid double-counting from overlap with the forestry sector modeling. The analysis also did not project taking cropland out of production. Nutrient management practices were not quantified for the 2030 GGRA Plan but are included in this analysis for a fuller representation of Maryland implementation and to allow a separate assessment of nitrous oxide emissions. Table 1 lists the management practices modeled in this analysis and their Natural Resources Conservation Service (NRCS) Conservation Practice Standard (CPS) definition.

Table 1: Management practices modeled

Management Practice	**NRCS Definition**
Conventional Tillage to Reduced Tillage (CPS 345)	Managing the amount, orientation and distribution of crop and other plant residue on the soil surface year round while limiting the soil-disturbing activities used to grow and harvest crops in systems where the field surface is tilled prior to planting.
Conventional Tillage to No Till (CPS 329)	Limiting soil disturbance to manage the amount, orientation and distribution of crop and plant residue on the soil surface year around.
Cover Crops (CPS 340)	Grasses, legumes, and forbs planted for seasonal vegetative cover.
Conservation Crop Rotation (CPS 328)	A planned sequence of crops grown on the same ground over a period of time (i.e. the rotation cycle).
Nutrient Management - Improved Nitrogen Fertilizer Management (CPS 590)	Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments. [Nitrogen fertilizer rates reduced by 15 percent.]
Nutrient Management - Replace Synthetic Nitrogen Fertilizer with Soil Amendments (CPS 590)	Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments. [In this analysis soil amendments include dairy manure and chicken broiler manure.]

Management Scenario

Management scenario describes a set of management practices and farm operations. To represent predominant management cases in Maryland, a range of region-specific management scenarios were designed for this analysis.

Table 2 below summarizes the design of four management scenarios and the assumptions used to ramp up the model prior to 2000. The management scenarios are further defined by additional specifics that are not presented here such as planting and harvest dates, quantities and concentrations of nutrient inputs, and crop yields. Figure 1 displays the assignment of Maryland counties to geographic regions. Future analysis may add additional management scenarios to represent Maryland's cropland in even greater detail.

COMET-Farm requires that historic management for pre-1980 and 1980-2000 time periods be specified in order for the model to build up the soil profile for the post-2000 analysis period. **For Maryland, the No Action scenario should not be thought of as the absence of conservation but**

instead represents a base level of modern (post-2000) implementation - crops in rotation with reduced tillage and nutrient management. The next three scenarios are successive modifications all featuring no till and cover crops. Building from No Action, the Cover Crop Addition scenario changes from reduced tillage to no till and adds a cover crop. To this, the Cover Crop and Precision Nutrient Management scenario increases crop yields and reduces manure inputs, while the Biodiverse Cover Crop and Precision Nutrient Management scenario further modifies with a change in the cover crop species. COMET-Farm currently does not represent additional precision nutrient management techniques, such as manure incorporation or nitrogen-inhibitors.

Table 2: Summary of management scenario assumptions

Management Scenario	**Region**	**Tillage Practice**	**Crop Rotation**	**Nutrient Inputs**
Pre-2000	all	Intensive tillage	Annual crops in rotation	n/a
No Action	Western Maryland	Reduced tillage	Year 1: Corn Silage & Alfalfa Years 2-5: Alfalfa	Dairy slurry, MAP, UAN*
	Central Maryland		Year 1: Corn Year 2: Soybean	MAP, UAN
	Eastern Shore		Year 1: Corn Year 2: Soybean	Poultry litter, MAP, UAN
Cover Crop Addition	Western Maryland	No-till	No Action with cover crop of winter wheat in Year 5	[same as No Action]
	Central Maryland & Eastern Shore		No Action with cover crop of winter wheat	
Cover Crop and Precision Nutrient Management	Western Maryland	[same as Cover Crop Addition]		Increased corn silage yield
	Central Maryland			Increased crop yields
	Eastern Shore			Reduced poultry litter Increased crop yields
Biodiverse Cover Crop and Precision Nutrient Management	all	No-till	No Action with cover crop of annual rye - legume - radish	[same as Cover Crop and Precision Nutrient Management]

* MAP = Monoammonium Phosphate; UAN = Urea Ammonium Nitrate

Implementation Scenario

Implementation scenario refers to the year-to-year assignment of total cropland area to particular management scenarios. Every acre of cropland in a county, and in turn the state, is represented by one of the four management scenarios. This assignment of county-level cropland acres changes over time as management practices are adopted. This approach allows for historic, projected, and hypothetical levels of implementation to be evaluated.

