THE GREAT DISMAL SWAMP: WATER MANAGEMENT PRACTICES AND EFFECTS ON LAND AND PEOPLE

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Introduction

The Great Dismal Swamp is a wildlife refuge that is 80 square kilometers and contains over 120,000 acres of land. The swamp provides habitat for over 200 hundred bird species with a wide array of flora, fauna, mammals, amphibians, reptiles, and many more. Seasonally, the swamp experiences seasonal changes that are wet and dry (USFWS, 2016). These variances bring with it high and low ranges of water levels and with that, billions of gallons of water are flowing in and out of the swamp per year. Annually, the swamp gets 22 billion gallons of water inputted by just precipitation in the months of November through April where rainfall is at its peak (USFWS, USGS, 2017). The 22 billion gallons of water accounts for 89% of the inflow of water in the swamp. About 39 inches of all the water input into the system, whether it is surface flow, groundwater, or precipitation recharge, will be the output by evapotranspiration with groundwater discharge as a secondary output (USGS, USFWS, 2017). Aside from natural occurrences such as rain, the swamp contains 158 miles of canals and ditches that carry water through water control structures, inflow from rivers and outflow into the rivers, or output into nearby farmlands and counties. Over 42 water control structures have been put into the swamp since the late 70's with the newest ones added as recently as 2016. These water control structures (WCS) help dry or rewet the system at specific times of the year or under certain circumstances such as severe weather. Rewetting is necessary due to the drying out of organic peat soils in the swamp. When peat soils dry out, they oxidize and often cannot be rewet. After soils oxidize they release carbon into the atmosphere, adding to the already staggering amounts currently in the atmosphere today. Inflows of water from the surface have increased due to practices such as road building, tiling, and housing along the Suffolk Scarp on the western side of the swamp. This increase in surface water yields higher water levels during times of severe weather and storm events as well as during winter months. Overall, these water control structures are necessary for the swamp waterways and ditch networks to keep the area from oversaturating, but to also keep the swamp from experiencing extreme dryness and to create a system that mimics natural flow.

A simulation model has been created by the US Fish and Wildlife Service (USFWS) and the US Geological Survey (USGS) to simulate what the swamp may experience during wet/dry seasons as well as average wetness/dryness. What this software also offers is a way to simulate the effectiveness of these water control structures. Data has been collected and analyzed to portray how the swamp would be with or without the water control structures (WCS) and to figure out if the structures, implemented by humans into a natural system, serve a great purpose to the swamps hydrology. In the model, all water control structures within the survey area are simulated and put through eight different scenarios, which are laid out in the next section.

Model Data and Tables

Scenarios include first 3 without new water control structures, scenario 1, Base case (Average low weir), scenario 2, wet season (weir settings low), scenario 3 dry season (weir settings high), and then 4 other scenarios with the newly added water control structures as well as already used ones. With scenario 4 being future added WCS average (low weir), scenario 5 being, flood swamp wet season (very high weir settings), scenario 6 being flood swamp Dry season (very high weir settings), scenario 7 drain the swamp under wet season (weir very low), and finally scenario 8 drain swamp under dry (weir very low). USGS and the USFWS ran the model on all water control structures but focusing on the more Northern and Southern structures that will affect surrounding private properties and be affected by inflow and outflow with future sea level rise projections, are outlined. These important water control structures, with their numbers on the map (figure 1) include, WCS number 5- Big entry fixed weir 2, WCS number 8- Big Entry ditch/Canal, WCS number 13- Juniper/Road, WCS number 16- Portsmouth/Northeast, WCS number 20- Portsmouth Dam, WCS number 63- Head of River 1 ditch, WCS number 64- Insurance/County Line ditch, 65- County Line at Pasquotank River/Insurance ditch, and WCS

number 67- Weyerhauser ditch.

	Scenario	Climatic Conditions	Weir Level Settings	Water-control structures Included
1	Base Case	Average	Low	Those active in 2015
2	Wet	Wet	Low	Those active in 2015
3	Dry	Dry	High	Those active in 2015
4	Future WCS Added	Average	Low	Proposed + active 2015
5	Flood the Swamp Wet	Wet	Very High	Proposed + active 2015
6	Flood the Swamp Dry	Dry	Very High	Proposed + active 2015
7	Drain the Swamp Wet	Wet	Very Low	Proposed + active 2015
8	Drain the Swamp Dry	Dry	Very Low	Proposed + active 2015

Table 3: This is Table 16 from the USGS/USFWS model detailing each scenario done by the model with climate conditions, weir levels, and newly added WCS accounted for. (Eggleston, J et al., 2017)

