Analyzing Golf Courses' Ability to Face the Imminent Challenge of Climate Change

A Research Paper Submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Civil Engineering

Joseph Holland III

Spring 2025

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR

Prof. Sean Murray, Department of Engineering and Society

Introduction

Climate change promises to be one of the most important challenges faced by humans in the next 100 years. It is no longer a theoretical possibility; it is here. Many industries have implemented new regulations to lessen the impact and severity of climate change in the past few decades, including the transportation, manufacturing, and energy industries, to name a few. These may be the biggest industries related to climate change on a global scale, but climate change still affects local communities too.

The United States contains around 15,500 golf courses (*Short guide on the number of golf courses in the US,* 2024). The average golf course acreage is 150 acres, so a rough estimate of total golf course land in the United States is 2,325,000 acres or 3633 square miles. For comparison, Yellowstone National Park is 3472 square miles, bigger than Rhode Island and Delaware combined (Fitzgerald, 2025). If an environmental disaster threatened to decimate the states of Delaware and Rhode Island, fighting it would be the nation's top priority, but the sustainability of golf courses has not received any large-scale attention. The success or failure of courses' response to the effects of climate change will not only affect the courses, but also the surrounding communities, making the issue even more important. This research will look at all facets of the current problem and investigate a possible path forward.

The main reasons that golf courses sometimes struggle to handle the effects of climate change are closely related to increased frequency and severity of major flooding events. Golf courses' stormwater management infrastructures can sometimes be outdated, meaning floodwater can go wherever it pleases. The course may be closed for a few days, but everything goes back to normal when the floodwaters recede, right? Wrong. Uncontrolled floodwaters cause a variety of negative results that put the health and wellbeing of many people at risk long after the floodwaters disappear.

Literature Review

Increased Flood Event Intensity and Frequency

Hurricanes are the most ferocious storms on Earth and their frequency and intensity have grown in the past few hundred years. Hurricane researchers express that “in contrast to the frequency of HUs striking the USA, there is a clear and pronounced increase in the basin-wide [North American Hurricane and Major Hurricane] NA HU and MH frequency recorded in the HURDAT2 database between 1851 and 2019, with about triple the recorded NA MHs in recent decades compared to the mid-19th century” (Vecchi, G.A., Landsea, C., Zhang, W. et al., 2021). Vecchi’s and others’ research on historical hurricane trends found that the number of hurricanes in the North American basin has increased, along with the number of major hurricanes (Figure 1). The number of hurricanes that strike the United States has remained relatively the same, but Vecchi and others state that could be attributed to naturally changing storm patterns across the entire North American basin. In reality, climate change is here and part of that means the flooding events will only continue to worsen.

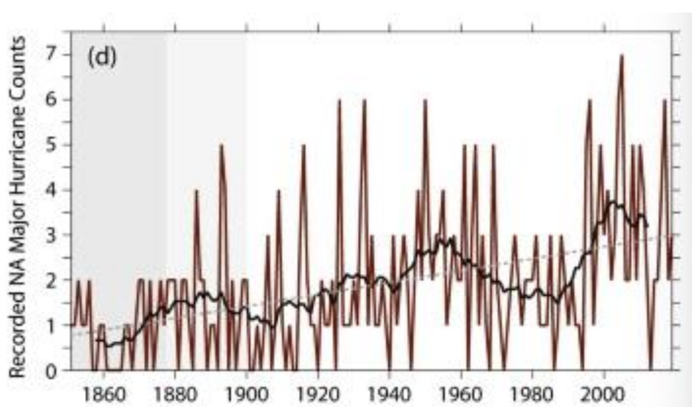


Figure 1: Major hurricanes in the North American basin (Vecchi, G.A., Landsea, C., Zhang, W. et al., 2021)

Detrimental Effects of Flooding on Waterway Health

Hurricanes are known for the damage they cause along the coast and in their paths once they make landfall. Though these areas generally get the most news coverage, effects are felt on a much greater scale, though they are often hard to see right away. Hurricanes cause flooding over vast swathes of land, ranging far from the original landfall location. Dey and Mandal's research discussed how worsening major flooding events negatively impact inland streams, which arguably leads to a larger affected population than is affected by sea level rise (2022). Since streams weave throughout the most populated areas, their health affects millions of people. Dey and Mandal state that bank erosion is one of the biggest threats to the strength of inland streams. Poorly managed flood waters can undermine the stability of riverbanks and cause property damage. Poorly defined river boundaries from erosion also welcome the introduction of pollutants into domestic water supplies. Rickson's research finds "soil erosion control measures are designed to reduce sediment production (source) and mobilisation/transport (pathway) on hill slopes, with consequent mitigation of pollution incidents in watercourses (receptors)" (2014).