Maryland's Climate Pollution Reduction Plan evaluates two policy scenarios: 1) Current Policies, which reflects existing GHG reduction programs and policies, and 2) Current + Planned Policies, which includes existing and new policies needed to achieve Maryland's 2031 gross emissions reduction goal. The Forestry and Land Use sector is not counted in gross emissions but is included in net emissions accounting. For evaluating this sector's contribution to Maryland's 2045 net-zero emissions goal, the sector is represented in the plan's Current + Planned Policies scenario as a technical potential of carbon sequestration that could be achieved, with an ambitious level of additional action, rather than a policy commitment.

This analysis considers two implementation scenarios: 1) Current Policies, and 2) Technical Potential. The Current Policies scenario is based on maintaining the current level of implementation of conservation practices, while the Technical Potential reflects expanding adoption of these practices. The Current Policies scenario holds current implementation (as of 2022) constant through 2035. For the Technical Potential scenario the level of future no-till and cover crop adoption was projected linearly based on the historical trend, such that 80% of cropland is implementing in 2035. In both implementation scenarios, years 2000-2022 reflect the historical record. Total cropland acres were held constant over time and reflect the land use data of the Chesapeake Bay Program's Watershed Model (https://cast.chesapeakebay.net/). See Table 4 below for a crosswalk of the management scenarios to the implementation scenarios tested.

The historical record of management practice implementation is based on data that Maryland reports to EPA's Chesapeake Bay Program Office through the National Environmental Information Exchange Network (NEIEN) protocol. The practices reported to NEIEN undergo extensive inspection and verification. The database includes details such as practice name, units implemented, county of implementation, inspection status, and dates of implementation and retirement. The NEIEN data were used to divide total county cropland acres into one of the four management scenarios of this analysis.

Table 3, Table 4, and Figure 2 below are detailed as follows:

Table 3 provides the statewide assignment of cropland acres to management scenarios for the first and last years of the historic period. Table 4 provides the statewide assignment of cropland acres per the two implementation scenarios for 2035, the last year of the projected period. Figure 2 below shows the acreage assignment for both scenarios for the entire time series. For ease of presentation, the three management scenarios of Cover Crop Addition, Cover Crop & Precision Nutrient Management, and Biodiverse Cover Crop & Precision Nutrient Management are shown in aggregate and referred to as No-till & Cover Crop. While the acreages are presented here statewide, the assignment of acres was county specific for the analysis.

Table 3: Historic management scenario acreage assignment

Year ⍰	**2000**		**2022**	
Management Scenario ⍰	Acres	% of Total	Acres	% of Total
No Action	1,155,196	94%	589,785	48%
Cover Crop Addition	33,099	3%	404,085	33%
Cover Crop and Precision Nutrient Management	34,210	3%	217,979	18%
Biodiverse Cover Crop and Precision Nutrient Management	80	0.01%	10,735	1%
Total Cropland	1,222,585	100%	1,222,585	100%

Table 4: Projected 2035 management scenario assignment by implementation scenario

Implementation Scenario ⍰	**Current Policies**		**Technical Potential**	
Management Scenario ⍰	Acres	% of Total Cropland	Acres	% of Total Cropland
No Action	589,785	48%	244,517	20%
Cover Crop Addition	404,085		596,441	
Cover Crop and Precision Nutrient Management	217,979	52%	228,766	80%
Biodiverse Cover Crop and Precision Nutrient Management	10,735		152,861	
Total Cropland	1,222,585	100%	1,222,585	100%

