United States Department of Agriculture

Natural Resources Conservation Service

Conservation Effects Assessment Project (CEAP)
CEAP-Wetlands Science Note

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Depressional Wetland Water Storage Volume on the Delmarva Peninsula

Potential to Improve Storm Flow Mitigation

Summary of Findings

- This assessment validated the use of airborne LiDAR for accurate measurement of depressional wetland elevation and morphology in a low-relief landscape.
- A majority (58 %) of the identified depressions on the Delmarva Peninsula are classified as prior converted cropland.
- Another 18 % of total identified depressions are in mixed land use (i.e., cropland and forestland), many of which are likely drained.
- Total estimated storage volume associated with identified depressions was 35,900 ha-m, including 16,900 ha-m on cropland, 12,400 ha-m on forestland, and 6,600 ha-m on mixed forest and cropland.
- Mid-Atlantic Region restored wetland study sites had substantially less storage volume than average depressions located on forestland and cropland, indicating that there is potential to enhance performance of wetland restorations for improved storage volume on Delmarva landscapes.
- In general, the agricultural landscape of the Delmarva Peninsula has a very high capacity for increased surface water storage volume and could benefit from implementation of wetland restoration and drainage control structures.
- When landowners restore wetlands, the potential gains are large, especially where prior converted croplands are marginal for crop production. Controlled drainage structures, on ditches and tile drains, can be used to increase seasonal water storage capacity within prior converted croplands that are currently productive cropland. Remaining forested natural wetlands store substantial surface water volume, supporting regulation of natural hazards (e.g., flooding) and hydrologic flow services within agricultural landscapes.

Background

Wetlands provide an important ecosystem service by modulating storm flows and reducing the frequency of stream flood stage and subsequent flooding of urban, suburban, and rural landscapes. Watersheds with drained wetlands have reduced water storage capacity and less modulated (i.e., spiky) stream flows, making them more subject to flooding (Miller and Nudds 1996).

The majority of wetland loss within the United States has occurred through drainage. Organized ditch drainage on the Delmarva Peninsula dates to the 17th century with formation of the first recognized public drainage association in North America (Bell and Favero 2000). Although depressional wetlands are prominent in the Delmarva landscape, they were once even more common. Many have been drained to allow for agricultural cultivation, primarily corn and soybean production, in support of a substantive poultry industry (McCarty et al. 2008). Between the 1780s and the 1980s, the states that compose the Delmarva Peninsula lost significant amounts of wetland area (Delaware 54%, Maryland 73%, Virginia 42%; Dahl 1990).

Depressional features, similar to Carolina bays, are regionally known as Delmarva bays and occur primarily near the border between Maryland and Delaware in the northern and central portions of the Delmarva Peninsula (Tiner 2003; Fenstermacher et al. 2014). A detailed geomorphometric analysis using a LiDAR-derived digital elevation model (DEM) estimated that 17,000 depressional features exist on the Delmarva Peninsula, most of these being current or former Delmarva bays (Fenstermacher et al. 2014). This estimate was an order of magnitude higher than reported in previous studies (Stolt and Rabenhorst 1987).

The extensive drainage of Delmarva bays, primarily via ditches, to support agricultural activities has undoubtedly had marked effects on water storage capacity and hydrologic flow regulation services. However, the status of depressional wetland water storage and the potential for increased storage with wetland restoration on the Delmarva Peninsula are unknown, as is the extent of water storage volume loss due to the conversion of natural wetlands to croplands.

This Mid-Atlantic Region (MIAR) CEAP-Wetland study provides an estimate of surface water storage volume once associated with depressional wetlands on the Delmarva Peninsula, assesses the proportion of storage volume loss in this landscape due to drainage for agricultural production, and compares this loss with the gain of storage volume associated with implementation of wetland restoration practices on cropland.

Assessment Approach

Study Area and Sites

The research area encompassed the entire Delmarva Peninsula, with validation of extrapolation methodology occurring in New Castle and Kent counties in Delaware, and Dorchester, Talbot, Caroline, and Queen Anne's counties in Maryland. For validation, representative subsets were selected from the known Delmarva Peninsula depressions, including natural and restored wetlands, as well as prior converted croplands. Natural wetlands were selected from the Delmarva bays on forestland. Restored wetlands included cropland areas that had been hydrologically restored to depressional wetlands through USDA conservation programs. Prior converted cropland sites included in the survey were located on active croplands containing roughly circular depressional areas with morphologies approximating those established for Delmarva bays (Fenstermacher et al. 2014).

Outline of Storage Volume Scaling Approach

This study used the following multistep calibration and validation process for scaling storage volume estimates across land cover within the Delmarva Peninsula: 1) Validate the use of LiDAR-derived DEMs to estimate storage volume using a field-based approach at 20 depressional wetlands; 2) Calibrate and validate a generalized formula to estimate depression volume based on surface area, relief, and a constant optimized for Delmarva bays using a set of 58 representative depressional wetlands; 3) Test the utilization of median depression area against measured area for assigning land cover to wetlands within the set of 58 wetlands using high resolution imagery for validation; 4) Characterize distributions of measured relief and radius for a random subset (1,372) of the regional Delmarva bay population and further test use of median radius for land cover assignment using coarse resolution (30 m) National Land Cover Dataset (NLCD); 5) Use the distributions measured in the subset to randomly assign relief and radius to the full Delmarva bay population (about 14,500) and calculate storage volume using the calibrated general formula; 6) Assign land cover to the full population using the intersection of a median radius polygon with the land cover map.

