VIRGINIA WATER RESOURCES RESEARCH CENTER

Development of Aquatic Life Use Assessment Protocols for Class VII Waters in Virginia

2020 Report of the Academic Advisory Committee for Virginia Department of Environmental Quality

SPECIAL REPORT

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DEVELOPMENT OF AQUATIC LIFE USE ASSESSMENT PROTOCOLS FOR CLASS VII WATERS IN VIRGINIA

2020 Report of the Academic Advisory Committee for Virginia Department of Environmental Quality

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Author Biography

Andrew Garey began his participation in this investigation in 2012 while working at Virginia Commonwealth University (VCU) as the manager of the Aquatic Ecology Lab, under the direction of Dr. Leonard Smock (AAC member). Andrew became a member of the Academic Advisory Committee (AAC) in 2013. Andrew was employed at VCU and served on the AAC until September, 2016, when he was hired by the Virginia Department of Environmental Quality (DEQ). He now serves as the Water Quality Monitoring Team Leader for DEQ. Andrew participates as a DEQ-based investigator and technical consultant on projects of the AAC.

Introduction

Swamp waters are legally defined in Virginia as: "waters with naturally occurring low pH and low dissolved oxygen caused by (i) low flow velocity that prevents mixing and reaeration of stagnant, shallow waters and (ii) decomposition of vegetation that lowers dissolved oxygen concentrations and causes tannic acids to color the water and lower the pH" (Virginia Code: 9VAC25-260-5).

This report details the ongoing efforts by the Virginia Department of Environmental Quality (DEQ) and the Academic Advisory Committee (AAC) toward identifying and classifying freshwater, non-tidal swamp waters in the Coastal Plain physiographic province of Virginia. This ongoing work includes development of GIS (geographic information system) and on-site habitat evaluation methods that best separate least-disturbed swamps from least-disturbed streams. This work has largely been halted by current suspensions in agency activities and expenditures precipitated by the COVID-19 pandemic. Planned next steps are briefly outlined in the final section this report (Future Work).

No field data collection occurred for this project in 2020. Several datasets from the 2019 field campaign were not available at the time of the fiscal year 2019 (FY 2019) report. These datasets included fish assemblage and benthic macroinvertebrate assemblage samples and laboratory analyses of total nitrogen and total phosphorus samples. The objective of this report is to provide a brief update of the project based on these data, which are now available. Appendices A–E, which contain detailed versions of the data referred to in this report, are included in a supplementary Excel (.xlsx) file (*Swamps_2020_Appendices.xlsx*).

Field Methods

Swamp and stream sites selected for investigation and presented in this report are those that, based on preliminary review of digital imagery and GIS land cover data, exhibited watershed characteristics indicative of least-disturbed conditions. Subsequent evaluation of collected data indicated that the sites exhibited all or most of the characteristics agreed upon by AAC members as indicative of reference (least-disturbed) conditions (referred to as reference filters; Table 1). However, final designation of reference filters as well as reference sites is ongoing. Such designation is not the focus of this report. Initial designation of sites as streams or swamps was made based on best professional judgement of DEQ and Virginia Commonwealth University (VCU) field staff at the time of site visits.

Water quality and benthic macroinvertebrate data were collected for this investigation following DEQ standard operating procedures (DEQ 2008, 2017). Macroinvertebrate identifications were made by AAC member Dr. Leonard Smock and by DEQ biologists. Fish data were collected following U.S. Environmental Protection Agency protocols (Barbour *et al.* 1999). Fish were collected by VCU staff using a direct-current, backpack electrofisher and conducting a single pass in approximately 100–120 meters of the main channel reach and several sweeps in backwater areas. Fish identifications were made by VCU ichthyologists, Dr. Stephen McIninch and Mr. David Hopler. The eight-metric Blackwater Habitat Protocol (BHP; Garey *et al*. 2014) was used to evaluate habitat conditions at each study site. The BHP is a rapid, field-based method to identify swamp systems using characteristics such as channel and floodplain geomorphology, hydrology, and vegetation. Higher BHP scores indicate an increased prevalence of swamp conditions. Additional details on the field methodology used for data collection are included in the FY 2019 AAC report (Garey 2019). For reference, basic location information of sites discussed in this report is included in Appendix A.

Table 1: Academic Advisory Committee draft reference filters for swamp waters.

Parameter	Reference Threshold	Stressed Threshold
Physicochemistry		
Specific Conductance	<150 µS/cm	>350 µS/cm
Total Nitrogen	<1.5 mg/L	>3 mg/L
Total Phosphorus	<0.05 mg/L	>0.1 mg/L
pH	<6.5*	>7.5
Other	No other measured parameters indicate site should be 303d listed for aquatic life use impairment	Other chemical stressors present that are likely to affect community
Land Cover		
GIS Land Use/Land Cover	>70 percent forested land cover in watershed	<50 percent forested land cover
Intact Riparian Vegetation	>50 m from both banks	<10 m, either bank, or <25 m from both banks
General Site Characteristics		
Point Sources/Others	No NPDES sites within watershed	NA
Site Reconnaissance Land Use/Land Cover	No extensive development in the watershed that is likely to impact the system	NA
Visible System Impairment	No visible signs of direct alteration to the water body (*e.g.*, dams, weirs, levees, artificial channelization)	NA

*The maximum pH filter for reference swamps is under review and may be removed or revised in future drafts.

