Prepared in cooperation with The Conservation Fund and Audubon Maryland-DC

Hydrologic Study at Farm Creek Marsh, Dorchester County, Maryland, from April 2015 to April 2016

Scientific Investigations Report 2019–5032

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photographs of Farm Creek Marsh taken near marsh surface-water monitor DO Fe 45, top, on September 23, 2015, and bottom, during the coastal storm on October 5, 2015 (Photographs by Todd R. Lester, U.S. Geological Survey).

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DAVID BERNHARDT, Secretary

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James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

ppm parts per million

ppb parts per billion

USGS U.S. Geological Survey

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Abstract

In 2015, the U.S. Geological Survey began a 1-year hydrologic study to investigate the extent and cause of inundation at Farm Creek Marsh, in Dorchester County, Maryland. In combination with a tide and precipitation gage, a representative section of the marsh was instrumented with surface-water monitors and shallow groundwater piezometers to capture the spatial and temporal extent of inundation. In addition, water-quality data (major ions and nutrients) were collected to help discern the cause of inundation. Results indicate that during the year-long study, all sites were periodically inundated, ranging from a total of 108 days to the entire study period of 353 days. The depth of inundation was typically between 0 and 0.2 feet (ft) (above land surface), with the exception of large storm events. Less than 0.5 ft of elevation was the difference between a site being inundated during the entire study period of 353 days and a site being inundated for 36 consecutive days out of 108 total days of inundation during the study period. Water-quality data showed a large difference in pH between marsh surface water (6.1 to 6.9 standard pH units) and shallow groundwater (3.0 to 3.6 standard pH units), with differences also observed in concentrations of silica, iron, manganese, and potassium. Collectively, the combination of water-quality, hydrologic, and soils data indicate that inundation is caused by tide and storm events rather than groundwater discharge.

Introduction

The U.S. Geological Survey (USGS), in cooperation with The Conservation Fund and Audubon Maryland-DC, began a hydrologic study of Farm Creek Marsh in April 2015. During the study period, areas of the marsh (notably stands of pine trees) were observed to be in declining vegetative health. Observations by landowners also have suggested that the marsh is being inundated more frequently and for longer periods of time. Because of the observed increased inundation, this study was designed to determine the spatial and temporal extent of inundation on a subsection of the marsh to provide baseline data that could be used to help design a water management feature and to determine the cause of inundation, which could include factors such as precipitation, groundwater discharge, and sea-level rise (SLR).

Between 1901 and 2010, global mean sea level rose between 0.55 and 0.68 feet (ft) (Intergovernmental Panel On Climate Change, 2014) at a rate of 0.005 feet per year (ft/yr). There is also evidence of a "hotspot" of recent accelerated SLR occurring along the east coast of North America that spans 621 miles from Cape Hatteras, North Carolina, north to Cape Cod, Massachusetts (Sallenger and others, 2012). Boon and others (2010) determined the absolute SLR for Cambridge, Maryland, to be 0.012 ft/yr between 1976 and 2007. Coastal marshes along the east coast with elevations close to sea level are likely to experience many hydrologic effects of SLR, including increased spatial and temporal extent of inundation, which could ultimately lead to loss of marsh. For example, Blackwater National Wildlife Refuge, located near Cambridge, Maryland, on the Eastern Shore of the Chesapeake Bay, has lost nearly 5,000 acres of estuarine marsh over the last 80 years (Cahoon and others, 2010). Marsh ecosystems are particularly affected by SLR if the rate of marsh elevation change is less than the rate of SLR.

Coastal marsh hydrology controls a number of different processes that can affect the surface elevation of marshes. Organic matter and mineral sediment accumulation, both highly dependent on hydrology, contribute to sediment accretion (Bricker-Urso and others, 1989; Cahoon and others, 2011). Conversely, wetland subsidence can lower the land-surface elevation of marshes and may occur during both wet and dry periods. During dry periods, shrinking surface soils can lead to subsidence, whereas excessive inundation, caused by storm events, can lead to aquifer compaction and also result in subsidence (Cahoon and others, 2011).

In addition to wetland subsidence, prolonged periods of drought or inundation can lead to reduced vitality of coastal marshes. Periods of drought can lead to increases in soil salinity, which may have contributed to the acute marsh dieback experienced along the Gulf Coast (Hughes and others, 2012). Lower water-table levels, produced by droughts, could also lead to air infiltrating the soil pore space that was once occupied by water, thereby oxidizing compounds that are sensitive to the presence or absence of oxygen, such as iron. The vitality of a marsh is therefore critically affected by extreme (wet or dry) weather events and their effect on hydrology.

The Intergovernmental Panel on Climate Change (IPCC) predicts that extreme precipitation events are likely to become more intense and frequent with an increase in mean air-surface temperature (Intergovernmental Panel On Climate Change, 2014). Increased episodic precipitation could have multiple effects on marsh vitality, such as increased sedimentation from more runoff or more erosion from storm surge events (Charles and Dukes, 2009). Storm events can also alter the marsh surface. Nuttle and others (1990) documented deformation of the marsh surface layer from about 4 inches (in.) of inundation, which was caused by a single storm event. In addition to physical deformation, inundation can also cause biogeochemical changes within the wetland substrate (Baldwin and Mendelssohn, 1998). After a prolonged period of inundation, reducing conditions that promote the conversion of sulfate to sulfide are present. Elevated levels of sulfide can be toxic to plants, again reducing marsh vitality by decreasing the amount of vegetation (such as above-ground biomass) or changing the species composition of the vegetation community.

In summary, Farm Creek Marsh may be susceptible to a combination of several different phenomena that have been observed in other marsh systems. The geographic location of Farm Creek Marsh indicates that it may be vulnerable to SLR and high tide events. These events may cause vegetation loss and subsidence, and result in increased inundation. Increased inundation may, in turn, lead to biogeochemical changes within the marsh, thereby increasing plant mortality and decreasing bird habitat.

Purpose and Scope

The purpose of this report is to describe the results collected during a hydrologic study at Farm Creek Marsh from April 2015 through April 2016. This report describes (1) the frequency and duration of inundation observed at Farm Creek Marsh, (2) marsh surface-water and shallow groundwater elevations, (3) surface-water and groundwater quality in the marsh and adjacent Farm Creek, and (4) precipitation. Data in this report will provide information that can be used to aid in the design of a water-control structure to minimize inundation and will document baseline conditions that may be used for comparison after implementation of the structure.