Comparing Volume Estimates: Ground-based Surveys vs. Aircraft-based LiDAR

A set of 20 depressions representing natural and restored wetlands and prior converted croplands were selected for comparison of storage volume estimates based on ground-based surveys and airborne LiDAR. The ground-based surveys took place during the summer and fall of 2012 (dry season), ensuring the greatest access to all sections of the wetland using construction-grade robotic total station survey equipment. Elevation readings were taken in 0.3-m increments in areas of rapid change, such as ditches and berms, and 5-m increments in areas of minimal relief.

Total station data points were corrected and processed with Trimble GPS Pathfinder and imported into ArcMap (ESRI, Redlands, CA). LiDAR data were collected from the Maryland Department of Natural Resources, the state of Delaware, or the Agricultural Research Service (ARS). All LiDAR data had a vertical accuracy of ≤ 18 cm RMSE and were designed to meet or exceed Federal Geographic Data Committee National Standards for Spatial Data Accuracy for data at a scale of 1:2,400. Estimated horizontal positional accuracy of point returns exceeds 50 cm. Triangulated Irregular Networks (TINs) were created for individual wetlands using the total station or LiDAR data points (Figure 1).

Volume calculations were performed in ArcMap using the hydrology function within the Spatial Analyst extension. The spill point—the elevation at which water exits the depression—was selected using the spill point function in 3D Analyst and confirmed using multiple years of aerial imagery and DEMs. This elevation point was then used in the Volume and Surface Area tool in ArcMap. Volume calculations from LiDAR-derived DEMs and total station surveys were compared.

Pairing Restored Wetlands with Representative Natural Wetlands and Prior Converted Croplands

Eleven wetland groups were formed to assess the effectiveness of wetland restoration for the reestablishment of surface water storage volume. Each group contained one natural wetland, one restored wetland, and one prior converted cropland resulting in 33 representative sites across the wetland alteration gradient, most of which were also used to assess LiDAR reliability. The natural wetland and prior converted cropland pairs were selected to be within a 5 km buffer of each restored wetland. This approach minimized

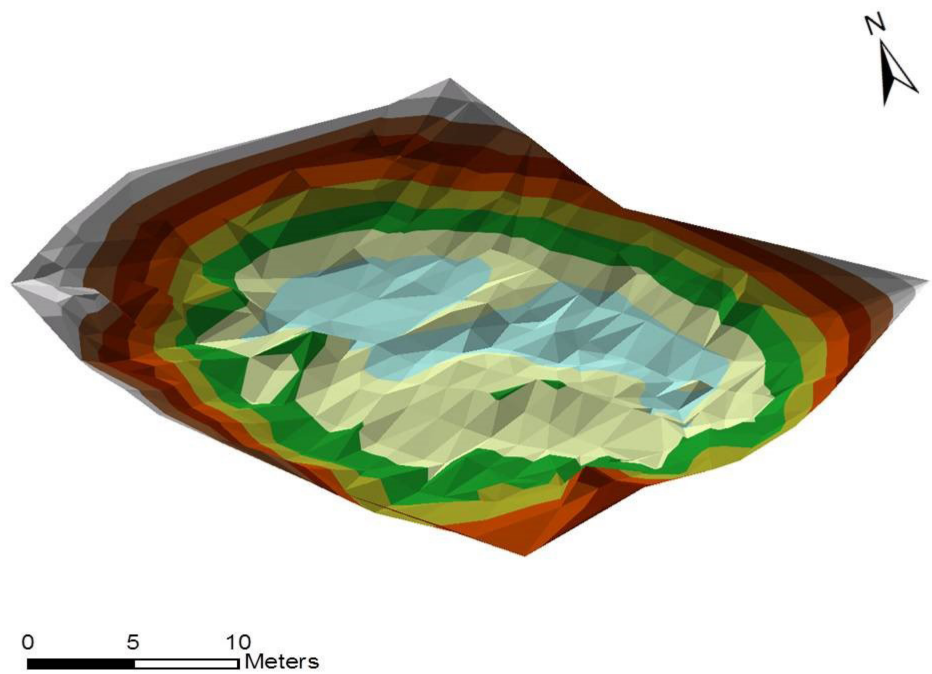

Figure 1. Example of a TIN created from ground-based survey data.

the influence of observed geographic gradients in depression morphology (Fenstermacher et al. 2014). Wetland morphologic characteristics (i.e., area, relief, and volume) typical for the region were derived from the 33 representative sites using the LiDAR-derived DEMs and volume calculation protocols described above.

Derivation of Equation for Calculating Regional Storage Volume

Hayashi and van der Kamp (2000) developed a generalized formula for deriving the volume of depressional wetlands, which was used to calculate storage volume in vernal pools (Brooks and Hayashi 2002). Vernal pools exhibit many of the same characteristics as Delmarva bays. The formula relates storage volume to surface area and relief by inclusion of a dimensionless constant P.

The Hayashi and van der Kamp (2000) formula, in which A = Area, V = Volume, h = depth (relief), and P = a constant, is:

$$V = (A * h)/(1 + 2/P)$$

Calibration of the formula for a given area requires calculation of a constant (P), which varies from values of less than one to values greater than one for convex and concave depressions, respectively. The average value of P for Delmarva bays—29 prior converted croplands and 29 natural bays (total of 58)—were characterized by measurement of storage volume, surface area, and relief using LiDAR-derived DEMs and ArcMap. Analysis of restored wetlands was not included because they did not fit the model based on natural processes. The sites selected were within the interval between the 1st and 3rd quartile of the median size of depressional wetlands in the region (based on Fenstermacher et al. 2014). The distribution of P was found to be normal, and the average P along with measurements of area and relief were used to estimate storage volume across the Delmarva Peninsula (see next section).

