

**VIRGINIA WATER RESOURCES RESEARCH CENTER**

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

**2013 Report of the Academic Advisory Committee  
for  
Virginia Department of Environmental Quality**



Virginia  
**WATER RESOURCES**  
Research Center

**SPECIAL REPORT**



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

## 2013 Report of the Academic Advisory Committee for Virginia Department of Environmental Quality

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## **Introduction**

Biological organisms that are endemic to blackwater habitats are physiologically and behaviorally adapted to natural conditions of low pH and low oxygen concentration or saturation that might represent impaired conditions elsewhere. For example, many of the fishes native to blackwaters (Class VII) are facultative air-breathers or possess other adaptations to these unusual—but natural—conditions. In contrast, aquatic taxa with more cosmopolitan (i.e., geographically broad) distributions lack specific adaptations to blackwater conditions, are uncommon in ecologically healthy blackwater systems, and may be indicators of impairment in these streams. As a consequence, it may be possible to use the taxonomic and functional composition of biotic assemblages (e.g., fishes, macroinvertebrates) sampled in coastal freshwaters of Virginia to accurately assess the status of Class VII blackwaters and to evaluate the level of ecological health—or conversely, impairment—using biological (cp. chemical) criteria. Other states with blackwater streams and swamps (e.g., Maryland and New Jersey) have also recognized the problem of using physicochemical criteria (low pH, hypoxia) to determine impairment where such conditions are natural and contribute to unique communities of endemic taxa. The development of bioassessment tools for Virginia Class VII waters has been a task of the Academic Advisory Committee (AAC) for the Virginia Department of Environmental Quality (DEQ) since 2011.

A recent report of the AAC described the development of a biology-based stream assessment tool (the Blackwater Condition Index, BCI) specifically for use in Class VII blackwater stream and swamp systems (Garman et al. 2012). In a related effort, Garman et al. (2012) developed a working protocol for the use of field-based, non-biological criteria to identify blackwater systems as distinct from other Class VII waters in the region. Subsequent feedback from AAC members and DEQ personnel suggested that both of these procedures were effective but remain insufficiently developed for formal testing and validation.

As one of the next steps in the development of a BCI for Class VII blackwater streams in Virginia, it was deemed necessary to further develop and then validate a protocol that employs the best combination of field-based habitat evaluation metrics and/or GIS-based data to quantitatively separate Class VII blackwater streams from other types of Class VII waters as well as from Coastal Plain streams not appropriate for Class VII designation (Task 1 of this report). Not until this task is accomplished can a protocol be developed that is effective for indicating anthropogenic stress in systems identified as blackwater. The second necessary step in the development of a functional BCI for Virginia was to expand the results of fish community analysis completed in 2012 and to develop and test specific metrics and scoring criteria (cp. Pont et al. 2009) to identify impairment of blackwater stream and swamp systems (Task 2 of this report).

The overall long-term objective of our work is to develop and validate an assessment protocol for Class VII blackwater streams and swamps based solely on biological criteria, specifically fish

assemblage structure. The work detailed in this report focuses on the development of a habitat classification protocol for blackwater streams (referred to hereafter as the blackwater habitat protocol, or BHP). The initial deliverable is a field protocol that can be used by Virginia Department of Environmental Quality biologists as an aid to their best professional judgment in determining whether field sites are appropriate for designation as a Class VII blackwater and thus to be assessed using the BCI protocol currently under development. This classification protocol thus is intended to serve as a decision support tool for augmenting best professional judgment regarding the proper classification of wadeable, freshwater systems on the Virginia Coastal Plain. The current report, the results of which were presented to AAC and DEQ staff on April 19, 2013, describes the next steps in the evolution of a BHP and BCI for assessment of Class VII waters in Virginia.

## **Task 1 Blackwater Habitat Protocol**

### *Methods*

We used topographic maps and aerial photographs to select sites that represented a wide range of variation with respect to the chosen habitat parameters. In addition to the 12 study sites selected for the 2012 report, we visited an additional 32 sites to collect habitat data (total n=44 sites, Fig. 1, and see Appendix A for latitude/longitude coordinates of sites).

At all sites, a 100 m reach was evaluated. Before extensively measuring or evaluating any site characteristics we began each survey by subjectively classifying each site as either a blackwater swamp system, a non-blackwater swamp system, or a free-flowing Coastal Plain stream. The first two of these classification categories were considered as potential Class VII waters. We then measured pH, dissolved oxygen, temperature and conductivity using YSI and Hydrolab multimeters (YSI Inc., Yellow Springs, OH; Hach Inc., Loveland, CO). After the physiochemical measurements were completed, we estimated a series of in-stream and watershed habit characteristics:

- Channel Formation and Flow Characteristics: this category included metrics associated with the number of clearly-defined channels along the study reach, flow velocity and directionality, and benthic substrate.
- Riparian Zone Characteristics: this category included evaluations of riparian zone vegetation type and prevalence, the presence of riparian wetlands, and topography.

All data collected at the 12 sites in the 2012 investigation were also collected at the 32 new sites, with five notable changes:

- 1) Due to the difficulty of the original method for judging water color (evaluation of a vial of water against a Munsell color chart), the method was modified to include evaluating stream

water collected in a full, white, 5-gallon bucket and scoring the water based on color (with scores of: 0=clear; 1=pale yellow/brown; 2=brown; and 3=dark brown; Metric 11, Table 1).

2) The percentage of overhead canopy cover was added as a metric (Metric 14, Table 1).

3) The depth variation metric used in 2012 was changed to the ratio of maximum channel width to maximum depth (Metric 15, Table 1)

4) A metric was added to judge the presence and relative abundance of two tree species that commonly occur in blackwater swamp systems: baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*; Metric 17, Table 1).

5) A metric was added to estimate the elevation of the riparian floodplain above the wetted area (Metric 18, Table 1).

### *Data analysis*

From the field observations, 18 quantitative habitat metrics were calculated (see Table 1 for brief explanations of metrics and their calculations). Parameters for those measurements or estimations that yielded continuous data were simply scored using the raw data (e.g., meters of riparian wetland, mg/L of dissolved oxygen), whereas those indicating categorical attributes (e.g., single, multiple, or undefined channel) were given numerical scores based on *a priori* hypotheses regarding the potential for each categorical condition to occur in Class VII waters (Table 1).

To visualize relationships among the study sites with respect to all of the observed habitat metrics, we conducted Principal Components Analysis (PCA) ordination, a linear multivariate analysis technique, using PC-ORD, Version 5.0 (McCune and Mefford 2006). Sites are represented on ordination plots by points, whereas the distances among points represent the degree of the overall differences among sites in terms of overall habitat structure. The axes on the ordination plots are unitless and simply represent linear composites of the observed habitat metrics. To eliminate the effects of variations in scaling among metrics of different numerical types (i.e., percentages, continuous measurements, and discrete scores), the percentile rank of each metric score was calculated, and these data were used in the PCA analysis.

We found that collection of the data required for all 18 metrics was very time-consuming at sites where access was limited or where lines of site were short. In addition field biologists not involved in the original development of the protocol reported some difficulty in interpreting metrics. Based on these challenges, we attempted to simplify the protocol to produce a more time-efficient and easy-to-interpret suite of metrics. To simplify the protocol, we first excluded the physicochemical water quality measurements and water color evaluation, as these require additional equipment and are more likely to be confounded by anthropogenic impairment or short-term temporal variation than the other metrics. Next, we constructed a correlation matrix,

which included the Pearson correlation coefficient (r) for all pairwise comparisons of metrics, and eliminated metrics so that none remained that were correlated with others at r-values  $\geq 0.75$  or  $\leq -0.75$  (Table 2). When such correlations occurred, we eliminated metrics that we judged to be the most difficult or time-consuming to evaluate and those that exhibited correlations with multiple other metrics.

We have changed the metric suite and analyses slightly since the presentation given to the Academic Advisory Committee on April 19, 2013. During that presentation, the *Trees in Channel* metric (Metric 6, Table 1) was used, and the *Forest Type* metric (Metric 17, Table 1) was excluded as the two metrics were highly correlated (r: 0.80, Table 2); however, upon further examination of the data, we determined that the *Trees in Channel* metric showed moderate correlations (r: 0.64-0.74) with several other metrics, whereas the *Forest Type* metric did not, indicating that the latter explains more new information relative to site classification. In addition, the latter metric is the only one that includes information on the type of riparian vegetation present at a given site, and, therefore, likely provides a more robust description of the habitat conditions. Therefore, for this report, we use the *Forest Type* metric rather than the *Trees in Channel* metric, and recommend this change for future assessments.

The revised, simplified protocol contained eight core metrics: 1) the degree of channel formation (*Channel Development*); 2) flow velocity along the reach (*Flow Velocity*); 3) the percentage of the bottom area covered by organic matter (*Benthic OM*); 4) the commonness of submerged and/or emergent aquatic vegetation in the wetted area (*Submerged/Emergent Vegetation*); 5) the percentage of overhead canopy cover (*Canopy*); 6) the lateral width of wetlands in the riparian zone (*Wetland Width*); 7) *Forest Type* (as discussed above); and 8) the elevation of the floodplain adjacent to the site (*Floodplain Elevation*).

We conducted a second PCA analysis using only the eight core metrics to determine if the simplified protocol was as effective at classifying the sites as the original 18-metric protocol. We then refined the protocol further by developing a simplified scoring criterion, wherein the metric values were divided by quartiles, and sites falling into each 25 percent interval were given scores of 0, 1, 2, or 3, with increasing values indicating an increased likelihood that the site should be considered Class VII and blackwater. This new scoring criterion and the resulting field classification protocol are discussed more extensively in the following section.

#### *Preliminary Geographic Information Systems (GIS) Analysis*

At the 2012 AAC meeting, members expressed interest in determining whether geospatial data such as soils and topography could be used to classify sites as Class VII. To this end, we obtained a 10-meter digital elevation model (DEM) from the National Elevation Dataset (NED). We used the DEM to delineate the watershed upstream of each sampling site, to derive mean slope values for each watershed, and to assess slope variability by determining the standard deviation of the slope values within the watersheds. We also obtained U.S. Department of

Agriculture Soils Data to determine the proportion of each watershed occupied by commonly-flooded soils, by commonly-ponded soils, by hydric soils, and by sandy soil types, as well as the average depth to the water table in each watershed (see Appendix A for further explanation of GIS variables). All GIS data used in this analysis and supporting metadata are available, free of charge, via the National Resources Conservation Services Data Gateway (<http://datagateway.nrcs.usda.gov/>). All GIS analyses were conducted using ARCMAP, version 10.0 (ESRI, Inc., Redlands, CA). All statistical analyses conducted on the derived GIS data were conducted using R, version 2.15.2 (R Core Team 2012).