Description of Study Area

Farm Creek Marsh, a 700-acre sanctuary owned by the Chesapeake Audubon Society, is a high/transitional brackish marsh preserve in Dorchester County, Maryland, on the Eastern Shore of the Chesapeake Bay (fig. 1). Within the preserve, the marsh is experiencing interior erosion to bare soil and open water. This study focuses on approximately 80 acres of this declining habitat. The study area, located on the central Delmarva Peninsula, is situated in the Northern Atlantic Coastal Plain. There are two creeks near the study area, Farm Creek and Bridge Creek. Farm Creek, located south of the marsh, drains directly into Fishing Bay, whereas Bridge Creek, located east of the marsh, drains into Farm Creek, prior to Fishing Bay (fig. 2).

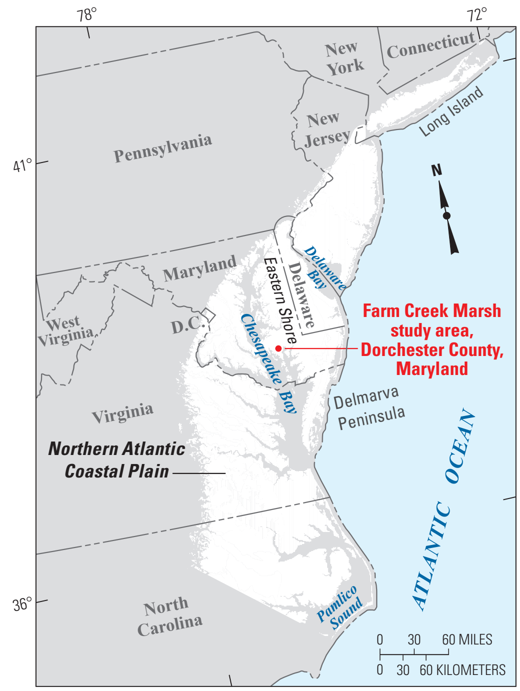

Figure 1. Location of Farm Creek Marsh study area, Dorchester County, Eastern Shore of Maryland.

Methods

Groundwater and surface-water levels were measured over a 1-year period (April 2015 to April 2016) to describe the frequency, extent, and depth of inundation within Farm Creek Marsh. A USGS surface-water monitoring gage also was established on Farm Creek, near Toddville, Maryland, which was used for precipitation measurements and continuous water-quality measurements for specific conductance and temperature. In addition, water-quality information was collected from groundwater and surface-water monitoring sites to aid in determining the cause of inundation.

A radar water-level sensor, multi-parameter water-quality sonde, and rain gage were installed in March 2015, on the upstream side of a highway bridge along Wesley Church Road, near Toddville, Maryland. This gage (Farm Creek near Toddville, Maryland, USGS station number 01490200) monitored the level of tidally influenced Farm Creek, as well as specific conductance and temperature. In addition, a tipping bucket precipitation sensor was installed at this location. Water levels, water temperature, and specific conductance were collected at 6-minute intervals and precipitation readings were recorded at 15-minute intervals. The station was serviced bi-monthly. During a routine service visit, water-level measurements were made, the water-quality sonde was checked for fouling and calibration drift, and the tipping bucket rain gage was checked for calibration using tip counters combined with known volumes of water.

In addition to monitoring Farm Creek, a total of 10 sites were selected to monitor marsh surface water or shallow groundwater (DO Fe 41—50) on Chesapeake Audubon's Farm Creek property, located off of Cedar Creek Road (fig. 2). Three sets of monitors were installed in pairs, with each pair consisting of one shallow groundwater piezometer (approximately 10 ft x 2.0 in. in diameter, DO Fe 41, 44, and 47) and one shallow marsh surface-water monitor (3.4 ft x 2.0 in. in diameter, DO Fe 42, 45, and 48). The placement of the surface-water monitors and shallow piezometers on a color orthophotograph, in which different vegetation types can be seen, is shown in figure 2. The monitor pairs were arranged in a triangular pattern surrounding a dying stand of pine trees, representing what appeared to be subtle changes in land-surface elevation and surface vegetation. The pine trees appeared to follow a gradient from completely dead trees, towards the southeast of the study area, to unaffected trees in the northeast part of the study area. A single marsh surface-water monitor (3.4 ft x 2.0 in. in diameter, DO Fe 43, 46, and 49) was installed in between each of the pairs. In addition, a surface-water monitor (approximately 6 ft x 4 in. in diameter, well DO Fe 50) was installed adjacent to a small tributary of Farm Creek.

After sites were selected, pilot holes were drilled with a hand auger, and soil characteristics were documented (table 1). Piezometers were then driven into the pilot hole, and developed using a peristaltic pump. During development, a YSI 6920 data sonde was used to record water-quality parameters for pH, temperature, specific conductance, and dissolved oxygen for each location. After installation, the piezometers and surface-water monitors were leveled in using a combination of a real-time kinematic global positioning system (RTK GPS) and optical level. The RTK GPS recorded the elevation using the North American Vertical Datum of 1988 (NAVD 88). Each of the monitors was instrumented with a non-vented pressure transducer, which internally recorded water level. In addition to water level, one pair of piezometers (DO Fe 44 and 45) was instrumented to record temperature and specific conductance. The instruments were serviced on a bi-monthly schedule. Water-level data were corrected based upon atmospheric

