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Title and Subtitle: Baseline for Climate Change: Modeling Watershed Aquatic Biodiversity Relative to Environmental and Anthropogenic Factors

Author: Eugene G. Maurakis, Ph.D.
Performing Organization Name: Science Museum of Virginia
2500 West Broad Street
Richmond, Virginia 23220

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Abstract: Objectives of the two-year study were to (1) establish baselines for fish and macroinvertebrate community structures in two mid-Atlantic lower Piedmont watersheds (Quantico Creek, a pristine forest watershed; and Cameron Run, an urban watershed, Virginia) that can be used to monitor changes relative to the impacts related to climate change in the future; (2) create mathematical expressions to model fish species richness and diversity, and macroinvertebrate taxa and macroinvertebrate functional feeding group taxa richness and diversity that can serve as a baseline for future comparisons in these and other watersheds in the mid-Atlantic region; and (3) heighten people's awareness, knowledge and understanding of climate change and impacts on watersheds in a laboratory experience and interactive exhibits, through internship opportunities for undergraduate and graduate students, a week-long teacher workshop, and a website about climate change and watersheds. Mathematical expressions modeled fish and macroinvertebrate richness and diversity accurately well during most of the six thermal seasons where sample sizes were robust. Additionally, hydrologic models provide the basis for estimating flows under varying meteorological conditions and landscape changes. Continuations of long-term studies are requisite for accurately teasing local human influences (e.g. urbanization and watershed alteration) from global anthropogenic impacts (e.g. climate change) on watersheds. Effective and skillful translations (e.g. annual potential exposure of 750,000 people to our inquiry-based laboratory activities and interactive exhibits in Virginia) of results of scientific investigations are valuable ways of communicating information to the general public to enhance their understanding of climate change and its effects in watersheds.

FINAL REPORT

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Baseline for Climate Change: Modeling Watershed Aquatic Biodiversity Relative to Environmental and Anthropogenic Factors

Prepared for Office of Science
United States Department of Energy
By
Science Museum of Virginia

Eugene G. Maurakis, Ph.D.
Principal Investigator
Director of Science and Museum Scientist
Science Museum of Virginia
2500 West Broad Street
Richmond, Virginia 23220

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Abstract

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Summary

1. Objectives of the technical research study were twofold: (1) Measure and record fish and macroinvertebrate species richness and diversity; macroinvertebrate functional feeding group (GGF) richness and diversity; physical characteristics (i.e., stream order, elevation, stream width, stream depth, stream current, stream flow, stream gradient, pH, water temperature, and river kilometer); and anthropogenic and watershed factors (i.e., human population, impervious cover, undeveloped land cover) in a forested watershed (Quantico Creek) and in an urban watershed (Cameron Run) in northern Virginia; and (2) create mathematical expressions to model species richness and diversity relative to physical characteristics, anthropogenic, and watershed characteristics in streams of two, lower Piedmont-Fall Line watersheds of the Potomac River drainage, Virginia.
2. Objectives of the outreach portion of this project were to: (1) create a laboratory experience in the Science Museum of Virginia to heighten visitor's awareness and knowledge of climate change and potential impacts on watersheds; (2) create an interactive exhibit on watersheds and climate change; (3) provide internship opportunities for undergraduate and graduate students; (4) host a week-long teacher workshop on watershed and climate change; (5) post a website about climate change and watersheds; and, (6) present findings of the technical research project.
3. The present investigation resulted in establishing baseline data for fish communities and mathematical equations to model for fish species richness and diversity in each of two mid-Atlantic region, lower Piedmont forest (Quantico Creek) and urban (Cameron Run) watersheds that can be used to compare changes in fish communities relative to climatic and urban development changes in the future. This is the first systematic, comprehensive long-term watershed-wide research of fish communities in Quantico Creek and Cameron Run.
4. There is a direct correlation between increases in human population and increased impervious cover in the Cameron Run watershed. The difference in impervious cover was one of the significant factors in accounting for reduced species richness in Cameron Run watershed compared to that of Quantico Creek.
5. Of particular note is the trenchant difference between the parameters that comprise the mathematical models for Quantico Creek (a forested watershed) and for Cameron Run (an urban watershed). Fish species richness in Quantico Creek watershed currently is a function of season, stream order, elevation, river km, stream width and depth, watershed size and percent of undeveloped land cover. In contrast, fish species richness in Cameron Run cannot be modeled using any of these parameters from the Quantico Creek model. Factors that reflect the current fish species diversity in Cameron Run are stream gradient, stream flow, and water temperature, and percent undeveloped land cover. Likewise, only two factors

(season and % undeveloped land cover) were common to the fish species diversity models of Quantico Creek and Cameron Run.

6. Species diversity in Cameron Run was a function of five factors (i.e., season, elevation, water temperature, undeveloped land cover, and % undeveloped land cover) rather than seven factors in the species diversity model in Quantico Creek. Two factors (season and % undeveloped land cover) were common to species diversity models both watersheds.
7. Based on the differences in species richness and species diversity models between Quantico Creek and Cameron Run watersheds, we purport that stream order and its other correlated factors used to model species richness in forested watersheds where human disturbance is minimal, are not appropriate for streams in highly modified urban environments.
8. Warren Buffett once commented "Beware of geeks bearing formulas." It should be noted that mathematical models are not absolutes. Our models, based on a host of various types of parameters collected over almost a two year period, present a picture of the relationships among these parameters and fish communities. We suggest that our models can be used as indicators of general trends and changes in communities and how the communities function, and can change relative to changes in environmental conditions.
9. We propose that stream order emulates an ecological unit, and can be used to account for variation in species diversity along a river continuum.
10. Macroinvertebrate taxa richness (range = 79-92) in all stream orders of Quantico Creek were higher than those (range = 19-39) in Cameron Run. All stream orders of Cameron Run had low EPT (i.e., Ephemeroptera, Plecoptera, Trichoptera) taxa richness and a complete absence of Plecoptera.
11. Percentages of functional feeding groups represented in Quantico Creek were similar to those in Cameron Run. However, taxa richness of each functional feeding group in Quantico Creek was significantly higher than those in each functional feeding group of Cameron Run.
12. The results of this study agree with the findings of Feld (2007) where degradation caused a decrease in sensitive taxa, rather than a shift from community of sensitive to one of primarily tolerant organisms. Even though Quantico Creek and Cameron Run have the same FFG composition, lower taxa richness of each FFG in Cameron Run indicates that these communities are unstable and vulnerable to a loss of community diversity. Disturbances that are anthropogenic in nature (i.e., increases in populations, increases in amount of impervious surfaces, decreases in the number of forested hectares) also pose a great threat to less diverse communities.

13. Macroinvertebrate taxa richness, FFG richness and FFG diversity were related to more individual parameters in Cameron Run than in Quantico Creek, illustrating that it is difficult to separate the impact of physical, anthropogenic and watershed characteristics on biotic communities in urban areas.
14. Hydrologic models provide the basis for estimating flows under varying meteorological conditions and landscape changes. Among the various hydrologic modeling options, continuous models that are calibrated and validated using historic data, such as the Cameron Run and the Quantico Creek watershed models, are more difficult to build, but they are also more reliable. These watershed models can be used by planners, government agencies and local watershed organizations to evaluate the impacts of land use changes that may ultimately affect flooding, erosion, water quality and ecology along stream corridors. These models may be used to study mitigation alternatives related to flows and develop watershed management plans. Effects of climate change on local hydrology can also be evaluated by providing various precipitation scenarios.
15. As climatic patterns change with more frequent and severe floods and drought conditions, lotic benthic communities in watersheds dominated by urbanization will be more susceptible to the loss of taxa and functional diversity than primarily forested watersheds.
16. In order to increase the general public's awareness, knowledge, and understanding of climate change and its potential impacts to watersheds in the mid-Atlantic region, the Science Museum of Virginia created a webpage, a hands-on interactive laboratory experience (EcoLab), created interactive exhibits and graphics that were installed at three locations in Virginia, hosted a teacher professional development workshop, presented lectures to middle to high school students and the public, and to peers at scientific meetings; and provided internships to undergraduate and graduate students.

Acknowledgments

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Introduction

Increased frequency and intensity of storms, and extended periods of drought as a function of climate change have been forecasted for the mid-Atlantic region (U.S. Global Change Research program, 2009; IPCC, 2007; Moore, et al., 1997). Climate change will have a significant impact on ecosystems in Virginia (Bryant, 2008). Currently, it is projected that warming in the region will continue, with greatest temperature increases in summer (U.S. Global Change Research program, 2009). Freshwater ecosystems will experience increased water temperatures, decreased oxygen concentrations, and extremes in flow regimes (U.S. Global Change Research program, 2009).

Measuring the effects of climate change in biological systems such as coral reef, grassland, steppe, and forests ecosystems, has been gaining importance as concentrations of carbon dioxide continue to increase. Much of the emphasis for study has been placed in marine and coastal areas that have been hypothesized to be at greatest risk, and to understand ways to potentially mitigate the effects of climate change. Little attention, however, has been given to the effects of climate change on the biodiversity, ecology, and food chains and webs in freshwater lotic systems. Freshwater lotic ecosystems are different from estuarine, marine, and lentic freshwater environments whose carbon energy supplies are derived from autochthonous sources (i.e., phytoplankton) that convert solar energy into chemical energy. In contrast, the primary carbon energy input in freshwater lotic ecosystems is from allochthonous detritus (e.g. leaf litter) derived from terrestrial vegetation within the basin (Mancinelli and Rossi, 2001; Yee and Juliano, 2005;

Graham, 2008; Webster et al., 1999; Woolcott, 1974). Understanding the energy flow through food webs in lotic systems has been accomplished by measuring changes in aquatic biodiversity (e.g. fish and macroinvertebrate diversity, richness, and relative abundance) as well as ecological systems relative to variations in environmental conditions and anthropogenic alterations of these environments (Minshall, 1967; Woolcott, 1974).

Watersheds in urban areas often undergo 'hydromorpological degradation' which encompasses land use, the amount of riparian vegetation, bank modification and flow regulation on multiple spatial scales (Feld, 2007). In streams of watersheds with high amounts of urbanization, it can be difficult to separate the natural impacts of geomorphology, elevation, soils and precipitation from the degradation of anthropogenic impacts on stream biota (Maloney, 2005) (DeGasperi, 2009). A strong correlation between environmental condition measures and macroinvertebrate metrics can be used to model how baseline natural conditions impact stream biota. These models can be then be applied to understand how large scale natural or anthropogenic changes will impact lotic biota and the state of ecosystem services provided by streams.

Lotic ecosystems echo human alteration of watersheds through changes in land use. Watershed land cover, local habitat and amount of impervious surfaces are often used to quantify human influences on land. Anthropogenic changes in land use, such as deforestation plus increased amount of impervious surfaces that reduce rainfall infiltration and increase the flow to collecting streams (DeGasperi, 2009), alter the energy resource budget of lotic systems. The impact on stream communities can be measured as a difference in biota among impacted streams and reference conditions, which can be used to indicate the amount of human influence (Weigel, 2003).

Watersheds in urban areas often undergo 'hydromorpological degradation' which encompasses land use, the amount of riparian vegetation, bank modification and flow regulation on multiple spatial scales (Feld, 2007). In streams in watersheds with high amounts of urbanization, it can be difficult to separate the natural impacts of geomorphology, elevation, soils and precipitation from the degradation of anthropogenic impacts on stream biota (Maloney, 2005) (DeGasperi, 2009). A strong correlation between environmental condition measures and macroinvertebrate metrics can be used to model how baseline natural conditions impact stream biota. These models can be then be applied to understand how large scale natural or anthropogenic changes will impact lotic biota and the state of ecosystem services provided by streams.

As a great majority of lotic systems have been altered significantly by human influences (e.g. agricultural, industrial and urban development), few systems exist where anthropogenic impacts do not occur. As such, measuring effects of climate change in lotic systems are challenging because of the difficulty in separating anthropogenic effects from those of climate change. We propose that relatively pristine watersheds, not impacted by human development, have the potential to serve as a tool in measuring impacts of climate change on lotic ecosystems. For example, the drainage basin of Quantico Creek is wholly within a national park (Prince William Forest Park) and a marine corps base (Quantico Marine Corp Base) where virtually no agricultural and urban development has occurred within the past 80 years. As such, Quantico Creek has been used as a benchmark control site for short-term environmental and ecological studies of watersheds in the mid-Atlantic region (Peterson, 2008). Studies of longitudinal zonation of fishes in freshwater streams have been used to identify and monitor changes in fish distributions and species diversity relative to natural changes (e.g. elevation, gradient, and stream order) and anthropogenic perturbations (e.g. damming) (Hutchinson, 1993; Lotrich, 1973; Maurakis et al., 2003, 1987; Mundy and Boschung, 1981; Paller, 1994). More recently, Argent et al. (2003) used landscape-level physical variables in a GIS system to predict freshwater fish distributions in river drainages in Pennsylvania but did not examine chemical and biological factors.

With 116 fish species, of which 86 are considered native (including one endemic, *Cottus cognatus*) and 30 as introduced, the Potomac River has one of the richest ichthyofaunas in Chesapeake Bay drainage (Cummins, 2006; Jenkins and Burkhead, 1994). Historically, distributions of freshwater fishes in the Potomac River drainage have been presented for the entire drainage and used in biogeographic and aquatic impact studies. However, information on changes that may occur in species diversity within discrete stretches (i.e., within the confines of a tributary) relative to either natural or human induced changes in the environment in the Potomac River drainage is exiguous. Kelso et al. (2001) sampled Quantico Creek from May-July in each of 1998 and 1998 to gather baseline information on stream water quality and habitat quality to compare with other site in northern Virginia. Dawson (2010) examined the ecological values and ecosystem services of natural forests in Prince William Forest Park in northern Virginia. There have been no long-term monitoring studies of fish populations in a systematic manner that can serve as a basis to understand changes in fish community structure in Quantico Creek, a forested undisturbed environment, and Cameron Run, a highly disturbed urban environment.

The objectives of the technical research study were twofold:

a. Measure and record fish and macroinvertebrate species richness and diversity; macroinvertebrate functional feeding group (GGF) richness and diversity; physical characteristics (i.e., stream order, elevation, stream width, stream depth, stream current, stream flow, stream gradient, pH, water temperature, and river kilometer); and anthropogenic and watershed factors (i.e., human population, impervious cover, undeveloped land cover) in a forested watershed (Quantico Creek) and in an urban watershed (Cameron Run) in northern Virginia;
b. Create mathematical expressions to model species richness and diversity relative to physical characteristics, anthropogenic, and watershed characteristics in streams of two, lower Piedmont-Fall Line watersheds of the Potomac River drainage, Virginia.

Objectives of the outreach portion of this project were to:

c. Create a laboratory experience in the Science Museum of Virginia to heighten visitor's awareness and knowledge of climate change and potential impacts on watersheds;
d. Create an interactive exhibit on watersheds and climate change;
e. Provide internship opportunities for undergraduate and graduate students;
f. Host a week-long teacher workshop on watershed and climate change;
g. Post a website about climate change and watersheds; and,
h. Present findings of the technical research project.

For this study, functional feeding group metrics (macroinvertebrates richness, evenness and Shannon diversity index) as well as macroinvertebrate taxa richness were used in comparisons of forested and urban lotic ecosystems. Functional feeding group (FFG) characterization groups stream invertebrates by mode of feeding, which in turn, provides information on the size and type of food ingested and the morphology of mouthparts (Mihuc, 1997). Functional feeding group analyses provide information from an ecosystems perspective on stream invertebrate community structure, resource availability and assimilation (Mihuc, 1997) (Bacey, 2007). Grouping methods based on ecological traits may show different, and higher, levels of diversity than groups based on biological traits (Polatera, 2000). For example, disproportions in functional feedings group metrics can indicate an unstable resource availability or assimilation, indicating an ecosystem under stress (Bacey, 2007).

Study Area

The two study areas of this investigation, Quantico Creek and Cameron Run watersheds, are located in northern Virginia, and are lower Piedmont tributaries of the Potomac River, Chesapeake Bay drainage (Figs 1 and 2). Located about 56 km S of Washington, DC, Quantico Creek watershed, is approximately 4,778 hectares (ha), and is almost entirely contained within a national park (i.e., Prince William Forest Park), and the Quantico Marine Corps Base (Fig. 1). Quantico Creek watershed was selected to serve as the baseline of natural fish community structure as it is predominately a forested watershed that has not been disturbed for about 80 years (Paul Peterson, pers. comm.). The park is a Piedmont forest that includes an abandoned pyrite mine and "sub-marginal" farmland. From 1935-1942, 4,451 hectares of this property was minimally developed, including the addition of cabins, trails, bridges and roads, by the Civilian Conservation Corps from 1935-1942 (U.S. National Park Service, 2008). The land at the U.S. Marine Corps Base Quantico was historically tobacco farms until the military began developing the property in 1917 (History of Quantico, nd.). These two locations in the Quantico Creek watershed have been used as benchmark sites for low anthropogenic impact regional studies (Peterson, pers. comm.).

Prince Will Forest Park totally encompasses the Quantico Creek watershed and is the largest protected natural area in the metropolitan area of Washington, DC. About 81 percent of the watershed has undeveloped land cover, and has only about 611 hectares of impervious cover. Total population of the watershed is 3,500, the majority of which are in the lower reaches of the system. As a baseline for natural fish community structure, Quantico Creek can serve as a reference standard for current and future studies that investigate the human impacts (e.g. urban and suburban development) of fishes and macroinvertebrates in watersheds of comparable size and physiographic location (e.g. Cameron Run, Chopawamsic Creek, and Aquia Creek).

The second study area is the Cameron Run watershed, located approximately 15 km South of Washington, DC (Fig. 2). The portion of Cameron Run watershed that was sampled is approximately 4,808 hectares, and did not include the area that drains into Lake Barcroft (Fig. 2). The Cameron Run watershed is in a highly developed area (i.e., urban environment with industry). About 60 percent of the watershed has impervious cover; undeveloped land cover is 42 hectares; and human population is approximately 220,000 (Table 1), 62.8 times greater than that of the Quantico Creek study area.

Materials and Methods

Fifteen sampling locations, representing stream orders 1, 2 and 3 were established in the Quantico Creek watershed and sampled from November, 2008 through June, 2010 (Table 2). Seven sampling locations, representing stream orders 1, 2, 3, and 4 were established in Cameron Run watershed and sampled during the same period of time for the Quantico Creek watershed (Table 2).

Fishes were collected with a 1.2 x 3 m seine (stretch mesh=0.64 cm), a 12 Volt Smith-Root Model VII DC backpack electroshocker or a 24 Volt Smith-Root Model backpack electroshocker. Fishes were identified, counted and then returned to the stream with one exception. When needed, a voucher specimen of selected species and anomalous specimens were preserved in 10 % formalin or 90 % isopropynol, and examined and identified in the laboratory.

Beginning at the lower reach of the sampling station and moving upstream, D-frame dips nets were used to qualitatively sample riffle areas, overhanging riparian vegetation submerged in the water, exposed tree roots and debris masses where present. In streams with well sorted, rocky substrate, cobbles were overturned to collect attached macroinvertebrates using forceps. Samples were rinsed of silt and other fine particulates and large pebbles were removed. Twigs, leaves and other debris were retained in the sample and preserved with 91% isopropyl alcohol.