Regional Estimation of Storage Volume

Using LiDAR coverage of the Delmarva, Fenstermacher et al. (2014) identified and hand digitized the point locations of nearly 15,000 Delmarva bays and then extrapolated findings to areas without LiDAR coverage for a total population estimate of 17,000 bays. Fenstermacher et al. (2014) further characterized the morphology of 1,494 depressions selected through stratified random selection (roughly 10 % of the measured population) by determining surface area, major/minor axis, and orientation by manual construction of morphometric polygons (Figure 2). The relief of these depressions was determined by measuring the elevation of three random points in the depression relative to rim locations. In the present study, a portion of this population subsample (n=1,372) was used to estimate storage volume for the full population set based on the Hayashi and van der Kamp (2000) equation.

To account for skewness, each depression was randomly assigned a surface area bin based on the distributions of depression radii for their respective land cover classes. The mixed class locations were randomly assigned to bins in the combined (all) distribution. The depressions were then randomly assigned to relief histogram bins based on distributions of depression relief for their respective land cover classes. This use of double randomization was found to have validity because analysis of

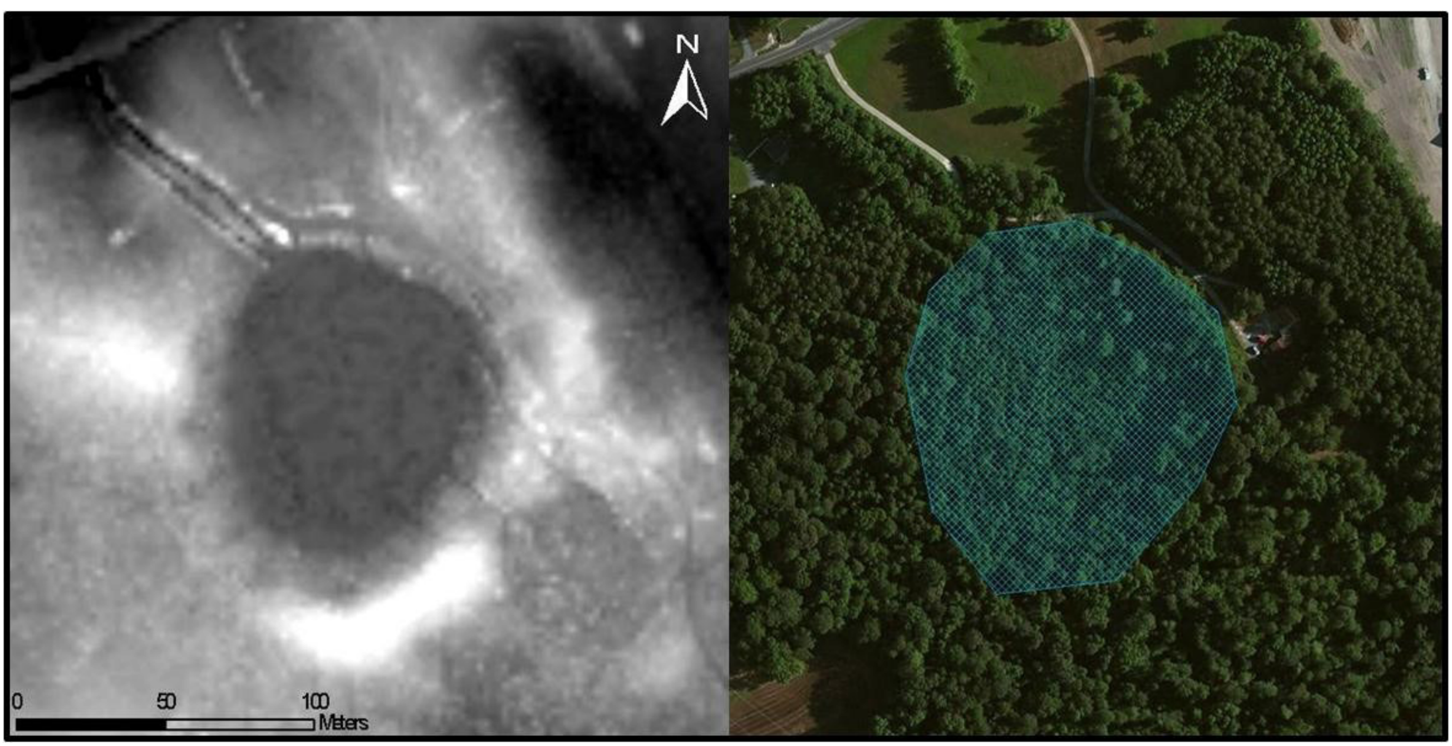

Figure 2. Example of a LiDAR-derived DEM (left) depicting a depressional forested wetland and the associated hand-delineated polygon created to represent the depression surface area over-laid on an aerial photograph (right).

the approximately 1,500 delineated polygons demonstrated that surface area and relief were not correlated (r = 0.08). With completed attribute assignment for surface area and relief, volume was then calculated using the Brooks-Hayashi formula using a P equal to 1.91, as determined using the 58 calibration sites.

Land Cover Assignment

Land cover data were retrieved from the 30 m resolution 2006 Multi-Resolution Land Characteristics NLCD (Homer et al. 2015). Intersection of wetland polygons with the NLCD land cover map was used to classify land use for each depression and determine whether the depression is farmed. The threshold criteria used to designate a single land cover classification was 80 % of depression surface area. When less than 80 % of the depression area was occupied by one land cover class, the depression was classified as having a mixed land cover. In the case of the 58-wetland subset, land cover assignment based on NLCD was compared to that obtained using high resolution (about 1 m) aerial photography. In the case of the approximately 1,400-wetland subset, NLCD was used to assign land cover based on both measured radii of the morphometric polygons and median radii of the subset population.

