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Title of Thesis: INVESTIGATING THE SPATIAL AND TEMPORAL WATER QUALITY PATTERNS IN THE UNIVERSITY OF MARYLAND BALTIMORE COUNTY'S WATERSHED

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ABSTRACT

Title of Document: INVESTIGATING THE SPATIAL AND TEMPORAL WATER QUALITY PATTERNS IN THE UNIVERSITY OF MARYLAND BALTIMORE COUNTY'S WATERSHED

Erin Rebecca Hamner, M.S. Geography and Environmental Systems, 2025

Directed By: Dr. Matthew E. Baker & Dr. Andrew J. Miller, Geography and Environmental Systems

The University of Maryland Baltimore County (UMBC) implemented stormwater control measures (SCMs) to mitigate stormwater quantity and quality impacts. While policies focus on controlling pollution, water quality measurements are not required to confirm downstream impacts. This work addressed the question of how UMBC influences the surrounding water quality of its local streams. Spatial and temporal patterns of nitrate-N, ammonium-N, and specific conductance were observed at 14 measurement locations, including inflows to campus, outflows from campus, and intermediate locations on campus. Although nitrate-N was not spatially variable, seasonal changes in plant uptake did influence nitrate-N. Ammonium-N was also influenced by seasonal changes in uptake and leaf litter in streams, and one site showed a potential indication of a sewage leak on campus. Specific conductance was influenced by impervious cover in the watershed and winter salt application. The patterns observed in this study can help UMBC with future stormwater management plans.

INVESTIGATING THE SPATIAL AND TEMPORAL WATER QUALITY PATTERNS IN THE UNIVERSITY OF MARYLAND BALTIMORE COUNTY'S WATERSHED

By

Erin Rebecca Hamner.

Thesis submitted to the Faculty of the Graduate School of the
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Purpose of Research

Policies managing urban and suburban watersheds emphasize controlling pollution runoff. State and local institutions require designing and implementing various stormwater management facilities that mimic the natural hydrology of an area to offset urban runoff (Fletcher et al., 2015; Jefferson et al., 2017). However, these policies do not require water quality measurements to confirm mitigation efforts. My research sought to answer the question: How does the University of Maryland Baltimore County's (UMBC) campus influence the downstream water quality of its local streams? I sampled three water quality parameters, nitrate-N, ammonium-N, and specific conductance, in stormwater ponds and at specific sites along the stream networks within UMBC's watershed. Sampling and analyzing water quality measurements gave a general understanding of how the campus' land management and seasonal changes influence local stream chemistry. Rather than studying individual stormwater control measures (SCMs), this work focused on the cumulative impacts of land cover and SCMs on the local streams flowing through UMBC. SCM location and intended purposes were documented in this study, as UMBC is required to implement and maintain them. The results of this work can be used to inform campus staff on current water quality and potential ways to further mitigate stormwater runoff. This work was also used to outline and pilot a student-led water monitoring program, in hopes of creating a long-term water quality database for the campus.

Literature review

Background on Urban Stormwater

The increase of impervious surfaces in urban spaces has drastically altered the natural hydrology of those areas. Impervious cover and storm drain networks have decreased the time it takes for surface water to reach a stream, which increases channel velocities and peak flows in streams within urban watersheds (Booth, 1990; Leopold, 1968; Hammer, 1972; Miller et al., 2021). For most developments before 2000, stormwater management focused on routing excess water off streets, storing runoff, and addressing water quantity problems (Jefferson et al., 2017; Li et al., 2019). Along with issues of increased runoff in urban watersheds, changes in water quality have led to other problems in streams (Jefferson et al., 2017; Orta-Ortiz & Geneletti, 2022). Urban pollutants can accumulate on impervious surfaces during dry periods, contributing to different pollution loads (Behrouz et al., 2022). When it rains, these pollutants get carried into local waterways. Fertilizers from lawns, heavy metals from urban infrastructure, vehicles, and deicing salts get washed down storm sewers without treatment (Bernhardt et al., 2008; William et al., 2017). Heavy metals and salts do not have natural cycles and persist within streams (Fanelli et al., 2019; Lake, 2000). Continued water quality degradation can result in aquatic biodiversity loss (Fanelli et al., 2019; Loperfido et al., 2014). Especially in urban watersheds, incremental upstream inputs of pollution accumulate downstream. Mitigating stormwater runoff is part of larger concerns regarding environmental health and watershed conservation. Over time, federal, state, and local policies and regulations have reflected the different priorities for managing water quality in urban spaces.

Federal Water Quality Policies and Regulations

Policies regarding water quality regulations in the U.S. have greatly evolved over the past 60 years. The Federal Water Pollution Control Act of 1948 was the first federal legislation to address water pollution from human sources (33 U.S.C. §1251 et seq. (1972). This 1948 policy addressed water pollution as a human health issue. In 1965, the Water Quality Act was passed. This Act provided standards of water quality for interstate waterways. It allowed the US government to enforce water quality standards if states did not set standards. The Water Quality Act started putting pressure on industries to limit water pollution, but it only addressed point source pollution and illicit discharges.

The 1972 Clean Water Act (CWA) was created in response to the persistent environmental crisis of national waterways. The CWA prohibited the dumping and discharging of pollutants into waterways and set to end waste dumping by 1985. Under this policy came the National Pollutant Discharge and Elimination System (NPDES) permit program. The NPDES permit program first focused on point source pollution from wastewater treatment plants and industrial facilities. Federal, State, and other developed municipalities larger than 5 acres (e.g., colleges and universities, federal and state campuses, etc.) are to report efforts to reduce harmful water quality impacts (Maryland Department of the Environment, 2004). The NPDES permit has since expanded to require the mitigation of non-point source pollution, including stormwater runoff.

Under section 303(d) of the 1972 CWA, states were required to establish and meet the total maximum daily loads (TMDL), a pollution diet, of targeted pollutant loads for watersheds that the USEPA labeled “impaired.” TMDLs highlighted mitigating pollution from point and non-point sources, including stormwater discharges (Copeland, 2014). With the revision of the CWA in 1987 came with a heavier emphasis on managing pollution loads, especially at the district and city levels. The Municipal Separate Storm Sewer (MS4) permit established five-year goals for different municipalities to limit various pollution loads in compliance with federal legislation (Maryland Department of the Environment, 2004). In 1992, the EPA started to enforce the TMDL initiative and gave more guidance to states on creating a TMDL for impaired waterways. MS4 permits were used to help reach TMDL goals for their waterways. TMDLs predominantly focused on excess nutrients and sediment pollution, but some jurisdictions expanded to include pollutants like heavy metals and trash (Copeland, 2014; Jefferson et al., 2017). Regulatory requirements, like TMDLs, mean permittees need to have detailed planning strategies to track and reduce pollution loads (William et al., 2017). Federal policies and initiatives encouraged states to create state-level policies to address stormwater concerns related to water quality in a more local context.

State and Local Regulations

Maryland and other states in the Chesapeake Bay watershed stress the importance of improving water quality and protecting aquatic environments. The Chesapeake Bay has the most extensive TMDL plan in the U.S. (Copeland, 2014; William et al., 2017). Created in 2010, the Bay TMDL applies to the six Bay watershed states and the District of Columbia and outlines their efforts to reduce pollutant loads. Because of the vast area the Chesapeake Bay's TMDL includes, it utilizes watershed-scale stormwater management plans to address pollution loads across the entire watershed. Smaller jurisdictions create and update management plans to document efforts for pollution reduction.

State governments create stormwater guidelines using information relevant to their geographic region, like average precipitation, soil type, and native vegetation. Maryland's first stormwater policy was passed in 1982. This state-wide policy focused on flood control for new developments (Maryland Department of the Environment, 2009). The stormwater facilities constructed at that time were centralized facilities that captured large volumes of runoff. Because of this law, stormwater management facilities after this time also had to report water quality treatment, although it was not the primary focus of management.

The Maryland Stormwater Design Manual was created in partnership with the Maryland Department of the Environment (MDE) and the Center for Watershed Protection. Originally published in October 2000, this manual highlights the advancements in stormwater management to help Maryland counties and municipalities achieve pre-development stormwater conditions (Maryland Department of the Environment, 2009). The Maryland Stormwater Act was passed in 2007 and implemented in 2008. The Stormwater Act expanded the state's Design Manual by requiring stormwater best management practices and Environmental Site Design (ESD) to be implemented to the maximum extent practicable (Md. Code Ann. Env. 4 §201.1-§203 (2007)). This Act led to the 2009 update of the Stormwater

Design Manual. Since then, the 2008 Stormwater Act has been updated to include specific pollution loads and enact regulatory measures (Env. 4 §201.1-§203). The 2008 Stormwater Act and the Bay TMDL have heavily influenced the stormwater practices designed in recent years.

UMBC's Stormwater Control Measures

According to the MDE Stormwater Manual, any municipality or developed area greater than five acres is required to implement measures to reduce runoff, including academic institutions (Maryland Department of the Environment, 2009). UMBC must comply with MS4 phase II permits, which include keeping an inventory of implemented stormwater facilities and maintenance records and reporting stormwater mitigation efforts to the state government every two years. The changes in water quality policies can be reflected in UMBC's stormwater management practices. Various stormwater management practices throughout the campus have different purposes and mitigation methods to manage stormwater.

The University of Maryland Baltimore County (UMBC) is a public university subject to federal and state policies regarding water quality and stormwater management. The various stormwater facilities on campus were designed to address different problems associated with urban stormwater: reduce runoff volumes, decrease runoff velocities, and mitigate and remove sediment and nutrients. UMBC has had facilities that manage stormwater runoff since UMBC was first constructed. Changes in policies over time are reflected in stormwater facility design types and their distribution.

Stormwater control measures (SCMs) are structural and non-structural facilities that address the impacts of urban runoff (Fanelli et al., 2019; Fletcher et al., 2015). SCMs are designed to store and treat stormwater runoff before it reaches larger bodies of water (Behrouz et al., 2022). Different SCM designs are intended to help address water quantity and quality problems associated with stormwater. UMBC has many examples of SCM design types that have been built and maintained throughout the campus's history.

Some of UMBC's oldest facilities include detention and retention ponds, built between 1992 and 2003 in response to the 1982 stormwater law (Maryland Department of the Environment, 2009). Large detention and retention facilities were designed to control high flows from more extreme storm events (Li et al., 2017). When constructed, they are required to capture a 10-year 24-hour design storm based on the construction location (Maryland Department of the Environment, 2009). The most popular examples of this design are dry and wet ponds, which have been traditionally designed to store excess runoff. Storing runoff lowers peak runoff flows associated with increased impervious surfaces (Bell et al., 2016; Loperfido et al., 2014). As their names suggest, the difference between these structures is that dry ponds are empty until runoff flows in, while wet ponds retain water year-round. Dry ponds provide a slow release of stormwater, while wet ponds allow for storage and sedimentation (Flanagan et al., 2021). These design types are distributed across UMBC's campus. Unfortunately, studies have shown that dry and wet ponds are less effective in controlling runoff volumes and peak flows for more common rain events, especially in urban watersheds (Emerson et al., 2005; Emerson & Traver, 2008;

Miller et al., 2021). These design types were also not initially designed to mitigate pollution in runoff.

Other older facilities on campus include sand filters. Sand filters and infiltration trenches primarily filter out sediment from stormwater and are also commonly used along highways (Blecken et al., 2017; Maryland Department of the Environment, 2009). On campus, the oldest sand filters were built in 1998, and the two newest ones were built in 2001 and 2004. The soil media in these facilities capture sediment particles picked up from runoff. Sand filters usually have a layer of grass for vegetation on top and soil media for sedimentation and water infiltration.

After the 2008 MD Stormwater Act and the 2010 Chesapeake Bay TMDL, facility designs began to focus on mitigating nutrients and sediment for water quality benefits. The revised 2009 MDE Manual introduced new sizing criteria and required stormwater reduction and treatment to be implemented to the maximum extent practicable. This led to the popularity of infiltration-based SCMs. Infiltration-based designs are stormwater facilities that allow runoff to seep into the soil quickly. These facility types are often distributed across a drainage area, being placed at multiple locations to treat runoff (Akter et al., 2020; Hopkins et al., 2017). The most common infiltration-based design on campus is the bioretention cell. On campus, the bioretention cells were installed closer together and distributed across their sub-drainage. Bioretention cells have vegetation, engineered soil media, and an optional underdrain to allow treated water to drain out. These facilities are typically designed to control water quantity on a more localized scale. Infiltration-based SCMs are designed to drain water from 1 inch of rainfall within 48 hours (Maryland Department of the Environment, 2009). Rain gardens and bioretention cells utilize native plants to facilitate nutrient uptake and reduce runoff (Jefferson et al., 2017; Reddy et al., 2021). Bioretention cells and rain gardens across UMBC also provide nice aesthetics near outdoor seating areas.

Stormwater wetlands are shallow pools designed to mitigate excess nutrients and sediment (Burchell et al., 2007; Carleton et al., 2001). UMBC has a submerged gravel wetland on the Northeast side of campus, which is a specific type of stormwater wetland that utilizes gravel in its substrate. Wetland facilities are especially successful in nitrogen cycling and removal (Blecken et al., 2017; Burchell et al., 2007). Stormwater wetlands have been designed to consider water quality and volume retention.

The campus is required to implement SCMs to mitigate impervious surfaces and other urban stormwater impacts specified by the MS4 permit. After the construction of stormwater facilities, visual inspections are done, and plant maintenance is implemented throughout the year. UMBC's stormwater management practices have evolved with the changes in federal and state policies. Changes in policy implementation and management focus can be reflected in the age, design, and distribution of UMBC stormwater practices.

<u>Research Questions</u>

Here are the following questions this research sought to answer:

How does UMBC influence the surrounding water quality of its local streams?

a. What are the spatial and temporal variations in water quality across the sample sites?

b. What is the association between water quality parameters, land cover, and aggregate mitigated area in upstream catchments?

The primary question for this research was: How does UMBC influence the surrounding water quality of its local streams? This broad question was a baseline that began the investigation of water quality measurements around campus. UMBC utilizes many SCM design types and updates older facilities to maintain state regulations. It is assumed that once stormwater facilities are constructed, they will function as intended (Blecken et al., 2017; Li et al., 2019). The lack of water monitoring requirements is an oversight in these policies and initiatives**.**

Before campus staff can understand how the implemented stormwater efforts impact the watershed, there should be an understanding of the water quality patterns within the watershed. This research used water quality measurements to assess a suburban campus's contribution to local water quality. Water quality parameters, nitrate-N, ammonium-N, and specific conductance, were measured throughout the local streams and wet ponds over the course of five months. Water quality testing, land cover, and SCM information were used to highlight changes in local water quality and possible pollution sources within or around campus. This question was addressed using the following sub-questions.

The first sub-question was: What are the spatial and temporal variations in water quality across the sample sites? Answering this question would provide a basic understanding of the water quality trends within the watershed. The spatial comparisons were performed to identify places that could be local hotspots for any of the parameters tested. All three parameters were expected to have some spatial variability across the sample sites. The upstream drainages of the sample sites had a range of land cover types, which could influence water quality. The temporal comparisons were analyzed to assess whether there were significant changes in water quality throughout the sampling period. The seasonal changes in the water budget and land management practices (e.g., lawn mowing, fertilizing, deicing salt application) could impact the concentrations of any of the parameters. The concentrations of each parameter were expected to change throughout the sampling period. Nitrogen (nitrate-N and ammonium-N) concentrations were expected to change seasonally due to seasonal changes in metabolic processes and nutrient demands. Specific conductance was expected to increase due to road salt application in the winter months (December–January).

The second sub-question was: What is the association between water quality parameters, land cover, and aggregate mitigated area in upstream catchments? Expanding on the spatial comparisons, linear regressions between upstream land cover and parameter measurements were used to predict spatial variations in water quality. The independent variables used for the regression were land cover and the area mitigated by a campus SCM. Knowing land cover and mitigation efforts in the upstream drainage area could help explain the water quality observed. For example, drainages with more turf cover would be expected to have higher nitrate-N and ammonium-N concentrations, and drainages with more impervious cover were expected to have higher specific conductance measurements. Drainages with more area mitigated by stormwater facilities were expected to have lower nitrate-N and ammonium-N concentrations because many were designed for that purpose; however, SCMs were not generally designed to influence specific conductance.

Site Description

University of Maryland Baltimore County (UMBC) Campus

The University of Maryland, Baltimore County (UMBC) is a public research institution founded in 1966. The 512-acre campus includes academic buildings, residential areas, and two research and technology parks. UMBC is a suburban campus located about 3.5 miles away from the Baltimore City limits. The campus is within the fall zone of the Piedmont and Coastal Plain of Maryland and is located within the Herbert Run watershed. The Herbert Run tributary drains to the Lower Patapsco River. Two perennial streams flow around the east and west sides of campus. Just south of campus, these two streams converge into West Branch Herbert Run and continue flowing through the town of Arbutus. These are shallow freshwater streams. Small fish and macroinvertebrates inhabit the streams and support different species of birds.

UMBC's Current Stormwater Implementation Management Plan

UMBC, with the help of the environmental consulting firm Biohabitats, created the most recent stormwater Implementation Management Plan (IMP) in 2016. This plan applies to the property's 432 acres of academic and residential area, excluding the BWTech Research Park, which is leased to tech start-up companies and non-profits. There were over 70 SCMs before this plan was implemented, treating around 33 acres (27%) of campus impervious surfaces. The current IMP follows the requirements of the updated 2009 MDE Stormwater Manual. All facilities were added to a GIS database and assigned to their corresponding subdrainage area. The facilities added following the adoption of this IMP were predominantly infiltration-based facilities. These facilities are distributed around the new construction and renovated spaces. The as-built designs were modeled in AutoCAD and converted into GIS-accessible files for facility access and the development of an SCM database.

There are currently 98 SCMs on campus, which treat 62 acres of campus impervious cover (Figure 1). Many of the new projects proposed in the recent IMP were considered redevelopment. This meant UMBC was required to mitigate 40% of the surrounding impervious cover for those projects. Permit information, maintenance checks, and renovation dates are recorded in a geodatabase. Different SCMs of different ages and various design purposes are placed throughout the campus. Some facilities include green roofs, detention and retention ponds, permeable pavement, sand filters, and distributed bioretention cells. Campus SCMs were designed to store, infiltrate, and mitigate stormwater before it reaches the West Branch of Herbert Run. Two goals for the IMP include facilities treating runoff volume for a 1" storm and not exceeding the existing conditions' peak flows for a 10-year and 100-year storm at the sub-drainage level.

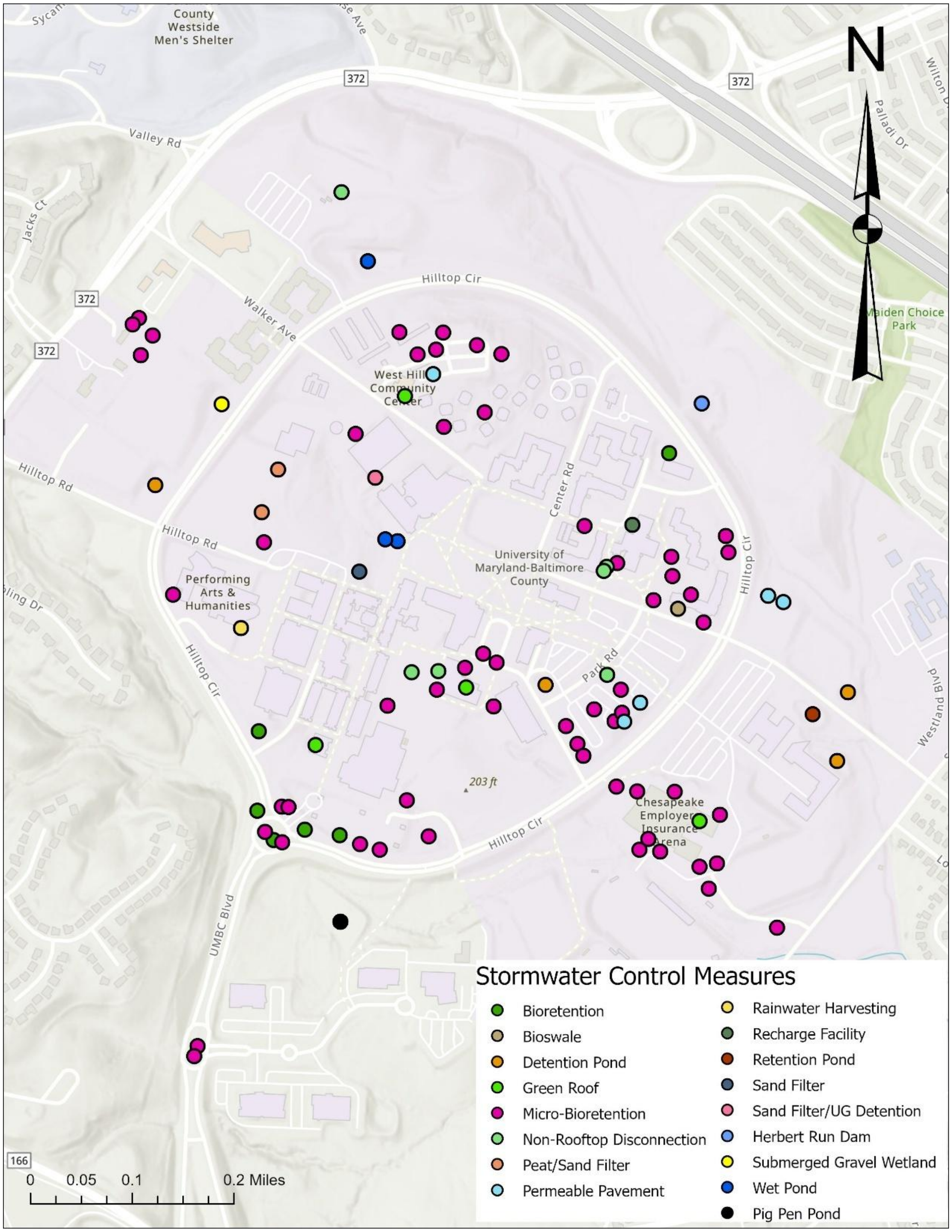

Figure 1: Map of the stormwater control measures (SCM) across the University of Maryland Baltimore County Campus. Color-coded by facility type.

UMBC's Watershed and Land Cover

The UMBC watershed encompasses 512 acres of campus property, with a larger upstream drainage area of about 1698 acres. There are two sides of the watershed, each draining to a tributary that flows around campus and converges downstream (Figure 2). Each stream captures drainage from the campus and from the surrounding areas. Side A consists of the area on the southwest side of the watershed, and side B consists of the area on the northeast side. Both sides are characterized by different land covers on and off campus property.