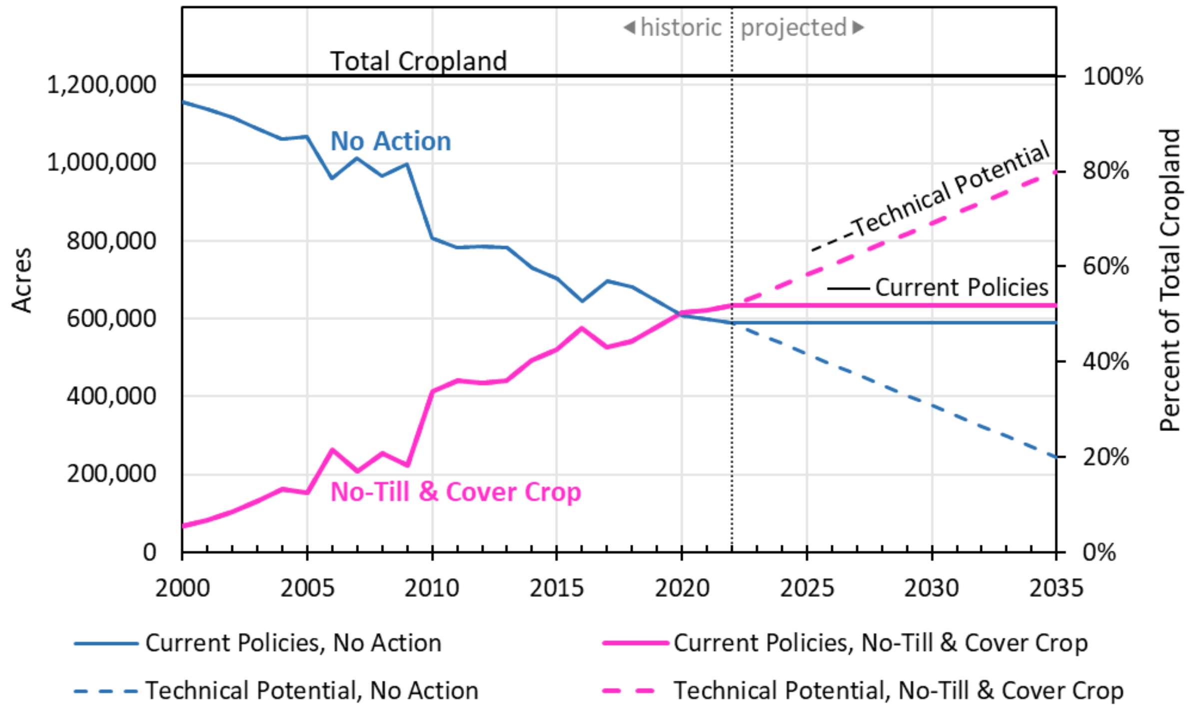

Figure 2: Historic and projected management scenario* assignment by implementation scenario
* The three management scenarios of Cover Crop Addition, Cover Crop & Precision Nutrient Management, and Biodiverse Cover Crop & Precision Nutrient Management are shown in aggregate here as No-till & Cover Crop.

Methodology steps

Once the above concepts of sample fields, management practices, management scenarios, and implementation scenarios are understood and determined, the methodology is quite straightforward. The major modeling or calculation steps and outputs from each step are summarized below in Table 5.

Table 5: Summary of modeling and calculation steps

Step		Result
1	Combinations of management practices are grouped into management scenarios. The management scenarios are modeled in COMET-Farm at each sample field.	Time series of annual soil carbon stock change rates per management scenario for each sample field.
2	The model outputs from the sample fields within each county are averaged per management scenario.	Time series of annual soil carbon stock change rates per management scenario for each county.
3	Implementation scenarios allocate total cropland acres to a distribution of management scenarios, per county. County implementation acres are multiplied by the soil carbon stock change rate of the assigned management scenarios.	Time series of annual soil carbon stock change per implementation scenario for each county.

Results

The primary output of COMET-Farm is the year-to-year change of carbon stock in the soil. Figure 3 below displays the rate of annual soil carbon stock change on a unit area basis for each management scenario for one of the 23 counties. These are the results of steps 1 and 2 of the methodology summarized in Table 5 above. The cyclical fluctuations seen in the results are the effect of crop rotation. The decreasing trend in the rate of soil carbon stock change indicates gradual saturation of carbon in the soil as the carbon stock is built up. Negative values of carbon stock change signify the net release of carbon from the soil to the atmosphere in the given year.