Assessment Findings

Comparing Volume Estimates: Ground-based Surveys vs. Aircraft-based LiDAR

Traditionally ground-based surveys have been used to obtain accurate estimates of depressional storage volume, but the advent of aircraft-based LiDAR systems holds promise for expanded coverage. Variable wetland characteristics, such as vegetation cover, can obstruct bare earth determinations required for accurate LiDAR DEM development, thus biasing LiDAR-based estimates of storage volume. We explored this potential limitation by comparing estimates of storage volume derived using ground- and LiDAR-based methods. The depressions used in the analysis varied widely in ground-based volume estimates (i.e., 79 m^3 to 26,700 m^3). Overall there was good agreement between volume estimates derived from ground- and LiDAR-based methodologies (Figure 3); on average, LiDAR-derived volume estimates were within 3 % of those based on ground surveys. The largest discrepancies occurred with two of the restored wetlands, perhaps due to the inability of ground surveys to capture the irregular shape (i.e., large islands and microtopography) of some restorations.

Evaluating Ability to Estimate Storage Volume Based on Surface Area and Relief

A population of depressions with similar geomorphic characteristics (i.e., Delmarva bays; Fenstermacher et al. 2014) raises the likelihood of being able to predict storage volume based on surface area and relief alone. This ability was enhanced by use of the generalized Hayashi and van der Kamp (2000) volume formula. The population of 58 depressional wetlands used to determine the range of P for Delmarva depressional wetlands displayed a wide range of relief, volume, and surface area. All three of these parameters had skewed distributions, with natural wetlands displaying greater skewness (Figure 4). By contrast, values of P were normally distributed for the total (natural + prior converted cropland) population with a mean value of 1.91, and there was no statistically significant difference in P between natural wetlands and prior converted croplands. Moreover, within the study area, P was found to be independent of a considerable range in volume, relief, and surface

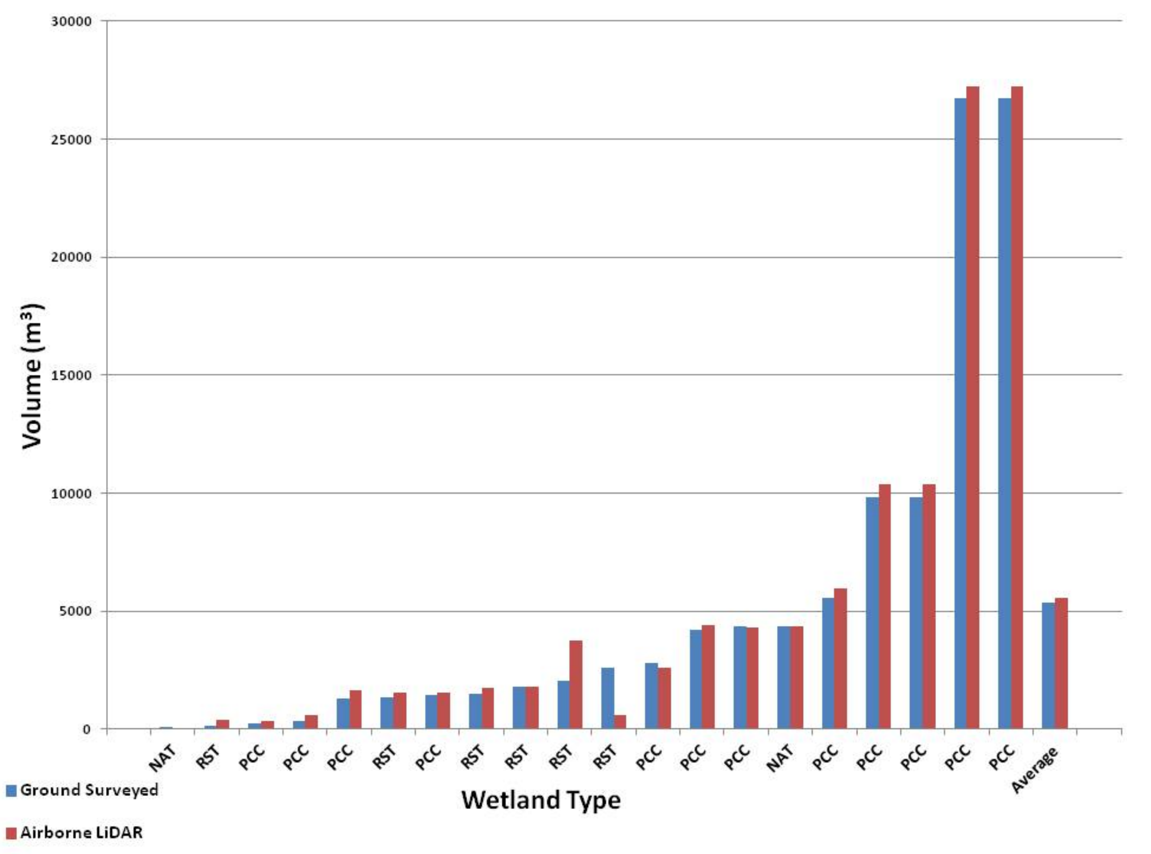

Figure 3. Comparison of volume estimates using ground surveys and airborne LiDAR digital elevation models at prior converted cropland [PCC], natural [NAT], and restored [RST] sites.

area. An average P of around 2 indicates a substantial concave morphology, which agrees with the findings of Fenstermacher et al. (2014) for Delmarva depressions. A more extensive assessment of morphometric attributes was conducted using 1,372 natural depressional wetlands and prior converted croplands that were probably former depressional wetlands whose perimeters had previously been hand delineated (Fenstermacher et al. 2014). Analyses of this population also found that both radius and relief were not normally distributed (Figure 5).