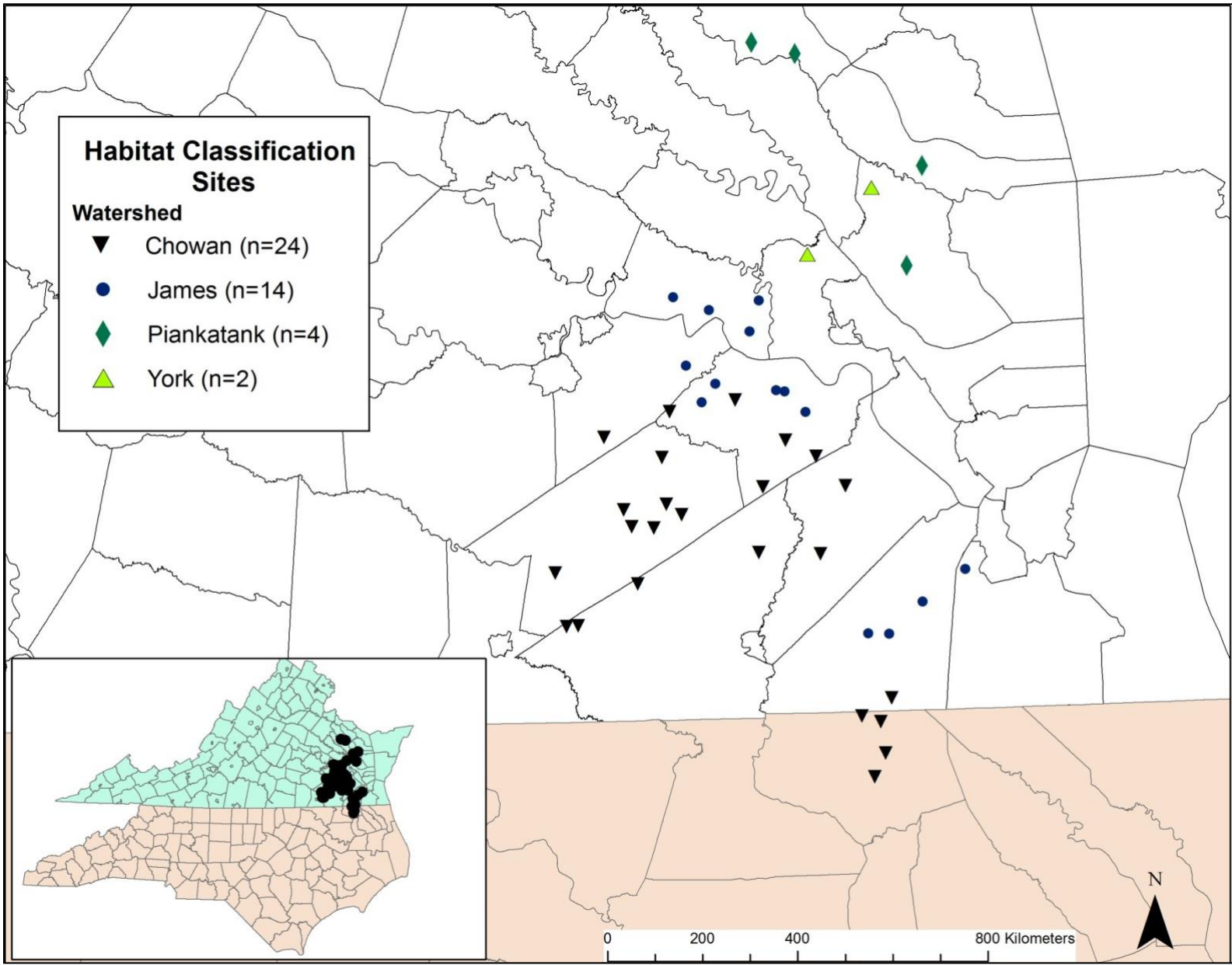


Figure 1: Map of the 44 habitat classification sites.

Table 1: Explanation of habitat metrics and water chemistry parameters used in site classification.

Data Parameter or Category Name	Description	Units	Score <sup>1</sup>	Final Metric <sup>2</sup>
Single channel	Proportion of reach composed of a single, defined channel	Percent of 100m reach	2	1) <u>Channel Development</u>
Multiple channels	Proportion of reach composed of multiple channels	Percent of 100m reach	1	
Undefined channel pattern	Proportion of reach with no defined channel	Percent of 100m reach	0	
No flow	No perceptible flow	Percent of 100m reach	0	2) <u>Flow Velocity</u>
Slow flow	Sluggish, but apparent flow	Percent of 100m reach	1	
Moderate flow	Moderate, laminar flow	Percent of 100m reach	2	
Rapid, laminar flow	Rapid, laminar flow	Percent of 100m reach	3	
Turbulent flow	Rapid, turbulent flow	Percent of 100m reach	4	
One flow vector	One clearly-defined direction of flow	Percent of 100m reach	0	3) <u>Flow Direction</u>
Multiple flow vectors	Multiple, clearly-defined flow directions	Percent of 100m reach	1	
No flow vectors	Undefined flow direction (no discernible flow)	Percent of 100m reach	2	

Data Parameter or Category Name	Description	Units	Score <sup>1</sup>	Final Metric <sup>2</sup>
Silt	Frequency of silt substrate	Percent of 100m reach	1	4) Mineral Substrate Size
Sand	Frequency of sand substrate	Percent of 100m reach	2	
Clay hardpan	Frequency of hard-pan clay substrate	Percent of 100m reach	3	
Rock	Frequency of gravel and cobble substrate	Percent of 100m reach	3	
Fine particulate organics	Frequency of substrate composed of fine particulate organic matter	Percent of 100m reach	0	
Coarse particulate organics	Frequency of substrate composed of coarse particulate organic matter	Percent of 100m reach	0	
Silt	Frequency of silt substrate	Percent of 100m reach	1	5) <u>Benthic Organic Matter</u>
Sand	Frequency of sand substrate	Percent of 100m reach	0	
Clay hardpan	Frequency of hard-pan clay substrate	Percent of 100m reach	0	
Rock	Frequency of gravel and cobble substrate	Percent of 100m reach	0	
Fine particulate organics	Frequency of substrate composed of fine particulate organic matter	Percent of 100m reach	2	
CPOM/wood	Frequency of substrate composed of coarse particulate organic matter and large woody debris	Percent of 100m reach	2	

Data Parameter or Category Name	Description	Units	Score <sup>1</sup>	Final Metric <sup>2</sup>
Trees in channel	Frequency of trees within wetted area	0- absent 1-rare/sparse 2-common 3-abundant	0-3	6) Trees in Channel
Other vegetation in channel	Frequency of emergent and/or submerged aquatic vegetation	0- absent 1-rare/sparse 2-common 3-abundant	0-3	7) <u>Submerged/Emergent Vegetation</u>
pH	pH	Standard units	rank of values	8) pH
Dissolved oxygen	Dissolved oxygen	mg/l	rank of values	9) Dissolved Oxygen
Conductivity	Conductivity	µs/cm	rank of values	10) Conductivity
Water color	Water color in white 5-gal. bucket	0-3, score increasing with darkness	0-3	11) Water Color
Turbidity	Water turbidity -- estimated	0-clear 1-slightly turbid 2-turbid 3-highly turbid	0-3	12) Turbidity
Bank erosion	Frequency of eroded areas along banks	Percent of 100m reach (both sides)	rank of values	13) Bank erosion
Canopy cover	Percent of overhead cover	Percent along 100m reach	rank of values	14) <u>Canopy</u>
Width/depth	Ratio of maximum channel width to max. depth	Difference in meters	rank of values	15) Width/Depth

Data Parameter or Category Name	Description	Units	Score <sup>1</sup>	Final Metric <sup>2</sup>
Wetland width	Width of apparent wetland area -- percentage of area within 100 meters from center of wetted channel	Percent of 200m wide riparian zone	rank of values	16) <u>Wetland Width</u>
Forest type	Dominance of tupelo ( <i>Nyssa aquatica</i> ) and baldcypress ( <i>Taxodium distichum</i> ) in wetted and riparian area	0-absent 1-rare, one species present 2-codominant with other species and/or both species present 3-dominant forest species	0-3	17) <u>Forest Type</u>
Floodplain elevation	Elevation of floodplain above wetted channel	cm	rank of values	18) <u>Floodplain Elevation</u>

<sup>1</sup> Score values for metrics 1-5 indicate category weights to be assigned to percentage estimates rather than final metric scores. Final score values for metrics 1 through 5 were calculated by multiplying each category score by the percentage of the study reach occupied by that category and summing these products.

<sup>2</sup> Underlined metrics indicate the eight core metrics retained for scoring after simplifying the protocol.

Table 2: Correlation matrix for all pairwise comparisons of habitat metrics.<sup>1</sup>

	pH	Dissolved Oxygen	Spec. Cond.	Water Color	Water Turbidity	<u>Channel Dev.</u>	Bank Erosion	<u>Flow Velocity</u>	Flow Direction	<u>Organic Matter</u>	Mineral Subst.	Width/Depth	<u>Wetland Width</u>	<u>Canopy</u>	<u>Floodplain Elevation</u>	Trees in Channel	<u>Sub./Emerg. Veg.</u>	<u>Forest Type</u>
pH	0.00	0.73	0.00	0.43	0.47	0.68	0.83	0.55	0.91	0.95	0.44	0.35	0.32	0.56	0.87	0.99	0.10	0.98
Dissolved Oxygen	0.05	0.00	0.64	0.01	0.10	0.08	0.02	0.00	0.04	0.03	0.06	0.46	0.14	0.13	0.23	0.03	0.65	0.08
Spec. Conductance	0.69	0.07	0.00	0.02	0.61	0.36	0.96	0.18	0.32	0.14	0.07	0.75	0.55	0.46	0.24	0.58	0.87	0.65
Water Color	-0.12	-0.41	-0.36	0.00	0.66	0.01	0.09	0.00	0.00	0.07	0.01	0.22	0.44	0.31	0.02	0.03	0.85	0.00
Water Turbidity	0.11	-0.25	0.08	0.07	0.00	0.65	0.22	0.22	0.90	0.20	0.06	0.51	0.14	0.02	0.65	0.71	0.82	0.23
<u>Channel Dev.</u>	0.06	0.27	0.14	-0.40	-0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.25	0.00
Bank Erosion	-0.03	0.35	0.01	-0.26	-0.19	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.01	0.00
<u>Flow Velocity</u>	0.09	0.49	0.21	-0.57	-0.19	0.72	0.60	0.00	0.00	0.00	0.00	0.00	0.03	0.66	0.00	0.00	0.85	0.01
Flow Direction	0.02	0.32	0.15	-0.48	-0.02	0.91	0.76	0.77	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.22	0.00
<u>Organic Matter</u>	-0.01	-0.33	-0.23	0.28	0.20	-0.44	-0.60	-0.44	-0.48	0.00	0.00	0.14	0.00	0.27	0.00	0.00	0.03	0.16
Mineral Substrate	0.12	0.28	0.28	-0.37	-0.28	0.53	0.67	0.47	0.56	-0.84	0.00	0.01	0.00	0.17	0.00	0.00	0.01	0.03
Width/Depth	-0.14	-0.11	-0.05	0.19	-0.10	-0.82	-0.65	-0.49	-0.77	0.22	-0.39	0.00	0.00	0.20	0.00	0.00	0.37	0.00
<u>Wetland Width</u>	0.15	-0.23	0.09	0.12	0.23	-0.59	-0.80	-0.32	-0.55	0.58	-0.62	0.49	0.00	0.92	0.00	0.00	0.10	0.00
<u>Canopy</u>	0.09	-0.23	0.11	0.16	-0.34	-0.04	0.01	-0.07	-0.12	-0.17	0.21	0.20	-0.01	0.00	0.28	0.04	0.07	0.00
<u>Floodplain Elevation</u>	0.03	0.19	0.18	-0.35	-0.07	0.71	0.64	0.53	0.70	-0.52	0.61	-0.59	-0.59	0.17	0.00	0.00	0.01	0.01
Trees in Channel	0.00	-0.32	-0.09	0.32	-0.06	-0.69	-0.74	-0.55	-0.70	0.49	-0.55	0.70	0.64	0.32	-0.55	0.00	0.19	0.00
<u>Submerged/Emerg. Veg.</u>	0.25	0.07	0.02	0.03	0.04	-0.18	-0.39	-0.03	-0.19	0.33	-0.37	0.14	0.25	-0.28	-0.39	0.20	0.00	0.33
<u>Forest Type</u>	0.00	-0.27	-0.07	0.45	-0.18	-0.49	-0.57	-0.40	-0.55	0.22	-0.33	0.59	0.43	0.42	-0.41	0.80	0.15	0.00

<sup>1</sup> Values in the lower triangle (unshaded) are correlation coefficients (Pearson r-values); red shaded values indicate correlations exceeding +/- 0.75. Values in the upper half (shaded) are p-values. Underlined metrics were used in the simplified protocol.