NPDES = National Pollutant Discharge Elimination System

NA = Not applicable; these filters are not typically used to designate systems as stressed.

Analysis and Results

Water Quality

After submission of the FY 2019 report, laboratory analyses of total nitrogen (TN) and total phosphorus (TP) samples were completed at ten swamp sites (Table 2). These data were compared to the reference filter thresholds previously agreed upon by AAC to determine whether sites should be considered in reference (best-available) conditions and therefore included in future investigations on the natural conditions of swamp systems (Table 2). All but two sites exhibited TN and TP concentrations below the reference thresholds (1.5 mg/L for TN and 0.05 mg/L for TP). Two sites, Warren Swamp and an unnamed tributary (UNT) to the Nottoway River, exhibited TP concentrations of 0.10 mg/L. An additional site in Seacorrie Swamp exhibited TN and TP concentrations below reference thresholds in 2019, but a TP concentration of 0.20 in 2018 (Appendix B).

Laboratory analyses of TN and TP samples collected at stream sites in April 2019 were completed following submission of the FY 2019 report. These analyses included TP samples at Gravelly Run and Hazel Swamp and TN/TP pairs at Mill Run and at UNTs of Hatcher Run, Seacock Swamp, and the Nottoway River (Table 3). Based on the new data, two stream sites exhibited nutrient concentrations above the reference threshold in 2019. Hazel Swamp exhibited TN and TP above the reference thresholds (TN was 2.74 mg/L; TP was 0.10 mg/L), and an UNT of Seacock Swamp exhibited a TP concentration (0.1 mg/L) above the reference threshold. The Hazel Swamp site has consistently exhibited high nutrient concentrations over several years of sampling. The UNT Seacock Swamp site also exhibited a TN concentration that was below the reference threshold of 1.5 mg/L but above the concentrations recorded at the other prospective reference stream sites in the dataset, aside from Hazel Swamp (mean TN among other sites = 0.64 mg/L vs. 1.24 mg/L measured at UNT Seacock Swamp in 2019; Table 3). The nutrient data collected from Hazel Swamp and the UNT of Seacock Swamp are indications that they should be removed from further consideration as reference sites.

For quality assurance purposes, samples from three sites were replicated, and the sample preservation method was varied to determine if freezing and holding samples beyond the 28-day laboratory holding time (as accidentally occurred in 2018) would affect TN and TP concentrations. At each site (Warren Swamp, Mill Run, and an UNT of Seacock Swamp), one sample pair, to be analyzed for TN and TP, was submitted to the laboratory in April 2019 within a week of collection; a second pair was collected at the same time and location as the first pair but was frozen and held for analysis until late September, 2019. Sample replicates exhibited relatively good agreement between treatment types in most cases (Table 4). In all but one case, relative percent disagreement (RPD; difference between results divided by mean of results) was less than the DEQ-specified acceptable RPD threshold of 10% (DEQ 2017). In one case (TN at Warren Swamp), the RPD was 15%; however, the TN concentration in the frozen sample that was held for 5 months was higher than that in the sample analyzed within the procedural holding time. It seems unlikely that nitrogen could increase in the sample while frozen and held in the freezer; therefore, the difference between the replicates was likely due to differences other than preservation and holding time.

Table 2: Water quality data collected at swamp sites in 2019.

Agency Site Code	Water Body Name	Initial Condition Rating	Initial Class.	Date	Time	TN (mg/L)	TP (mg/L)	pH	Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)
5AIVY001.37	Ivy Branch	Reference	Swamp	3/27/2019	13:15	0.74	BDL	6.3	14.6	8.9	25.0
5AWRN000.46	Warren Swamp	Reference	Swamp	4/25/2019	9:10	0.86	0.10	6.7	18	4.8	51.5
5AXBRa001.40	UNT Blackwater River 1	Reference	Swamp	4/17/2019	12:05	0.88	BDL	6.9	18.2	4.23	84.5
5AXSRE000.13	Seacorrie Swamp	Reference	Swamp	3/27/2019	11:10	0.62	BDL	7.6	7.9	10.6	24.0
5AJNH010.18	Jones Hole Swamp	Reference	Swamp	4/25/2019	10:40	0.93	BDL	6.45	19.9	3.53	49.6
5AMS000.40	Mill Swamp	Reference	Swamp	4/17/2019	9:10	0.81	BDL	7.16	15	5.68	51.0
5APRK000.40	Parker Run	Reference	Swamp	4/11/2019	11:00	1.05	BDL	5.47	15.13	8.86	55.0
5AXJO000.10	UNT Joseph Swamp	Reference	Swamp	4/17/2019	13:22	1.07	BDL	5.9	24.1	4.98	32.1
5AXNOTb000.45	UNT Nottoway River 2	Reference	Swamp	5/1/2019	11:00	1.14	0.10	NA	NA	NA	NA
5AXJH000.31	UNT Johnchecohunk Swamp	Reference	Swamp	4/17/2019	11:30	0.02	BDL	6.72	14.5	7.69	31.0

Class. = Classification; TN = total nitrogen; TP = total phosphorus; Temp. = temperature; DO = dissolved oxygen; Spec. Cond. = specific conductance; BDL = below detection limit of 0.02 mg/L; UNT = unnamed tributary; NA = no data. Underlined cells indicate data presented for the first time in this report. Light shaded cells do not meet the proposed swamp waters reference nutrient thresholds (TN<1.5 mg/L or TP<0.05 mg/L).