Side A is outlined in green in Figure 2. To the west of campus, there is the Rolling Road Golf Course and suburban communities between UMBC, Rolling Road (MD-166), and Wilkens Avenue (MD-372) off-campus. These areas drain into unnamed streams that flow southeast towards campus and converge into one stream that is directed under the UMBC traffic circle. As the stream resurfaces, its drainage area includes the off-ramp of I-195 entering UMBC Blvd, and two traffic circles, and a portion of the west side of campus within Hilltop Circle. A segment of the stream that flows through side A was renovated in 2021 as a stream restoration project located between Hilltop Circle and UMBC athletic fields on the south side of campus. The stream restoration includes drainage from UMBC's academic buildings and parking garages, the BW Tech Research Park, which houses tech start-ups, the Maryland-Delaware-D.C. location for the U.S. Geological Survey Water Science Center, and several other facilities and businesses. Another unnamed stream flows through UMBC's Conservation and Environmental Research Area (CERA). CERA is a natural, wooded area used by students and faculty for research and includes nature trails that contain Sulphur Spring Road and several wetlands. Also on side A is a stream segment that almost entirely drains the center of campus (Figure 2). This campus stream drains campus green space, walkways, academic buildings, and parking lots. Portions of the stream are piped underground but resurface past Hilltop Circle and converge with the stream restoration segment before flowing south off campus.

Side B encompasses the northeast and east sides of campus, but predominantly has off-campus area (Figure 2). West of I-695 is the West Branch of the Herbert Run that starts off-campus, draining Spring Grove Hospital, a part of the Rolling Road Golf Course, and suburban neighborhoods. This stream flows under Wilkens Avenue and resurfaces in the forested area near the northeast side of campus. As the stream flows onto campus property, it drains forested areas, the campus residential buildings, Hilltop Circle, and parking lots. East of I-695 is the East Branch of the Herbert Run. The East Branch starts near Maidens Choice Lane and flows through residential and commercial areas off campus and converges with the West Branch on the edge of UMBC's property, by the Technology Research Center.

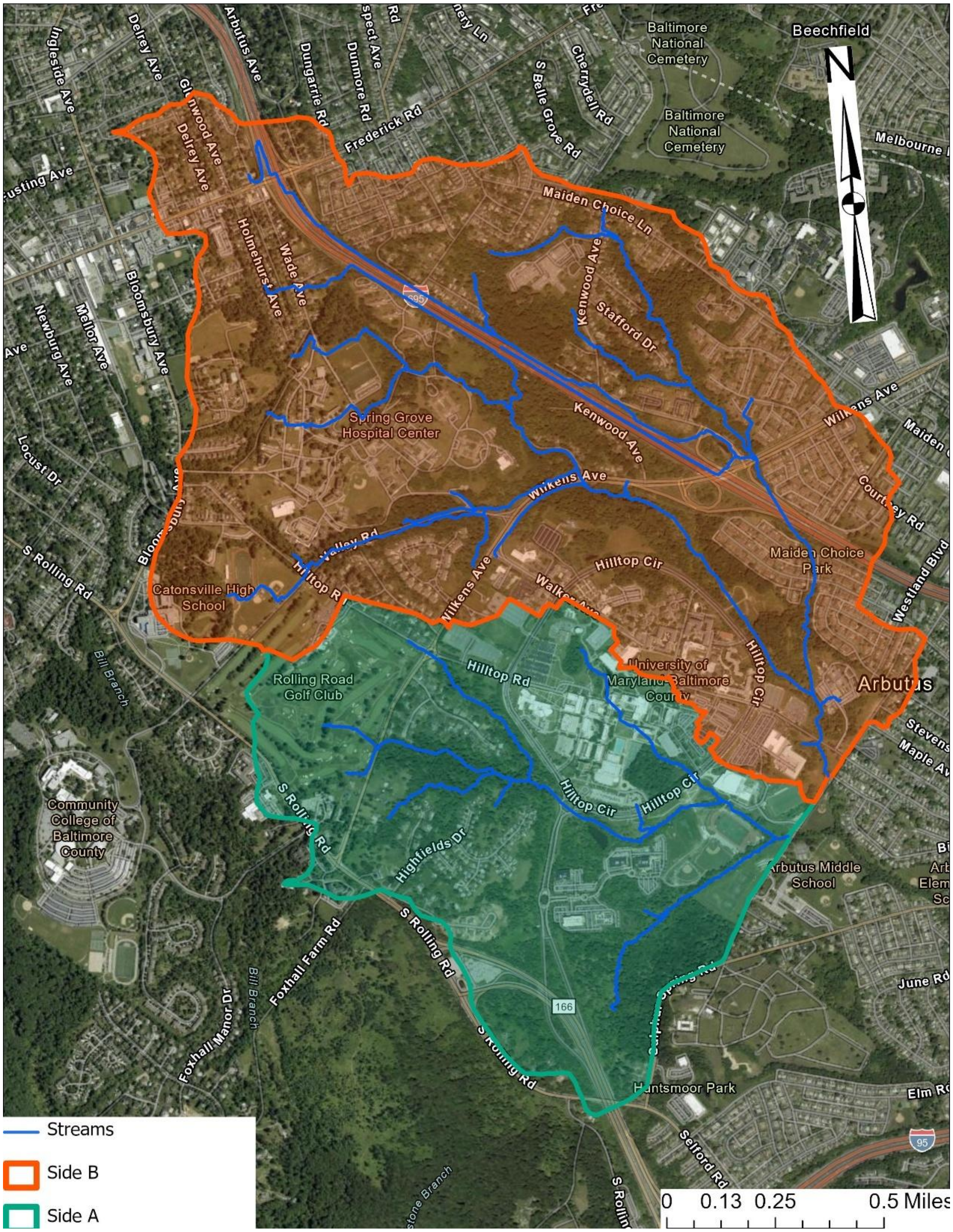

Figure 2: Map outlining Sides A and B of the study area watershed. The stream network is also depicted.

Sample Sites

A total of 14 sites within the study area were selected for measuring nitrate-N, ammonium-N, and specific conductance (Figure 3). Twelve sites, consisting of perennial stream flow and stormwater ponds, were sampled during dry and wet weather conditions. The sites Paradise and InflowA have most or all of their drainage originating off campus. These sites represent the water quality upstream of campus. Sites Outfall_A and Outfall_B represent water quality that leaves the campus. Outfall_B was the most accessible point downstream, although the stream did have additional drainage within the campus property. Seven other sites, three ponds, and four within streams, were selected across campus. Two sites, RainA and RainB, were only sampled when it rained. These sites are storm drains that are fed from the street and SCM underdrains.

Water Quality Parameters

Nitrogen is a limiting nutrient in brackish and saline waters of the Chesapeake Bay. In excess, nitrogen causes eutrophic zones that lead to dead zones. Because of this concern, it was important for this study to measure nitrogen throughout the sample sites. Nitrogen and its species cycle and fluctuate across terrestrial and aquatic ecosystems. Nitrogen is often in an aqueous state, which makes it easy to sample in water. Nitrate-N and ammonium-N were the two nitrogen species measured in this study. Nitrate-N is often found in higher concentrations in streams, due to rates in nitrification and groundwater sources (Johnson & Stets, 2020; Kemp & Dodds, 2002). Fertilizers often contribute to elevated nitrate-N concentrations in urban streams. Like other suburban areas, college campuses utilize and maintain turf lawns for student activities. Studies have shown spatial and temporal variabilities in nitrate-N concentrations from turf lawns (Law et al., 2004). Factors like soil type and timing of fertilizer application influence nitrate-N contributions from lawns in urban watersheds (Cheng et al., 2014; Law et al., 2004; Toor et al., 2017). Ammonium-N is a nitrogen species found in smaller concentrations than nitrate-N, as it is more readily available to bacteria and plants (Barlett & Leff, 2010; Kemp & Dodds, 2002). Elevated ammonium-N concentrations in urban streams could indicate discharge from sewer drains and wastewater (Potter et al., 2014; Spataru, 2022). Lawn fertilizer is often nitrogen in the form of ammonium, which can also be an urban source (Carey et al., 2012; Toor et al., 2017). Measuring these two nitrogen species could give insight into potential nitrogen inputs across campus.

Specific conductance, or conductivity, is a parameter that is often used to estimate the concentration of dissolved ions in water. In natural streams, dissolved ion concentrations are usually characteristic of the natural geology and bedrock in the area (EPA, 2011; Griffith, 2014). In developed watersheds, anthropogenic sources may exceed the concentration of dissolved ions from natural sources.

Universities build and maintain infrastructure to accommodate increasing student populations and improve campus academic and recreational experiences. UMBC is located in the mid-Atlantic region, where freezing temperatures, snow, and ice occur during most winters. The campus applies deicing salts to keep roads and walkways accessible. Urban infrastructure and winter road salts have added dissolved salts into freshwater streams, negatively impacting aquatic life (Baker et al., 2019; McManus et al., 2020). Elevated specific conductance is known to be very stressful to aquatic life (Fanelli et al., 2019; Center for Watershed Protection, 2003). Elevated specific conductance is a concern in urban and suburban streams.

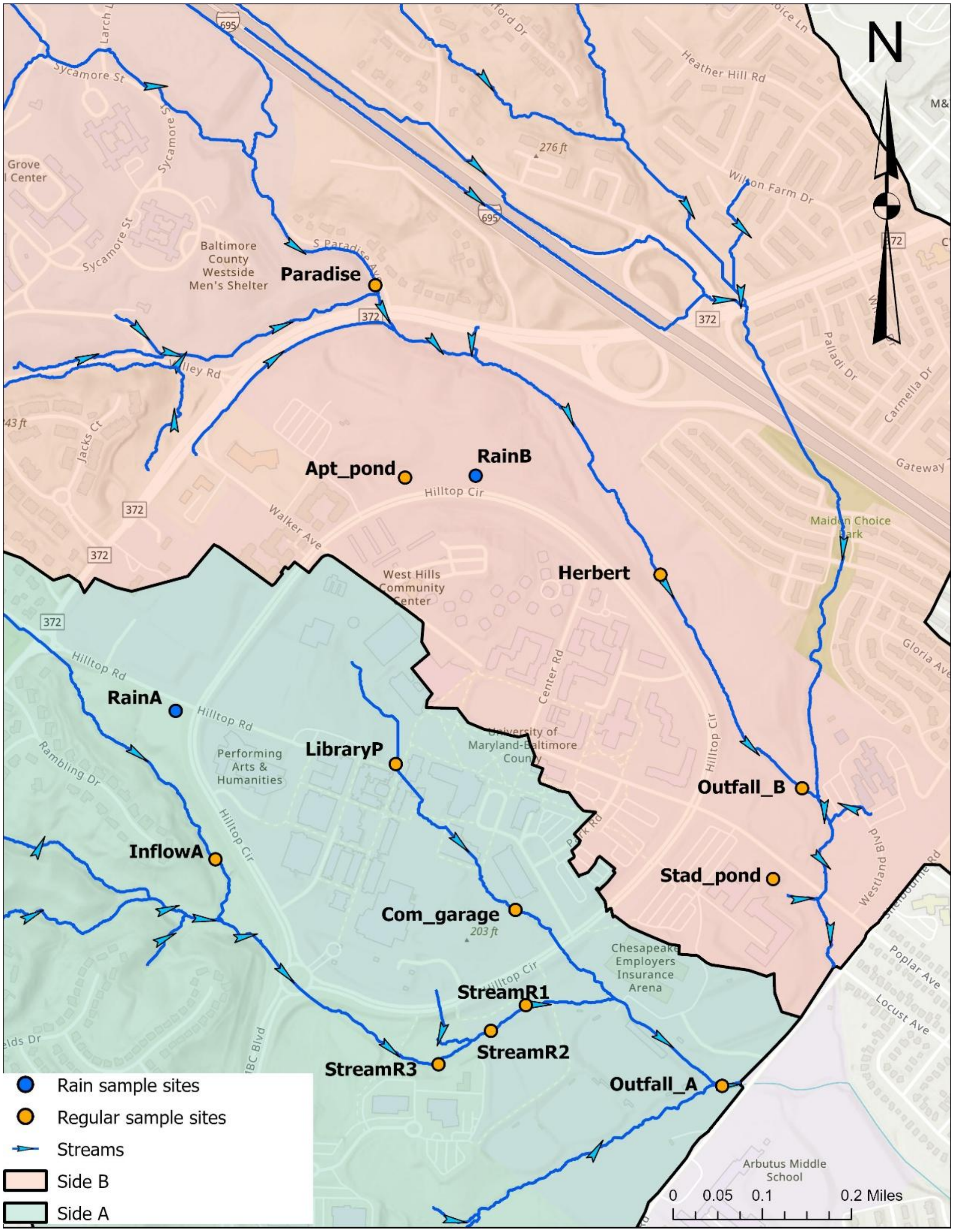

Figure 3: Map of the UMBC campus depicting the selected sampling sites where nitrate-N, ammonium-N, and specific conductance were measured. The borders of sides A and B of the watershed are also shown.

Methods

Water Quality Sampling

From September 2023 until February 2024, I used YSI DSS Pro handhelds and their parameter probes to measure nitrate-N (#626905), ammonium-N (#626906), and specific conductance (#626902) concentrations at each sample site. Each probe was calibrated once a week. At each site, the probes were left in the water for two and a half minutes. The DSS Pro recorded the parameters continuously, logging data every 15 seconds. This was done to eliminate the possibility of random spikes during sampling, which could skew the data. The values collected during the two-and-a-half-minute continuous set of measurements were averaged for each site on each day of measurement. The average of the set of measurements created the weekly measurements for each site.

Most sites were sampled weekly; however, there were some limitations throughout the sampling period. For example, renovations for the stadium pond (Stad_pond) were being completed from November to January, preventing me from measuring water quality at this location. Also, I did not add the inflowA site until November due to vegetation preventing me from getting a clear path to the site. When it rained, I included sites RainA and RainB and used the same sampling method. RainA and RainB are dry swales in front of stormwater drains that have an outflow of stormwater when it rains. RainA was located on the northwest side of campus, and RainB was on the north side of campus (Figure 3). These sites represented direct stormwater discharges, as opposed to stormwater mixed with existing pond water or stream flow. All water quality data were uploaded using YSI's Kor software, organized in Excel, and converted to a .csv file to be analyzed in RStudio.

Delineating Watersheds

UMBC provided a geodatabase of all the SCMs, storm drains, sub-drainages, and other important construction features of the campus. The features and layers were loaded into ArcGIS Pro (version 3.2.2) and used to characterize how water flows across the surface and through storm drains on campus. From Baltimore County's 2015 1-meter LiDAR DEM, flow direction and flow accumulation rasters were created to assess topographic sinks and understand how surface water flows across campus. The DEM raster was clipped to the UMBC watershed polygon. The flow accumulation raster modeled sinks, places where surface water could pool when it rained. However, some of the sinks in the accumulation raster included storm pipes that route stormwater flow. UMBC's storm drain polyline file was used to remove topographic sinks in the DEM that did not actually exist. With the storm drain layer overlaid on the sink raster, I selected lines that connected sinks to a known outflow. I also paid attention to storm drains that crossed under roads or crossed sub-drainage divides. Storm drain lines were made into a new layer and converted to rasters using the Polyline to Raster tool, then lowered relative to the surrounding terrain using focal minimum statistics performed on the DEM with a 10-meter radius. The minimum focal elevation within each storm drain region was assigned using Zonal Statistics to create low-elevation paths. The storm drain raster was burned to the focal minimum DEM to depict water routing that was more consistent with the storm drain information in the geodatabase. The corrected DEM raster was filled to remove minor imperfections and then used to create a flow direction layer with the Hydrology toolbox.

With the corrected flow direction and accumulation rasters, the Watershed analysis tool from the Hydrology toolbox created watershed boundaries for the sample sites and UMBC's SCMs. For the sample sites, the points were used to delineate the watershed area that flowed to each sample location (Figure 4). This watershed layer was important in calculating the proportion of land cover and mitigated area for each site, and in better understanding potential influences on water quality. When delineating the SCM watersheds, the three green roofs were removed from the SCM layer and were not considered in this study because it was assumed that the rain that was captured on the green roofs did not contribute to surface runoff. The Watershed tool does not allow polygons to be pour points. Therefore, the SCM polygon layer was converted to a raster. The SCM watershed layer was turned into a binary raster. The Tabulate Area function was used to calculate the SCM watershed area draining to each sampling site. This calculated area best represents the area within each site watershed that was potentially mitigated by a campus SCM.

UMBC's Watershed Land Cover

Land use/land cover (LULC) data (Chesapeake Conservancy 2018) was used to calculate different land cover proportions within the watershed area draining to each sample site. This 1-meter LULC raster consisting of 12 classes, including tree canopy over other land cover classes, was cropped to the UMBC watershed polygon (Figure 4). In ArcGIS Pro, the Tabulate Area function created a table of the land cover categories by site watersheds. The table was exported into Excel to calculate the fraction of land cover in each site's watershed.

Different land uses may contribute to different pollution sources. For this analysis, I focused on impervious and turf cover (Figure 4). Impervious cover contributes to specific conductance from the weathering of urban infrastructure (Baker et al., 2019; Center for Watershed Protection, 2003). Turf grass tends to be fertilized in urban spaces, which can leach nitrate-N (Behrouz et al., 2022; Cheng et al., 2014). Fertilizer can also be a source of ammonium-N if the ammonium-N doesn't convert to nitrate-N (Gilbert et al, 2012). High levels of ammonium-N can also indicate sewage pipe leaks or excess organic inputs from soils (Hatt et al., 2004; Taylor et al., 2005). Isolating impervious cover and turf cover throughout campus could show if the parameter measurements are associated with these land cover classes.

A campus area polygon layer from the geodatabase was turned into a binary boundary to separate the campus area from the off-campus area. When the campus polygon was created, the BWTech Research Park to the south and the Walker Apartments were not included in the stormwater plan. These areas were added back to the campus area polygon because they are property owned by UMBC. The Tabulate Area function was used to calculate land use, campus area, and impervious cover strictly on campus within each site watershed. The sample site watershed area information was tabulated in Excel.

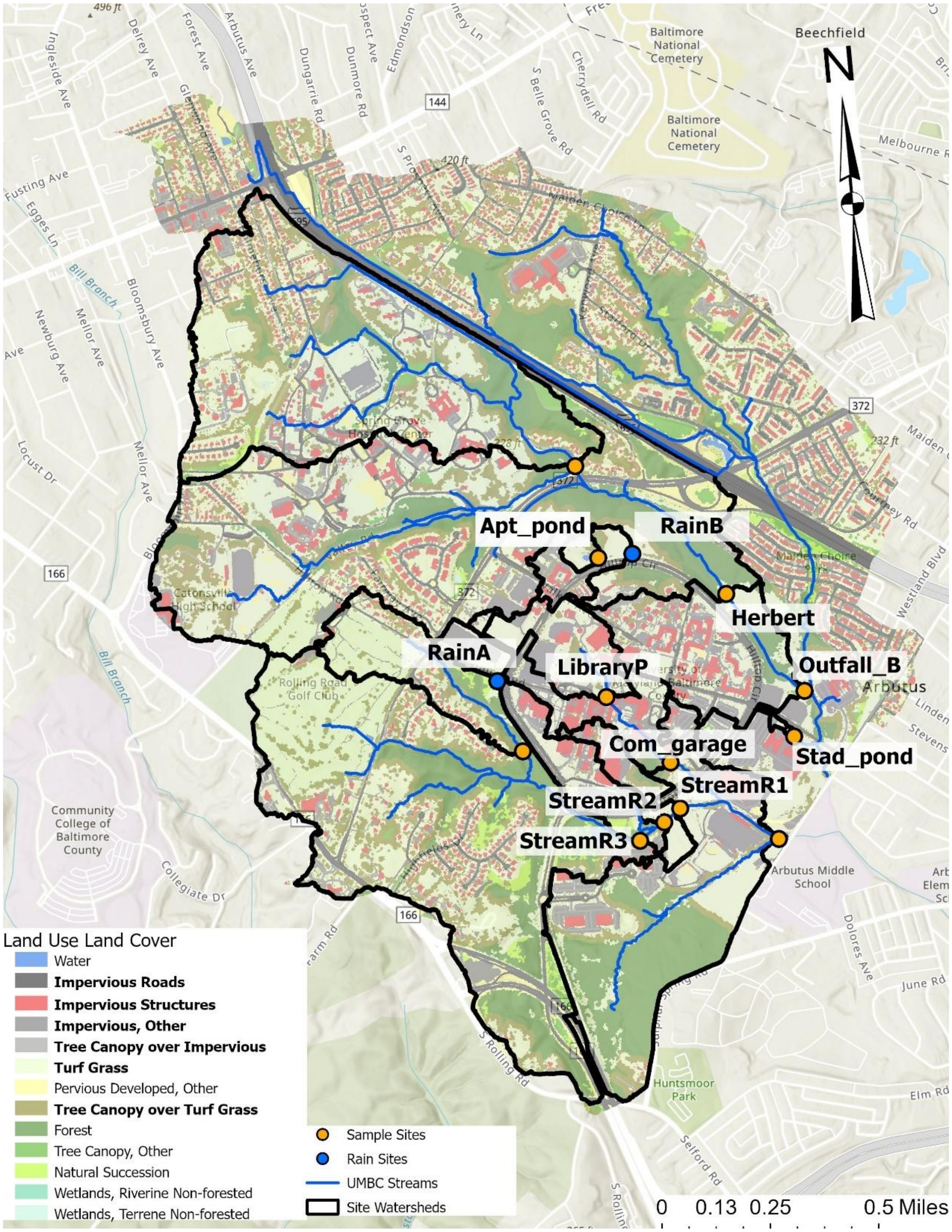

Figure 4: Map depicting land cover in each sample site's upstream catchment. Land covers in bold are the classes that were focused on in this study.