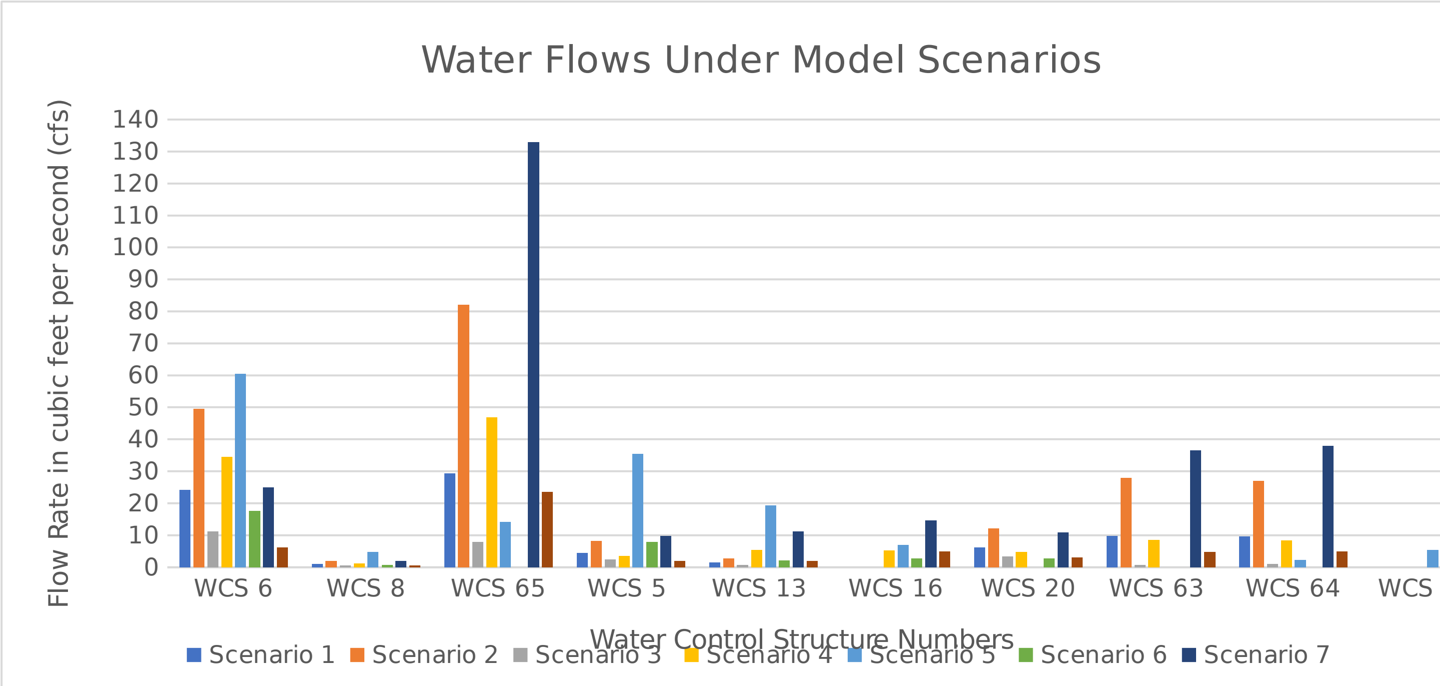


Figure 1: This is a graph detailing flow rates in cfs for each eater control structure under each scenario.

Structure Name	**Structure #**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 8**
Portsmouth Ditch to Big Entry	WCS 6	24.2	49.5	11.2	34.4	60.4	17.6	25	6.2
Big Entry Ditch Discharge to Canal	WCS 8	1	1.9	0.5	1.2	4.8	0.7	1.9	0.5
County Line Ditch Discharge to Pasquotank River	WCS 65	29.3	82	7.8	46.8	14.1	-	132.9	23.5
Big Entry Fixed Weir 2	WCS 5	4.35	8.22	2.5	3.49	35.32	7.81	9.72	1.99
Juniper @ Road	WCS 13	1.37	2.69	0.63	5.34	19.23	2.15	11.12	1.97
Portsmouth /Northeast	WCS 16	-	-	-	5.16	7.01	2.71	14.63	5.02
Portsmouth Dam	WCS 20	6.17	12.17	3.29	4.71	-	2.73	10.92	3.01
Head of River 1	WCS 63	9.83	27.92	0.65	8.56	-	-	36.54	4.82

Insurance/Countyline	WCS 64	9.62	26.94	1.06	8.34	2.32	-	37.82	4.9
Weyerhauser	WCS 67	-	-	-	-	5.34	-	2.78	-

Table 4: This is a self-made table using data from the model. Data presented here are flow rates given in cubic feet per second. This table serves to visualize data given in graph form in figure 1.