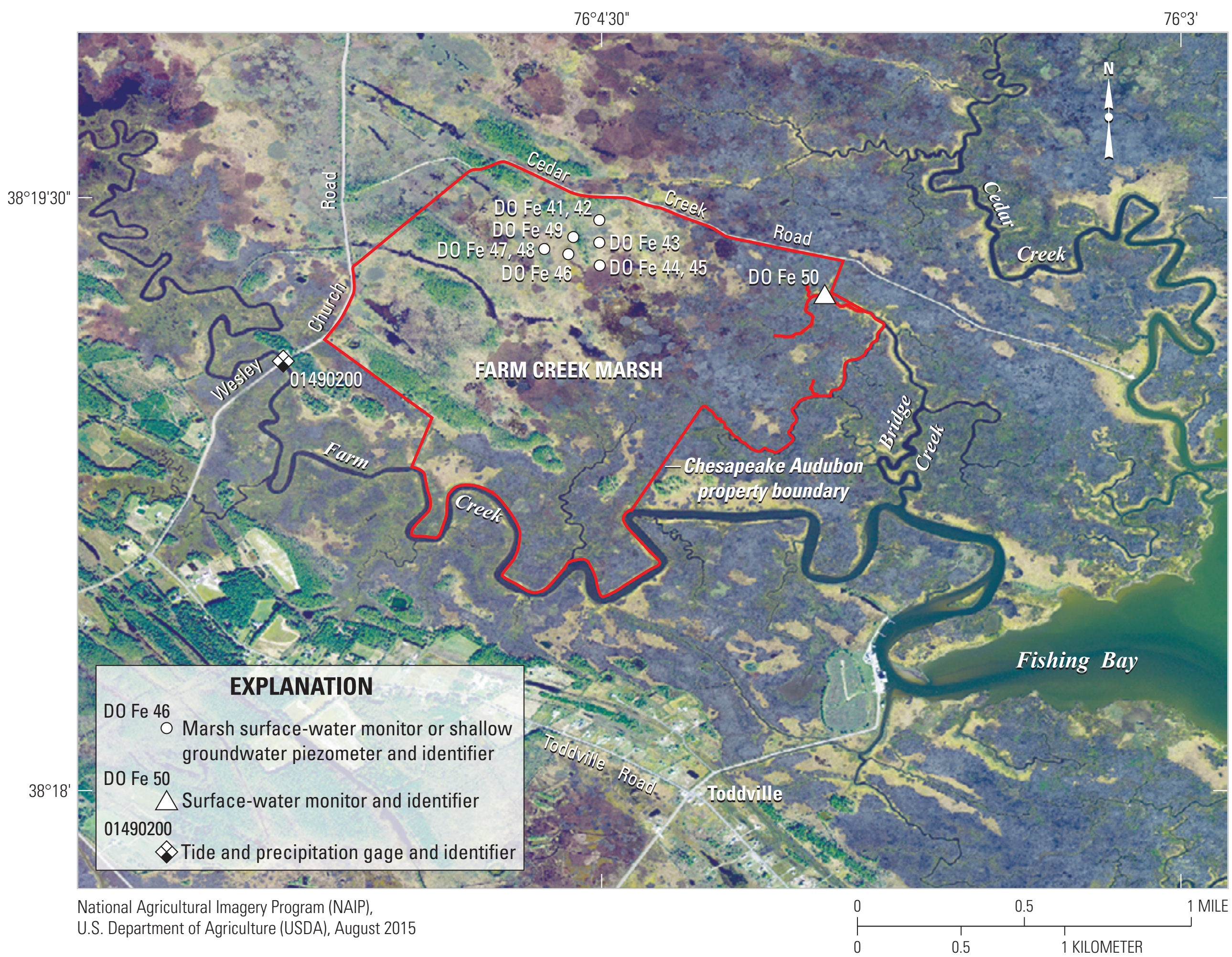

Figure 2. Location of marsh surface-water monitors, shallow groundwater piezometers, and the tide and precipitation gage.

Table 1. Well construction information for the Farm Creek Marsh study area, Dorchester County, Maryland.

[Elevation is referenced to the North American Vertical Datum of 1998; ft, feet; NA, not applicable]

U.S. Geological Survey station number	Station name	Monitor type	Well depth (ft)	Land-surface elevation (ft)	Depth to clay layer (organic surface horizon) (ft)	Depth to sand layer (ft)
381929076043001	DO Fe 41	Shallow groundwater piezometer	10.63	1.11	0.25	6.2
381929076043002	DO Fe 42	Marsh surface-water monitor	0.85	1.05	NA	NA
381925076043001	DO Fe 43	Marsh surface-water monitor	0.85	1.13	NA	NA
381922076043001	DO Fe 44	Shallow groundwater piezometer	11.03	1.13	1	7.3
381922076043002	DO Fe 45	Marsh surface-water monitor	1.11	1.16	NA	NA
381923076043501	DO Fe 46	Marsh surface-water monitor	0.87	0.76	NA	NA
381924076043901	DO Fe 47	Shallow groundwater piezometer	10.97	0.79	1	7
381924076043801	DO Fe 48	Marsh surface-water monitor	1.22	1.02	NA	NA
381926076043401	DO Fe 49	Marsh surface-water monitor	1.18	1.19	NA	NA
381917076035501	DO Fe 50	Tidal ditch	3.55	0.36	NA	NA

barometric pressure and discrete water-level measurements. The specific conductance probes were checked for fouling and calibration drift during the same service intervals. Any discrepancies found during field visits resulted in data corrections, which were pro-rated over the period of record. Data with corrections greater than 30 percent were removed from the record (Wagner and others, 2006). Water-level, precipitation, and continuous water-quality data are available at https://waterdata.usgs.gov/nwis.

Water-Quality Sampling

Water-quality samples were collected from shallow groundwater piezometers, marsh surface-water monitors, and from Farm Creek during a synoptic event in December 2015. Groundwater samples were collected in accordance with USGS field methods (U.S. Geological Survey, variously dated). The shallow groundwater piezometers (DO Fe 41, 44, and 47) and marsh surface-water monitor (DO Fe 49) exhibited low recovery rates, and the sampling pump did not maintain a constant flow rate. Peristaltic pumps were used to maintain low pumping rates to compensate for slow well recovery. Prior to sampling, tubing was lowered to a desired depth within each piezometer or monitor (approximately 0.3 ft from the bottom) and pumping started. The pumping volume was quantified with a large graduated cylinder to ensure that each location was purged of at least three well volumes of water. During the purge period, water-quality parameters were collected for pH, temperature, specific conductance, and dissolved oxygen by use of a multi-parameter water-quality sonde, which utilized a flow-through chamber. Measurements were recorded at 5-minute intervals, with the exception of stations DO Fe 41, 44, 47, and 49, where measurements were collected on a more irregular schedule due to low recovery rates and intermittent pumping. Once the water-quality measurements had stabilized and three well volumes had been purged, sample collection began. All bottles were field rinsed with native sample water prior to sample collection. Samples were then preserved (as needed), iced, and shipped to the USGS National Water Quality Laboratory in Denver, Colorado, within 48 hours.

Surface water-quality samples were collected at the Farm Creek tide gage location (USGS station number 01490200) from the upstream side of a highway bridge along Wesley Church Road. Multiple vertical samples were collected with a weighted bottle sampler at seven locations spanning the width of the stream. Individual samples were composited in a Teflon churn, and then processed as directed in the USGS Field Manual (U.S. Geological Survey, variously dated). All bottles were preserved (as needed), iced, and shipped to the USGS National Water Quality Laboratory in Denver, Colorado, within 48 hours. Water-quality parameters were collected for pH, temperature, specific conductance, and dissolved oxygen by use of a multi-parameter water-quality sonde at each of the seven locations.