## Results

### Analysis using the original 18-metric protocol

The PCA ordination of the 44 sites using all 18 original metrics showed relatively strong agreement with the *a priori* designations of sites that we assigned based on best professional judgment (Fig. 2). The sites that we considered likely non-Class VII (blue squares on Fig. 2) were completely separate from the sites considered non-blackwater Class VII (green circles) and blackwater Class VII sites (black triangles). This separation is important because it indicates that reliance on the habitat protocol is unlikely to result in assigning a site to the Class VII designation when best professional judgment would indicate that it should be assessed with the Coastal Plain Macroinvertebrate Index (CPMI) or other established protocol for free-flowing streams.

The ordination plot shows some overlap between sites assigned *a priori* to the Class VII non-blackwater group and the Class VII blackwater group, although most of the blackwater sites are clustered in the lower left-hand corner of the plot, whereas most of the non-blackwater sites are located higher on axis 2. The best two dimensions collectively explained 80 percent of the variation in the original Euclidean distance matrix ( $r^2$  values of 0.71 for axis 1 and 0.09 for axis 2, respectively), indicating that the PCA provided a good representation of the sites in habitat space.

### Analysis using the eight core metrics

The PCA ordination using only the eight core metrics after removing highly correlated metrics also showed relatively strong agreement with the *a priori* site designations (Fig. 3). Again, sites assigned to the non-Class VII group were completely separated from sites that were likely Class VII. Also, there was some overlap between the non-blackwater Class VII sites and the blackwater Class VII sites, although the latter group was mostly clustered together on the ordination plot. Three habitat metrics showed strong positive correlations with axis 1, including *Forest Type* ( $r=0.63$ ), *Benthic OM* ( $r=0.69$ ), and *Wetland Width* ( $r=0.76$ ). Because the majority of the blackwater sites were clustered on the right side of the plot, this positive correlation indicates a positive association with blackwater conditions. Three metrics were negatively correlated with axis 1, indicating a negative association with blackwater conditions. These metrics included *Floodplain Elevation* (elevation of the floodplain,  $r=-0.86$ ), *Channel Development* ( $r=-0.85$ ), and *Flow Velocity* ( $r=-0.72$ ). The *Submerged/Emergent Vegetation* metric was positively correlated with axis 2 ( $r=0.59$ ), indicating a negative association with blackwater conditions, as likely blackwater sites were positioned low on the axis. *Forest Type* and *Canopy* were negatively correlated with axis 2 ( $r$ -values of  $-0.53$  and  $-0.85$ , respectively; Fig. 3), indicating a positive association with blackwater conditions. The likely blackwater sites clustered in the lower right corner of the plot occurred primarily in the Chowan watershed (see Fig. 4). The best two dimensions of the PCA using the eight core metrics collectively explained

80 percent of the variation in the original Euclidean distance matrix ( $r^2$  values of 0.60 for axis 1 and 0.20 for axis 2, respectively), indicating that the PCA provided a good representation of the sites in habitat space.

#### Development of a simplified scoring system

Figure 5 shows the same PCA solution as displayed in Figures 3 and 4. The relative position of each site on the plot is based on the percentile ranks with respect to each of the eight metrics. The sizes of the symbols representing sites indicate the habitat scores, based on the new simplified system, where metric values were assigned scores of 0-3 by dividing the data into quartiles. Using this simplified system, the minimum possible score is 0 (highly unlikely to be blackwater or Class VII), and the maximum is 24 (very likely to be Class VII and blackwater). The actual range of scores in the dataset was 1-21. The pattern on Figure 5 shows general agreement between the simplified scoring system using discrete scores and the analysis using continuous data. Large symbols, indicating high likelihoods of blackwater conditions, occur to the right on axis one, and (mostly) low on axis 2. The pattern is clearer along axis 1, indicating the greater importance of the metrics associated with axis 1 than axis 2, as was the case with the original PCA analysis.

To provide a perspective on the implications of the use of this newly-developed BHP for site classifications, we calculated the 66<sup>th</sup>, 80<sup>th</sup>, 90<sup>th</sup>, and 95<sup>th</sup> percentiles of the observed BHP scores as potential cut-off values (corresponding to scores of 16, 17, 18, and 19, respectively; Table 3). At each cut-off level, those sites meeting or exceeding the score were considered blackwater sites, whereas those with scores lower than the cut-off value were considered non-blackwater and, therefore, not appropriate for the newly-developed BCI.

We then compared the resulting classifications to the *a priori* site classifications based on best professional judgment. This comparison resulted in six possible outcomes, based on the six possible combinations of *a priori* classifications (Non-Class VII, non-blackwater swamp, and blackwater swamp) and BHP scoring outcomes (blackwater or non-blackwater). These six combinations can result in three types of agreements and three types of disagreements between the determinations (Table 3).

As a thought exercise to assess the outcomes of relying on the BHP for site classifications, we considered the *a priori* classifications to be correct, and evaluated the consequences of decision making based on the BHP protocol. Based on this logic, we considered the first type of disagreement listed in Table 3, assigning the site to the non-blackwater group when it is actually blackwater, to be the least severe. Under this condition, such a site would simply retain its Class VII status and not be assessed with the BCI, even though the protocol may be appropriate. Such errors would not decrease the overall quality of the assessment practices currently conducted by DEQ, though the impairment condition of sites where such disagreements occurred would remain unknown, even though the BCI might provide valuable information to this end. In

contrast, the two remaining types of disagreement—assigning non-Class VII sites or non-blackwater sites to the blackwater class—would result in the use of an inappropriate biological assessment technique to evaluate the site if the decision maker relied solely on the BHP for classification.

At all four cut-off levels, the BHP and *a priori*, best-professional judgment classifications agreed 100 percent of the time when the sites were considered non-Class VII systems. This result is important because it indicates that the BHP is not likely to provide information that suggests sites that may otherwise be assessed with established protocols should instead be assigned to the Class VII designation. At the 66<sup>th</sup> percentile cut-off (BHP score of 16), 12 sites were assigned to the blackwater category using both best professional judgment and the BHP score; however, four sites were assigned to the blackwater category using the BHP score, whereas best professional judgment indicated that they should be classified as non-blackwater. The number of disagreements where the BHP score indicated blackwater conditions was reduced to three for the 80<sup>th</sup> and 90<sup>th</sup> percentile cut-offs and to one at the 95<sup>th</sup>, but at a cost of only eight sites being assigned to the blackwater group in agreement with the *a priori* classifications at the 80<sup>th</sup> percentile, five sites at the 90<sup>th</sup> percentile, and only two (out of a total of 16 initially considered blackwater) at the 95<sup>th</sup> percentile. If the cutoff value is reduced below a score of 16 index, performance is poor. At a score of 15 the single site attaining this score would be misclassified, and at 14, two of four sites would be misclassified.

Figure 6 shows the PCA solution with the site classifications derived from the BHP 66<sup>th</sup> percentile cut-off (score of 16/24) and highlights the four sites where the classification indicated blackwater conditions, but the field biologists classified the sites as non-blackwater. Of these sites where disagreements occurred, the three sites located centrally on axis 2 of the plot were sites located in the Chowan River watershed. Whereas the field biologists chose the designation of non-blackwater swamp for these three sites, it was noted that conditions were marginal between the blackwater and non-blackwater classifications. In contrast, the site located at the upper right corner of the plot (upper Dragon Run, in the Piankatank River watershed) represents a more egregious disagreement. This site was classified as blackwater by the BHP even at the highest cutoff value, as the BHP score was 19, placing it at the 95<sup>th</sup> percentile of score values. Whereas the overall site score indicates blackwater conditions, water at the site was only very slightly stained with tannins, and the blackwater-characteristic tree species water tupelo (*Nyssa aquatica*) and baldcypress (*Taxodium distichum*) were completely absent from the site, with the dominant tree species being smooth alder (*Alnus serrulata*). The riparian forest around the stream system appeared intact and undisturbed, with no obvious sources of impairment for at least 500m from the wetted channel. Therefore, we would have expected at least one of the two blackwater-characteristic tree species to be present, and for the stream water to be more darkly stained if the site were a true blackwater system. Like the other blackwater sites, the Dragon Run site was located to the far right on axis 1 of the PCA plot, but unlike the other sites, it was located very high on axis 2, though it was still assigned to the blackwater classification using the

BHP. This position on the ordination plot again indicates the greater relative importance of the habitat metrics associated with axis 1 in the overall classifications.

### *Preliminary GIS analysis*

We analyzed seven GIS-derived metrics associated with watershed topography, soil texture, and soil hydrology (see Table 4a and Appendix A for explanations of each GIS metric). Of these, the standard deviation of slope (a measure of slope variability or basin roughness) appeared to be the most effective for site classification. Significant differences for the metric occurred among site classification groups, both in the case of the *a priori* classification and when the BHP was employed (ANOVA,  $p < 0.05$ , Tables 4a and 4b). In the case of the *a priori* classifications, multiple comparisons via Tukey's Honestly Significant Difference (HSD) test indicated a significantly higher standard deviation of slope in the non-blackwater swamp watersheds than in the blackwater swamp watersheds at  $p < 0.05$ , but no significant differences between swamp watersheds and non-Class VII watersheds occurred (Table 4a, Fig. 7). Mean watershed slope and mean depth to the water table (expected depths in December – January) showed a similar pattern—mean values were lower in blackwater swamps than in non-blackwater swamps, but no difference occurred between the swamp watersheds and non-Class VII watersheds. The differences with respect to mean slope and mean depth to water table were only significant at  $p = 0.07$  (Tables 4a and 4b, Figs. 7 and 8). The remaining metrics observed (proportions of watersheds that were commonly flooded or ponded, occupied by hydric soils or by sandy soils) showed no significant differences among the site classifications ( $p > 0.10$ , Tables 4a and 4b).