The Dangers of the Proximity of Most Golf Courses to Major Population Hubs

Though some famous golf courses are in remote, scenic locations, many are concentrated near major metropolises: "With climate change, flood risk is expected to increase in urban areas due to intensification of extreme rainfall and a lack of pervious surfaces" (Wasko et al., 2021). Thus, stormwater management on golf courses is extremely important, because poor stormwater management practices can exacerbate existing challenges in urban areas. If a city is already struggling with the effects of increased climate-related flooding, untreated golf course runoff will only add to the problem and the city's infrastructure may not have the capacity to handle it.

Though this would be a problem everywhere, it is especially dangerous in this case, because more people are at risk, due to the population density in cities.

Historical Example of Humans Grappling with Floods

Humans have lived with the reality of seasonal flooding for thousands of years. The prominence of the ancient Egyptian empire stemmed largely from their ability to successful live in harmony with flood patterns in the Nile River basin. In his article, Davis lays out the situation:

> "At the peak of flooding, the floodplains (Figure 2) would be covered by waters that were 1.5 meters deep. When the water receded, the nutrient-rich silt carried from Ethiopian rains would fertilize the plains, making the soil composition ideal for farming. This was an efficient but sensitive system, as a single low flood could have brought about famine, while overflooding could have washed away irrigation barriers" (2022).

We continue to face flooding problems in the 21st century, and heightened major storm occurrence rates and severity due to climate change add another layer of difficulty to the flood management process.

Figure 2: Fertile regions and early settlements along the Nile River basin (Davis, 2022)

Rural vs. Urban Stormwater Management

Today, most literature on stormwater management practices focuses on management in urban areas, where sewers handle most of the water volume. Rural areas often do not experience the same stormwater issues, because permeable surfaces like open fields naturally treat and alleviate stormwater, as it filters through the ground. Golf courses are different in this regard, because though they are permeable, the high levels of fertilizer treatment on golf course grass negate the positive treatment aspects that other open green spaces provide. Golf course stormwater management is usually handled by river, pond, and stream systems on the course, with pipe networks, not sewers. Golf has been a popular American pastime throughout the last century, as the first 18-hole course was constructed in Chicago in 1892 (*A look back at the history of golf in America,* 2023). Due to the long history of golf course construction, stormwater management design on some courses has inevitably become obsolete. The increasingly intense flood events of today cannot be adequately handled by outdated stormwater management infrastructure, such as blocked or collapsed pipes and old ponds that have nearly filled in due to sediment deposition.

Examples of Infrastructure Types That Are Relevant to Golf Courses

Burgis investigated many green infrastructure methods for stormwater quality management in his research at the University of Virginia, including passive irrigation technology, retention ponds, and permeable pavers (2020). If properly applied on a golf course, these methods would help control runoff volume and quality, while supporting the course and surrounding community health. Retention ponds and bioretention areas specifically apply to the golf course situation, because water hazards are an integral part of golf course design and bioretention infrastructures could be easily incorporated into golf course design. Though most golf courses have numerous water features on them, including ponds, lakes, rivers, and even ocean coastline, these bodies of water do not always treat stormwater effectively, because they were not specially engineered to do so. Bioretention infrastructure (Figure 3) and stormwater retention ponds are designed specifically to reduce runoff quantities and harmful nutrient leaching (Burgis, 2020). Retention ponds' depths and volumes and bioretention areas' underdrains exponentially increase stormwater treatment effectiveness, compared to simple recreational golf course water features.

