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SPATIAL DIFFERENCES IN HYDROLOGIC AND GEOCHEMICAL CHARACTERISTICS ACROSS A TEMPERATE COASTAL PLAIN PEATLAND: THE GREAT DISMAL SWAMP, USA

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INTRODUCTION

Spatial differences in hydrologic and geochemical characteristics across forested peatlands can control the distribution of wetland species and affects their resiliency to natural and anthropogenic disturbances. Knowledge of these characteristics can be critical to (1) the effective management of the peatlands, (2) the selection of research sites to achieve specific research objectives, and (3) the interpretation of research results. The Great Dismal Swamp (the swamp) is a peatland that originally covered about 600,000 hectares (ha) in the Atlantic Coastal Plain of southeastern Virginia and northeastern North Carolina, USA (fig. 1). Draining the swamp for timber harvesting and agriculture has reduced the size of the swamp to the 45,325 ha managed by the U.S. Fish and Wildlife Service (the Service) as a national wildlife refuge and 6,475 ha managed by the State of North Carolina as a park (U.S. Fish and Wildlife Service, 2006). The existing distribution of forest species across the swamp is a remnant of the original communities altered by timber harvesting, hydrologic alteration by canals and adjacent spoil piles, and fire. Water levels in the canals are controlled by use of adjustable-height dams on the canals to manage the wetland-species composition and resiliency, increase carbon storage to mitigate the effects of climate change, and other purposes.

Since 2009, research into the hydrologic and geochemical characteristics of the swamp by the U.S. Geological Survey (USGS) in cooperation with the Service has expanded knowledge of groundwater and canal-water levels and flow paths, water chemistry, hydrologic response to precipitation events, peat characteristics, and relations between water and vegetation. Much of this research has been funded by the Service. The USGS Great Dismal Swamp Carbon project also funds an evaluation of the carbon budget and ecosystem services of the swamp. This paper describes a conceptual model of sources of water to the peat near land surface and hydrologic flow paths and describes selected geochemical characteristics across the swamp. It also discusses how these hydrologic and geochemical characteristics can affect (1) the management of swamp as resilient wetland habitats and for sequestering carbon to mitigate the effects of climate change, (2) the selection of research sites to achieve specific research objectives, and (3) the interpretation of research results.

