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Natural Resources Conservation Service
Conservation Effects Assessment Project

CEAP Science Note

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Assessing Wetland Morphometrics and Ecosystem Functions in Agricultural Landscapes of the Atlantic Coastal Plain Using Fine Scale Topographic Information

Summary

- Topography is a known control on multiple ecosystem processes, influencing the movement of water, soil, and other constituents.
- In the Atlantic Coastal Plain, even subtle differences in topography can lead to substantial variations in these processes, including those related to biogeochemistry (i.e., nutrient cycling), erosion/deposition, and surface and groundwater movement.
- Traditionally available digital elevation models (DEMs) created using aerial photography have much coarser vertical accuracies 3.28 – 32.81 feet (1 – 10 m) than those derived from LiDAR ~ 0.50 feet (~ 15 cm).
- LiDAR-derived DEMs also have relatively fine horizontal resolutions ~ 3.28 – 9.84 feet (~ 1 – 3 m).
- Using LiDAR, a total of 14,969 bays were visually identified, and it was estimated that areas without LiDAR data contained approximately 2,000 additional bays for a total of ~ 17,000 bays within the entire study area.
- Mean bay density was found to be approximately 5 bays per mi^2 (2 bays per km^2) ranging up to ~ 69 bays per mi^2.
- Bays had an average area of 6.99 ac (2.83 ha) with mean relief within bays of 3.97 feet (1.21 m; median 3.64 feet [1.11 m]).
- This study provided regional assessment of wetland landscape morphetric information to help identify local soil and hydrologic conditions suitable for supporting wetland functions and wetland restoration.
- For additional information regarding LiDAR technology and wetland conservation applications please see the CEAP Science Note: "Light Detection and Ranging (LiDAR) for Improved Mapping of Wetland Resources and Assessment of Wetland Conservation Practices" (Lang and McCarty 2014).

Background

Topography is a known control on multiple ecosystem processes, influencing the movement of water, soil, and other constituents. In the Atlantic Coastal Plain, even subtle differences in topography can lead to substantial variations in these processes, including those related to biogeochemistry (i.e., nutrient cycling), erosion/deposition, and surface water and groundwater movement. In turn, these processes influence a number of ecosystem services which are highly relevant in agricultural landscapes including the provision of clean water, the management of climate, mitigation of flood hazards, availability of fresh water, and support for soil character and function. In addition, the influence of topography on water flux and availability, soil quality, and nutrient cycling strongly affects crop production. The importance of topography is especially evident near the boundary between wetlands and uplands. This boundary was in large part established by scientists to identify the area at which water regimes, which are greatly influenced by elevation, produce markedly different plant communities and soils. However until recently the spatial resolution of commonly available topographic data were not sufficient for mapping the subtle changes in topography frequently associated with the presence of wetlands, especially in landscapes that are relatively flat, like the Atlantic Coastal Plain.

Light Detection and Ranging (LiDAR)-based digital elevation models (DEMs; see summary at left) enable mapping of landscape features that were previously difficult if not impossible to distinguish with commonly available DEMs produced using stereo-interpretation of aerial photographs. Fenstermacher et al. (2014) highlights the importance of LiDAR-based DEMs for mapping Delmarva bays, elliptical depressional landforms that are commonly found on the agriculturally dominated Delmarva Peninsula, including portions of Delaware, Maryland, and Virginia (Figure 1). Although not all Delmarva bays currently contain wetlands, it is likely that the vast majority did at one time. Furthermore, prior converted croplands (i.e., historical wetlands converted to upland cropland before 1985 and continuously used for agriculture through the present time) have been found to support some wetland characteristics and processes (Fenstermacher et al. 2011; Denver et al. 2014; Hunt et al. 2014; McCarty et al. 2014). Before publication of the Fenstermacher et al. (2014) study, Delmarva bay wetland studies focused on a small number of sites and little was known about the larger population of bays, including their morphology and spatial characteristics as well as their current land cover.