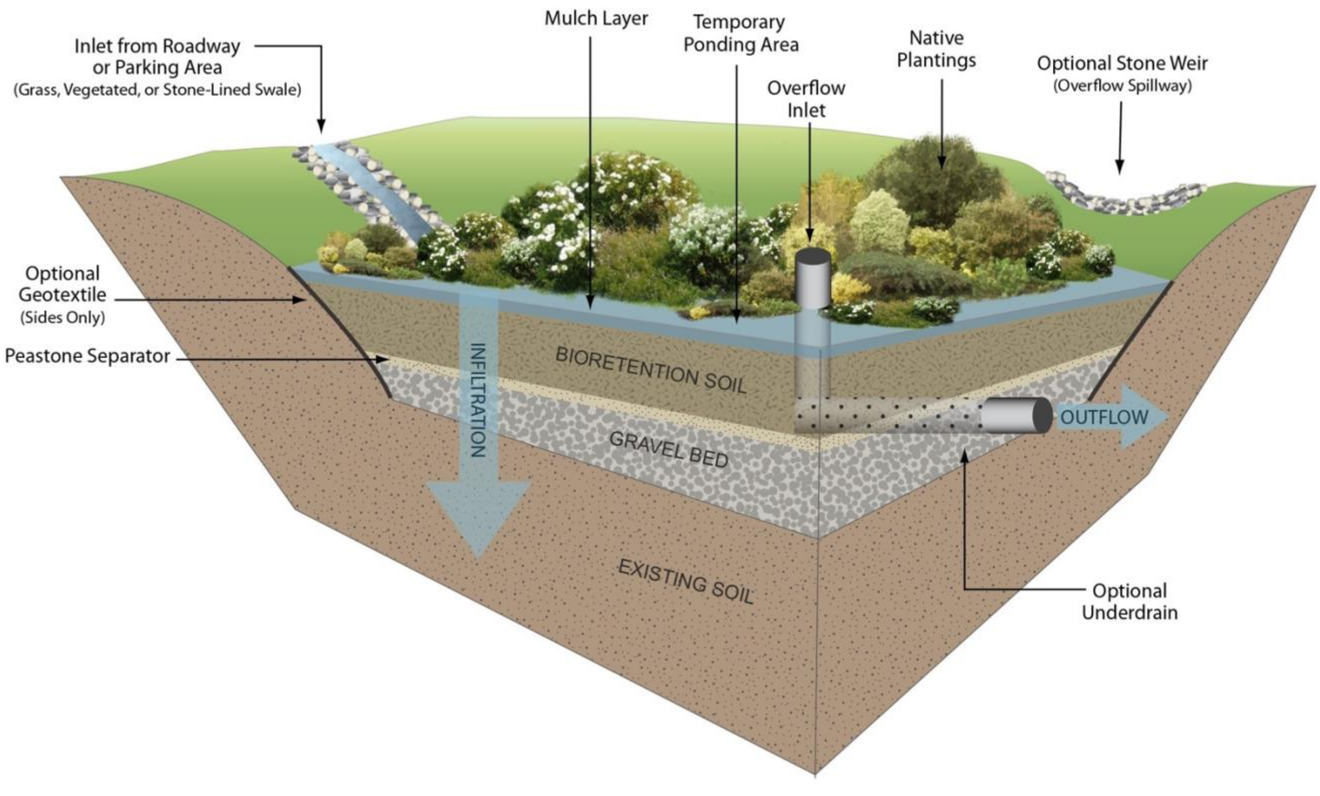


Figure 3: Biorientation infrastructure (Bioretention Areas & Rain Gardens)

The Negative Effects of Fertilizer Runoff

Researchers project that agricultural, and in this case recreational, fertilizers will have major impacts on the environment in the future (Crosson and Brubaker, 2016). Golf courses are some of the most highly fertilized areas. When the stormwater flows over the highly fertilized grass, it carries fertilizer chemicals that will eventually drain into local waterways. Dumping the nitrogen from fertilizers into river, lake, and pond ecosystems can be compared to pouring gas on a fire, when it comes to algae. Excessive fertilizer runoff causes algal populations to grow out of control and consume all the oxygen in the water. This can decimate fish and other aquatic wildlife populations. Once the algae die due to the lack of oxygen, they rot and sink to the bottom of the body of water. This makes it shallower and reduces the volume of water it can contain, reducing its water treatment and floodwater quantity control effectiveness by extension. When less water can be contained in rivers, ponds, and lakes, they are more easily flooded in the future. This creates a cycle where poorly managed flood waters cause lasting damage and cripple waterways' capacity for future floods.