Shallow groundwater, marsh surface-water and surface-water samples were analyzed for major ions, nutrients, iron, and manganese at the USGS National Water Quality Laboratory using methods described in Fishman and Friedman (1989). When concentrations of analytes measured were below the reporting level but at or above the detection level, results were given a value qualifier code of "n;" these results are considered semi-quantitative (Bonn, 2008). The occurrence of hydrogen sulfide was evaluated during the collection of groundwater samples and recorded as present or absent.

Hydrologic Results

All sites measured during 2015 and 2016 were periodically inundated throughout the measurement period. In general, the sites with lower land-surface elevation were inundated longer than those with a higher land-surface elevation. A site was considered inundated when the mean daily water level was higher than the marsh surface elevation. The distribution of the days and the magnitude of inundation for each of the marsh surface-water monitors installed at the sites are shown in figure 3. Site DO Fe 46 exhibited the greatest amount of inundation, both in frequency (353 days) and in depth (up to 1.0 ft above marsh surface). However, the land-surface elevation of DO Fe 46 was 0.3 to 0.4 feet lower than the other five marsh surface-water monitors. Sites DO Fe 45 and DO Fe 49 had the fewest days of inundation, with 108 and 117 days, respectively. The depth of inundation for most of the sites typically ranged from 0 to 0.2 ft, except for sites DO Fe 45 (0 to 0.5 ft) and DO Fe 46 (0 to 1.0 ft).

It is not uncommon for marsh areas to be inundated. However, long periods of inundation can lead to biogeochemical changes within the marsh and may alter the vegetative makeup of the marsh. The distribution of the maximum number of consecutive days inundated at the six surface-water monitors is shown in figure 4. DO Fe 46 was inundated over the entire study period (353 days). Sites DO Fe 42 and DO Fe 48 were inundated for 198 and 166 consecutive days, respectively, whereas site DO Fe 49 was only inundated for a maximum of 18 consecutive days. Except for sites DO Fe 42 and DO Fe 48, which differed in elevation by 0.03 ft, the number of consecutive days inundated was directly related to the land-surface elevation at each site (fig. 5). The difference in land-surface elevation from the lowest site to the highest site was 0.43 ft.

The study area that was monitored for inundation encompassed several different landscape features (including ponds, ditches, and dead or live pine trees) that were representative of the area as a whole. Site DO Fe 46, which was inundated over the course of the study, was adjacent to a ponded area with little to no vegetation. Site DO Fe 42 was once part of a pine forest, but is now surrounded by dead pine trees. This site had the second highest number of days inundated, and the third lowest land-surface elevation at 1.05 ft. DO Fe 42 was also adjacent to a ditch, which may have contributed to the inundation. Alternatively, site DO Fe 49, the least inundated site (by number of days and depth of inundation) with the highest elevation, was in a forested area with live pine trees.

Although there were approximately 300 horizontal ft between sites and the sites were located in different types of vegetation, the surface-water level trends at the sites within this marsh were very similar to each other. The mean daily water levels for the six surface-water monitoring sites are shown in figure 6. Increases and decreases in water levels are episodic; however, they could be seen across the study area nearly simultaneously. Mean daily water levels were also consistent among the six sites. The average standard deviation of mean daily water levels for all six sites collected over 353 days was 0.06 ft.

Surface-water levels peaked in early October 2015, during Hurricane Joaquin, which brought heavy rain and strong onshore winds to the area. Site DO Fe 46 had the highest water level of 1.89 ft (above NAVD 88) during this event. The lowest water level was observed at site DO Fe 45, which was 0.72 ft (0.44 feet below land surface) on June 1, 2015.

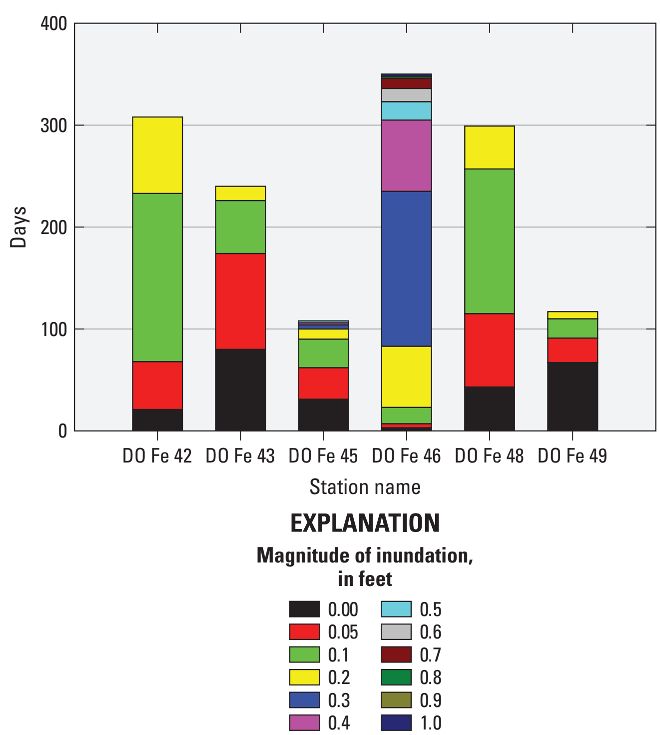

Figure 3. Distribution of days and depth of inundation for six marsh surface-water monitors shown on figure 2.

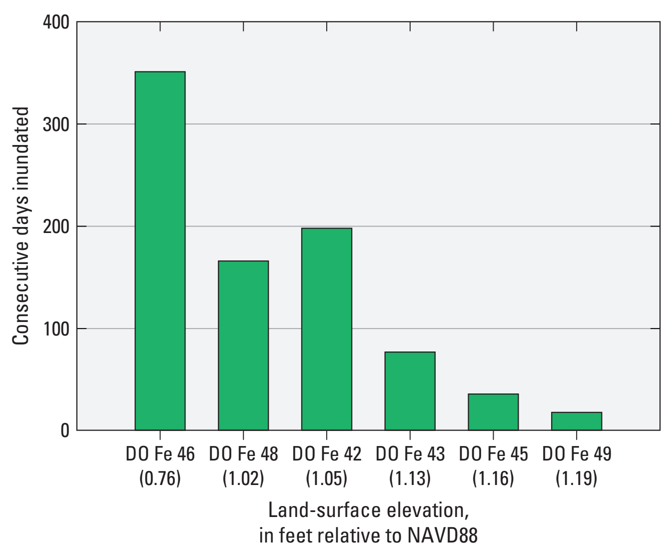

Figure 4. Maximum number of consecutive days inundated at six marsh surface-water monitors as shown in figure 2 (NAVD88, North American Vertical Datum of 1988).