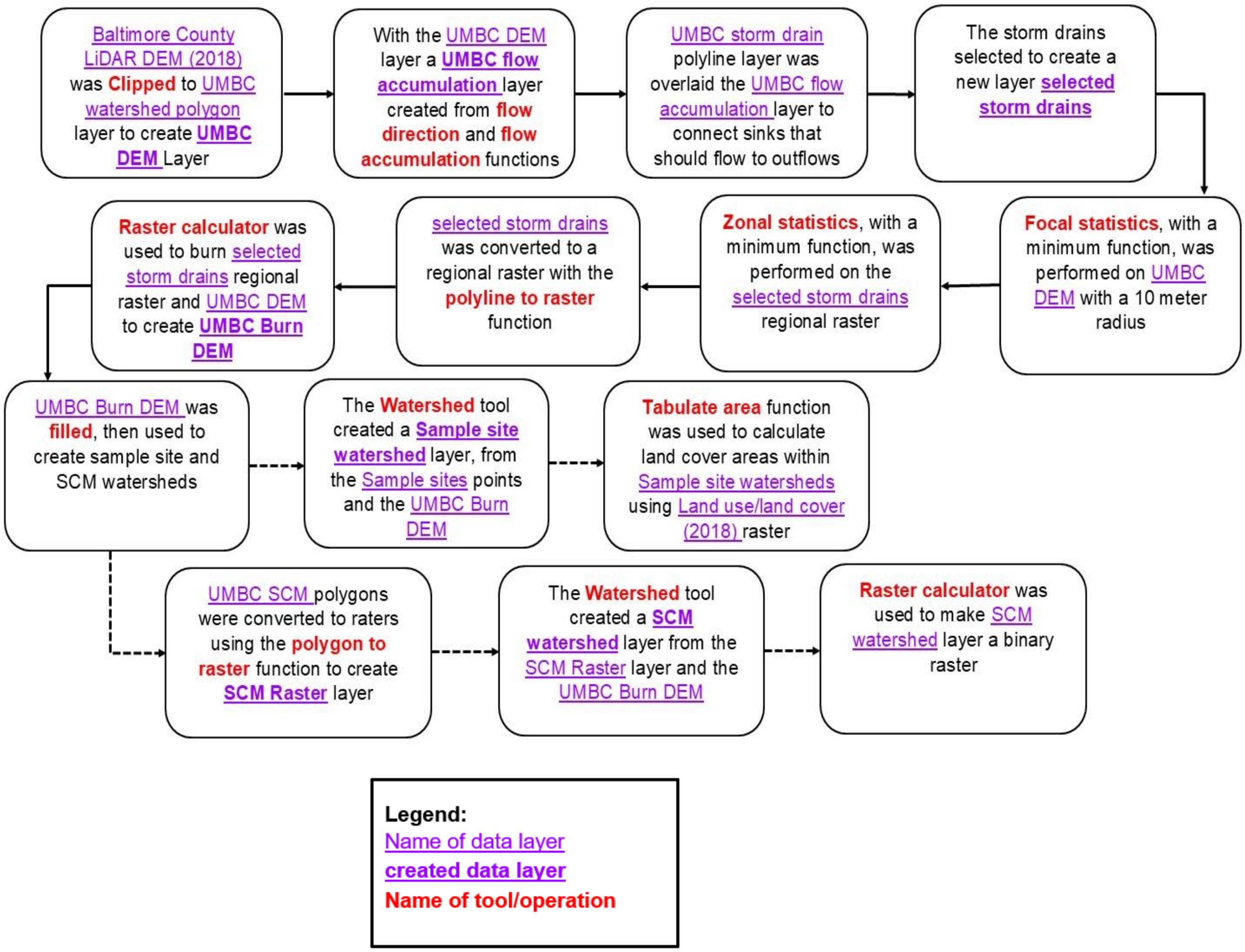

Figure 5: Flow chart explaining the functions and the data used to create the different watershed layers necessary for the land cover analysis in this study. All these steps were done in ArcGIS Pro 3.2.2.

Statistical Analysis

ANOVA tests were used to assess spatial and temporal differences in water quality throughout the campus. The ANOVAs were performed using the lm() function in R (version 4.3.1). All three sampled parameters were analyzed separately, so each comparison was performed three times. The null hypothesis was that there were no significant differences in the mean concentrations across spatial groups or time frames. For all ANOVAs, $\alpha = 0.05$ was the threshold for significance. Using the ggplot2 package, box plots were created to visualize each comparison to highlight potential spatial and temporal trends. Most of the spatial and temporal analysis included only the data collected on dry weather days.

Spatial groupings were the categorical variable, and each parameter measurement was the dependent variable. First, ANOVAs for each parameter were compared to determine if there were differences on either side of the watershed (Figure 2). This was further explained by comparing the four inflow and outflow sites (InflowA, Outfall_A, Paradise, Outfall_B) to see if there was a net addition or dilution on either side. Nested ANOVAs were used to compare the four sites (two inflow, two outflow). The first factor was the side of campus, either A or B. The nested factor was the inflow and outflow site on each side. This compared all four sites but focused on comparing whether one side of the watershed had a higher average for any of the parameters and comparing the inflow to the outflow site on either side. ANOVAs were also performed to compare the 12 regular sample sites (Figure 3). The null hypothesis was that all sites had the same average concentration for each parameter. These comparisons showed the spatial differences in water quality across all sample sites, to potentially highlight any additions of any parameter.

For the first temporal comparisons, ANOVAs were used to determine if any of the monthly averages for a parameter differed from another. The monthly average was calculated using the regular site measurements within the same month. The null hypothesis was that there were no differences in concentrations across months. The last sample date fell on February 2nd; this measurement was included in the month of January since it was the same week.

The data was also split between the first five weeks and the last five weeks of sampling. The time frames (Sept/Oct – January) were selected to contrast the differences in seasonal temperatures. These records were made into their own data table, with a factor column indicating the first or last five weeks of the sampling period. A two-way ANOVA was used to compare whether there was a significant difference between the time frames across sites. The two categorical variables were the sample sites, and the time frame the sample was taken.

A mixed effects model was used to compare the dry and rain data using the lmer() function as an unbalanced, repeated measures design using the package lme4 (Bates, 2015). In this design, the mean value of each parameter was a function of fixed effects from the treatment factor weather (dry or rain) and the sample date, whereas the sample site was a random effect. The null hypothesis was that there were no differences over time or the weather conditions using repeated measures at the sample sites. The two additional rain sites were compared separately with an ANOVA (Figure 3).

Land Cover and Water Quality Relationships

To answer the second sub-question, linear models for each parameter were fitted based on different land cover proportions in the site's upstream drainages. A linear model was created using six sample sites, sites that had mostly independent drainages from each other: InflowA, Outfall_A, LibraryP, Apt_pond, Paradise, and Outfall_B (Figure 4). The average concentrations from site drainages for each parameter throughout the sample period were regressed on their land cover proportions. The linear model of the six sites was plotted as a scatter plot with the 12 regular sites (Figure 3). Three sets of scatter plots were used, with the percent impervious and percent turf cover as the independent (x) variable and the measured parameter (nitrate-N, ammonium-N, or specific conductance) as the dependent (y) variable. These plots assisted in identifying spatial differences in water quality and in highlighting potential outliers.

Along with land cover, this study explored how SCMs on UMBC's campus impacted water quality. With the same six sites, a linear model was made using the average parameter concentration at each site (y variable) and the aggregate mitigated area by a campus SCM (x variable). A linear model and a multiple linear regression (MLR) model were fit for each parameter. For the MLR, the two independent variables were percent land cover and percent mitigated area. The R predict() function was then used for each linear model. This was used to assess if including the SCM mitigated area changed the prediction model compared to just knowing land cover. Scatter plots were used to compare predicted (y) vs measured (x) values for each parameter. R2 values and p-values were compared. A 1:1 line was plotted with the predicted values to visualize the agreement of the models.

Results

Spatial and Temporal Variations in Water Quality Across the Sample Sites

Spatial and temporal comparisons of the tested parameters showed general differences in water quality throughout the watershed. However, in initial explorations, measurements for the site Stad_pond had consistently low concentrations for all parameters, likely due to ongoing construction. This outlier was removed from subsequent ANOVA comparisons as well as other analyses.

Side A and B Comparison

The first spatial comparisons for each parameter looked at whether the two sides of the watershed differed from each other (Figure 2). All of the sites on side A were binned together, and all the sites on side B were binned together for the ANOVA. Then a nested ANOVA, followed by a pairwise test, was performed on the four inflow and outflow sites.

Sides A and B showed no significant difference in nitrate-N ($p = 0.0589$; t-test). Figure 6 shows a box plot of nitrate concentrations with measurements from the sites within their respective sides. On both sides, A and B, their averages were larger than the medians (Figure 6). Both sides of the watershed had outliers higher in the upper ranges.

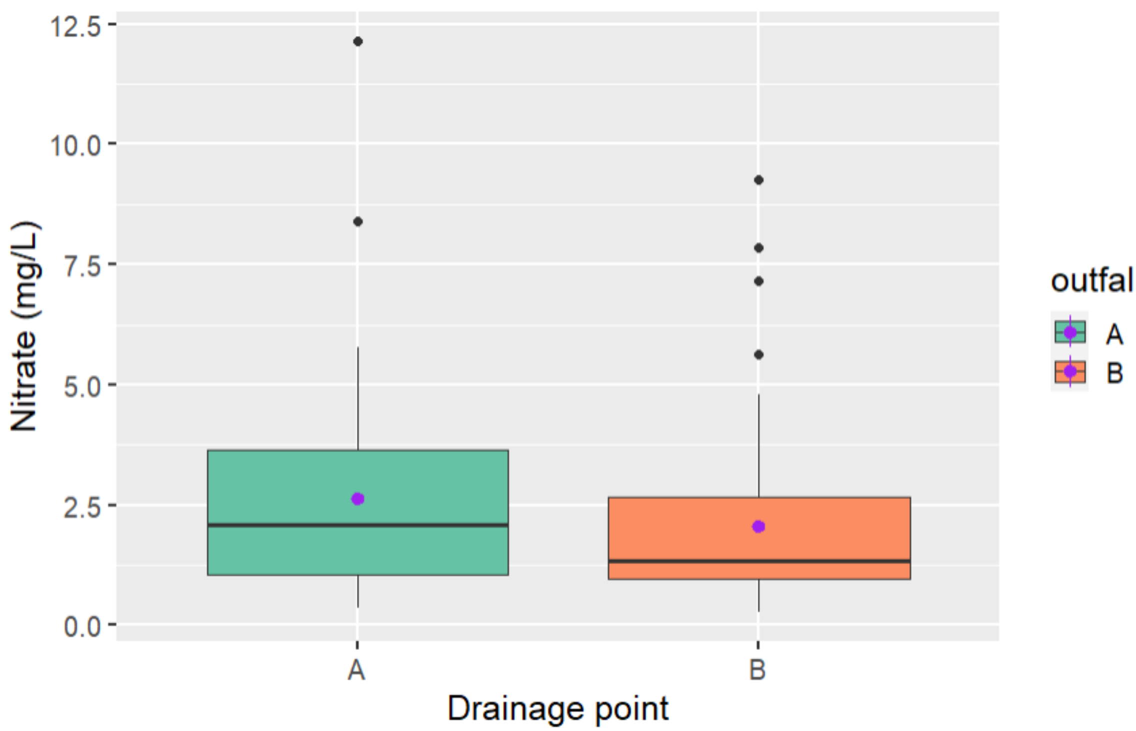

Figure 6: Box plot of nitrate-N concentrations collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. Comparisons were grouped by tributary streams with outfalls on each side of the campus. Side A had seven sites (InflowA, Com_garage, LibraryP, StreamR1, StreamR2, StreamR3, Outfall_A), side B had four sites (Paradise, Apt_pond, Herbert, Outfall_B). The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site.

For nitrate-N, the nested ANOVA showed no significant difference between the sides of campus ($p = 0.083$) or between the inflow and outflow sites on each side ($p = 0.107$). A pairwise test comparing all four sites (Table 1) showed that InflowA had a higher average than Outfall_A ($p = 0.036$), Paradise ($p = 0.021$), and Outfall_B ($p = 0.015$). Site inflowA had the highest average nitrate-N concentration compared to the other four sites (Figure 7). All four of the sites had averages that varied from their respective medians. Outfall_A was unique in that the average was lower than its median, but there were no outliers at this site.

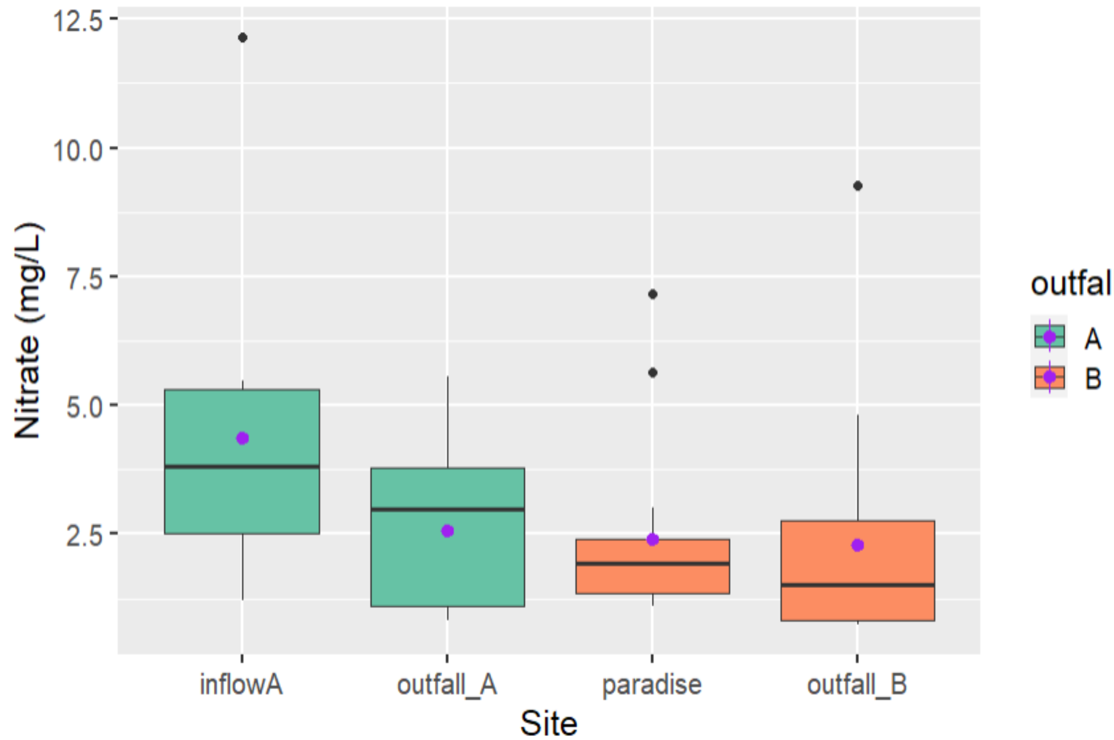

Figure 7: Box plot of nitrate-N collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. The four inflow and outflow sites were isolated for this comparison. The boxes are colored based with respect to each outfall the site drains. The purple dot shows the average concentration for that site. Sample n in weeks: Inflow A = 12; Outfall_A = 15; Outfall_B = 15; Paradise = 14

Table 1: Pairwise test for nitrate-N concentrations (mg/L) at sites InflowA, Outfall_A, Paradise, and Outfall_B. Measurements collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. Sample n in weeks: Inflow A = 12; Outfall_A = 15; Outfall_B = 15; Paradise = 14. " * " indicates a significant p-value.

	InflowA	Outfall_A	Paradise
Outfall_A	0.036*	-	-
Paradise	0.021*	0.829	-
Outfall_B	0.015*	0.717	0.882

The observed contributions of ammonium-N appeared very similar on either side of campus. ANOVA results indicated there was no statistical difference in ammonium-N concentrations between measurements from each side of campus ($p = 0.073$). The means and medians were close together for both sides A and B (Figure 8). Side B had higher outliers, coming from sites Paradise and Apt_pond. The outliers on side A are measurements from Com_garage.

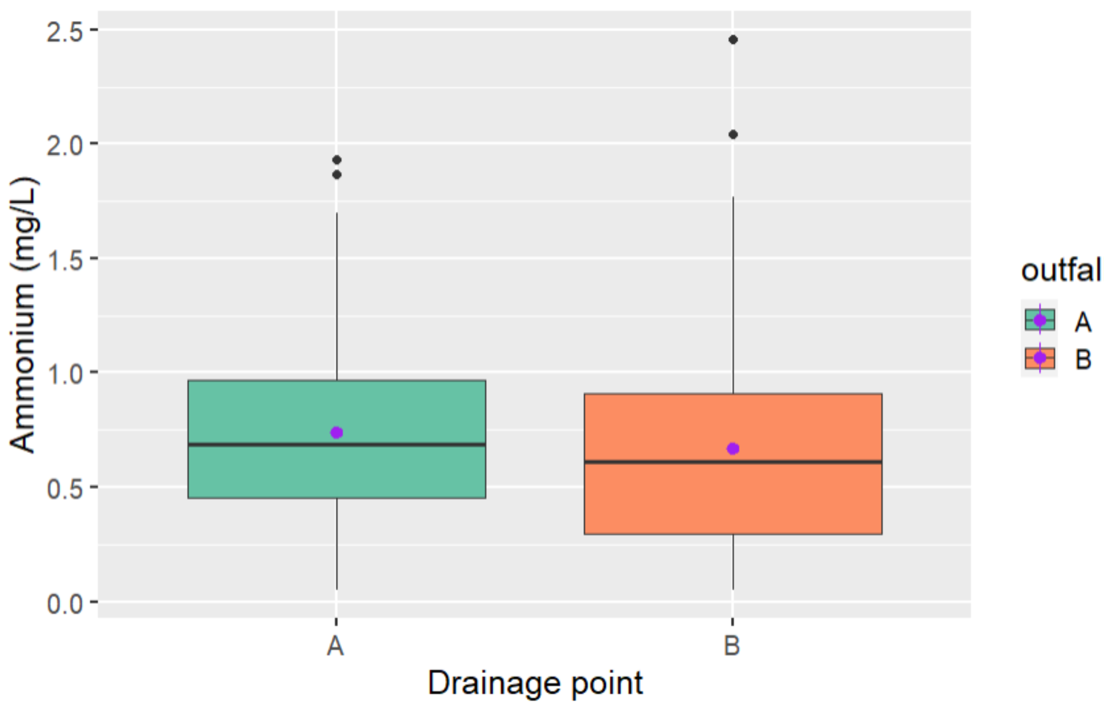

Figure 8: Box plot of ammonium-N concentrations collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. Comparisons were grouped by tributary streams with outfalls on each side of the campus. Side A had seven sites (InflowA, Com_garage, LibraryP, StreamR1, StreamR2, StreamR3, Outfall_A), side B had four sites (Paradise, Apt_pond, Herbert, Outfall_B). The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site.

There were no differences in ammonium-N across the inflow or outflow sites (Figure 9). InflowA, Paradise, and Outfall_B had higher averages than their medians.

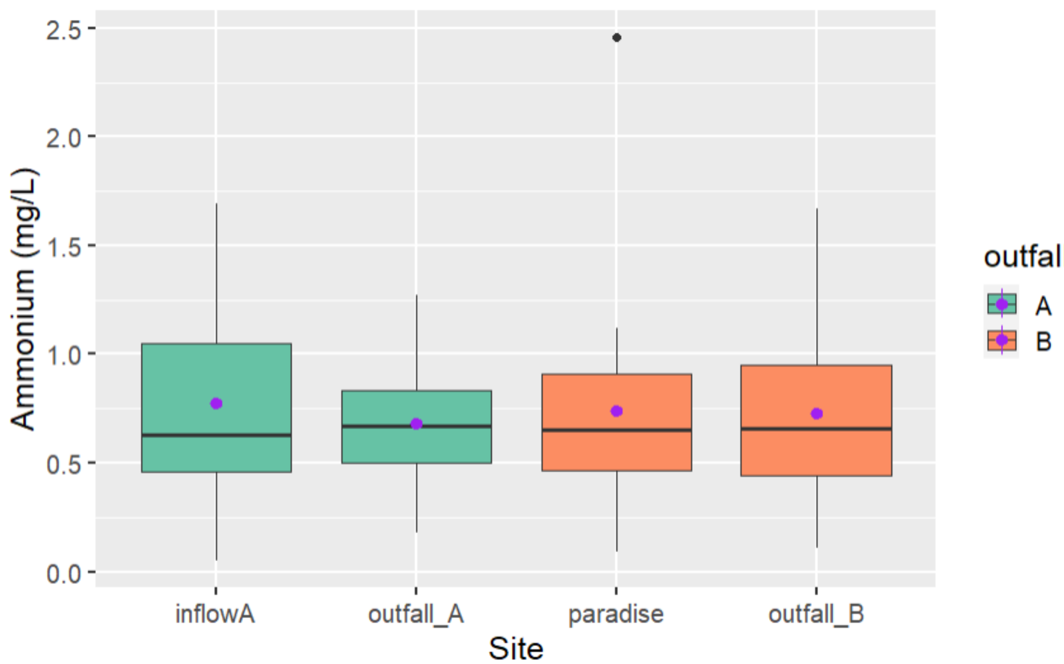

Figure 9:Box plot of ammonium-N collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. The four inflow and outflow sites were isolated for this comparison. The boxes are colored based with respect to each outfall the site drains. The purple dot shows the average concentration for that site. Sample n in weeks: Inflow A = 12; Outfall_A = 15; Outfall_B = 15; Paradise = 14

Table 2: Pairwise test for nitrate-N concentrations (mg/L) at sites InflowA, Outfall_A, Paradise, and Outfall_B. Measurements collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. Sample n in weeks: Inflow A = 12; Outfall_A = 15; Outfall_B = 15; Paradise = 14. " * " indicates a significant p-value.

	InflowA	Outfall_A	Paradise
Outfall_A	0.62	-	-
Paradise	0.83	0.75	-
Outfall_B	0.79	0.8	0.95

As an overall measure of dissolved material, specific conductance measurements were higher on average, from side B than from side A ($p = 0.0053$). Among the many outliers, side B had three that exceeded 4000 µS/cm (Figure 10).

These outliers likely skewed the average to be higher than the median. Side A’s average was closer to its median value. Side B’s median was close to Side A’s 75th quartile, which further emphasized the difference in specific conductance measured between the sides of the watershed.