Algal blooms can also produce cyanobacteria growth. Hudnell details the deadly effects of cyanobacteria blooms in domestic waterways (2008). Reports of cyanobacteria poisonings go back to the late 1800s. Symptoms can include stomach and intestinal issues, trouble breathing, allergic responses, skin irritation, liver damage, and neurotoxic responses. Some studies have even linked long-term low-level cyanobacteria bacteria exposure to liver cancer and digestive-system cancer (Hudnell, 2008). As discussed previously, many golf courses are located near major cities and cyanobacteria can be unhealthy and even fatal for the millions of people living in these cities.

The Negative Effects of Erosion

When flood waters run uncontrolled over land that it not designed to handle them, erosion invariably happens. Sediments that erode from golf courses and surrounding land during flooding events is also deposited in the bottoms of waterways, making them shallower and causing the same problem as dead algae. Additionally, when excessive sedimentation occurs in rivers, “shoals are formed over the channel due to the deposition of sediments. Shoals generally obstruct the channel flow and pass huge volumes of water during the peak season through the narrow channel causing an asymmetry of erosion on the opposite bank.” Additionally, “the accumulation of more water along with the generation of enormous flow velocity in the main course or channel creates immense pressure on the riverbank, which accelerates riverbank erosion” (Dey and Mandal, 2022). Erosion also can cut channels into courses and surrounding land to create headcuts, which can undermine foundations and cause waterfront buildings to collapse (Figure 4).