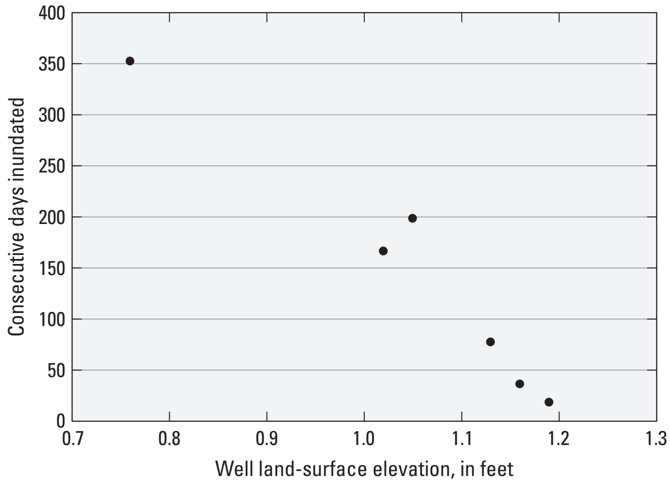

Figure 5. Relation between land-surface elevation and consecutive days of inundation.

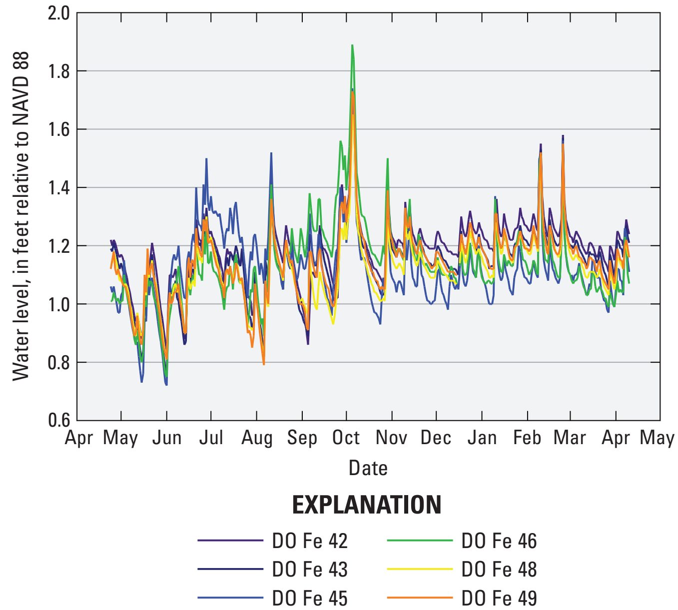

Figure 6. Mean-daily water levels for six marsh surface-water monitoring sites (NAVD88, North American Vertical Datum of 1988).

Prior to the October 2015 coastal storm event, the marsh went through pronounced wet and dry cycles; the water levels rapidly increased followed by a period of gradual decrease. However, after the coastal storm event, the marsh did not experience the same magnitude of low water levels. As a result, the number of days of inundation increased approximately 30 percent after the storm than prior to the storm determined by measurements made at the marsh surface-water monitors. One exception was site DO Fe 45, which experienced approximately 25 percent fewer days of inundation. DO Fe 45 had one of the highest land-surface elevations at 1.16 ft above NAVD 88.

In anticipation of the October 2015 coastal storm, a time-series camera was installed near site DO Fe 45 (facing northwest). Photographs taken before and during the coastal storm are shown in figures 7*A* and 7*B*. The photograph in figure 7*B* was taken during the peak of the coastal storm on October 5, 2015, when the mean daily water level at site DO Fe 45 was 1.74 ft (0.58 ft above land surface). For comparison, the photograph in figure 7*A* was taken on September 23, 2015, when the mean daily water level at the site was 1.13 ft (0.03 ft below land surface). Although the immediate area in front of DO Fe 45 was not inundated, a ponded area is visible on the left side of the photograph. This area is similar to the landscape surrounding site DO Fe 46, which was inundated with 0.55 ft of water on the same day.

Three shallow groundwater piezometers were installed at sites DO Fe 41, DO Fe 44, and DO Fe 47 and were paired with surface-water monitors. The piezometers were installed approximately 10 ft below the land surface. Although they were installed below at least 6 ft of clay, the three piezometers had similar water-level patterns as the surface-water monitors. In addition to the pattern of responses, mean daily water levels were similar to the levels observed in the surface-water monitors (fig. 8). A positive difference between the piezometer and the surface-water monitor could indicate upward flow, whereas a negative difference could indicate downward flow. The largest positive difference between a piezometer and surface-water monitor was 0.09 ft, observed at the end of the study period, on April 7, 2016 (sites DO Fe 47 and DO Fe 48). The largest negative difference between a piezometer and surface-water monitor was -0.23 ft on July 30, 2016 (sites DO Fe 44 and DO Fe 45). Overall, given the relatively small vertical gradients and the thick layer of clay between the surface-water monitors and the piezometers, there was no indication of substantial upward or downward movement of water between the shallow groundwater and the marsh surface. The clay layer appeared to be continuous throughout the site; however, if the clay layer is not continuous, it is possible that groundwater could be contributing to the surface water. In addition, no discernible horizontal groundwater flow was observed, as inferred from the similarity among water-level elevations from the three sites (DO Fe 41, 44, and 47 (see https://waterdata.usgs.gov/nwis).

The marsh surface-water monitor at site DO Fe 50 was located in a ditch that was connected to Farm Creek. Although this site was approximately 3,000 ft away from the main study area, it had a direct tidal influence similar to the one observed on Farm Creek (USGS station number 01490500, fig. 9). Maximum water levels at DO Fe 50 were slightly higher than the water levels at the tide gage located on Farm Creek, possibly due to the ditch at site DO Fe 50 being narrower than Farm Creek.

Water-quality samples were collected from marsh surface-water monitors, shallow groundwater piezometers, and from Farm Creek during a synoptic event in December 2015. Results from the synoptic event, which occurred over a 2-day period, indicate that the marsh surface water and the shallow groundwater exhibited different characteristics (table 2). The most notable difference observed between the surface water and shallow groundwater was pH. Marsh surface-water pH

Figure 7. Photographs of Farm Creek Marsh taken near marsh surface-water monitor DO Fe 45, *A*, on September 23, 2015, and *B*, during the coastal storm on October 5, 2015 (Photographs by Todd R. Lester, U.S. Geological Survey).