Macroinvertebrate Identification Procedure

Sampled were sorted in the lab by trained volunteers and stored in 91% isopropyl alcohol for identification. Organisms were identified using a Nikon SMZ100 stereoscopic dissecting microscope and the classification keys of Ward and Whipple (1959), Merritt and Cummins (1995), Mason (1968), and Thorpe and Covich (2001) to the lowest taxa with a specified functional feeding group, not including species. Functional feeding group (FFG) assignments based on those described by Merritt and Cummins (1995) included: scraper, shredder, predator, filtering collector and gathering collector. If the lowest taxon had more than one associated functional feeding group, not including obligate and facultative behavior, a combination group was used to describe the feeding mode. These combination groups included: shredder-gatherer, gatherer-scraper, gatherer-predator, filterer-gatherer, filterer-scraper, filterer-predator and shredder-gatherer-predator. Taxa with a single functional feeding group assignment are considered specialists while taxa with more than one assignment are considered generalists, as in Mihuc (1997). Organisms were recorded and preserved in vials of isopropyl alcohol until all identifications were complete and verified. Samples were then destroyed as per research permit conditions issued by the US National Park Service. EPT refers to Ephemeroptera, Plecoptera, and Trichoptera.

The following parameters were measured and recorded at each sampling location: latitude, longitude, stream order, elevation (m), stream width and depth (m), gradient (m/km), river kilometer (distance from the mouth of the river to a collection point (km), water temperature (C), water velocity (m/sec), water flow (m^3/sec), and pH; and human population density, land use, hectares and percent of impervious cover, and hectares and percent of undeveloped land cover per sub-watershed by stream order.

Stream order was determined by methods of Horton (1945) except that intermittent streams were not classified as first order. Stream order was determined by tracing drainages on altitude scalar maps (1:250000 scale) and checked with GIS. A first order stream is a permanent stream with no other perennial stream inflows. A second order stream is the result of confluence of two first order streams, and a third order the confluence of two second order streams, with the stipulation that acquisition of other lower order tributaries than that of the receiving stream does not increase stream order. Map contours were also used to determine gradients (m/km) for each collecting location per stream order. Elevation (m) was determined from a Garman Oregon 550t receiver and converted to meters, and from topographical maps (1:125,000). Stream width (m) and stream depth (m) were measured with a meter stick, and water temperature (C^o) with a hand held thermometer. River kilometer (km) was determined by tracing the distance between a collecting location in a stream and the mouth of its parent river with a planimeter. Intra-drainage human population was determined from US census and Arcview data, and development changes (i.e., percents of impervious cover and undisturbed land cover, converted to their arcsin equivalents prior to statistical analyses) from Arcview maps from the Virginia Department of Conservation and Recreation.

Fish species richness was calculated using raw number of species at each location. Fish species diversity, as expressed by Shannon Wiener Index, and Species Evenness Index, were calculated using abundances of each fish species at each collection site. Jaccard Coefficient (Sneath and Sokal, 1973) was used to determine the similarity between each combination of stream orders (e.g. 1st and 2nd order streams) within a drainage: S= a /a+b+c,

where S=similarity between two orders;

a=total number of taxa shared by two orders;

b=number of taxa in one order but not in the second; and,

c=number of taxa in the second order but not in the first. Jaccard values, multiplied by 100, are presented as a percent, and were converted to their arcsin equivalents for statistical analyses.

A deliberate decision was made to not use the Index of Biotic Integrity (IBI), which has gained popularity over the years since the concept for it arose out of the Clean Water Act in 1972 (Daniels et al., 2002; Smogor and Angermeier, 2001); Angermeier et al., 2000; Smogor and Angermeier, 1999a; 1999b). IBIs are a summation of several indicative parameters, and attempt to describe the integrity of community structure, summarize biological condition, and distinguish degraded sites based on multi-metric indices of physical and biological parameters (Niemi et al., 2004; Smoger and Angermeier, 2001). IBIs reduce complex array of ecosystem responses to various disturbances to one number (Suter, 2009). To be able to apply one index number that reflects the condition of a community is attractive to many fisheries scientists. However, Suter (2009) demonstrated that such indices have no meaning, cannot be predicted, are not applicable to most regulatory problems, have no diagnostic power, the effects on one component are eclipsed by responses of other components; and thus, the underlying reason for a high or low index value is unknown. IBI scores can results from thousands of possible combinations of indicator values (PEEIR, 2010). For example, researchers at PEEIR (2010) used 12 indicators and found there were 8,074 ways of obtaining an IBI value of 48. As a result, our study used individual species occurrences and abundances, and population and community values (e.g. species richness and species diversity) to establish a baseline for comparative studies in the future related to anthropogenic and natural variations in environmental conditions affecting the two watersheds under study.

Hydrologic Models

Separate continuous hydrological models were developed for the Cameron Run and the Quantico Creek watersheds using the HEC-HMS model (”HEC-HMS”) from the U.S. Army Corps of Engineers (2010). Geo-HMS, a geographic information system (GIS) based preprocessing software of HEC-HMS, was also used in conjunction with ArcGIS (ESRI, 2010) to process spatial data and prepare model input. The HEC-HMS model requires primarily topographic, land cover and other GIS data to delineate drainage area boundaries, establish stream network and compute physical input data.

The models were calibrated using data from one flow gage in each watershed before generating long-term flow data at the each of the sampling locations.

Model Development

The HEC-HMS Model

Two comprehensive rainfall-runoff models for the Cameron Run and the Quantico Creek watersheds were developed to accurately estimate flows at different water quality sampling stations in the watersheds. To simulate long-term flows in each watershed, the U.S. Army Corps of Engineers (2010) HEC-HMS, version 3.4, was used. HEC-HMS, a freely available software developed by USACE Hydrologic Engineering Center (HEC), is designed to simulate the precipitation-runoff process in branched watershed systems. The model has been extensively used by the hydrologic community including the Federal Emergency Management Agency (FEMA) for its National Flood Insurance Program.

In HEC-HMS a watershed is segmented into smaller logical sub-watersheds that are connected by a network of streams, lakes and reservoirs. Precipitation data assigned to each sub-watershed generates surface and subsurface flows that drain to nearby stream reaches based on watershed characteristics, mathematical models selected by the user to represent various processes and parameter values. Flows entering stream segments or reaches are routed downstream and combined with additional flows from downstream sub-watersheds and reaches. The model computes flows at all the reaches and sub-watershed outlets for the entire simulation period at a user specified time increment.

Description of Data

Setting up a comprehensive hydrologic model, such as HEC-HMS, requires significant amount local data. The data requirement also depends on specific methods selected for individual processes. Selection of methods in turn depends on the type of simulation, professional judgment of the modeler and data availability. Topographic data is the basis for delineating sub-watershed boundaries and estimating slopes and areas of sub-watersheds. Soil, land use and impervious cover GIS data allow estimation of impervious areas in each sub-watershed and selection of reasonable parameters values related to infiltration and subsurface storage and flows. Channel characteristics are estimated from readily available GIS hydrography data or computed from topographic data. Local precipitation data is an important input that drives the model. Historic precipitation time series at small time increment is necessary for accurate simulation of flow. USGS stream gage data provides historic flows that allow comparison of modeled flows with observed data and estimate correct model parameters values. This section discusses the sources of various data used in developing the models.

Topography: NVRC obtained 1/3 arc-second (approximately 10 meters) National Elevation Dataset (NED) for the Cameron Run and Quantico Creek watersheds from the U.S. Geological Survey (USGS, 2006). USGS developed the seamless raster data by compiling information from various sources and processing to a specification with a consistent resolution, coordinate system, elevation units, and horizontal and vertical datums. NED uses the North American Datum of 1983 (NAD 83) as horizontal datum and North American Vertical Datum of 1988 (NAVD 88) as vertical datum with an elevation unit of meters. The GIS data were further processed in ArcGIS using Geo-HMS tools prior to delineating sub-watershed boundaries and calculating sub-watershed characteristics data.

Impervious Land Cover: Hydrologic models use impervious cover data to determine the fractions of pervious and impervious areas in a watershed. Precipitation on impervious areas does not infiltrate the ground and, therefore, does not contribute to subsurface storage, losses and flows. The impervious land cover data was obtained from the Chesapeake Bay Program (USGS, 2010a). The data set was originally developed by the Regional Earth Science Applications Center (RESAC) at the University of Maryland and made available to the Chesapeake Bay Program. The impervious cover is a raster based GIS data that also includes percent imperviousness. This data was processed in ArcGIS to determine the overall imperviousness in each sub-watershed – a required input to HEC-HMS.

Streams, Lakes and Reservoirs: Streams, lakes and reservoirs collect water from pervious and impervious lands and route flow downstream. Lakes and reservoirs may provide significant storage and, thereby, reducing peak flows and modifying low flows in streams. Temporary storage in stream segments or reaches also flattens storm hydrographs as flows are routed downstream. The USGS National Hydrography Data (USGS, 2010b) provided the base GIS dataset showing the stream network and locations of significant lakes and reservoirs. For modeling purposes, however, Geo-HMS was used to compute necessary channel characteristics from the digital topographic data. Two large manmade reservoirs – Fairview Lake and Lake Barcroft are located in the Cameron Run watershed. Stage-storage-discharge relationships at the hydraulic structures controlling the outflow from these lakes were obtained from the Cameron Run Watershed Management Plan (Versar, 2007) and incorporated in the model. Table 41 lists the stage-storage-discharge relationships for the two reservoirs that were added as input to the model. There are a number of small lakes and pools in the Prince William Forest Park within the Quantico Creek watershed. Because of their small sizes and unavailability of stage-storage-discharge relationships at the outlets, these lakes and ponds were not incorporated in the Quantico Creek model.

Water Quality Sampling Stations: Coordinate information of the sampling stations was used in ArcGIS to map seven sampling stations in the Cameron Run watershed and 15 sampling stations in the Quantico Creek watershed. According to the objective this study, flows were modeled at these locations over a two year period from October 1, 2007 through September 30, 2009.

Precipitation and Evapotranspiration: High quality precipitation data is the most important input in estimating accurate flows through hydrologic modeling. Precipitation data for Reagan Washington Airport was obtained from the National

Climatic Data Center (NCDC), which is part of the National Oceanic and Atmospheric Administration. Although Reagan Washington Airport is approximately 11 miles from the Cameron Run watershed, it has a long record of high quality hourly precipitation data. The Quantico Creek watershed is located approximately 26 miles away from Reagan Washington Airport necessitating a local source of precipitation data. Fortunately, the Quantico Marine Base weather station, which is located in the watershed, recorded precipitation at 15-minute interval for most days in the last few years. As commonly found with weather data, precipitation data at Quantico Marine Base contained many missing records. NVRC staff manually filled the missing records using 0.0 rainfall during dry weather periods and interpolated values during storm events. A comparison of precipitation data from Reagan Washington Airport and those from Quantico Marine Base showed significant differences and time lags. Therefore, precipitation data from Reagan Washington Airport was not used to fill the data gaps. Monthly evapotranspiration data were obtained from the University of Virginia Climatology Office for the Reagan Washington Airport and the Fredericksburg stations (UVA Climate Office, 2010)(Table 42). The Reagan Washington Airport monthly evaporation was applied directly to the Cameron Run watershed. For the Quantico Creek watershed, monthly evaportranspiration was approximated as the average of the Reagan Washington Airport and Fredericksburg stations values based on their geographic locations with respect to the Quantico Creek watershed. A pan coefficient of 0.76 was used for both watersheds (U.S. Department of Commerce, 1968).

Stream Flow: Historic stream flow data is not a direct input in hydrologic modeling, but a key element in calibrating and validating hydrologic models. Because of many parameters in mathematical models representing individual hydrologic processes that cannot be measured in the field, model calibration is essential in establishing proper parameter values in site-specific hydrologic models. The USGS flow gages at the Cameron Run at Alexandria, VA (USGS 01653000) and S F Quantico Creek near Independent Hill, VA (USGS 01658500) provide long-term flow measurements in the Cameron Run and the Quantico Creek watersheds, respectively. Historic flow data was obtained from the USGS (2010a) for model calibration and validation.

Model Setup

The ArcView version 9.3 GIS software along with the Geo-HMS software were used to process GIS data and derive model input. The first step in processing hydrologic data is to define watershed and sub-watershed boundaries. Sub-watershed outlets were determined based on the location of the water quality sampling stations, USGS flow gages, major tributaries confluences and dams. Then the DEM data in conjunction with the sub-watershed outlets were utilized in Geo-HMS to automatically delineate boundaries and develop a network of stream reaches associated with these sub-watersheds. The Cameron Run watershed was segmented into 57 sub-watersheds and the Quantico Creek watershed was divided into 56 sub-watersheds. Geo-HMS also calculated sub-watershed and stream reach characteristics (e.g. area, length and slope) from the DEM data. Impervious area in each sub-watershed was calculated by overlaying sub-watershed boundary on impervious coverage GIS data. Time of concentration was estimated using built-in Geo-HMS tools and associated spreadsheet. Channel cross-section of each reach was determined by manually drawing a cross-section line in GIS, obtaining cross-section profile from the DEM data along that line and calculating cross-section input data in a spreadsheet through a curve fitting exercise. HEC-HMS requires that channel cross-section geometry be entered into the model assuming a trapezoidal cross-section. Therefore, natural geometry of channel cross-section as read from GIS was imported to a customized spreadsheet where graphical plots of actual and estimated cross-sections were visually compared to estimate representative bottom width and side slopes through trial and error. Finally Geo-HMS was used to develop a model schematic linking the sub-watersheds and branching stream network and exported the 'basins data model' ready to be loaded into HEC-HMS.

A HEC-HMS model for a specific watershed generally comprises of a basins data model, meteorological data, control specification and observed flow data. The basins data model as created by Geo-HMS contains primarily the physiographic input data. The model still requires that the user populate parameter values for selected surface runoff, subsurface flow and stream routing processes. These parameter values were initially estimated based on professional judgment and then refined through model calibration. Meteorological input data included precipitation time series and monthly average evapotranspiration. Precipitation time series from the Regan Washington

Airport and the Quantico Marin Base were assigned to all Cameron Run and Quantico Creek sub-watersheds, respectively. Similarly monthly evapotranspiration data for the Reagan Washington Airport and Quantico Creek, as shown in Table 42, were assigned to the Cameron Run and the Quantico Creek sub-watersheds, respectively.

The control specification section defines the simulation period and the computational time step. The control specification, therefore, varied for the calibration, validation and the final model runs.

Statistical Analyses

Correlation analyses (SAS, 2009) was performed to determine significant relationships among numbers and communities of fish species (species richness; species diversity, species evenness), stream order, elevation, stream width, stream depth, gradient, pH, water temperature, river kilometer, and human population, hectares of impervious surface, hectares of forest cover, and hectares of urban forest cover per stream order sub-drainage in individual and combined drainages. A General Linear Model followed by Duncan's Multiple Range Test (SAS, 2009) was used to determine significant differences among average numbers of species (richness), species diversity and evenness, and physical and chemical parameters and Jaccard Coefficients by stream order, month or season. Multiple stepwise regression (forward entry at p=0.15, SAS, 2009) was used to determine factors accounting for significant variation in species richness and species diversity.

Six seasons were generated by examining breaks in water temperature data for Quantico Creek and Cameron Run, and are defined as follows: Winter=January; Ealry Spring=March; Late Spring=April and May; Summer=June, July, August, and September; Early Fall=October and November; and Late Fall=December).

Geographic Information System (GIS) Analysis Methods

The base map for the GIS (ESRI's ArcView 9.3) analysis was developed by importing: jurisdictional boundaries; streams and 1:24k topographic maps of the study area into a project geodatabase (Prince William County, Fairfax County, City of Alexandria, USGS)(Fig. 3). The geographic coordinate system (GCS) for the GIS analysis was defined as Virginia State Plane North NAD83 (feet) and the projection was defined as Lambert Conformal Conic. Collection stations for the study area were imported to the base map as x, y data using latitudes and longitudes collected in the field using a Garmin Oregon 550t GPS receiver.

A polygon of the Quantico Creek study area watershed was developed by merging sub-watershed polygons (Fig. 4). A polygon of the Cameron Run study area watershed was developed by tracing the boundaries of the watershed as defined by the 1:24k topographic maps (Fig. 5). Both the Quantico Creek and Cameron Run watershed features were extended downstream to the point of the furthest downstream collection station. The Cameron Run study area watershed did not include the portion of the watershed above the Lake Barcroft dam as it was assumed the lake would attenuate flows from that portion of the watershed.

Sub-watersheds associated with each collection station were developed through a hydrology analysis of 30m gridded Digital Elevation Models (ESRI, USGS)(Fig. 6). Stream flow direction, flow accumulation, stream order and sub-watershed boundaries were determined using a flow accumulation weight of 400. Sub-watershed polygons were used to determine the total population, percent impervious surface and percent vegetated land cover associated with each collection station's sub-watershed (Figs 7, 8 and 9).

Sub-watershed polygons were layered onto a 2000 Census Block Group (CBG) layer (U.S. Census Bureau) to determine total population for each sub-watershed (Fig. 7). If 90% or more of a CBG was contained within the sub-watershed then the total population number for that CBG was assigned to the sub-watershed. If less than 90% of a CBG was contained within the sub-watershed then the total population was proportionally split between sub-watersheds using landuse as a weighting factor. As the majority of the Quantico Creek study area is covered by two CBGs, and the majority of the land use within these CBG geographies is federal land with no resident population, total population for the Quantico Creek sub-watersheds was distributed by assigning the total population for the two CBGs to the populated places identified on the land use layer. Total population was proportionally assigned based on relative size of the populated place.

Station specific sub-watershed polygons were used to extract impervious surface areas and vegetated land cover areas from 30m gridded impervious surface and vegetated land cover rasters (RESAC 2000 CBW Impervious Surface Product – Version 1.3, CBW Land Cover – Version 1.5)(Figs. 8 and 9). Results of the extraction were exported to an Excel spreadsheet to calculate percent impervious surface and vegetated land cover for each-sub-watershed. Land cover groups included in the vegetated land cover dataset were: 1) urban residential deciduous forest, evergreen forest and mixed forest (Fig. 9). A weighting factor of 0.6 was applied to these attributes; 2) deciduous forest, evergreen forest and mixed forest. A weighting factor of 1.0 was applied to these attributes; and 3) deciduous wetlands, evergreen wetlands, mixed wetlands and emergent wetlands. A weighting factor of 1.0 was applied to these attributes.

Results

A total of 210 collections of fishes and physio-chemical parameters were made at 15 locations (representing stream orders, 1, 2, and 3) in the Quantico Creek watershed from November, 2008 to June, 2010. In the Cameron Run watershed, 98 collections were made at seven locations (representing stream orders 1, 2, 3, and 4) from November, 2008 to June, 2010.

Results of physical characteristics of collecting locations in each watershed are presented by stream order, month, and season in Appendices 1-8. The following analyses are presented by stream order and month for each watershed.