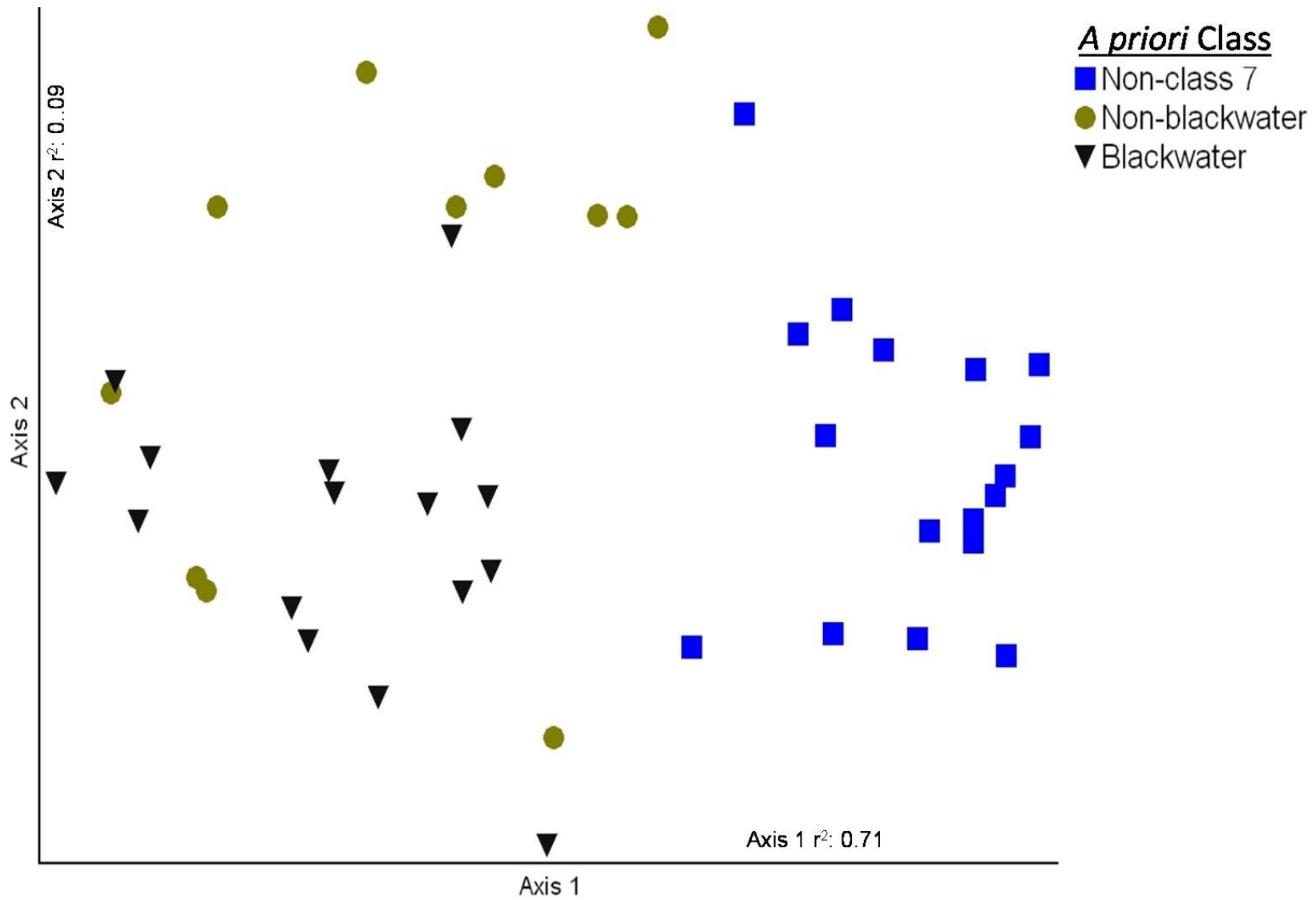


Figure 2: Ordination of the 44 study sites by 18 habitat metrics. Sites are symbolized according to their *a priori*-assigned classification based on best professional judgment.

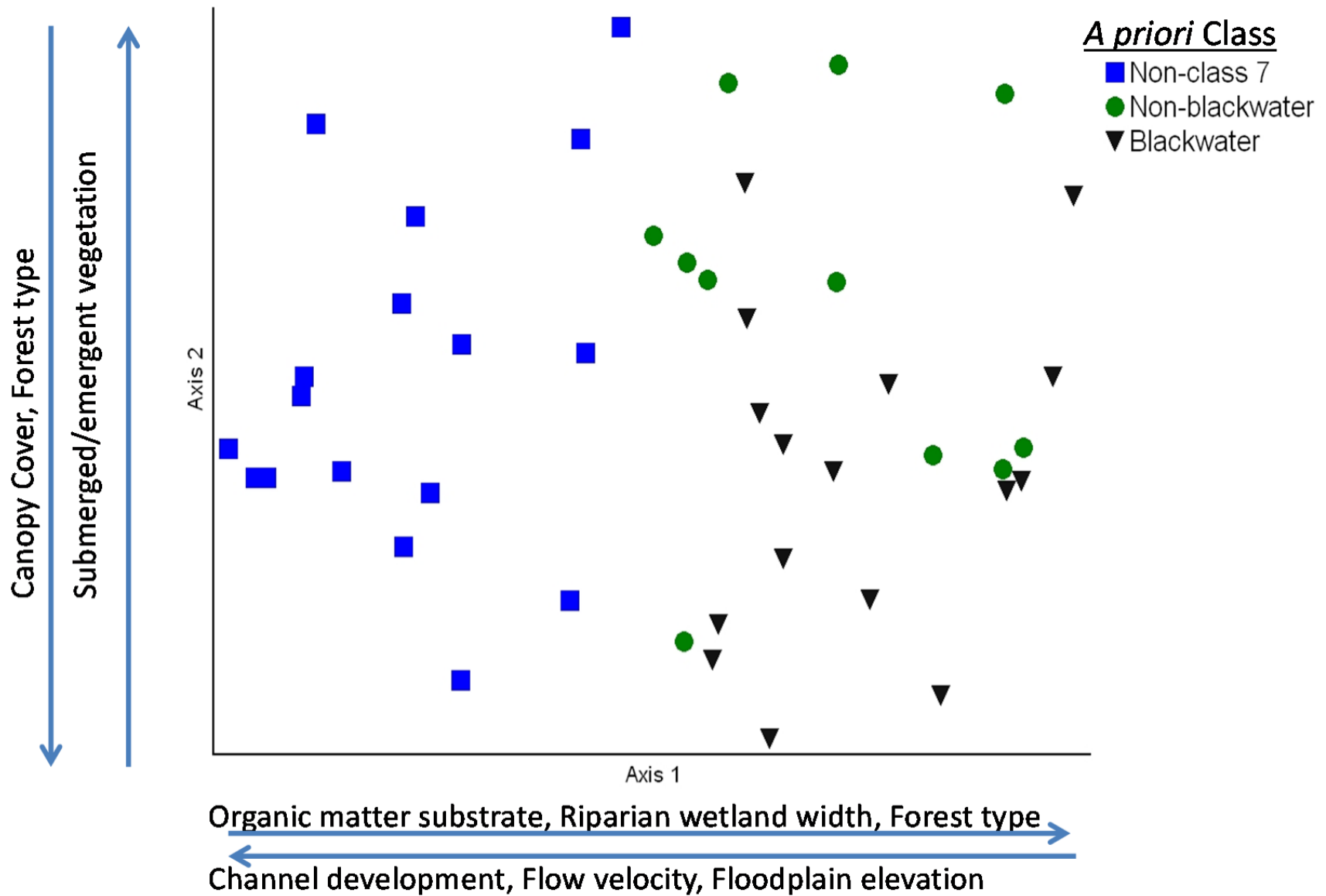


Figure 3: Ordination of the 44 study sites by the eight core habitat metrics. Sites are symbolized according to their *a priori*-assigned classification based on best professional judgment. Arrows show the direction of correlations between the listed habitat metrics and the ordination axes.

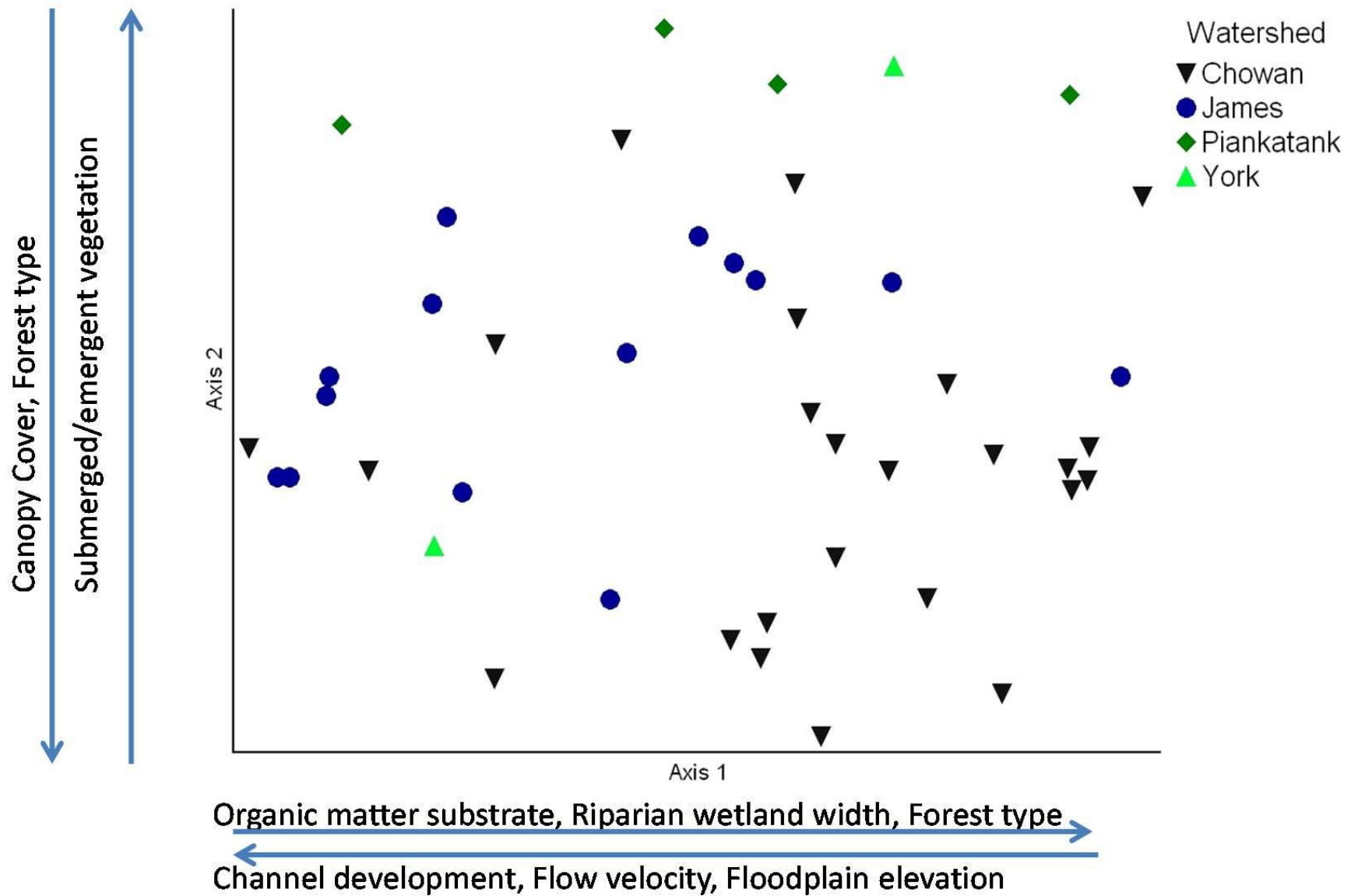


Figure 4: Ordination of the 44 study sites by the eight core habitat metrics. Sites are symbolized according to the major river watershed within which each occurs. Arrows show the direction of correlations between the listed habitat metrics and the ordination axes.