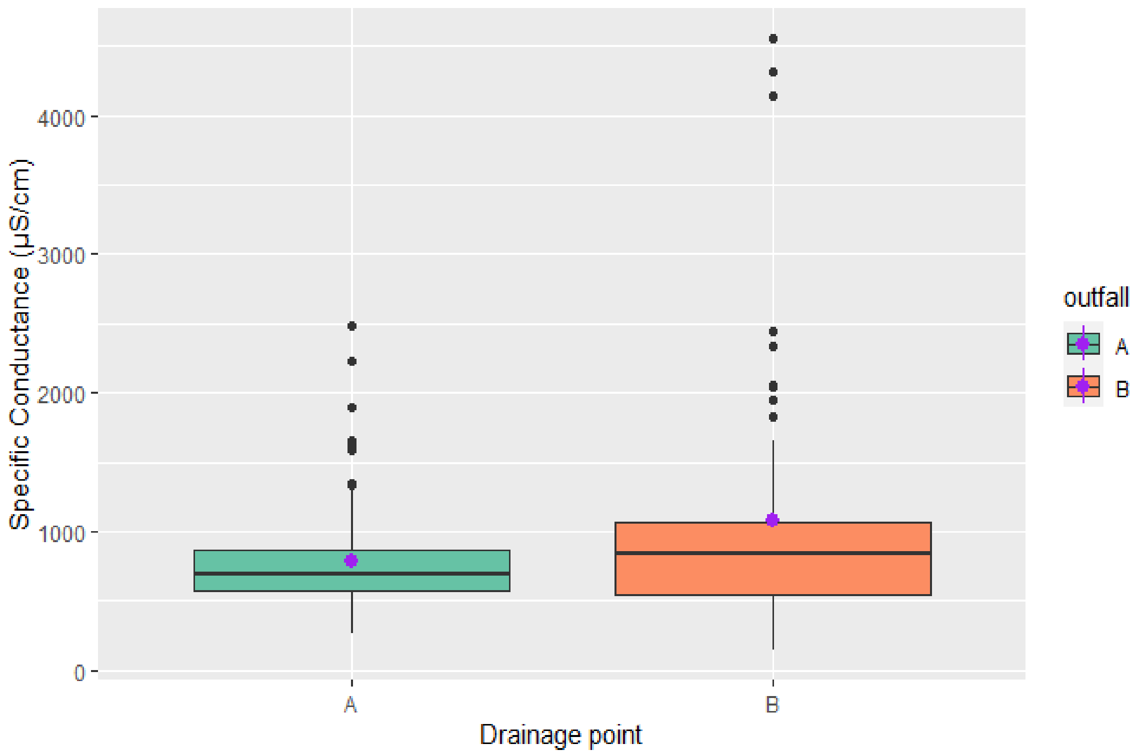

Figure 10: Box plot of specific conductance collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. Comparisons were grouped by tributary streams with outfalls on each side of the campus. Side A had seven sites (InflowA, Com_garage, LibraryP, StreamR1, StreamR2, StreamR3, Outfall_A), side B had four sites (Paradise, Apt_pond, Herbert, Outfall_B). The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site.

Specific conductance was different across the inflow and outflow sites ($p = 0.0226$). When performing a nested ANOVA across these four sites, there was a significant distinction between sides A and B. The sites Paradise and Outfall_B had significantly higher specific conductance than sites inflowA and Outfall_A (Figure 11). This was consistent with the ANOVA visualized in Figure 10. Pairwise testing

(Table 3) showed InflowA was significantly different than Outfall_B ($p = 0.024$). Although Paradise had a visually higher average than Outfall_A, Outfall_A's median was slightly higher than Paradise's median (Figure 11).

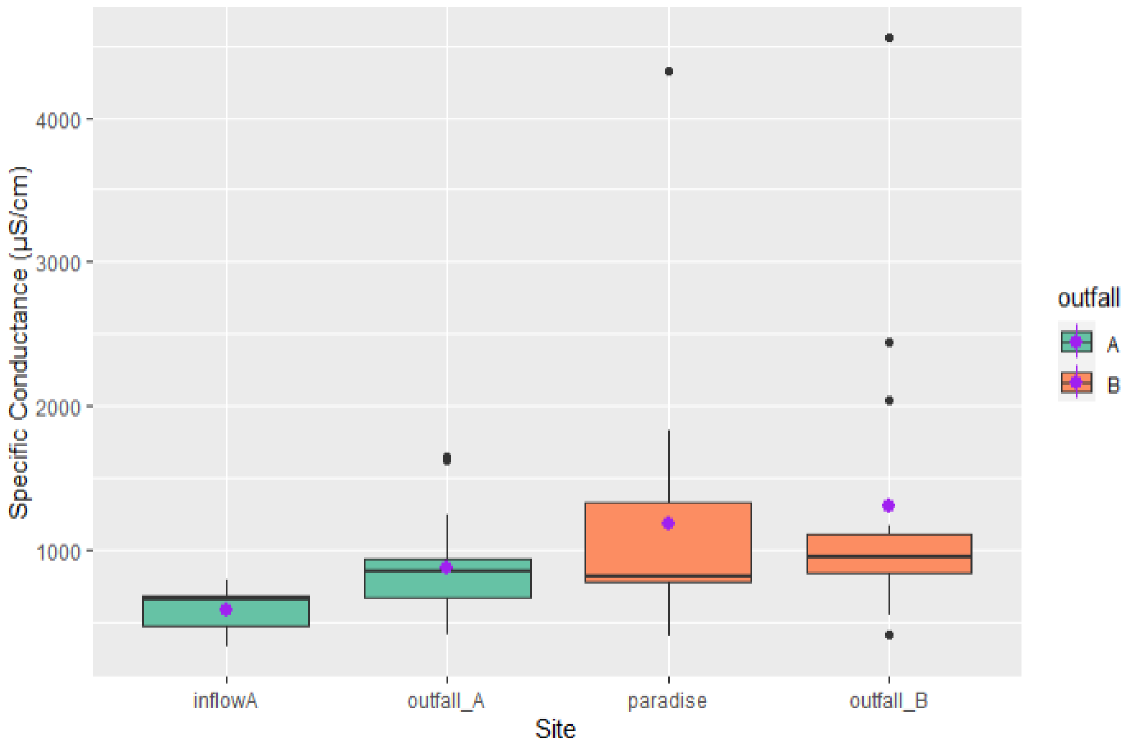

Figure 11: Box plot of specific conductance collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. The four inflow and outflow sites were isolated for this comparison. The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site. Sample n in weeks: Inflow A = 12; Outfall_A = 15; Outfall_B = 15; Paradise = 14

Table 3: Pairwise test for specific conductance (µS/cm) at sites InflowA, Outfall_A, Paradise, and Outfall_B. Measurements collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. Sample n in weeks: Inflow A = 12; Outfall_A = 15; Outfall_B = 15; Paradise = 14. "*" indicates a significant p-value.

	InflowA	Outfall_A	Paradise
Outfall_A	0.359	-	-
Paradise	0.06	0.297	-
Outfall_B	0.024*	0.143	0.66

Regular Sample Site Comparisons

All regular sample sites were compared to each other using ANOVAs. The box plots with the sample sites visualized general patterns for each parameter. Across all sample sites, nitrate-N concentrations ranged from about 1.0 to 12.5 mg/L. The ANOVA of nitrate-N concentrations suggested that mean concentration differences among sites were significant (p = 0.025). A post-hoc Tukey HSD test showed significant differences between sites InflowA and apt_pond (p = 0.001) and inflowA and library (p = 0.027) (Figure 12).

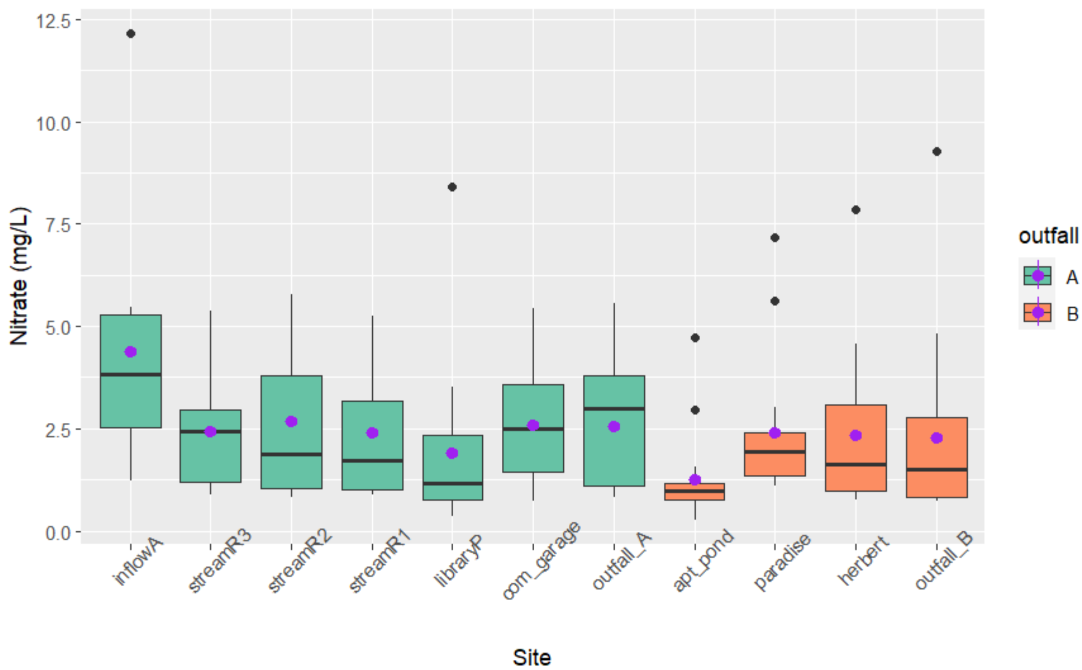

Figure 12: Box plot of nitrate-N concentrations at sample sites collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site. Sample n in weeks: Apt_pond, Herbert, LibraryP, Outfall B, Paradise = 16; Com_garage, StreamR1,2,3 = 15; InflowA = 12.

Ammonium-N concentrations across campus had a range from 0.05 to 2.46 mg/L (Figure 13). Without the Stad_pond outlier, there were no significant differences in ammonium-N concentrations across sites (p = 0.323). Despite the visual difference in LibraryP and Com_garage, a post-hoc test confirmed their average concentrations were not significantly different (p = 0.237; Tukey test). All the sites had a large range of concentrations. Only two sites had outliers: Paradise and Apt_pond.

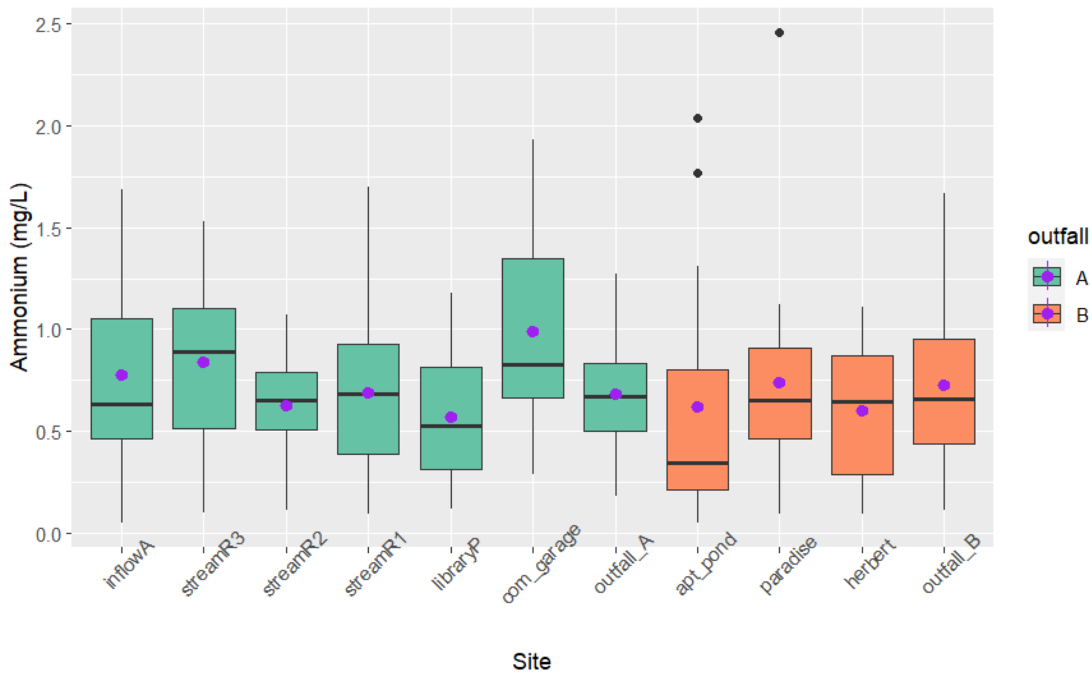

Figure 13: Box plot of ammonium-N concentrations at each sample site collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site. Sample n in weeks: Apt_pond, Com_garage, StreamR3 = 16; Herbert, Outfall A & B, StreamR 1 & 2 = 15; Paradise, LibraryP = 14; InflowA = 12

Specific conductance differed among sites across campus, with the data ranging from 89.68 to 4555.1 µS/cm ($p = 0.0013$; ANOVA). The spatial comparison is shown in Figure 14. The only significant differences were Herbert and Apt_pond ($p = 0.020$; Tukey), and Outfall_B and Apt_pond ($p = 0.031$; Tukey).

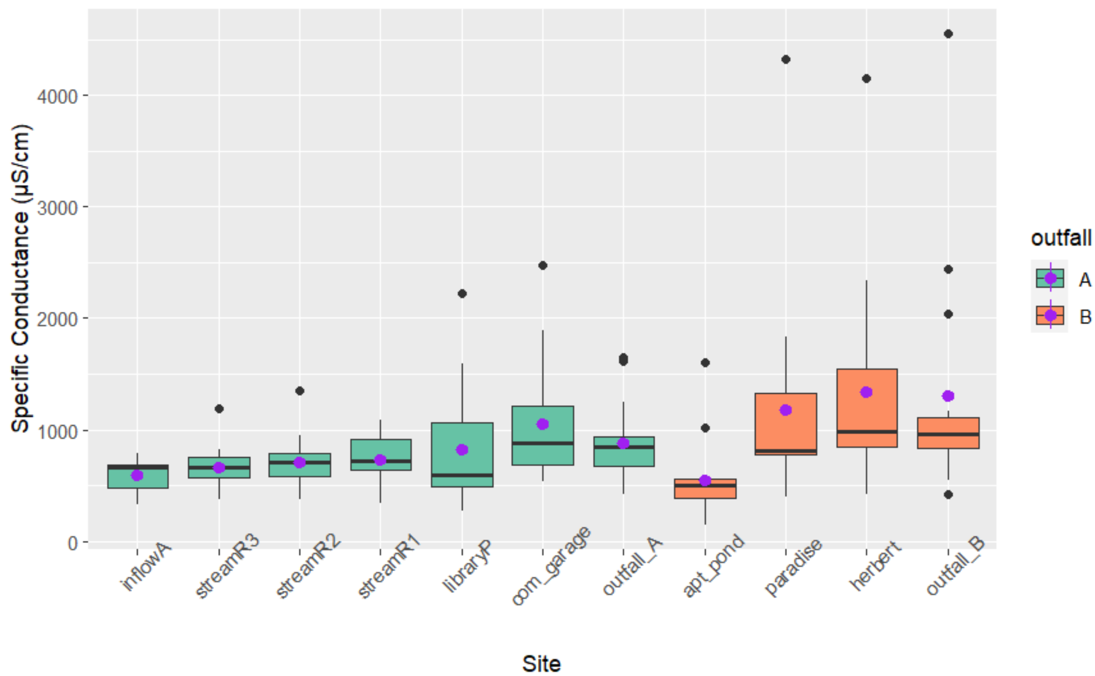

Figure 14: Box plot of specific conductance at each sample site collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. The boxes are colored based on the outflow of each site. The purple dot shows the average concentration for that site. Sample n in weeks: Apt_pond, Com_garage, StreamR3 = 16; Herbert, Outfall A & B, StreamR 1 & 2 = 15; Paradise, LibraryP = 14; InflowA = 12

Temporal Comparisons

The first temporal comparison was the monthly average of each parameter. The monthly average included all the sites' averages taken within the same month. Then, the first and last five weeks of the sampling period were compared to show how the averages at each site changed throughout the sampling period. The first and last five weeks of the sampling period were therefore examined to understand seasonal changes that might influence monthly comparison and confound interpretation. The comparison also assessed how average site concentrations changed over time. InflowA did not have data for the first five weeks because the site was added later in the sampling period.

Nitrate-N concentrations increased throughout the sampling period ($p < 2.2e-16$). Visually, January had the highest average concentration of nitrate-N, followed by December (Figure 15). Even though InflowA was not represented throughout the whole sample period, removing the site from the monthly comparison did not impact the significance ($p < 2.2e-16$). January also had the most skewed data of all the months. Its two outliers were from sites InflowA and Outfall_B. Samples from September through November all had about the same average concentration and range. A Tukey HSD test was used to confirm these trends (Table 4).

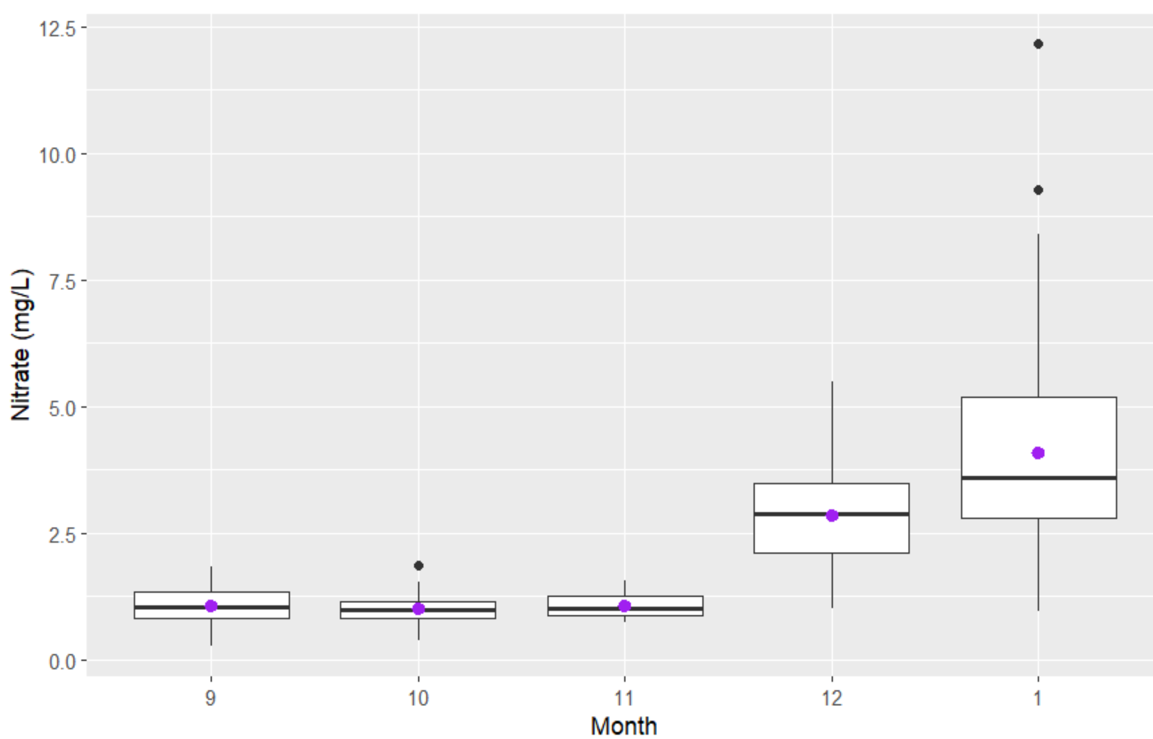

Figure 15: Box plot of nitrate-N concentration from all sample sites collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. Comparisons were grouped by the month of the sample across all

sites. The purple dot shows the average concentration for that month. Sample n in weeks: Sept = 2; Oct = 4; Nov = 2; Dec = 3; Jan = 5.

Table 4: Tukey test for nitrate-N (mg/L) grouped by the month the sample was measured. Measurements collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. Sample n in weeks: Sept = 2; Oct = 4; Nov = 2; Dec = 3; Jan = 5.“ * ” indicates a significant p-value.

	Sept (9)	Oct (10)	Nov (11)	Jan (1)
Sept (9)	-	-	-	0*
Oct (10)	1.00	-	-	0*
Nov (11)	1.00	1.00	-	0*
Dec (12)	4.00E-05*	1.30E-06*	4.90E-06*	2.54E-04*

For nitrate-N, the temporal comparison with the smallest p-value was the comparison of the sampling time frames across all sites (Figure 16). The two-way ANOVA showed that samples measured during the last five weeks were higher than during the first 5 weeks across the sample sites ($p = 1.283e-09$). Figure 15 shows a clear contrast between concentrations in the first five weeks and the last five weeks across all sites. Statistically, the sites that had higher averages during the last five weeks of sampling were Herbert ($p = 0.0415$), StreamR2 ($p = 0.0418$), and Outfall_B ($p = 0.0148$).

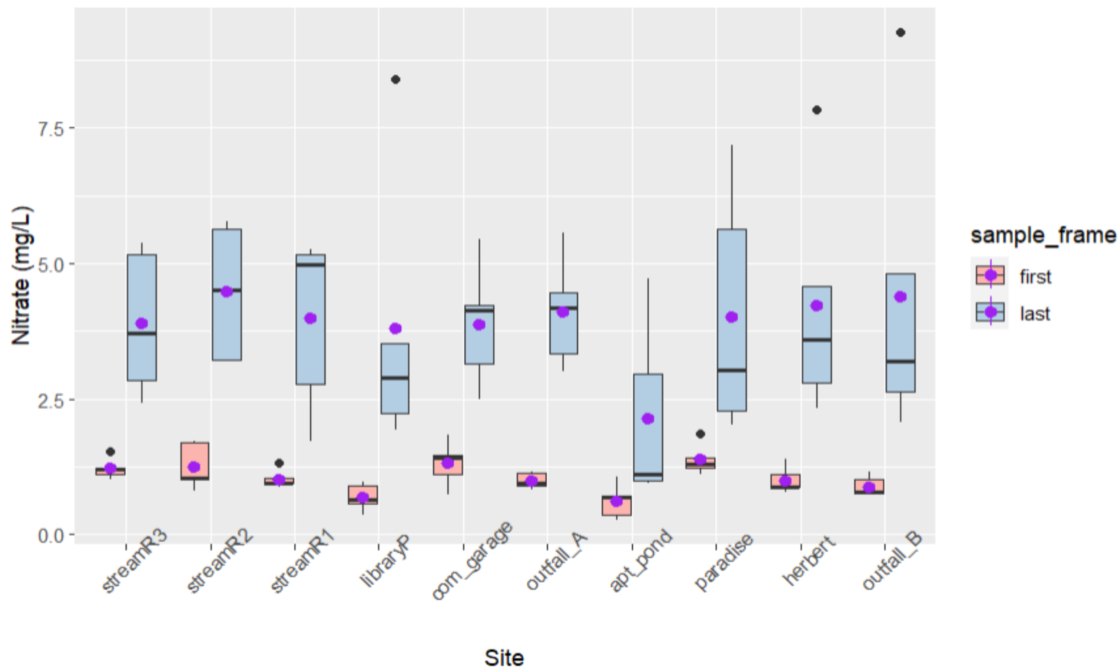

Figure 16: Box plot showing nitrate-N concentrations between the first and last five weeks of the sampling period for each site. Data was collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. The boxes are color-coded based on the sampling period. The purple dot represents the average concentration at the site. Sample n in weeks = 5 (inflowA not represented for the whole sample period, therefore excluded).