Quantico Creek watershed

Elevation of sampling locations varied inversely with stream order. Average elevation (74.16 m) of 1st order streams was significantly higher than those (31.8 m) in 3rd order streams (Table 3). River kilometer (13.3) of 3rd order streams was significantly lower than those (15.0-17.5 km) of 1st and 2nd stream order site. Similarly, stream gradient (10.6 m/km) of 3rd order streams was significantly lower than those (avg. range=15.1-15.45 m/km) at 1st and 2nd order sites. Average stream width (1.85 m) of 1st order sites was significantly lower than those (avg. range=3.5-8.0 m) at 2nd and 3rd order sites. Average depth (0.3 m) and flow (1.65 m^3/sec) of 3rd order streams were significantly greater than depths (avg. range=0.25-0.27 m) and flows (avg. range=0.17-0.48 m^3/sec) in 1st and 2nd order streams (Table 3). Average current (0.26 m/sec) in 1st order streams was significantly lower than those (avg. range=0.43-0.51 m/sec) of 2nd and 3rd order streams. Average water temperature (11.6 C) in 1st order streams was significantly lower than those (avg. range=12.8-13.4 C) in 2nd and 3rd order streams. Average pH values (6.63-6.7) did not vary significantly among 1st, 2nd, and 3rd stream orders in Quantico Creek (Table 3).

Quantico Creek - stream order 1

Average stream width (2.3 m) in December was significantly greater than those (avg. range=1.4-1.6 m) in July, August, September, and November (Table 4). Stream depth (0.76 m) in March was significantly greater than those (avg. range=0.11-0.22 m) in other months. Average water current (0.82 m/sec) in January was significantly greater than those (avg. range=0.01-0.42 m/sec). Average water current (mean range=0.18-0.42 m/sec) in November, March, April, and June were significantly greater than those (avg. range=0.01-0.11 m/sec) in May, July, August, September, October, and December (Table 4). Water discharge (0.48 m^3/sec) in March was significantly greater than those (avg. range=0.001-0.19 m^3/sec) in all months except January when flow averaged 0.29 m^3/sec). Water temperature varied seasonally throughout the study period (Table 4). Highest average water temperature (20 C) in August was significantly higher than average temperatures (range=1.2-18.0 C) in all months except July when average water temperature was 18.5 C). Average pH (7.6) in August was significantly greater than those (range=6.3-7.05) in all other months (Table 4).

Quantico Creek - stream order 2

Average stream width (range=3.36-4.15 m) from January-June, September and November were significantly greater than those (avg. range=1.96-3.14 m) in July, August, October, and December (Table 4). Average width (1.96 m) in August was significantly lower than those (avg. range=2.81-4.15 m) in all other months. Average water depth (avg. range=0.31-0.37 m) in March and April were significantly greater than those (avg. range=0.18-0.24 m) in all other months. Average water current (range=0.75-0.89 m/sec) in January and March were significantly greater than those (avg. range=0.004-0.47 m/sec) in March, May, July-October, and December. Water flow (avg.=1.33 m^3/sec) in April was significantly higher than those (avg. range=0.001-0.73 m^3/sec) in all other months. Average flows (range=0.43-0.73 m^3/sec) in January, March, June, and November were significantly higher than those (avg. range=0.001-0.01 m^3/sec) in August, September, and October (Table 4). As in 1st order streams, water temperatures in 2nd order streams varied seasonally throughout the study period. Average water temperatures (range=20.0-20.5 C) in July and August were significantly higher than those (avg. range=0.0-18.67 C) in all other months throughout the year. Average pH (range=6.94-6.99) in May, June, and August were significantly higher than those (avg. range=6.3-6.8) in all other months. Lowest average pH values (range=6.3-6.4) in July, December and April were significantly lower than those in other months (Table 4).

Quantico Creek - stream order 3

Average stream width (range=9.17-9.22) in March and April were significantly greater than those (avg. range=4.3-7.5) in a five month stretch from August to December (Table 4). Average depth (0.4 m) in April was significantly greater than those (avg. range=0.17-0.33 m) in all other months. Water depths (avg. range=0.17-0.25 m) during late autumn (October, November, and December) were significantly lower than those (avg. range=0.0.27-0.30 m) from March-July. Average water current (1.6 m/sec) in April and that (0.94 m/sec) in January were significantly greater than those in other months. Average flow (range=0.06-0.09 m/sec) in August, September and October were significantly lower than those (avg. range=0.26-0.61 m/sec) in March, May, June, July, and November (Table 4). Average water flow (4.95 m^3/sec) in April was significantly higher than those (avg. range=0.09-2.12 m^3/sec) in all other months. Average flows (range=1.81-2.12 m^3/sec) in January and March were significantly higher than those (avg. range=0.09-0.70 m^3/sec) in May, and for a five month stretch from August through December. As in 1st and 2nd order streams, water temperatures in 3rd order streams varied seasonally throughout the study period. Average water temperatures (range=20.9-21.3 C) in July and August were significantly higher than those (avg. range=0.2-18.8 C) in all other months of the year (Table 4). Average pH (7.3) in August was significantly higher than those (avg. range=6.3-6.9) in all other months. Average pH values (range=6.8-6.9) in January and during a three month stretch from May through July, were significantly higher than those (avg. range=6.5) during a six month stretch from November through April (Table 4).

Correlation Analyses – Quantico Creek watershed

Fish species richness was significantly correlated with stream order, stream width, depth, and current, and water temperature (Table 5); and inversely correlated with gradient and fish abundance (Table 5). Stream order was significantly correlated with stream width, depth, current and flow; species richness and species diversity; size of sub-watershed; human population; impervious cover; and undeveloped land cover. Stream order was inversely correlated with elevation and gradient of sampling locations; and fish abundance (Table 5). Sampling site elevation was significantly correlated with river km; and inversely correlated with gradient, stream width, sub-water shed size, human population, impervious cover, undeveloped land cover, and water flow (Table 5). River km of sampling locations was inversely correlated with stream gradient and width, sub-watershed size, human population, impervious cover, undeveloped land cover, and flow (Table 5). River km was positively correlated with fish species diversity (Table 5). Sampling location gradient was inversely correlated with stream width, depth, and current; fish species richness, diversity and evenness (Table 5). Stream width was significantly correlated with stream depth, current, and flow; fish species richness, diversity and evenness; and with sub-watershed size, human population, impervious cover, and undeveloped land cover (Table 5). Stream width was inversely correlated significantly to fish abundance (Table 5). Water depth was significantly correlated with species richness, diversity and evenness; and sub-watershed size, human population, impervious cover, undeveloped land cover, and stream flow (Table 5). Water current was significantly correlated with fish species richness, diversity, and evenness; and sub-watershed size, human population, impervious cover, undeveloped land cover, and stream flow (Table 5). Water current was inversely correlated with water temperature and pH, and season (Table 5). Water temperature was significantly correlated with season, pH, fish species richness and abundance, and negatively correlated with fish species richness and impervious cover (Table 5). Sub-watershed size was significantly correlated with human population, impervious cover, undeveloped land cover, and water flow (Table 5). Human population was significantly correlated with impervious cover and undeveloped land cover (Table 5). Impervious cover was correlated with undeveloped land cover and stream flow; and undeveloped land cover was correlated with stream flow (Table 5). Percent undeveloped land cover was inversely correlated with human population and impervious cover (Table 5).

Cameron Run watershed

Elevation of sampling locations in Cameron Run watershed varied inversely with stream order. Average elevation (75.4 m) of 1st order streams was significantly higher than those (avg. range=29.7-46.7 m) in 2nd, 3rd, and 4th order streams (Table 6). River kilometer (17. 9) of 1st order streams was significantly higher than those (6.0-9.0 km) of 2nd, 3rd, and 4th stream order sites. Similarly, stream gradient (12.8 m/km) of 1st order streams was significantly higher than those (avg. range=3.1-6.6 m/km) at 2nd, 3rd and 4th order sites (Table 6). Average stream width (4.15 m) of 1st order sites was significantly lower than those (avg. range=5.0-XX.X m) at 2nd, 3rd, and 4th order sites. Average depth (0.19-0.21 m) of 2nd and 3rd order streams were significantly lower than those (avg. range=0.242-0.244 m) of 1st and 4th order stream sites. Average currents (0.97 and 0.71 m/sec) in 3rd and 4th order streams, respectively, were significantly higher than those (avg. range=0.27-0.28 m/sec) of 1st and 2nd order streams. Average flows (1.97- 2.4 m^3/sec) in 3rd and 4th order stream sites were significantly higher than those (avg. range=0.24-0.28 m^3/sec) in 1st and 2nd order stream sites. Average water temperatures (range=11.7-12.0 C) in 1st and 2nd order streams were significantly lower than those (avg. range=15.9-116.4 C) in 3rd and 4th order streams (Table 6). The average pH (7.19) of 3rd order stream sites was significantly higher than those (avg. range=6.6-6.7) in 1st, 2nd, and 4th stream orders in Cameron Run.

Cameron Run – stream order 1

Average stream width (range=3.37-3.71 m) did not vary significantly in 1st order streams of Cameron Run throughout the year (Table 7). Average water depth did not vary significantly with one exception. Average water depth (0.32 m) in September was significantly greater than that (0.18 m) in January. Average water currents (0.78 m/sec) in November, and those (avg. range=0.43-0.46 m/sec) in March and April were significantly higher than those (avg. range=0.006-0.23 m/sec) in all other months (Table 7). Average water flow (0.78 m^3/sec) in November was significantly greater than those (avg. range=0.001-0.51 m^3/sec) in other months. Similarly, flows (avg. range=0.40-0.51 m^3/sec) in March and April were significantly higher than all other months except November. Water temperature varied seasonally throughout the study period. Average water temperatures (range=17.3-18.3 C) in June, July and September were significantly higher than those (avg. range=-0.7-14.5 C) in all other months (Table 7). Average pH values (6.8-7.0) in May and June were significantly higher than those (avg. range=6.3-6.5) in March, April, and December.

Cameron Run – stream order 2

Average stream width (6.2 m) in November was significantly greater than those (avg. range=3.7-5.4 m) in other months (Table 7). Similarly, average stream widths (range=5.1-5.4 m) in January, March, April, and June were significantly greater than those (avg. range=3.7-4.5 m) in September, October, December, and May. Average water depths (0.28-0.30 m) in April and June were significantly greater than those (avg. range=0.14-0.18 m) over a six month period (October-March). Average currents (range=0.38-0.50 m/sec) in March, April, November, and January were significantly greater than those (avg. range=0.001-0.19 m/sec) in all other sampling months. Water flow (0.69 m^3/sec) in April was significantly higher than those (avg. range=0.0007-0.42 m^3/sec) in all other sampling months (Table 7). As in 1st order streams, water temperature in 2nd order streams varied significantly throughout the sampling period. Average water temperatures (20 C) in each of July and September, and that (18.6 C) in June were significantly higher than those (avg. range=0.0-15.0 C) from October through May (Table 7). Average pH values (range=6.8-7.0) in May, July, and November were significantly higher than those (avg. range=6.3-6.4) in June, April, December, and March.

Cameron Run – stream order 3

Average stream width (17.7 m) in April, and those (13.8-15.4 m) in June, May, December and January were significantly great than those (8.0-12.0 m) in other sampling months (Table 7). Average water depth (0.29 m) in April and those (range=0.20-0.22 m) in May, January, and October were significantly greater than those (avg. range=0.14-0.16 M) in other sampling months. Average water current (3.3 m/sec) in November was significantly greater than those (avg. range=0.18-1.0 m/sec) in all other months (Table 7). Average stream flows (range=5.4-5.7 m^3/sec) in April and November were significantly higher than those (avg. range=0.29-1.59 m^3/sec) in all other sampling months. As in 1st and 2nd order streams, average water temperatures in 3rd order streams varied significantly with time of year. Average water temperatures (25.1 C) in June and (0.29 C) in January were significantly different from those (avg. range=7.5-23.0 C) during other sampling months of the year (Table 7). Average pH values (range=6.3-7.4) did not vary significantly throughout the year.

Cameron Run – stream order 4

Average width (11.3 m) of 4th order streams in Cameron Run watershed in April was significantly greater than those (avg. range=8.4-10.2 m/sec) in other sampling months (Table 7). Average water depths (0.30-0.31 m) in April and March were significantly greater than those (avg. range=0.17-0.25 m) in all other sampling months. Average water currents (2.5 m/sec) in November and those (avg. range=1.2-1.4 m/sec) in April and March were significantly greater than those (avg. range=0.18-0.53 m/sec) in other sampling months (Table 7). Water flows (avg.=6.9 m^3/sec) in November, 5.4 m^3/sec in April, and 2.8 m^3/sec in March were significantly higher than those (avg. range=0.23-1.30 m^3/sec) in other sampling months. As in 1st, 2nd and 3rd order streams, water temperatures in 4th order streams varied seasonally throughout the study period. Highest average water temperature (26.5 C) in July was significantly higher than those (avg. range=1.3-23.6 C) in all other sampling months (Table 7). Average pH values (range=6.7-7.0) in July, May, April, November, and June were significantly greater than that (6.3) in December and March.

Correlation Analyses – Cameron Run watershed

Fish species richness in Cameron Run was significantly correlated with stream order, width, current, flow, and water temperature; and fish diversity (Table 8). Fish species richness was inversely correlated with sampling location elevation, river km, and gradient; fish abundance (Table 8). Stream order was significantly correlated with stream width, depth, current, flow and temperature; fish species diversity and richness; sub-watershed size, human population, impervious cover, and undeveloped land cover (Table 8). Stream order was inversely correlated with sampling location elevation, river km, and gradient (Table 8). Sampling location elevation was significantly correlated with river km and gradient (Table 8); but inversely correlated with stream width, current, flow, water temperature; fish species richness and diversity; and sub-watershed size, human population, impervious cover, and undeveloped land cover (Table 8). River km of sampling locations was significantly correlated with gradient; but inversely correlated with stream width, current, and flow; fish species richness and diversity; sub-watershed size, human population, impervious cover, and undeveloped land cover (Table 8). Stream gradient at sampling locations was significantly correlated with stream depth; but inversely correlated with stream width, current, flow, and water temperature; sub-watershed size, human population, impervious cover, undeveloped land cover; fish species richness and diversity (Table 8). Stream width was significantly correlated with stream current, flow and pH; fish species richness and diversity; and sub-watershed size, human population, impervious cover, and undeveloped land cover (Table 8). Stream depth was significantly correlated with fish species abundance; but inversely correlated with pH and fish species richness (Table 8). Stream current was significantly correlated with fish species richness and diversity, stream flow, human population, impervious cover, and undeveloped land cover (Table 8). Water temperature was significantly correlated with pH; fish species richness and diversity; season, month, stream order, stream flow, sub-watershed size, and human population; and inversely correlated with sampling location elevation, river km and gradient; water depth; and fish species evenness (Table 8). Sub-watershed size and human population were correlated with impervious cover, undeveloped land cover, and stream flow (Table 8).

Comparisons of physical variables between Quantico Creek and Cameron Run watersheds

Average elevation (75.9 m) of 1st order sampling locations in Cameron Run were significantly greater than those (avg. range=30.8-49.6 m) at all other stream orders in both Cameron Run and Quantico Creek (Table 9). There were no significant differences among average elevations (range=30.8-37.0 m) among 3rd order streams of Quantico Creek and Cameron Run, and 4th order streams of Cameron Run. Average river kilometers (range=6.1-6.3 km) in 3rd and 4th order streams of Cameron Run, and that (9.2 km) of 2nd order streams of Cameron Run were significantly lower than those (avg. range=13.1-16.2 km) of 1st order streams of Cameron Run, and 1st, 2nd, and 3rd order streams in Quantico Creek (Table 9). Average gradient (23.1 m/km) in 1st order tributaries of Quantico Creek was significantly higher than that (12.8 m/km) in 1st order Cameron Run, and those (avg. range=3.2-14.5 m/km) in all other stream orders of both Quantico Creek and Cameron Run. Similarly, gradients of Quantico Creek stream orders 2 (14.5 m/km) and 3 (10.2 m/km) were significantly greater than their 2nd order (7.3 m/km) and 3rd order (3.2 m/km) counterparts in Cameron Run. Average stream widths of 3rd (12.9 m) and 4th (9.6 km) order Cameron Run streams were significantly greater than that (8.1 m) of 3rd order Quantico Creek. Annual average stream width (5.2 m) of 2nd order Cameron Run streams was significantly greater than that (3.5 m) of 2nd order Quantico Creek streams (Fig. 10). Similarly, annual average stream width (4.4 m) of 1st order Cameron Run streams was significantly greater than that (1.6 m) in 1st order Quantico Creek streams. Annual average stream depth (0.32 m) in 3rd order Quantico Creek was significantly greater than that (0.19 m) in 3rd order Cameron Run (Fig. 11). Annual stream depth (0.25 m) in 2nd order Cameron Run was significantly greater than that (0.17 m) in 1st order Quantico Creek (Fig. 11). Annual average stream current (0.91 m/sec) in 3rd order Cameron Run was significantly greater than that (0.54 m/sec) in 3rd order Quantico Creek (Table 9). There were no significant differences in annual average water current between 2nd order Quantico Creek (avg.=0.45 m/sec) and Cameron Run (avg.=0.27 m/sec); and between 1st order Quantico Creek (0.19 m/sec) and 1st order Cameron Run (avg.=0.22 m/sec)(Fig. 12). Annual average flow did not vary significantly among 3rd order Cameron Run (2.28 m^3/sec), 3rd order Quantico Creek (2.1 m^3/sec), and 4th order Cameron Run (1.9 m^3/sec)(Table 9; Fig. 13). Similarly, there were no significant differences in flows between 2nd order Quantico Creek (0.51 m^3/sec) and 2nd order Cameron Run (0.32 m^3/sec), and between 1st order Quantico Creek (0.08 m^3/sec) and 1st order Cameron Run (0.21 m^3/sec)(Fig. 13). There were no significant differences among annual water temperatures (avg. range=11.0-14.0 C) among all stream orders in both Cameron Run and Quantico Creek (Table 9; Fig. 14). Annual average pH of 3rd order Cameron Run (7.0) was significantly higher than average pH values at all other

1st, 2nd, and 4th order streams of Cameron Run and 1st, 2nd, and 3rd order streams of Quantico Creek (Fig. 15).

In general, substrate composition and the percent of disturbed riparian habitats varied with watershed and stream order (Table 10). Quantico Creek stream substrates were more varied than those of Cameron Run. Two significant features of streams in Cameron Run were the preponderance of gravel substrates (avg. range=45-60 %) compared to those (avg. range=15-25%) of Quantico Creek, and the high percentage (avg. range=70-90 %) of disturbed riparian banks (cf. Quantico Creek: avg. range=0-6.0)(Table 10). In contrast, cobble comprised a greater proportion of stream substrates in Quantico Creek (avg. range=22.0-34.0 %) compared to those (avg. range=5.0-15.0 %)(Table 10).

GIS Parameters

Sub-watershed size of 4th order Cameron Run was significantly different from all other sub-watersheds (1st, 2nd, 3rd) within Cameron Run; and also those of 1st and 2nd order sub-watersheds of Quantico Creek (Tables 11 and 12). Quantico Creek 3rd order watershed size (3371 ha) did not differ significantly from that (2011 ha) of 3rd order Cameron Run (Tables 11 and 12). Average watershed sizes (avg. range=71-2011) did not vary significantly among 1st and 2nd order streams within and among the Quantico Creek and Cameron Run watersheds (Tables 11 and 12).