Keywords: *Hydrology, geochemistry, nutrients, peatland, wetlands*

STUDY AREA

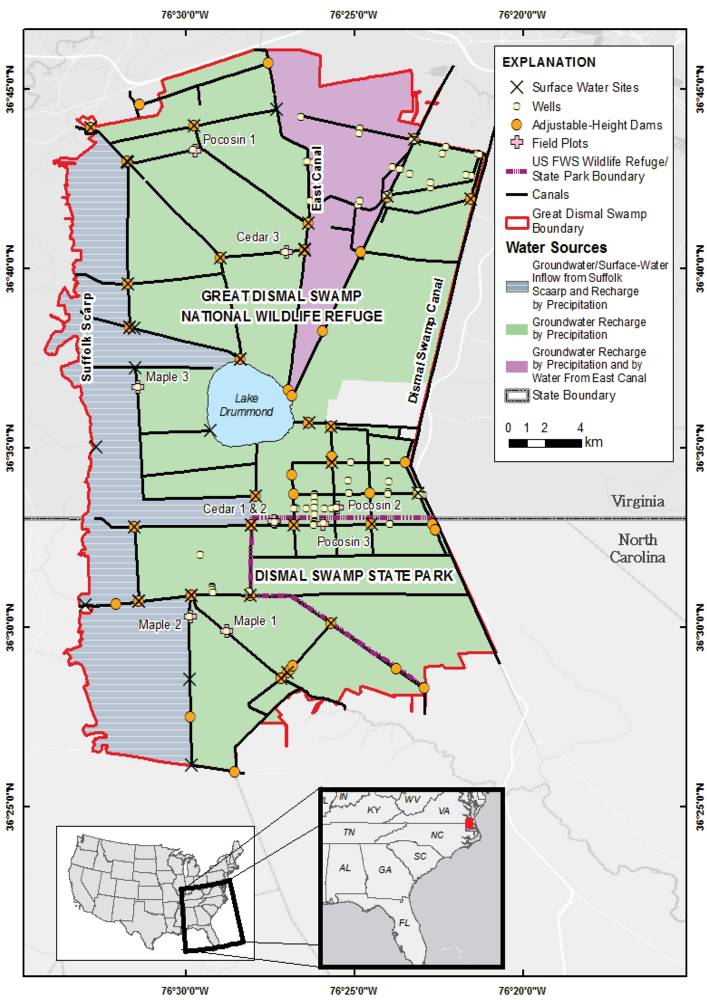

Figure 14. Conceptual model of sources of water to the peat near the land surface, data-collection sites, and other feature, the Great Dismal Swamp, Virginia and North Carolina, USA

The swamp is bounded to the west by the Suffolk Scarp, to the north by the urbanizing Hampton Roads area of southeastern Virginia, to the east by the Dismal Swamp Canal, and to the south by agricultural areas of northeastern North Carolina (fig. 1). Hydrology has been altered by a 235 kilometer network of canals and adjacent spoil piles constructed to drain the swamp for timber harvesting and agriculture. The first canals were constructed in the 1760's; the Dismal Swamp Canal (the largest canal) was constructed in the early 1800's to provide an inland route for commerce between Chesapeake Bay to the north and Albemarle Sound to the south (not shown). Shaler (1890) indicates that the spoil pile on the western side of the Dismal Swamp Canal formed a dam to the natural flow of water from the west and created up to 1 meter (m) of standing water during wet periods. Standing water persisted across much of the swamp during the dry parts of the growing season of most years. Although several canals were present in 1890 (Shaler, 1890) and a few additional canals were constructed by 1940, most of the canals were constructed between 1954 and 1977 based on a comparison of Shaler's map (Shaler, 1890) and topographic maps of the area (U.S. Geological Survey, 1940; 1954; 1977).. The expanded extent of the canal network and associated breaches in the spoil pile west of the Dismal Swamp Canal drained large parts of the swamp. Although ditches drain parts of the swamp directly adjacent to the ditches, spoil piles on the other sides of the canals impede the flow of water and locally retain standing water in parts of the swamp. Drier conditions have altered tree growth as reflected in tree-ring analyses (Phipps *et. al.*, 1978.) The ditch network creates a pattern of variously sized and shaped blocks across the swamp (fig. 1).

Land-surface-altitude characteristics change abruptly across the Suffolk Scarp. On the plain just west of the scarp land-surface altitude is 17 to 20 m above National Geodetic Vertical Datum of 1929 (NGVD 1929) with the altitude of stream valleys 8 to 9 m above NGVD 1929. Topography across the swamp east of the scarp, however, is flat, decreasing only about 3 m from about 8 m to about 5 m above NGVD 1929 across the 14 to 20 kilometers (km) between the toe of the scarp and the Dismal Swamp Canal. Shaler (1890) describes how critical differences in wetness of the peat over short distances that resulted from changes in land-surface altitude of less than 1 m that "the eye fails to detect" caused differences in the forest species. Locally, hummocks and hollows create relief of 0.5 to 1 m. Drainage of groundwater from the peat by the canals has altered this wetness regime and caused subsidence of the peat surface from the loss of physical support by groundwater and decomposition of the drained peat. Subsidence of up to 1 m is indicated by exposure of tree roots, particularly those of red maple (Acer rubrum), and differences in LiDAR altitudes across canals caused by the damming of water on one side and draining of water on the other.