Ammonium-N concentrations differed significantly among months ($p = 0.009694$; ANOVA), specifically between September and January ($p = 0.0044$). Removing InflowA also did not impact the significance ($p = 0.00719$). The average concentration in January was very close to the median (Figure 17). The outliers in September were from Paradise and Com_garage.

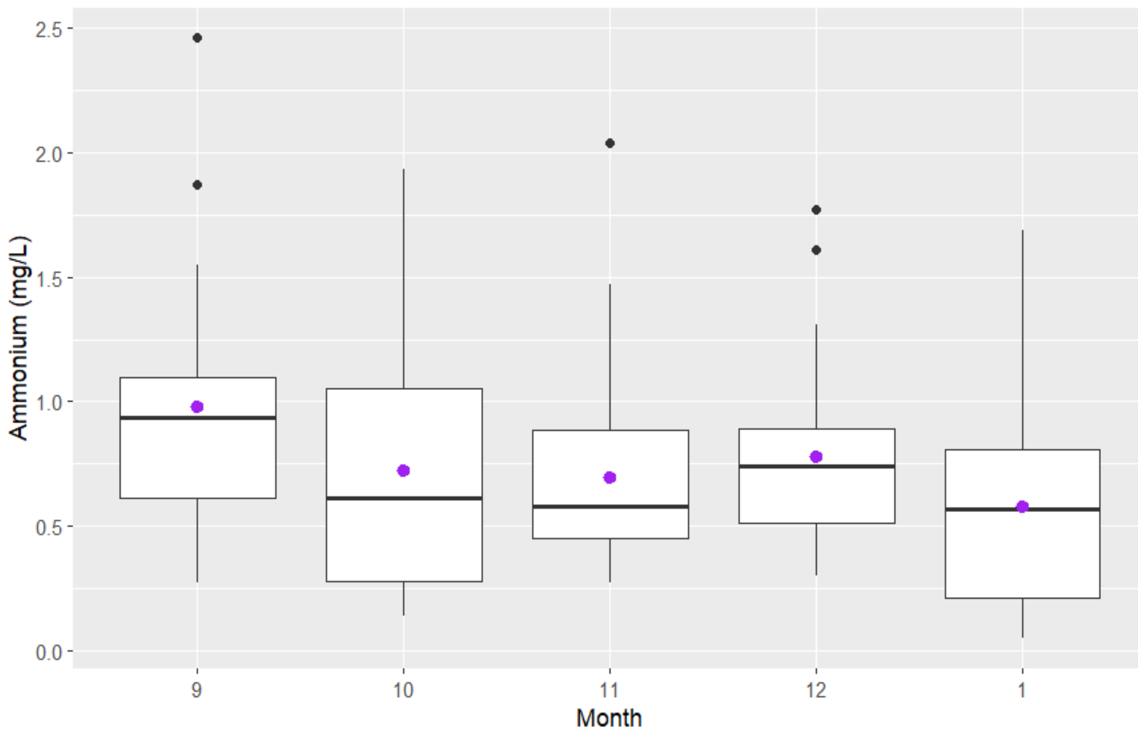

Figure 17: Box plot of ammonium-N concentration from all sample sites collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. Comparisons were grouped by the month of the sample across all sites. The purple dot shows the average concentration for that month. Sample n in weeks: Sept = 2; Oct = 4; Nov = 2; Dec = 3; Jan = 5.

Table 5: Tukey test for ammonium-N (mg/L) grouped by the month the sample was measured. Measurements collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. Sample n in weeks: Sept = 2; Oct = 4; Nov = 2; Dec = 3; Jan = 5.“ * ” indicates a significant p-value.

	Sept (9)	Oct (10)	Nov (11)	Jan (1)
Sept (9)	-	-	-	0.004*
Oct (10)	0.248	-	-	0.572
Nov (11)	0.167	0.999	-	0.772
Dec (12)	0.481	0.986	0.940	0.216

Ammonium-N concentrations were not significantly different between the sample period's first and last five weeks of sampling (p = 0.1303). The boxplot shows that the outlier from Paradise was measured within the first five weeks of the sampling period (Figure 18). Com_garage, visually, had the largest difference in average concentrations between sampling periods, but it was not statistically significant (p = 0.350; t-test). When comparing the site data for September to January data in two-way ANOVA, the results were not significantly different (p = 0.2102).

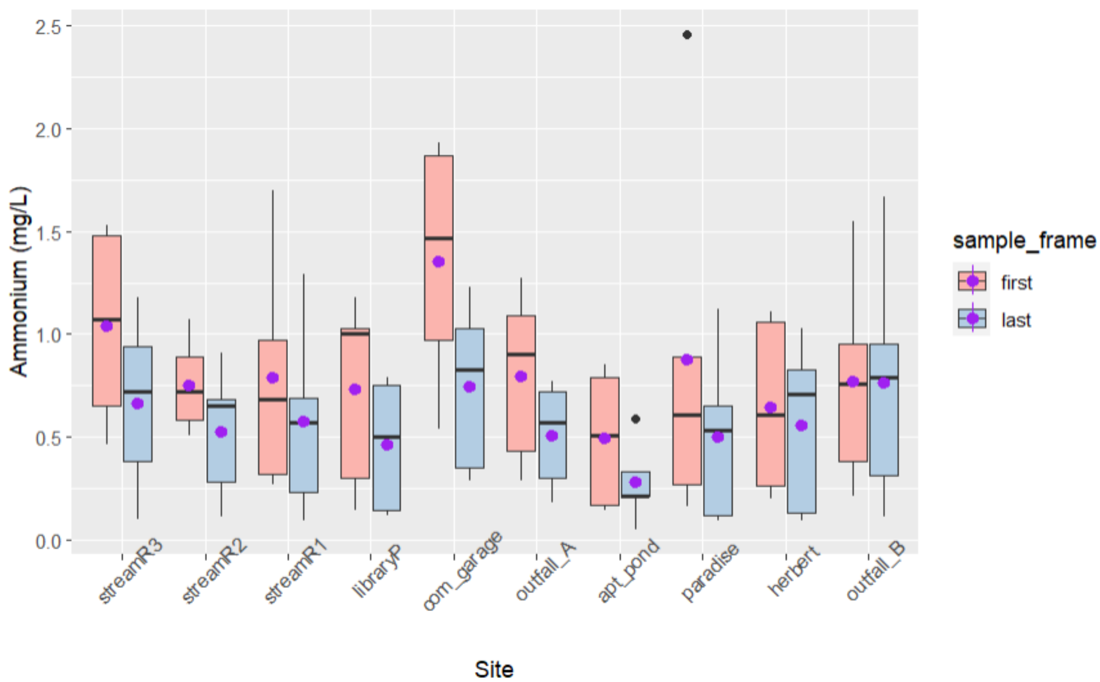

Figure 18: Box plot showing ammonium-N concentrations between the first and last five weeks of the sampling period for each site. Data was collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. The boxes are color-coded based on the sampling period. The purple dot represents the average concentration at the site. Sample n in weeks = 5 (inflowA not represented for the whole sample period, therefore excluded).

Specific conductance also had no clear monthly trend but had significantly different average monthly concentrations (p = 2.766e-07; ANOVA). Removing InflowA did not impact the significance (p = 5.039e-07). October and January had the highest averages of specific conductance (Table 6). January had outliers all exceeding 2000 µS/cm, all of which are higher than October's average and median. December was the only month with outliers below the average, from sites Herbert and Outfall_B (Figure 19). There were no differences in specific conductance across sites between the first five weeks and the last 5 weeks ($p = 0.063$).

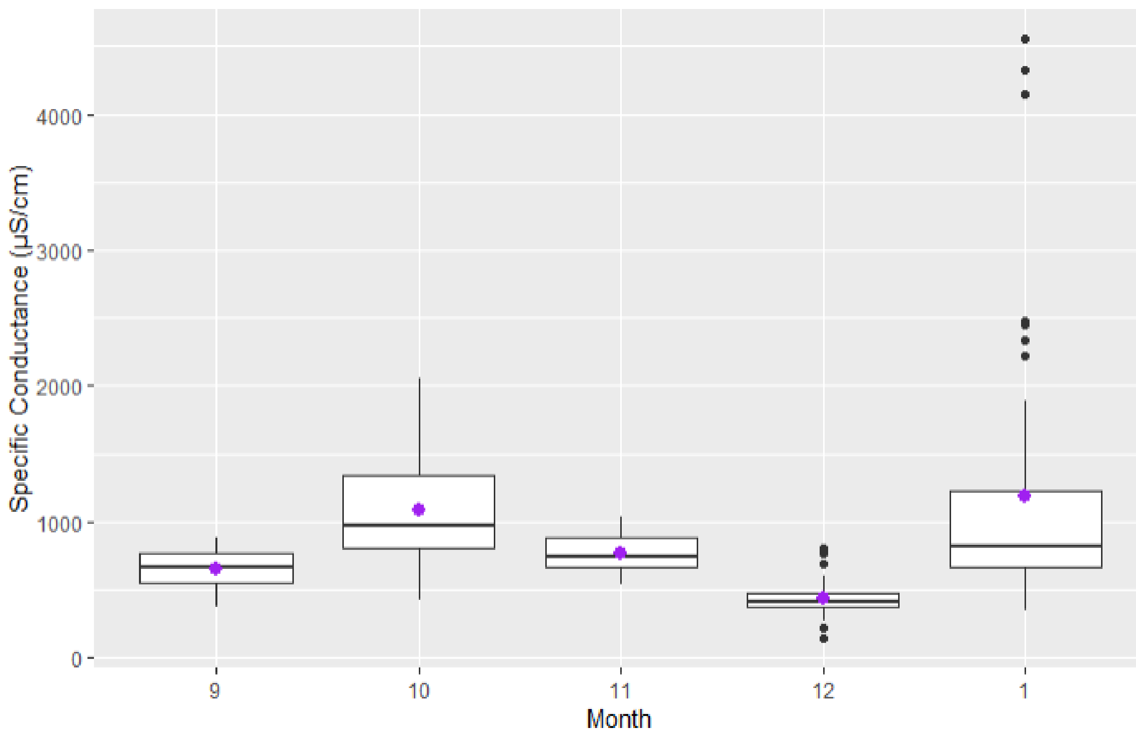

Figure 19: Box plot of specific conductance from all sample sites collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. Comparisons were grouped by the month of the sample across all sites. The purple dot shows the average concentration for that month. Sample n in weeks: Sept = 2; Oct = 4; Nov = 2; Dec = 3; Jan = 5.

Table 6: Tukey test for specific conductance (µS/cm) grouped by the month the sample was measured. Measurements collected from streams flowing around and emerging from the University of Maryland Baltimore County campus in fall/winter 2023-2024. Sample n in weeks: Sept = 2; Oct = 4; Nov = 2; Dec = 3; Jan = 5.“ * ” indicates a significant p-value.

	Sept (9)	Oct (10)	Nov (11)	Jan (1)
Sept (9)	-	-	-	0.036*
Oct (10)	0.182	-	-	0.943
Nov (11)	0.974	0.234	-	0.022*
Dec (12)	0.820	1.6E-04*	0.178	4.00E-07*

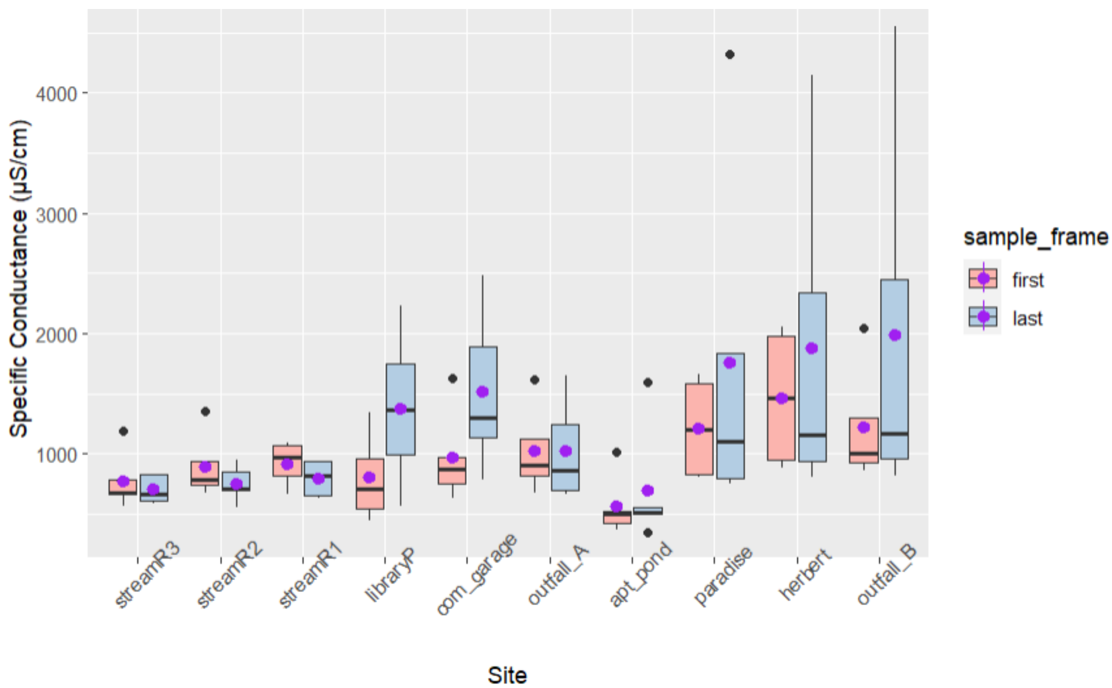

Figure 20: Box plot showing ammonium-N concentrations between the first and last five weeks of the sampling period for each site. Data was collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. The boxes are color-coded based on the sampling period. The purple dot represents the average concentration at the site. Sample n in weeks = 5 (inflowA not represented for the whole sample period, therefore excluded).

Weather Comparisons

The mixed-effects models tested whether parameters varied at each site based on weather conditions (dry or rain) using an unbalanced, repeated measures design. Thus, only four rainy days were sampled, and the majority occurred near the end of the sampling period. The comparisons were visualized using box plots.

For nitrate-N concentrations, the sample sites did have statistically different concentrations based on different weather conditions ($p = 9.15e\text{-}13$). The estimated y-intercept was 1.334 mg/L (estimated nitrate-N based on dry weather), and the estimated nitrate concentration when it rained was 3.608 mg/L larger than the y-intercept. Figure 21 visualizes the weather comparison for nitrate-N. However, later sampling periods also showed significant increases in nitrate-N concentrations, so these comparisons may have been somewhat confounded.

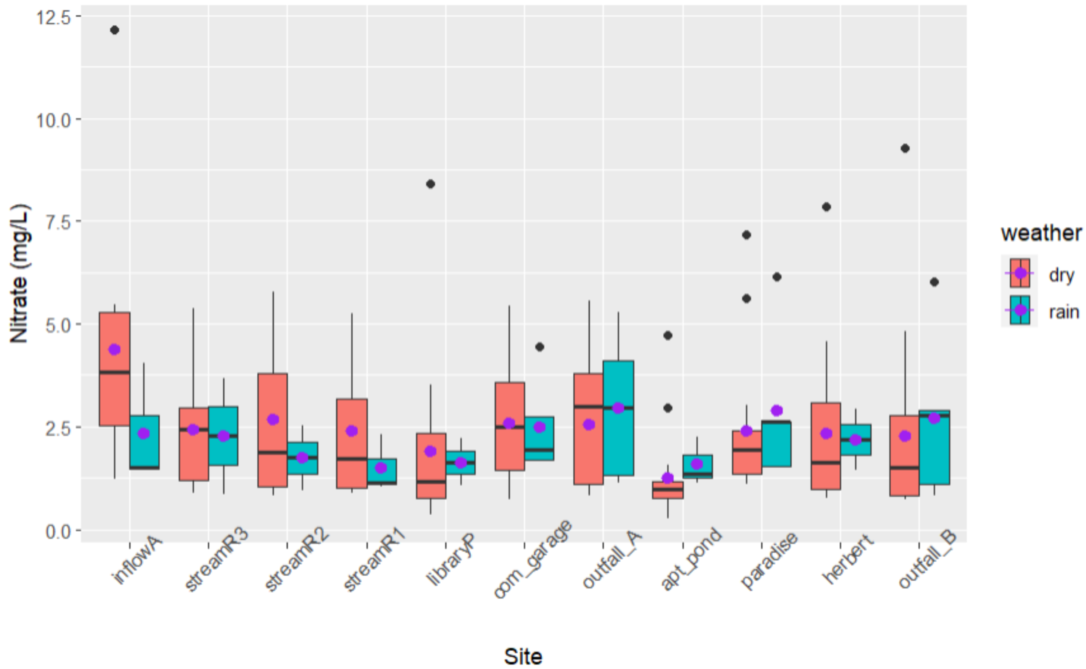

Figure 21: Box plot comparison comparing nitrate-N (mg/L) dry weather and rain data at all sites. collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. Four rain days were collected. The purple dot represents the average concentration at a site.

For ammonium-N, there were no differences in concentration at the sample sites based on weather conditions ($p = 0.2099$). Figure 22 visualizes the weather comparison for ammonium-N.

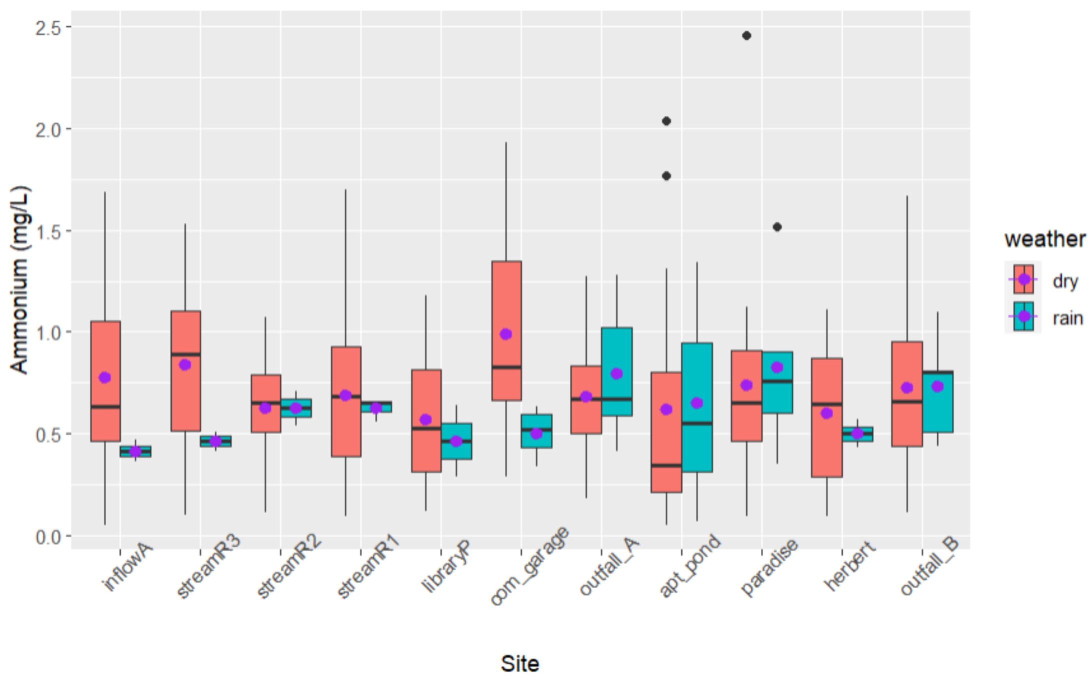

Figure 22: Box plot comparison comparing ammonium-N (mg/L) dry weather and rain data at all sites. collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. Four rain days were collected. The purple dot represents the average concentration at a site.

Specific conductance was also not statistically different based on weather conditions ($p = 0.26515$). Figure 23 visualizes the weather comparison for specific conductance.

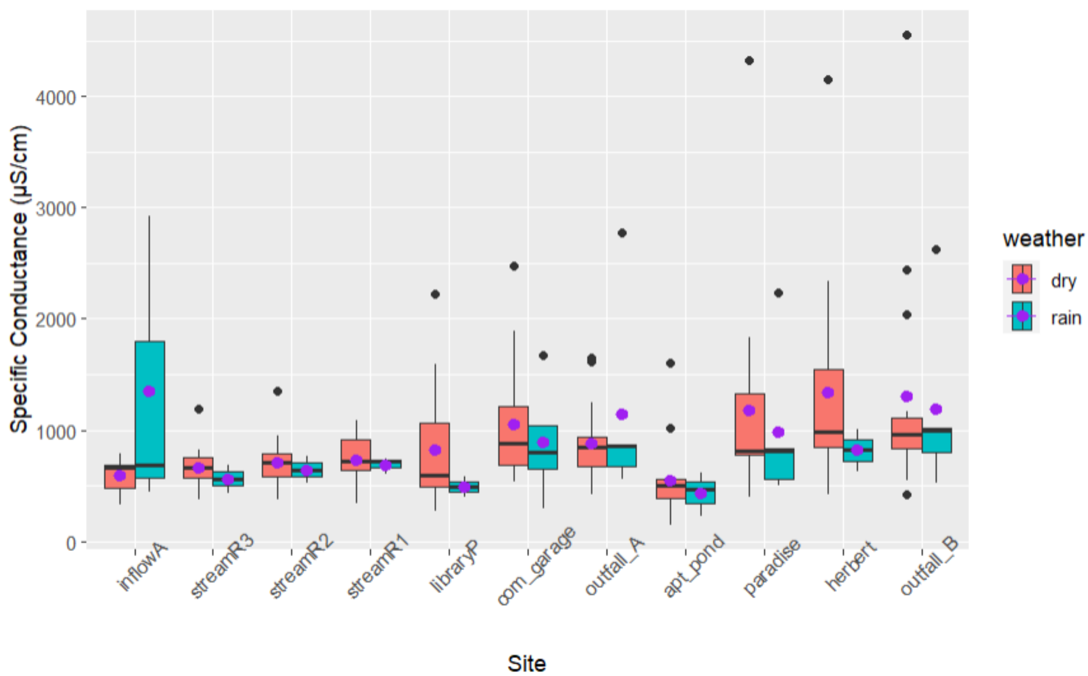

Figure 23: Box plot comparison comparing specific conductance (µS/cm) dry weather and rain data at all sites. collected from streams flowing around the University of Maryland Baltimore County campus in fall/winter 2023-2024. Four rain days were collected. The purple dot represents the average concentration at a site.