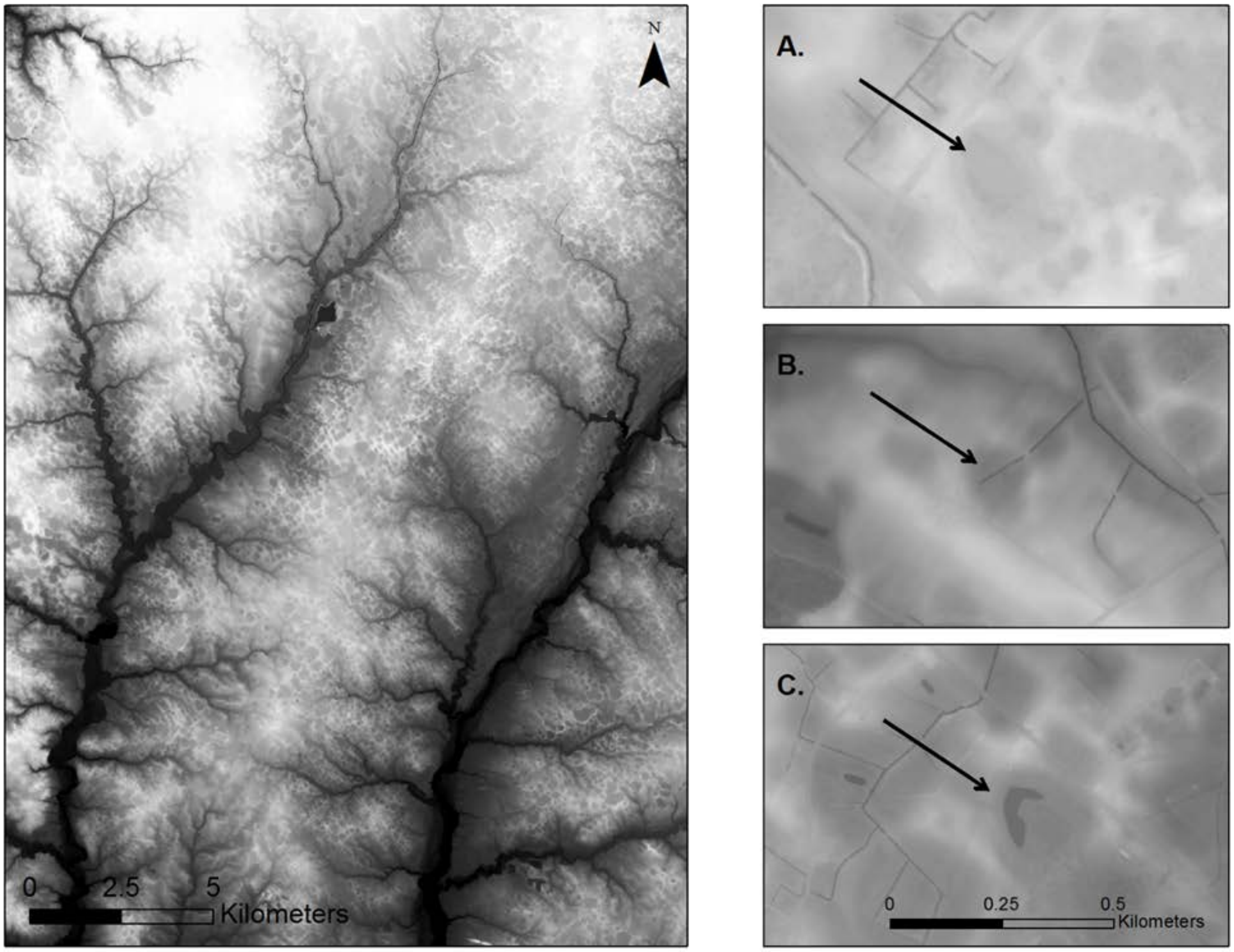

Figure 1. A LiDAR-based digital elevation model (DEM) for a portion of the Choptank Watershed, including areas within Maryland and Delaware. Three expanded views can be seen to the right. Note the abundance of relatively small circular depressions or Delmarva bays which are present across all land covers including both cropland and forest. The images to the right provide a more detailed look at (A) natural, (B) historical, and (C) restored Delmarva bays. Historical Delmarva bays are often drained by ditches and can be seen in all images. Note that only the northwest portion of the restored wetland (C) has been restored through excavation, while the southeastern portion of the bay was not converted to cropland.

This CEAP Science Note summarizes the Fenstermacher et al. (2014) study findings and highlights the importance of this type of morphometric assessment for the estimation of ecosystem services provided by natural, restored, and historical wetlands (i.e., prior converted croplands) and assessment of agricultural management practice effects.