Table 3: Water quality data collected at stream sites in 2018 or 2019 along with historical data from previous years' investigations.

Agency Site Code	Water Body Name	Initial Condition Rating	Initial Class.	Date	Time	TN (mg/L)	TP (mg/L)	pH	Temp. (°C)	DO (mg/L)	Spec. Cond. (µS/cm)
5AGRV000.08	Gravelly Run	Reference	Stream	1/3/2019	7:50	0.59	0.03	6.5	9.7	10.8	63.0
5AGRV000.08	Gravelly Run	Reference	Stream	2/11/2019	9:00	NA	NA	6.7	6.7	12.0	61.0
5AGRV000.08	Gravelly Run	Reference	Stream	3/14/2019	9:40	NA	NA	6.5	9.3	11.2	57.0
5AGRV000.08	Gravelly Run	Reference	Stream	4/4/2019	9:40	0.41	BDL	7.4	10.4	10.6	64.0
5AHZL000.77	Hazel Swamp	Reference	Stream	4/22/2014	13:15	1.81	0.10	6.6	14.3	9.3	107.0
5AHZL000.77	Hazel Swamp	Reference	Stream	11/19/2014	11:15	6.32	0.40	6.1	4.8	8.5	189.0
5AHZL000.77	Hazel Swamp	Reference	Stream	4/3/2019	10:10	2.74	0.10	6.7	8.9	11.5	95.0
5AMRN000.38	Mill Run	Reference	Stream	4/12/2019	11:00	1.13	BDL	6.6	17.7	7.8	101.0
5AXHAT000.40	UNT Hatcher Run	Reference	Stream	4/4/2019	14:30	0.35	BDL	6.9	14.2	9.5	41.0
5AXSCKa001.82	UNT Seacock Swamp	Reference	Stream	4/25/2019	12:40	1.24	0.10	6.5	22.0	NA	76.8
5AXNOTc000.40	UNT Nottoway River 3	Reference	Stream	4/11/2019	13:00	0.71	BDL	6.7	18.4	9.5	84.0
5ACABR000.64	Caney Branch	Altered	Stream	4/11/2018	8:45	0.76*	0.10*	7.0	9.6	8.6	55.3

Class. = Classification; TN = total nitrogen; TP = total phosphorus; Temp. = temperature; DO = dissolved oxygen; Spec. Cond. = specific conductance; NA = no data; BDL = below detection limit of 0.02 mg/L; UNT = unnamed tributary. Underlined cells indicate data presented for the first time in this report. Light shaded cells do not meet the proposed swamp waters reference nutrient thresholds (TN<1.5 mg/L or TP<0.05 mg/L). Dark shaded cells exceed the proposed swamp waters stressed-site nutrient thresholds (TN<3.0 mg/L or TP>1.0 mg/L). *Sample analyzed by the lab in exceedance of method holding time.

Table 4: Comparison of replicate samples submitted to the laboratory within the 28-day laboratory holding time (unfrozen) to those that were frozen and held for 5 months before submission (frozen).

	Warren Swamp - 4/25/2019 5AWRN000.46		Mill Run - 4/12/2019 5AMRN000.38		UNT Seacock Swamp - 4/25/2019 5AXSCKa001.82	
	TN	TP	TN	TP	TN	TP
Unfrozen sample (mg/L)	**0.86**	**0.10**	**1.13**	**BDL**	**1.24**	**0.10**
Frozen sample (mg/L)	**1.00**	**0.10**	**1.04**	**BDL**	**1.26**	**0.10**
RPD	**15.1%**	**0.0%**	**8.3%**	**NA**	**1.6%**	**0.0%**

TN = total nitrogen; TP = total phosphorus; BDL = below detection limit of 0.02 mg/L; RPD = relative percent difference.

Fish

Twelve additional fish collections, each made by VCU staff from a unique prospective reference site in the Chowan River basin in 2019, are now available. These data are included along with the fish dataset that was presented in the FY 2019 report (Appendix C).

To evaluate the potential for fish assemblages to vary among sampling years, fish assembalges observed at the 12 sites in 2019 were compared to those observed at 12 prospective reference sites in 2018. Five sites were sampled in both years. At one of the repeated sampling locations, the sampling point was moved approximately 500 m to allow for easier access on the downstream side of a road crossing (site 5AXBRa001.08 sampled in 2018 was moved to site 5AXBRa001.40 in 2019; see Appendix A for additional site information). Habitat conditions and riparian land cover observed in the field were similar among the two site locations.

To visually assess patterns of variation in the fish assemblages among sites and between years, a non-metric multidimensional scaling (NMDS) ordination of the sample units was conducted based on the fish assemblage data in R using the Vegan package (R Core Team 2019, Oksanen *et al*. 2019). The Bray-Curtis distance measure was used for the ordination, and the distances were calculated from a matrix of the relative abundances of all fish species collected at each site. The autotransform option (for further transformation of the relative abundance data) was not used. The default settings in the metaMDS function in Vegan were otherwise used for the ordination.