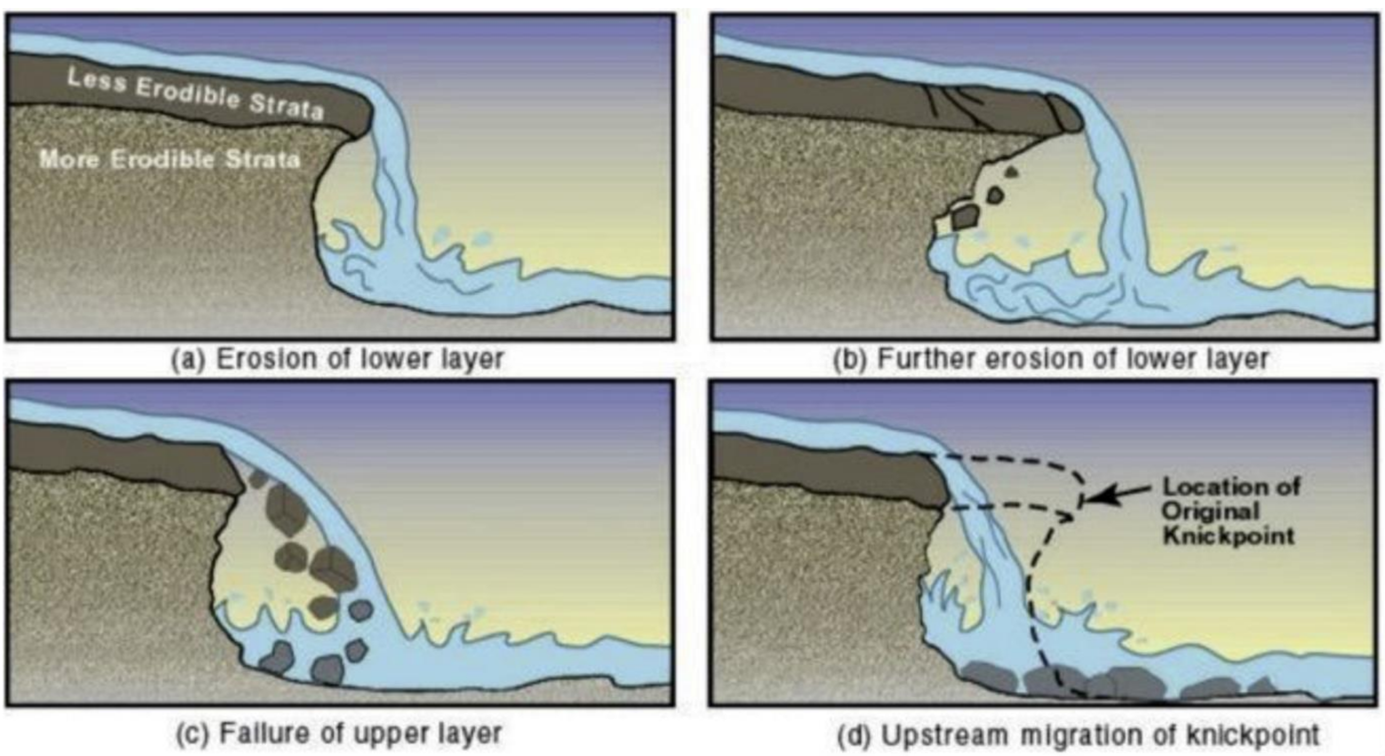


Figure 4: Headcut migration process (*Virginia Stormwater Management Handbook*, p. 19)