The county-level soil carbon stock change rates, averaged over the three sample fields, range statewide for the No Action scenario from -54.4 to 127.5 grams of carbon per square meter per year (gC/m^2/yr) (or -0.81 to 1.89 of metric tons of carbon dioxide equivalent, MTCO2e/ac/yr), over the entire time series. For Cover Crop Addition, Cover Crop & Precision Nutrient Management, and Biodiverse Cover Crop & Precision Nutrient Management scenarios, soil carbon stock change rate ranges from -50.0 to 171.5 gC/m^2/yr (-0.74 to 2.54 MTCO2e/ac/yr).

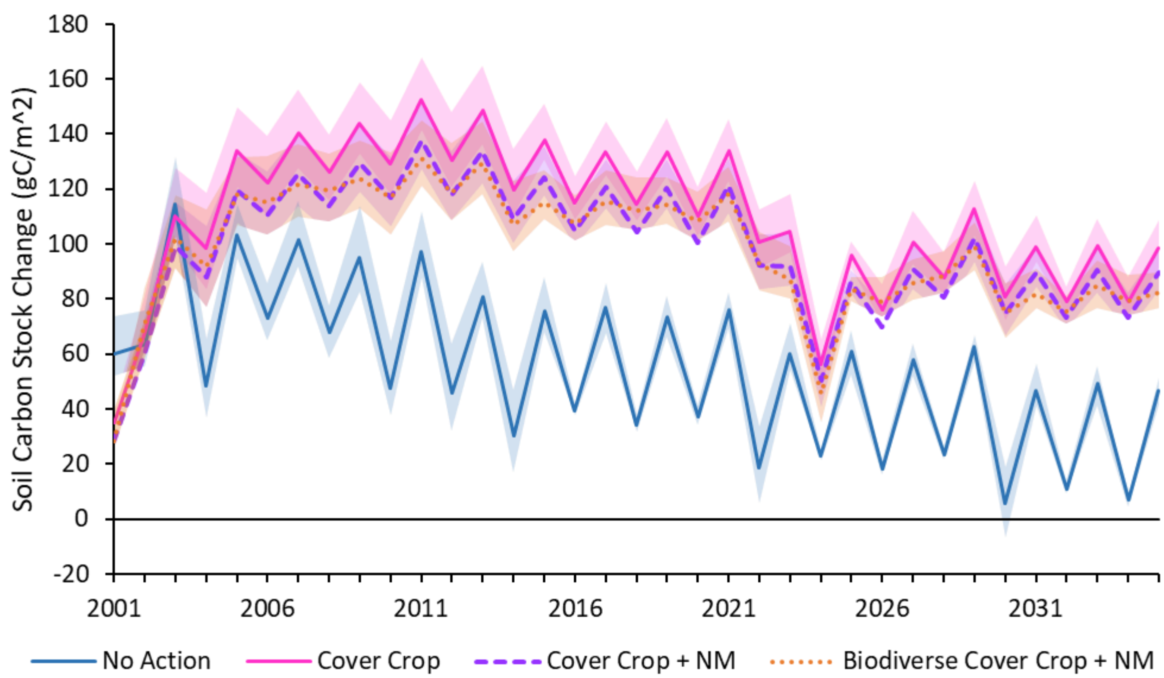

Figure 3: Annual soil carbon stock change rate* per management scenario for one example county (Talbot County)**

* For each management scenario, the solid or dotted line indicates the average of the three sample fields and the shaded area indicates the minimum and maximum of the three sample fields. Negative values indicate a net release of carbon from the soil to the atmosphere.

**The anomaly seen in the projected results for 2024 does not impact the future years of interest (2031 and beyond) and so was not investigated further for this analysis.

Multiplying out the per area soil carbon stock change rate of each management scenario by the acres assigned to each management scenario under the two implementation scenarios results in a time series of county-wide annual carbon stock change, as summarized in step 3 of Table 5. These results are summed statewide and converted to net carbon flux, expressed as an equivalent mass of carbon dioxide.