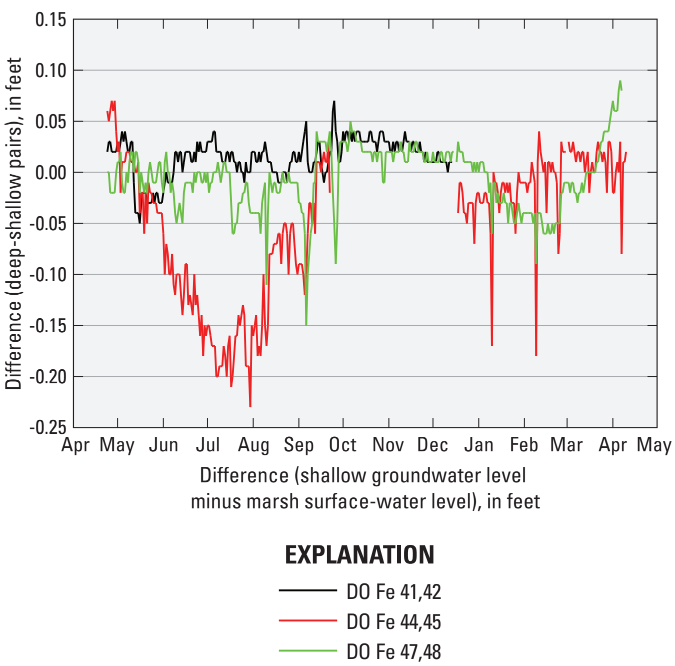

Figure 8. Difference between shallow groundwater levels (piezometers) and associated marsh surface-water monitor pairs.

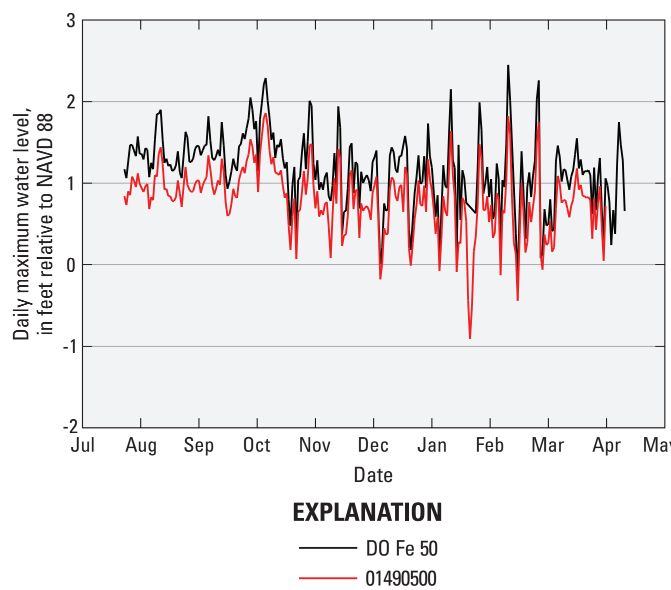

Figure 9. Daily maximum water levels for Farm Creek (U.S. Geological Survey station number 01490500) and Tidal Ditch (surface-water monitoring site DO Fe 50) (NAVD88, North American Vertical Datum of 1988).

Table 2. Water-quality results for samples collected at Farm Creek Marsh during December 2015 synoptic.

[GW, groundwater; SW, surface water; mm of Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; M, presence verified but not quantified; U, analyzed for but not detected; d, sample was diluted; n, below the reporting level but at or above the detection level; <, less than; --, no data; µg/L, micrograms per liter]

U.S. Geological Survey station number	Station name	Date	Sample start time	Record number	Medium code	Sample type	Barometric pressure (mm of Hg)	Temperature, air (°C)	Dissolved oxygen, water, unfiltered (mg/L)	pH, water, unfiltered, field, standard units	Specific conductance, water, unfiltered (µS/cm at 25 °C)	Temperature, water (°C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)
381926076043401	DO Fe 49	12/16/2015	1350	1600288	GW	Regular	768	15	4.4	6.5	11,600	14.2	49.6 d	198 d	46.6 d	1,740 d
381924076043901	DO Fe 47	12/16/2015	1240	1600289	GW	Regular	768	15	1	3.1	11,800	14.2	57.9 d	257 d	5.65 d	1,550 d
381924076043801	DO Fe 48	12/16/2015	1230	1600290	GW	Regular	768	15	0.2	6.7	17,800	11.5	116 d	369 d	104 d	3,100 d
381923076043501	DO Fe 46	12/16/2015	1130	1600291	GW	Regular	768	15	0.2	6.9	19,000	13	113 d	366 d	104 d	3,120 d
381917076035501	DO Fe 50	12/16/2015	940	1600292	GW	Replicate	768	13	6.5	7.2	21,700	10.4	135 d	413 d	126 d	3,430 d
381925076043001	DO Fe 43	12/15/2015	1530	1600293	GW	Regular	761	15	0.8	6.4	15,200	14.1	77.7 d	260 d	68.6 d	2,220 d
381922076043002	DO Fe 45	12/15/2015	1500	1600294	GW	Regular	761	15	1.5	6.1	14,500	12.9	73.5 d	251 d	80.2 d	2,060 d
381922076043001	DO Fe 44	12/15/2015	1430	1600295	GW	Regular	761	15	7.2	3	14,200	13.8	102 d	358 d	9.13 d	1,820 d
381929076043002	DO Fe 42	12/15/2015	1220	1600296	GW	Regular	761	15	0.2	6.6	14,700	14.3	99.0 d	341 d	81.4 d	2,740 d
381929076043001	DO Fe 41	12/15/2015	1200	1600297	GW	Regular	761	14	2.2	3.6	6,710	15.2	58.9 d	167 d	12.3 d	898 d
01490200	Farm Creek near Toddville, Md.	12/15/2015	900	1600298	SW	Regular	761	12	8	7.5	22,100	13.1	141 d	445 d	126 d	3,680 d

Table 2. Water-quality results for samples collected at Farm Creek Marsh during December 2015 synoptic.—Continued

[GW, groundwater; SW, surface water; mm of Hg, millimeters of mercury; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm at 25 °C, microsiemens per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; SiO_2, silicon dioxide; N, nitrogen; P, phosphorus; M, presence verified but not quantified; U, analyzed for but not detected; d, sample was diluted; n, below the reporting level but at or above the detection level; <, less than; --, no data; µg/L, micrograms per liter]

