USDA United States Department of Agriculture

Conservation Effects Assessment Project (CEAP)

Science Note

A Novel Geospatial Modeling Tool Can Infer Wetland Function

Key Takeaways

- An improved understanding of inundation area and timing at the landscape scale will help determine the extent of wetland functions and ecosystem services.
- Recent developments in remote sensing allow higher resolution estimates of wetland inundation but are limited to winter or “leaf-off” periods in forested systems.
- Remotely sensed inundation patterns show good agreement with climatic rainfall data
- By correlating “leaf-off” estimates of inundation with daily stream flow in downstream waters, it is possible to infer wetland inundation patterns at more frequent timescales
- Inferred inundation patterns are highly correlated with National Wetlands Inventory classifications of wetland water regime (hydroperiod).
- This information will aid conservation planners by helping to establish the connections between geographically isolated wetlands, their functional attributes, and downstream water quality and quantity.



Photo by Dan Murphy

Wetland ecosystem services are affected by the level and extent of wetland inundation, meaning the wetland’s ground surface is submerged with water. Remote-sensing tools such as Landsat images and LiDAR, are able to assess inundation but typically are only effective during colder periods when the leaves have fallen off deciduous trees.

Flooding and Function

Healthy wetlands provide a range of valuable ecosystem services that benefit agriculture and human wellbeing, including flood mitigation, water quality improvement, groundwater recharge, carbon storage, and fish and wildlife habitat. Most or all of these services are affected by the level and extent of wetland flooding or inundation, although some, like the nitrification-denitrification pathway, may require alternating wet-dry cycles. While it may not predict the degree of function, surface water or soil saturation can be used as an indicator of the presence of these functional attributes. In addition to ecosystem services directly related to wetland areas, the hydrologic and biogeochemical cycles within wetlands have been found to exert significant influence on the chemical, physical, and biological integrity of downstream waters (Phillips and Shedlock 1993).

Recent developments in remote sensing technologies allow mapping of the land surface that can provide information about wetland inundation patterns at the landscape level. For example, wetland connectivity with streams in the Prairie Pothole Region was successfully assessed using inundation information developed from time-series remotely sensed data (Vanderhoof et al. 2016). Moreover, by integrating multiple types of remotely sensed data (e.g., Landsat images and LiDAR intensity data) the percent of a given area or spatial extent occupied by surface water can be determined at subpixel resolution (i.e., smaller than the 30 m by 30 m pixels in Landsat images, Huang et al. 2014).

Mapping the inundation dynamics of geographically isolated wetlands (GIWs) will enhance the ability to estimate outcomes of wetland restoration at the landscape level, as well as of conservation practices that reduce sedimentation and increase uptake of excess nutrients. In the coastal plain these outcomes include potential water quality improvements benefitting downstream surface waters like the

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Chesapeake Bay. Unfortunately, in forested wetlands the inundation patterns are only discernable by remote sensing during a limited time, when leaves are off deciduous trees during colder periods.

Goals of the Study

In order to extend our ability to estimate inundation patterns of forested wetlands throughout the year, this study attempts a more innovative approach that correlates these remotely sensed data with more frequent hydrologic observations. The U.S. Geological Survey (USGS) Groundwater and Streamflow Information Program supports the collection of both streamflow and water-level information for more than 8,500 sites nationwide. By establishing correlations of flow data with observed inundation patterns in wetlands, the availability of continuously observed streamflow can enable assessment of wetland function over longer periods of time.

Exploring the relationship between wetland inundation and downstream waters, however, requires expensive monitoring networks that measure flow from wetlands to downstream areas via multiple pathways for several years (Denver et al. 2014) and such data rarely exist. Due to spatial heterogeneity of land use and soil characteristics at landscape scales, field-level monitoring of area and temporal extent (hydroperiod) of inundation has been limited to characterization of catchment-level patterns. This study, funded by NRCS through the Conservation Effects Assessment Project (CEAP), developed a novel geospatial modeling method to elucidate connectivity of GIWs with downstream waters that will help predict wetland functioning at the landscape scale.

Photo by U.S. Fish and Wildlife Service



A wetland in the Delmarva.