Figure 4 below presents the annual statewide flux of carbon from agricultural soils for the historic period of 2001-2022 and as projected forward for the two implementation scenarios. In this figure, negative value indicates net sequestration, or carbon removal from the atmosphere. Results for years 2023-2035, the projected period, were averaged with the preceding 4 years (i.e., a five year rolling average) to mute the cyclical effect of crop rotation on the net carbon flux projection used in Maryland's Climate Pollution Reduction Plan. Further, because the time period of this analysis extended to 2035, while the economy-wide modeling for Maryland's Climate Pollution Reduction Plan extended to 2050, the estimates of net soil carbon sequestration for 2036-2050 were held constant at 2035.

As shown in Figure 4, from 2001-2022 carbon sequestration in agricultural soils has ranged from 0.55 to 1.53 million metric tons of carbon dioxide equivalent (MMTCO2e) removed from the atmosphere annually. By continuing current levels of management practice implementation, future annual sequestration will range from 0.83 MMTCO2e in 2031, to 0.75 MMTCO2e by 2035, as shown by the Current Policies line. As seen in the Technical Potential line, expanding adoption of practices can increase annual removals to 0.92 MMTCO2e in both 2031 and 2035.

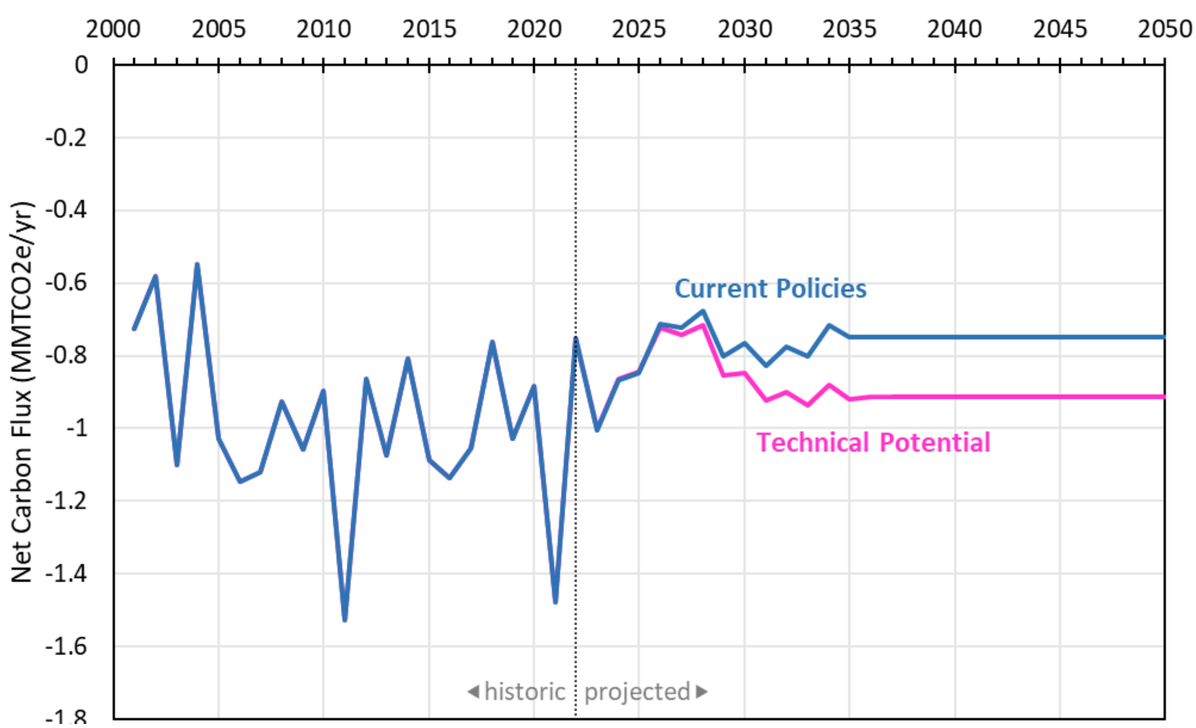

Figure 4: Annual statewide flux of carbon* from agricultural soils per historic and projected levels of implementation

* Expressed as an equivalent mass of carbon dioxide. Negative values indicate net removal and sequestration of carbon from the atmosphere to the soil.