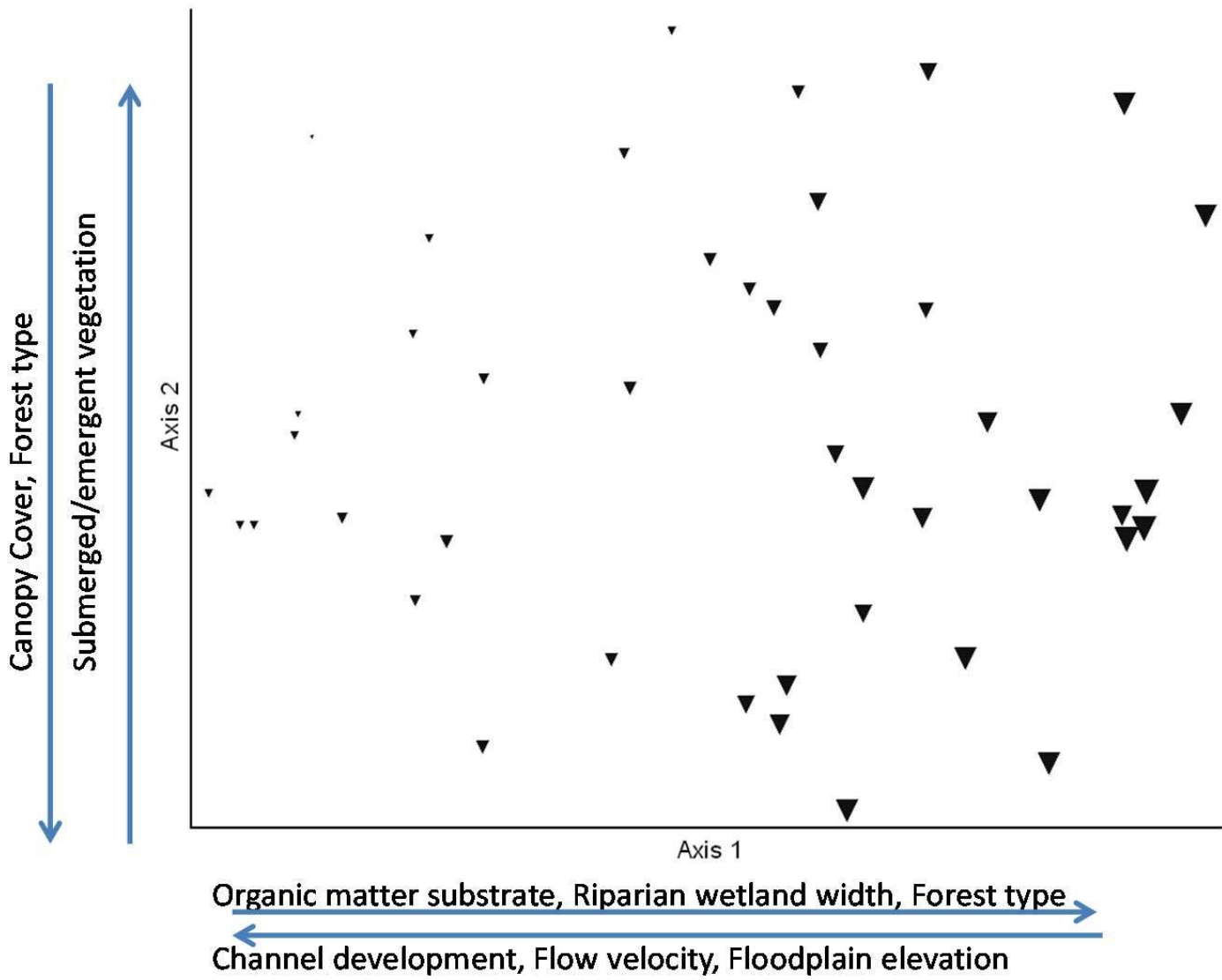


Figure 5: Ordination of the 44 study sites by the eight core habitat metrics. The size of the site symbols represents their score, based on the discrete, quartile-based scoring system. Larger symbols exhibit a greater potential of blackwater conditions.

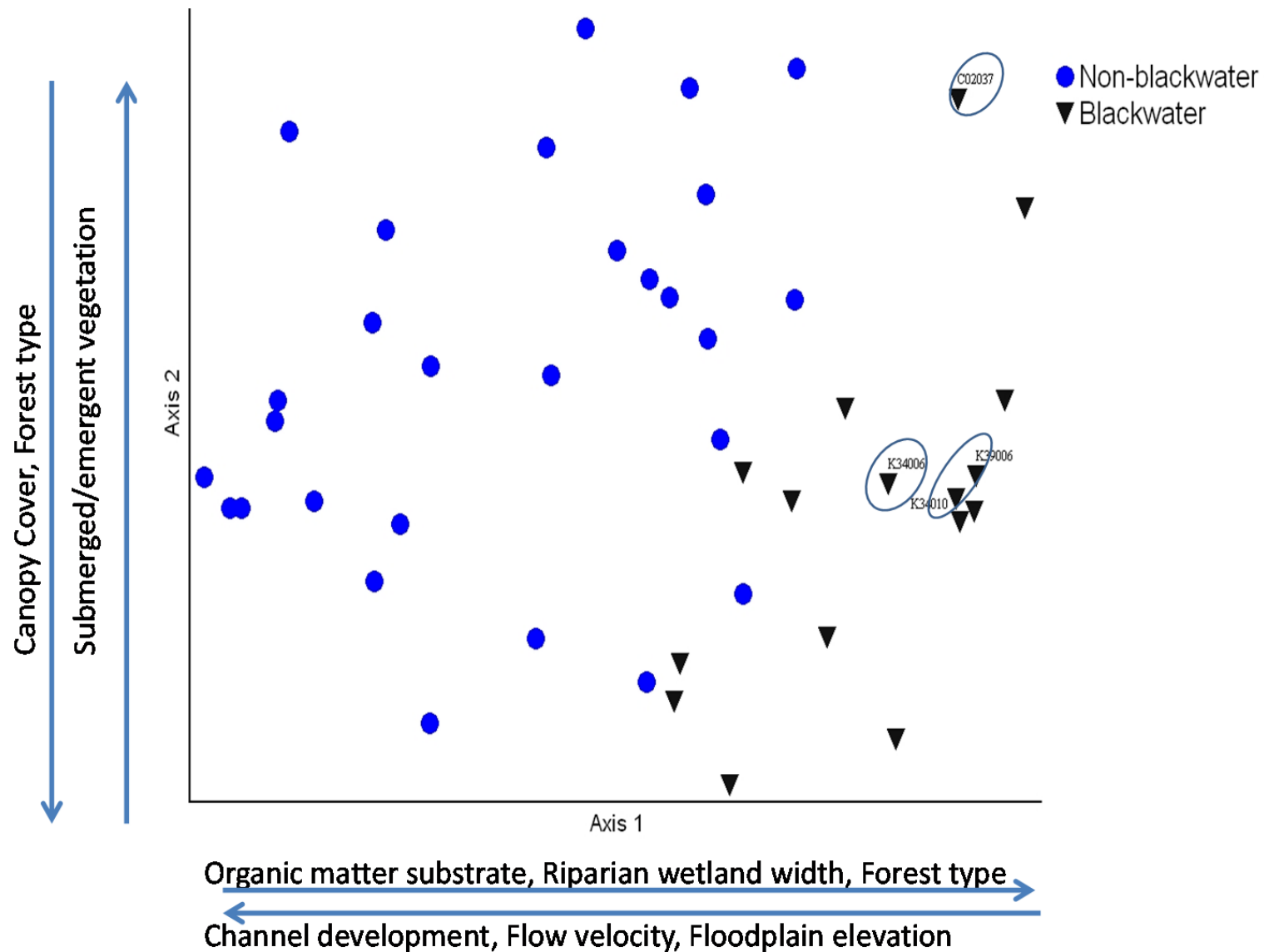
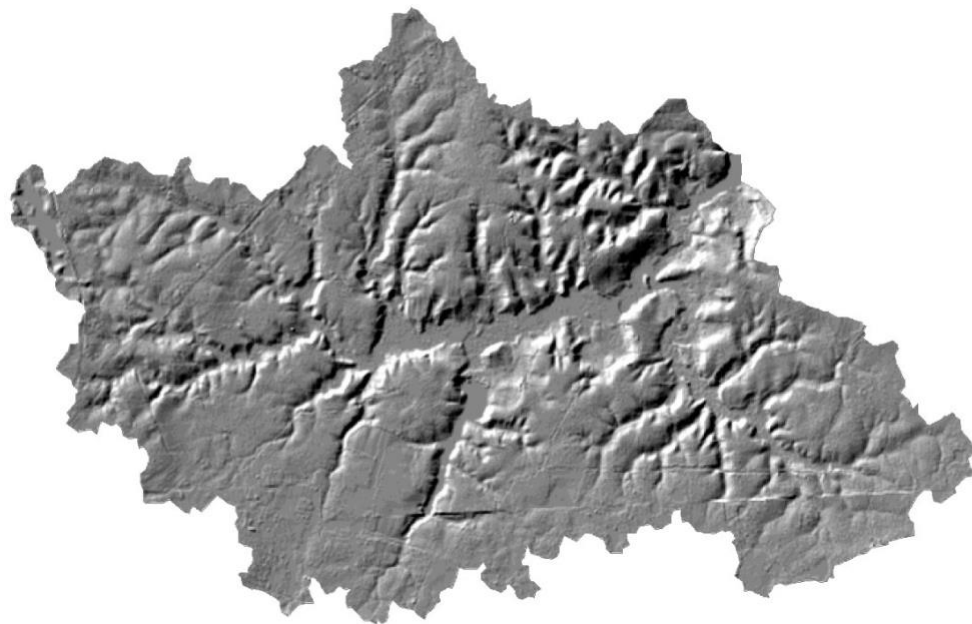


Figure 6: Ordination of the 44 study sites by the eight core habitat metrics. Sites are symbolized based on their classification according to the Blackwater Habitat Protocol (BHP) at the 66<sup>th</sup> percentile cut-off value. Ovals indicate sites where the BHP classification indicated blackwater conditions, but the *a priori* site classification did not.



Cypress Swamp. Mean Slope: 8.38% Rise



Dark Swamp. Mean Slope 1.94% Rise

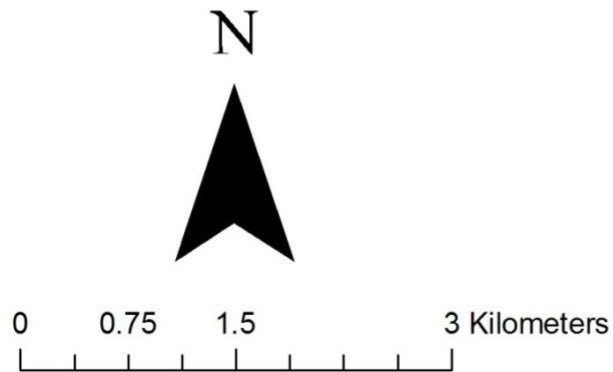


Figure 7: Topography in the watersheds of a representative blackwater site (Cypress Swamp) and a representative non-blackwater site (Dark Swamp).