Current forest communities appear to be the matured surviving remnants from the harvesting that include individuals of the harvested species that were considered too small to harvest and species not considered of sufficient value for harvesting, particularly red maple. The original wetland forests primarily consisted of two types: the bald cypress (Taxodium distichum)/black gum or tupelo (Nyssa aquatic L.) communities present in the wettest areas and the Atlantic white cedar (Chamaecyparis thyoides) communities found on slightly drier low ridges (Shaler, 1890; Kearney, 1901). Harvesting apparently focused on the cypress and cedar because of their resistance to rot. By the late 1800's, the cypress had been harvested extensively although red maple remained short and a minor part of the forest community (Shaler, 1890). Today, maple/gum is the dominant forest community, occupying over 62 percent of the swamp (U.S. Fish and Wildlife Service, 2006). Pine-forest communities identified by Shaler (1890) on slightly higher ground likely were pocosins, a pine and shrub wetland, which also covers an appreciable part of the present-day swamp. Pollen analysis of peat cores indicates that pocosins began to replace parts of the cedar communities with the arrival of colonists and increased fire frequency (Stevens and Patterson, 1998). Current forest communities thrive, in part, because of the drier conditions. Even where mature individuals of wetland species are present, it is not certain if these species can regenerate and compete against non-wetland species to establish and maintain resilient, wetland, forest communities.

The organic peat soil is a key characteristic exerting a major control on the hydrology of the swamp. The thickness of the peat ranges from near zero to 5 m across the swamp (Oaks and Coch, 1973). Kearney (1901) identifies two types of peat based on their forest cover: juniper (cedar) peat is a reddish-brown fibric peat and black gum peat is a dark, decomposed muck. Although more recent descriptions of the peat typically describe it as a decomposed muck throughout its depth (Henry, 1971; Oaks and Coch, 1973), the peat has a distinctly coarser upper zone to a depth of about 0.5 m overlying a dense, mucky lower peat. Main (1971) differentiates these zones as colloidal (upper peat) and non-colloidal (lower peat.) Hydrologically, although not by the degree of decomposition, these layers are similar to the acrotelm and catotelm, respectively, common in many peatlands (Ingram, 1978).

The upper peat forms a surficial aquifer that can store large amounts of water and transmit it rapidly to the canals. The peat is underlain by interlayered sand, silt, and clay that extend throughout nearby parts of the Coastal Plain including those wests of the Suffolk Scarp, forming the surficial and the Yorktown/Eastover aquifers (McFarland and Bruce, 2006). Although these aquifers can be important sources of water west of the Suffolk Scarp, the flow of water through these sand aquifers likely is limited beneath the swamp because the sand has a substantially lower permeability than the upper peat (based on water yield when each is pumped separately) and the low hydraulic gradient caused by the low topographic gradient across the swamp would limit flow based on Darcy's Law (Freeze and Cherry, 1979). The lower peat impedes the flow of groundwater between the sand and the upper peat.

METHODS

A map depicting a conceptual model of the sources of water to the peat surface across the swamp was developed. Delineation and descriptions of the areas are based on knowledge of (1) the interconnections of the peat with canals, and other surface waters, (2) data collected during previous and ongoing monitoring and research, and (3) general field observations of seasonal and other patterns in water levels and flow directions. Knowledge of the system also was derived from basic hydrologic principles such as Darcy's Law (Freeze and Cherry, 1979).

A discussion of general water chemistry is based on results from analysis of water samples from selected well and canal sites (Fig. 1). A large part of the groundwater samples were from the Great Dismal Swamp carbon project (Land Carbon) with one well sampled every other month at each of nine field plots (fig. 1). Field plots included three plots in each of three forest habitats: cedar, pocosin, and maple/gum. Canal and other groundwater samples also were collected as a part of other past studies. Some of the canal sites are located in areas known to have differing contributions of flow from streams crossing the Suffolk Scarp. Samples were analyzed for pH, specific conductance, dissolved-oxygen concentrations, and concentrations of major ions, nutrients, dissolved organic carbon (DOC), and dissolved gasses. Water-level and water-quality data are available on the USGS Nation Water Information System web interface (NWIS web: http://waterdata.usgs.gov/nwis).