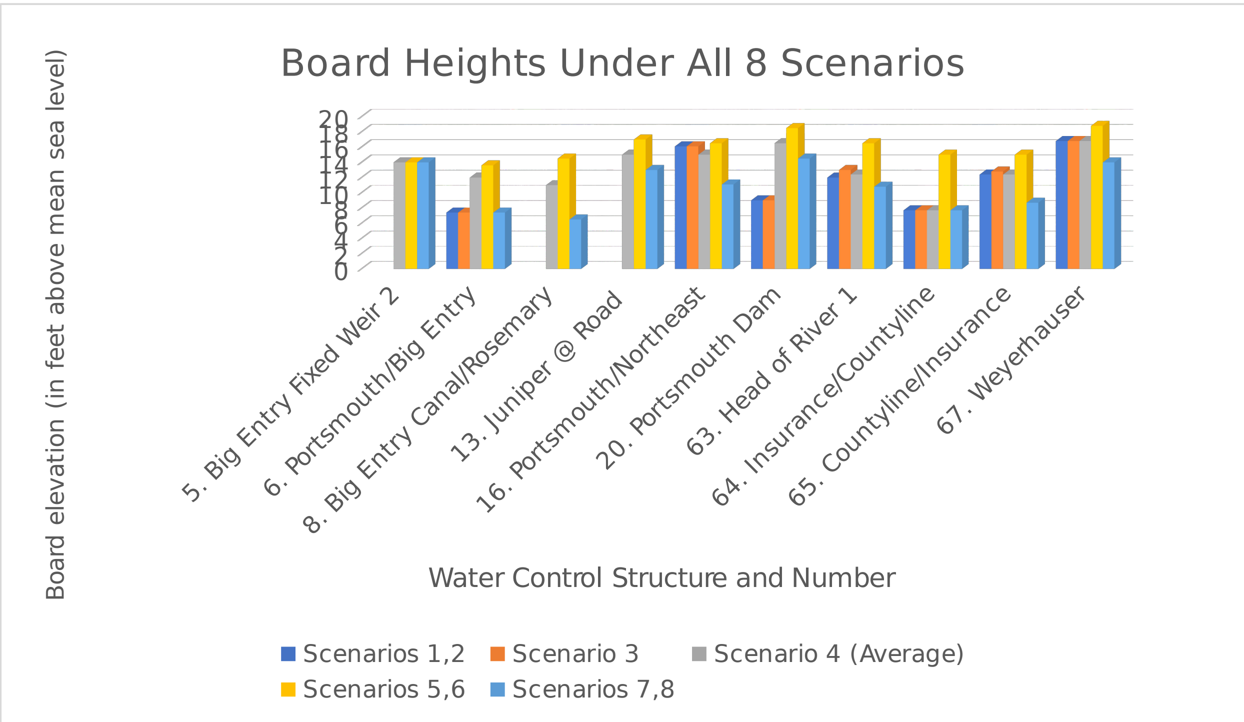


Figure 2: The graph shows board height elevations at each water control structure under each scenario. These boards heights would have a direct effect on how much water flowed through them.

The graphs and tables above depict data from the USGS/USFWS Hydrology Model. Table 1 provides information on each scenario, the weir settings associated with each scenario, and climactic conditions for each. Figure 1 portrays water flows in cubic feet per second at each water control structure under each scenario. Table 2 gives the same information but in chart form to provide exact values of flows seen in the graph in Figure 1.

Lastly, Figure 2 shows board heights for each structure under each scenario. This is provided to show what levels the boards are set to better understand how much water is going through each structure, as provided by figure 1 and table 2. Information provided in the next section provides detail on each water control structure and the flow of water through each of these structures.

When observing board elevation levels and the flow rates at each water control structure, we start to see a correlation between the two. During scenarios where boards are placed in at a high elevation, the flow rates at those boards heights are smaller because water is not able to flow through structures as easily. On the other hand, when board levels are lower, more water can flow through the water control structures; in this circumstance we see higher flow rates. The model simulation allows for swamp staff and hydrologists to see how much water flows or does not flow through the water control structures at specific board heights. This comes in handy when preparing for severe weather or at times of crisis. If the swamp is suspected of being dry in certain areas, board heights will be adjusted for all the water control structures around that dry area to hold extra water and saturate the land in that area; under that circumstance, boards would be raised. The same would be true for areas of high saturation or flooding, board heights would be lowered to allow the water to flow more regularly through these areas to pass water through structures at a faster rate. Below is each weir/water control structure, their board elevations under each scenario, and the flow rates under each scenario as well.

WEIR 5. Big Entry Fixed Weir 2

Weir location number 5 is Big Entry Fixed Weir 2. Under scenario one, average flows without new WCS added after 2015, a flow of 4.35 cfs. Under scenario 2 without new WCS, 8.22 cfs was recorded. A flow measurement of 2.5 cfs was recorded under scenario 3 for this structure. Under scenario 4, 3.49 cfs was recorded with a board elevation height of 14 FAMSL (feet above mean sea level). Board elevations for one, two, and three were unavailable. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 35.32 cfs, 7.81 cfs, 9.72 cfs, and 1.99 cfs. The board heights for those scenarios were also all 14 FAMSL (Eggleston, J et al., 2017).

WEIR 6. Portsmouth Ditch/Big Entry

Weir location number 6 is Portsmouth Ditch where it discharges to Big Entry Ditch. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 24.2 cfs was recorded. With a board height elevation of 7.4 FAMSL. Under scenario 2 without new WCS, 49.5 cfs was recorded with board height of 7.4 FAMSL. A flow measurement of 11.2 cfs was recorded under scenario 3 and had an average board height elevation of 7.4 FAMSL. Under scenario 4, 34.4 cfs was recorded with an average board height elevation of 12 FAMSL. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 60.4 cfs, 17.6 cfs, 25.0 cfs, and 6.2 cfs. Average board height elevations for scenarios 5 and 6 were 13.6 FAMSL, while heights were 7.4 FAMSL under scenarios 7 and 8 (Eggleston, J et al., 2017).

WEIR 8. Big Entry/Canal

Weir location number 8 is Big Entry Ditch with a discharge towards the Canal. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 1.0 cfs was recorded. Under scenario 2 without new WCS, 1.9 cfs was recorded. A flow measurement of 0.5 cfs was recorded under scenario 3 for this structure. Under scenario 4, 1.2 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 4.8 cfs, 0.7 cfs, 1.9 cfs, and .5 cfs (Eggleston, J et al., 2017). The board heights associated for WCS 8 are, 11 FAMSL for scenario 4, 14.5 FAMSL for scenarios 5 and 6, and 6.5 FAMSL for scenarios 7 and 8 (Eggleston, J et al., 2017). The board elevations for scenarios 1, 2, and 3 are unavailable in the model data (Eggleston, J et al., 2017).