<u>RainA vs RainB</u>

Sites RainA and RainB only had data for days when it rained. On January 25th, there was a significant spike in all concentrations at the RainB site. Nitrate-N, ammonium-N, and specific conductance concentrations read as 26.49 mg/L, 10.16 mg/L, and 47737.80 µS/cm, respectively. The sensor was calibrated the day before, and the other sample sites did not show similar anomalous measurements. I compared the sites with and without the RainB outlier on January 25th. Regardless of the outlier, there were no significant differences between concentrations among the rain sites. When isolating the inflow and outflow sites, none of the sites had significantly different concentrations from each other for all parameters.

Association between water quality parameters, land cover, and aggregate mitigated area in upstream catchments

Land cover information was used to provide context for the field measurements recorded throughout the sample period. Initial scatter plots graphed the percent land cover and average parameter concentration for each site. For this analysis, impervious and turf cover were considered. Many of the sites were downstream of each other along the stream network. Linear regressions were carried out for the sites that were mostly independent of each other: InflowA, LibraryP, Outfall_A, Outfall_B, Paradise, and Apt_pond. The following scatter plots show average parameter concentrations at each site graphed with either percent impervious or turf cover in their upstream drainage. The plots were used to observe how all the sites compared to the linear models of average concentrations and land cover. Figure 3 shows the downstream relationships of the sample sites. Tables were also created to show the different linear regression models for each parameter.

The same six sites used in the regression were plotted on prediction plots. The following prediction models are intended to show how well land cover proportions and the mitigated area within a site watershed predict parameter concentrations. Single linear regressions were modeled for land cover proportion and percent mitigated area within a site watershed. A multiple linear regression (MLR) was modeled using land cover and mitigated area. The graphs produced plotted predicted values against measured parameter values relative to a 1:1 line of perfect agreement.

Visualizing how the models predict the parameter values on the same graph was intended to show which one provided the best fit for each parameter.

The linear regression for nitrate and impervious cover showed that most sites were close to the line (Figure 24). However, the linear regression was not significant ($p = 0.74$). Most of the sites had averages between 2 - 3 mg/L. However, Apt_pond, InflowA, and LibraryP were far from the line. Apt_pond had the lowest average concentration of 1.26 mg/L and had 4% impervious cover in its drainage area. InflowA had the highest average nitrate-N concentration of 4.38 mg/L, with 23% impervious cover in its drainage area. LibraryP had an average concentration of 1.91 mg/L and 42% impervious cover in its drainage area. Considering the sampling locations between InflowA and Outfall_A in downstream order, there was a sharp reduction in nitrate-N. The sites that drain only the campus (LibraryP and Com_garage) did not contribute enough nitrate-N to the downstream concentration to raise the concentration. Sites along the stream on side B (Paradise, Herbert, Outfall_B) looked very similar in nitrate concentration, with minimal decrease in impervious cover.

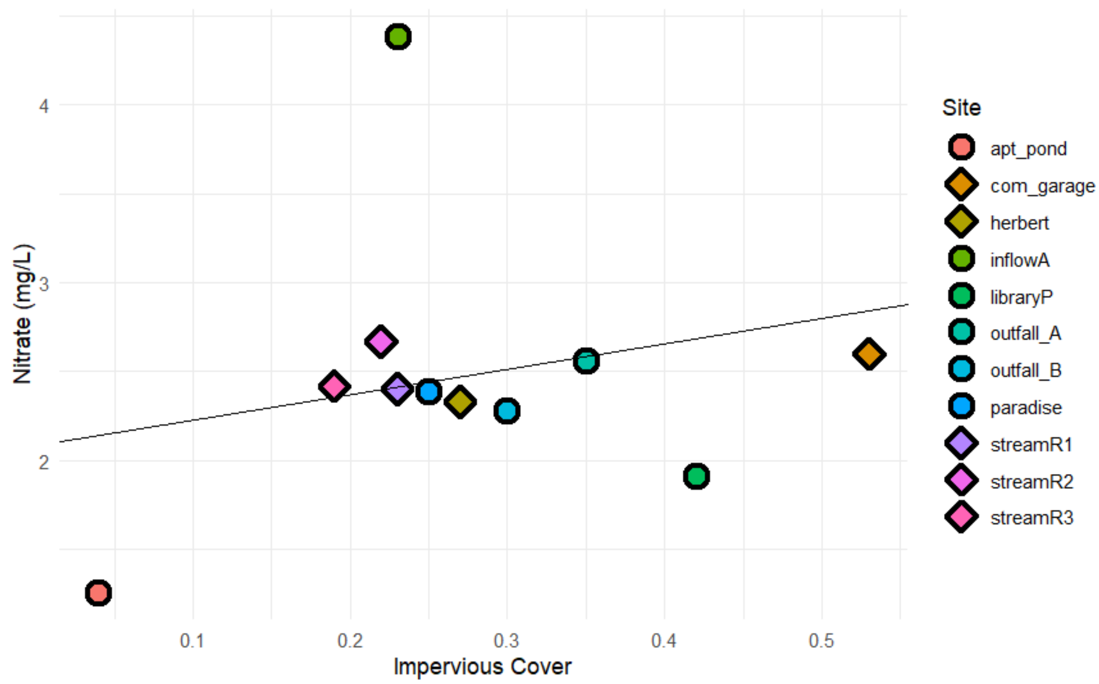

Figure 24: Scatter plot of average nitrate-N concentrations at each sample site and the impervious cover within the site's watershed. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. The circle points indicate the sites used in the linear regression, and the diamond points were not included.

The linear model for nitrate-N and turf cover was also not significant ($p = 0.73$), as shown in Table 7. Most of the sites had less than 40% turf cover in their drainage area (Figure 24). Apt_pond, InflowA, and LibraryP have the highest turf cover in their drainages. From InflowA to StreamR3, there was a noticeable decrease in upstream turf cover and nitrate concentration. The campus area between these two sites mostly added impervious cover. There was an increase in nitrate from LibraryP to Com_garage, and a decrease in turf grass. Again, Apt_pond was isolated from the rest of the data, having the highest percent turf cover but the lowest nitrate-N concentration. The cumulative percent turf cover at Herbert and Outfall B is slightly lower than at Paradise, and the average nitrate-N concentration at Herbert and Outfall B is only slightly lower than at Paradise.

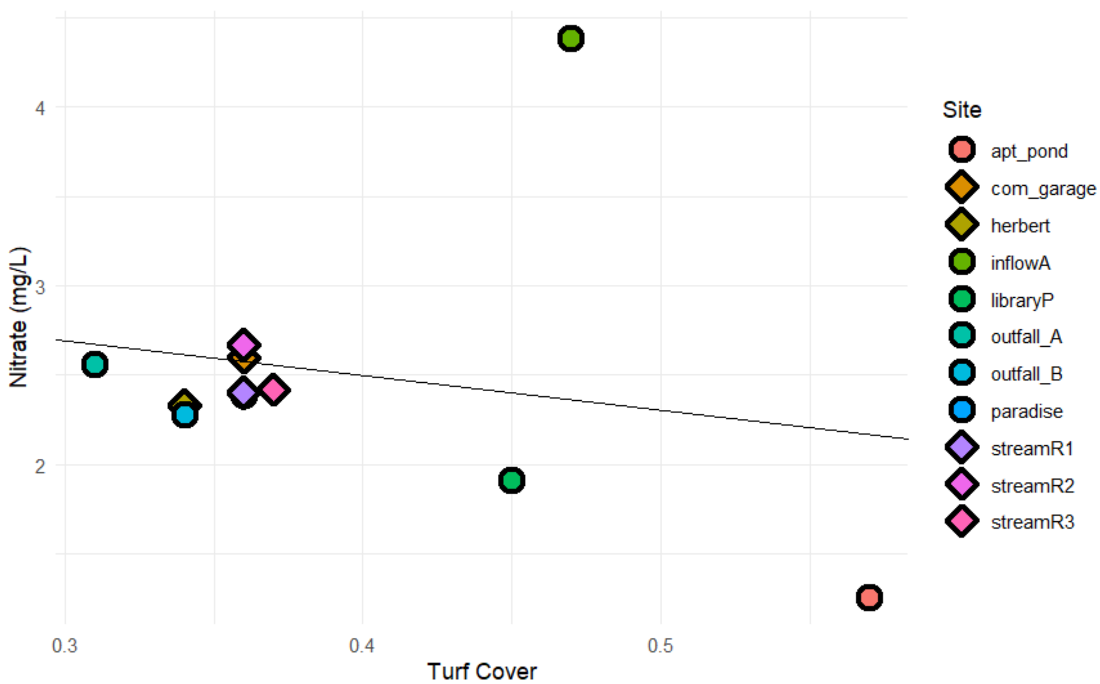

Figure 25: Scatter plot of average nitrate-N concentrations at each sample site and the turf cover within the site's watershed. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. The circle points indicate the sites used in the linear regression, and the diamond points were not included.

Table 7: Different linear regressions for nitrate-N concentrations, land covers, and mitigated area models. Regressions were made using the sites InflowA, Outfall_A, LibraryP, Apt_pond, Paradise, and Outfall_B. "*" indicates a significant p-value.

	R^2	p-value	Linear Regression
Impervious	-0.2106	0.7365	y = 1.429x + 2.082
Imp + mitigated	0.03176	0.4871	y= -0.156*Imp - 1.738*mitigated + 3.119
Turf	-0.209	0.7312	y = - 1.937x + 3.270
mitigated area	0.2258	0.192	y = -1.721x + 3.071
Turf + mitigated	-0.308	0.4871	y= -0.1559*turf - 1.7378*mitigated + 3.1187

None of the nitrate-N models had significant p-values for any of the land cover proportions. Figure 26 is an example graph for predicted nitrate concentrations with percent impervious cover (Imp model) and percent mitigated area in the upstream drainage area. The first two points (Apt_pond and InflowA) were closer to the 1-1 line when the mitigated area within the drainage was added to the model. The third point and fourth points (LibraryP and Outfall_A) were closer to the line with the impervious cover model. The fifth point from the left, Outfall_B, did not change in any of the models. The last point, Paradise, was far from the line, and adding a mitigated area did not help the model much at all. The points for the mitigated model and the MLR for impervious cover and mitigated area were basically the same. The linear model of the mitigated area with nitrate-N had the lowest p-value of 0.19 (Table 7).

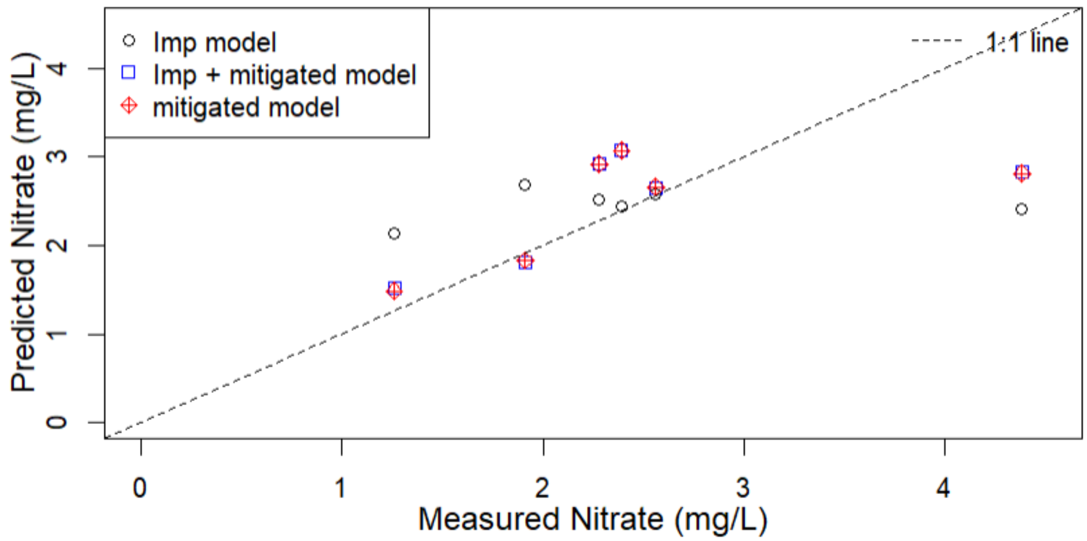

Figure 26: Graph plotting the predicted values of nitrate-N concentrations based on the percent impervious cover and the percent mitigated area within the sites' drainage area. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. 1:1 line graphed to show how well the models predict concentrations. The sites graphed from left to right are Apt_pond, InflowA, LibraryP, Outfall_A, Outfall_B, and Paradise.

For most sites used in the regression, ammonium-N concentrations decreased as impervious cover increased (Figure 27). However, Apt_pond being skewed to the bottom left flattened the slope, which made the line not significant ($p = 0.82$; Table 8). Removing Apt_pond made the regression significant ($p = 0.006485$). Com_garage was another point that stuck out, as it had the highest impervious cover of 53% and the highest ammonium-N concentration of 0.99 mg/L. From libraryP to Com_garage, there was an increase in impervious cover and ammonium-N. While the range of ammonium-N was very small, this was interesting to note because LibraryP had the lowest average concentration of 0.57 mg/L.

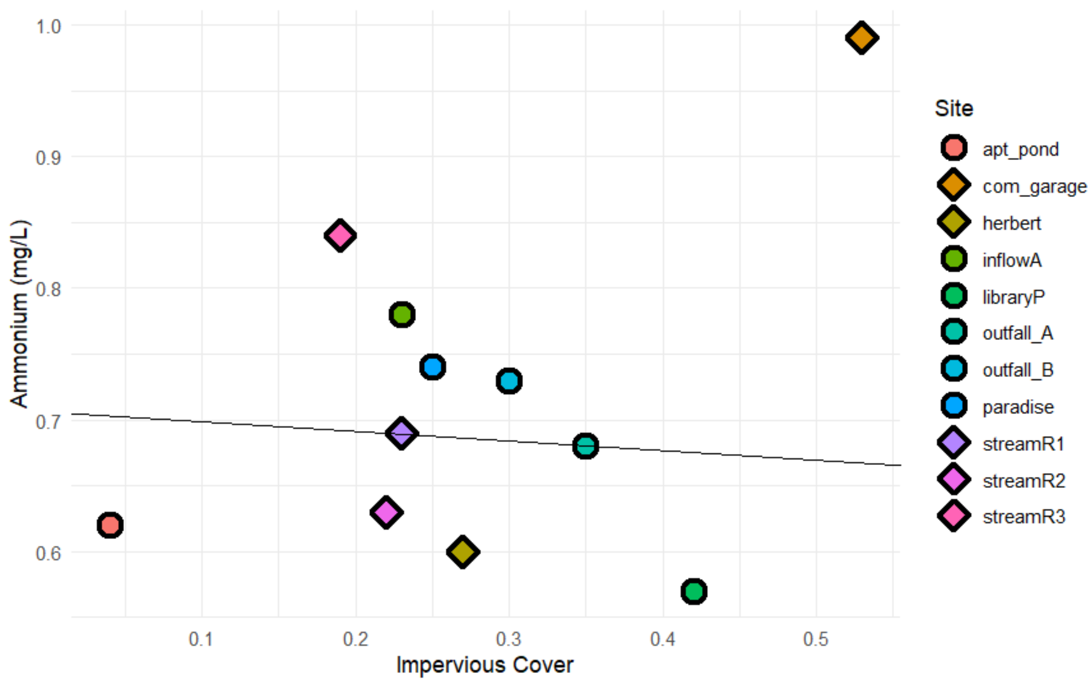

Figure 27: Scatter plot of average ammonium-N concentrations at each sample site and the impervious cover within the site's watershed. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. The circle points indicate the sites used in the linear regression, and the diamond points were not included.

The linear model for ammonium-N and turf cover was not significant ($p = 0.46$), as shown in Table 8. Visually, the sites did not have a clear trend, even without knowing what the linear model would look like (Figure 28). Most of the sites had between 30% and 37% turf cover in their drainage. Looking at sites InflowA and Outfall_A, there was a reduction in ammonium concentration, even with the spike in ammonium contribution from Com_garage. The sites downstream of each other on side B, Paradise, Herbert, and Outfall_B, did not change much in concentration.

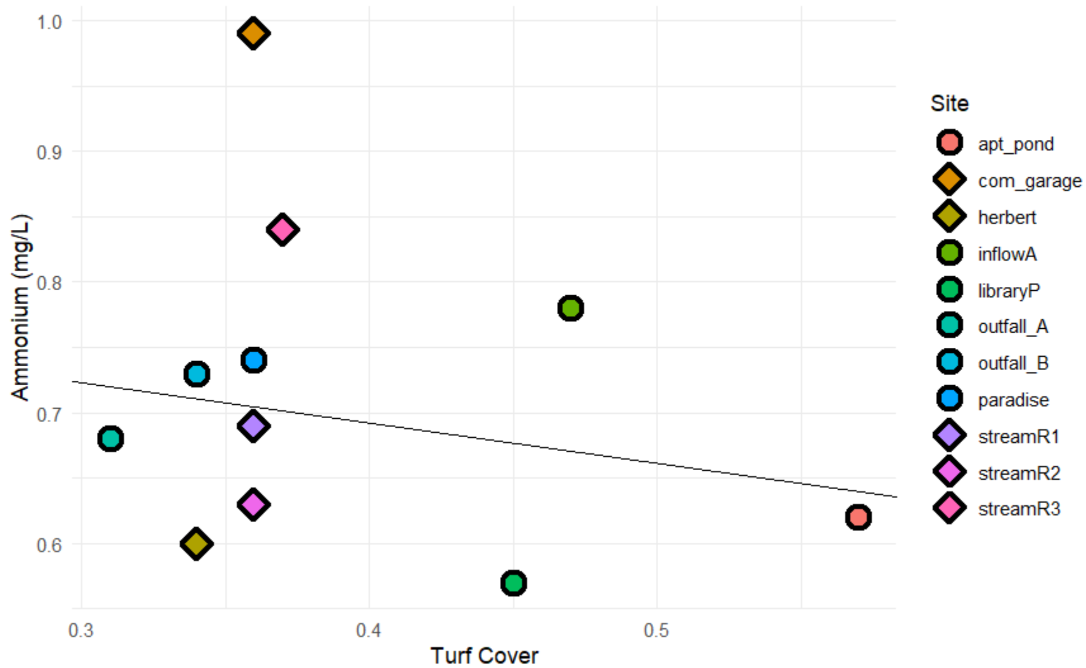

Figure 28: Scatter plot of average ammonium-N concentrations at each sample site and the turf cover within the site's watershed. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. The circle points indicate the sites used in the linear regression, and the diamond points were not included.

Table 8: Table showing the different linear regressions for ammonium-N concentrations, land covers, and mitigated area models. Regressions were made using the sites InflowA, Outfall_A, LibraryP, Apt_pond, Paradise, and Outfall_B. "*" indicates a significant p-value.

	R2	p-value	Linear Regression
Impervious	-0.232	0.821	y = -0.0733x + 0.706
Imp + mitigated	0.871	0.022*	y = -0.267*imp - 0.213 + 0.833
Turf	-0.070	0.458	y = -0.308x + 0.8150
mitigated area	0.688	0.026*	y = -0.183x + 0.751
Turf + mitigated	0.905	0.014*	y = 0.5538*turf - 0.2939*mitigated + 0.5598

For ammonium-N, the mitigated model (p = 0.026) and MLR for impervious cover and mitigated area (p = 0.022) were significant (Table 8). Most of the MLR and the mitigated points are closer to the 1:1 line than the impervious cover points (Figure 29). The third point from the left, LibraryP, had the least change between the models. Except for Paradise (last point from the left), MLR's predictions were close to the 1:1 line.

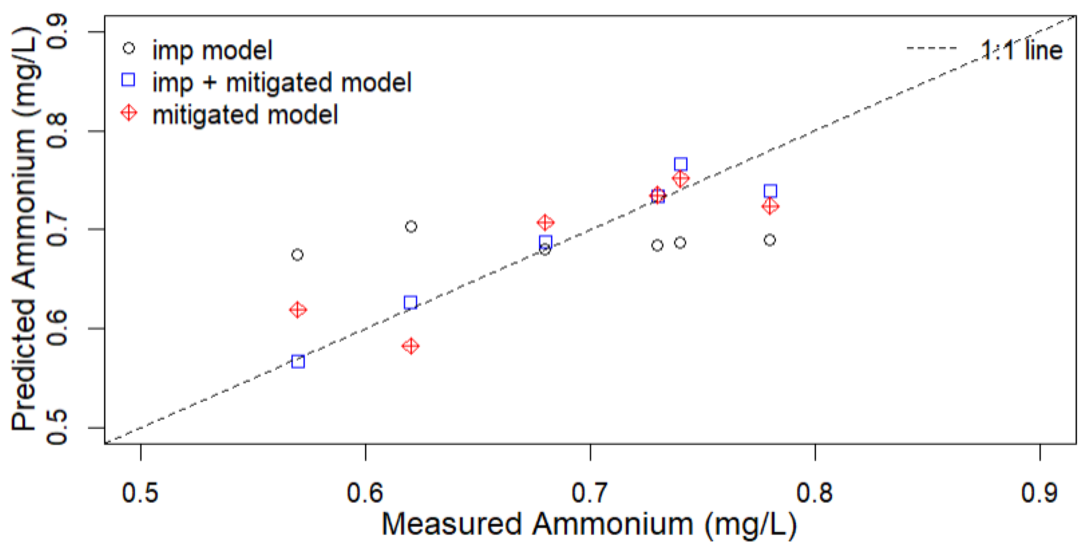

Figure 29: Graph plotting the predicted values of ammonium-N concentrations based on the percent impervious cover and the percent mitigated area within the sites' drainage area. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. 1:1 line graphed to show how well the models predict concentrations. The sites graphed from left to right are Apt_pond, InflowA, LibraryP, Outfall_A, Outfall_B, and Paradise.

The MLR for ammonium-N, turf cover, and mitigated area was also significant (p = 0.014; Table 8). For all the ammonium-N models, adding the mitigated area improved the fit of the model (Figure 30). The turf model alone overpredicted ammonium-N concentrations for Apt_pond, InflowA, and LibraryP (the first three points from the left). The turf model under-predicted concentrations for Outfall_A, Outfall_B, and Paradise (last three from left).