Solving the Problem

The study area comprised the wetland-rich Greensboro watershed (~ 292 km²), within the Coastal Plain of the Chesapeake Bay watershed. The spatial extent of surface water across the study area was determined from Landsat and LiDAR data and used to produce subpixel water fraction (SWF) maps. Subpixel water fraction refers to the percent of a given Landsat pixel area or spatial extent that is identified by LiDAR as being covered by surface water. SWF maps can typically be generated only once per year for the coastal plain due to cloud cover and forest canopy conditions that constrain the use of remotely sensed optical data to map the surface.

In order to extend our estimates of GIW inundation patterns throughout the year, we needed to correlate the yearly SWF maps with more frequent climate and streamflow observations. We first confirmed that SWF maps could be related to climate by comparing the annual SWF maps with a range of climatic conditions. Conditions for the dates of the Landsat and LiDAR data were characterized as dry, normal, or wet using the Palmer Drought Severity Index (PDSI) and the Palmer Z Index obtained from the National Oceanic and Atmosphere Administration (NOAA) National Climatic Data Center (NCDC). Low and high values of the climatic indices indicate wet and dry conditions, respectively. The 30 x 30 m Landsat pixels in the SWF map were categorized into four different groups based on the percentage of the pixel that is inundated (1 – 25%, 25-50%, 50-75%, and 75-100%).

Figure 1 illustrates that these inundation patterns on selected dates were in good agreement with climatic variability from dry to wet conditions as defined by the PDSI and Palmer Z indices. We next correlated the same categories of inundation percentage with observed streamflows and aggregated climate data. A daily stream hydrograph was developed from USGS streamflow data downloaded from USGS station #01491000 and used to estimate the base flows (i.e., the portion of streamflow contributed by groundwater).

The aggregated inundation areas for the watershed are compared with weather conditions for the month of SWF map data acquisition (based on Palmer Z Index score) in Fig. 2 and with daily stream and baseflow observations at image acquisition dates in Fig. 3. Inundation extent increased with wetter conditions

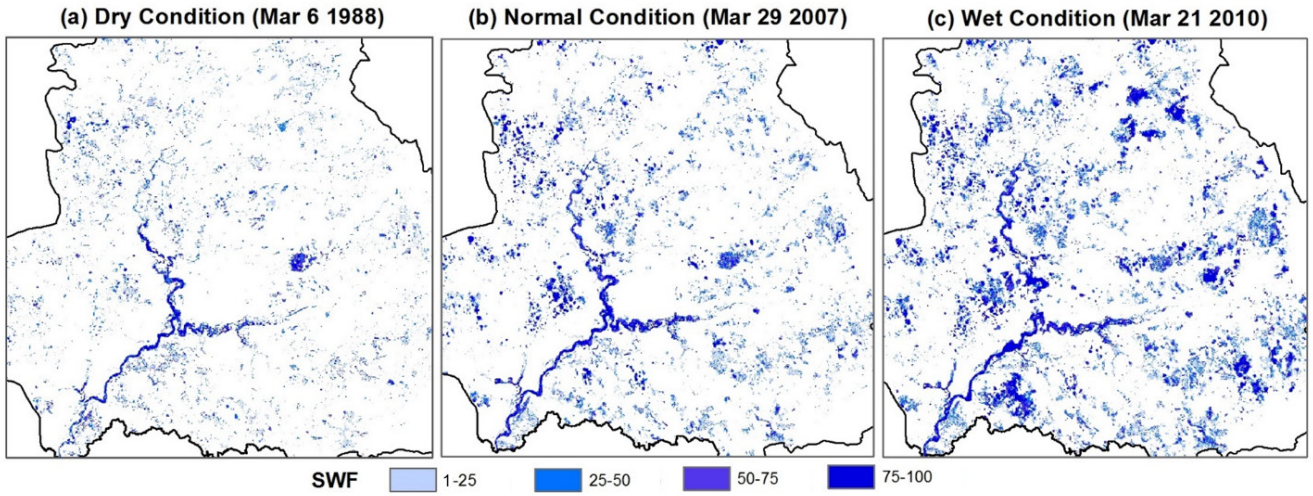


Figure 1. Spatial patterns of inundation under dry, normal, and wet climatic conditions. Inundation patterns were mapped by subpixel water fraction (SWF) analysis that compares Landsat and LiDAR data.