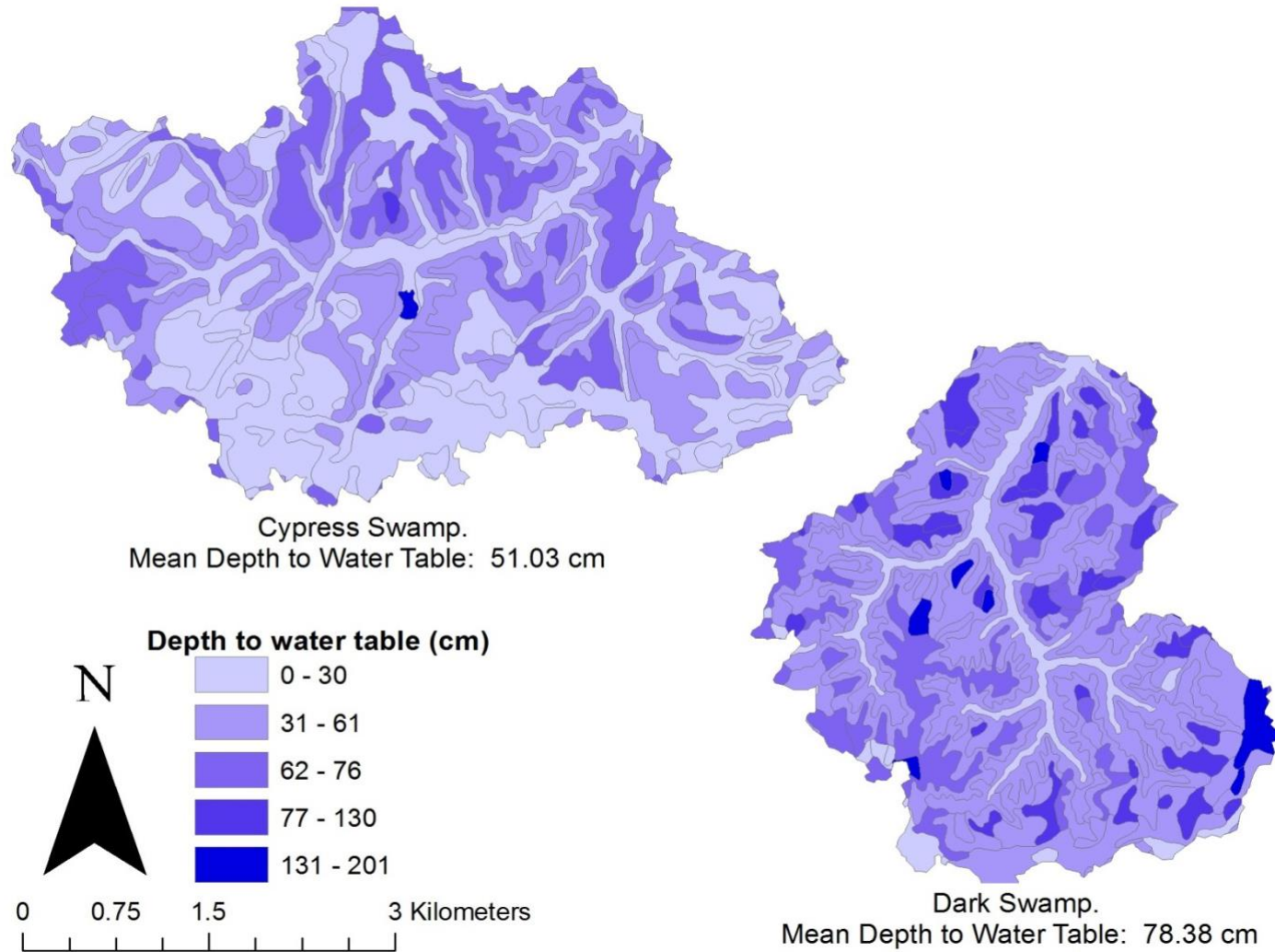


Figure 8: Mean depth to water table (cm) in the watershed of a representative blackwater site (Cypress Swamp) and a representative non-blackwater site (Dark Swamp).

Table 3: Comparison of classifications using the Blackwater Habitat Protocol (BHP) to those based on best professional judgment.<sup>1</sup>

Best Professional Judgment Classification	BHP Score Classification	Agreement	BHP score percentile (actual score in parentheses)				Consequence of Classification based on BHP Compared to Best Professional Judgment
			66 (16)	80 (17)	90 (18)	95 (19)	
Blackwater	Non-BW	NO	3	7	10	13	Site incorrectly retains Class VII designation
<b>Non-BW Swamp</b>	<b>Blackwater</b>	<b>NO</b>	<b>4</b>	<b>3</b>	<b>3</b>	<b>1</b>	<b>Site is incorrectly assessed with BCI protocol</b>
<b>Non-class VII Stream</b>	<b>Blackwater</b>	<b>NO</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>Site is incorrectly assessed with BCI protocol</b>
Blackwater	Blackwater	YES	12	8	5	2	Site correctly evaluated with blackwater protocol
Non-BW Swamp	Non-BW	YES	7	8	8	10	Site correctly retains class designation
Non-class VII Stream	Non-BW	YES	18	18	18	18	No evidence of Class VII, site correctly evaluated with CPMI

<sup>1</sup> Numbers in the body of the table represent occurrences within each of the possible outcomes (3 types of agreements and 3 types of disagreements) for each of the 44 study sites at four different BHP score cut-off values. Non-BW=non-blackwater; Stream=non-Class VII site appropriate for the Coastal Plain Macroinvertebrate Index (CPMI) or other established assessment method; BCI=Blackwater Condition Index.

Table 4a: Mean values for the geographic information system (GIS) metrics for each *a priori* habitat classification.<sup>1</sup>

	Commonly Flooded (proportion)	Commonly Ponded (proportion)	Hydric Soils (proportion)	Sand Soils (proportion)	Mean Depth to Water Table (cm)	Mean Slope (percent rise)	Std. Dev. Slope (percent rise)
Non-Class VII	0.10 (0.02)	0.00 (0.00)	0.58 (0.07)	0.12 (0.03)	79.92 (5.73)	3.13 (0.43)	2.95 (0.30)
Non-blackwater swamps	0.07 (0.01)	0.01 (0.00)	0.55 (0.08)	0.10 (0.03)	80.68 (7.51)*	2.96 (0.59)*	3.09 (0.61)**
Blackwater swamps	0.10 (0.01)	0.02 (0.01)	0.67 (0.06)	0.06 (0.02)	66.27 (5.44)*	1.94 (0.20)*	2.03 (0.16)**

<sup>1</sup> Explanation of GIS data: Commonly Flooded=proportion of watershed area rated as "occasionally", "frequently", or "very frequently" flooded; Commonly Ponded=proportion of watershed area rated as "occasionally" or "frequently" ponded; Hydric Soils=proportion of watershed area rated as "all hydric" or "partially hydric"; Sand Soils=proportion of watershed area with sand surface soils (>85% sand content); Mean Depth to Water Table=average depth from land surface to water table surface in each watershed in December through January; Mean Slope=arithmetic mean of topographical slope in each watershed in percentage rise; Std. Dev. Slope=standard deviation of topographical slope in each watershed in percentage rise. A single asterisk (\*) denotes pairwise comparisons that indicated significant differences at p<0.10; double asterisks (\*\*) denote pairwise comparisons that indicated significant differences at p<0.05 (Analysis of Variance with Tukey's HSD test for multiple comparisons).

Table 4b: Mean values for the geographic information system (GIS) metrics for blackwater and non-blackwater sites as indicated by the Blackwater Habitat Protocol Score 66<sup>th</sup> percentile cutoff value.<sup>1</sup>

	Commonly Flooded (proportion)	Commonly Ponded (proportion)	Hydric Soils (proportion)	Sand Soils (proportion)	Mean Depth to Water Table (cm)	Mean Slope (percent rise)	Std. Dev. Slope (percent rise)
Non-Blackwater (66th score percentile)	0.09 (0.01)	0.01 (0.00)	0.56 (0.05)	0.10 (0.02)	81.52 (4.42)	3.31 (0.40)*	3.26 (0.38)**
Blackwater (66th score percentile)	0.1 (0.01)	0.02 (0.02)	0.71 (0.06)	0.07 (0.02)	74.04 (5.95)	2.01 (0.23)*	2.14 (0.16)**

<sup>1</sup> A single asterisk (\*) denotes pairwise comparisons that indicated significant differences at p<0.10; double asterisks (\*\*) denote pairwise comparisons that indicated significant differences at p<0.05 (Analysis of Variance with Tukey's HSD test for multiple comparisons).

### *Conclusions and recommendations*

The habitat evaluation conducted using our original 18-metric protocol was generally in agreement with our best professional judgment of which sites should be designated as Class VII and blackwater. The original protocol was overly time-consuming at some sites. Further analysis indicated that many of the original metrics were redundant. The simplified protocol presented here provides a more time-efficient method of site classification, and the quality and reliability of the resulting classifications are not reduced compared to the original protocol. This conclusion is supported by the analysis conducted here that indicates that the eight core metrics provide a clear and discernible separation of the study sites that, in most cases, agrees with our best professional judgment of which sites should be classified as blackwater.

The GIS-derived classification metrics showed some potential as empirical aids to site classification, most especially those associated with basin topography and water table depth. It should be noted that the analysis conducted here was limited to only seven metrics, each was analyzed individually, and at only one spatial scale (within the upstream watershed of each site). Assessment of additional variables or spatial scales, or the application of more complex approaches, such as weighted models that consider multiple geospatial parameters simultaneously, may further improve site classification, though such analyses are generally quite time-consuming and labor-intensive.

The BHP classifications did, in some instances, disagree with field biologists' judgments of the correct site classifications. This disagreement was likely because the most correct site classification was marginal, exhibiting only some characteristics of blackwater systems. It is important to note that, whereas site categorization such as this may be necessary for consistent and defensible water quality assessment, such categorization should be done cautiously, as natural systems generally function along continuums, rather than within discrete categories.

The final products we present as a result of the 2013 iteration of Task 1 are Appendices B and C of this report. These appendices include the field data sheet for the newly-developed BHP (Appendix B) and a complete explanation of the correct interpretation and scoring of each metric (Appendix C). We recommend that DEQ personnel that regularly encounter potential Class VII sites on the Virginia Coastal Plain receive a brief training session from us regarding the BHP. As data from additional sites are included, the protocol may need to be altered and refined, which would likely include changing the interpretation of metrics, adding or deleting metrics, and changing the scoring criteria for each metric. The apparent misclassification of the upper Dragon Run site provides an example of a potential need for further calibration of the BHP. The site was classified as blackwater by the BHP; however, it displayed several characteristics that distinguished it from the other blackwater sites, most notably its lack of the characteristic riparian-zone tree species, water tupelo and baldcypress, which occur at blackwater sites. If misclassifications of this type are commonly observed as common in a larger dataset, weighting of the *Forest type* metric, or down-weighting of other metrics may improve the classification

scheme. Further analysis should also focus on the biological relevance of the habitat metrics considered here: that is, those characteristics of Coastal Plain systems that can most reliably predict the structure and functioning of faunal communities, and therefore be most reliably used as natural covariates in the choice and application of biological assessment protocols.

Most importantly, the limitations of this protocol highlight the importance of best professional judgment in the classification process. The judgment of experienced biologists should be considered the primary tool for classification, with structured protocols such as this used as decision support tools used to supplement site classification and selection of the most appropriate methods for assessment.

