United States Department of Agriculture

Conservation Effects Assessment Project (CEAP)

WETLANDS

Science Note

Headwater wetlands buffer variability in water levels and ecosystem services at the catchment scale.

Key Takeaways

- Understanding the role of geographically isolated wetlands (GIWs) in the hydrology of headwater landscapes is critical for effective wetland and water resources management.
- GIWs are hydrologically connected to downstream waters and affect their ecological integrity.
- Measuring hydrological connectivity is challenging at the landscape level, but analysis of geospatial datasets provides evidence of GIW connections to downstream waters.
- These spatial analyses alone, however, are not sufficient to assess long-term, continuous wetland connectivity and associated functions.
- This study applied a hydrological modeling approach to assess the connectivity of GIWs with downstream waters, their aggregate impacts on the partitioning of precipitation into evapotranspiration and soil water storage components (i.e. water budget), and other potential functions over multiple time scales.
- Our findings highlight GIW contributions to groundwater and downstream waters, their effectiveness for mitigating streamflow variability, and the importance of ongoing wetland restoration and protection efforts. These findings may not apply to all physiographic regions since GIW contributions vary with local soil and landscape characteristics.

This study used hydrological modeling to help understand how geographically isolated wetlands (GIWs) contribute to groundwater and interact with downstream waters, as well as their effects on soil water storage and other functions over multiple time scales.

Headwater Wetlands Are Important Contributors to Streamflow

Headwater streams make up 79% of U.S. stream networks, while non-floodplain wetlands comprise 6.59 million hectares in the conterminous USA that strongly influence ecological functions and fisheries in downstream rivers, lakes, and coastal areas (Colvin et al., 2018). These geographically isolated wetlands (GIWs) are a major component of many headwater landscapes and are frequently connected hydrologically to downstream waters (Lane et al., 2018), affecting their function and the ecosystem services they provide. Understanding the contribution of GIWs to services such as stream flow and water quality at the catchment scale is critical for conservation and management of water resources. Headwaters account for a substantial portion of river networks (Freeman et al., 2007) as well as a large proportion of the water and nitrogen fluxes within the landscape (Alexander et al., 2007). Effective protection of the wetlands embedded in headwater regions, and the ecological services they provide, requires understanding the hydrological processes by which these important landscapes influence the fate and transport of water and solutes (McDonnell and Beven, 2014).

The influence of headwater wetlands on downstream hydrology is currently not well understood. The degree and type of hydrological connectivity varies depending on the size, density, and

Natural Resources Conservation Service

position of GIWs as well as other landscape and climatic factors (Lane et al., 2018). While understanding hydrological connectivity is important for conservation planning and restoration of wetland ecosystems and services (Ali et al., 2018), actually measuring these connections is challenging at the landscape level. Explicit representation of hydrological connectivity within the landscape is often impractical because it requires expensive field monitoring of all water pathways (Denver et al. 2014). Analyses of geospatial datasets provide evidence of GIW connections with downstream waters, but these spatial analyses are not sufficient for assessing long-term, continuous wetland connectivity and associated functions. Since many of the ecosystem services provided by GIWs are dependent on temperature, plant growth, or other seasonally variable factors, the ability to estimate hydrologic conditions of these wetlands throughout the year would provide important information for conservation planners.

Wetlands are a key component of headwater landscapes on the Coastal Plain of the Chesapeake Bay watershed due to their abundance and dense distribution (Lang et al., 2012). GIWs in this region have been shown to affect headwater hydrology, channel network development, and ecological functions of downstream waters (Alexander et al., 2018). The geospatial modeling approach in our previous work (Yeo et al., 2019a) used remotely sensed data to demonstrate hydrological connectivity for wetlands in this region, but the limited temporal resolution of remotely sensed data made it difficult to predict hydroperiod (i.e. hydrology over time) and therefore assess and monitor wetland function at seasonal or intra-annual scales.

Modeling Landscape-level Wetland Functions at Multiple Time Scales

In this study we introduce a comprehensive hydrological modeling approach to extend our understanding of wetland functions and connectivity over multiple time scales. Two modeling scenarios, with and without wetlands, were compared to quantify the role GIWs play in nutrient dynamics, water storage, and other ecosystem functions within the landscape. We focused our analysis on the Greensboro watershed, a sub-basin of the Choptank River Watershed of the Delmarva Peninsula (Figure 1).