WEIR 13. Juniper at Road

Weir location number 13 is Juniper at Road. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 1.37 cfs was recorded. Under scenario 2 without new WCS, 2.69 cfs was recorded. A flow measurement of .63 cfs was recorded under scenario 3 for this structure. Under scenario 4, 5.34 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 19.23 cfs, 2.15 cfs, 11.12 cfs, and 1.97 cfs (Eggleston, J et al., 2017). Board height elevations for scenarios 1, 2, and 3 for Juniper WCS were unavailable but for scenario 4 is 15 FAMSL, scenarios 5 and 6 were measured at 17 FAMSL, and scenarios 7 and 8 averaged at 13 FAMSL (Eggleston, J et al., 2017).

WEIR 16. Portsmouth/Northeast

Weir location number 16 is the Portsmouth/Northeast weir. Under each scenario, these are the flow measurements in cfs (cubic feet per second). At the Portsmouth/Northeast location, Scenarios 1, 2, and 3 had no data collection recorded. Under scenario 4 a measurement of 5.16 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 7.01 cfs, 2.17 cfs, 14.63 cfs, and 5.02 cfs (Eggleston, J et al., 2017). For scenarios 1-3 board elevations are 16.1 FAMSL. Scenario 4 averaged a height of 15 FAMSL. Scenarios 5 and 6 had an average board elevation of 16.5 FAMSL and scenarios 7 and 8 were measured at 11.1 FAMSL (Eggleston, J et al., 2017).

WEIR 20. Portsmouth Dam

Weir location number 20 is Portsmouth Dam. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 6.17 cfs was recorded. Under scenario 2 without new WCS, 12.17 cfs was recorded. A flow measurement of 3.29 cfs was recorded under scenario 3 for this structure. Under scenario 4, 4.71 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of no data for 5, 2.73 cfs, 10.92 cfs, and 3.01 cfs (Eggleston, J et al., 2017). Average board elevations for Portsmouth Dam were 16.1 FAMSL for scenarios 1, 2, and 3 (Eggleston, J et al., 2017). For scenario 4, a measurement of 15 FAMSL was recorded (Eggleston, J et al., 2017). For scenarios 6 and 7, 18.5 FAMSL was measured, and for scenarios 7 and 8, 14.5 FAMSL was measured (Eggleston, J et al., 2017).

WEIR 63. Head of River 1

Weir location number 63, the Head of River 1 location. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 9.86 cfs was recorded. Under scenario 2 without new WCS, 27.92 cfs was recorded. A flow measurement of .65 cfs was recorded under scenario 3 for this structure. Under scenario 4, 8.56 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings. Scenarios 5 and 6 had no data recorded, but 7 and 8 had measurements of 36.54 cfs and 4.82 cfs. (Eggleston, J et al., 2017) The averages of board height elevations were measured as well and influenced these water flows. The average board height elevation for scenarios 1 and 2 was 12 FAMSL, scenario 3's board elevation was 13 FAMSL, and scenario 4 had a measurement of 12.4 FAMSL (Eggleston, J et al., 2017). Scenarios 5 and 6 were averaged at 16.5 FAMSL and scenarios 7 and 8 were averaged at 10.8 FAMSL (Eggleston, J et al., 2017).

WEIR 64. Insurance/County Line

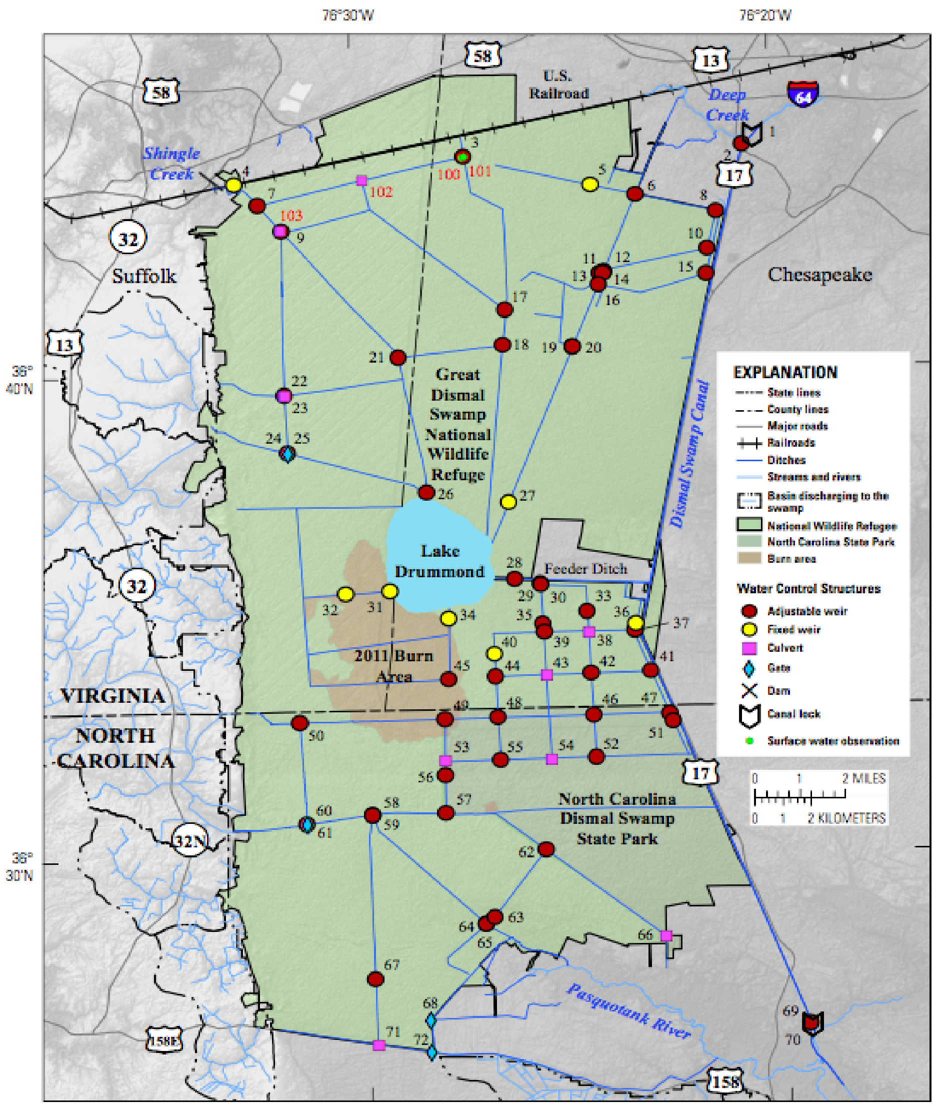
Weir location number 64, the Insurance and Countyline ditch. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 9.62 cfs was recorded. Under scenario 2 without new WCS, 26.94 cfs was recorded. A flow measurement of 1.06 cfs was recorded under scenario 3 for this structure. Under scenario 4, 8.34 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 2.32 cfs, no data for 6, 37.20 cfs, and 4.9 cfs (Eggleston, J et al., 2017). WCS 64 had average board height elevations that were extremely consistent for each simulated scenario. For scenarios 1, 2, 3, 4, 7, and 8, the average board height was measured at 7.7 FAMSL (Eggleston, J et al., 2017). For scenarios 5 and 6, the average height was 15 FAMSL (Eggleston, J et al., 2017).