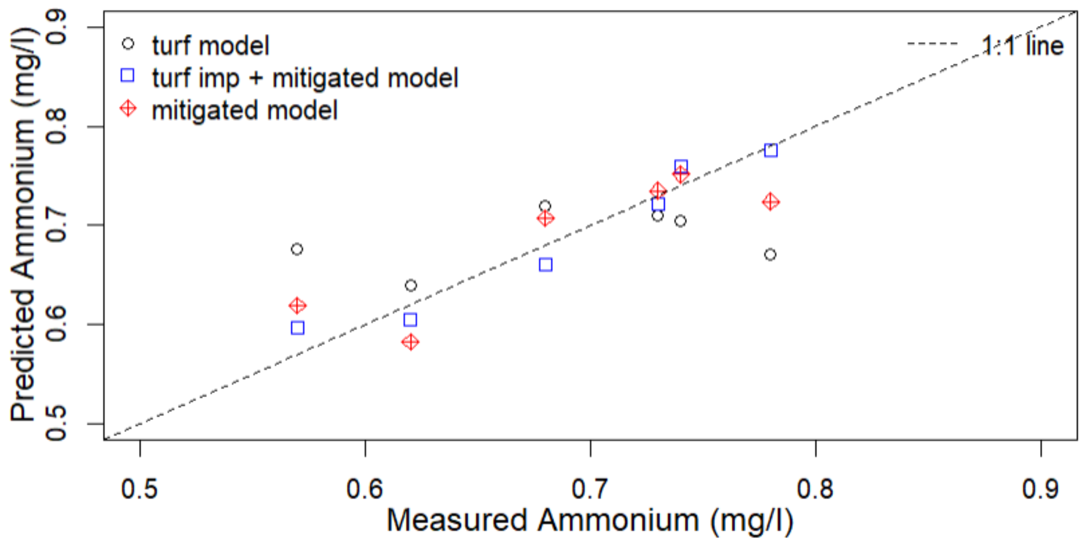

Figure 30: Graph plotting the predicted values of ammonium-N concentrations based on the percent turf cover and the percent mitigated area within the sites' drainage area. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. 1:1 line graphed to show how well the models predict concentrations. The sites graphed from left to right are Apt_pond, InflowA, LibraryP, Outfall_A, Outfall_B, and Paradise.

The linear model for impervious cover and specific conductance was not significant ($p = 0.39$). Paradise, Herbert, and Outfall_B are visually separate from the other sites, having the highest specific conductance averages, but did not have the most impervious cover in their drainages (Figure 31). However, when Outfall_B and Paradise were removed from the regression, the model was still not significant ($p = 0.1186$). From LibraryP to Com_garage, specific conductance increased from 826.11 to 1057.90 µS/cm. The slight downstream increase from InflowA to Outfall_A seemed to mostly come from the LibraryP and Com_garage stream segment.

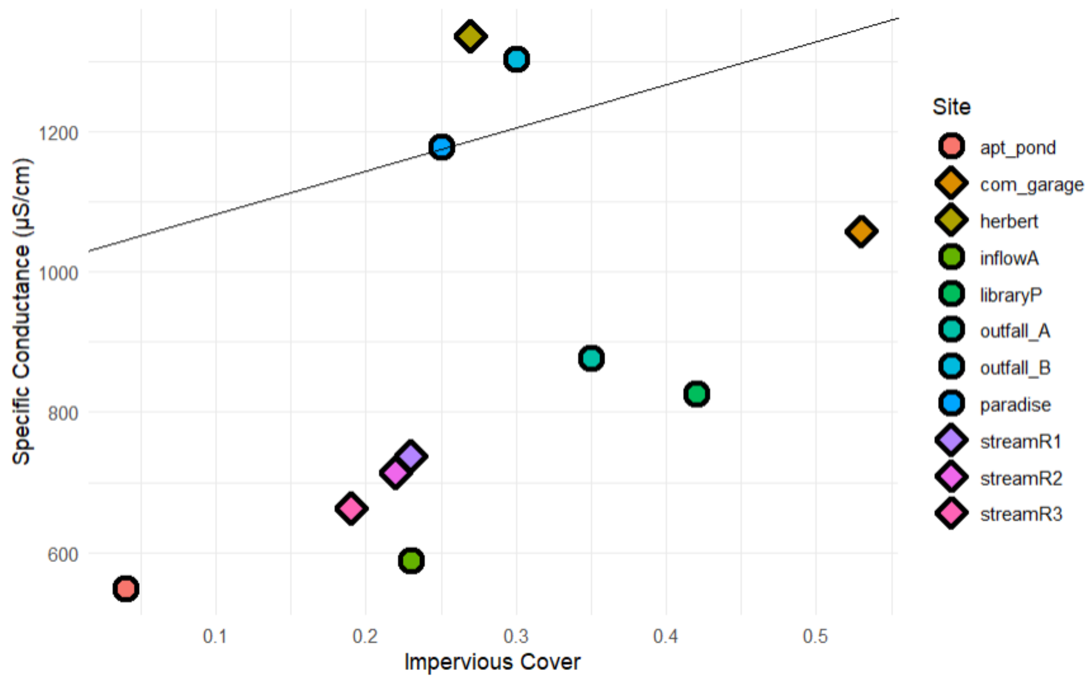

Figure 31: Scatter plot of average specific conductance at each sample site and the impervious cover within the site's watershed. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. The circle points indicate the sites used in the linear regression, and the diamond points were not included.

The linear model for specific conductance and turf cover had the lowest p-value ($p = 0.065$) for all the specific conductance models (Table 9). Although the linear model was not significant, the points do seem to decrease in specific conductance as turf cover increases (Figure 32). The sites Com_garage, LibraryP, and Apt_pond follow closest to the line.

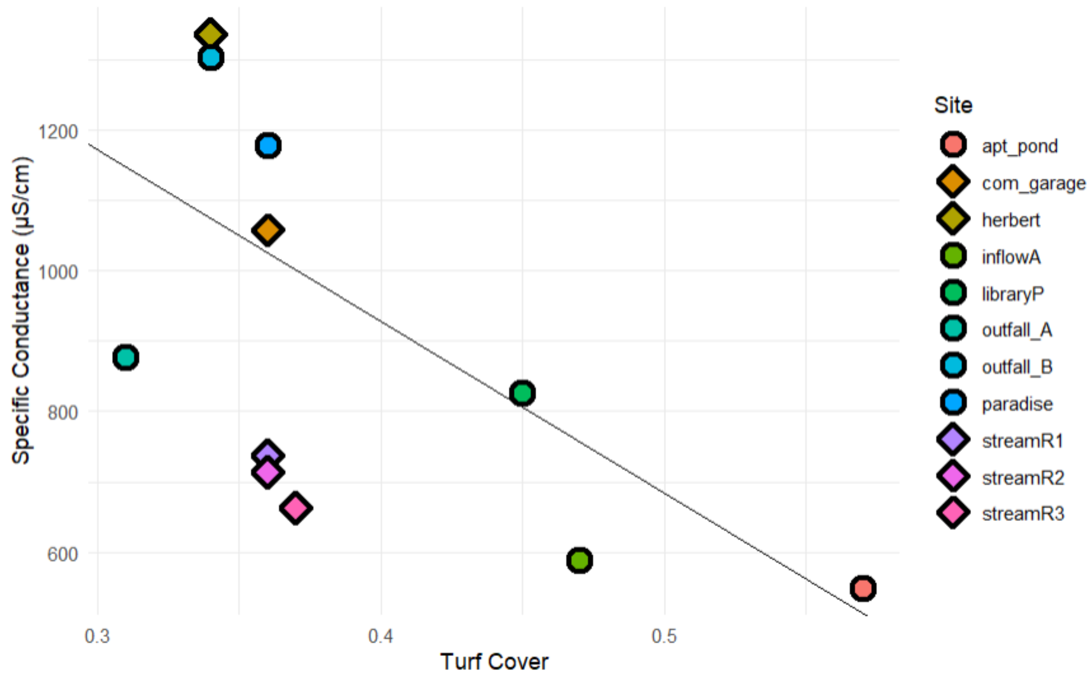

Figure 32: Scatter plot of average specific conductance at each sample site and the turf cover within the site's watershed. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. The circle points indicate the sites used in the linear regression, and the diamond points were not included.

Table 9: Different linear regressions for specific conductance concentrations, land covers, and mitigated area models. Regressions were made using the sites InflowA, Outfall_A, LibraryP, Apt_pond, Paradise, and Outfall_B. "*" indicates a significant p-value.

	R2	p-value	Linear Regression
Impervious	0.01328	0.3884	y = 616.7x + 1021.6
Imp + mitigated	0.1122	0.3888	y = 609.3*imp + -452.1*mitigation + 885.7
Turf	0.5184	0.06491	y = -2444x + 1906
mitigated area	0.01328	0.1731	y = -518.8x + 1070.7
Turf + mitigated	0.3636	0.2359	y = -2227.36*turf - 74.04*mitigated +1841.61

The mitigated area and both MLR for specific conductance models were not significant (Table 9). The turf model predictions were similar to the predictions made with the turf and mitigated MLR (Figure 33).

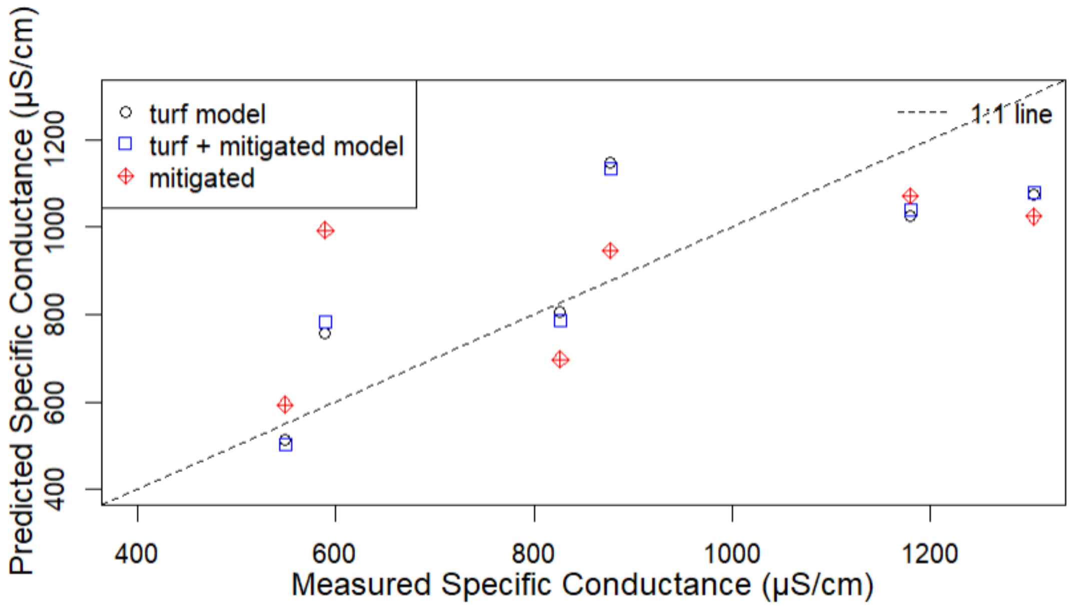

Figure 33: Graph plotting the predicted values of specific conductance based on turf cover and mitigated area within the sites' drainage area. Data was collected from streams flowing around and emerging from the campus of the University of Maryland Baltimore County in fall/winter 2023-2024. 1:1 line graphed to show how well the models predict concentrations. The sites graphed from left to right are Apt_pond, InflowA, LibraryP, Outfall_A, Outfall_B, and Paradise.

Discussion

This work examined how water quality varied spatially and temporally within UMBC's watershed. The observations of the measured parameters, nitrate-N, ammonium-N, and specific conductance, are characterized by different spatial and temporal patterns. Between the nitrogen patterns observed across sites and throughout the sampling period, monthly changes in concentrations were the most apparent. Nitrate-N and ammonium-N had different spatial patterns, indicating potential sources of nitrogen. Specific conductance overall had elevated measurements across all sites and throughout the sampling period. Spatial and temporal trends were also observed with specific conductance measurements. The patterns observed for each parameter highlighted the changes in water quality within the local streams.

Variation in Nitrogen

Nitrate-N concentrations were not statistically different when comparing sides A and B of the watershed (Figure 5). However, when comparing concentrations between smaller spatial groupings, nitrate-N did seem to vary. Post hoc tests showed InflowA was statistically different than multiple sites and had a visually higher average than all the other sites (Figure 12). InflowA's average was likely skewed from the 12.16 mg/L measurement on January 24th. InflowA had the highest nitrate outlier of 12.16 mg/L. When this was removed, there were no differences among the sites ($p = 0.174$). The winter outlier at this site could have been attributed to groundwater flux. In winter, nitrate concentrations can be sourced from legacy nutrients in groundwater (Johnson & Stets, 2020). Without the outlier from InflowA, there were no statistical differences in nitrate across the sites (Figure 12). When InflowA was removed from the turf linear regression, there was a negative trend between turf cover upstream and nitrate-N (Figure 25). Other studies in suburban watersheds observed fertilizer use for lawn care, adding to the nitrate concentrations in streams (Law et al., 2004; Toor et al., 2017). Other than the InflowA outlier, there did not seem to be an outlying source of nitrate-N.

The temporal comparisons showed that nitrate-N concentrations changed the most over time compared to the spatial comparisons. There was an obvious increase in nitrate concentrations from November to the later months, December and January. Based on the literature, an increase in nitrate-N concentrations in streams during winter months should be expected in the campus' watershed. The increase in nitrate-N during winter months was likely due to less solar radiation and decreased biotic activity in the watershed, leading to less uptake of dissolved nitrate-N (H. M. Johnson & Stets, 2020; Roberts et al., 2007). The monthly medians and averages of nitrate-N concentrations measured in this study were not unusual for streams in Maryland (Groffman et al., 2004; H. M. Johnson & Stets, 2020). The most significant trend in nitrate-N concentrations was an increase as the season changed from fall to winter.

On average, ammonium-N concentrations were lower than nitrate-N. This was expected due to ammonium-N being more available to stream biota, which leads to higher uptake rates in streams (Barlett & Leff, 2010; Kemp & Dodds, 2002). There were no significant differences in ammonium-N concentrations across the sampling sites. However, the visual increase of ammonium-N from LibraryP to Com_garage could indicate a new local source between those sites (Figures 13 and 27). Com_garage is fed by an underground pipe coming from LibraryP and could be impacted by an unknown sewage leak from adjacent sewage pipes. In urban watersheds, sewage is known to be a source of ammonium-N (Potter et al., 2014). Overall, ammonium-N had a very small range and showed to have little to no difference in concentrations throughout the sample sites. Apt_pond was a clear visual and statistical outlier in the impervious cover regression (Figure 27). When that site was removed, there was a negative correlation between impervious cover and ammonium-N concentrations. Apt_pond is a stormwater pond on the northeast side of campus (Figure 3). This site consistently had the smallest range and some of the lowest averages for all the parameters. The water quality influences on Apt_pond seemed to have been more localized because it is not fed by a stream. Upstream turf cover did not correlate with ammonium-N concentrations measured at the sample sites. Another urban watershed study also observed the lack of correlation between ammonium-N and watershed land cover (Brett et al., 2005). The linear models with ammonium-N and mitigated area were significant and had better predictions for ammonium-N concentrations (Table 8). These correlations could mean that the area that is mitigated by an SCM might have an impact on ammonium-N concentrations. SCM designs, like bioretention cells, are intended to reduce nutrients through reducing stormwater runoff and biochemical cycling (Jefferson et al., 2017; Li et al., 2019). A way to test for SCM influencing ammonium-N would be to compare the inflow and outflow of individual SCM facilities on campus.

September had higher ammonium-N concentrations than January. Summer concentrations of ammonium-N being higher than winter concentrations were also observed by Mulholland (2004) in first-order streams in Tennessee. Leaf litter breaking down in the streams adds ammonium-N to the stream in late summer and fall (Sebestyen et al., 2014). Tree canopies and leaf litter cover streams, which reduces light availability and can limit nitrification, also causing an increase in ammonium-N in streams (Roberts et al., 2007; Sebestyen et al., 2014). January having lower ammonium-N concentrations could be due to higher uptake rates in the fall, resulting in low concentrations as you get into winter (Hoellein et al., 2007; Simon et al., 2005). Similar to nitrate, sampling ammonium-N throughout the year could help differentiate between regular seasonal fluxes and potential anomalous discharges.

Variation in Specific Conductance

Multiple ANOVA tests confirmed that side B had higher averages of specific conductance than side A. The sites Paradise, Herbert, and Outfall_B, all on side B, had averages higher than their median values, probably because these sites had the highest outliers compared to the side A sites (Figure14). Side B had an impervious cover of 30%, and yet only 7% of it was on campus. Because most of side B's impervious cover was off campus, specific conductance was probably controlled by off-campus processes. The off-campus area on side B included suburban neighborhoods and I-695. Although there was no significant increase between InflowA and Outfall_A, Figure 11 showed a noticeable increase in specific conductance. The 25^{th} quartile of Outfall_A was about the same as InflowA's 75^{th} quartile. Regardless of the spatial trends, all sites had average measurements above the EPA benchmark of 300 µs/cm (USEPA, 2011; Griffith, 2014). This is a concern for aquatic life in the streams (USEPA, 2001; McManus et al., 2020). Bedrock geology is an important factor in understanding specific conductance in streams (Griffith, 2014; Olson & Cormier, 2019). However, the increase in anthropogenic sources (urban infrastructure, agriculture, road salts) has been shown to contribute to dissolved ions in recent years (Fanelli et al., 2024). At a certain threshold of impervious cover, the baseline specific conductance levels are higher than the natural levels (Utz et al., 2016; Baker et al. 2019). SCMs are not designed to remove salts from stormwater, which makes managing dissolved ions in the streams a challenge (Denich et al., 2013). Although off-campus areas potentially influenced specific conductance the most, both sides of the watershed experienced an accumulation of dissolved ions downstream. Both the impervious cover on UMBC's campus and off-campus contributed to the elevated specific conductance measurements observed across the watershed. The spatial variations showed how the presence of impervious cover, and how it's managed, can influence the concentration of dissolved ions in urban streams.

Seasonal changes also influenced specific conductance, specifically when looking at monthly averages. October and January had the highest levels of specific conductance. Evapotranspiration could explain higher specific conductance levels in October. In the US, the end of September or early October is when the water table is typically the lowest in this region. During this time, streams have lower stream flows and shallower depths. This can lead to increased solute concentrations in the water, increasing specific conductance (McManus et al., 2020). Looking at local USGS stream gauge data from the Herbert Run, September had frequent storms that elevated the streamflow more frequently than in October. It seems that the storms in September seemed to replenish the subsurface water enough to keep base flow stable through October. So, during this sampling period, the difference in baseflow did not explain the specific conductance observed between September and October in the watershed. January's exceedingly high specific conductance could be explained by road salts used for winter weather events (Baker et al., 2019; Tu et al., 2007, p. 200).

MDE has created a manual providing information on how to reduce salt application in winter (Bourassa, n.d.). Being conscious of how salt is applied around campus can impact and reduce the winter spike in specific conductance often seen in urban streams.

Variations in Weather Conditions

Nitrate-N was the only parameter to have statistical differences depending on the weather conditions. The model showed that there was an increase in nitrate when it rained. Ammonium-N and specific conductance concentrations were not impacted by weather conditions, based on the model. While the mixed effect model could account for the lack of balance between the groups, it was still noted that the strength of the tests could have improved with more rain data over a wider range of time. The first rain event was not recorded until November, which also could have influenced the variation between the weather conditions. Nitrate had the most seasonal variability compared to the other parameters, which could have impacted ability to distinguish weather effects in the model.

The rain outlier measured at RainB on January 25th was a unique observation while sampling. The reasons for the spikes in pollutants in stormwater were not fully explored. A potential explanation could be that if the sample was measured close enough to the beginning of the storm, the measurements could have been a result of the "first flush" effect. Between rain events, pollutants build up on land surfaces, and when it rains, most of the pollution load is flushed closer to the beginning of the storm before becoming diluted (Hatt et al., 2009; Hopkins et al., 2017). RainB was fed by a stormwater drain and was not diluted by stream water or groundwater. Future work on campus could continue to explore how rain and stormwater runoff impact local water quality and how campus SCM influences water quality.

Constraints and Reflections

The methods of this study came with assumptions and constraints. The assumptions and choices made impacted the analysis and data interpretation. There were also some constraints due to uncontrollable factors. After reflecting on the methods, there were some things that could have improved the study.

The sample sites were selected to represent sections of the local stream that flow into campus, around campus, and leave campus. The sites were selected after walking around campus and selecting sites that were safe and more convenient to get to alone. The sample sites were also selected before creating flow direction and flow accumulation rasters for the watershed. The flow accumulation layer gave more information on where stream segments converged and what land area contributed to what sites. If there were a chance to go back and change sample locations, I would have changed a few of the site locations. InflowA's drainage included a small portion of the campus. Ideally, InflowA's location would have been further upstream so none of the campus's area would have been in its drainage. Unfortunately, where I initially wanted to sample had dense vegetation, and the slope to the stream was very steep. The timing of InflowA sampling also had an impact on the temporal comparisons because it was not sampled during the entire sampling period. Not getting measurements in September or October could have influenced the range data recorded at InflowA and missed potential seasonal trends from a site that represented what flows onto campus property. By the site Paradise, a small stream entered right below my sample site, which includes an area north of campus (Figure 3). Ideally, I would have sampled below this confluence to include that stream segment. Instead, that area was included in the Herbert site drainage further downstream.

The location of Outfall_B excluded drainage from the East Herbert Branch, which is almost entirely off-campus (Figure 3). While this allowed for easier discernment of potential addition or dilution of parameters from campus, Outfall_B's drains do not include the Technology Research Center (TRC) and some of the parking lots on the southeast side of campus. From a campus compliance perspective, this also gives limited information as to how the campus contributed to water quality on side B of the watershed. To correct this, two more sampling points could be added: one further downstream, closer to the campus boundary, and the other on the East Branch of the Herbert Run, right before the campus property. These additional sampling points would have given more information on how on and off-campus areas influence the downstream water quality on side B.

One of the potential goals of this study was to investigate the potential addition or dilution of water quality parameters between rain and dry weather. Only four measurements were taken when it rained. One potential change would have been to not just sample while it was raining, but also include measurements taken soon after rain events, while stream flow was still higher than baseflow. This information could have still given information about how rain impacted water quality without the strict limitation of the duration of a rain event.

A setback that was out of my control was the timing of the Stadium Pond (Stad_pond) renovation. Midway through the sampling period, renovations restricted access to the pond. There were not enough sample measurements at Stad_pond to include it in the analysis. However, the contributions from the Stadium Pond enter the eastern tributary of W.Br. Herbert Run downstream of Outfall_B, so the missing information is not relevant to our understanding of on-campus contributions to water quality at Outfall_B.