Regional Storage Volume Estimates
Results demonstrate that NLCD, with its coarser spatial resolution, predicted prior converted croplands with 97 % accuracy and natural wetlands with 87 % accuracy when using actual digitized wetland boundaries. Accuracy was only slightly reduced (average 90 %) when median depressional radius (53 m) was used in conjunction with NLCD to determine land cover. Land cover was assigned to the previously delineated depressions using the NLCD based both on measured radii from the Fenstermacher et al. (2014) delineations and median radii (53 m), as well as the 80 % criteria (Table 1). Based on this approach, roughly 80 % of depressions fell within a single land type, including 53 % within the agricultural class and 27 % within the natural forestland class. These findings verified the suitability of using median radius and threshold values for scaling storage volume measurements per land cover type to the Delmarva Peninsula.

Fenstermacher et al. (2014) detected about 14,500 depressions on cropland and forestland that were consistent with classification as a Delmarva bay. For those point locations, land cover was assigned using the NLCD and median radius. The depressions were then classified as either forestland, cropland, or mixed using the median radius and 80 % inclusion rules. This assessment found that 81 % of the 14,500 depressions fell within a single land cover class, which is in close agreement with the 80 % finding pertaining to the approximately 1,400-depression subset. For the 14,500 population, a majority (58 %) of the depressions were found to be located on cropland, whereas 23 % were estimated to be on forestland and 18% on mixed land cover (Figure 6). These results are again comparable to those obtained with the use of the 1400-depression subset.

Total storage volume of the 14,500 depressions on cropland and forestland was determined to be 35,900 ha-m. Estimated water storage volume for depressions on cropland sites totaled 16,900 ha-m, compared to 12,400 ha-m for natural sites and 6,600 ha-m for sites with mixed classification. A substantial portion of the mixed class

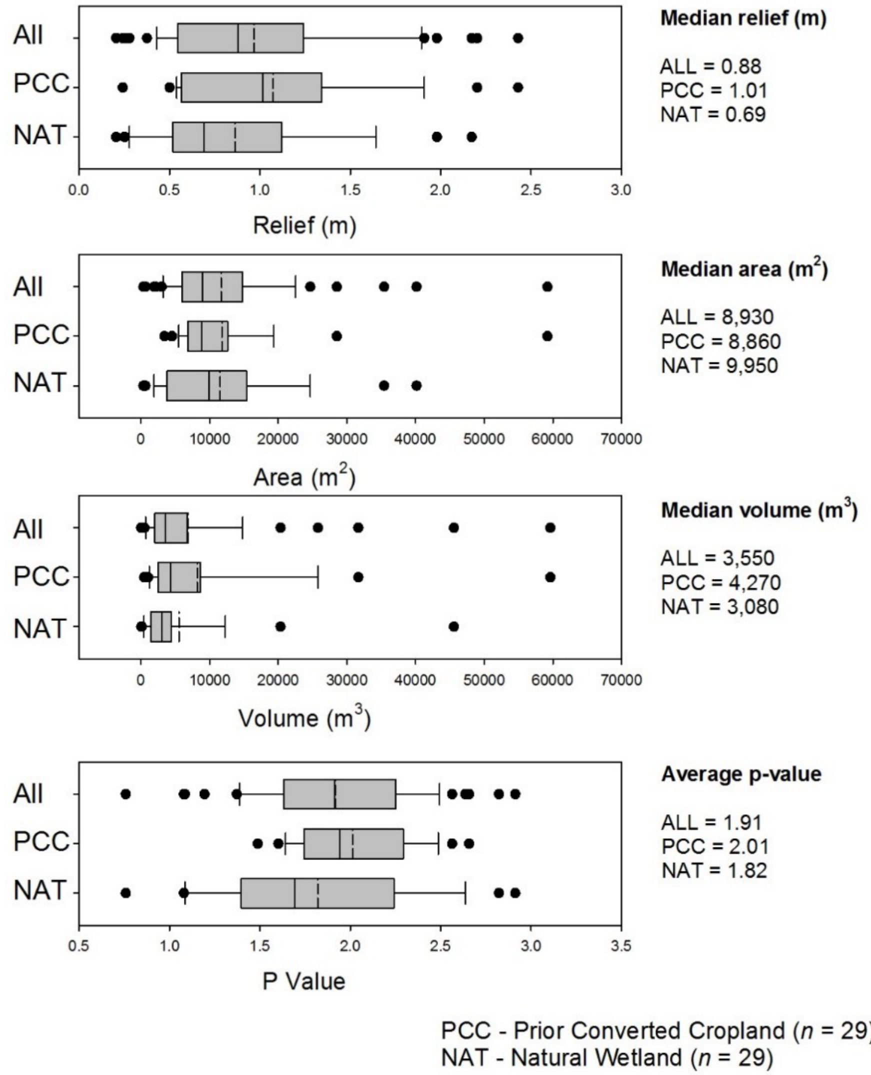

Figure 4. Range in morphometric properties for 29 prior converted croplands (PCC) and 29 natural wetlands (NAT) used for calibration. Graph representations: boxes = 25th and 75th percentiles; whiskers = 10th and 90th percentiles; dots = outliers; solid line = median; dashed line = mean.

Table 1. Comparison of land cover classifications using hand-delineated polygons to those based on median radius and 80 % area threshold for single land type classification.