U.S. Geological Survey station number	Station name	Alkalinity, water, filtered, inflection-point titration method (incremental titration method), field (mg/L as $CaCO_3$)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Carbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Hydrogen sulfide, water, unfiltered (mg/L)	Silica, water, filtered (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Ammonia, water, filtered (mg/L as N)	Nitrate plus nitrite, water, filtered (mg/L as N)	Nitrite, water, filtered (mg/L as N)	Orthophosphate, water, filtered (mg/L as P)	Iron, water, filtered (µg/L)	Manganese, water, filtered (µg/L)
381926076043401	DO Fe 49	53.1	64.7	< 0.1	3,300 d	0.18 n,d	U	6.97	34.2 d	0.26	< 0.040	0.002	0.008	5,340 d	62.5 d
381924076043901	DO Fe 47	--	--	--	3,050 d	3.89 d	U	61.7 d	401 d	0.54 d	0.053 n	< 0.001	0.016	59,700 d	1,100 d
381924076043801	DO Fe 48	154	187	0.1	5,530 d	0.27 n,d	M	6.49	509 d	1.33 d	0.040 n	< 0.004 d	< 0.012 d	98.5 n,d	31.3 d
381923076043501	DO Fe 46	281	342	0.3	5,100 d	0.30 n,d	M	7.32	375 d	3.00 d	< 0.040	0.004 n,d	< 0.040 d	< 80.0 d	41.9 d
381917076035501	DO Fe 50	76.8	93.3	0.2	6,820 d	0.31 n,d	U	1.67	868 d	0.21	0.040 n	< 0.001	< 0.004	136 n,d	54.4 d
381925076043001	DO Fe 43	160	194	0.2	3,960 d	0.27 n,d	M	3.96	268 d	0.32	< 0.040	< 0.001	< 0.004	162 d	48.0 d
381922076043002	DO Fe 45	83.4	102	< 0.1	3,810 d	< 0.45 d	M	2.76	344 d	0.21	< 0.040	0.001 n	< 0.004	214 d	28.6 d
381922076043001	DO Fe 44	--	--	--	4,120 d	6.69 d	U	68.8 d	586 d	0.49 d	0.066 n	< 0.001	0.018	9,080 d	1,410 d
381929076043002	DO Fe 42	147	178	0.1	4,410 d	0.21 n,d	M	6.86	303 d	1.20 d	< 0.040	< 0.005 d	< 0.028 d	< 80.0 d	78.8 d
381929076043001	DO Fe 41	--	--	--	1,880 d	0.33 n,d	U	45.2 d	290 d	0.71	0.069 n	< 0.001	0.012	84,300 d	2,210 d
01490200	Farm Creek near Toddville, Md.	63.2	76.5	0.3	6,990 d	0.38 n,d	--	0.39	910 d	0.2	< 0.040	< 0.001	< 0.004	< 80.0 d	7.84 n,d

ranged from 6.1 to 6.9 standard units, which was similar to the Farm Creek pH of 7.5 standard units. However, the pH measured in the shallow groundwater piezometers ranged from 3.0 to 3.6 standard units. Silica, iron, manganese, and potassium concentrations were also markedly different between the shallow groundwater and marsh surface water, with the water-quality samples from Farm Creek more similar to the marsh surface water. Despite the consistent differences in pH, silica, iron, manganese, and potassium between the shallow groundwater and the marsh surface water, other parameters such as dissolved oxygen and specific conductance did not display notable differences. Nutrient concentrations were relatively low at all of the sites. A number of the marsh surface-water sites had aromas of hydrogen sulfide; those sites also had low dissolved oxygen levels, which could indicate stagnant waters.

A Trilinear (Piper) diagram, which represents the water-quality data collected during the December 2015 synoptic event, is shown in figure 10. Piper diagrams plot the percentages of major ions found in a sample, which can be useful for visualizing differences and similarities of geochemical data. Subtle differences between the shallow groundwater and marsh surface water can be seen in figure 10; however, there are two distinct groupings. The differences represented on the Piper diagram can primarily be attributed to the lower potassium percentages in the groundwater when compared to percentages in the surface water. It is also evident from the Piper diagram that major ion percentages in marsh surface water are more consistent with major ion percentages in Farm Creek water than those in shallow groundwater.

The integration of shallow groundwater levels, marsh surface-water levels, Farm Creek tidal levels, precipitation, and water-quality information presented in this report can help improve the understanding of the causes of inundation for the Farm Creek Marsh study site (fig. 11). Information shown in the figure integrates the average marsh surface-water levels with precipitation and tide levels observed at site DO Fe 50. It is evident from analysis of this information that marsh water levels increase mainly during elevated tide levels; however, there is also some response to certain precipitation events. The relatively small vertical hydraulic gradients between the marsh surface-water monitors and the paired shallow groundwater piezometers combined with the thick layer of clay between the two indicate that groundwater discharge is not the main factor causing inundation.