In this study, only campus mitigation and UMBC stormwater facilities were considered. This does not consider off-campus stormwater mitigation efforts and whether the water entering campus was treated in any capacity. The mitigated area that was calculated in this study only includes the UMBC campus SCM. The stormwater management practices off campus and the areas they treat were not included. How the mitigated area was calculated does not address whether or how stormwater is treated before reaching campus.

One of the biggest challenges in urban watersheds is human infrastructure used to reroute water. With the campus's storm drain polyline layer, a corrected DEM was created to burn storm drain channels in the topography. However, interpreting the direction in which roof gutters and storm drains are moving water was not straightforward. Multiple versions of the corrected DEM were created to add more storm drains that influence the sample site drainage areas. However, there were probably still pipes that should have been included but were not. If a similar study were to take place at UMBC in the future, an accurate record of stormwater drains would be important in representing how water flows across the campus.

Calculating Campus Contribution Attempt

A method that was explored attempted to estimate the concentration of each parameter that came from on-campus or off-campus areas. The method involved using a mass balance equation derived from the "old" water and "new" water model introduced by Sklash and Farvolden (1970) and explained in Hornberger et al. (2014).

$$\text{Equation 1: } (Q_t * C_t) = (Q_O * C_O) + (Q_n * C_n)$$

For this study, the drainage (DA) area replaced streamflow (Q), and the equation was solved for the estimated concentration between sample sites.

$$\text{Equation 2: } C_x = ((C_2 * DA_2) - (C_1 * DA_1)) / DA_x$$

When applying Equation 2, negative incremental changes were sometimes calculated for nitrate-N and ammonium-N. In these cases, the average measured concentration of the downstream point was lower than the upstream site. This issue was investigated by performing the same calculation for each week. Even the weekly calculations sometimes resulted in negative values. Both nitrate-N and ammonium-N concentrations were highly variable throughout the study, and did not have consistent increasing or decreasing trends downstream. The assumptions of the equation probably did not consider a decrease in downstream concentrations between sample sites relatively close to each other. Ultimately, with the available data, too many of the equations' assumptions were violated. Although the concept had merit in trying to unpack campus contributions between sampling sites, the results could not be used and therefore were not presented here.

<u>Conclusion</u>

The results of this work highlight the patterns of nitrate-N, ammonium-N, and specific conductance across UMBC's watershed. This work was intended to be the starting point for a longer conversation about how the campus influences surrounding water quality. After removing the winter outlier measurement from InflowA, there were no spatial differences in nitrate. Even with the outlier included, the campus seemed to dilute or not contribute a considerable amount of nitrate-N downstream. For ammonium-N, Com_garage having elevated concentrations could indicate a sewage leak near the center of campus. This could be further investigated with bacterial testing to confirm if this is an input of organic matter. Urban influences within the watershed led to the overall elevated specific conductance measurement observed throughout the study. Winter salt application was also a clear source of dissolved ions. Specific conductance measurements observed were concerning. While this is not unusual for suburban areas, the specific conductance measurements recorded are unsuitable for aquatic life. The campus could manage salt usage by waiting until low temperatures reach freezing to start salting roads and sidewalks. State and local governments are becoming more aware of the impact winter salts have on water quality and are making efforts to reduce salt use when possible. Being conscious about how much salt is used and only using it when temperatures are reported to be freezing can limit additional ions in the local streams.

Despite some water quality influences being out of UMBC's control, the campus can use the information in this study to help inform long-term watershed conservation and management efforts. Nitrate-N was mostly influenced by seasonal changes to nutrient uptake, resulting in higher concentrations in the winter months.

Ammonium-N was seasonally impacted by added organic matter from leaf litter in the fall. In the late summer and fall, specific conductance could be impacted by changes in stream base flow. While these seasonal changes are out of the campus's control, understanding the seasonal fluxes of nitrogen over time can help distinguish between normal temporal variation and potential abnormal pollution discharges throughout the year.

Future Work on Campus

Environmental policy requires the mitigation of urban pollutants in stormwater. Legislation has come a long way in regulating human impacts on the environment. Public universities, like UMBC, set ambitious environmental goals. UMBC has strong initiatives to offset its carbon footprint, reduce food waste, and mitigate urban stormwater pollutants. While this study does not address every aspect of mitigating stormwater impacts at UMBC, this work can be continued through student-led monitoring. This research has sparked professors' interest in integrating water quality testing into the undergraduate curriculum. I have also connected with an undergraduate course to implement water quality testing and recording in their curriculum. By starting a student-led water monitoring program, UMBC can develop a database that would track long-term trends in water chemistry. I have had conversations with UMBC's Office of Sustainability to create a water quality dashboard accessible on their website. The data from this study and the sample locations have been added to the dashboard.

With a water quality database, campus staff can create future management plans that incorporate long-term data. Future researchers can also expand on this work by focusing on individual SCMs or delving into other impacts on water quality. UMBC has the opportunity to utilize student monitoring to further promote campus research, inform land management plans, and bring awareness to UMBC's initiative to preserve the health of the local streams.

https://public.tableau.com/app/profile/umbc.sustainability/viz/CampusWaterQuality/LocationsMap

Appendices

Appendix A: Water Quality Data

Date	Site	Avg_NO3(mg/L)	Avg_NH4(mg/L)	SC(µS/cm)
9/12/2023	libraryP	0.90	1.18	n/a
9/12/2023	paradise	1.42	0.61	n/a
9/12/2023	stad_pond	0.66	0.28	152.07
9/12/2023	apt_pond	1.06	0.79	518.28
9/12/2023	herbert	1.39	0.61	n/a
9/12/2023	outfall_B	1.01	0.76	n/a
9/14/2023	com_garage	1.84	1.87	750.52
9/14/2023	streamR1	1.33	0.27	n/a
9/14/2023	streamR2	1.70	0.72	n/a
9/14/2023	streamR3	1.22	0.46	560.18
9/14/2023	outfall_A	1.16	0.29	n/a
9/26/2023	libraryP	0.35	1.03	447.58
9/26/2023	com_garage	0.74	0.97	630.07
9/26/2023	streamR1	0.87	0.97	660.39
9/26/2023	streamR2	1.72	1.07	676.59
9/26/2023	streamR3	1.01	1.48	664.72
9/26/2023	outfall_A	0.82	0.90	677.58
9/26/2023	paradise	1.10	2.46	805.21
9/26/2023	stad_pond	0.11	0.22	89.68
9/26/2023	apt_pond	0.27	0.51	367.85
9/26/2023	herbert	0.77	1.06	881.60
9/26/2023	outfall_B	0.75	1.55	859.32
10/3/2023	com_garage	1.12	0.54	869.47
10/3/2023	streamR1	0.94	0.32	1059.79
10/3/2023	streamR2	1.03	0.51	792.87
10/3/2023	streamR3	1.53	1.53	672.03
10/3/2023	outfall_A	0.89	0.43	962.25
10/5/2023	libraryP	0.57	0.30	1339.63
10/5/2023	paradise	1.23	0.27	1658.54
10/5/2023	stad_pond	0.31	0.05	302.83
10/5/2023	apt_pond	0.37	0.17	426.04
10/5/2023	herbert	0.87	0.26	2053.15
10/5/2023	outfall_B	0.74	0.38	2041.36
10/17/2023	libraryP	0.64	0.14	581.41
10/17/2023	paradise	1.30	0.16	831.44

10/17/2023	stad_pond	0.18	0.06	194.85
10/17/2023	apt_pond	0.69	0.14	497.83
10/17/2023	herbert	0.87	0.20	975.50
10/17/2023	outfall_B	0.77	0.21	951.51
10/26/2023	libraryP	0.96	1.00	835.15
10/26/2023	com_garage	1.45	1.47	1626.17
10/26/2023	streamR1	1.04	1.70	1085.88
10/26/2023	streamR2	1.02	0.89	1353.02
10/26/2023	streamR3	1.21	1.07	1193.77
10/26/2023	outfall_A	1.14	1.27	1619.53
10/26/2023	paradise	1.86	0.89	1559.19
10/26/2023	stad_pond	0.21	0.21	379.50
10/26/2023	apt_pond	0.72	0.85	1013.79
10/26/2023	herbert	1.11	1.11	1950.05
10/26/2023	outfall_B	1.15	0.95	1058.78
10/31/2023	com_garage	1.42	1.93	973.30
10/31/2023	streamR1	0.94	0.68	870.49
10/31/2023	streamR2	0.81	0.58	768.58
10/31/2023	streamR3	1.12	0.65	785.11
10/31/2023	outfall_A	0.94	1.09	857.26
11/2/2023	libraryP	0.75	0.71	600.45
11/2/2023	inflowA	1.21	0.63	671.67
11/2/2023	paradise	1.48	1.02	816.72
11/2/2023	stad_pond	0.20	0.11	153.22
11/2/2023	apt_pond	0.84	0.36	542.31
11/2/2023	herbert	0.96	1.00	993.87
11/2/2023	outfall_B	0.79	0.61	976.18
11/7/2023	com_garage	1.57	1.47	879.54
11/7/2023	inflowA	1.43	0.34	688.61
11/7/2023	streamR1	0.99	0.45	737.27
11/7/2023	streamR2	0.94	0.38	740.27
11/7/2023	streamR3	0.89	1.06	714.95
11/7/2023	outfall_A	1.27	1.05	880.52
11/9/2023	libraryP	0.73	0.32	602.90
11/9/2023	paradise	1.26	0.55	838.99
11/9/2023	stad_pond	0.31	0.11	155.46
11/9/2023	apt_pond	0.83	0.27	570.65
11/9/2023	herbert	0.99	0.30	1041.37
11/9/2023	outfall_B	0.84	0.50	1025.22
11/14/2023	libraryP	0.97	0.55	584.73
11/14/2023	com_garage	1.35	0.70	878.18
11/14/2023	inflowA	1.56	0.45	664.31
11/14/2023	streamR1	1.03	0.88	704.74

11/14/2023	streamR2	0.95	0.51	701.72
11/14/2023	streamR3	1.20	0.53	691.87
11/14/2023	outfall_A	1.04	0.63	842.44
11/14/2023	paradise	1.38	0.90	799.41
11/14/2023	stad_pond	0.37	0.13	154.71
11/14/2023	apt_pond	0.79	2.04	590.98
11/14/2023	herbert	1.15	0.68	978.84
11/14/2023	outfall_B	1.02	0.54	957.25
12/5/2023	libraryP	1.35	0.88	463.23
12/5/2023	paradise	2.12	0.94	698.82
12/5/2023	apt_pond	1.00	1.77	390.74
12/5/2023	herbert	1.85	0.78	803.19
12/5/2023	outfall_B	1.86	0.70	773.35
12/7/2023	com_garage	3.48	0.78	531.00
12/7/2023	inflowA	5.48	1.61	332.71
12/7/2023	streamR1	2.54	1.01	448.60
12/7/2023	streamR2	3.58	0.74	389.47
12/7/2023	streamR3	2.76	0.89	385.35
12/7/2023	outfall_A	3.79	0.67	455.60
12/14/2023	libraryP	2.58	0.38	320.30
12/14/2023	com_garage	3.67	0.63	549.70
12/14/2023	inflowA	4.90	0.47	381.60
12/14/2023	streamR1	3.38	0.51	423.20
12/14/2023	streamR2	4.04	0.53	381.50
12/14/2023	streamR3	3.06	0.50	379.80
12/14/2023	outfall_A	3.81	0.63	436.80
12/14/2023	paradise	2.82	0.85	472.80
12/14/2023	apt_pond	1.57	1.31	215.90
12/14/2023	herbert	3.06	0.38	558.30
12/14/2023	outfall_B	3.25	0.46	553.60
12/19/2023	libraryP	1.80	0.35	268.40
12/19/2023	paradise	2.23	0.65	396.30
12/19/2023	apt_pond	1.26	0.30	148.60
12/19/2023	herbert	3.15	0.45	416.50
12/19/2023	outfall_B	2.36	1.14	416.50
12/21/2023	com_garage	2.88	0.77	599.10
12/21/2023	inflowA	3.56	1.19	374.60
12/21/2023	streamR1	2.99	0.70	342.60
12/21/2023	streamR2	1.86	0.84	431.80
12/21/2023	streamR3	2.71	1.14	371.70
12/21/2023	outfall_A	2.99	0.75	417.10
1/2/2024	com_garage	3.14	0.35	1131.30
1/2/2024	inflowA	3.47	0.53	605.00

1/2/2024	streamR1	2.78	0.23	634.50
1/2/2024	streamR2	3.22	0.28	706.20
1/2/2024	streamR3	2.84	0.38	609.10
1/2/2024	outfall_A	3.33	0.18	696.90
1/4/2024	libraryP	1.93	0.14	n/a
1/4/2024	paradise	2.02	0.09	799.70
1/4/2024	apt_pond	0.95	0.05	348.10
1/4/2024	herbert	2.32	0.13	934.00
1/4/2024	outfall_B	2.07	0.31	956.10
1/8/2024	libraryP	2.24	0.79	567.80
1/8/2024	com_garage	2.49	1.03	780.60
1/8/2024	inflowA	3.81	1.69	571.80
1/8/2024	paradise	2.27	0.65	754.50
1/8/2024	streamR1	1.73	1.29	812.50
1/8/2024	streamR2	3.23	0.91	549.30
1/8/2024	streamR3	2.43	1.18	589.90
1/8/2024	outfall_A	3.01	0.77	667.60
1/8/2024	apt_pond	1.11	0.59	507.10
1/8/2024	herbert	2.79	0.71	810.30
1/8/2024	outfall_B	2.63	0.79	817.60
1/17/2024	libraryP	8.41	0.50	1592.70
1/17/2024	paradise	7.17	1.12	4324.40
1/17/2024	apt_pond	2.97	0.21	549.60
1/17/2024	herbert	7.84	1.03	4149.90
1/17/2024	outfall_B	9.27	1.67	4555.10
1/18/2024	com_garage	5.44	1.23	2478.80
1/18/2024	inflowA	5.18	0.91	792.70
1/18/2024	streamR1	5.26	0.69	936.10
1/18/2024	streamR2	5.64	0.65	851.70
1/18/2024	streamR3	5.17	0.72	825.30
1/18/2024	outfall_A	5.57	0.57	1247.90
1/24/2024	com_garage	4.22	0.83	1892.80
1/24/2024	inflowA	12.16	0.67	736.80
1/24/2024	streamR1	5.16	0.57	942.80
1/24/2024	streamR2	5.77	0.68	945.40
1/24/2024	streamR3	5.38	0.94	824.90
1/24/2024	outfall_A	4.19	0.72	1651.80
1/26/2024	libraryP	2.89	0.75	2227.30
1/26/2024	paradise	3.02	0.53	1833.90
1/26/2024	apt_pond	1.00	0.21	496.80
1/26/2024	herbert	3.59	0.83	2341.90
1/26/2024	outfall_B	3.19	0.95	2447.20
1/31/2024	com_garage	4.14	0.29	1298.00

1/31/2024	inflowA	5.41	0.05	661.80
1/31/2024	streamR1	4.98	0.09	654.40
1/31/2024	streamR2	4.51	0.11	694.40
1/31/2024	streamR3	3.72	0.10	665.40
1/31/2024	outfall_A	4.46	0.30	862.00
2/1/2024	libraryP	3.52	0.12	1134.00
2/1/2024	paradise	5.63	0.12	1099.80
2/1/2024	apt_pond	4.72	0.33	1599.40
2/1/2024	herbert	4.57	0.09	1153.40
2/1/2024	outfall_B	4.81	0.11	1168.60

This table includes all nitrate-N, ammonium-N, and specific conductance measurements taken at sample sites from ponds and emanating streams within the University of Maryland Baltimore County watershed. All measurements were taken on dry weather days. Samples were taken between 9/12/2023 and 2/1/2024.

Appendix B: University of Maryland Baltimore County Stormwater Control Measures

OBJ_ID	Facility_T	Outfall_Po	Drainage_A	BMP_Name

1	Wet Pond	A	A1	Library Pond
2	Wet Pond	A	A1	Library Pond
3	Retention Pond	B	B5	Stadium Parking Lot Pond
4	Detention Pond	B	B7	Parking Lot 24 Pond
5	Detention Pond	B	B5	FM Building Pond
6	Peat/Sand Filter	A	A1	Lot 8 Peat/Sand Filter-N
7	Peat/Sand Filter	A	A1	Lot 8 Peat/Sand Filter-S
8	Detention Pond	A	A2	Parking Lot 2 Pond
9	Bioretention	B	B2	Harbor Hall Bioretention
10	Bioretention	A	A4	ITE Bldg Bioretention
11	Sand Filter/UG Detention	A	A1	Walker Ave Garage Sand Filter
12	Wet Pond	B	B6	Walker Ave Apts Pond
13	Detention Pond	A	A3	Parking Lot 22 Pond
14	Sand Filter	A	A1	220 Avenue Sand Filter
15	Rainwater Harvesting	A	A3	PAHB Rainwater Harvesting
16	Permeable Pavement	A	A2	Parking Lot 1 Porous Paving
17	Permeable Pavement	A	A5	Parking Lot 3 Porous Paving
18	Permeable Pavement	B	B7	Parking Lot 23E Porous Paving
19	Permeable Pavement	B	B7	Parking Lot 23W Porous Paving
20	Recharge Facility	B	B2	Recharge Facility (Volleyball Ct)
21	Micro-Bioretention	B	B2	True Grit's Micro-Bioretention 1C
22	Bioswale	B	B2	Bioswale 1D
23	Micro-Bioretention	B	B2	True Grit's Micro-Bioretention 1E
24	Micro-Bioretention	B	B5	PAT Hall Micro-Bioretention 2B (Planter)
25	Micro-Bioretention	B	B5	PAT Hall Micro-Bioretention 2C (Planter)
26	Non-Rooftop Disconnection	B	B5	SUS Hall NRD Sidewalk/Trench N
27	Non-Rooftop Disconnection	B	B5	SUS Hall NRD Sidewalk/Trench S
28	Micro-Bioretention	B	B2	PAT Hall Micro-Bioretention 3B

29	Micro-Bioretention	B	B2	PAT Hall Micro-Bioretention 3C
30	Micro-Bioretention	B	B2	PAT Hall Micro-Bioretention 3D
31	Micro-Bioretention	B	B2	PAT Hall Micro-Bioretention 4B
32	Micro-Bioretention	B	B2	PMC Hall Micro-Bioretention 4C
33	Micro-Bioretention	B	B5	Parking Lot 1 Micro-Bioretention 1
34	Micro-Bioretention	A	A5	Parking Lot 1 Micro-Bioretention 2
35	Micro-Bioretention	A	A5	Parking Lot 1 Micro-Bioretention 3
36	Micro-Bioretention	B	B5	Parking Lot 1 Micro-Bioretention 4
37	Non-Rooftop Disconnection	B	B5	Parking Lot 1 NRD Sidewalk
38	Green Roof	B	B2	Apt. Community Center Green Roof
39	Permeable Pavement	B	B2	Parking Lot 6 Porous Paving
41	Micro-Bioretention	A	A2	Quad South Micro-Bioretention
42	Micro-Bioretention	B	B2	Terrace Drive Micro-Bioretention
43	Micro-Bioretention	B	B2	Terrace/Tuckahoe Micro-Bioretention
44	Micro-Bioretention	A	A1	PAHB Micro-Bioretention 1
45	Micro-Bioretention	A	A3	PAHB Micro Bioretention 2
46	Micro-Bioretention	A	A3	PAHB Micro-Bioretention 3
47	Micro-Bioretention	B	B1	West Hill Micro-Bioretention 1
48	Micro-Bioretention	B	B1	West Hill Micro-Bioretention 2
49	Micro-Bioretention	B	B1	West Hill Micro-Bioretention 3
50	Micro-Bioretention	B	B1	West Hill Micro-Bioretention 4
51	Micro-Bioretention	B	B1	West Hill Micro-Bioretention 5

52	Micro-Bioretention	B	B1	West Hill Micro-Bioretention 6
53	Micro-Bioretention	A	A4	Gateway Micro-bioretention 1A
54	Micro-Bioretention	A	A4	Gateway Micro-bioretention 1B
55	Bioretention	A	A4	Gateway Bioretention 2
56	Bioretention	A	A4	Gateway Bioretention 3
57	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 4
58	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 5
59	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 6
60	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 7
61	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 8
62	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 9A
63	Bioretention	A	A4	Gateway Bioretention 9B
64	Bioretention	A	A4	Gateway Bioretention 10
65	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 11
66	Micro-Bioretention	A	A4	Gateway Micro-Bioretention 12
67	Micro-Bioretention	B	B3	Parking Lot 29 Micro-Bioretention 1
68	Micro-Bioretention	B	B3	Parking Lot 29 Micro-Bioretention 2
69	Micro-Bioretention	B	B3	Parking Lot 29 Micro-Bioretention 3
70	Micro-Bioretention	B	B3	Parking Lot 29 Micro-Bioretention 4
71	Submerged Gravel Wetland	A	A1	Parking Lot 29 Submerged wetland
72	Non-Rooftop Disconnection	B	B6	Antenna Tower Non-rooftop Disconnection
73	Green Roof	A	A2/A4	Administration Bldg Green Roof
74	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 1
75	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 2

76	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 3
77	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 5
78	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 6
79	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 7
80	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 8
81	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 9
82	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 10
83	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 11
84	Micro-Bioretention	A	A5	Event Center Micro-Bioretention 12
85	Micro-Bioretention	A	A2	Commons Drive Micro-Bioretention 13
86	Micro-Bioretention	A	A2	Commons Drive Micro-Bioretention 14
87	Micro-Bioretention	A	A2	Commons Drive Micro-Bioretention 15
88	Green Roof	A	A5	Event Center Green Roof
89	Green Roof	A	A2	ILSB Green Roof
90	Micro-Bioretention	A	A2	ILSB Micro-Bioretention 1
91	Micro-Bioretention	A	A2	ILSB Micro-Bioretention 2
92	Micro-Bioretention	A	A2	ILSB Micro-Bioretention 3
93	Micro-Bioretention	A	A2	ILSB Micro-Bioretention 4
94	Micro-Bioretention	A	A2	ILSB Micro-Bioretention 5
95	Non-Rooftop Disconnection	A	A2	ILSB NRD Sidewalk E
96	Non-Rooftop Disconnection	A	A2	ILSB NRD Sidewalk W
97	unk (Pig Pen Pond)	N/A	N/A	
98	Sediment Dam	B	B4	Herbert Run Dam

Table of the stormwater control measures (SCM) on the University of Maryland Baltimore County Campus. The text in red indicates where information was added to the original database.

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