Conclusions

This project's methodologies and the analysis conducted in support of Maryland's Climate Pollution Reduction Plan are a significant advancement in agricultural soil carbon flux accounting . Leveraging state-specific data combined with the best available peer-reviewed models allows for a comprehensive representation of actual cropland management. The project provides temporal and spatial representation not previously captured – temporally reflecting crop rotations and soil saturation, while spatially offering a county-scale accounting of both carbon losses and sequestration across all Maryland cropland.

The analysis evaluated the potential opportunity for increasing carbon sequestration in agricultural soils by accelerating adoption of conservation practices beyond current commitments for Chesapeake Bay water quality goals. While continuing current levels of implementation can provide a stable level of annual carbon sequestration, expanding practice adoption can increase the annual rate of sequestration by 23% – furthering the achievement of Maryland's climate goals.

Future improvements for this analysis may include,

- additional management scenarios for finer representation of statewide cropland,
- adding pasture lands,
- increasing the number of sample points within each county,
- incorporating additional practices as data allows,
- constraining estimates with additional state-specific field data as appropriate, and
- accounting for land use changes over time.

Acknowledgements

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Blue Carbon: Wetland Area and Carbon Change in 2030 and 2045

Maryland Department of Natural Resources

Blue carbon in Maryland refers to the carbon captured by the ocean and coastal ecosystems, including coastal salt marshes and seagrasses. For the Maryland GHG inventory, blue carbon stocks and fluxes comprise the state's estuarine wetlands and seagrasses, otherwise referred to as submerged aquatic vegetation (SAV). Methane emissions are an important consideration when assessing the climate impact of wetlands. Freshwater and brackish wetlands tend to support a bacterial community within their soils that produces methane, with higher salinity (18 ppt+) wetland soils typically not producing methane. For that reason, we only considered wetlands in the southern, saltier region of the Chesapeake Bay and the Coastal Bays for the MD GHG Inventory and for the projections here. This includes the mesohaline region, where salinities range between 5 and 18 ppt and significant methane emissions do exist, but carbon sequestration in soils has a larger climate benefit, on average. The relationship between salinity and methane emissions is not observed for SAV, so all SAV in the Bay is included in the inventory. It should also be noted that the choice of global warming potential (GWP) for methane greatly impacts the net GHG impact of wetlands. Under a 20-year GWP where methane is 84 times that of carbon dioxide the coastal wetlands sink is negligible. Results here are presented using the 100-year GWP of methane (28 times that of CO2), however the 20-year GWP is applied when incorporating the results in the economywide plan.. The 2020 GHG inventory includes net emissions from wetland land-use change. This factor was omitted here because of the high uncertainty around the timing and magnitude of carbon stock change associated with conversion to or from wetlands. This factor is a relatively small (~1.5%) component of the overall blue carbon inventory.

Wetland Area and Carbon Change in 2030 and 2045

In 2021 Maryland DNR partnered with The Nature Conservancy, George Mason University and Warren Pinnacle, Inc. to simulate change in coastal wetlands and other lands over a 100 year period in 10 year increments under six different sea level rise (SLR) scenarios using the Sea Level Affecting Marshes Model (SLAMM). The scenarios ranged from 1.2 to 1.5 feet of SLR by 2050, with results for the scenario simulating 1.4 feet by 2050 used here. Results for 2045 were obtained by averaging the 2040 and 2050 model results. In all of the scenarios wetland area increased over time, due to migration into areas that are now upland forests, agriculture, or open areas and existing marshes largely being able to keep up with SLR through building of new soils. Low elevation counties on the southern Eastern Shore in particular are expected to experience extensive wetland migration into uplands. This region is already experiencing the impacts of saltwater intrusion as sea level rises, with ghost forests and less productive or barren agricultural fields becoming more common. Carbon loss due to land-use conversion driven by SLR is likely to be significant, but is not quantified here. The changes projected are just due to expected SLR and do not account for any ecological restoration efforts the state may engage in, such as thin layer placement or tidal wetland creation. Rates of coastal wetland restoration implementation have been low; only 510 acres have been restored by the state and 2,096 acres restored by federal agencies since 2006.