(Fig. 2) and when streamflow and base flow were high (Fig. 3). Overall, these results illustrate that inundation patterns determined from remotely sensed data are strongly correlated with climatic conditions as well as with downstream water levels.

While this correlation suggests that wetlands and streams are connected through groundwater, we wanted to further explore the strength of the relationship with flow. Wetlands in the study area were categorized based on information in the National Wetland Inventory (NWI) geospatial dataset. NWI is a publicly available resource that provides detailed information on the abundance, distribution, and characteristics of U.S. wetlands, including four water regime types representing the hydroperiod or duration of inundation: saturated, temporarily flooded, seasonally flooded, and seasonally flooded/saturated. NWI water regime classifications were determined for all GIWs identified in the study area and each category analyzed for consistency between the classifications and quantitative measures of inundation extent and frequency. These measures were quantified from the time-series SWF

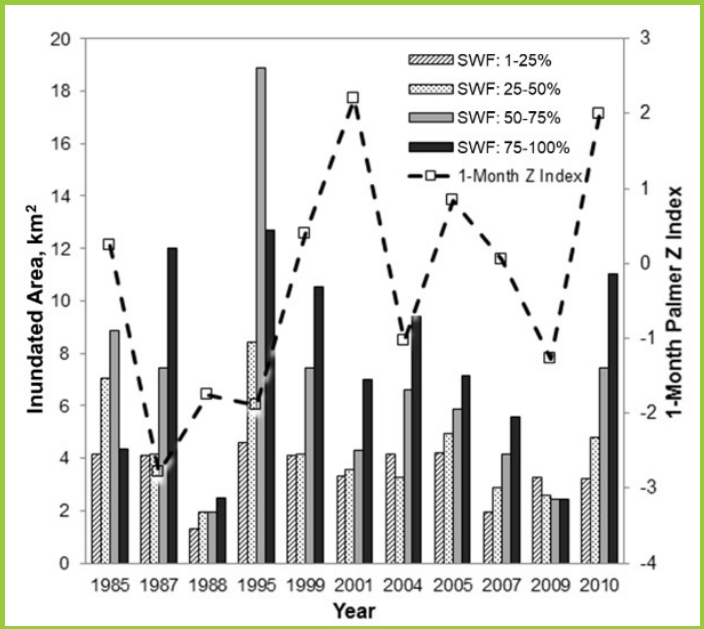


Figure 2. Inundated area of the study watershed compared with Palmer Z Index scores for month of SWF data acquisition. Note that in both 1987 and 1995, the study area was affected by extreme storms prior to image acquisition.

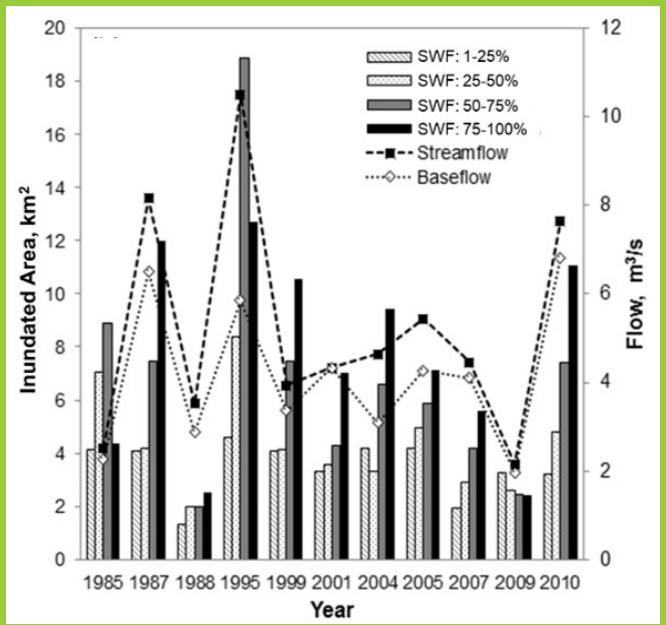


Figure 3. Inundated area of the study watershed compared with downstream stream and base flows. Note that in both 1987 and 1995 the study area was affected by extreme storms prior to image acquisition.

maps for the area of each NWI regime class within the total area of GIWs in the study area. Metrics included the proportion of total simple inundation extent (i.e., surface water present within each pixel [SWF > 0%]) and mean relative frequency of high inundation (i.e., more than 50% of 900 m² pixel inundated [SWF > 50%]) relative to the areal extent per wetland type.