Human population (103,728) in the 4th order Cameron Run sub-watershed was significantly greater than those (avg. range=0-44,811) in all Cameron Run and Quantico Creek sub-watersheds (Tables 11 and 12; Fig. 16). Similarly, population (44,811) in the 3rd order sub-watershed of Cameron Run was significantly greater than those (avg. range=0-10,957) in 1st through 3rd order sub-watersheds of Quantico Creek and 1st and 2nd order sub-watersheds of Cameron Run (Tables 11 and 12; Fig. 16).

Impervious cover (3,428.4 ha) in the 4th order sub-watershed of Cameron Run was significantly greater than those (avg. range=12.4-1412.2 ha) in all other sub-watersheds of both Cameron Run and Quantico Creek (Tables 11 and 12; Fig. 17). Likewise, impervious cover (1,412.2 ha) in the 3rd order sub-watershed of Cameron Run was significantly greater than all other sub-watersheds in Cameron Run and Quantico Creek (Tables 11 and 12; Fig. 17). Impervious cover (avg. range=12.4-287.8) did not vary significantly within and among 1st through 3rd sub-watersheds of Quantico Creek and 1st through 2nd sub-watersheds of Cameron Run (Tables 11 and 12; Fig. 17).

The percentage (avg. range=83.35-94.39) of hectares of undeveloped land cover in 1st, 2nd, and 3rd sub-watersheds of Quantico Creek were significantly greater than those (avg. range=26.67-48.22) in 1st, 2nd, 3rd, and 4th order sub-watersheds of Cameron Run (Tables 11 and 12; Figs. 18 and 19).

Fishes

Quantico Creek watershed

A total of 29 species of fishes (representing 10 families) were collected in Quantico Creek (Tables 13 and 14). The most frequently collected species were *Rhinichthys atratulus* (12.3%), *Etheostoma olmstedi* (9.1%), *Lepomis auritus* (9.0%), *Clinostomus funduloides* (7.2%), *Semotilus atromaculatus* (6.1%). *Exoglossum maxillingua* (5.7%), *Semotilus corporalis* (5.6%), *Catostomus commersoni* (5.6%), *Lepomis cyanellus* (5.6%), *Notropis procne* (5.5%), *Noturus insignis* (5.5%) and *Erimyzon oblongus* (5.0%), which accounted for 82.2 % of occurrences of all fishes during the study period (Table 13). Six species (i.e., *N. procne*, *S. corporalis*, *Notemigonus crysoleucas*, *N. insignis*, *L. microlophus*, and *Esox niger*) were common to 2nd and 3rd order streams but not present in 1st order streams. Ten species (i.e., *Cyprinella analostana*, *Notropis hudsonius*, *Hybognathus regius*, *Ameiurus natalis*, *Ameiurus nebulosus*, *Fundulus diaphanus*, *Micropterus salmoides*, *Channa argus*, *Lampetra aepyptera*, and *Petromyzon marinus*) occurred in 3rd order streams only (Table 13). Total abundances of fishes in Quantico Creek varied by stream order, month, and season (Tables 15-17; Appendix 9).

Total species richness in Quantico Creek increased with stream order (1st order=12 species; 2nd order=19 species; and 3rd order=29 species)(Table 13). Average species richness (9.6) in stream order 3 was significantly greater than those (6.3 and 2.5 species) in stream orders 2 and 1, respectively (Tables 18 and 19). Shannon Weiner Index (1.84) of stream order 3 was significantly greater than those (1.54 and 0.45) in stream orders 2 and 1, respectively (Tables 18 and 19). Species evenness index value (0.7479) in stream order 1 was significantly lower than those of stream order 2 (avg.=0.8337) and stream order 3 (avg.=0.8674)(Tables 18 and 20). Species richness (9.57) in August was significantly greater than those (avg. range=4.88-6.1) in January, December and June (Tables 18 and 20). Species richness (avg.=9.6) and Shannon Weiner species diversity (avg.=2.236) in August were significantly higher than those (richness avg. range=4.9-6.1 in all other months; species diversity avg. range=1.057-1.2965) in January, December and June (Table 20).

Cameron Run watershed

A total of 21 species (representing seven families of fishes) were collected in the Cameron Run watershed (Tables 13 and 21). The most frequently collected species were *R. atratulus* (17.8%), *S. atromaculatus* (10.8%), *C. commersoni* (10.4%), *C. analostana* (7.0%), *A. natalis* (7.6%), *E. olmstedi* (7.6%), *N. procne* (6.7%), and *L. auritus* (6.5%), which accounted for 74.4 % of all occurrences of species during the study period Tables 13 and 21). Three species (i.e., *R. atratulus*, *C. commersoni*, and *Lepomis macrochirus*) occurred in all four stream orders. Three species (i.e., *C. funduloides*, *A. natalis*, and *E. olmstedi* occurred only in stream orders 2, 3, and 4. Eight species (i.e., *N. procne*, *C. analostana*, *P. notatus*, *A. rostrata*, *Fundulus heteroclitus*, *F. diaphanus*, *L. auritus*, and *Lepomis gibbosus*) were collected only in stream orders 3 and 4. *Notropis hudsonius* occurred only in stream order 4. Abundances of fishes varied with stream order, month and season (Tables 21-25; Appendix 10).

Total species richness increased with increasing stream order (i.e., 1st order=3 species; 2nd order=11 species; 3rd order=15 species; and 4th order=19 species) in Cameron Run (Table 13). Average species richness values (avg. range=7.6-8.1) in 4th and 3rd stream orders, respectively, were significantly higher than those (avg. range=2.1-5.3) in 1st and 2nd stream orders, respectively (Tables 18 and 19). Likewise, Shannon Weaver Indices (avg. range=1.36-1.54) in 3rd and 4th stream orders were significantly higher than those (avg. range=0.448-1.07) in 1st and 2nd order streams (Tables 18 and 19). There were no significant differences in species evenness indices among stream orders (Table 19). There were no significant differences in species richness, diversity and evenness among months in Cameron Run sampling locations (Table 26).

Comparisons of fish richness, diversity, and species composition between Quantico Creek and Cameron Run watersheds

Average species richness (avg.=9.65) in 3rd order sampling locations in Quantico Creek was significantly higher than those (avg. range=7.6-8.1) in 3rd and 4th order sampling locations in Cameron Run (Table 27; Fig. 20). There were no significant differences between species richness values (avg. range=5.3-6.3) in 2nd order streams in Quantico Creek and Cameron Run watersheds. Also, there were no significant differences between species richness (avg. range=2.1-2.5) in 1st order streams of Quantico Creek and Cameron Run watersheds (Table 27; Fig. 20).

Species diversity (avg.=1.84) in 3rd order sampling locations of Quantico Creek was significantly higher than those (avg. range=1.36-1.54) in 4th and 3rd order locations in Cameron Run watershed (Table 27; Fig. 21). Similarly, species diversity (1.54) at 2nd order Quantico Creek was significantly higher than that (avg.=1.07) at 2nd order Cameron Run locations. There were no significant differences in average species diversity between 1st order Quantico Creek and Cameron Run sampling locations (Table 27; Fig. 21).

Species evenness (0.8337) in 3rd order Quantico Creek was significantly greater than those (avg. range=0.6794-0.7155) in 4th and 3rd order locations in Cameron Run (Table 27). Similarly, species evenness (0.8674) in 2nd order Quantico Creek was significantly great that than (avg.=0.6500) in 2nd order Cameron Run. There were no significant differences in species evenness between 1st order Quantico Creek and Cameron Run locations (Table 27).

Overall, nine species (i.e., *L. cornutus*, *E. maxillingua*, *S. corporalis*, *N. crysoleucas*, *Hybognathus regius*, *Lepomis microlophus*, *Chann argus*, *Lampetra aepyptera*, and *Petromyzon marinus*) present in Quantico Creek were not collected in Cameron Run watershed during the course of our study (Table 13). Nine species (i.e., *C. funduloides*, *L. cornutus*, *E. maxillingua*, *E. oblongus*, *A. rostrata*, *L. auritus*, *L. gibbosus*, *L. cyanellus*, and *E. olmstedi*) were present in 1st order streams of Quantico Creek but not collected from

1st order streams of Cameron Run. In a comparison of 2nd order streams, *L. cornutus*, *E. maxillingua*, *N. procne*, *S. corporalis*, *N. chrysoleucas*, *N. insignis*, *A. rostrata*, *F. diaphanus*, *L. auritus*, *L. gibbosus*, and *L. microlophus* were present in Quantico Creek 2nd order streams but not in those of Cameron Run. A total of 14 species (i.e., *L. cornutus*, *E. maxillingua*, *S. corporalis*, *N. hudsonius*, *N. chrysoleucas*, *H. regius*, *E. oblongus*, *A. nebulosus*, *L. cyanellus*, *L. microlophus*, *M. salmoides*, *C. argus*, *L. aepyptera*, and *P. marinus*) occurred in 3rd order streams of Quantico Creek but were absent from 3rd order streams of Cameron Run (Tables xx and xx).

In contrast, only two species (i.e., *Pimephales notatus* and *Fundulus heteroclitus*) occurred in both 3rd and 4th order streams of Cameron Run but not in any stream orders of Quantico Creek (Tables 13).

Within the Quantico Creek watershed, similarity of species composition between 1st and 2nd order streams was 60 percent (12 species in common); that between 2nd and 3rd order streams was 63 percent (19 species in common)(Table 28). In Cameron Run, similarity of species composition was 36 percent between 1st and 2nd order streams, 32 percent between 2nd and 3rd order streams, and 70 percent between 3rd and 4th order streams (Table 28). Species composition similarity in Quantico Creek 1st and 2nd order streams (60 %) and that between 2nd and 3rd order streams (63 %) were about twice those in Cameron Run 1st-2nd order (36 %) and Cameron Run 2nd-3rd order (32 %). Cameron Run species composition similarity (70 %) between 3rd and 4th order streams was comparable to that (63 %) for Quantico Creek 2nd-3rd order species composition similarity (Table 28). However, the number of species in 1st order (12), 2nd order (20), and 3rd order streams (28) of Quantico Creek were two to three times greater than the number of species in 1st order (4), 2nd order (11), 3rd order (15), and 4th order (19) in Cameron Run (Table 28).

Fish Species Richness and Diversity Models

Quantico Creek Fish Species Richness Model- Multiple stepwise regression analyses (8 steps) resulted in the following equation to calculate fish species richness by stream order in the Quantico Creek watershed (Table 29):

$$\begin{aligned}\text{Fish Species Richness} = {} & 0.51449+(0.43460*\text{Season})+(1.73006*\text{Stream Order})+(0.04152*\text{Elevation})+\\ & (0.25609*\text{River km})+(0.23222*\text{Stream Width})+(2.00873*\text{Stream Depth})+\\ & (0.00081546*\text{Sub-Watershed Size})+(-0.08121*\text{Percent Undeveloped Land Cover})\end{aligned}$$

The model resulted in a relationship where fish species richness is a function of season, stream order, elevation of the sampling location, the distance from the mouth of Quantico Creek upstream to the sampling location, stream width, stream depth, water temperature and human population unique to the sub-watershed of a sampling location (Table 29; Figure 22).

Quantico Creek Fish Diversity Model – Multiple stepwise regression (9 steps) resulted in the following equation to model fish diversity (i.e., Shannon Weaver Index) in the Quantico Creek watershed (Table 30; Fig. 23):

$$\begin{aligned}\text{Fish species Diversity} = {} & 1.82408+(0.07887*\text{Season})+(0.14638*\text{Stream Order})+(0.04835*\text{River km})+\\ & (-0.03540*\text{Gradient})+(0.08194*\text{Stream width})+(0.50794*\text{Stream depth})+\\ & (-0.01902*\text{Percent Undeveloped land cover}).\end{aligned}$$

Cameron Run Fish Species Richness Model– Multiple stepwise regression analyses (4 steps) produced the following equation to calculate fish species richness by stream order in Cameron Run watershed (Table 31; Fig. 22):

$$\text{Fish Species Richness} = 10.10139+(-0.62161*\text{Gradient})+(0.11283*\text{Water Temperature})+ (0.18116*\text{Stream Flow})+(-0.03953*\text{Percent Undeveloped Land Cover}).$$

In Cameron Run, fish species richness was a function of river km (i.e., the distance from the mouth of Cameron Run upstream to the sampling location), stream gradient, water temperature, pH, human population unique to the sub-watershed of a sampling location, and impervious cover (Figs. 14, 15, 16 and 17).

Cameron Run Fish Diversity Model – Multiple stepwise regression (5 steps) resulted in the following equation to model fish diversity (i.e., Shannon Weaver Index) in Cameron Run watershed (Table 32; Fig. 22):

$$\text{Fish Diversity}=2.54731+(0.05584*\text{Season})+(-0.02945*\text{Elevation})+ (0.01455*\text{Water temperature})+ (-0.00028581*\text{Undeveloped Land Cover})+(-0.00699*\text{Percent Undeveloped Land Cover}).$$

In a comparison of the factors that accounted for the decreased species richness in the Cameron Run watershed relative to Quantico Creek watershed, four factors were significant (Table 33; Fig 23): lower water flow (m^3/sec) and decreased macroinvertebrate functional feeding group diversity; and higher impervious coverage and higher water temperatures in Cameron Run (Table 33; Fig. 23).

Analyses of Macroinvertebrate Collections

Macroinvertebrate taxa richness (range = 79-92) in all stream orders of Quantico Creek were higher than those (range = 19-39) in Cameron Run (Table 34). Macroinvertebrate taxa richness increased with stream order in Quantico Creek. In Cameron Run, taxa richness (39) peaked in 2nd order streams and then decreased to 27 in 4th order Cameron Run. Average taxa richness (11.727) in 1st order streams of Quantico Creek was significantly higher than that (6.375) in 1st order streams of Cameron Run (Table 35). Average taxa richness (15.101) in 3rd order streams of Quantico Creek were significantly higher than that (8.059) in 3rd order parts of Cameron Run (Table 35). All stream orders of Cameron Run had low EPT (i.e., Ephemeroptera, Plecoptera, Trichoptera) taxa richness and a complete absence of Plecoptera (Table 34).

Average functional feeding group (FFG) richness (4.958) in 1st order Quantico Creek streams was significantly higher than that (2.118) in 1st order Cameron Run streams (Table 35). Average FFG richness (6.152) in 3rd order Quantico Creek streams was significantly higher than those (avg. range=2.042-2.176) in 3rd and 4th order reaches of Cameron Run (Table 35).

Percentages of functional feeding groups represented in Quantico Creek were similar to those in Cameron Run (Figure 24). Both Quantico Creek and Cameron Run are dominated by specialist feeding strategies (Table 36). The dominant FFG in both Quantico Creek and Cameron Run was predators, followed gathering collectors and filtering collectors (Table 36, Table 40). However, taxa richness of each functional feeding group in Quantico Creek was significantly higher than those in each functional feeding group of Cameron Run (Table 36). For example, 103 taxa comprised twelve functional feeding groups in Quantico Creek watershed, while only 47 taxa comprised 10 functional feeding groups in Cameron Run watershed (Table 37). The trend in percentages of specialist and generalist functional feeding groups by stream order in the Cameron Run watershed do not conform to those observed in Quantico Creek. For example, some groups in Cameron Run appeared and disappeared (e.g. shredders, gathering-collectors, gathering scrapers and filtering-collector predators) and others were completely absent in all stream orders (e.g. shredder gatherer predators). In contrast, specialist functional feeding groups by stream order in Quantico Creek watershed increased with increased stream order, whereas generalist functional feeding groups increased from 1st to 2nd order streams and then leveled off (Figure 35).

Results of Duncan's Multiple Range test showed that mean macroinvertebrate taxa richness of 1st (6), 3rd (9.25) and 4th (6.75) streams in Cameron Run watershed were significantly lower than those (avg. range= 23-38) of all stream orders in Quantico Creek ($p>F = <0.0001$) (Table 38). Mean functional feeding group (FFG) richness in 1st order (4.0) Cameron Run and 4th order (4.0) Cameron Run were significantly lower than FFG richness (mean range = 6.75-9.5) in all Quantico Creek streams ($p>F = 0.0002$). Mean FFG richness in 2nd order (9.5) Quantico Creek and 3rd order (9.5) Quantico Creek were significantly higher than those (range = 4.0-5.75) in all Cameron Run streams (Table 38). There were no significant differences in mean FFG evenness between or within watersheds (p>F = 0.7129). Average FFG Shannon Diversity Indices in Cameron Run 1st order (1.153) and 4th order (1.2593) were significantly lower than those of 2nd (1.9761) and 3rd order streams (1.9972) in Quantico Creek (Table 38).

Macroinvertebrate taxa richness and FFG richness were calculated between and within Quantico Creek and Cameron Run watersheds by month, from June to October (Table 39). In Quantico Creek, taxa and FFG richness were greatest during June across all stream orders and decreased through October. In Cameron Run, taxa and FFG richness across all stream orders were greatest during July (Table 39). However, in October, both FFG richness and taxa richness decreased dramatically to the point that each FFG was comprised of about 1 taxon (Table 39, Figure 26).

Macroinvertebrate Correlation Analysis

In Quantico Creek watershed, macroinvertebrate taxa richness is negatively correlated (-0.38445) with month (p=0.0011)(Table 5). FFG richness is related to river kilometer (0.29651, p=0.0134) and FFG Shannon Diversity Indices is related to river kilometer (0.28608, p=0.0172).

In Cameron Run watershed, macroinvertebrate taxa richness is related to stream order (0.3616, p=0.0356), the number of forested hectares (0.34885, p=0.0432) and elevation (-0.37045, p=0.0310) (Table 8). Macroinvertebrate FFG richness in Cameron Run is related to stream order (0.36398, p=0.0343), elevation (-0.42098, p=0.0132), gradient (-0.4384, p=0.0095), average current (0.34028,p=0.0489) and water temperature (0.43080, p=0.0110) (Table 8). FFG Shannon Diversity Indices in Cameron Run are related to stream order (0.44087, p=0.0091), elevation (-0.48337, p=0.0038), gradient (-0.50178, p=0.0025), average current (0.49318, p=0.003) and water temperature (0.47572, p=0.0045) (Table 8).

Although not significant, there is a relationship between macroinvertebrate taxa richness (0.18349) and stream order (p=0.1313) in Quantico Creek. FFG diversity in Quantico Creek is related to month (-0.21218, p=0.0801), amount of impervious area (-0.18152, p=0.1355) and average current (0.19943, p=0.1004) (Table 5). Although not significant, taxa richness in Cameron Run watershed is related to watershed size (0.33565, p=0.0523), population in the sub-watershed (0.32354, p=0.062), amount of impervious surfaces (0.32447, p=0.0612), gradient (-0.32755, p=0.0586) and water temperature (0.32662, p=0.0594). FFG richness in Cameron Run is related to flow (0.30786, p=0.0765). FFG diversity in Cameron Run is also related to watershed size (0.30723, p=0.0772), population in the sub-watershed (0.33205, p=0.055), amount of impervious surfaces (0.31441, p=0.0701) and forested hectares (0.33025, p=0.0564), although these relationships are not statistically significant.