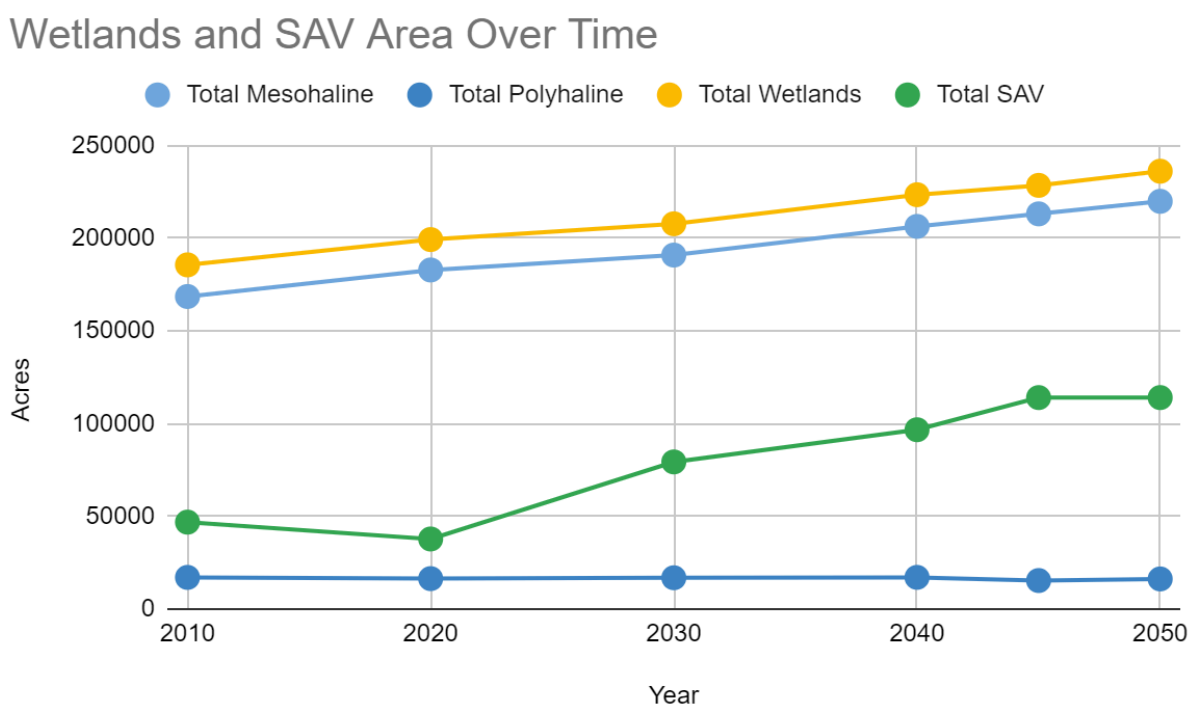

Figure 1: Change in Maryland's mesohaline and polyhaline wetlands and SAV over time under a 1.4 feet of SLR by 2050 scenario and assuming SAV restoration goals are achieved

According to the SLAMM results for wetland area change under the chosen SLR scenario and our current best understanding of wetland carbon accumulation and methane emission rates Maryland's blue carbon sink is projected to increase by 14%, from -336,000 metric tons of CO2e per year in 2020 to -383,000 metric tons of CO2e per year in 2045. While this is one plausible scenario, different models of SLR and wetland change may result in different results, although the differences between models and scenarios becomes greater as they extend into the future. In the scenarios modeled under this SLAMM run 2070-2080 is an important inflection point, with higher rates of SLR outpacing many wetlands' ability to keep up through soil building and rapid, extensive wetland loss projected to occur. However, under lower SLR projections, such as those expected to be experienced under a stable emissions scenario, many wetlands are able to keep up with those lower rates and wetland area is projected to be relatively stable.[2]

[2] Warren Pinnacle. 2021. Application of the Sea-Level Affecting Marshes Model to Coastal Maryland https://warrenpinnacle.com/prof/SLAMM/EESLR_MD/EESLR_MD_SLAMM_Report_12-28-2021.pdf