The ordination produced a 3-dimensional solution with a final stress of 0.13, which is considered an acceptable representation of the original assemblage distance matrix (McCune *et al*. 2002). Based on the proximity of the sampling units in the ordination space, the ordination plot showed relatively close associations of data collected at the same site for the two years, and no clear pattern of distinction between the two years (Figure 1).

To provide further confirmation of the observed pattern indicated in the ordination solution, a multivariate technique known as non-parametric analysis of variance on distance matrices was conducted (Anderson 2001). This method includes the calculation of the average pairwise ecological distance among sites between years followed by a series of randomizations of the data. This analysis was used to test the hypothesis that the assemblage distances between samples collected in 2018 and those collected in 2019 were not significantly greater than distances among samples expected by chance. These analyses were conducted using the adonis function in the R Vegan Package (R Core Team 2019, Oksanen *et al*. 2019). Two such analyses were conducted: 1) using all samples, grouped by year, in an unblocked design, and 2) using only the samples from five sites that were sampled in both years, with a blocked design to eliminate the confounding effects of among-site differences on the analysis of the year effect. The Bray-Curtis distance measure was used for these analyses, and the distances were calculated from a matrix of the relative abundances of all fish species collected at each site. The default settings in the adonis function were otherwise used.

Neither the unblocked nor the blocked analysis indicated a significant difference between samples collected in 2018 from those collected in 2019 ($p = 0.34$ for unblocked analysis; $p = 0.88$ for blocked analysis). A total of 999 random permutations of the data were conducted in the unblocked analysis, however, only 31 permutations of the five replicated sites were possible in the blocked design. The latter analysis therefore represents only a preliminary evaluation of the difference in assemblage structure between years while controlling for among-site differences.

Nevertheless, these results support the conclusion that fish assemblage structure in the low-gradient, Chowan River basin systems of interest is robust to temporal variability, and that samples collected in multiple years should be relatively comparable over relatively short time scales (*e.g.*, 1 year apart). It should be noted, however, that all samples were collected in spring, at baseflow conditions, and no changes in riparian land cover or habitat conditions were noted at the sites included. The analysis presented here provides no information on the effects of seasonal variation or changes in hydrologic regime, riparian zone or habitat conditions on the temporal variations in fish assemblages.