Macroinvertebrate Multiple Stepwise Regression Analysis

The following models for macroinvertebrate taxa richness and functional feeding group (FFG) richness and Shannon Diversity Indices were developed using physical, anthropogenic and watershed parameters as predictors of biotic and functional metrics (Table 40) in multiple stepwise regression analysis (SAS, 2009). No mathematical expression was created to model FFG evenness because there were no significant differences in FFG evenness between and among stream orders of Quantico Creek and Cameron Run (Table 38).

Quantico Creek watershed

Taxa Richness = 12.57518 + 6.86044(Stream Order) + -0.4976(River km) + 0.01589(Watershed Size) + -0.00438(Population in the Sub-watershed) + -0.01994(Undeveloped Land Cover Hectares)

FFG Richness = 4.56929 + 1.30416(Stream Order) + -0.01705(Elevation) + -0.00077(Undeveloped Land Cover Hectares)

FFG Diversity = 1.84658 + 0.17754(Stream Order) + -0.04009(Average Width) + -0.00581 (Percent Undeveloped Land Cover Hectares)

Cameron Run watershed

Taxa Richness = -25.09794 + 7.81614(Month) + 0.38474(Elevation) + -2.17792(Gradient) + 0.76503(Average Width) + -0.90849(Water Temperature) + 0.04868(Watershed Size) + -0.06506(Amount of Impervious Surfaces) + -0.32548(Percent Undeveloped Land Cover Hectares)

FFG Richness = 5.69777 + 3.37471(Month) + 1.78262(Stream Order) + 0.20657(Elevation) + -1.55543(Gradient) + 0.47074(Average Width) + -7.15292(Average Current) + -0.98292(Water Temperature) + -0.16547(Percent Undeveloped Land Cover Hectares)

FFG Diversity = -2.15556 + 0.54623(Month) + 0.07009(River km) + -0.12109 (Gradient) + 0.49597(Flow)

Hydrologic Models for Cameron Run and Quantico Creek

Model Calibration and Validation

Calibration allows users to establish site-specific parameter values in a hydrologic model and validation provides reasonable assurance of predictability of flows in the subject watershed. Calibration and validation are performed using two independent data sets. Historic flows from the Cameron Run at Alexandria, VA (USGS 01653000) and the South Fork Quantico Creek near Independent Hill, VA (USGS

01658500) gages between March 01, 2009 and July 31, 2009 were used to calibrate the Cameron Run and the Quantico Creek models, respectively. Figure 27 shows the model calibration results comparing the observed and the modeled flows at the gage. Figure 28 plots the modeled versus the observed flows and computes the correlation coefficient (R^2 = 0.885) between the two datasets. For a perfect match between the modeled and the observed data, all the points must lie on a straight line, which has a slope of 1.0. Thus the corresponding correlation coefficient for a perfect match will be 1.0. A high correlation coefficient in the calibrated Cameron Run model suggests that the model was calibrated well. The Cameron Run model was validated by comparing the simulated and the gaged data during the period from April 1, 2008 through July 31, 2008. Figures 29 and 30 show the time series plots and the relationship between the modeled and the observed flows, respectively. These plots demonstrate a good match between the modeled and the observed flows during the validation period.

Figures 31 and 32 present the calibration results of the Quantico Creek model. Figure 31 compares the modeled flows with the observed flows at South Fork Quantico Creek near Independent Hill, VA (USGS 01658500) gage over the calibration period. Figure 32 shows a good correlation (R^2 = 0.81) between the modeled and the observed flows. The Quantico Creek model validation during the period between April 1, 2008 and July 31, 2008 as presented in Figures 33 and 34 show a generally good match between the modeled and the observed flows except for dry weather flows and two major storms. These differences resulted in a lower correlation coefficient compared to that during the calibration run.

VIII. Discussion

The importance and value of long-term studies conducted in discrete stream segments or stream orders in a systematic manner is crucial to understanding changes that occur within watersheds over time. Such data serve as continuous records of the occurrences and relative abundances of species that can be used to assess changes in species composition and community structure over time. The present investigation resulted in establishing baseline data for fish communities and models for fish species richness and diversity in each of two mid-Atlantic region, lower Piedmont forest (Quantico Creek) and urban (Cameron Run) watersheds. This is the first systematic, comprehensive long-term watershed-wide research of fish communities in Quantico Creek and Cameron Run. Previous studies by others (e.g. Kelso, et al., 2001; Va Dept. of Game & Inland Fisheries data base (VDGIF, 2007), Fairfax County Water Authority) were limited in spatial and temporal scope within Quantico Creek periodically from 1999-2006. Only one collection in Cameron Run on 20 September 2006 made by Chad Grupe was found in the VA Department of Game & Inland Fisheries database (VDGIF, 2007). It included a total of 15 species but no specific locality data were provided. Individual collections made infrequently without regard to season and the changes in stream characteristics are limited in conveying changes of the temporal and spatial distributions of fishes in lotic systems over time.

Results generated from data and models in the current study are requisite for comparative purposes in future studies of mid-Atlantic streams relative to changes in human population, and corresponding anthropogenic effects (e.g. development of undeveloped land cover) in the two watershed; and changes in stream flows and habitats related to potential climatic changes that have been modeled for the mid-Atlantic region. For example, the Cameron Run watershed exists in two areas (Fairfax County and Alexandria, VA), which have been projected for increases in human population (based on 2000 census data) of 10-25 % by 2020, 25-85 % by 2030, 25-100 % by 2040, and 25 % to over 100% by 2050 (Consortium for Atlantic Regional Assessment, 2006). In our study, there is a direct correlation between increases in human population and increased impervious cover in the Cameron Run watershed (Table 8; Figs. 16 and 17). The difference in impervious cover was one of the significant factors in accounting for reduced species richness in Cameron Run watershed compared to that of Quantico Creek (Table 33). Two factors, human population growth and impervious cover, have the potential to impact fish communities in the Cameron Run watershed as human population and land development have and continue to increase over time. As such, results of the present study can be applied to land use planning, stream restoration efforts, and in determining changes in fish species richness and diversity relative to physical, chemical, and biological variations in the future. This is particularly significant in that species richness in Cameron Run is not as robust as that in Quantico Creek, a forested watershed with high numbers of undeveloped land cover hectares, where the percentages of undeveloped lands within sub-watersheds is high, and where both human population and impervious cover in Quantico Creek are minor factors compared to those in the Cameron Run, an urban watershed.

Of particular note is the trenchant difference between the parameters that comprise the mathematical models for Quantico Creek (a forested watershed) and for Cameron Run (an urban watershed). Fish species richness in Quantico Creek watershed currently is a function of season, stream order, elevation, river km, stream width and depth, watershed size and percent of undeveloped land cover (Table 29). In contrast, fish species richness in Cameron Run cannot be modeled using any of these parameters from the Quantico Creek model. Factors that reflect the current fish species diversity in Cameron Run are stream gradient, stream flow, and water temperature, and percent undeveloped land cover (Table 31). Likewise, only two factors (season and % undeveloped land cover) were common to the fish species diversity models of Quantico Creek and Cameron Run (Tables 29 and 31).

Species richness models for 1st, 2nd, and 3rd stream orders did a good job in predicting species richness in Quantico Creek in all season except winter when the modeled over-predicted the species richness by two species for 3rd order streams (Table 29; Fig. 22). The species richness model for 1st-4th stream orders in Cameron Run did not perform as well overall (Table 31; Fig. 22). For example, it did not predict species richness well in 4th order streams in winter, nor 2nd order streams in early spring, 3rd order streams in summer and late fall, and 4th order streams in early fall (Table 31; Fig. 22). Failure of the models to precisely reflect species richness in one season in the Quantico Creek watershed, and multiple seasons in the Cameron Run watershed is related to sample size for months where model predictions did not give a good portrayal of the actual values of species richness observed in the field. However, the models can be used as relatively accurate guides of species richness and diversity in each stream order of both watersheds. For example, the species diversity model for 3rd order Cameron Run expected a mean value of ~1.8 in early spring (Fig. 23). The actual average species diversity was ~0.40, a value that adequately reflected the complete absence of fishes in Holmes Run (3rd order tributary of Cameron Run) in early spring (Fig. 23).

Species diversity in Cameron Run was a function of five factors (i.e., season, elevation, water temperature, undeveloped land cover, and % undeveloped land cover) rather than seven factors in the species diversity model in Quantico Creek (Tables 30 and 23). Two factors (season and % undeveloped land cover) were common to species diversity models both watersheds (Tables 30 and 32).

Anthropogenic effects have been demonstrated to impact species richness and species diversity independent of stream order as seen in Cameron Run. For example, Schlosser (1987) stated that species richness tended to increase from modified to natural upstream areas. Based on the differences in species richness and species diversity models between Quantico Creek and Cameron Run watersheds, we purport that stream order and its other correlated factors used to model species richness in forested watersheds where human disturbance is minimal, are not appropriate for streams in highly modified urban environments.

Warren Buffett once commented "Beware of geeks bearing formulas." It should be noted that mathematical models are not absolutes. Our models, based on a host of various types of parameters collected over almost a two year period, present a picture of the relationships among these parameters and fish communities. We suggest that our models can be used as indicators of general trends and changes in communities and how the communities function, and can change relative to changes in environmental conditions. Pilkey and Pilkey-Jarvis (2007) make the point clear: "Qualitative models are used in trying to understand natural processes. They can be used as indicators of general trends, relative impacts, probable causes, directions of flow, timing of events."

Tilman (2006; 2001) who studied plant species richness in grasslands and Steiner et al. (2005) who investigated species richness in aquatic food webs have demonstrated that more species diverse communities are more resilient to environmental changes than those with fewer species. Higher degrees of biodiversity in a community or in an ecosystem give the systems stability. A worthwhile research project in the future will be to determine if the already compromised fish communities in each of the stream orders of Cameron Run will be able to sustain themselves relative to the projections of increased human population and concomitant impacts (e.g. additional stream pollutants, habitat alteration, and potential decreases in remaining forest cover), and hydrologic changes that may be associate with climate change proposed for the area.

Research in the longitudinal zonation of fishes in freshwater streams has been demonstrated to be useful in identifying and monitoring variations in species richness and diversity, and fish distributions relative to natural changes (e.g. elevation, gradient, and stream order) and anthropogenic perturbations (e.g. damming) (Hutchinson, 1993; Lotrich, 1973; Maurakis and Grimes, 2003; Maurakis et al., 1987; Mundy and Boschung, 1981; Paller, 1994). Within the Quantico Creek watershed, similarity of species composition between 1st and 2nd order streams was 60 percent (12 species in common); that between 2nd and 3rd order streams was 63 percent (19 species in common). In Cameron Run, similarity of species composition was 36 percent between 1st and 2nd order streams, 32 percent between 2nd and 3rd order streams, and 70 percent between 3rd and 4th order streams (Table 28). Species composition similarity in Quantico Creek 1st and 2nd order streams (60 %) and that between 2nd and 3rd order streams (63 %) were about twice those in Cameron Run 1st-2nd order (36 %) and Cameron Run 2nd-3rd order (32 %). Cameron Run species composition similarity (70 %) between 3rd and 4th order streams was comparable to that (63 %) for Quantico Creek 2nd-3rd order species composition similarity (Table 28). However, the number of species in 1st order (12), 2nd order (20), and 3rd order streams (28) of Quantico Creek were two to three times greater than the number of species in 1st order (4), 2nd order (11), 3rd order (15), and 4th order (19) in Cameron Run (Table 28). Low similarity of species composition between stream orders, and species richness and species diversity per stream order identified in our study situated from the lower Piedmont province to the Fall Line, particularly in the Cameron Run watershed, is not unlike those of harsh environments (e.g. streams in desert and boreal environments) summarized by Hutchinson (1993), who also reported low species diversity per stream order in the Murray River, Australia. By comparison, our average numbers of species (2.13 in Cameron Run; 2.71 in Quantico) 1st order streams are acutely different from those in temperate zone drainages (i.e., 13-25 species in 1st order streams of Montane and Piedmont sections of the Rappahannock River, Virginia nearby Quantico Creek and Cameron Run watersheds (Maurakis et al., 1987). However, species richness and species diversity in 2nd and 3rd order streams in Quantico Creek watershed were significantly higher than those in 2nd, 3rd, and 4th order streams in the Cameron Run watershed (Table 27; Figs. 20 and 21), which reflects the differences in habitat characteristics (stream widths and depths, water temperature, human population, impervious cover, and percent undeveloped land cover between the forest (i.e., Quantico Creek) and urban (i.e., Cameron Run) watersheds (Tables 9-12; Figs. 11-19). Of particular note are the significantly higher values of human population, impervious cover and percent undeveloped land cover in the Cameron Run watershed compared to those in Quantico Creek (Table 12; Figs. 16-19).

Based on the results of our fish species richness and diversity models for Quantico Creek watershed, a forest watershed, and those of Paller (1994), Hutchinson

(1993), and Lotrich (1972), we propose that stream order emulates an ecological unit, and can be used to account for variation in species diversity along a river continuum. Our findings corroborate those of Hutchinson (1993) who stated that stream order is in itself a variable inter-correlated with many other variables (e.g. stream width, gradient, and river km), and is correlated with species diversity. Maurakis et al. (1987) indicated that stream order was correlated with elevation, gradient, and species diversity in a study of six stream orders of the Rappahannock River, Virginia. Paller (1994) statistically related stream order directly to habitat changes in lotic environments of Coastal Plain streams in South Carolina. Lotrich (1973) found that available niches increase with increasing stream order, and as a result, species diversity increases in his study of fishes inhabiting first, second, and third order streams in Kentucky. Horwitz (1978) related temporal variability patterns to the distributional patterns of stream fishes.

Anomalies and unique events during the study period – One of the 1st order streams (station 21) in Quantico Creek watershed became intermittent in July, 2009 and was not included in analyses. Interestingly, three months prior in April, the paltry flowing stream had extensive foam and smelled of sewage. No fish species were collected at this location after the first three collections (Nov. 2008, Jan. 2009 and March, 2009) when only one individual of *Rhinichthys atratulus* was collected during each of these months.

About 50% of the course of site 16 (1st order tributary in Quantico Creek system) was modified during heavy storms and high waters in June, 2009. Average species richness for the five months preceding the alteration in stream course was 7 (range=5-9). In July, species richness was 2, but recovered in August (6) and averaged 6.4 over the next five months. This recovery is not unlike that reported by Woolcott (1974) in a long-term ecological study of the fish community in the Piedmont section of the James River, Virginia. The James River experienced a record 100-year flood in June 1972. The short term effect was seen in July 1972 when the total fish population in the river was the lowest recorded during the study. The condition was temporary, however, as total numbers of species and individuals were high in August, and continued in September and succeeding months.

The sampling areas for station 2 and station 7 were slightly modified in July, 2009 and June, 2009, respectively as follows: collections at station 2 were made 200 m upstream rather than 100 m downstream of the confluence of this 3rd order segment of Quantico Creek and a 2nd order stream because of fallen trees littering the downstream sampling area after winter and early spring storms. Previously, a 100 m stretch downstream of the confluence had been sampled. There were no differences in species richness between the two sampling reaches (cf. avg. richness=10 before reach change; avg. richness=10.25 three months after reach change). Collections at station 7, previously made upstream of the bridge, were made downstream of the bridge after June, 2009 because the upstream area was used for outdoor environmental education classes that disturbed that particular reach of stream. No differences in species richness were noted before and after the change in collecting reach (cf. avg. richness=12.3 before reach change; avg. richness=12.3 three months after reach change).

Two incidents at Holmes Run (3rd order tributary of Cameron Run) indicate that fish populations there, and perhaps in other portions of Cameron Run as a whole may be subject to a host of anthropogenic influences that periodically extirpate local fish populations. For example, we did not collect nor see any fishes in a 200 m section of Holmes Run (station 15) in March, 2010, which was running clear with a pH of 6.4, but smelled like phenol. Its pH was lower than that (7.0) of another 3rd order stream of Cameron Run during the same month. Normally, this stream section of Holmes Run harbors high abundances of fishes (e.g. *P. notatus* and *C. analostana*) and usually has relatively good species richness. Additionally, high pH (9.3) at this location occurred in April 2010, and again in May, 2010 when pH was 7.5. Secondly, while collecting fishes in Holmes Run during a snowstorm in January, 2009, the electroshocker stopped working as a result high concentrations of ions in the water coming from deicing agents (including salt brine, magnesium chloride and calcium chloride, Kravitz, 2009), that entered the stream through stormwater discharge pipes from roadways, which turned the clarity of the stream from clear to black in a matter of minutes. These observations in the urban Holmes Run stream highlight the great variation that can occur in stream conditions in urban environments.

On two occasions (January and July, 2009), the exotic species, *C. argus* (Northern snakehead fish), was collected at station 8 in the lower reaches of Quantico Creek, just upstream of the I-95 bridge. None were collected at this or other sampling sites after July, 2009. Our collections of *C. argus* occurred in an area between Aquia Creek to the south and Neabsco Creek to the north (USGS, 2010) where the species has previously been captured, and were reported to the National Snakehead fish hotline.

When collections were made during periods of low flow in September, October, and November, 2009, two species of lamprey, *Lampetra aepyptera* (Least brook lamprey; ~ 100 mm) and *Petromyzon marinus* (Sea lamprey; 170-190 mm) were collected in 3rd order Quantico Creek (site 2). Both species were collected from sandy areas underneath large rocks, and easily spotted when shocked in the shallow, clear water. Kelso et al. (2001) did not collect either species in their collections of Quantico Creek during summer. The Virginia Department of Game & Inland Fisheries (VDGIF, 2007) reported nine collections of *L. aepyptera* from Quantico Creek from 1999-2006.

Lepomis microlophus was recorded from a 2nd order and 3rd order stretch of Quantico Creek in November, 2008, and January and March 2009. Its appearance in the field prompted an onsite identification as its head and body shape, and body and fin colors and patterns and anal fin ray count (11) indicated an anamolous form of *Lepomis gibbosus*, which has 9-10 anal rays. This is the second report (Maher, Amy, 26 October 1999; Sci. Coll. Permit # 013348 reported in fish database of VA Department of Game & Inland Fisheries VDGIF, 2007) of the species in the Quantico Creek system, and its presence in the stream is likely derived from an upstream, stocked pond on the Quantico Marine Corps Base (T. Stamps, pers. comm.).

Several species collected by other investigators in the Quantico Creek watershed between 1999-2006 were not collected during our study period (i.e., *Pimephales notatus*, *Moxostoma erythrurum*, *Percina peltata* reported Maher, 1999 (VDGIF database), and *Alosa aestivalis*, *Alosa pseudoharengus*, and *Dorosoma cepedianum* reported by Kelso in 2004-2005 (VDGIF database).