LiDAR Reveals the Density, Distribution and Morphology of Delmarva Bays

Introduction to Delmarva Bays

Delmarva bays are believed to be a geographic subset of the depressional features that have more broadly been termed Carolina bays. Although the Carolina bays of North and South Carolina are the best known examples, natural depressions with a unique elliptical shape are found along the Atlantic Coastal Plain from New Jersey to Florida and along the Gulf of Mexico. In the Alabama and Georgia Coastal Plain areas, these depressions are locally known as "Grady ponds." Carolina bays are often oriented along a northwest – southeast major axis (Sharitz & Gibbons 1982; Stolt & Rabenhorst 1987b; Bruland et al. 2003) and typically have a sandy rim at their southeast end (Prouty 1952; Thom 1970; Stolt and Rabenhorst 1987a; Tiner 2003). Bays range in size from tens of meters to kilometers in length and cover as much as 50% of the land area where they are most abundant (Prouty 1952). Although there are a number of theories regarding the origin of Carolina and Delmarva bays, available field evidence suggests that they were wind blow-outs formed during the Pleistocene that filled with water and were elongated by wind-driven currents, resulting in their unique shape and characteristic sandy rim (Grant et al. 1998; Prouty 1952; Savage 1982; Stolt and Rabenhorst 1987b; French and Demitroff 2001). Less information is known about Delmarva bays than Carolina bays. Delmarva bays are generally smaller than Carolina bays, which are found to the south in North and South Carolina. Delmarva bays are known to be extremely common in portions of the Delmarva Peninsula including Queen Anne's, Caroline, and Talbot Counties in Maryland and New Castle and Kent Counties in Delaware. Their common occurrence exerts strong controls on field and landscape scale processes in this region (Figure 1). Delmarva bays that have not been drained for agricultural or urban development typically contain wetlands. These wetlands can act as both recharge wetlands that replenish groundwater and discharge wetlands that receive groundwater during different times of the year and in accordance with large or prolonged weather events. Where Delmarva bays are abundant, they constitute the majority of wetlands and provide important habitat to a disproportionately high number of rare and endangered species (Sharitz 2003; Olivero and Zankel 2000; Sharitz and Gibbons 1982).

Assessment Approach

Study Area

The Fenstermacher et al. (2014) study was conducted on the ~ 6,000 mi^2 (15,540 km^2) Delmarva Peninsula, in areas of Maryland and Delaware. The Delmarva Peninsula is located within the outer Coastal Plain Physiographic Province and has a humid subtropical climate with an average annual rainfall of 44 inches (Denver et al. 2004). The landscape is generally flat (elevation between 0 and 102 feet [0 and 31 m]) and is dominated by agriculture (48%), primarily corn and soybean fields, but also includes forests (33%), and a smaller amount of urban areas (7%; Denver et al. 2004).

Publicly available LiDAR based DEMs with a spatial resolution between ~ 6.6 and 9.8 feet (2 and 3 m) and a vertical accuracy of approximately 7.1 inches (18 cm) were obtained from the USDA Geospatial Data Gateway and the Maryland Department of Natural Resources. These data were used to manually identify Delmarva bays based on their characteristic elliptical shape. Although automated processes are available to identify landscape features with distinct shapes, a manual process was selected due to the complex morphology of many Delmarva bays which have been superimposed upon each other, bisected by ditches, or otherwise modified. Bays with a continuous elliptical perimeter were identified as a single feature. Where the rims of overlapped bays were sufficiently distinct they were recognized and counted as separate features. Man-made depressions, such as ponds or reservoirs, which typically have a linear side for an earthen dam, were excluded from the study. When LiDAR-derived DEMs were not available for sites, their density was assumed to be similar to adjacent areas.

A stratified random approach based on bay density was used to select areas for more detailed morphologic analysis. Using this approach a total of 1,494 bays were selected, manually outlined, and their area, perimeter, major and minor axis, relief and land cover were determined using ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, CA). Bays were categorized as having a natural, agricultural, residential, and/or fallow land cover class using false-color near-infrared aerial photography obtained from the USDA Geospatial Data Gateway. Additional information regarding the methods used to map and characterize Delmarva bays can be found in Fenstermacher et al. (2014).