Figures 4 through 6 summarize inundation patterns grouped by NWI water regime classifications. These were generally consistent with the water regime rankings. Figure 4 indicates the wetland area of each NWI water regime category as a percent of the total area of GIWs in the watershed. The proportion of each water regime that was identified as inundated, as well as the mean relative frequency of high inundation are shown in Figure 5. The mean relative frequency of high inundation (SWF > 50%) categorized by water regimes ranged from 8.6% to 33% (Figure 5) and increased consistently in the flooding durations predicted by the NWI water regime classifications. Standard deviations reflect the climatic variability over the 15 years of data acquisition for the 11 images used in the analysis.

The strength and significance of the relationship between inundation patterns of GIWs and downstream waters also differed according to water regime (Figure 6), increasing with duration of flooding (from saturated to seasonally flooded-saturated).

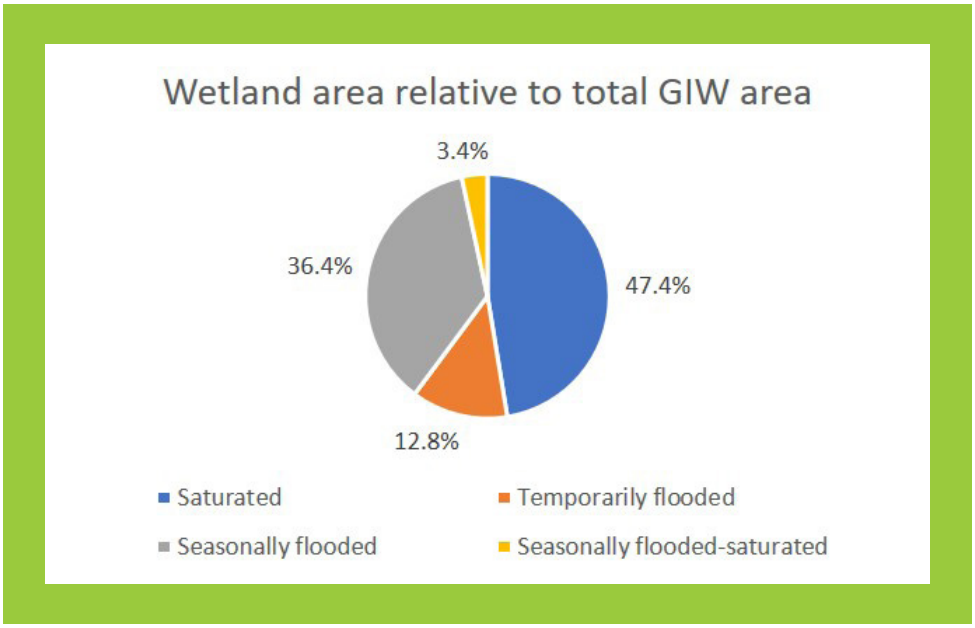


Figure 4. The relative area of the NWI water regime category as a proportion of the aggregated extent of GIWs within the watershed. GIWs are identified using NWI polygons and a new stream map developed in this study.