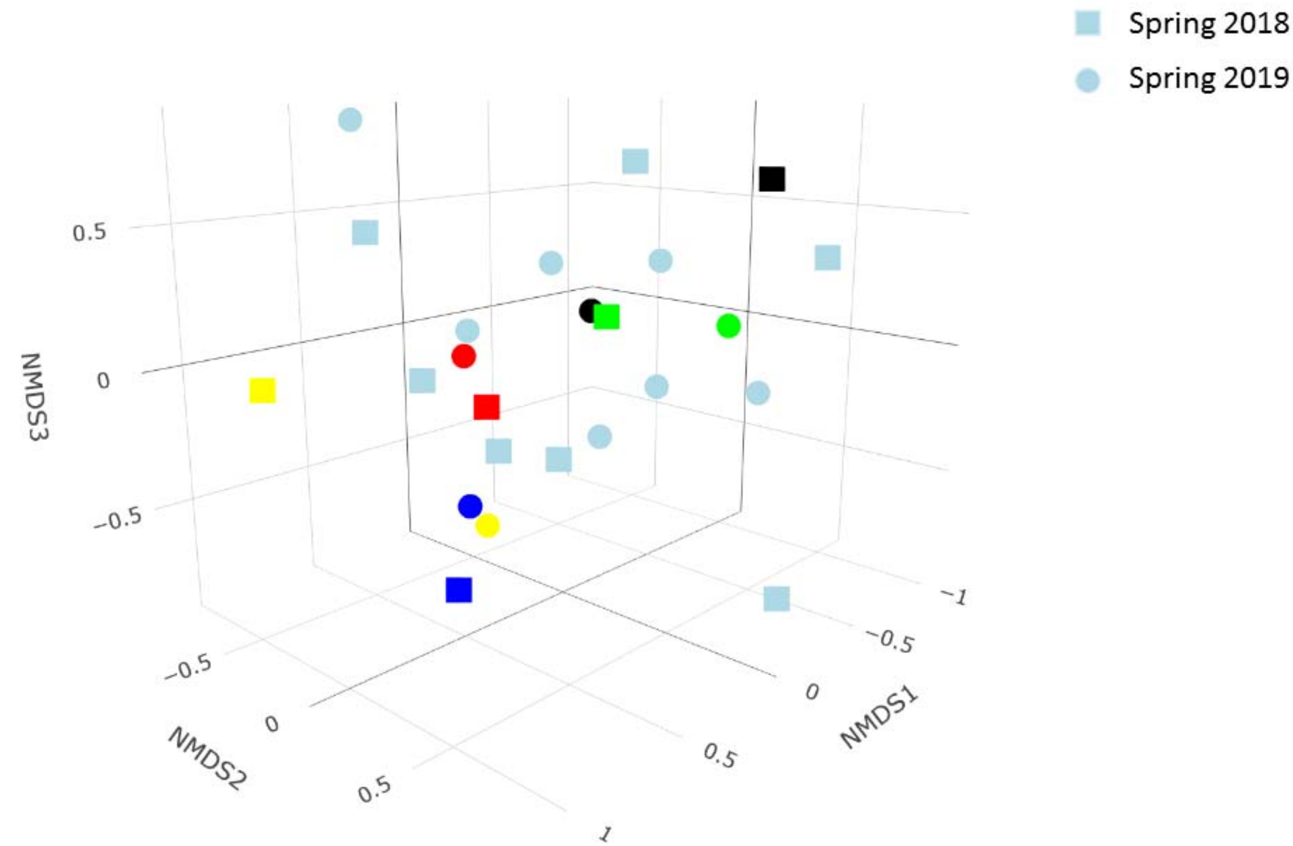

Figure 1: Fish assemblage data collected in 2018 and 2019 in 3-dimensional ordination space. Symbol shapes correspond to collection years as indicated in the figure legend. Light blue symbols indicate sites that were not replicated in 2018 and 2019. Symbols in other colors represent replicated sites, with symbols of the same color representing samples from the same site from 2018 and 2019. NMDS1, NMDS2 and NMDS3 = Non-metric multidimensional scaling axes 1, 2 and 3, respectively.

Benthic Macroinvertebrates

Data from macroinvertebrate collections made at 16 sites in 2019, which were not presented in that year's report, are included in Appendix D, and Virginia Coastal Plain Macroinvertebrate Index (VCPMI) scores and metrics for these data, along with historical data, are presented in Appendix E. The VCPMI is the official assessment index used for Virginia Coastal Plain streams (Dail *et al.* 2013). In 2019 benthic macroinvertebrates were sampled at all 6 prospective reference stream sites and at 10 of the 18 prospective reference swamp sites. The remaining eight prospective reference swamps sites were sampled in 2018, such that a relatively recent benthic macroinvertebrate dataset is now available that includes all of the prospective reference swamp sites identified in the Chowan River Basin. At three sites (Ivy Branch, an UNT of Seacorrie Swamp, and Warren Swamp) benthic macroinvertebrates were collected in both 2018 and 2019 (Figure 2).

Stream sites generally corresponded with higher VCPMI scores compared to swamp sites. Sites with low BHP scores (an indicator of stream, rather than swamp conditions) generally scored above the VCPMI assessment threshold score of 40. Exceptions to this were Hazel Swamp and the UNT of Seacock Swamp, which received VCPMI scores of 27.8 and 13.9, respectively; both were well below the typical impairment threshold. These two sites were discussed in the water quality section of this report as exhibiting nutrient concentrations above the reference thresholds. The VCPMI and nutrient results provide evidence that these two sites should be removed from consideration as reference sites, especially in the case of Hazel Swamp, which has exhibited consistently high nutrient concentrations over the past several years.

In contrast to the stream sites, the prospective reference swamp sites consistently exhibited VCPMI scores below the typical impairment threshold. Results from only 2 of 21 samples collected at prospective reference swamp sites in 2018 and 2019 indicated passing VCPMI scores (UNT of Seacorrie Swamp collected in 2018 and Jones Hole Swamp collected in 2019). These results confirm those in previous reports. With a relatively complete macroinvertebrate and habitat dataset, the results provide strong support for the conclusion that sites exhibiting swamp conditions, as indicated by the BHP, should not be assessed for aquatic life use attainment using the VCPMI.