Results and Discussion

A total of 14,969 bays were visually identified (Figure 2), and it was estimated that areas without LiDAR data contained approximately 2,000 bays for a total of ~ 17,000 bays within the entire study area (Fenstermacher et al. 2014). Previous estimates based on aerial photography are an order of magnitude less, including an estimate of 1,500 – 2,500 (Stolt and Rabenhorst 1987b) and an estimate of 10,000 to 20,000 for the entire Atlantic Coast (Richardson and Gibbons 1993). Mean bay density was found to be approximately 5 bays per mi^2 (2 bays per km^2) but was as high as ~ 69 bays per mi^2 (27 per km^2) accounting for over 50% of land area (Fenstermacher et al. 2014). Bays had a mean area of 6.99 ac (2.83 ha; median 3.58 ac [1.45 ha]), with 80% between 1.14 and 14.04 ac (0.46 and 5.68 ha).

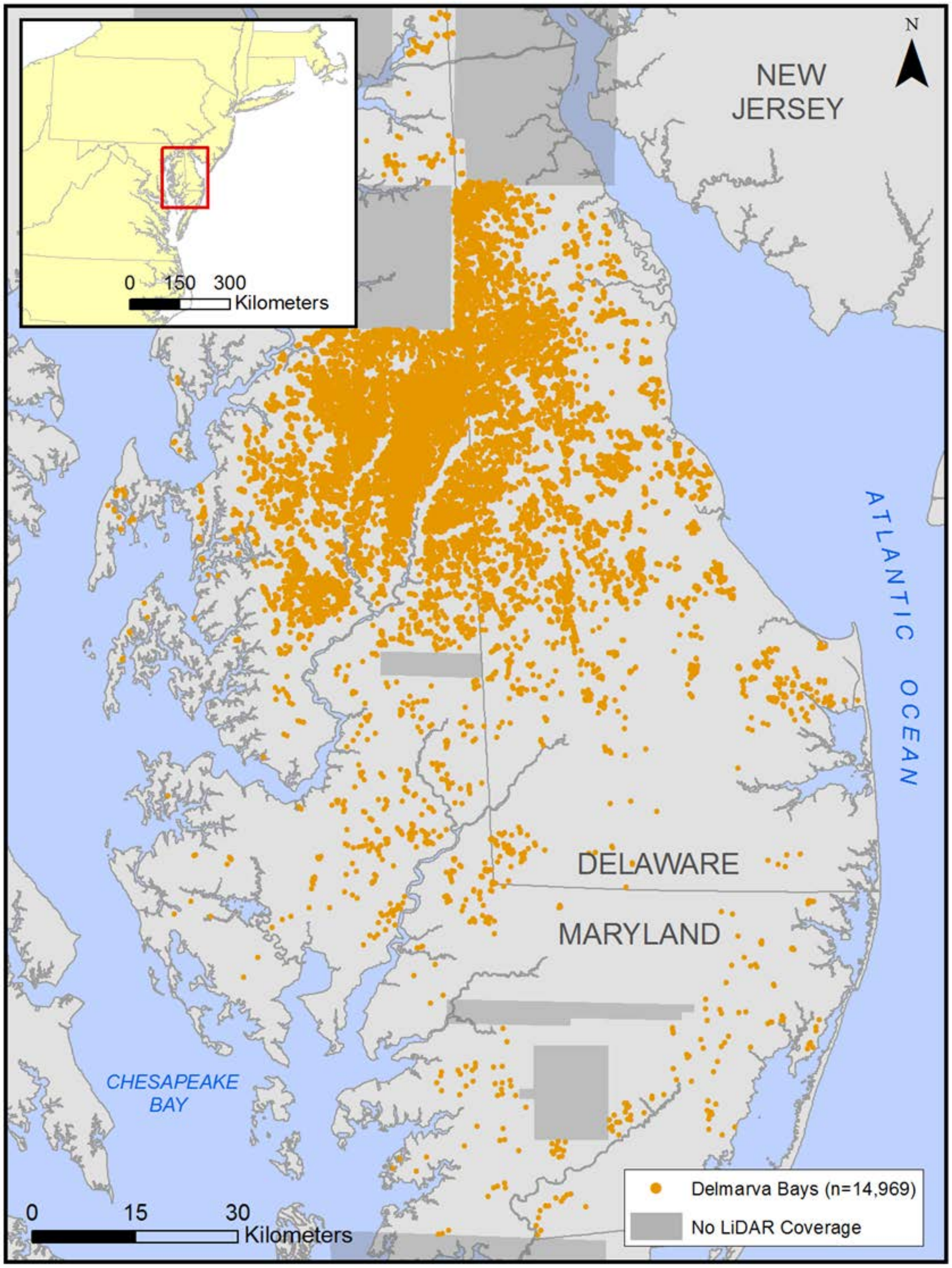

Figure 2. The abundance and distribution of Delmarva bays within the Delmarva Peninsula study area. Each dot represents one Delmarva bay. A total of 14,969 bays were manually identified using a LiDAR-based digital elevation model (DEM). Areas where LiDAR data were not available are marked in gray. Note that bays are concentrated in the northern portion of the Peninsula and are less likely to be found near large streams and the shoreline.