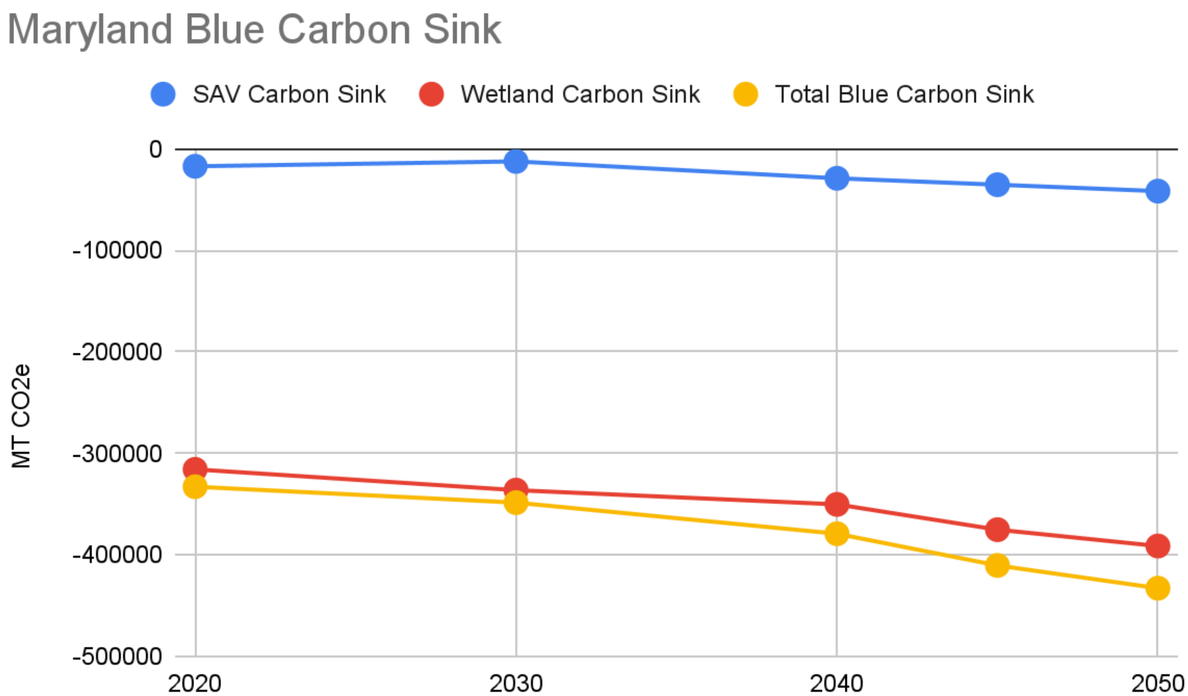

Figure 2: Change in Maryland's Blue Carbon Sink over time (negative values indicate a net removal of carbon from the atmosphere; figure uses the 100 year GWP of methane)

Submerged Aquatic Vegetation (SAV)

Projections of carbon sequestration and methane emission in submerged aquatic vegetation (SAV) utilize acreage projections provided by the Maryland Department of Natural Resources. For SAV, the Current Policies scenario holds 2020 acreage constant and the technical potential reflects the SAV goals for Maryland's portion of the Chesapeake Bay. In this analysis the 2025 goal of 79,355 acres was used for 2031 and the long term goal of 114,065 acres was used for 2045.

Blue Carbon Funding

As mentioned previously, restoration of coastal wetlands has not been widely implemented in Maryland, apart from the large island creation projects where dredge material is used to build up islands that are partially composed of wetlands. While coastal wetlands are vital ecosystems that provide important ecosystem services like erosion prevention and wildlife habitat restoration of these systems is quite expensive, frequently exceeding $50,000 per acre restored. Maryland DNR has partnered with The Nature Conservancy and ESA, Inc. to conduct a blue carbon feasibility study of several existing or potential wetland restoration projects in Maryland. Results indicate that the sale of blue carbon credits would not be able to support the costs associated with project implementation, even if the price of carbon were to rise dramatically. Under certain price points it is possible for the sale of credits to fund a portion of the cost of maintaining the project. Given project costs, it is likely that going forward projects will be done for reasons other than blue carbon, like enhancing coastal resiliency or ensuring habitat for endangered species, but blue carbon will remain an important co-benefit of this work.