A modified version of the Soil and Water Assessment Tool (SWAT), with improved representation of wetland hydrological processes, was executed under the two contrasting scenarios of GIW presence or absence. SWAT is a semi-distributed hydrologic model developed to assess the impacts of anthropogenic and environmental stressors on hydrology and solute discharge (Neitsch et al., 2011). Input variables included daily precipitation, temperature, and stream flow, as well as land use, soils, elevation, and time series inundation maps developed previously (Yeo et al., 2019a). Compared to prior versions of SWAT, this modified version has the added ability to constrain inflow to wetlands based on their relative spatial position and to represent bi-directional exchange between riparian wetlands and nearby streams.

The modified SWAT model was calibrated to streamflow data from a US Geological Survey gauge station at the outlet of Greensboro watershed, as well as meteorological data from the NOAA National Climate Data Center for the time period examined. The presence of GIWs was incorporated into the model using the US Fish and Wildlife Service National Wetlands Inventory (NWI) geospatial dataset, while the second scenario was run without the NWI wetlands for comparison. The two simulations were run over the period 1985 – 2018 and analyzed to show GIW influence on overall water budget and seasonal variations of hydrological fluxes. Water budget includes precipitation, evapotranspiration from water surface and wetland vegetation, inflows, outflows, seepage, and exchange between surface and sub-surface water. Results are referred to below as WetLU and NoWetLU for simulations with and without wetlands, respectively. These results were compared to explore how the presence or absence of GIWs affect headwater hydrology and downstream waters. Further details about simulation processes are provided in Yeo et al. (2019b).

Overall, WetLU exhibited less variable annual water fluxes for all water budget components (Fig. 2), indicating that the presence of GIWs induced decreases in actual evapotranspiration (AET) due to increased leaf area of vegetation resulting in reduced evaporation from soil surfaces, as well as lower soil water content (SW) in the subsurface soil layers above the groundwater table, or the unsaturated zone. Lower SW is indicated by reduced lateral flow