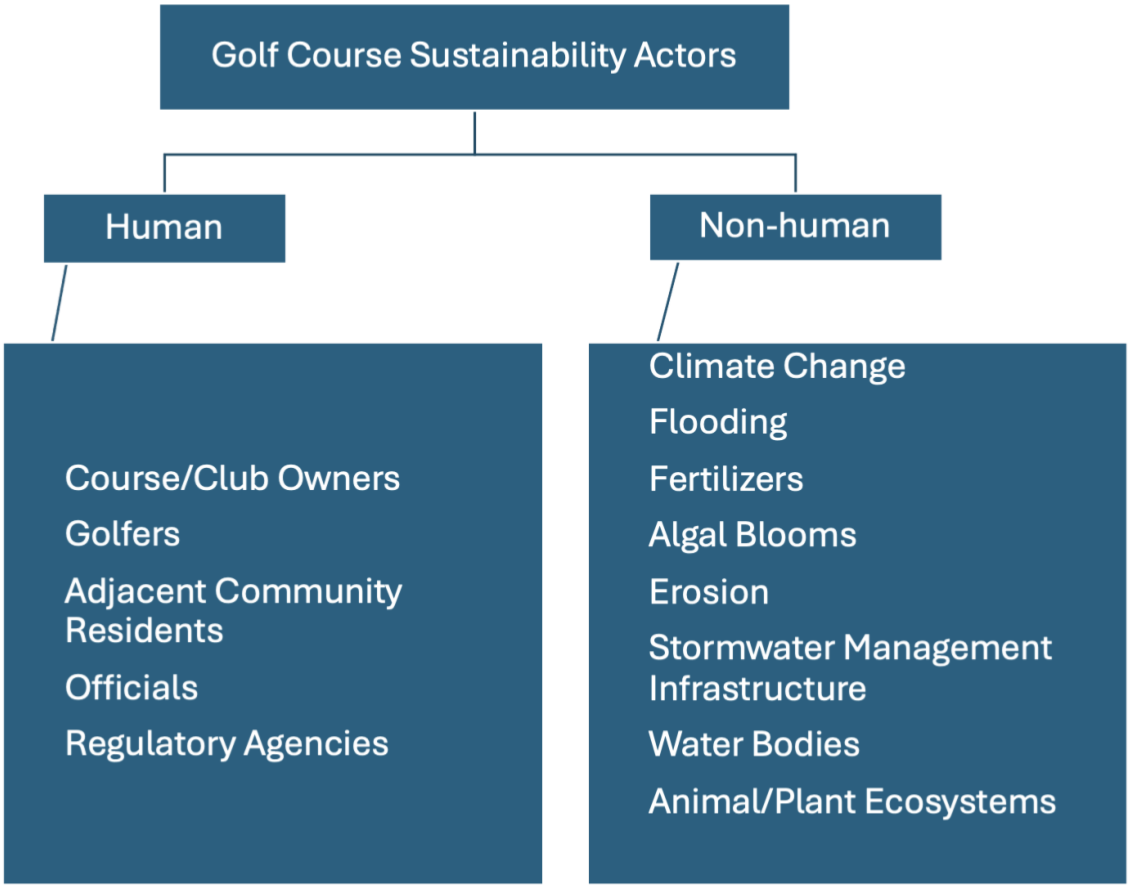
Analysis

Approach: Actor-Network Theory

An engineer's knee-jerk reaction to solving a problem may be to find what causes the problem, then fix that one variable. For example, if a city has repeated episodes of raw sewage leakage onto the streets, a decision maker may state that the solution is to revamp the sewer system. This would fix the problem, but it is often not that easy. There are likely deeper issues at play, such as feuding city officials, funding problems, and even possible illegal dumping activities taking place, to name a few. Thus, simply proposing a sewer renewal project may not solve the problem, and if it does solve the problem, it still may not be the most effective solution.

The primary analysis framework used in this research is Actor Network Theory (ANT). ANT identifies all factors in a system, both human and nonhuman, and explores their complex web of relationships. An important part of ANT is that it values all actors the same. This allows for an unbiased analysis and ensures no players are overlooked. By looking at the system from many angles, a researcher can get a great look at the intricacies of a problem. Insights gained from an ANT-based analysis can generally better inform decision makers, due to the robust nature of the approach. ANT is an ideal research framework to use for this issue, because there are many actors with complex relationships when it comes to golf courses' response to climate change. The research will conclude with a relevant case study from my capstone research work that gives insight into the problem.

To perform an ANT analysis on the problem of golf courses' response to climate change, all the involved entities must be named (Graphic 1). On the human side, there are golf course owners, golfers and club members, residents in communities surrounding the courses, and city and county sustainability officials. For the inanimate players, there are climate change, floods, fertilizers, algal blooms, erosion, outdated golf course stormwater management infrastructure, waterways on and near courses, and animal and plant ecosystems. All these actors affect each other directly or indirectly.



Graphic 1: Actor-Network Theory visual summary

Many would agree that golf is the main pastime of most country club members. Many country clubs pride themselves on being steeped in history and membership of the most exclusive clubs is reserved for those who are wealthy enough to pay the high initiation and membership fees. The members at these clubs often number among the richest and most powerful people in the world, though there are exceptions. Generally, the nicer the club, the more private it is. Their grounds are usually fenced, and all maintenance is done by grounds crews that are focused on keeping the courses perfectly manicured, not sustainable. Due to the innate private nature of most clubs, they can sometimes go unnoticed and unbothered by local sustainability officials. For these reasons, though the clubs are usually located near modern cities, they can have extremely outdated infrastructure. Though courses affect surrounding waterways and residents, their poor response to the realities of climate change can sometimes be ignored due to the history and power behind them. Sometimes courses can get away with poor sustainability practices that affect surrounding land and individuals. However, I am not labeling this as a systemic, intentionally malicious practice. To clarify, I am suggesting it is an issue worth examining and sustainability practices on golf courses would lead to an improved society.

Case Study: Meadowcreek Golf Course

The beginning of this analysis has been general and could be construed as containing overgeneralized, opinionated content. To better develop the discussion on the issue of golf course sustainability, the remainder of this section will be comprised of a case study analysis. Meadowcreek Golf Course is a popular public golf course in Charlottesville, Virginia. The 155 acre 18-hole course opened in 1974 and is owned by the City of Charlottesville (*The course*). The Rivanna River and Meadow Creek serve as the course's southern boundaries. Water flows through a series of ponds and streams along the red line and crosses under the 17th hole fairway in a 36" reinforced concrete pipe where the white line is, draining into the river in the red box (Figure 5). This course is a representative example of an average public course in the United States mid-Atlantic region, in terms of landscape and challenges.