WEIR 65. County Line/Pasquotank River

County Line Ditch with a discharge towards the Pasquotank River was WCS number 65 on figure 1. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Under scenario one average without new WCS added after 2015, a flow of 29.3 cfs was recorded. Under scenario 2 without new WCS, 82.0 cfs was recorded. A flow measurement of 7.8 cfs was recorded under scenario 3 for this structure. Under scenario 4, 46.8 cfs was recorded. Starting with scenario 4 and all the way through 8, the new water control structures after the Sandy Project of 2015 were added in the swamp. Scenarios 5, 6, 7, and 8 are recorded with wet and dry seasons as well as different weir settings with recordings of 14.1 cfs, no recorded measurement for scenario 6, 132.9 cfs, and 23.5 cfs (Eggleston, J et al., 2017). Board height elevations for scenarios 1, 2, and 4 were 12.4 FAMSL while scenario 3 was recorded at 12.8 FAMSL (Eggleston, J et al., 2017). Scenarios 5 and 6 had a recording that was the highest for this structure at 15 FAMSL and scenarios 7 and 8 were recorded at 8.7 FAMSL (Eggleston, J et al., 2017).

WEIR 67. Weyerhauser

Weir location number 67, the Weyerhauser ditch area. Under each scenario, these are the flow measurements in cfs (cubic feet per second). Unfortunately, data collection was scarce for this water control structure. Scenarios 1-4, 6, and 8 are all unavailable. Under scenario 5, which is when the new Sandy project WCS were added, a flow of 5.34 cfs was recorded. The flow recorded for scenario 7 was 2.78 cfs. (Eggleston, J et al., 2017) Board height elevations for scenarios 1, 2, 3, and 4 for this structure were consistent at 16.8 FAMSL (Eggleston, J et al., 2017). Scenarios 5 and 6 were 18.8 FAMSL, and scenarios 7 and 8 were recorded at 14 FAMSL (Eggleston, J et al., 2017).



Base from U.S. Geological Survey National Elevation Data 1/3 arc-second
Lambert Conformal Conic projection
Standard Parallels 36° 45' 57.6" N and 37° 57' 57.6" N; central meridian 78° 30' W
North American Datum of 1983 State Plane Virginia South

Figure 3: from the USGS document. This figure illustrates each water control structure on the swamp marked by red dots, while weirs are marked by yellow. Each water control structure is assigned a number. Specific WCS outlined in this paper are named below. (Eggleston, J. et al., 2017)

Hazards

The swamp is an extremely flat, fire-vulnerable area between two states. With future sea level rise projections, areas such as the Pasquotank River and inland shores near the Chesapeake Bay will flood under possible projections of three feet and six feet rise in sea level. Because of the high water table throughout changing wet and dry seasons, unless rewet, the peat soils can become porous and grainy and unable to hold sufficient amounts of water. Malnutrition of peat soils can lead to more fire prone surface area and increased rates of wildfires. Because of the flat and fire-prone nature of the swamp, the staff have been working to change swamp hydrology and actively rewet the swamp. Hydrology has been changing since the first installation of ditches and tilling of soils at the time of George Washington. To maintain the hydrology, the weir levels at these water control structures are closely monitored and changed depending on seasonality and wet/dry time of year. Water control structures are installed to hold water when the ground gets drier and the water table has risen. Conversely, board levels at water control structures can be dropped to let water flow on the surface and as ground water when areas have been sufficiently moistened. If kept unchecked, the drying out of peat soils is possible in some areas where water is less likely to flow. Dried peat is more prone to releasing increased amounts of CO_2 which is a hazard for the swamp and the atmosphere. According to the USGS study with the Great Dismal Swamp, CO_2 levels are estimated to be higher when peat soils are subsided or oxidized (USGS, 2014). In the occurrence of fires and increased change in hydrology, carbon dioxide levels are being monitored in this study. Storm surge and flood waters are a hazard as well for the swamp and can result in complaints from surrounding property owners and city officials. Because swamp waters, especially after times of increase winds (upwind tides), have no other outlet, excess water is being funneled through counties such as Camden and

Pasquotank. Through communication, education, and this USGS/USFWS data model, we can further discover exactly how flows effect the swamp water levels as well as in areas where it also effects the public. Inflow of debris, fertilizer, and other harmful chemicals can be introduced, damaging water ways and harming peat soil. The chemicals can also contaminate food for animals in the swamp. The weir settings of these water control structures are critical to the swamps hydrology.