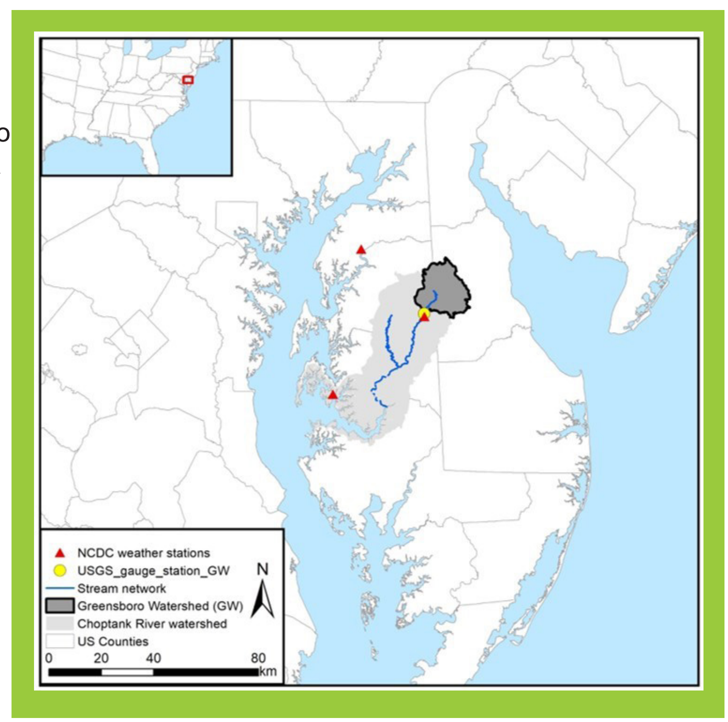


Figure 1. The geographical location of the Greensboro watershed

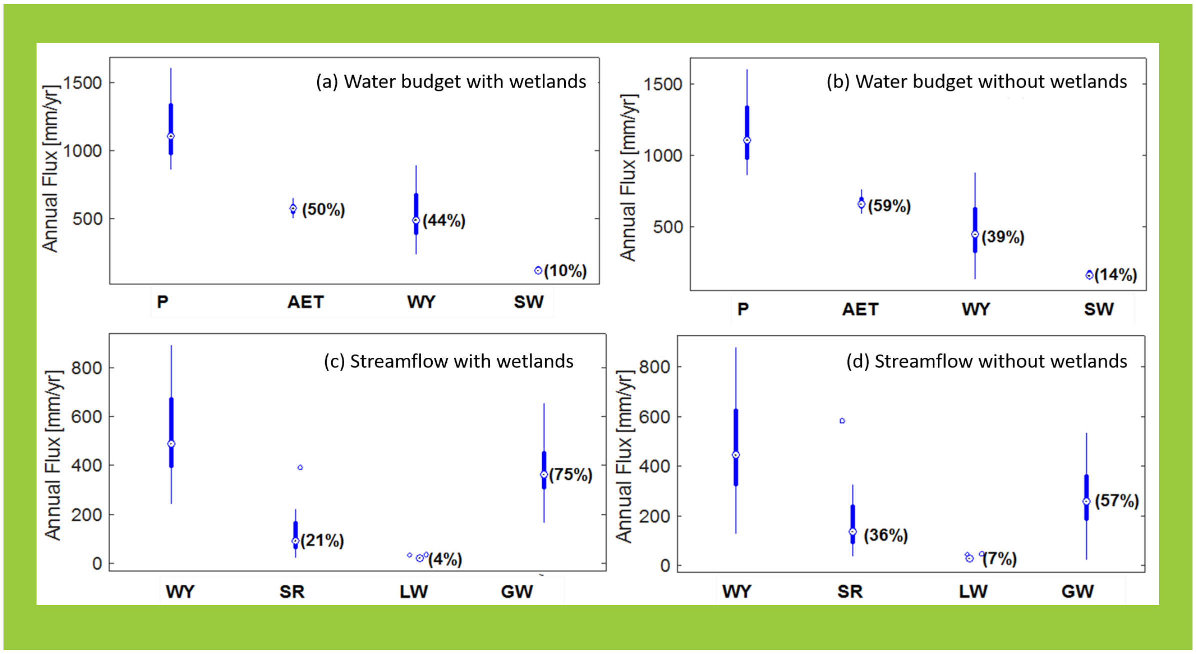


Figure 2. The 30-year average impact of GIWs on the watershed water budget (a, b) and the streamflow generation process (c, d). Note: P precipitation, AET actual evapotranspiration, WY water yield, SW soil water content, SR surface runoff, LW lateral flow, and GW groundwater flow. The percentage number in the parenthesis indicates the proportion contributed by each component to the total water budget (a, b) and streamflow (c, d). Sum of the three components in (a) and (b) can exceed 100 % since SW includes antecedent soil moisture.

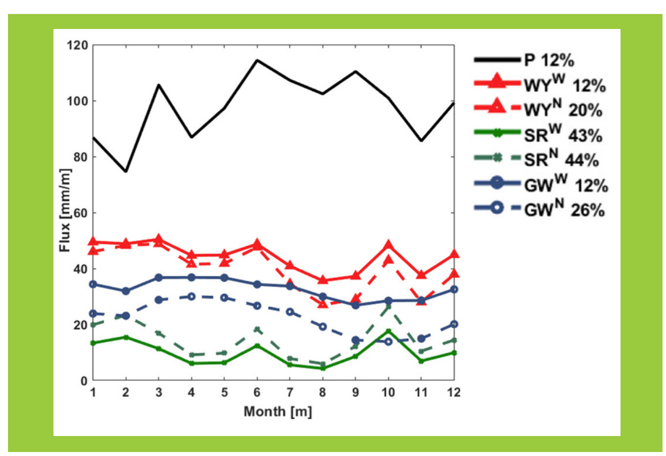
to the stream (LW) and increased groundwater influence (GW) on stream flow, demonstrating a higher groundwater table and increased water stored in the saturated zone. These factors subsequently result in an increase in streamflow normalized by watershed area, or water yield (WY). The presence of GIWs caused changes in water budget partitioning, leading to less variable annual mean water yield and greater contribution of groundwater flow under WetLU relative to NoWetLU. The increased groundwater contributions due to GIWs increase baseflows and influence the processes that generate streamflow, emphasizing the strong connection between groundwater and streamflow.