Site type	Original polygons		Median radius	
	Single land type	Mixed	Single land type	Mixed
All sites	1,095	257	1,117	238
Cropland	732	118	729	107
Forestland	363	139	388	131

depressions is also likely drained for crop production adding to the loss of storage volume. The median storage capacities of depressions were 13,000, 17,100, and 15,300 m^3 for cropland, forestland, and mixed land cover, respectively. The natural depressions tended to have greater surface area (Figure 4), which likely accounted for their greater storage capacity. Nevertheless, because of the larger number of depressions found on cropland, the cropland land cover classification has the greatest potential for storage volume if the land were not drained for agricultural purposes. These results reveal the great potential for storage volume gain with wetland restoration programs.

This Delmarva Peninsula study covered an area of about 1.55 million ha. In comparison, Gleason et al. (2007) assessed storage volume in the Prairie Pothole Region (PPR) over an area of 445,000 ha and estimated a total depressional storage capacity of approximately 56,500 ha-m. The higher storage capacity per unit of land area in the PPR is likely accounted for by a couple of factors. One factor is that landscape relief on the Delmarva is less than that on the PPR, and another is that Delmarva bays are concentrated in the upper portion of the Peninsula, with the southern portion having a low density of depressions (Figure 6). If analysis was limited to the high-density region of the Peninsula, regional estimates would become more comparable on a depression per-area basis.

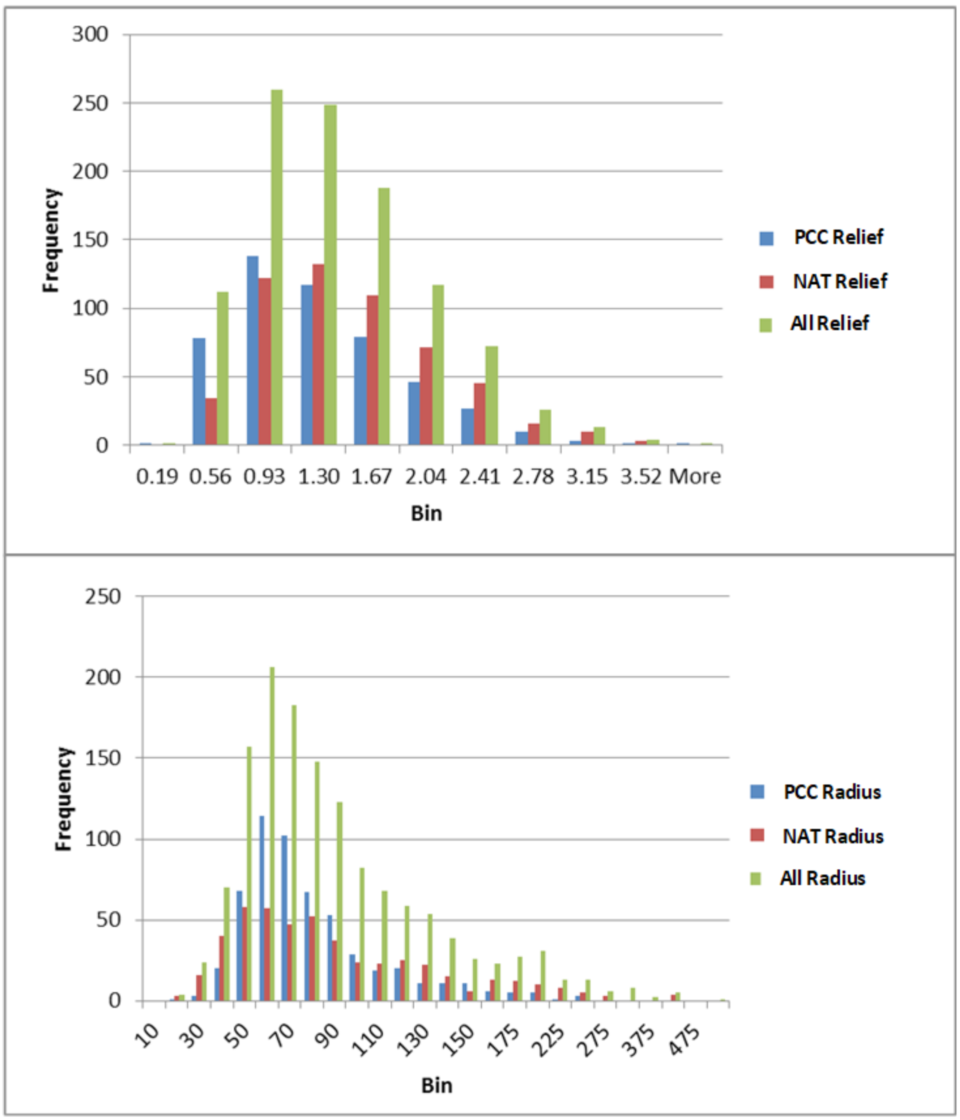

Figure 5. Distributions for relief and radius of about 1,400 natural wetlands and prior converted croplands. Histograms were created using 26 bins for depression radius and 11 bins for depression relief. Values on both X axes are in meters.

Storage Volume in Wetland Restorations

In the paired wetland assessment, the morphometric properties of 11 restored wetlands were compared to those of geographically similar natural wetlands and prior converted croplands. Data showed that the range of restored wetland properties tended to be less than those observed for natural wetlands and prior converted croplands (Figure 7). This trend was particularly strong for area and volume. Median storage volume of restored wetlands (1,480 m^3) was between 53 and 60 % of that for prior converted croplands and natural wetlands, respectively (Figure 7). The measured storage volume for restored wetlands was also considerably smaller than the median volumes estimated for wetlands in the 58-site calibration set (natural = 5,450 m^3, prior converted cropland = 8,260 m^3) and almost a factor of 10 smaller than the population estimates of volume for depressions on cropland and forestland covering the Delmarva.These findings, in conjunction with the substantially lower number of restored wetlands on the Delmarva Peninsula relative to prior converted croplands and natural wetlands, indicate that current restorations likely have limited impact on storage volume within the region, but that the potential surface water storage volume gain from restoration is great.