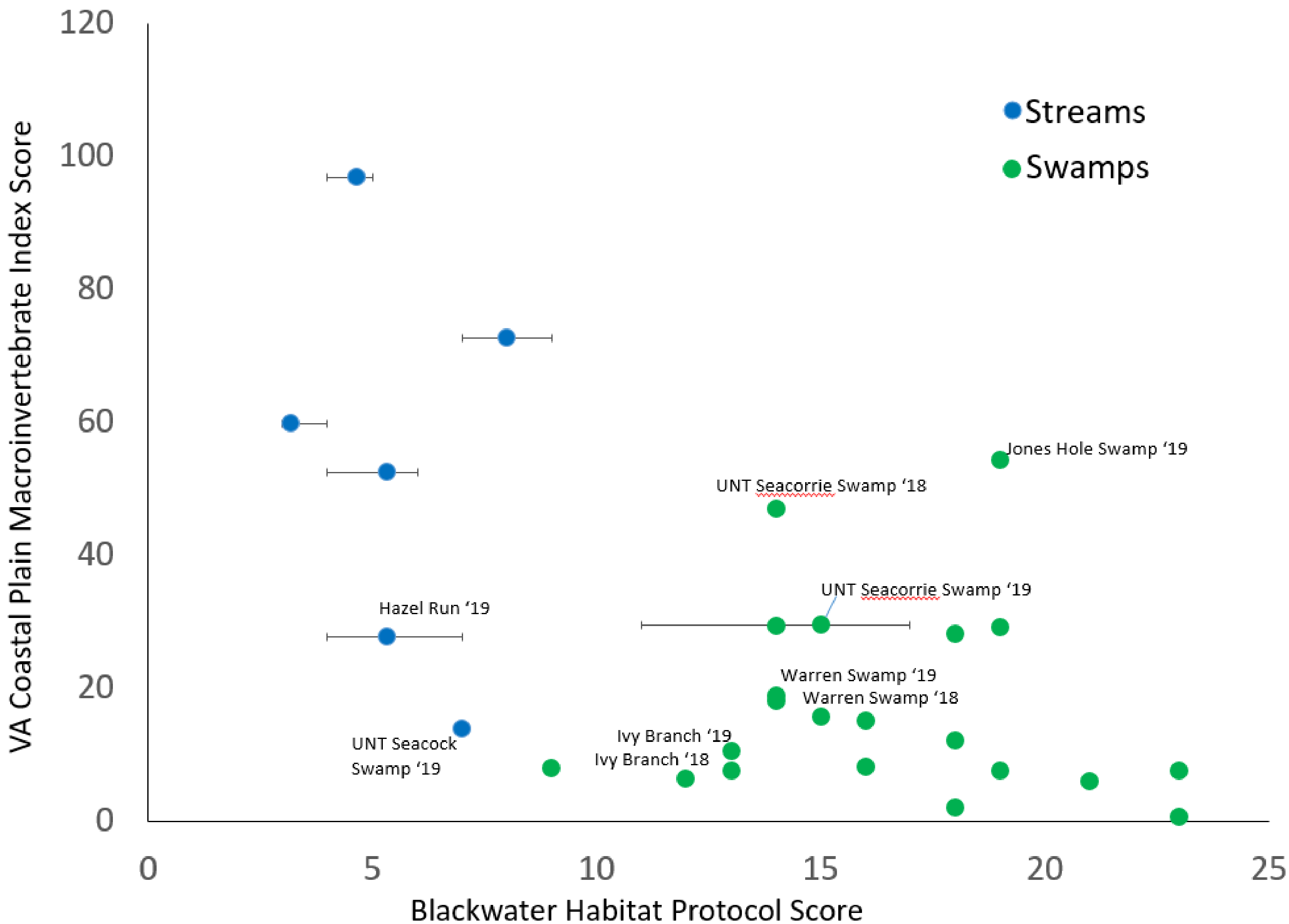

Figure 2: Virginia Coastal Plain Macroinvertebrate Index scores and Blackwater Habitat Protocol (BHP) scores at prospective reference swamp and stream sites investigated in 2018 and 2019. Sites referenced in the text are labeled. UNT = unnamed tributary; '18 = 2018; and '19 = 2019. Error bars indicate range of BHP scores among multiple investigators during the same site visit.

Future Work

Based on input from the AAC during and after the 2019 meeting, the future work plan was focused in two areas: 1) an extended water quality investigation to evaluate diel variation in water quality at swamp and coastal stream sites, and 2) development of an automated GIS application to evaluate watershed geomorphology and land cover variables that may provide utility in classifying swamps. These efforts were planned to begin in spring or summer 2020, however, this timeline has been delayed because of the COVID-19 pandemic. Field reconnaissance necessary for site selection was not completed because of DEQ's fieldwork suspension, which began on March 17, 2020. Furthermore, contracting between DEQ and AAC partners at VCU and Virginia Tech, which is necessary for initiating this work, has not been completed because of state budgetary concerns associated with the pandemic. DEQ has received instructions for planning the FY 2021 budget that includes suspending issuance of any contracts obligating discretionary spending (State General Fund). DEQ will revisit this restriction after more details are provided by the Department of Planning and Budget and any revisions to the Governor's Executive Orders. Draft study designs for the extended water quality analysis and GIS application development are included as Appendices F and G, respectively (included at the end of this document). These study designs will likely be further developed and modified once contracting with VCU and Virginia Tech partners is settled.

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Appendices A–E

Data from monitoring sites associated with this project are provided in Appendices A–E in an accompanying Excel file (*Swamps_2020_Appendices.xlsx*).

Appendix A: Site Information

Appendix B: Water Quality

Appendix C: Fish

Appendix D: Macroinvertebrates

Appendix E: VCPMI Metrics

Appendix F: Draft Study Design for Extended Water Quality Investigation

The draft study design below was developed by DEQ for review by Dr. Paul Bukaveckas, an AAC member at VCU who indicated an interest in assisting with this investigation. This design has not been revised by Dr. Bukaveckas and will likely be adjusted once work resumes. Initial modifications suggested to this study design by Dr. Bukaveckas included the following:

- Consider reducing deployment time of continuous monitors to 1–2 weeks to reduce maintenance effort and increase the number of sites evaluated.

- Consider including spring and fall deployments of continuous monitoring equipment to evaluate and compare the variations in water quality that occur in spring, fall, and summer.

- Add a method to quantify photosynthetically active radiation to evaluate the potential effects of light-stimulated algal activity on water quality.

- Eliminate the replication of dissolved organic matter and colored dissolved organic matter samples (one sample per event rather than three).

The final study design will be developed with this input when a contract is executed between VCU and DEQ for the assistance of the Bukaveckas lab on the project. Dates included in the design below will also be updated at that time.

Water Quality Investigation for Swamp Waters Classification in Coastal Virginia

Objectives

1) Obtain continuous (5–30-minute interval) measurements of the following water quality parameters: dissolved oxygen (DO), pH, specific conductance, temperature and turbidity from 18–20 coastal Virginia stream and swamp sites.
   - Describe diel variations in the above parameters at the study sites in order to determine how water quality assessments at the sites depend on the time of sampling.
   - Determine if and how water quality differs between sites considered swamps and those considered free-flowing streams. Swamp and stream classifications will be based on stream channel, riparian zone, and watershed characteristics. These characteristics will be evaluated at each site using on-site habitat surveys and GIS analysis of watershed digital elevation models.