Mean relief within bays was 3.97 feet (1.21 m; median 3.64 feet [1.11 m]) with 80% falling within the range of 1.81 to 6.63 feet (0.55 to 2.02 m). Delmarva bays had an average major to minor axis ratio of 1.32 (median 1.26), with 80% falling within the range of 1.08 to 1.65 (Fenstermacher et al. 2014). Overall Delmarva bays were found to be smaller, shallower, and rounder than Carolina bays, which have been found to have a mean area of 113.67 ac (46 ha) (Bennett and Nelson 1991), relief of 5.94 feet (1.81 m) (Prouty 1952; Thom 1970), and major-minor axis ratio of 1.51 (Melton and Scriever 1933). Fenstermacher et al. (2014) hypothesized that the difference between Delmarva and Carolina bay morphologies may be due to the relatively colder temperatures of the Pleistocene during the development of the higher latitude Delmarva bays. Frozen water would have been more common with the Delmarva bays and could have inhibited development of bay morphology due to wind driven waves, therefore limiting the size and elliptical shape of these features. This hypothesis is supported by the relatively large size of bays found in the southern portion of the Delmarva relative to the northern Delmarva.

The vast majority of Delmarva bays have been influenced by human development, mainly agriculture, with only 29% (4,930 out of the estimated 17,000 total; Fenstermacher et al. 2014) located within areas of natural vegetation. Many of these have been drained and all have likely been affected by regional declines in groundwater due to irrigation, human consumption, and other uses. Delmarva bays found entirely within natural land covers had significantly greater ($p < 0.001$) relief (4.17 feet or 1.27 m) than those in agriculture (3.54 feet or 1.08 m; Fenstermacher et al. 2014). This reduction in relief within cropland bays may have been caused by erosion and sedimentation following tillage or resulted from the preferential selection of shallower bays with better drainage for agricultural development. The average area of Delmarva bays found in natural and agricultural landscapes was not shown to be significantly different (Fenstermacher et al. 2014).

The Importance of Landscape-Scale Wetland Assessment

Although successful wetland restoration is generally considered to provide net benefits to society, the large investment that USDA has made in wetland restoration and increasing societal need for wetland ecosystem services highlight the importance of environmental research and monitoring. These efforts are needed to better understand the effects and effectiveness of conservation practices, such as wetland restoration, and to develop wetland restoration and agricultural management practices that result in greater societal benefits.

Fenstermacher et al. (2014) demonstrates the significant and growing importance of remote sensing for supporting these efforts, both through the extrapolation of field scale information and greater understanding of landscape scale processes that would have been costly and difficult to ascertain on the ground. The functions that occur within individual or groups of wetlands are unique to their placement on the landscape (Bedford 1999; Simenstad et al. 2006). Therefore the landscape perspective that remote sensing provides is critical to ensuring the optimum provision of wetland ecosystem services through restoration at the individual wetland and watershed scale. The use of remotely sensed data can also provide temporal context. The importance of this historic perspective was emphasized by Bedford (1999): “By definition [wetland restoration] seeks to replace what has been lost. By definition then, it should be undertaken with knowledge of what has been lost.”

Wetland restoration has proven to be difficult, partly because wetlands are regionally and locally distinct (Zedler and Callaway 1999), and restoration of wetland hydrology is considered to be one of the most difficult and critical components of restoration. Lang et al. (2012) found relief to be well correlated with patterns of inundation on the Delmarva Peninsula and developed a LiDAR-based technique to map elevation driven controls on wetland distribution and hydroperiod. The link between hydroperiod and thus relief and the distribution of plant and animal species is well known (e.g., Pechmann et al. 1989; Corti et al. 1996; Snodgrass et al. 2000).