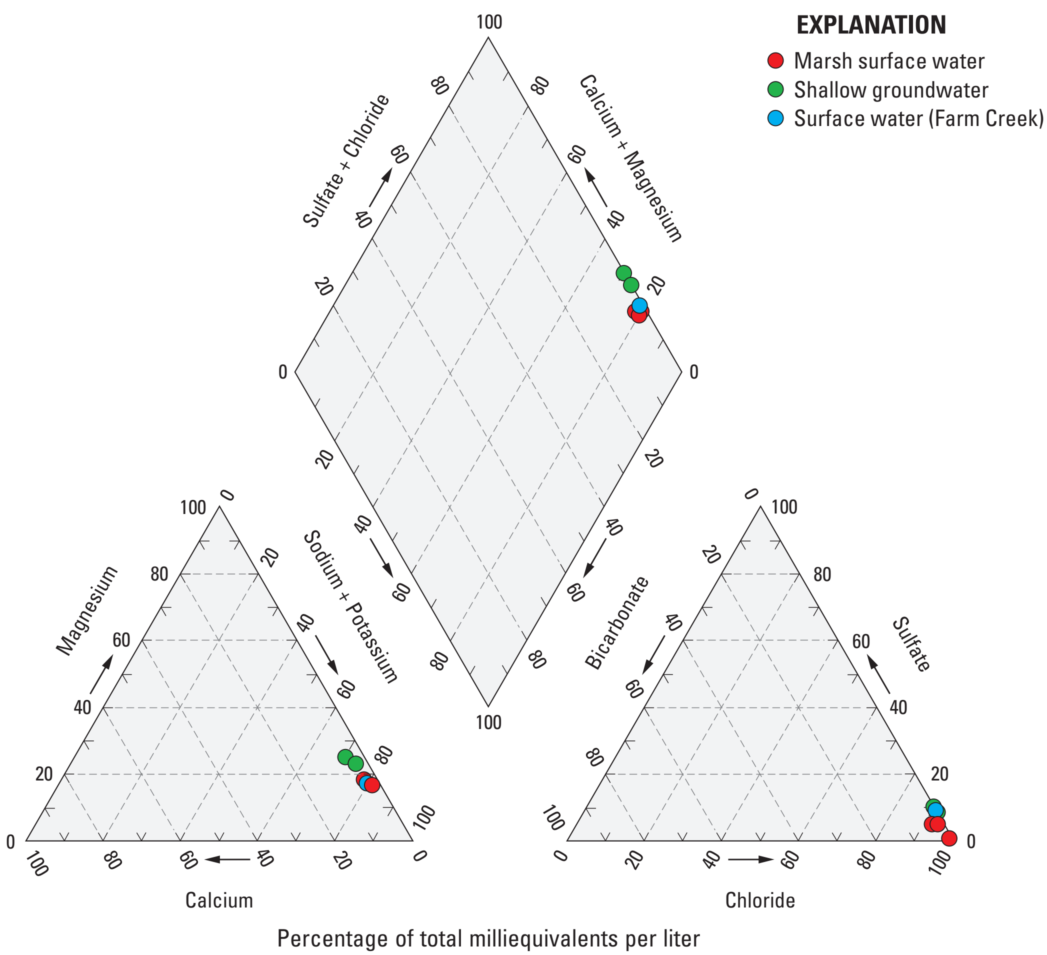

Figure 10. Trilinear (Piper) diagram of water-quality samples taken from Farm Creek Marsh, December 2015.

Inundation duration and depth varied across the relatively small study area, with land-surface elevation being the most important factor. Land-surface elevation ranged from 0.76 ft to 1.19 ft for each of the monitoring sites. Less than 0.5 ft of elevation was the difference between being inundated during the entire study period of 353 days and being inundated for 36 consecutive days out of 108 total days of inundation over the study period. The area with the lowest elevation was ponded with no woody vegetation, whereas the least inundated area was in a stand of pine trees with the highest land-surface elevation. Other sites were in vegetative transition areas, evidenced by the abundance of dead pine trees. Inundation generally increased after the area experienced a large coastal storm event that brought wind and rain to the study area. However, it should be noted that the storm coincided with the end of the growing season, which may have reduced the evapotranspiration (the process by which water is transferred from the land to the atmosphere by evaporation and by transpiration from plants) rate, potentially leading to additional inundation.

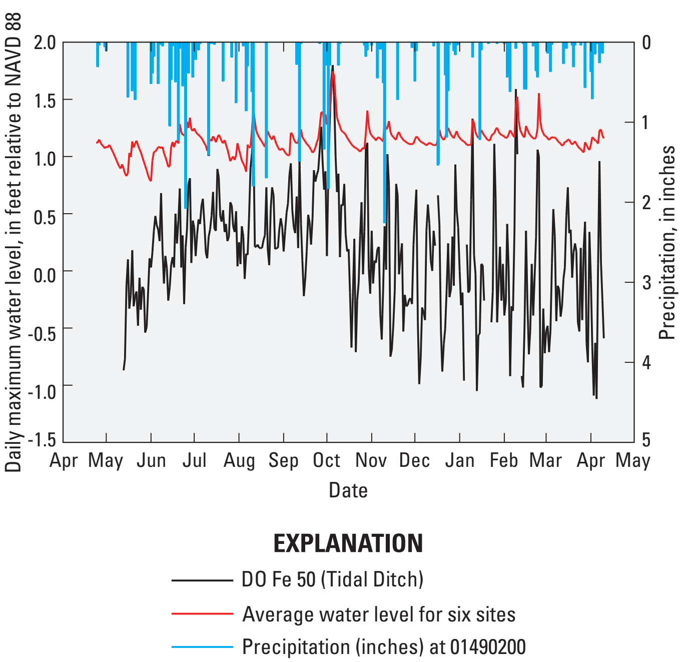

Figure 11. Average water level for six marsh surface-water monitoring stations, DO Fe 50 (Tidal Ditch) water level, and precipitation at U.S. Geological Survey station number 01490200 compared to time. (NAVD88, North American Vertical Datum of 1988).

Summary

In 2015, the U.S. Geological Survey began a 1-year hydrologic study to investigate the extent and cause of inundation at Farm Creek Marsh, in Dorchester County, Maryland. In combination with a tide and precipitation gage, a representative section of the marsh was instrumented with surface-water monitors and shallow groundwater piezometers to capture the spatial and temporal extent of inundation. In addition, water-quality data, including major ions and nutrients, were collected to help differentiate water sources that contributed to the cause of inundation.

All sites measured during 2015 and 2016 were periodically inundated throughout the measurement period. The depth of inundation for most of the sites typically ranged from 0 to 0.2 feet (ft), except for sites DO Fe 45 (0 to 0.5 ft) and DO Fe 46 (0 to 1.0 ft). Increases and decreases in water levels are episodic, and mainly related to elevated tide levels; however, they could be seen across the study area nearly simultaneously. Mean daily water levels were also consistent among the six sites. The average standard deviation of mean daily water levels for all six sites collected over 353 days was 0.06 ft.

Water-quality samples were collected from marsh surface-water monitors, shallow groundwater piezometers, and from Farm Creek during a synoptic event in December 2015. Results from the synoptic event, which occurred over a 2-day period, indicate that the marsh surface water and the shallow groundwater exhibited different characteristics. These differences can primarily be attributed to the lower potassium percentages in the groundwater when compared to percentages in the surface water. It is also evident that major ion percentages in marsh surface water are more consistent with major ion percentages in Farm Creek water than those in shallow groundwater.

The integration of all the data collected during the study period has led to several conclusions that can be drawn from this study. Inundation occurred at all monitoring sites, with only 0.5 ft of elevation being the difference between sites that were continuously inundated and those that were inundated for about one-third of the study period. Multiple lines of evidence, including the water-quality data, indicate that shallow groundwater did not appear to play a role in the inundation. However, water levels, and subsequently inundation, did respond to both precipitation and tidal events. Although a coastal storm event did produce the highest magnitude of inundation, its timing at the end of the growing season made it difficult to discern if the storm led to an increasing trend in inundation after the storm event – increased inundation through the cooler months could have been due to lower levels of evaporation and evapotranspiration. Future engineering solutions aimed at reducing inundation at the Farm Creek Marsh site should address both tidal and precipitation influences.

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