RESULTS

Although groundwater and surface water collectively interact to control the hydrologic characteristics of the swamp, groundwater is the dominant water volume stored and transmitted throughout the swamp and has a dominant control on the hydrology of the swamp. Surface water consists of water in the canals, in Lake Drummond, and standing on the peat surface. Water in the canals is derived from five streams flowing across the Suffolk Scarp and into the swamp, groundwater that flows from west of the scarp through the surficial and Yorktown/Eastover aquifers and discharges to the canals, precipitation falling directly on the canals, and groundwater discharge from the peat. Water in Lake Drummond is derived primarily from groundwater discharged from the peat, direct precipitation, and canal inflows. Standing water typically is present from winter into early spring in low areas and areas where water is dammed by the spoil piles, Standing water reflects the shallow water table in many areas. Standing water also is derived from water in the canals near the scarp when high inflows inundate that part of the swamp. Surface runoff generally is limited to locations having a water table at land surface or standing water because of the highly permeable upper peat. Only when water levels rise enough to interconnect these low areas does water flow across the peat. Such flow is widespread only after selected, extremely large precipitation events. At the end of a dry period in 2011, even a couple days producing more than 30 centimeters of precipitation did not produce widespread evidence of surface runoff.

Groundwater is derived from one main source and two lesser sources. Recharge by precipitation that falls directly on the peat and percolates to the water table is the dominant source of groundwater across the entire swamp (fig. 1) and nearly the only source of water across much of the swamp (fig. 1, green area). Groundwater also is derived from flow from the west, beneath the scarp through the surficial and Yorktown/Eastover aquifers that discharges into the peat between the toe of the scarp and the first canals east of and parallel to the scarp (fig. 1, blue area). An even more limited source of groundwater is the lateral flow from East Canal that recharges the upper peat in the block to the east (fig. 1, violet wedge to the north). This source likely is greatest in the mid-section of the canal where a flow divide occurs and water levels tend to remain high because of inflows from ditches from the west. Across the swamp, groundwater rapidly discharges from the upper, high-permeability peat to the ditches and to the vegetation as evapotranspiration.

Concentrations of dissolved organic carbon ranged from 73 to 156 milligrams per liter (mg/L) and generally increased with increased pH (R^2=0.53) (fig. 2a). All groundwater and most canal-water samples were acidic; pH typically was less than 5.0 and less than 4.0 for many samples (fig 2b). The specific conductance of samples generally increased as the pH decreased (fig. 2a). This relation was stronger for the Land-Carbon wells (R^2=0.69) than other wells (R^2=0.52), and least for the ditches (R^2=0.12).