Macroinvertebrates

Using Functional Feeding Group (FFG) analyses vs. Index of Biological Integrity (IBI) analyses

A deliberate decision was made to use FFG analyses instead of IBI. IBI summarizes multiple physical and biological metrics to describe community structure, condition and level of degradedness as a single numerical ranking (Smogor and Angermeier, 2001). In contrast, the FFG analysis used in this study separated taxa richness, FFG richness and FFG diversity, allowing for examination of how individual parameters impacted these metrics independently and to show similarities and trends between certain parameters and biotic metrics. Overall, FFG analysis is more explicit and information rich than IBI. FFG analysis provides more information to highlight or track minor changes in physical, biotic or functional condition instead of requiring a significant enough change in physical or biotic metrics or a certain combination of effects to impact IBI rank.

Previous studies support the use of community functional ecology metrics in stream assessment. In macroinvertebrate stream models in Wisconsin, Weigel (2003) found that including feeding metrics in the model affected other metrics and in some cases, aided in the indirect explanation of variation. Because FFGs can be assigned at higher taxonomic levels and FFG analyses are appropriate for ecological studies of the functional structure of communities (Polatera, 2000), they reduce the amount of time and expertise required for identification. Finally, a comparison of the raw number of species in different communities does not provide enough information to draw conclusions about the vulnerability of community composition and structure. Some species with certain functional traits may have a greater impact on ecosystem processes than others and therefore their loss or addition to the community has a more significant overall impact (Tilman, 1997; Tilman 2006). For example, the absence of shredder species in upstream communities reduces the amount of leaf litter that is shredded to fine particulate organic matter (FPOM). This in turn reduces the amount of particles that microbes and fungi colonize to make this food resource more available and more nutritious to downstream gatherers and filterers. Thus shredder species play an indirect but critical, large-scale role in stream energy metabolism, beyond their immediate distribution.

Macroinvertebrate taxa richness and FFG richness and diversity

The most taxa and FFG rich and diverse communities occur in environments with disturbances of intermediate frequency and intensity (Connell, 1979; Townsend, 1997). In streams, disturbance often occurs as bed movements during periods of high discharge. Bed disturbance transports and redeposits substrate sediments. The proportion of the substratum comprised of small particles is related to taxa richness (Townsend, 1997).

Variation in substrates and flow regimes among streams of Cameron Run would cause disturbances of different extents and frequencies (Townsend, 1997). Unique geomorphic features of 2nd order Cameron Run streams may explain why macroinvertebrate taxa richness and functional feeding group richness did not differ from those of Quantico Creek. Physical parameters such as depth and flow along 2nd order Cameron Run reaches indicates pooling of water. Pooling allows detritus and suspended particles to slow and settle, providing resources to benthic consumers such as gathering-collectors. Slow flow or stagnant waters associated with pooling also allows for increased algae growth and reduced oxygen levels, providing suitable habitat for scrapers (Bacey, 2007). Because of the geomorphic and hydrological characteristics of 2nd order Cameron Run, it may be under a disturbance regime that maximizes taxa and FFG richness and diversity.

Low richness of sensitive or intolerant taxa (i.e. EPT) in Cameron Run may be attributed to environmental stress from a highly urbanized watershed. However, tolerant taxa (i.e. Oligochaeta, Chironomidae, Gastropoda) were overall evenly present across all stream orders in Quantico Creek and Cameron Run, indicating that these groups may be less affected by the level of stress. The results of this study agree with the findings of Feld (2007) where degradation caused a decrease in sensitive taxa, rather than a shift from community of sensitive to one of primarily tolerant organisms.

Functional composition of communities

Surprisingly, Quantico Creek and Cameron Run are not dominated by separate feeding strategies. The top three dominant functional feeding groups (predator, gathering collector and filtering collector), in both systems were similar to that of Bacey (2007). A functional composition of principally specialist feeding strategies suggests a long term condition of limited resource availability that created a highly competitive community and led to species development of evolutionary adaptations towards resource specialization. Lower percentages of taxa with generalist feeding strategies in both Quantico Creek and Cameron Run, which was expected to be dominant in Cameron Run due to a lack of consistency in available food resources due to degradation, suggests that only a few species have been successful at reducing the amount of interspecific resource competition to utilize multiple food resources (Mihuc, 1997).

Even though Quantico Creek and Cameron Run have the same FFG composition, lower taxa richness of each FFG in Cameron Run indicates that these communities are unstable and vulnerable to a loss of community diversity. When disturbances occur, functionally rich and diverse communities are less vulnerable to large changes in community structure and composition (Tilman, 1997; Tilman, 2006). Less functionally rich and diverse communities such as those in Cameron Run, which experience extreme natural perturbations, such as changes in precipitation, river discharge, temperature or larger climatic conditions may succumb to extreme conditions. Disturbances that are anthropogenic in nature (i.e., increases in populations, increases in amount of impervious surfaces, decreases in the number of forested hectares) also pose a great threat to less diverse communities.

A decrease in the number of forested (i.e., undeveloped land cover) hectares within a watershed reduces the amount of leaf litter that is delivered to receiving streams. This allochthonous leaf litter input is the main source of energy for lotic primary consumers. This imported material can either be broken down or transported downstream, becoming available to be metabolized by downstream communities and thus serves as the primary energy source of the entire benthic community (Minshall, 1967; Webster, 1999; Yee, 2006). Therefore, a reduction in forested hectares with increasing urbanization or a change in climate that reduces plant richness and diversity, particularly in small, wadeable streams such as those in this study, will negatively impact all downstream communities.

An increase in the amount of impervious surfaces (i.e. roads, rooftops, paved areas), especially in the riparian area adjacent to the stream, when coupled with the reduction in forested hectares, intensifies the negative impacts on stream energy budgets and macroinvertebrate communities (Lammert, 1999). During normal precipitation events, a high amount of impervious surfaces causes an increase the quantity of water delivered to receiving streams. The quality of this runoff water is reduced as it picks up sediments, nutrients and chemical and physical pollutants and transports it to the stream. Because macroinvertebrate leaf processing rate is dependent on water level and discharge, high discharge events that results from an increase the severity and frequency of floods will reduce the efficiency of benthic metabolism (Maridet, 1995) by removing individuals and flushing leaf litter resources downstream. The removal of food resources and reductions in taxa richness and functional diversity, due to anthropogenic disturbance, causes stress and limits the resources required for benthic recolonization (McCabe, 2000).

Effects of month and season

In forested systems like Quantico Creek, higher water flows in the spring time provide favorable hydrological conditions for macroinvertebrate growth and development (Bacey, 2007), resulting in richer and more diverse communities in late spring and early summer. However, the lack of pervious land or forested areas in urban centers results in too much water entering the receiving stream during these times, overwhelming and flushing macroinvertebrate populations downstream.

Current precipitation, river discharge, temperature and weather patterns in the highly urbanized Cameron Run watershed have limited taxa richness and FFG richness, compared to Quantico Creek. Urbanization has impacted the normally stable summer base flow condition, causing a reduction in biological richness and diversity as described by DeGasperi (2009). The loss of richness is higher in certain months (i.e. June and October) as the stream undergoes rapid changes in response to seasonal changes in the region. However, as climatic patterns change, with more frequent and severe floods and drought conditions and that impact the characteristics and duration of seasons, lotic benthic communities in watersheds dominated by urbanization will be more susceptible to the loss of taxa and functional diversity than primarily forested watersheds.

Relationship between parameters and biotic condition

Macroinvertebrate taxa richness, FFG richness and FFG diversity were related to more individual parameters in Cameron Run than in Quantico Creek, illustrating that it is difficult to separate the impact of physical, anthropogenic and watershed characteristics on biotic communities in urban areas. Physical parameters were more related to biological richness and diversity than watershed and anthropogenic parameters. In Cameron Run, richness and diversity increased with increases in some physical parameters (e.g. stream order, average current, water temperature) and decreased with increased elevation and gradient. Watershed and anthropogenic parameters had no effect on FFG richness in Cameron Run or Quantico Creek. Not surprisingly, a large amount of forested hectares has a positive effect on taxa richness and FFG diversity, because of the availability of leaf litter input to support multiple feeding modes.

Weigel (2003) found that local habitat and land cover do not properly predict all findings. We agree with Weigel (2003), particularly in that some of analysis outcomes in parameters that were not significantly related to biotic condition in this study is important for future studies as sample size in some seasons was limited. We recommend that a more robust sample size is needed for future models of comparative studies to be more reflective of the changes in parameters that effect macroinvertebrate taxa, and macroinvertebrate FFG richness and diversity.

Hydrologic Models

The Cameron Run and the Quantico Creek hydrologic models generally showed a good match between the modeled and the observed flows during their calibration and validation runs. However, the remaining differences can be attributed to the deficiency in representativeness and accuracy of precipitation data and the lack of information about actual discharge from lakes and reservoirs under low flow condition. Precipitation data used in the models were collected at point locations and assumed to be the same over the entire watersheds. This assumption may hold for a good number of storms, but not for all the storms. The Quantico Creek model validation run clearly shows that some storms recorded at the Quantico Marine Base station were not consistent with the flow pattern observed at the flow gage. Therefore, in absence of more rain gages or spatially varying precipitation data, the accuracy of the models cannot be improved only through the calibration exercise. Communications with the Lake Barcroft Watershed Improvement District and the Prince William Forest Park personnel confirmed that water is released from lakes and reservoirs under dry weather condition to maintain flow in the streams. However, the actual release is unknown and no specific rules are followed in setting the outflows at the dams. In order to improve the long-term simulation results it is essential that the models incorporate representative outflow patterns – either the actual outflow time-series or applicable discharge rules through rating curves. It is also important to note that the drainage area contributing to the South Fork Quantico Creek near Independent Hill, VA gage is 7.64 square miles. The rainfall-runoff relationship in a small watershed is very sensitive and a slight variation in input data or parameter values may cause significant differences between the modeled and the observed flows. Flow measurements further downstream will help better calibrate the model and improve model results.

Finally the models were used to compute long-term (October 1, 2007 through September 30, 2009) flows at all the water quality sampling stations except for EGM-VA-1010 in the Cameron Run watershed and EGM-VA-1021 in the Quantico Creek watershed. Long-term flows at these locations were estimated by multiplying the flows at the outlets with the ratio of local drainage areas to those at the outlets.

Hydrologic models provide the basis for estimating flows under varying meteorological conditions and landscape changes. Among the various hydrologic modeling options, continuous models that are calibrated and validated using historic data, such as the Cameron Run and the Quantico Creek watershed models, are more difficult to build, but they are also more reliable. These watershed models can be used by planners, government agencies and local watershed organizations to evaluate the impacts of land use changes that may ultimately affect flooding, erosion, water quality and ecology along stream corridors. These models may be used to study mitigation alternatives related to flows and develop watershed management plans. Effects of climate change on local hydrology can also be evaluated by providing various precipitation scenarios.

Outreach and Information Dissemination

One of the most important components of any scientific research program is to convey the results and significance of the research to the public. Conveying information to the public can be both effective and successful in reaching people from various backgrounds by using a variety of methods of conveyance (e.g. hands-on activities, interaction with docents, real artifacts, and various media such as visuals and interactive games). Conveyance increases awareness, promotes understanding of the need and application of scientific investigations, and stimulates thought and discussions among peoples. One of our primary goals was to use 21st Learning and Innovation Skills as a basis of conveying information to the public, from kindergarten aged students to retired persons. We used the Institute of Museums and Library Services' (IMLS, 2009) guide to 21st Learning and Innovation Skills (i.e., Critical Thinking and Problem Solving, Creativity and Innovation, Communication and Collaboration, Visual Literacy, Scientific and Numeracy Literacy, Cross-Disciplinary Thinking, and Basic Literacy) in EcoLab. In order to increase the general public's awareness, knowledge, and understanding of climate change and its potential impacts to watersheds in the mid-Atlantic region, the Science Museum of Virginia created a webpage, a hands-on interactive laboratory experience (EcoLab), created exhibits and graphics that were installed at three locations in Virginia, hosted a teacher professional development workshop, presented lectures to middle to high school students and the public; and to peers at scientific meetings; and provided internships to undergraduate and graduate students.

Following are brief descriptions of each of the outreach and educational components of our project.

1. **Webpage on Climate Change and Watersheds**: http://www.smv.org/climatechange/Introduction.html

Measuring the Impact

Freshwater ecosystems are home to many aquatic organisms. Submerged aquatic vegetation (SAV) including mosses and underwater grasses provide shelter and food for a variety of fish and insect larvae. Worms, insect larvae, crustaceans and other macroinvertebrates live in the stream bed. Frogs, turtles and salamanders live in freshwater streams during some part of their lives. Freshwater ecosystems provide a home for many fish and serve as a spawning ground for anadromous fish that normally live in salt water.

What impact will global climate change have on these unique ecosystems?

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2. **EcoLab activities** at **the Science Museum of Virginia**

EcoLab literally puts visitors in the shoes of scientists by providing an array of equipment and tasks that the scientists do when conducting the research in the field and laboratory. The goals for participants in the EcoLab experience are to put on boots, grab buckets, dipnets, D-nets, and binoculars for a photo-op in front of a wall mural of a stream while the docent gives a brief overview of their experience and tasks;

collect a sample bottle of macroinvertebrates at the Collecting Station; stop at the Magnify Station to see and learn different kinds of aquatic invertebrates projected on a large flatscreen monitor where as a docent makes a short presentation; then sort the macroinvertebrates from the river debris in sorting trays at the Sorting Station; and finally to the Identify Station where each visitor uses a dissecting microscope to identify the macroinvertebrates in their samples, and mark the different kinds on a data sheet. But the task is not over yet. Based on the kinds of macroinvertebrates a visitor finds in her sample, she then uses a reference sheet to determine if the samples came from a forested stream or an urban stream.

Giant wall mural of stream in EcoLab.

Magnify station in EcoLab.

Sorting Station in EcoLab.

Identify Station in EcoLab.

At least 3,000 visitors took advantage of the 15-25 minute EcoLab experience. This minimum number is based on the number of "Junior Ecologist" buttons (pictured  here) we handed to each participant after they completed the lab experience.

The biggest draws to the lab are the hands-on activities that emulate what real scientists do, and the docent interactions with visitors. Families took photographs in front of the stream mural. Some families photographed their kids moving through the whole exhibit and they were asked to submit their pictures to the museum via email or Facebook.

Every kid was excited to receive a "Junior Ecologist" button and a stream sampling kit, which included a brief instruction sheet, plastic forceps, hand magnifying lens, dipnet, and petri dish. Some parents and teachers knocked on the lab when the door was shut because they'd seen or heard about the exhibit and the kit and wanted to pick one up. Teachers (home school and public school) were given a write-up with the VA Science Standards and how to set-up the activity. Overall, every person that came through the EcoLab really enjoyed the hands-on, individually-led activities (Tables 41-43).

A survey of adults visiting EcoLab with children and teenagers was conducted from March-August, 2010. A total of 26 people responded using the survey instrument presented in Table 41. Four user groups were identified: individuals with a child or two; immediate family members with children; extended family members with children; and school and community groups with students (Table 42). About half (44 %) of the survey participants indicated they knew nothing about ecology and environmental science (Table 43). Each survey participant by category (i.e., individual, immediate family, extended family, and school/community group), however, consistently marked the quality of their experiences (i.e., EcoLab atmosphere, helpfulness of staff, Ecophoto experience, the sorting, identifying, magnifying and water quality wrap-up) as excellent (73-100%)(Table 41). A total of 100 % of individual participants wrote comments; 41.2 % of immediate family participants); 50 % of extended family participants; and 75 % of school/community group participants (Table 43). The following selected quotes represent the enthusiasm, excitement, and effectiveness of the EcoLab experience:

"Great interactive activity; Great for older kids; Volunteer was very helpful and informative"
"Awesome exhibit- staff worked so well with children on their level- great experience"
"This lab was wonderful and very educational. The staff person was so patient and informative"
"Great information and answered many questions. Very interactive!"
"We loved this! Info was short and appropriate, many questions- high interest. Thanks"

EcoLab Inspirational Stories

A mother with two daughters came into the lab. One girl appeared to be around 10-11, the other 2 years younger. After welcoming them to the lab and explaining the activity the mother cautioned me that her older daughter wasn't going to be "that into it" but the younger girl "loved playing with bugs and being outside and exploring." I led both girls through the demonstration and they sorted their samples and began the microscope identification together, having little trouble matching the insects they found in their sample with the picture keys provided.

The mother asked her older daughter how she liked identifying the insects. The girl replied, very cautiously, that she was having fun. The girl then turned to me and said, “My teacher told me that I’m just not good at science.” I gestured back to the microscope and told her that there are lots of different ways of learning and doing science and maybe a hands-on approach to ecology would be a science she would be good at.

Although this scenario never explicitly played out again, there were lots of children and teens that came into the lab who weren’t initially very excited for science or learning about streams. But the opportunity to work in a small, non-competitive group with a sample that they were responsible for, that was going to contribute to a larger community of data and information about streams, and that allowed for discovery and understanding from multiple perspectives, energized and inspired people. Rewarding and encouraging their excitement by providing a kit to sample at home really was the capstone of the Eco-Lab experience.

Experience with Groups

The Eco-Lab demonstration was designed to be a small (1-7 seats) activity. However, the Science Museum of Virginia frequently receives large tour and school groups. In order to accommodate the schedules of large groups, we developed an alternate activity.

A preserved insect specimen would be placed at the microscope that was connected to a wall-mounted flat panel TV screen. This allowed large groups to have the experience of viewing an insect through a microscope without having to cycle through individually. The group would then be handed flashcards featuring labeled pictures of benthic macroinvertebrates. The demonstration leader would then ask the person or people in the group to hold up flashcards of insects that matched the one on display. When possible, the demonstration leader would walk through the group with the insect in hand so visitors could see the actual size and sometimes touch the insects, especially the different types of caddisfly cases.

Exhibits on Climate Change and Watersheds: An interactive exhibit, *Come Play in the Water*, was created on watersheds and climate change.

“Come Play in the Water” Exhibit.

First screen of “Come Play in the Water” exhibit.

Here, a visitor interacts with a touchscreen monitor shown above to understand how watersheds relate to stream order (Size Up a Stream); identify the fishes that live in different parts of a stream (Go Fish!); determine water quality (Rate the Water) by the kinds of aquatic invertebrates found; explore climate change and its impacts on streams (Where's the water); and experience additional information on climate change (Peek Behind the Scenes).

Three of these interactive exhibits and five accompanying graphic panels were installed at each of the Science Museum of Virginia, the Visitor Center of Prince William Forest Park (US Department of the Interior: US National Park Service), and the Visitor Center of Lower Potomac Field Station (US Department of the Interior: US Bureau of Land Management). These three facilities have a combined annual attendance of approximately 1.25 million visitors.

Presentations at scientific meetings (Virginia Academy of Science Annual Meeting, May 27-29, 2009).

BASELINE FOR CLIMATE CHANGE: MODELING FISH SPECIES DIVERSITY IN WATERSHEDS. Eugene G. Maurakis[1,2,3], Summer Schultz[1], and David V. Grimes[1]. [1]Science Museum of Virginia, 2500 W. Broad St., Richmond, VA, 23220, [2]Biology Dept., University of Richmond, and [3]Dept. of Environmental Science and Policy, George Mason University. Objectives are to model fish species richness, diversity and evenness in watersheds of Quantico Creek (a pristine undisturbed drainage) and Cameron Run (a highly developed urban drainage) using biological (e.g. macroinvertebrate richness and abundance, allochthonous detritus concentration), and physio-chemical factors (e.g. pH, temperature, stream order, width, depth, current, flow, elevation, gradient, river km, substrate composition, land use, and human population per intra-drainage stream order area. To date, 30 species of fishes representing 10 families, including *Channa argus*, the snakehead fish, have been collected from 23 sampling sites over a 6-month period of the two-year study. Funded by U.S. Department of Energy grant DE-FG02-08ER64625.