## **Task 2 Blackwater Condition Index**

### *Methods and Results*

We completed a new and more extensive (cp. Garman et al. 2012) multivariate analysis (Detrended Correspondence Analysis, DCA, and Ordination) of a randomly-selected set of fish community data for streams (n=150) in the Virginia lower Coastal Plain (Chesapeake and Chowan basins). The source of these data was Virginia Commonwealth University’s Interactive Stream Assessment Resource (INSTAR) database, which has been developed with funding from several agencies, including Virginia DEQ. Based on these analyses of species assemblages, together with our best professional judgment, we identified ecological guilds representing various Coastal Plain aquatic habitats (Fig. 9). Specifically, we identified a “blackwater” (or “diagnostic”) guild of 10 species that are routinely associated with ecologically healthy blackwater streams and swamps in both the Chesapeake Bay and Chowan basins. In addition, we identified an “opportunistic” guild of nine fishes that are routinely associated with degraded blackwater streams, but that may also be common in brownwater (non-blackwater Class VII) streams and swamps within the same region. Several other species (e.g., pirate perch, mud sunfish) that occur commonly in coastal and even blackwater streams, but have a relatively wide distribution, were not considered diagnostic for either condition, and thus they were not included in the guilds that follow:

#### Blackwater Guild

Swampfish (*Chologaster cornuta*)  
Sawcheek darter (*Etheostoma serrifer*)  
Lined topminnow (*Fundulus lineolatus*)<sup>1</sup>  
Ironcolor shiner (*Notropis chalybaeus*)  
Bridle shiner (*N. bifrenatus*)  
Redfin pickerel (*Esox americanus*)  
Blackbanded sunfish (*Enneacanthus chaetodon*)<sup>1</sup>  
Banded sunfish (*E. obesus*)  
Swamp darter (*Etheostoma fusiforme*)  
Flier (*Centrarchus macropterus*)

#### Opportunistic Guild

Creek chubsucker (*Erimyzon oblongs*)  
Eastern mosquitofish (*Gambusia holbrooki*)  
Eastern mudminnow (*Umbra pygmaea*)  
Golden shiner (*Notomigonus crysoleucus*)  
Redear sunfish (*Lepomis microlophus*)<sup>2</sup>  
Bluegill sunfish (*L. macrochirus*)<sup>2</sup>  
Largemouth bass (*Micropterus salmoides*)<sup>2</sup>  
Bluespotted sunfish (*E. gloriosus*)  
Brown bullhead (*Ameiurus nebulosus*)

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<sup>1</sup> Chowan only

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<sup>2</sup> Introduced

The taxa represented by these guilds were the basis for two metrics included in the draft BCI (Table 5). Evaluation of other candidate index metrics resulted in the addition of a metric for relative abundance (ecologically healthy blackwater systems are oligotrophic and exhibit low faunal densities) and a metric describing ecological “evenness” (Simpson’s Index), as healthy blackwater streams exhibit high evenness (a component of diversity) among taxa. The resulting BCI score ranges between 4 and 20. Scoring criteria (i.e., breakpoints) for these four metrics were assigned based on analysis of INSTAR data pooled across basins (i.e., Chesapeake plus Chowan) and were used to assign conditional BCI scores to a random sample (n=52) of coastal streams (Table 5). The distribution of BCI scores (Fig. 10) approximated a normal distribution

and included both very high (20) and very low (6) index scores; 60 percent of scored streams received a “14” or higher, and we propose that blackwater streams with a BCI score  $\geq 14$ , should be considered unimpaired, whereas blackwater streams with a BCI score  $\leq 12$  should be considered as impaired for aquatic life use.

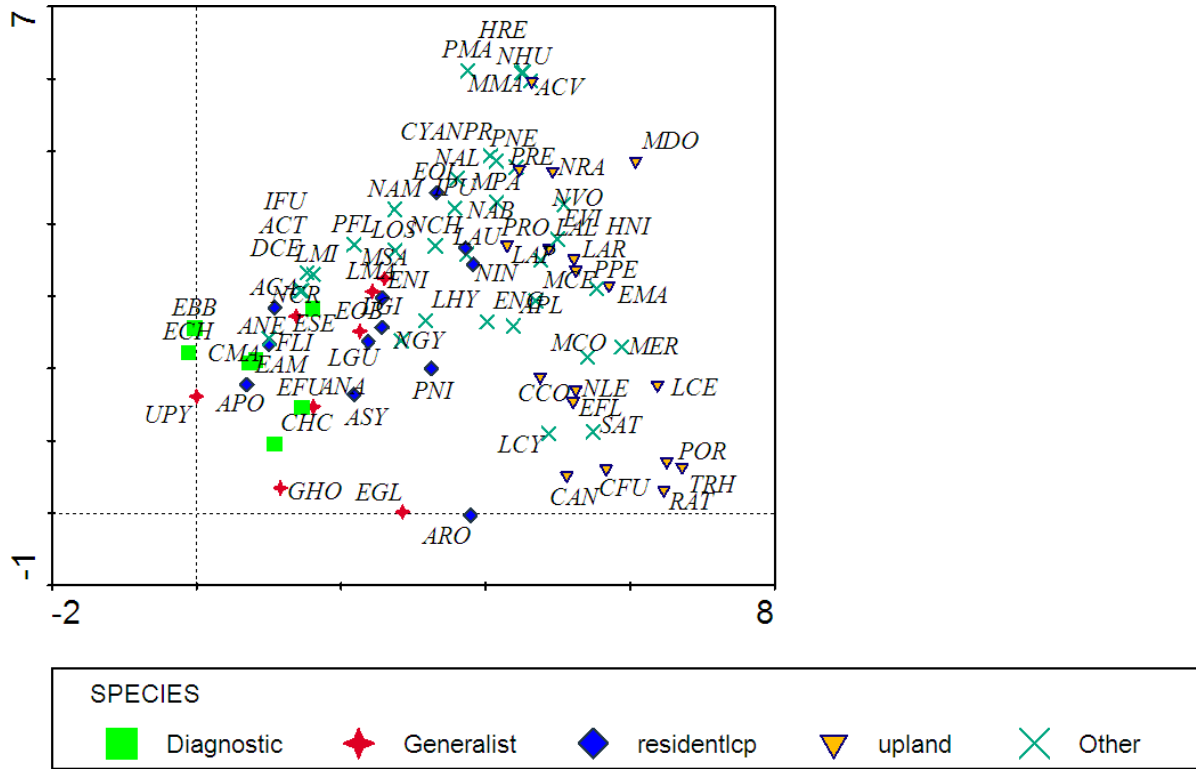


Figure 9: Ordination plot of fish species from INSTAR collections representing 150 Coastal Plain streams in the Chesapeake and Chowan basins of Virginia. Codes are individual species (e.g., ECH=*Enneacanthus cheatodon*). Symbols represent ecological guilds assigned *a priori*. “Diagnostic” species represent a guild of blackwater fishes, whereas the “generalist” category includes opportunistic species associated with degraded blackwater streams and swamps. The code “residentlcp” stands for resident species, lower Coastal Plain; “other” refers to taxa that are not placed into one of the other guilds.

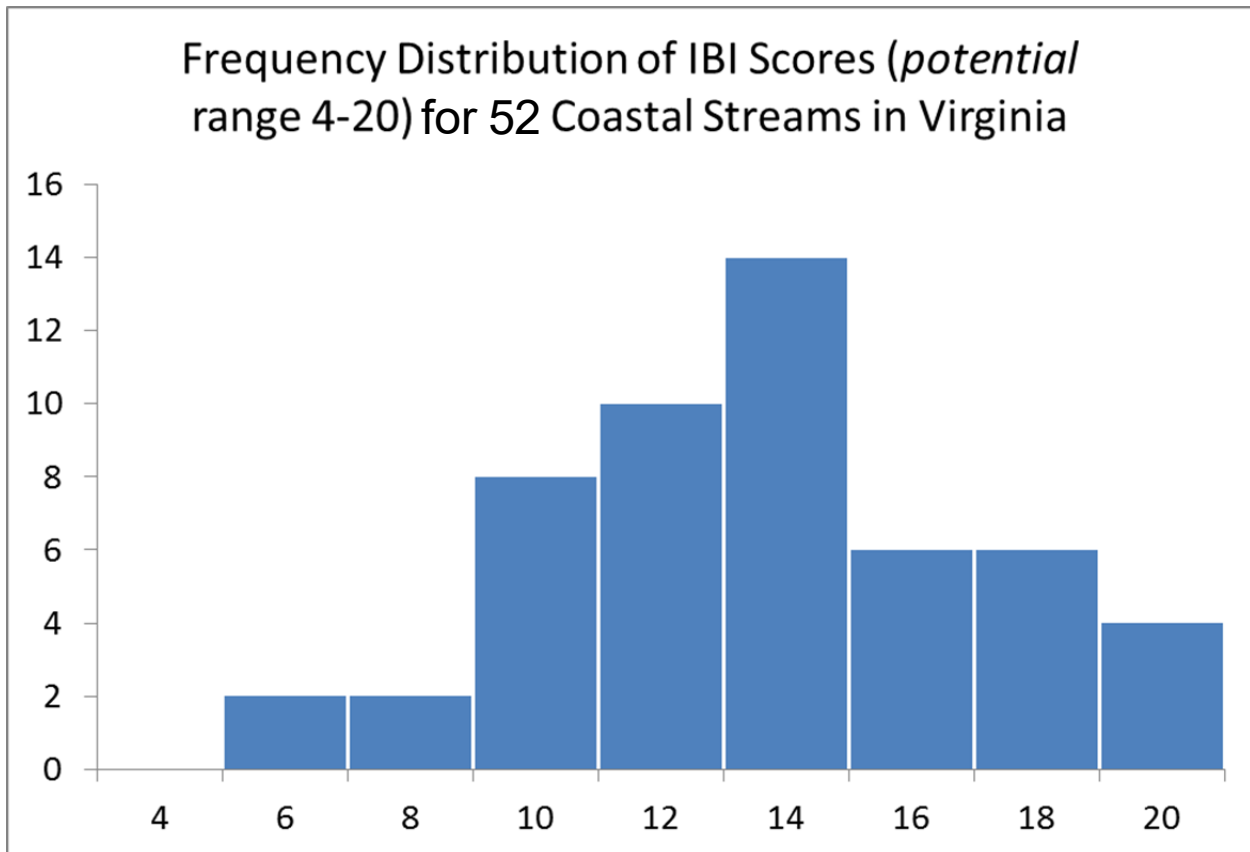


Figure 10: Frequency distribution of Blackwater Condition Index scores for a sample of 52 Chesapeake and Chowan Coastal Plain streams likely to be classified as blackwater within Class VII. Possible BCI scores range from 4 to 20.

Table 5: Metrics, empirical ranges, and scoring criteria for a proposed Blackwater Condition Index (BCI).<sup>1</sup>

Metric	Range	Scores “1”	Scores “3”	Scores “5”
Number of blackwater species	0-6	0-1	2	≥3
Number of opportunistic species	1-7	≥5	3-4	≤2
Relative abundance (CPUE, seconds)	0.01-0.6	>0.1	0.05-0.1	<0.05
Simpson’s Evenness Index	0.2-0.8	<0.5	0.5-0.6	>0.6

<sup>1</sup> Metrics and criteria were developed from a random sample (n=52) of coastal streams in the INSTAR database (Chesapeake and Chowan basins). Data were collected by Virginia Commonwealth University in 2012 and represent quantitative fish community samples identified to species; electrofishing effort is in seconds. CPUE=catch per unit effort.

## **Conclusions and Recommendations**

The analyses presented in this report suggest that a simple Blackwater Condition Index (BCI), based on analysis of fish community guilds, is able to accurately determine impairment of blackwater (Class VII) streams and swamps in Virginia. Furthermore, a rapid field protocol, based on non-biological measures, was successful in separating blackwater and non-blackwater streams within the Virginia Coastal Zone. We believe that a combination of both analyses should be validated as a potential assessment protocol for Class VII waters, and for blackwater streams specifically. We believe that such an approach has several advantages, including the ability to leverage extensive and expanding biological databases (INSTAR, DEQ ProbMon) for the region and the ability to conduct *real-time* stream assessments by appropriately trained DEQ personnel. Our recommendations for next steps include:

- 1.) Presentations of the proposed blackwater indices to DEQ biologists at their annual meeting on June 21, 2013 (on the agenda) and revisions to both assessment tools based on those discussions;
- 2.) Test the relative performance of the Habitat (Task 1) and BCI (Task 2) tools on the same dataset of coastal streams;
- 3.) Validate the blackwater models with an independent set of non-biological variables (cp. Virginia Stream Condition Index).