Vulnerabilities

The Great Dismal Swamp has a long history of logging, tilling, and ditch building systems dating back to times of George Washington and construction on the Dismal Swamp Canal commencing in 1793. Since then, the swamp has had many different owners who constructed additional ditches and roads, all leading up to eventually a 144-mile road network (Litchtler and Walker, 1974). Ditch and road systems have drastically changed swamp hydrology by first compacting peat soils. The highly permeable peat soils collect a high percentage of rainfall, recharging groundwater and making ditches major collectors of this high groundwater discharge. The collection of groundwater in the ditches then lowers groundwater levels which makes a large surface area of swamp land much drier than what it normally would have been, preditched (Sperian and Wurster, 2017). Because of this recharge-groundwater exchange due to the change in land consistency, subsidence of peat soils is more common, and the hydrology of the whole system is changed. To prevent the dry out of soil, rewetting the system using the installed water control structures is important to prevent tree stress and risk of wildfire. Once peat soils are dried, air pockets underground are often formed, which then creates an even higher risk for wildfire. Conversely, if the system is too wet, tree lines along ditch systems experience high mortality of trees due to increased saturation of root systems. Therefore, careful measurements of water levels at water control structures is practiced by swamp staff. Board height elevations are varied among locations and each average board height is specific to that area due to different elevations in the swamp; more or less water is subjected to different areas. Board heights and elevations are also critical at times of severe weather, for the swamp as well as form surrounding citizens. Swamp staff and city officials often coordinate between one another in anticipation of these weather events to prepare swamp and surrounding private lands. If these hydrological systems were not in place, the swamps water levels could be drastically different. To understand just how important human management of water control structures and swamp hydrology is, the development of the model simulation was set into motion.

Foresight and Options for the Future

NOAA projections for Sea Level Rise: Current, 3 ft., and 6 ft.

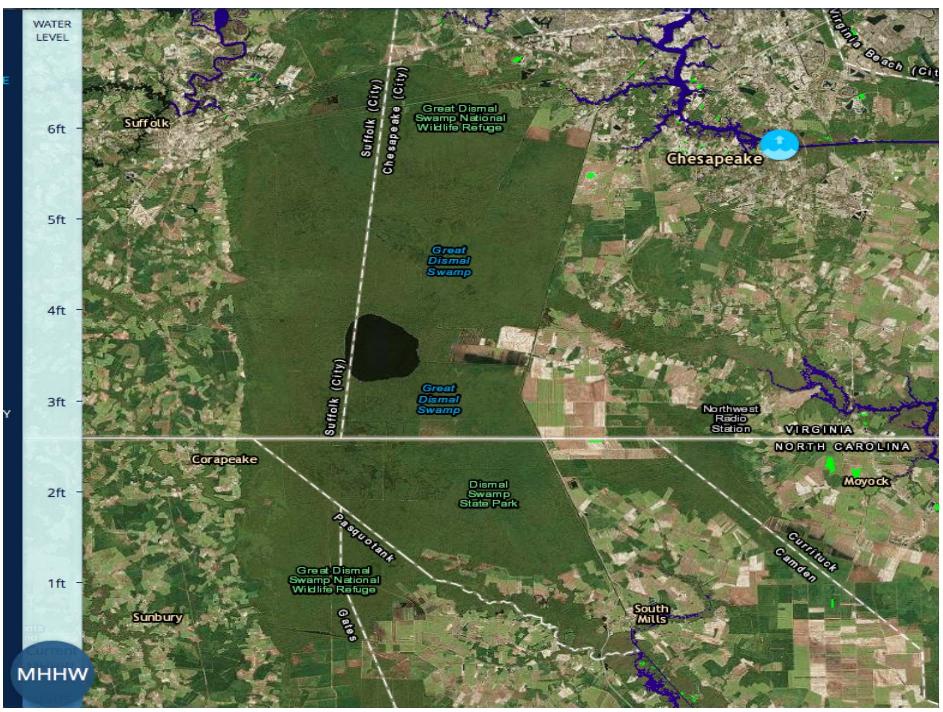


Figure 4: NOAA's Current projections with no sea level rise.