2) Conduct a preliminary evaluation of spatial variability at each site for the measured water quality parameters.

3) Determine if and how dissolved organic carbon (DOC) and colored dissolved organic matter (CDOM) differ between stream and swamp sites.

4) Conduct laboratory-based verification of field pH measurements to determine the accuracy of these measurements.

Preliminary Study Design

Site selection: Sites for this investigation will be those that appear least-disturbed based on nutrient data (no measurements of TP ≥ 0.05 mg/L or TN ≥ 1.5 mg/L), land cover (watershed comprised of ≥ 70% natural land cover) and several additional associated factors. Sites will be selected such that those considered swamps and those considered streams, as based on stream channel, riparian zone, and watershed characteristics, will be selected in approximately equal number. Approximately half of the study sites will be located in the Chowan River/Albemarle Sound basin, which includes the highest density of swamp waters in Virginia. The remaining sites will be located in the James, Piankatank, York, Rappahannock or Potomac River basins. All sites will be wadeable (max. depth ≤ 1.2 m) and non-tidal. Site selection is ongoing. Candidate study sites are in southeastern Virginia and require 1–2 hours of travel time from Richmond.

Objective 1) Obtain continuous monitoring data: DEQ-owned YSI EXO 3 sondes equipped with DO, pH, specific conductance, temperature and turbidity probes will be deployed at each site for 3 weeks. Deployments will occur in summer when stress on aquatic life owing to naturally suppressed DO and pH is expected to be greatest. Deployments will occur such that approximately six sondes (one sonde each at three stream and three swamp sites) are deployed during each 3-week interval during this time period, and deployment sites are changed after 3 weeks. Sondes will be located in areas where flow is relatively high and the water column appears well mixed. Site visits will be conducted weekly, during which sondes will be calibrated each time and cleaned and repaired as needed. Data will be downloaded from sondes during each site visit and replicate measurements of each water quality parameter will be obtained with a calibrated, hand-held multimeter to verify sonde measurements.

In addition to the summer deployments, sondes will be deployed for 1 week at three study sites in spring, preceding summer deployments in order to test equipment and methodology.

Objective 2) Conduct a preliminary evaluation of spatial variability: At each study site, five equidistant transects will be established over a stream distance of approximately 100 meters, and measurements will be taken at three locations along each transect. Monitoring locations along each transect will be determined in the field but are intended to include shallow backwater areas near each bank as well as the channel thalweg. Depth will be measured at each monitoring location. Hand-held multiprobes will be used to measure DO, pH, specific conductance, temperature and turbidity. Measurements will be obtained from approximately 2 cm above the bottom and at 10 cm increments along each depth profile. These transect measurements will be conducted twice during each summer deployment, and once during each of the three spring test deployments.

Objective 3) Determine if DOC and CDOM differ between stream and swamp sites: During weeks 1 and 3 of summer deployment and during the initial site visit during spring deployments, three replicate samples will be collected for laboratory analysis. Up to 129 DOC and 129 CDOM samples would be obtained.

Objective 4) Conduct laboratory-based verification of field pH measurements: At each site where pH verification is being conducted, an EXO 3 sonde that is identical to the unit being deployed will be used to obtain an additional field pH measurement. Concurrently, three replicate, headspace-free water samples will be obtained for laboratory pH analysis. The EXO 3 unit and the samples will be transported to the lab, and the samples will be measured using a laboratory pH probe calibrated for low-conductivity solutions and again measured using the EXO 3. The pH verification samples may not need to be obtained at all study sites but should be obtained at a minimum of six sites that exhibit specific conductance <50 μS/cm (relatively common in many swamp systems).

Appendix G: Draft Study Design for Development of an Automated GIS Application for Classification of Swamp Systems

The draft study design below was submitted by AAC member Dr. Daniel McLaughlin with Virginia Tech. The final study design will be developed when a contract is executed between Virginia Tech and DEQ for the assistance of the McLaughlin lab on the project. Dates included in the design below will also be updated at that time.

An Automated Geospatial Analysis Tool for Class VII Waters Designation

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Below, we propose work to develop an automated application to assist Virginia Department of Environmental Quality (DEQ) in classifying Class VII swamp waters. This web-based application will employ a series of geospatial analyses to derive topographic and vegetation metrics and an associated statistical model to classify swamp waters. The application will allow DEQ staff to conduct these analyses with minimal training and without specialized knowledge of computer programming. The analytical results produced by this application are not available using any existing resource. Once developed, the R-based, automated application may be hosted on a DEQ server for internal use and expanded or modified by DEQ staff. Although the initial focus of the application will be on swamp waters classification, many of its features (*e.g.*, site-specific watershed delineation, evaluation of watershed water storage capacity) will be directly applicable to other agency business such as probabilistic water quality monitoring and Chesapeake Bay water quality management planning. This work is organized into two tasks. Task 1 will conduct a series of analyses to develop geospatial variables and a statistical model to classify Class VII waters. Task 2 will incorporate these data and analyses into the web-based application for operational use by DEQ staff for Class VII waters classification and other related agency business.

<u>Task 1: Geospatial Analyses to Delineate Class VII Waters</u>
Task 1 will quantify a series of geospatial variables associated with watershed topography, vegetation, and stream morphology and conduct a statistical analysis to determine which of these variables best discriminate between known streams (Class III) and swamp waters (Class VII).