May 19-21, 2010 - Virginia Academy of Science Annual Meeting, May 19-21, 2010.

MODELING MACROINVERTEBRATE FUNCTIONAL FEEDING ASSEMBLAGES IN FORESTED AND URBAN STREAMS. Amanda E. Schutt[4,1], Eugene G. Maurakis[1,2], David V. Grimes[3,1], & Suzy Short[1], [1]Science Museum of Virginia, 2500 W. Broad St., Richmond, VA 24642, [2]Biology Dept., University of Richmond, VA 23173, [3]VA Dept. of Environmental Quality, Richmond, VA 23060 and [4]Center for Environmental Studies, Virginia Commonwealth University, Richmond, VA 23284. Macroinvertebrate functional feeding group richness was compared in first through fourth order forested and urban streams to gain a better understanding of trophic structure, resource availability and acquisition. Sampling took place over six collections from April to October in the Quantico Creek watershed in Prince William Forest Park and the Marine Corps Base Quantico and Cameron Run in Alexandria, Virginia. Data analysis indicates significant differences in functional feeding group richness between first, third and fourth order forested and urban streams. Urban streams had lower functional feeding group richness and resource stability and therefore populations in these streams may be more at risk than those in forested streams. Funded by the U.S. Dept. of Energy.

MODELING FISH SPECIES DIVERSITY IN FORESTED AND URBAN STREAMS: A BASELINE FOR CLIMATE CHANGE. Eugene G. Maurakis (1,2), David V. Grimes (3,1) Suzy Short (1), and Amanda Schutt (4,1). (1) Science Museum of Virginia, 2500 W. Broad St., Richmond, VA 23220 (2) University of Richmond, VA 23173, (3) VA Dept. Environmental Quality, Richmond, VA 23060, (4) Center for Environmental Studies, Virginia Commonwealth University, Richmond, VA 23284. Objectives are to model fish species richness, diversity and evenness in watersheds of Quantico Creek (forested watershed) and Cameron Run (urban watershed) using biological, physio-chemical factors, and land use and human population data per intra-drainage stream order area. To date, 32 species of fishes (11 families) have been collected in 272 collections made from Nov. 2008-May, 2010. Overall, species richness, diversity, and evenness in forested areas are significantly higher than those in urban streams. Stream order, water depth, and month account for the variation in species richness in the forested watershed. In contrast, elevation and stream flow account for the variation in species richness in the highly modified stream beds of the urban watershed. Funded by the U.S. Department of Energy grant DE-FG02-08ER64625.

Four manuscripts, based on the results of studies in this research, are in preparation for submittal to journals for publication.

Climate change lectures:

1. A one-hour presentation at Lunch Break Science Lecture Series at the Science Museum of Virginia, May 2010. Attendance = 43.
2. A one-hour hands-on lecture to 118 Richmond middle and high school students, July 2009;
3. A 45-minute hands-on activity and lecture to 68 Prince William Co. High School students, March, 2009;
4. A 5-hour field experience and a 2-hour lecture session to 16 international students in University of Richmond-Athens Summer Leadership Institute, July 2009.

Teacher Professional Development:

A week-long (August 10-14, 2009) teacher professional development workshop in northern Virginia was attended by 10 teachers (400 contact hours) from elementary, middle and high schools from five counties in Virginia.

Name	School	Subject/grades

Andersen, D.	Collegiate	6-8 grades English/Reading/Advisor Earth N Mind Club Sponsor
Bedell, A.	Mt Vernon HS	9-12 Bio
Conrad, B.	Freedom HS	9-12 (mostly 10) Team Taught Biology, Regular Biology, PreAP Biology
D'Agostina, D.	Atlee High School	APES/Ecology Teacher
Farouq, F.	lake Braddock Secondary School	9th bio, AP bio
Fenchel, Steve	Annandale HS	9-12 Bio and sciences
Milton, T.	city of Leesburg	Young Adults Project: LCPS and dept family services
Misencik, E.	Robinson Secondary School, Fairfax Co	HS bio
Musgrove, J.	Oakton HS	Biology 9th graders, AP Environmental 11th & 12th graders
Zulauf, N.	Southerland ES Dinwidee	3rd grade

Agenda of teacher professional development workshop.

The Science Museum of Virginia's Field Study for Educators: August 10-14, 2009

Agenda

Day 1: Designing a study

10:00 AM: meet at Holiday Inn Express, 14030 Telegraph Road, Woodbridge, VA; check in

Travel to Freedom High School, 15201 Neabsco Mills Road, Woodbridge, VA

Enviro Icebreaker (activity)

The Nature of Science / The Scientific Method (lecture and discussion)

Race to Publish (class activity)

Intro to "A baseline for Climate Change" (discussion)

Lunch break

Mapping and GPS (activities)

    Stream order, depth/width, elevation, river mile

Mark and Recapture (activity)

Fish Behavior (videos and discussion)

Mattaponi River Reservoir: a study in ethics (lecture, activity, discussion)

Local issues (discussion)

Resources, Student Science projects, intro to VEE minigrants and VJAS (discussion / brainstorming)

Return to hotel, check in

Dinner out

Day 2: Intro to Equipment and Techniques; Thinking About Climate Change

7:30 AM: meet for breakfast in hotel

Intro to data sheets and field studies (discussion)

8:30 AM: Travel to Prince William Forest Park

Field work:

- Electrofishing
- Macroinvertebrates
- stream characteristics

Lunch break in the field

Return to hotel/ cleanup

Lost Crab, Lost Culture (film and discussion)

Dinner out

Speaker: Laura Grape, Senior Environmental Planner, Northern Virginia Regional Commission: "Adapting to Climate Change in Northern Virginia"

Day 3: Application of Techniques

7:30 - AM: breakfast in hotel

8:30 AM: Travel to Alexandria

Field work: impacted environment

Lunch break in the field

Return to hotel

Lab work: macroinvertebrate ID
  Data compilation

Dinner out

Planning for projects

Day 4: Application of Techniques

7:30 - AM: breakfast in hotel

8:30 AM: Travel to Prince William Forest Park

Field work: pristine environment

Lunch break in the field

Lab work:

- macroinvertebrate ID
- Data compilation

Dinner out

Planning for projects

Day 5: Data analysis and wrap-up; planning for the future

7:00 – 8:30 AM: checkout, breakfast

8:30 AM: travel to Freedom High School (all drive personal vehicles)

Site comparisons:

- Jaccard coefficient of similarity
- Species richness
- Species evenness

Project proposals: rough drafts for mini-grants

Resources from SMV: "shopping lists" for research supplies

Evaluations

Noon: drive home

Volunteer Internships: A total of 15 undergraduate and graduate students worked in the field, laboratory, and/or worked as docents in EcoLab.

1. A. Schutt, Virginia Commonwealth University, December, 2008-July, 2010, 50 hrs as volunteer, then hired as contractor to collect samples, identify macroinvertebrates, and assist with report preparation.
2. Four (4) National Park interns stationed at Prince William Forest Park, VA were trained in sampling and collecting protocols
3. Eleven (11) volunteer interns (see table below) from Virginia Commonwealth University, College of William and Mary, and Oregon State University sorted marcoinvertebrates from debris in samples from December, 2008-December, 2009; and were docents in the EcoLab from March-August, 2010.

First	Last	Semester	Hours
R.	Brown	F 2009	20
K.	Davenport	F 2009	20
M.	Hicks	F 2009	5
R.	Remennikova	S 2010	20
L.	Thomas	F 2009	20
K.	Turner	F 2009	5
T.	Younger	F 2009	10
T.	Rogers	S 2010	-
M.	Fisher	Summer	320
L.	Whitworth	Summer	240
D.	Rainney	Summer	75
TOTAL			**735**

Summary

17. Objectives of the technical research study were twofold: (1) Measure and record fish and macroinvertebrate species richness and diversity; macroinvertebrate functional feeding group (GGF) richness and diversity; physical characteristics (i.e., stream order, elevation, stream width, stream depth, stream current, stream flow, stream gradient, pH, water temperature, and river kilometer); and anthropogenic and watershed factors (i.e., human population, impervious cover, undeveloped land cover) in a forested watershed (Quantico Creek) and in an urban watershed (Cameron Run) in northern Virginia; and (2) create mathematical expressions to model species richness and diversity relative to physical characteristics, anthropogenic, and watershed characteristics in streams of two, lower Piedmont-Fall Line watersheds of the Potomac River drainage, Virginia.
18. Objectives of the outreach portion of this project were to: (1) create a laboratory experience in the Science Museum of Virginia to heighten visitor's awareness and knowledge of climate change and potential impacts on watersheds; (2) create an interactive exhibit on watersheds and climate change; (3) provide internship opportunities for undergraduate and graduate students; (4) host a week-long teacher workshop on watershed and climate change; (5) post a website about climate change and watersheds; and, (6) present findings of the technical research project.
19. The present investigation resulted in establishing baseline data for fish communities and mathematical equations to model for fish species richness and diversity in each of two mid-Atlantic region, lower Piedmont forest (Quantico Creek) and urban (Cameron Run) watersheds that can be used to compare changes in fish communities relative to climatic and urban development changes in the future. This is the first systematic, comprehensive long-term watershed-wide research of fish communities in Quantico Creek and Cameron Run.
20. There is a direct correlation between increases in human population and increased impervious cover in the Cameron Run watershed. The difference in impervious cover was one of the significant factors in accounting for reduced species richness in Cameron Run watershed compared to that of Quantico Creek.
21. Of particular note is the trenchant difference between the parameters that comprise the mathematical models for Quantico Creek (a forested watershed) and for Cameron Run (an urban watershed). Fish species richness in Quantico Creek watershed currently is a function of season, stream order, elevation, river km, stream width and depth, watershed size and percent of undeveloped land cover. In contrast, fish species richness in Cameron Run cannot be modeled using any of these parameters from the Quantico Creek model. Factors that reflect the current fish species diversity in Cameron Run are stream gradient, stream flow, and water temperature, and percent undeveloped land cover. Likewise, only two factors

(season and % undeveloped land cover) were common to the fish species diversity models of Quantico Creek and Cameron Run.

22. Species diversity in Cameron Run was a function of five factors (i.e., season, elevation, water temperature, undeveloped land cover, and % undeveloped land cover) rather than seven factors in the species diversity model in Quantico Creek. Two factors (season and % undeveloped land cover) were common to species diversity models both watersheds.
23. Based on the differences in species richness and species diversity models between Quantico Creek and Cameron Run watersheds, we purport that stream order and its other correlated factors used to model species richness in forested watersheds where human disturbance is minimal, are not appropriate for streams in highly modified urban environments.
24. Warren Buffett once commented "Beware of geeks bearing formulas." It should be noted that mathematical models are not absolutes. Our models, based on a host of various types of parameters collected over almost a two year period, present a picture of the relationships among these parameters and fish communities. We suggest that our models can be used as indicators of general trends and changes in communities and how the communities function, and can change relative to changes in environmental conditions.
25. We propose that stream order emulates an ecological unit, and can be used to account for variation in species diversity along a river continuum.
26. Macroinvertebrate taxa richness (range = 79-92) in all stream orders of Quantico Creek were higher than those (range = 19-39) in Cameron Run. All stream orders of Cameron Run had low EPT (i.e., Ephemeroptera, Plecoptera, Trichoptera) taxa richness and a complete absence of Plecoptera.
27. Percentages of functional feeding groups represented in Quantico Creek were similar to those in Cameron Run. However, taxa richness of each functional feeding group in Quantico Creek was significantly higher than those in each functional feeding group of Cameron Run.
28. The results of this study agree with the findings of Feld (2007) where degradation caused a decrease in sensitive taxa, rather than a shift from community of sensitive to one of primarily tolerant organisms. Even though Quantico Creek and Cameron Run have the same FFG composition, lower taxa richness of each FFG in Cameron Run indicates that these communities are unstable and vulnerable to a loss of community diversity. Disturbances that are anthropogenic in nature (i.e., increases in populations, increases in amount of impervious surfaces, decreases in the number of forested hectares) also pose a great threat to less diverse communities.

29. Macroinvertebrate taxa richness, FFG richness and FFG diversity were related to more individual parameters in Cameron Run than in Quantico Creek, illustrating that it is difficult to separate the impact of physical, anthropogenic and watershed characteristics on biotic communities in urban areas.
30. Hydrologic models provide the basis for estimating flows under varying meteorological conditions and landscape changes. Among the various hydrologic modeling options, continuous models that are calibrated and validated using historic data, such as the Cameron Run and the Quantico Creek watershed models, are more difficult to build, but they are also more reliable. These watershed models can be used by planners, government agencies and local watershed organizations to evaluate the impacts of land use changes that may ultimately affect flooding, erosion, water quality and ecology along stream corridors. These models may be used to study mitigation alternatives related to flows and develop watershed management plans. Effects of climate change on local hydrology can also be evaluated by providing various precipitation scenarios.
31. As climatic patterns change with more frequent and severe floods and drought conditions, lotic benthic communities in watersheds dominated by urbanization will be more susceptible to the loss of taxa and functional diversity than primarily forested watersheds.
32. In order to increase the general public's awareness, knowledge, and understanding of climate change and its potential impacts to watersheds in the mid-Atlantic region, the Science Museum of Virginia created a webpage, a hands-on interactive laboratory experience (EcoLab), created interactive exhibits and graphics that were installed at three locations in Virginia, hosted a teacher professional development workshop, presented lectures to middle to high school students and the public, and to peers at scientific meetings; and provided internships to undergraduate and graduate students.

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Tables

Table 1. Sub-watershed size (ha), collecting station, stream order, human population, % impervious land cover, impervious land cover hectares, % undeveloped land cover, and undeveloped land cover (ha) for each of Quantico Creek and Cameron Run watersheds, VA.

Watershed	Station	Stream Order	Watershed Size (ha)	Population	% Impervious Cover	Impervious hectares	% Undeveloped Land Cover	Undeveloped Land Cover (ha)
Quantico Creek							(0.6 Residential factor)	
	1	2	1787.50	0.00	0.60	10.73	97.74	1747.04
	2	3	4137.30	700.00	0.80	33.10	97.48	4032.93
	3	2	17.40	700.00	36.40	6.33	47.49	8.26
	4	1	43.60	0.00	3.10	1.35	89.40	38.98
	5	1	21.20	0.00	50.10	10.62	93.29	19.78
	6	2	172.60	0.00	0.00	0.00	95.85	165.43
	7	3	3811.70	700.00	0.30	11.44	96.59	3681.57
	8	3	4614.40	1400.00	10.20	470.67	86.33	3983.40
	16	1	163.60	0.00	0.70	1.15	97.40	159.35
	17	2	364.70	500.00	51.00	186.00	79.38	289.50
	18	2	561.70	0.00	0.30	1.69	96.35	541.19
	19	3	938.50	500.00	0.00	0.00	100.00	938.50
	20	3	1946.00	700.00	0.30	5.84	97.71	1901.50
	21	1	54.30	0.00	67.40	36.60	97.53	52.96
	23	3	4777.80	3500.00	12.80	611.56	79.93	3818.99
Cameron Run								
	9	1	33.10	374.00	85.40	28.27	11.32	3.75
	10	1	271.80	4309.00	56.80	154.38	42.02	114.21
	11	2	550.70	7130.00	44.60	245.61	49.33	271.66
	12	2	659.80	14784.00	50.00	329.90	47.11	310.81
	13	3	3272.00	59195.00	70.30	2300.22	39.44	1290.52
	14	4	4808.40	103728.00	71.30	3428.39	33.27	1599.54
	15	3	750.90	30426.00	69.80	524.13	43.76	328.56

Table 2. Locality descriptions, latitude, longitude, and stream order assignment for sampling stations in Quantico Creek and Camaeron Run watersheds in Virginia from November, 2008 - July, 2010.

Quantico Watershed

Station Number	Latitude	Longitude	Stream Order	Locality
1	38.57344	-77.34718	2	Quantico Creek drainage: unnamed 2nd order tributary of N. Fork of Quantico Creek on Pyrite Mine Trail in Prince William Forest Park, about 1 km NW of I-95, Prince William Co., VA
2	38.57193	-77.34712	3	Quantico Creek drainage: N. Fork Quantico Creek (3rd order) on Pyrite Mine Trail in Prince William Forest Park, about 0.9 km NW of I-95 at Triangle, Prince William Co., VA
3	38.60267	-77.34714	2	Quantico drainage: unnamed 2nd order tributary of Quantico Creek on Burma Rd in Prince William Park, about 4.5 km NW of I-95, Prince William Co, VA
4	38.60358	-77.36829	1	Quantico drainage: unnamed 1st order tributary of Quantico Creek on Burma Rd in Prince William Park, about 4.6 km NW of I-95, Prince William Co, VA
5	38.60175	-77.35795	1	Quantico drainage: unnamed 1st order tributary of Quantico Creek on Burma Rd in Prince William Park, about 4 km NW of I-95, Prince William Co, VA
6	38.5762	-77.36661	2	Quantico Creek drainage: Mary Bird Branch (2nd order) of S. Fork Quantico Creek in Prince William Forest Park, about 3.5 km NW of I-95 at Triangle, Prince William Co., VA
7	38.56736	-77.36453	3	Quantico Creek drainage: S. Fork Quantico Cr. (3rd order) on S. Valley trail in Prince William Forest Park, about 2.5 km NW of I-95 at Triangle, Prince William Co., VA
8	38.57014	-77.34289	3	Quantico drainage: Quantico Creek, 3rd order at Boundary of PW Forest Park, 0.5 km WNW of I-95 at Dumfries, Prince William CO., VA
16	38.59599	-77.44651	1	Quantico Creek drainage: unnamed 1st order tributary of S. Fork of Quantico Creek, 0.5 km N of Kopp (Rt. 618) on US Marine Corp Base, about 2.3 km NW of Belfair Crossroads, Prince William Co, VA
17	38.61356	-77.44759	2	Quantico drainage: N. Branch (2nd order) of S. Fork Quantico Cr. On US Marine Corp Base, about 4 km NNW of Belfair Crossroads, Prince William Co., VA
18	38.6132	-77.44823	2	Quantico drainage: S. Branch (2nd order) of S. Fork Quantico Cr., 2.4 km N of Kopp on US Marine Corp Base, about 4.1 km NW of Belfair Crossroads, Prince William Co., VA
19	38.61225	-77.44751	3	Quantico drainage: S.Fork Quantico Cr. (3rd order), about 2.1 km N of Kopp on US Marine Corp Base, about 3.9 km NW of Belfair Crossroads, Prince William Co., VA
20	38.58737	-77.4289	3	Quantico drainage: S. Fork Quantico Cr. (3rd order) on Co. Rt. 619, about 0.9 km N of Belfair Crossroads, Prince William Co., VA
21	38.61254	-77.43009	1	Quantico drainage: unnamed 1st order creek of S. Fork Quantico Creek on Co. Rt. 619, about 3.5 km N of Belfair Crossroads, Prince William Co., VA
23	38.56846	-77.33587	3	Quantico Creek drainage: Quantico Creek (3rd order) under I-95 bridge, Prince William Co., VA

Table 2. (continued)

Cameron Run Watershed

Station Number	Latitude	Longitude	Stream Order	Locality
9	38.79922	-77.16609	1	Cameron Run drainage: Backlick Run (1st order) at Indusrial and Backlick Roads at Professional Apartments, Alexandria, VA
10	38.8169	-77.17208	1	Cameron Run drainage: Indian Run (1st order) at Wenruth Ct off of Randolph St., Alexandria, VA
11	38.80628	-77.1595	2	Cameron Run drainage: Indian Run (2nd order) on Cherokee Rd., Alexandria, VA
12	38.80416	-77.14523	2	Cameron Run drainage: Turkeycock Creek (2nd order) above bridge on Edsal Rd., about 1.5 km E of I-395, Alexandria, VA
13	38.80338	-77.1328	3	Cameron Run drainage: Backlick Run (3rd order) at Pickett Plaza, cornern of VanDorn and Pickett St., Alexandria, VA
14	38.80575	-77.10817	4	Cameron Run drainage: Cameron Run (4th order) at Cameron Run Regional Park on Eisenhower Rd., Alexandria, VA
15	38.81756	-77.1247	3	Cameron Run drainage: Holmes Run (3rd order) adjacent to Holmes Run Parkway about 200 m from intersection of Van Dorn St & Holmes Run Parkway, Alexandria, VA

Table 3. Results of Duncan's Multiple Range Test for physical parameters and fish abundances by stream order for Quantico Creek watershed sampled from November, 2008 – June, 2010.