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## Appendices

APPENDIX A: Coordinates, major watershed locations, and geographic information system (GIS)-derived data for the 44 habitat classification sites.<sup>1</sup>

Site	Lat.	Long.	Watershed	Watershed Area (km <sup>2</sup> )	Commonly Flooded (proportion)	Commonly Poned (proportion)	Hydric Soils (proportion)	Sand Soils (proportion)	Mean Depth to Water Table (cm)	Mean Slope (% rise)	Std. Dev. Slope (% rise)
Benetts Creek Trib.	36.42622	-76.6643	Chowan	1529.72	0.05	0.00	0.96	0.00	49.98	0.95	1.64
White Marsh	37.80134	-76.8021	Piankatank	546.63	0.05	0.00	0.15	0.10	126.88	2.56	2.39
Dragon Run	37.82464	-76.9052	Piankatank	732.38	0.08	0.00	0.24	0.16	134.29	3.83	3.33
Piankatank River Trib.	37.58206	-76.5074	Piankatank	189.52	0.06	0.00	0.06	0.00	133.29	6.07	5.52
Fox Mill Run Trib.	37.39366	-76.5516	Piankatank	303.86	0.09	0.00	0.90	0.18	99.00	3.69	4.93
Joseph Swamp Trib.	37.08343	-77.2800	Chowan	236.83	0.06	0.00	0.47	0.04	104.00	2.86	2.33
Austin Branch	36.90946	-77.1677	Chowan	532.54	0.10	0.00	0.82	0.18	64.34	2.96	2.20
Nottoway River Trib.	36.91305	-77.2191	Chowan	211.96	0.15	0.00	0.75	0.38	58.68	2.06	2.00
Rattlesnake Creek	36.94489	-77.2378	Chowan	691.78	0.35	0.00	0.87	0.10	58.54	1.24	1.56
Racoon Creek	36.80435	-77.2082	Chowan	16187.29	0.11	0.00	0.72	0.20	90.65	3.21	2.58
Assamoosick Swamp Trib.	36.95360	-77.1365	Chowan	937.96	0.09	0.00	0.82	0.01	59.81	2.14	2.06

Site	Lat.	Long.	Watershed	Watershed Area (km <sup>2</sup> )	Commonly Flooded (proportion)	Commonly Poned (proportion)	Hydric Soils (proportion)	Sand Soils (proportion)	Mean Depth to Water Table (cm)	Mean Slope (% rise)	Std. Dev. Slope (% rise)
Black Swamp	37.04219	-77.1444	Chowan	1038.61	0.12	0.00	0.71	0.00	76.57	1.96	2.19
Seacorrie Swamp	36.93298	-77.1004	Chowan	2784.16	0.11	0.00	0.73	0.02	64.51	2.31	2.21
France Swamp	37.42151	-76.7842	York	1768.82	0.05	0.05	0.35	0.06	127.67	7.99	8.36
Poropotank River	37.54384	-76.6288	York	231.89	0.08	0.00	0.23	0.00	133.59	7.20	4.52
Gunns Run	37.34613	-77.1072	James	1841.32	0.07	0.03	0.70	0.02	74.68	1.88	1.99
Wards Creek	37.21577	-77.0811	James	4131.39	0.06	0.00	0.44	0.01	72.97	3.42	3.15
Mapisco Creek	37.32010	-77.0233	James	1019.70	0.06	0.03	0.52	0.01	77.36	2.56	2.79
Baileys Branch	37.18002	-77.0125	James	1476.01	0.06	0.00	0.15	0.00	69.23	4.68	3.99
Upper Chippokes Trib.	37.14600	-77.0468	James	413.67	0.13	0.00	0.20	0.04	72.65	4.54	3.27
Tomahund Creek	37.27727	-76.9281	James	982.30	0.04	0.00	0.85	0.02	67.85	1.69	2.23
Parsons Creek	37.33576	-76.9038	James	161.78	0.05	0.00	0.79	0.03	58.04	3.05	3.67
College Run	37.12224	-76.8017	James	327.88	0.13	0.00	0.34	0.06	76.36	3.35	2.76
Grays Creek	37.16511	-76.8693	James	964.52	0.03	0.04	0.08	0.02	74.34	6.55	6.94
Dark Swamp	37.16196	-76.8493	James	1167.63	0.07	0.03	0.20	0.02	78.38	8.38	8.83

Site	Lat.	Long.	Watershed	Watershed Area (km <sup>2</sup> )	Commonly Flooded (proportion)	Commonly Poned (proportion)	Hydric Soils (proportion)	Sand Soils (proportion)	Mean Depth to Water Table (cm)	Mean Slope (% rise)	Std. Dev. Slope (% rise)
Pitchkettle Creek	36.69707	-76.6190	James	675.13	0.02	0.00	0.69	0.42	90.89	1.83	2.77
Speights Run	36.69920	-76.6684	James	812.76	0.03	0.00	0.76	0.23	87.65	1.14	1.64
Burnette's Mill Creek	36.75576	-76.5388	James	3259.09	0.22	0.24	0.99	0.01	48.51	1.00	3.47
Bailey Creek	36.81495	-76.4360	James	665.74	0.12	0.00	0.96	0.08	60.51	0.97	1.86
Spring Creek Trib.	36.82842	-77.4022	Chowan	688.43	0.08	0.00	0.63	0.15	84.15	2.64	2.37
Applewhite Swamp	36.72726	-77.3508	Chowan	1345.11	0.12	0.00	0.62	0.29	86.97	3.75	2.84
Chatham Branch	36.72664	-77.3790	Chowan	1040.26	0.12	0.00	0.81	0.12	86.51	3.17	2.27
Cypress Swamp	37.14749	-76.9667	Chowan	1628.86	0.11	0.02	0.49	0.01	51.03	1.94	1.94
Otterdam Swamp	37.12923	-77.1234	Chowan	1556.65	0.14	0.00	0.20	0.01	64.68	1.95	2.01
Terrapin Swamp	36.98188	-76.9075	Chowan	1449.83	0.11	0.06	0.47	0.00	73.70	2.67	2.39
Burnt Mill Swamp	36.85212	-76.7763	Chowan	678.24	0.16	0.00	1.00	0.20	93.11	1.75	1.93
Passenger Swamp	37.03690	-76.7794	Chowan	1535.74	0.06	0.04	0.87	0.00	49.20	1.36	2.07
Stallings Creek Trib.	36.97909	-76.7125	Chowan	327.08	0.07	0.00	1.00	0.01	51.08	1.09	1.29
Moore's Swamp	37.06905	-76.8512	Chowan	1285.58	0.07	0.00	0.76	0.02	65.57	1.80	1.99

Site	Lat.	Long.	Watershed	Watershed Area (km <sup>2</sup> )	Commonly Flooded (proportion)	Commonly Poned (proportion)	Hydric Soils (proportion)	Sand Soils (proportion)	Mean Depth to Water Table (cm)	Mean Slope (% rise)	Std. Dev. Slope (% rise)
Round Hill Swamp	36.85745	-76.9209	Chowan	16344.56	0.12	0.00	0.83	0.10	82.25	2.10	2.27
Adams Swamp	36.57480	-76.6186	Chowan	650.21	0.09	0.00	0.66	0.34	93.00	1.23	1.38
Duke Swamp	36.47073	-76.6370	Chowan	8642.05	0.06	0.00	0.91	0.04	54.84	0.90	0.97
Goodman Spring	36.53074	-76.6454	Chowan	1175.69	0.10	0.00	0.74	0.22	78.68	1.17	1.12
Duke Swamp Trib.	36.54209	-76.6899	Chowan	194.87	0.05	0.00	0.63	0.04	61.23	1.42	1.41

<sup>1</sup> Explanation of GIS data: Commonly Flooded=proportion of watershed area rated as "occasionally", "frequently", or "very frequently" flooded; Commonly Poned=proportion of watershed area rated as "occasionally" or "frequently" ponded; Hydric Soils=proportion of watershed area rated as "all hydric" or "partially hydric"; Sand Soils=proportion of watershed area with sand surface soils (>85% sand content); Mean Depth to Water Table=average depth from land surface to water table surface in each watershed in December through January; Mean Slope=arithmetic mean of topographical slope in each watershed in percentage rise; Std. Dev. Slope=standard deviation of topographical slope in each watershed in percentage rise.

## Appendix B: Field datasheet for the Blackwater Habitat Protocol (BHP).

Metric	Subcategories (metrics 1 and 2)	Raw values	Weights	Scoring
1) Channel Development		Percentage of channel	Weight	Percentage*weight
	One defined channel	_____	2	_____
	Multiple, defined channels	_____	1	_____
	No defined channels	_____	0	_____
		Total weighted percentage: Metric score:	_____	_____
2) Flow Velocity		Percentage of channel	Weight	Percentage*weight
	No perceptible flow	_____	0	_____
	Slow flow	_____	1	_____
	Moderate, laminar flow	_____	2	_____
	Rapid, laminar flow	_____	3	_____
	Rapid, turbulent flow	_____	4	_____
	Total weighted percentage: Metric score:	_____	_____	_____
3) Floodplain Elevation	Value (cm):	_____	Metric score:	_____
4) Submerged and Emergent Vegetation			Metric score:	_____
5) Benthic Organic Matter	Percentage:	_____	Metric Score:	_____
6) Forest Type			Metric score:	_____
7) Wetland Width	Width (cm):	_____	Metric score:	_____
8) Canopy	Percentage of overhead cover:	_____	Metric score:	_____

## Appendix C: Metric interpretation and scoring for the Blackwater Habitat Protocol (BHP).

Metric Explanations	Metric value calculation	Scoring criteria				
<b>1) Channel Development</b> Percentages of 100m reach comprised of single channels, multiple channels (i.e. braided-channel systems), and undefined channels (large standing-water areas).	Metrics 1 and 2: multiply percentages for each subcategory by the subcategory weights to get weighted percentages, sum these values to get the total weighted percentage, and compare the total weighted percentage to the scoring criteria values listed to get the metric score	Total Weighted % Metric score	200 0	145-199 1	100-144 2	0-99 3
<b>2) Flow Velocity</b> Percentages of 100m reach comprised of each flow regime indicated on the field data sheet.	Compare the estimated value to the scoring criteria values	Total Weighted % Metric score	155 and greater 0	100-154 1	20-99 2	0-19 3
<b>3) Floodplain Elevation</b> Average elevation of riparian floodplain above the wetted channel.	Compare the estimated value to the scoring criteria values	Elevation (cm) Metric score	40 and greater 0	25-39 1	10-24 2	0-9 3
<b>4) Submerged/Emergent Vegetation</b> Commonness of submerged and/or emergent vegetation within the wetted area.	Score based on criteria indicated	Category Metric score	Absent 0	Rare 1	Common 2	Abundant 3
<b>5) Benthic Organic Matter</b> Percentage of the benthic area covered by large woody debris, coarse particulate organic matter, or fine particulate organic matter.	Score based on criteria indicated	Percentage Metric score	0-49 0	50-84 1	85-95 2	96 and greater 3
<b>6) Forest Type</b> Commonness of blackwater-indicator trees: <i>Nyssa aquatica</i> (water tupelo) and <i>Taxodium distichum</i> (baldcypress). Scores: Absent (0)- neither species present Rare (1)- other tree species are dominant but baldcypress and/or water tupelo are present, Common (2)- either baldcypress or water tupelo are present and codominant with other tree species OR both species occur and are relatively common, but not the dominant species, Abundant (3)- water tupelo and/or baldcypress are the dominant tree species.	Score based on criteria indicated	Category Metric score	Absent 0	Rare 1	Common 2	Abundant 3
<b>7) Wetland Width</b> Within 100 meters, laterally, from the center of the wetted area (200m total and including the wetted area), the percentage by area that is likely wetland (if variable, average over the 100m reach).	Compare the estimated percentage to scoring criteria percentages	Percentage: Metric score	0-24 0	25-44 1	45-74 2	75 and greater 3
<b>8) Canopy</b> Percentage of the overhead view of the sky view that, at full leaf-out, would be obstructed (requires estimation in late-fall to early spring).	Compare the estimated percentage to scoring criteria percentages	Percent Metric score	0-19 0	20-49 1	50-69 2	70 and greater 3