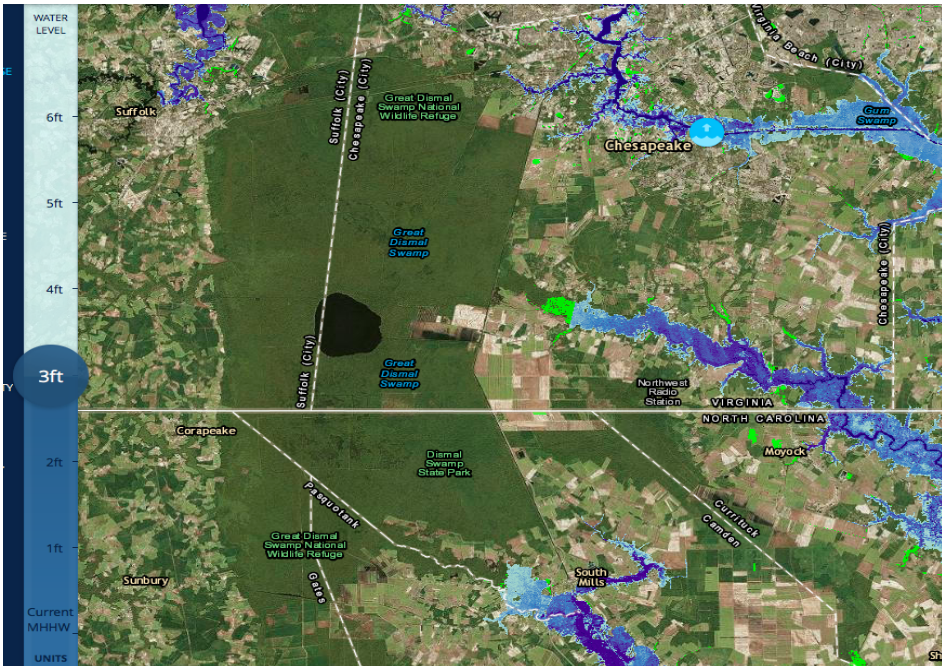


Figure 5: NOAA's Sea level rise projections with three-feet rise.

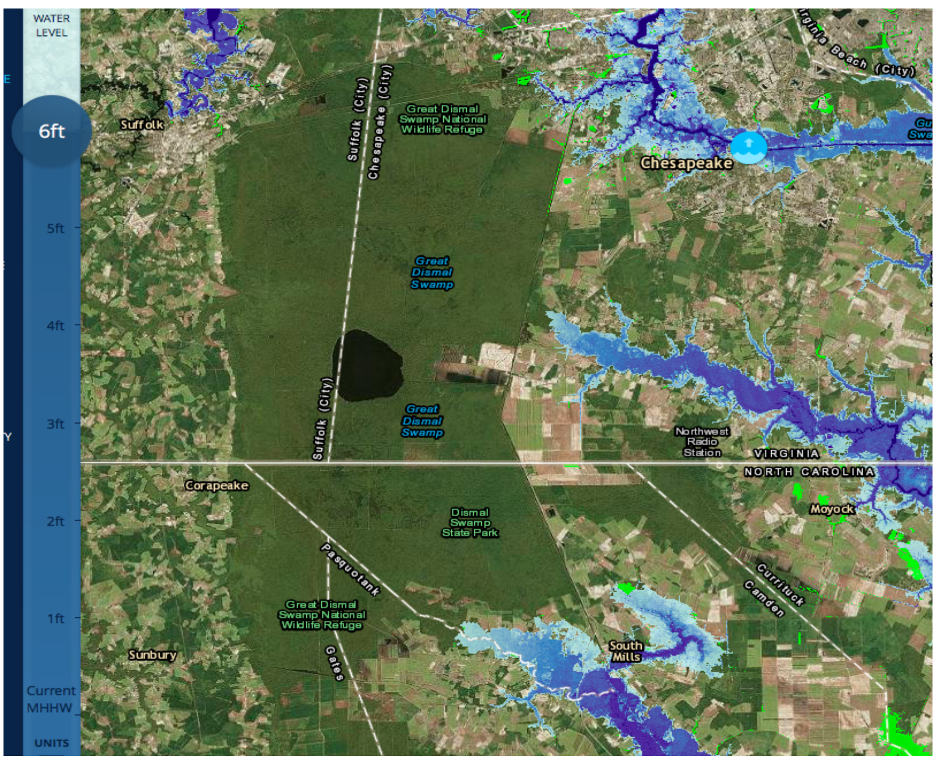


Figure 6: NOAA's Sea level rise projections with six-feet rise.

According to scientists, projections for future rise in sea level are still unclear and any projection is possible. Due to our excessive fossil fuel use, overpopulation, high CO_2 levels (in almost 400 ppm), and warming of the planet, business as usual projections with no change show favor towards sea level rise between one to three feet, with the highest projection to be six feet. To help prepare for the future, NOAA (the National Oceanic and Atmospheric Association), has created an online simulator to view areas around the world and what they will look like with zero change or sea level rise up to six feet (Melillo, J.M. et al., 2014). This change is projected to be seen by scientists within the next 50-100 years if we continue our business-as-usual way of living as human beings (Melillo, J.M. et al., 2014). It has been suggested even by locals such as Roland Culpepper of Culpepper Landing Neighborhood Association, that the City of Chesapeake, USACE, and DGIF coordinate with each other and insure that breaches in or around the swamp are carefully watched and dealt with accordingly. In some areas, even though sea level rise has not had much effect presently, we still see that high intense storms have the ability to create issues for these areas where citizens live. Mr. Culpepper also suggests in his letter to James Baker of the City of Chesapeake, that the City along with constituents, the US Army Corps of Engineers (USACE) and Department of Games and Inland Fisheries (DGIF), “conduct a study to assimilate the impacts of water retention structures on induced flooding.” It is important to these stakeholders as well as the citizens of North Carolina and Virginia to contain the problem and come up with effect and resilient ways to deter storm surge waters and flood waters from entering these cities and counties. Along with outreach from Culpepper Landing comes outreach from Camden County and South Mills in North Carolina where they seek to restore drainage outlets between the refuge and their county. It is described by Stephanie Humphries and Brian Lannon that "water from the western part of the Wildlife Refuge is diverted into the Newland 158 Canal then into the Pasquotank River instead of travelling to the Perquimans River…this water converges with water from the Dismal Swamp Canal and Joyce Creek just downriver from the locks in South Mills. As a result, major flooding occurs in the Bunker Hill Road area of South Mills and a large area of agricultural land in Pasquotank and Camden counties after large storms." Drainage restoration, research, and even the developments of a transient model in partnership with USFWS and USGS are options here to consider. Even the idea of a culvert off US interstate 158 right off the Great Dismal Swamp may contribute to the redirection of the excess water reaching these counties.