Conclusions

A recent survey of the Delmarva Peninsula discovered nearly 15,000 circular or semi-circular depressions with features consistent with the morphology of Delmarva bays (Fenstermacher et al. 2014). The MIAR study component described herein found that most of these depressions (58 %) are located on actively farmed cropland, representing a loss of 16,900 ha-m of potential storage volume to agricultural production. Furthermore, an additional 18 % identified depressions were found in areas of mixed cropland–forestland cover, representing a likely loss of potential storage volume of 6,600 ha-m. This combined estimated loss of 23,500 ha-m of potential surface water storage volume has likely had a substantial, negative impact on hydrologic flows, increasing the likelihood and duration of stream-overbank events and resultant floods.

Wetland restoration can help modulate hydrologic flows in adjacent streams, in contrast to prior converted croplands, which enable larger flash storm flows directly after precipitation events (McDonough et al. 2015). Restored wetlands exhibited surface water flows intermediate to those of natural wetlands and prior converted croplands. Wetland area was found to be significantly correlated with the periodicity of surface water flows. 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). Although wetland restoration has been found to have a positive effect on the regulation of hydrologic flows and natural hazard vulnerability, the extremely large volume of surface water storage that has been lost at a landscape scale relative to the modest gains in water storage made possible by restoration highlights the value of increased, sustained restoration. In general, the agricultural landscape of the Delmarva Peninsula has a very high capacity for increased surface water storage volume. This study provides important perspective on the degree to which implementation of wetland restoration and drainage control structures can take advantage of potential storage volume capacity on croplands.

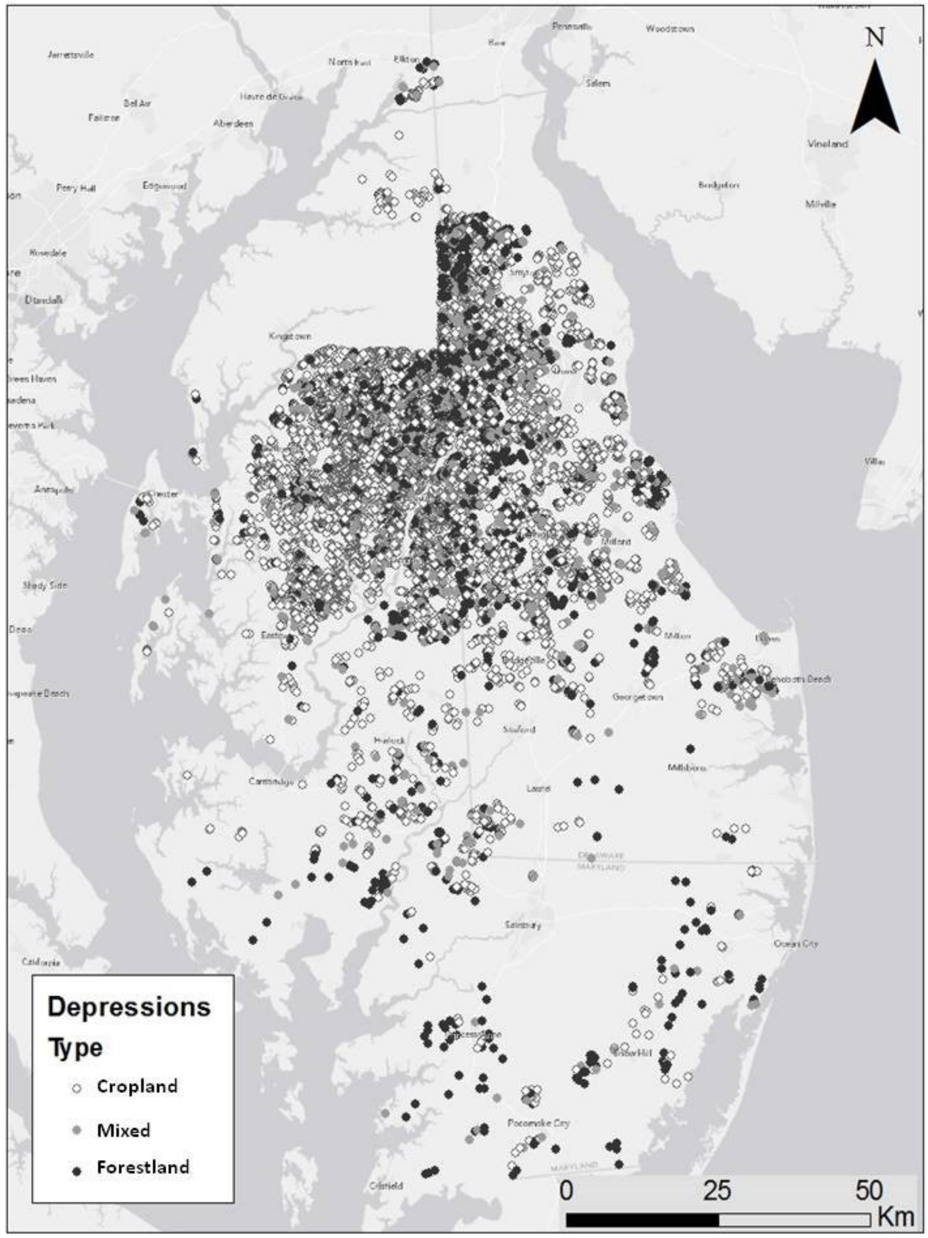

Figure 6. Distribution of depressions with cropland, forestland, and mixed land cover classifications.