Seasonal variations in water yield, surface runoff, and groundwater flow with the two modeling scenarios over the period of 1985 - 2015 are presented in Fig. 3. WetLU output showed less seasonal variability relative to NoWetLU. Trends in modeled water yield were similar for the two scenarios during winter and spring but diverged in summer and fall. This pattern corresponded to a slower decline in the rate of WetLU groundwater flow (GW) (1.4 mm/month) as a function of season relative to that of NoWetLU (2.3 mm/month), resulting in greater divergence of GW levels in late summer and fall and higher values when GIWs were present. This result implies that GIWs likely create hydrologic continuums and thus lead to tight coupling of surface water and groundwater, supporting groundwater recharge during wet seasons. Overall, the seasonal analysis showed a key role of GIWs in controlling surface water and buffering groundwater and downstream flow dynamics throughout the year.

Implications for Conservation

This study used a hydrological modeling approach to estimate the aggregate impacts of GIWs on upland water budget (i.e. partitioning of precipitation into evapotranspiration and soil water storage components) and resultant water transport. The results support the conclusion that GIWs are central to groundwater/surface water interactions that increase terrestrial groundwater water storage as well as its contribution to downstream waters. Groundwater is the major source of streamflow in the Delmarva Peninsula region, and these results emphasize the importance of GIW contributions to downstream baseflows. WetLU simulations indicate that GIWs are effective at buffering groundwater dynamics and help to sustain higher and less variable groundwater levels, resulting in greater terrestrial water storage and more stable streamflow across all seasons. Simulations show that GIWs serve as a hydrological continuum, tightly coupling surface and groundwater, and confirm that they are important landscape features that mitigate seasonal hydrologic variability

Figure 3. Seasonal variation in streamflow generation processes under the WetLU (superscript W) and NoWetLU (superscript N) scenarios. Note: P precipitation, WY water yield, SR surface runoff, and GW groundwater flow. The percentage numbers in the legend stand for coefficient of variation (CV), which measures the degree of variability in the flux.



and maintain stable baseflow.

The results of this study highlight the potential for GIWs to mitigate variability in water resources and provide support for ongoing wetland restoration efforts in the Delmarva Peninsula region. These findings, however, may not apply to other physiographic regions because GIW impacts vary with local soil and landscape characteristics. As an example, GIWs in the Prairie Pothole Region are primarily connected to downstream waters via overland flow and thus are effective at controlling peak flow but have minimal impacts on baseflow (Evenson et al., 2018).

Our model predicts that increasing the number and size of headwater wetlands can provide substantial benefits to downstream waters and significantly influence landscape hydrology (McLaughlin et al., 2014). These results predict that current wetland restoration has the potential to stabilize baseflows of streams, an important consideration in areas that may be at risk of greater variability due to changing climatic conditions such as the Mid Atlantic Coastal Plain. The model's groundwater flow and soil moisture results extend and confirm conclusions from related studies in our lab (Yeo et al. 2019a; Lee et al. 2019; Lee et al. 2020) that predict water quality benefits from restoration of ecosystem functions and services in GIWs.

These studies provide additional information to guide conservation planning, resource management decisions, and siting of restoration activities aimed at water quality outcomes in downstream waterbodies such as the Chesapeake Bay. Results from these and other watershed models will help inform planning tools like the Agricultural Conservation Planning Framework (ACPF) that was developed by the USDA Agricultural Research Service. ACPF provides a menu of site-specific conservation practices as well as high-resolution spatial data that facilitate discussion of producer preferences while considering resource concerns and landscape features.

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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 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 (UMD) College Park, the University of Newcastle, Australia and USDA-ARS Beltsville. Primary investigators on this project were Yeo, I.-Y., Lee, S., Lang, M.W., Yetemen, O., McCarty, G.W., Sadeghi, A.M., and Evenson, G. This Science Note was compiled by Drs. S. Lee, G. McCarty, and Joseph Prenger. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by USDA.

For more information, see http://www.nrcs.usda.gov/wps/portal/nrcs/main/nation-al/technical/nra/ceap, or contact Joseph Prenger (joseph.prenger@usda.gov).