Current wetland restoration practices seek to mimic more natural variation in relief, making them generally shallower and adding micro-topography. The Fenstermacher et al. (2014) study provides a guideline as to variations in depressional wetland relief that are naturally occurring, thus supporting the stated goal of the USDA NRCS Wetland Restoration (657) Practice Standard to “restore wetland function, value, habitat, diversity and capacity to a close approximation of the pre-disturbance conditions.” The ability to locate and restore former depressional wetlands with sufficient relief to support wetland hydrology without the need for excavation could be advantageous for the management of greenhouse gases and thus climate via carbon sequestration, since wetland excavation on the Delmarva Peninsula was found to lower soil organic carbon levels relative to even historical wetlands and this topsoil was found to be used in berms or other areas where oxidation and loss of carbon to the atmosphere was more likely (Fenstermacher 2011).

In conjunction with relief, depression size (i.e., volume) is also key to supporting wetland processes. McDonough et al. (2014) found wetland area to be correlated with flow in adjacent streams when depressional wetlands were connected to those streams via surface flows. Wetland volume relative to landscape position (e.g., catchment area) is considered to be critical to the establishment of wetland hydroperiod and therefore restoration success (Bedford 1999). Restored depressional wetlands have been found to generally be smaller than natural depressional wetlands (Galatowitsch and van der Valk 1996 [Prairie Pothole Region]; McDonough et al. 2014 [Delmarva Peninsula]; Mid-Atlantic CEAP-Wetlands *unpublished*). Thus larger wetland restorations may be needed to enhance the ability of restored wetlands to maintain surface water flows and likely to mitigate floods. Even when depressional wetlands are not directly connected to streams via surface water flow, their size and arrangement has been found to be critical for supporting flow in adjacent streams (McLaughlin et al. 2014). Remote-sensing based studies such as Fenstermacher et al. (2014) provide the context necessary to better approximate historical conditions, a USDA NRCS Wetland Restoration (657) Practice Standard goal, and wetland hydrology, a critical factor in restoration success.

Fenstermacher et al. (2014) provides insights regarding where local soil and hydrologic conditions may be suitable for supporting wetland function. These specific sites are more likely to be well suited for wetland restoration. This restoration information is especially critical considering the fact that on the Delmarva peninsula most wetland restorations have a depressional shape or morphometry although additional wetland types, including flats, and riparian wetland do occur there.

Information regarding the distribution, density, and morphology of Delmarva bays produced by Fenstermacher et al. (2014) is currently being analyzed to estimate the historical and current storage of surface water within Delmarva bays, as well as the contribution of USDA wetland restoration practices to enhanced wetland volume storage. This study was made possible by nationally available land cover maps produced using remotely sensed data and LiDAR-derived DEMs.

The wetland morphometric data (Fenstermacher et al., 2014) also support the extrapolation of results from a number of other studies supported by the Wetland Component of the National Conservation Effects Assessment Project, including studies documenting plant and amphibian biodiversity and abundance (Yepsen et al. 2014; Mitchell in review), carbon storage, quality, and movement (Fenstermacher 2011; McDonough et al. in review), and nutrient dynamics (Denver et al. 2014; Hunt et al. 2014) within natural, restored and historical wetlands in the Mid-Atlantic Region. Indeed, remotely sensed data greatly adds to wetland insights obtained on the ground and via modeling. CEAP team members are currently working to better incorporate remotely sensed data into process-based modeling, thus supporting the CEAP National Assessment for Cropland and Wetlands.

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The Conservation Effects Assessment Project (CEAP) is a multi-agency effort to build the science base for conservation. Project findings help to guide USDA conservation policy and program development and help farmers and ranchers make informed conservation choices.

One of CEAP's objectives is to quantify the environmental benefits of conservation practices for reporting at the national and regional levels. Because wetlands are affected by conservation actions taken on a variety of landscapes, the wetlands national assessment complements the national assessments for cropland, wildlife, and grazing lands. The wetlands national assessment works through numerous partnerships to support relevant assessments and focuses on regional scientific priorities.

This analysis was conducted by Daniel Fenstermacher, former UMD graduate student; supervised by Dr. Martin Rabenhorst, UMD. The Science Note was written by Dr. Megan Lang, UMD, Daniel Fenstermacher; Drs. Martin C. Rabenhorst and Brian Needelman at UMD, and Dr. Greg McCarty, USDA Agricultural Research Service Hydrology and Remote Sensing Lab, Beltsville, MD.

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