Figure 5: Meadowcreek Golf Course reference map

In September 2024, the course groundskeepers noticed a small headcut forming in the red box on the bank of the Rivanna River, where the majority of runoff from the course drained through the pipe. Continuous monitoring of the headcut revealed it was progressing, and it began to threaten undermining the green of the 17th hole, which is located just to the left of the red box in Figure 5. Hurricane Helene hit at the end of September and the flooding was catastrophic for the course, specifically the headcut. Figure 7 is a photo of the flooding taken on September 30th from where the white arrow is in Figure 5, the day after Hurricane Helene hit Charlottesville. The blue outline gives a rough outline of the extent of the flooding. In Figure 7, the headcut is in the red box and the 17th hole green is in the back right of the frame. As a result of the flooding, the headcut grew exponentially and was roped off to protect golfers and walkers from falling in. Figure 6 shows how fast the erosion progressed over the span of little more than a month.

Figure 6: Headcut progression due to hurricane flooding

Figure 7: Flooding post-Helene (maybe take a picture now from the same position for comparison before final submission)

The untrained layperson may chalk the extensive flooding and erosion on the course up to the historic nature and ferocity of Hurricane Helene. However, if the stormwater management infrastructure had been properly designed and upkept, the flooding likely would not have been as severe. My capstone team was tasked with evaluating the stormwater management practices on this site, which makes the situation at Meadowcreek Golf Course a perfect case study in golf course stormwater management and sustainability.

The first step to unraveling the cause of the severity of the flooding was to examine the integrity of the pipe that should be allowing water to flow under the 17^{th} hole. Because water was flowing over, not under, the hole, there was likely an issue with the pipe. A camera probe revealed that the pipe had collapsed and clogged about 100 feet into its 180-foot span (Figure 8). As a result, instead of draining cleanly under the hole without picking up any harmful fertilizer from the grass and eroding the surface, water was flowing straight over the course, causing erosion, riverbank collapse at the headcut, and polluting the river.

Figure 8: Camera probe image of collapsed pipe

Continual investigation of the site revealed that the multiple ponds upstream of the pipe had nearly filled with sediment and showed signs of algal growth. Healthy nitrate and phosphate levels in a waterway are below 1.0 mg/L and below 0.1 mg/L, respectively (*Nitrates and phosphates*). Nutrient testing of the area in the red box in Figure 5 where the course's runoff enters the river revealed a 1.760 mg/L nitrate concentration and a 0.300 mg/L phosphate concentration, both well over the ideal quantity. Levels in the upstream ponds were also above the healthy level, though not by as much. Had the ponds been designed with calculated volumes, their increased stormwater retention would have helped lower the nutrient levels, as Burgis's research above explains. An intact pipe system would also have reduced the harmful nutrient levels in the runoff by preventing the water from running over the course.

The goal of this research is not to prescribe a solution to every golf course's stormwater management issues, but to bring attention to the problem. This case study shows how simple oversights in stormwater management, such as poorly designed or maintained ponds and collapsed pipes, can lead to dangerous outcomes for the surrounding community and environment. If a research team had not been tasked with investigating the sustainability at Meadowcreek Golf Course, the issue could have gone unnoticed for years. Because Meadowcreek is a public course owned by a city, stormwater management problems are less likely to be overlooked, since profits go to the city, not a private owner. Pipe repairs and pond reconstruction efforts are expensive, and it would be easy for a private country club to blame the flooding on a catastrophic event and ignore the water quality and erosion issues, all for the sake of protecting their bottom line by not spending money to fix their infrastructure problems.

Conclusion

The golf course response to climate change is underdiscussed and undervalued. Lackluster golf course stormwater management practices lead to erosion and water quality issues both on and adjacent to the courses. The case study of Meadowcreek Golf Course illustrates how even seemingly minor infrastructure defects like one collapsed pipe and excessive pond sedimentation can have extensive negative effects. Erosion problems can harm courses and destroy riverbanks, both of which lead to more erosion and water quality problems down the line. Unacceptable nutrient levels in course runoff jeopardize the health and wellbeing of all surrounding plants, animals, waterways, and communities.

Climate change is an unchangeable present reality and total golf course acreage in the US is bigger than multiple states combined. The problem of the unacceptable state of golf course stormwater management exists on an considerable scale. The world has focused on fighting climate change and its effects for decades. We have taken large steps across many industries toward giving our descendants a chance to live and thrive. Golf courses are interspersed throughout many of the most densely populated areas, so their sustainability has a direct effect on millions of people worldwide, both now and in the future.