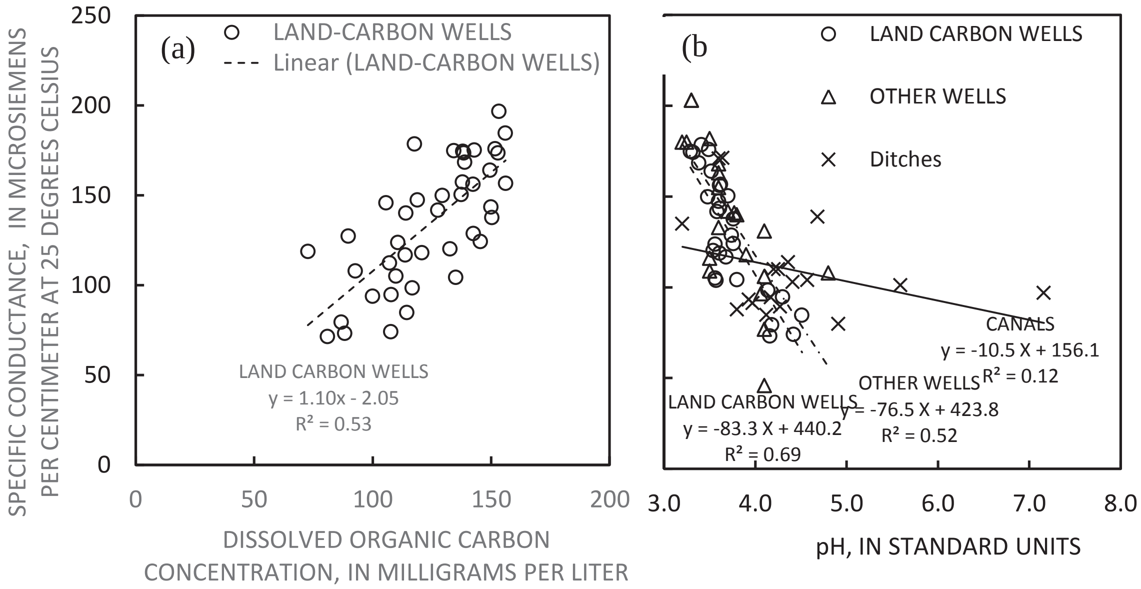

Figure 2. Relations of pH to specific conductance (a) and dissolved organic carbon concentration to specific conductance (b) of well and canal (ditch) water samples, the Great Dismal Swamp, Virginia and North Carolina, USA.

DISCUSSION

The hydrologic conceptual models of sources of water to the peat near land surface are important considerations for water-management decisions, research-site selection, and data interpretation. Because precipitation-recharge amounts likely are similar across the swamp, more water will be stored in and discharged from areas that also receive water from other sources (west of the Suffolk Scarp or canals). Areas receiving surface and groundwater from west of the scarp typically have wetter conditions during high precipitation periods because they also receive abundant water from west of the scarp. These areas continue to receive groundwater inputs from west of the scarp even after precipitation stops and stream inflows decrease. The wetter conditions created by the additional sources Although East Canal is an additional source of water to the block to its east, low water levels in canals north, east, and south of this block could help create the lateral gradient to promote such recharge. As more dams are constructed and operated, retaining high level in these other canals could limit such discharge and help retain water. Dams on selected canals could promote similar recharge from canals into the peat elsewhere.

The high yield and hydraulic conductivity of the upper peat and the effective hydraulic connection between the upper peat and canals make controlling water levels in the canals critical. Controlling the height of the adjustable-height dams can be critical to managing water and keeping the upper peat saturated to a desired depths throughout the swamp will support resilient wetland forest communities and promote carbon storage. The high DOC in the groundwater that discharges from the peat to the canals indicates a loss of carbon from the swamp through groundwater discharge to the canals that migh

The water chemistry is heavily influenced by the chemistry of the organic peat soil as indicated by the relations between dissolved organic carbon concentrations and specific conductance and pH and specific conductance of water samples (fig. 2). The 73 to 156 mg/L of DOC is high for the 30 to 40 mg/L average but within the 3 to 400 mg/L range reported for swamps (Thurman, 1985). The low pH results from the organic acids that make part of the DOC.

The chemistry appears to have limited influence from the mineral soil except for selected canal samples. The seven canal samples having the highest pH (4.36 to 7.16) are from canals flowing east from the Suffolk Scarp. Four of those samples are along Corapeake Canal and generally decrease from 7.16 nearest the scarp to and lower specific conductance tend to be more affected by the stream inflows across the scarp based on their locations. The general trend is for the specific conductance to increase as the pH decreases; hydrogen is the dominant cation in most of the samples. For wells at the carbon-project field plots, the pH of two of the three maple/gum filed plots was greater than 4.0; pH of all pocosin and cedar plots and the remaining maple/gum plot was below 4.0.

The low pH likely results from the abundance of organic acids from decomposition of the peat as also supported by concentrations of dissolved organic carbon (DOC) that ranged from 71 to 156 milligrams per liter (mg/L)(fig. 2b). These concentrations are high in comparison to the highest DOC concentration of 20 mg/L observed in a coastal plain black-water stream in Virginia (Speiran, 2000). Such streams typically are considered to be high in DOC.

Although the spatial distribution in the water chemistry has not be evaluated to the extent of the hydrology, differences in sources of water also could affect the chemistry of the water as indicated by differences in the chemistry among ditch samples. Inflows from west of the scarp can be affected by the mineral content of the aquifers and agricultural and other activities west of the scarp. Differences in water chemistry also can result from such factors as differences in the current forest communities or differences in peat as affected by historic forest communities as indicated y Kearney (1901). Differences in water sources and chemistry can be critical in selecting research sites to limit variable and in interpreting results from these sites.

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