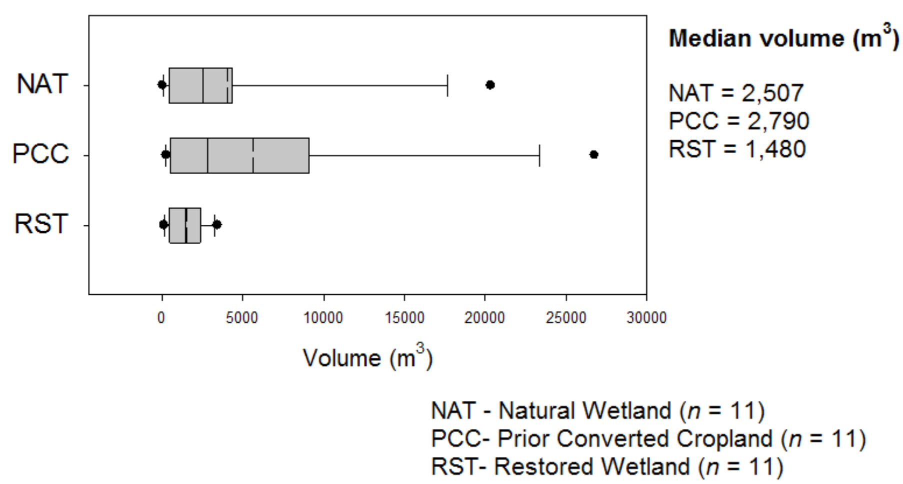

Figure 7. Range in storage volume for the paired sets of restored (RST), prior converted cropland (PCC), and natural (NAT) sites. Graph representations: boxes = 25th and 75th percentiles; whiskers = 10th and 90th percentiles; dots = outliers; solid line = median; dashed line = mean.

References

Bell, W.H. and P. Favero. 2000. Moving water. A report to the Chesapeake Bay Cabinet by the Public Drainage Task Force. Contribution No. 2000-1. Center for the Environment and Society, Washington College. http://www.dnr.state.md.us/Bay/tribstrat/public_drainage_report.pdf.

Brooks, R. and M. Hayashi. 2002. Depth-area-volume and hydroperiod relationships of ephemeral (vernal) forest pools in southern New England. *Wetlands* 22:247-255.

Dahl, T.E., U.S. Fish and Wildlife Service, National Wetlands Inventory Group. 1990. Wetlands losses in the United States, 1780's to 1980's. U.S. Dept. of the Interior, Fish and Wildlife Service, Washington, D.C.

Fenstermacher, D.E., M.C. Rabenhorst, M.W. Lang, G.W. McCarty, and B.A. Needleman. 2014. Distribution, morphometry and land use of Delmarva Bays. *Wetlands* 34:1219-1228.

Gleason, R.A., B.A. Tangen, M.K. Laubhan, K.E. Kermes, and N.H. Euliss, Jr. 2007. Estimating water storage capacity of existing and potentially restorable wetland depressions in a subbasin of the Red River of the North: U.S. Geological Survey Open-File Report 2007-1159, 36 pp.

Hayashi, M. and G. van der Kamp. 2000. Simple equations to represent the volume-area-depth relations of shallow wetlands in small topographic depressions. *Journal of Hydrology* 237:74-851.

Homer, C.G., J.A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N.D. Herold, J.D. Wickham, and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States—Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing* 81:345-354.

McCarty, G., L. McConnell, C. Hapeman, A. Sadeghi, C. Graff, W. Hively, M. Lang, T. Fisher, T. Jordan, C. Rice, E. Codling, D. Whitall, E. Lynn, D. Keppler, and M. Fogel. 2008. Water quality and conservation practice effects in the Choptank River watershed. *Journal of Soil and Water Conservation* 64:461-474.

McDonough, O., M. Lang, J. Hosen, and M. Palmer. 2015. Surface hydrologic connectivity between Delmarva Bay wetlands and nearby streams along a gradient of agricultural alteration. *Wetlands* 35:41-53.

McLaughlin, D., D. Kaplan, and M. Cohen. 2014. A significant nexus: Geographically isolated wetlands influence landscape hydrology. *Water Resources Research* 50:7153-7166.

Miller, M.W. and T.D. Nudds. 1996. Prairie landscape change and flooding in the Mississippi River Valley. *Conservation Biology* 10:847-853.

Stolt M.H. and M.C. Rabenhorst. 1987. Carolina Bays on the eastern shore of Maryland: I. soil characterization and classification. *Soil Science Society of America Journal* 51:394–398

Tiner, R.W. 2003. Geographically isolated wetlands of the United States. *Wetlands* 23:494-516.

Conservation Effects Assessment Project: Translating Science into Practice

The Conservation Effects Assessment Project (CEAP) is a multiagency effort to build the science base for conservation. Project findings will 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 Component 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 project was conducted through collaboration among researchers with University of Maryland/College Park (UMD) and USDA, Agricultural Research Service (ARS), Beltsville. Primary investigators on this project were Megan Lang (UMD), Gregory McCarty (ARS), and Shelly Devereaux (UMD). This Science Note was written by Drs. Megan Lang and Greg McCarty.

For more information, visit http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap, or contact Michael Carlo, Acting CEAP-Wetlands Component Leader, at michael.carlo@wdc.usda.gov.