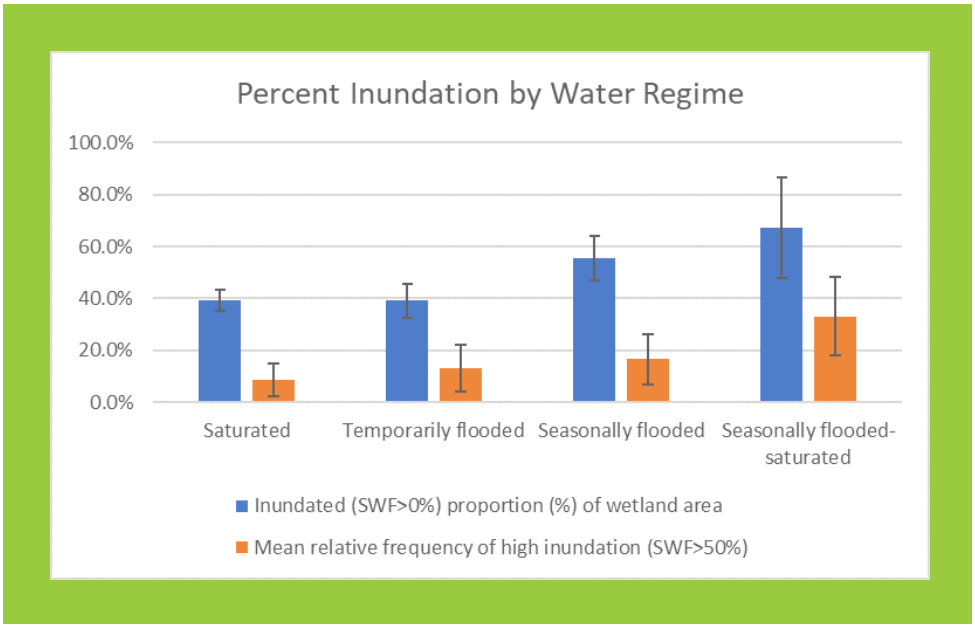


Figure 5. The proportion of flooded area (SWF > 0%) to the areal extent of each modifier group is indicated by blue bars. Orange bars depict the mean value of relative frequency of high inundation (SWF > 50 %) per pixels computed over the monitoring period for each NWI water regime. Standard deviations are shown with error bars.

Discussion

Our results demonstrate that the inundation patterns shown in SWF maps are in good agreement with observed climatic conditions and with downstream flow levels. In particular, wetlands identified as having long inundation duration in NWI water regimes showed higher aggregate measures of inundation computed from SWF maps relative to those with short hydroperiods.

Wetland inundation patterns strongly influence ecosystem functions such as biogeochemical transformations of nutrients, carbon sequestration, and groundwater recharge. Understanding existing or potential landscape inundation patterns is therefore an important prerequisite to estimating the ecosystems services that are compromised by wetland loss or that can be augmented through wetland conservation. Field-level monitoring is limited in its ability to represent landscape-level inundation patterns, but the increasing availability of SWF maps and remotely sensed data products (Jones 2015) offers a means to evaluate surface water dynamics at these scales where streamflow data is available. This study demonstrates a way to infer landscape-level wetland hydroperiods using publicly available data (NWI geospatial dataset, streamflow and climatic index) and SWF maps derived from remotely sensed geospatial datasets.

GIWs with a short flooding duration are likely to be controlled by surface inflow and precipitation and, while having highly variable inundation patterns in the short term, would

be expected to have a generally low SWF. In contrast, GIWs with long flooding durations would be expected to have a relatively permanent and larger area of inundation and a high SWF. This may indicate that GIWs with consistently high SWF values over multiple years have a stronger connection to groundwater (Brooks 2006) and thus to downstream waters. Consistent with this hypothesis, our results in Figure 6 demonstrated a stronger correlation between downstream waters and GIWs with high values of SWF relative to those with low values.

At the watershed scale, spatial and temporal patterns of inundation and hydrologic connectivity have significant effects on water storage capacity, biogeochemical cycles, vegetation structure, and wildlife habitat (Roley et al. 2012, Lane and D'Amico 2010). GIWs with longer inundation or hydroperiod likely have greater capacity to remove nutrients from surface runoff since longer contact with wetland vegetation provides greater opportunity for nutrient uptake. In addition, inundation or saturation of wetland soils leads to the anaerobic conditions required for denitrification (Cherry 2011).

Length of inundation influences other ecosystem services provided by GIWs, including both plant (Battaglia and Collins 2006) and animal biodiversity as well as regulation of pollutants and greenhouse gases (Lane and D'Amico 2010). While GIWs with longer hydroperiods would likely have more successful amphibian reproduction (Brooks 2006), smaller pools serve as important links between larger pools and allow for dispersal of juveniles and genetic exchange among metapopulations (Gibbs 1993, Semlitsch and Bodie 1998). Gradients in soil moisture and hydrologic connectivity influence carbon budgets and production of gases such as CO_2 and CH_4 (Batson et al. 2014), thus having significant impacts on greenhouse gas emissions from and carbon sequestration in wetlands.