Short term, with little to no sea level rise, we should consider the possibility of change. To prepare for short term or even long-term possibilities, buildup of offices, water control structures, and surrounding properties is a necessity. Educating locals, cities, counties, and local governments is also a priority. To achieve this, holding monthly/bimonthly meetings to effectively communicate issues and possibilities of sea level rise and flooding is important.

Long term goals would be to ascertain exactly how different the swamp would be with extra three-six extra feet of water coming in to the swamp as inflow. Preparing for the worst outcome is necessary to be resilient and sustainably protect the Great Dismal Swamp or any other area of importance that could be impacted by change in sea level. According to data gathered by the USFWS in coordination with USGS, ground and surface water inflow from the Suffolk scarp, aquifers, and during ditch exchange accounts for 634.5 cfs of water coming into the swamp out of the total inflow of water, which is 1,534.4 cfs. The rest of the water flowing through the swamp, 899.9 cfs, comes in from recharge/precipitation. Even though possible sea level rise projections would not directly flood the swamp, it may flood rivers, waterways around the swamp, and aquifers causing spill over and extra inflow through ditches and groundwater systems. A direct quote from Great Dismal Swamp Supervisor, Chris Lowie, is that “for the swamp to continue to thrive, a diverse selection of plants and trees need to be introduced. For future generations of refuge staff, a plan needs to be put in place to protect our swamp and the people around us. A more diverse swamp is a more resilient swamp, and in the occurrence of possible sea level rise, the swamp needs to be protected, conserved, and changed if need be.” Chris’s words provoke initiative to act and create comprehensive plans to better equip the swamp for future possible sea level rise projections.

Decision Making

The staff at the Great Dismal Swamp partners with the US Fish and Wildlife Service (USFWS), US Geological Survey (USGS), City of Chesapeake and Suffolk, Army Corp of Engineers, Nature Conservancy, Pasquotank County (Watershed Management Team), Camden County, and the Pasquotank/Camden Emergency Management. The main goal of these stakeholders and the USFWS is to create a stable and cohesive environment for not only for the organizations and their staff but also for the public. Partnering to raise funds for transient models that could be used to simulate water levels and possible futures for cities and counties around the swamp should be a main priority. This could help prepare citizens and swamp staff for higher water levels based on these models and data. Some plans with the help of stakeholders, may include the introduction of plants/trees that are acclimated to a wetter environment. Raising money for the model and translocation/planting of this vegetation can be achieved by more volunteer work and partnerships between stakeholders and organizations. Future sea level rise projections can be inputted into this new model and then can be used to simulate different flows at structures with varying water levels per area (current water levels and future water levels). According to data from the NOAA website, higher water levels are mostly seen in areas most Northern and Southern of the swamp where they are surrounded by major water ways (Southern Branch Elizabeth River and Pasquotank River). Areas most North Eastern and South Eastern are also areas where most private land owners and citizens are struggling with increased frequency of flood waters. Great Dismal Swamp staff and hydrologists can use this information to ascertain water weir settings and board height elevations that need to be established at each water control structure to keep water flowing and to keep from spilling over excess water. Using the model can broaden the horizons of the swamp's conservation plans and help to set the stage for an increase in diversity and resiliency among plants and animals thriving in the swamp. Model data used by smaller counties and private landowners in coordination with federal agencies will establish partnership and steady flow of change in preparation for possible frequent flooding and higher water levels. With the models help, achieving this goal now to get a jump-start on a more resilient national wildlife refuge is foreseeable. Collaboration of stakeholders and the USFWS with regularly scheduled meetings, a transient model, and a future-based comprehensive management plan are possible and can be implemented.

Recommendations

I formally recommend that the Great Dismal Swamp as well as other stakeholders, come together to create volunteer programs to help gather model and simulation data. Offering these volunteer programs between organizations can create more public understanding to surrounding property owners to give them more knowledge about the swamps specifications.

Under all options and scenarios:

- Educate public

- Hold monthly/bimonthly meetings with stakeholders (cities of Suffolk/Chesapeake, North Carolina cities and counties, US Army Core of Engineers, USGS, etc.)
- Make a transient model that can simulate different water levels and water control structure settings not just limited to the swamp.

Transient Model

- Partnering again with USGS and making a model that can simulate areas outside of the swamp would be beneficial.
- Simulating a culvert under/around US 158 and seeing how much water is diverted from major cities/counties in NC (Camden County and South Mills)
- Simulating storm surge, land in and around swamp being simulated and tested under normal and extreme conditions.
- Establishing transient model allows for all stakeholders to come together and solve issues.
- Simulate with future possible water level projections

Recommendations for 3ft and/or 6ft rise within the next 50 years

- Come up with flood-prevention/conservation plans by using the new transient model and existing USGS model; these plans will be an outline for future generations
- Install new structures (taller and larger to hold more water)
- Partner with cities of Chesapeake and Suffolk as well as US Army Core of Engineers to establish ideal places for animal corridors and culverts to redirect water from swamp and surrounding properties.
- Partner with stakeholders to raise money in order to build strcutres, culverts, or objects to divert water away from areas that see the full brunt out water spillage.

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