Deliverables: i) all geospatial data and statistics obtained, ii) a developed statistical model that uses these variables to best predict Class VII status, iii) a report detailing methods, results and potential applications, and iv) a script or R project file containing all programming code used to complete Task 1.

Background and Approach: Swamp waters occur in low-relief watersheds where wetland features dominate and provide distributed surface water storage. This water storage increases watershed residence times and thus the production of dissolved organic matter, resulting in downstream waters with high color, low dissolved oxygen, and low pH. As such, watershed topographic features and associated vegetation cover may be used to identify Class VII waters. In this task, we will use high-resolution, LiDAR-derived digital elevation models (DEM) and available spectral data (*e.g.*, Landsat imagery) to develop geospatial statistics that can be used to delineate Class VII waters.

In previous work, we developed a new method using LiDAR data to i) first delineate depressional wetlands, and ii) then to estimate their surface water storage capacity, defined as the maximum surface water volume that can be stored in a wetland feature before surface water outflow occurs (Jones *et al*. 2018). Surface water storage capacity thus indicates the water volumes and residence times that represent wetland water sources for downstream waters via surface and subsurface flow paths. This method was used across the entire Delmarva Peninsula, where it effectively identified 102,000 wetland features and estimated water storage capacity for each feature. As such, this method can be used over large areas to identify individual wetland features and their cumulative water storage capacity.

In the work proposed here, we will use our developed method (see Jones *et al*. 2018) and LiDAR data for the Coastal Plain physiographic province to determine statistics describing surface water storage capacity for each study watershed (n = 20–30). Specific statistics will include i) cumulative watershed storage capacity, ii) size class statistics describing the distribution of individual wetland storage capacity volumes, and iii) spatial statistics indicating the distribution of distances between "stream" features and wetland water storage capacities.

In addition to water storage capacity, we will conduct additional topographic and land cover analysis to produce other watershed metrics that may be associated with swamp systems. Specific topographic metrics will include, at varying spatial scales (*e.g.*, watershed-wide to specific distances from National Hydrography Dataset [NHD] stream lines): i) slope statistics, ii) mean and variance of wetland heights above nearest drainage (HAND; Nobre *et al*. 2011), iii) topographic wetland index (Beven and Kirkby 1979), and iv) stream gradient for main stem and for all NHD stream lines within the watershed. Landsat spectral data will be analyzed to delineate wetland vegetation cover, which will be used to verify wetland delineation and to indicate potential organic matter production.

We will conduct logistic modeling using all derived statistics and the binary *a priori* classification of Class III vs. Class VII waters. A top-down selection approach will identify the geospatial metrics and associated statistical model most predictive of Class VII waters.

<u>Task 2: Web-based Application for Class VII Water Classification</u>
Task 2 will build on the results of Task 1 by incorporating the data, geospatial analyses, and statistical models into an automated, web-based application that will aid DEQ staff in the correct classification of new study sites.

The application will accept a variety of user inputs (*e.g.*, map location selected on-screen, latitude/longitude data point, or pre-delineated study area). Derived data and statistics, as well as a report on the most appropriate classification, will be downloadable by the user. The application will be useable by DEQ staff with minimal (less than 1 hour) training, eliminating the extensive staff time expenditure that would be necessary for training on, and application of, advanced programming, GIS, and statistical analyses. In addition to swamp waters classification, the application should reduce DEQ staff time that is currently expended on routine agency operations such as site-specific watershed delineation and topographic analysis.

Deliverables: The web-based application and all data and code used in its development.

Background and Approach: In other ongoing work, together with Dr. Yang Shao in the Department of Geography at Virginia Tech, we are developing a user interface tool for the City of Virginia Beach to easily visualize and extract flood reduction statistics (*e.g.*, evapotranspiration, water storage). The goal of that work is to provide a tool that is operational for many users (*e.g.*, city officials, public works, and other stakeholders), where users can select areas (via selected or input polygons) or specific points and their runoff contributing areas (via automated watershed delineation) to obtain selected metrics. Data storage and real-time spatial and hydrologic analyses are supported with a server-side GIS package, providing the user-side ability to examine summary statistics, tables, and figures. Importantly, specific knowledge on GIS applications and modeling is not needed by users.

In the proposed work, we will use a similar approach to develop a web-based application to classify Class VII waters. Building from Task 1, we will store all needed input data (*i.e.*, LiDAR-derived DEM, Landsat-derived vegetation metrics) on a server. We will then add automated analysis algorithms using the R Shiny Library (RStudio) to conduct real-time topographic analysis and yield geospatial metrics identified in Task 1. Users will be able to either input shapefiles or directly draw areas of interest to visualize these metrics as spatial layers, as well as extract tables and figures summarizing attributes for specified areas. Furthermore, the user will be able to select a stream location and automatically obtain its contributing area, for which geospatial metrics will be summarized. Last, the application will classify selected waters either as Class VII or other waters using the statistical model developed in Task 1 along with the required metrics extracted for the selected stream and its watershed. As such, the application will provide users the ability to easily determine geospatial attributes for selected streams and if these streams are likely Class VII waters. Once completed, the web-based application and all data and R programming code used in its development will be provided to DEQ so that the application can be applied and further developed as needed for agency business.

<u>References for Appendix G</u>

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