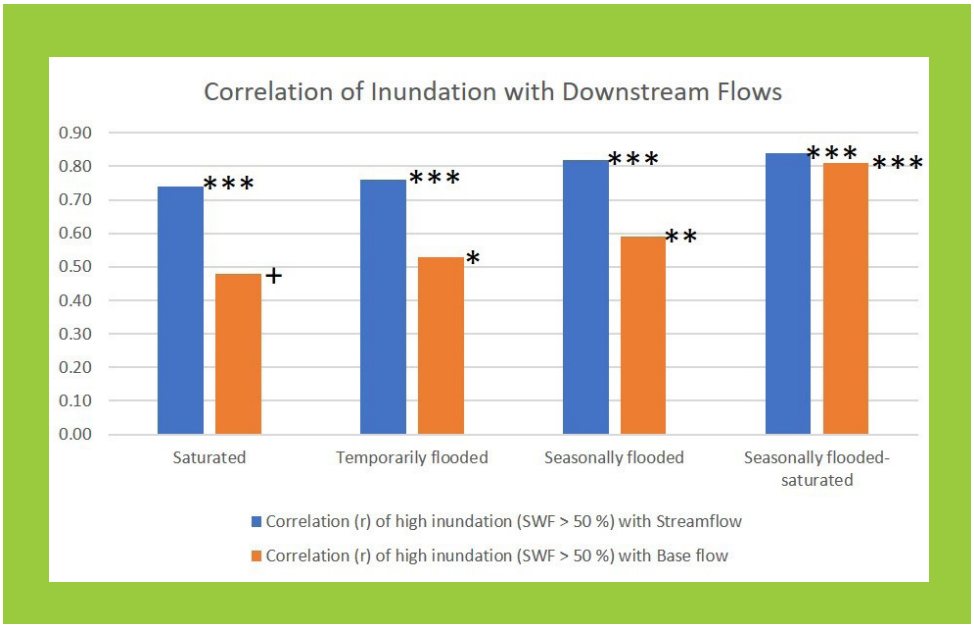


Figure 6. Correlation of downstream streamflow (blue) and base flow (orange) with highly inundated area (SWF > 50 %) were computed. The superscripts indicate the statistical significance of the relationship at the levels of +< 0.15, * < 0.1, **< 0.05, and *** <0.01.

Conservation Implications

Understanding the connection between wetlands and downstream flow provides insight into the role that wetlands play in the watershed as part of the network of streams and rivers. These roles have implications for efforts to protect and restore wetlands and riparian ecosystems and the services they provide downstream (Roley et al. 2012, Lee et al. 2020). Other CEAP-supported research explores in more depth some of the factors that influence the exchange between wetlands and downstream waters. Lee et al. (2019) established that in some cases longer hydroperiods are due to connection with groundwater through highly permeable wetland soils, indicating a greater potential to absorb stormwater and contribute to downstream baseflows through infiltration during dry periods when groundwater levels are low. On the other hand, they also identified cases where longer hydroperiods are due to subsurface soils that are less permeable, potentially resulting in reduced ability to accommodate successive rain events, greater surface flow, and less contribution to downstream baseflows (Lee et al. 2019). Such mediating factors have important implications for both on-site and downstream ecosystem function.

The geospatial modeling approach introduced here (Yeo et al. 2019) will help establish the connection of GIWs to downstream waters, enable better prediction of wetland hydroperiod, and allow estimation of landscape-level inundation patterns. With increasing availability of remotely sensed data, USGS and others are using this geospatial modeling approach to improve surface water detection and mapping (e.g., U.S. Dynamic Surface Water Extent; Jones 2015). These models may also contribute to improving geodatabases such as the U.S. Fish and Wildlife Service's National Wetlands Inventory. By allowing inference of important wetland functions and ecosystem services, information developed through these efforts could be applied to support wetland management decision-making at multiple scales, including prioritization of restoration projects and conservation practice implementation by NRCS planners and other agencies. Such information can also better support conservation planning through an improved understanding of the influence of wetland hydrology on water quality and quantity in downstream ecosystems.

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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 CEAP-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, the University of Newcastle-Australia, and USDA-ARS Beltsville, Maryland. Primary investigators on this project were I.-Y. Yeo, M.W. Lang, S. Lee, G.W. McCarty, A.M. Sadeghi, O. Yetemen, and C. Huang. This Science Note was compiled by Drs. S. Lee, G. McCarty, and J. Prenger.

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