There is no one-size-fits-all solution to the problem presented by an inadequate golf course response to climate change. Every course and region are different, so it would be foolish to try and create one. However, increased oversight and regulation, especially for private courses, would go a long way. Periodic inspections should include water quality assessments at major golf course runoff sites and evaluate the responses of courses' stormwater management infrastructures to flood events. Golf course sustainability is a challenge that civil and environmental engineers should attack full force, because the health of millions is at stake.

Catalytic converters, renewable energy practices, and the goal becoming net-zero one day were all accepted by our society with open arms. How difficult would it be to also facilitate the evolution of sustainable golf courses as the world moves toward a clean, green future?

References

A look back at the history of golf in America. Bloodline Golf. (2023, June 29). https://bloodline.golf/blogs/top-news/a-look-back-at-the-history-of-golf-in-america?srsltid=AfmBOorCwoX1AIvhjZFYRfBt3fSU2heNPI06QZR7RE-5fMvxUzW5G6gC

Bioretention Areas & Rain Gardens. megamanual.geosyntec.com. (n.d.). https://megamanual.geosyntec.com/npsmanual/bioretentionareasandraingardens.aspx

Burgis, C. (2020). Evaluation of Green Infrastructure for Stormwater Quality Management. Charlottesville, VA: University of Virginia, Civil Engineering - School of Engineering and Applied Science, PHD (Doctor of Philosophy), 2020. Retrieved from https://doi.org/10.18130/v3-tnme-ks87

Crosson, P. R., Brubaker, S., & Resources for the Future (2016). Resource and Environmental Effects of U.S. Agriculture. Oxon: Routledge.

Cruz, J.-L., & Rossi-Hansberg, E. (2023). The Economic Geography of Global Warming. *Review of Economic Studies*, *91*(2), 899–939. https://doi.org/10.1093/restud/rdad042

Dey, S., & Mandal, S. (2022). Riverbank Erosion Hazards and Channel Morphodynamics: A Perspective of Fluvial Geomorphology. Abingdon, Oxon: Routledge.

Fitzgerald, E. (2025, February 28). *10 Great Big yellowstone facts*. Yellowstone Forever. https://www.yellowstone.org/10-yellowstone-facts/#:~:text=Yellowstone%20encompasses%203%2C472%20square%20miles,Rhode%20Island%20and%20Delaware%20combined.

Hudnell, H. K. (2008). Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs. New York: Springer.

jrd6053. (2022, January 17). *Water management in ancient egypt*. John Davis. https://sites.psu.edu/johndavis/2021/02/02/water-management-in-early-dynastic-egypt/

Nitrates and phosphates. FreshWater Watch. (n.d.). https://www.freshwaterwatch.org/pages/nitrates-and-phosphates

Rickson, R. J. (2014). Can control of soil erosion mitigate water pollution by sediments? *Science of The Total Environment*, *468–469*, 1187–1197. https://doi.org/10.1016/j.scitotenv.2013.05.057

Short guide on the number of golf courses in the US. Stacker Inc. (2024, July 23). https://www.stackerinc.com/blog/golf-courses-in-the-us/

The course. Meadowcreek. (n.d.). https://www.meadowcreekgolf.org/the-course

Vecchi, G.A., Landsea, C., Zhang, W. et al. Changes in Atlantic major hurricane frequency since the late-19th century. Nat Commun 12, 4054 (2021). https://doi.org/10.1038/s41467-021-24268-5

Virginia Department of Environmental Quality. (n.d.). Chapter 2. In *Virginia Stormwater Management Handbook, Version 1.1* (pp. 19–19). essay. Retrieved from https://www.deq.virginia.gov/home/showpublisheddocument/24429/638555908077330000

Wasko, C., Nathan, R., Stein, L., & O'Shea, D. (2021). Evidence of shorter more extreme rainfalls and increased flood variability under climate change. *Journal of Hydrology*, *603*, 126994. https://doi.org/10.1016/j.jhydrol.2021.126994