Variable = ELEV

```
Stream Order              3             2             1
Mean                   31.780        37.104        74.158
                      --------      --------      --------
F = 249.28
p>F = <.0001, df = 2
```

Variable = RIVERKM

```
Stream Order              3             1             2
Mean                   13.2694       15.0074       17.5112
                      ---------     ---------     ---------
F = 67.70
p>F = <.0001, df = 2
```

Variable = GRADIENT

```
Stream Order              3             1             2
Mean                   10.5565       15.0731       15.4479
                      ---------     -----------------------
F = 69.62
p>F = <.0001, df = 2
```

Variable = WIDTHAVG

```
Stream Order              1             2             3
Mean                   1.8482        3.5004        7.9721
                      --------      --------      --------
F = 588.77
p>F = <.0001, df = 2
```

Variable = DEPTHAVG

```
Stream Order              2             1             3
Mean                   0.24728       0.26822       0.30323
F = 17.60             -----------------------     ---------
p>F = <.0001, df = 2
```

Variable = CURAVG

```
Stream Order              1             2             3
Mean                   0.25948       0.43160       0.51123
                      ---------     -----------------------
F = 14.54
p>F = <.0001, df = 2
```

Variable = FLOW

```
Stream Order              1             2             3
Mean                   0.1673        0.4881        1.6522
                      ----------------------      --------
F = 57.30
p>F = <.0001, df = 2
```

Variable = TEMP

```
Stream Order              1             2             3
Mean                   11.5619       12.8298       13.4176
F = 4.83              ---------     -----------------------
p>F = 0.0081, df = 2
```

Table 3 (cont'd)

Variable = pH

Stream Order	2	3	1
Mean	6.62846	6.67070	6.69703

F = 1.79
p>F = 0.1679
df = 2

Variable = ABUND

Stream Order	2	3	1
Mean	4.4604	5.4024	7.4000

F = 8.66
p>F = 0.0002
df = 2

Table 4. Results of Duncan’s Multiple Range test (SAS, 2009) of sampling location average stream width (m), stream depth (m), water current velocity (m/sec), discharge flow (m^3/sec), water temperature (C), pH, and total average abundance of fishes per stream order and month measured in Quantico Creek watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p = 0.05.

FIRST ORDER STREAMS

Variable = WIDTHAVG

Month	**Aug.**	**Sept.**	**July**	**Nov.**	**May**	**March**	**Jan.**	**Oct.**	**April**	**June**	**Dec.**
Mean	1.3900	1.3980	1.5985	1.6222	1.7246	1.8483	1.8624	1.8769	1.9272	2.0341	2.3171

F = 2.03
p>F = 0.0374
df = 10

Variable = DEPTHAVG

Month	**Aug.**	**Sept.**	**Dec.**	**June**	**July**	**Nov.**	**Oct.**	**May**	**Jan.**	**April**	**March**
Mean	0.1070	0.1080	0.1289	0.1384	0.1410	0.1592	0.1600	0.1646	0.1713	0.2202	0.7617

F = 7.52
p>F = <.0001
df = 10

Variable = CURAVG

Month	**Sept.**	**Aug.**	**July**	**Oct.**	**May**	**Dec.**	**June**	**March**	**April**	**Nov.**	**Jan.**
Mean	0.0010	0.0010	0.0010	0.0010	0.0209	0.1114	0.1785	0.3043	0.3472	0.4219	0.8240

F = 12.54
p>F = <.0001
df = 10

Variable = FLOW

Month	**Aug.**	**Sept.**	**July**	**Oct.**	**May**	**Dec.**	**June**	**April**	**Nov.**	**Jan.**	**March**
Mean	0.0001	0.0002	0.0002	0.0003	0.0028	0.0355	0.0594	0.1575	0.1895	0.2943	0.4799

F = 7.24
p>F = <.0001
df = 10

Table 4. (continued)

Variable = TEMP

Month	**Jan.**	**March**	**Dec.**	**May**	**Nov.**	**April**	**Oct.**	**June**	**Sept.**	**July**	**Aug.**
Mean	1.2222	6.1250	7.7500	10.8571	12.6923	12.8421	14.6000	16.6667	18.0000	18.5000	20.0000

F = 145.78
p>F = <.0001
df = 10

Variable = ABUND

Month	**Aug.**	**Jan.**	**June**	**Dec.**	**April**	**Sept.**	**Oct.**	**March**	**Nov.**	**May**	**July**
Mean	3.167	5.125	6.533	6.750	7.000	7.000	7.400	7.421	9.154	9.714	15.000

F = 0.93
p>F = 0.5056
df = 10

Variable = pH

Month	**Dec.**	**April**	**March**	**July**	**Nov.**	**Jan.**	**May**	**June**	**Aug.**
Mean	6.30000	6.34211	6.50500	6.60000	6.67692	6.86667	7.00000	7.05333	7.60000

F = 64.71
p>F = <.0001
df = 8

Table 4. (continued)

SECOND ORDER STREAMS

Variable = WIDTHAVG

Month	**Aug.**	**Oct.**	**Dec.**	**July**	**June**	**Jan.**	**Nov.**	**May**	**Sept.**	**April**	**March**
Mean	1.9633	2.8148	3.0251	3.1381	3.3557	3.4763	3.5383	3.6071	3.9132	4.0589	4.1513

F = 4.57
p>F = <.0001
df = 10

Variable = DEPTHAVG

Month	**May**	**Jan.**	**Oct.**	**Aug.**	**Nov.**	**Sept.**	**Dec.**	**July**	**June**	**April**	**March**
Mean	0.17603	0.18308	0.18461	0.20429	0.20651	0.21167	0.22100	0.22923	0.24248	0.30668	0.36842

F = 10.43
p>F = <.0001
df = 10

Variable = CURAVG

Month	**Aug.**	**Oct.**	**Sept.**	**July**	**May**	**Dec.**	**March**	**Nov.**	**June**	**Jan.**	**April**
Mean	0.0038	0.0166	0.0287	0.1263	0.1741	0.2183	0.4729	0.5670	0.6287	0.7478	0.8918

F = 22.28
p>F = <.0001
df = 10

Variable = FLOW

Month	**Aug.**	**Sept.**	**Oct.**	**Dec.**	**July**	**May**	**Jan.**	**June**	**Nov.**	**March**	**April**
Mean	0.0014	0.0121	0.0133	0.1382	0.1405	0.1523	0.4309	0.5053	0.5349	0.7328	1.3284

F = 14.91
p>F = <.0001
df = 10

Table 4. (continued)

Variable = TEMP

Month	**Jan.**	**March**	**Dec.**	**May**	**Nov.**	**April**	**Oct.**	**June**	**Sept.**	**Aug.**	**July**
Mean	0.0000	5.4750	7.1724	12.4118	12.4878	14.2698	15.2424	17.1429	18.6667	20.0000	20.4651

F = 377.69
p>F = <.0001
df = 10

Variable = ABUND

Month	**Jan.**	**April**	**Dec.**	**June**	**May**	**Aug.**	**March**	**July**	**Nov.**	**Sept.**	**Oct.**
Mean	2.391	3.159	3.690	3.893	4.000	4.706	4.833	5.047	5.195	6.722	6.788

F = 2.78
p>F = 0.0025
df = 10

Variable = pH

Month	**Dec.**	**April**	**July**	**March**	**Nov.**	**Jan.**	**June**	**May**	**Aug.**
Mean	6.30000	6.38571	6.40233	6.54667	6.63902	6.80000	6.93750	6.95588	6.98824

F = 41.43
p>F = <.0001
df = 8

Table 4. (continued)

THIRD ORDER STREAMS

Variable = WIDTHAVG

Month	**Dec.**	**Aug.**	**Oct.**	**Nov.**	**Sept.**	**June**	**Jan.**	**May**	**July**	**March**	**April**
Mean	4.2970	5.7354	6.2086	7.3725	7.5000	7.8212	7.9047	7.9448	8.3733	9.1731	9.2168

F = 11.71
p>F = <.0001
df = 10

Variable = DEPTHAVG

Month	**Dec.**	**Oct.**	**Nov.**	**Aug.**	**Sept.**	**Jan.**	**May**	**July**	**June**	**March**	**April**
Mean	0.17300	0.22592	0.24734	0.26764	0.27000	0.27088	0.28081	0.30126	0.32253	0.33082	0.40572

F = 25.95
p>F = <.0001
df = 10

Variable = CURAVG

Month	**Oct.**	**Sept.**	**Aug.**	**Dec.**	**July**	**May**	**June**	**March**	**Nov.**	**Jan.**	**April**
Mean	0.05786	0.06200	0.08973	0.19700	0.26486	0.27700	0.43761	0.50717	0.61112	0.93763	1.15684

F = 82.56
p>F = <.0001
df = 10

Variable = FLOW

Month	**Oct.**	**Sept.**	**Dec.**	**Aug.**	**May**	**July**	**June**	**Nov.**	**March**	**Jan.**	**April**
Mean	0.0911	0.1191	0.1464	0.1891	0.6983	0.8599	1.1204	1.1244	1.8118	2.1241	4.9534

F = 39.59
p>F = <.0001
df = 10

Table 4. (continued)

Variable = TEMP

Month	Jan.	March	Dec.	Nov.	May	April	Oct.	Sept.	June	July	Aug.
Mean	0.2041	6.1708	8.0000	11.2234	12.9615	13.9224	15.3333	18.5000	18.8421	20.8969	21.2955

F = 532.70
p>F = <.0001
df = 10

Variable = ABUND

Month	June	Jan.	Dec.	April	Sept.	May	Mach	July	Aug.	Oct.	Nov.
Mean	4.276	4.277	4.333	4.687	4.885	5.135	5.258	5.371	5.500	6.619	7.500

F = 1.29
p>F = 0.2333
df = 10

Variable = pH

Month	Dec.	April	Nov.	March	Jan.	July	June	May	Aug.
Mean	6.30000	6.41983	6.53191	6.54333	6.75918	6.77320	6.85263	6.90385	7.31250

F = 28.84
p>F = <.0001
df = 8

Table 6. Results of Duncan's Multiple Range test (SAS, 2009) of sampling location elevation (m), river kilometer (km), gradient (m/km), average stream width (m), stream depth (m), water current velocity (m/sec), discharge flow (m^3/sec), water temperature (C), pH, and total average abundance of fishes per stream order measured in Cameron Run watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p = 0.05.

Variable = ELEVATION

<table>
<tr><td>Stream Order</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Mean</td><td>29.6602</td><td>37.0000</td><td>46.6733</td><td>75.4231</td></tr>
<tr><td></td><td>―――</td><td>―――</td><td>―――</td><td>―――</td></tr>
</table>

F = 2196.96
p>F = <.0001, df = 3

Variable = RIVERKM

<table>
<tr><td>Stream Order</td><td>3</td><td>4</td><td>2</td><td>1</td></tr>
<tr><td>Mean</td><td>6.0287</td><td>6.0659</td><td>9.0383</td><td>17.9151</td></tr>
<tr><td></td><td colspan="2">――――――</td><td>―――</td><td>―――</td></tr>
</table>

F = 467.92
p>F = <.0001, df = 3

Variable = GRADIENT

<table>
<tr><td>Stream Order</td><td>3</td><td>4</td><td>2</td><td>1</td></tr>
<tr><td>Mean</td><td>3.13886</td><td>5.0347</td><td>6.5653</td><td>12.8353</td></tr>
<tr><td></td><td>―――</td><td>―――</td><td>―――</td><td>―――</td></tr>
</table>

F = 2018.32
p>F = <.0001, df = 3

Variable = WIDTHAVG

<table>
<tr><td>Stream Order</td><td>1</td><td>2</td><td>4</td><td>3</td></tr>
<tr><td>Mean</td><td>4.1501</td><td>5.0248</td><td>9.6689</td><td>13.0223</td></tr>
<tr><td></td><td>―――</td><td>―――</td><td>―――</td><td>―――</td></tr>
</table>

F = 347.34
p>F = <.0001, df = 3

Variable = DEPTHAVG

<table>
<tr><td>Stream Order</td><td>3</td><td>2</td><td>1</td><td>4</td></tr>
<tr><td>Mean</td><td>0.18851</td><td>0.20750</td><td>0.24295</td><td>0.24435</td></tr>
<tr><td></td><td colspan="2">――――――</td><td colspan="2">――――――</td></tr>
</table>

F = 12.34
p>F = <.0001, df = 3

Variable = CURAVG

<table>
<tr><td>Stream Order</td><td>1</td><td>2</td><td>4</td><td>3</td></tr>
<tr><td>Mean</td><td>0.2681</td><td>0.2785</td><td>0.7120</td><td>0.9656</td></tr>
<tr><td></td><td colspan="2">――――――</td><td>―――</td><td>―――</td></tr>
</table>

F = 20.39
p>F = <.0001, df = 3

Variable = FLOW

<table>
<tr><td>Stream Order</td><td>1</td><td>2</td><td>4</td><td>3</td></tr>
<tr><td>Mean</td><td>0.2386</td><td>0.2818</td><td>1.9684</td><td>2.3976</td></tr>
<tr><td></td><td colspan="2">――――――</td><td colspan="2">――――――</td></tr>
</table>

F = 26.21
p>F = <.0001, df = 3

Table 6 (continued).

Variable = TEMP

Stream Order	2	1	4	3
Mean	11.7376	12.0000	15.8617	16.3505

F = 12.67
p>F = <.0001, df = 3

Variable = pH

Stream Order	2	1	4	3
Mean	6.5747	6.6000	6.7329	7.1873

F = 11.93
p>F = <.0001, df = 3

Variable = ABUND

Stream Order	2	4	3	1
Mean	9.119	9.166	11.105	11.551

F = 0.93
p>F = 0.4276, df = 3

Table 7. Results of Duncan's Multiple Range test (SAS, 2009) of sampling location average stream width (m), stream depth (m), water current velocity (m/sec), discharge flow (m^3/sec), water temperature (C), pH, and total average abundance of fishes per stream order and month measured in Cameron Run watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p = 0.05.

FIRST ORDER STREAMS

Variable = WIDTHAVG

Month	**Jan.**	**June**	**July**	**May**	**Oct.**	**Dec.**	**April**	**Nov.**	**March**	**Sept.**
Mean	3.3733	3.5465	3.7080	3.7513	3.9945	4.2765	4.5779	4.6480	4.7179	4.8670

F = 0.91
p>F = 0.5247, df = 9

Variable = DEPTHAVG

Month	**Jan.**	**May**	**June**	**July**	**March**	**Nov.**	**Oct.**	**Dec.**	**April**	**Sept.**
Mean	0.17817	0.19767	0.22169	0.23829	0.24164	0.24500	0.24617	0.26917	0.27292	0.31583

F = 0.96, p>F = 0.4817, df = 9

Variable = CURAVG

Month	**Oct.**	**Sept.**	**July**	**May**	**Dec.**	**June**	**Jan.**	**April**	**March**	**Nov.**
Mean	0.00633	0.00917	0.05500	0.18217	0.19183	0.20408	0.23233	0.43208	0.45827	0.78400

F = 12.60
p>F = <.0001, df = 9

Variable = FLOW

Month	**Oct.**	**Sept.**	**July**	**May**	**Jan.**	**June**	**Dec.**	**March**	**April**	**Nov.**
Mean	0.0088	0.0138	0.0551	0.0575	0.0924	0.1438	0.1528	0.3997	0.5092	0.7788

F = 11.72, p>F = <.0001, df = 9

Variable = TEMP

Month	**Jan.**	**Dec.**	**March**	**May**	**Nov.**	**April**	**Oct.**	**June**	**Sept.**	**July**
Mean	-0.6667	5.5000	6.0000	11.0000	13.2000	13.3333	14.5000	17.3077	18.1667	18.2857

F = 174.98
p>F = <.0001, df = 9

Table 7. (continued)

Variable = ABUND

Month	**Jan.**	**March**	**Dec.**	**Sept.**	**April**	**Nov.**	**May**	**July**	**Oct.**	**June**
Mean	4.167	6.273	8.833	10.167	10.500	13.400	13.500	14.714	15.000	17.385

F = 0.67
p>F = 0.7293, df = 9

Variable = pH

Month	**March**	**Dec.**	**April**	**Jan.**	**June**	**Nov.**	**July**	**May**
Mean	6.3000	6.3000	6.5000	6.5833	6.6154	6.7200	6.8000	7.0000

F = 2.75
p>F = 0.0165, df = 7

Table 9. Results of Duncan's Multiple Range Test (SAS, 2009) for physical variables [elevation (m), river km, stream gradient (m/km), stream width (m), stream depth (m), water temperature (C), water current (m/sec), stream flow (m^3/sec), and pH among stream orders of Quantico Creek and Cameron Run watersheds.

Variable = ELEV

Habitat	**Cameron-4**	**Quantico-3**	**Cameron-3**	**Quantico-2**	**Cameron-2**	**Quantico-1**	**Cameron-1**
Mean	30.778	31.538	37.000	38.344	48.421	49.625	75.865

F = 30.33, p>F = <.0001, df = 6

Variable = RIVERKM

Habitat	**Cameron-3**	**Cameron-4**	**Cameron-2**	**Quantico-3**	**Quantico-1**	**Cameron-1**	**Quantico-2**
Mean	6.082	6.290	9.204	13.064	14.918	16.163	16.165

F = 21.84, p>F = <.0001, df = 6

Variable = GRADIENT

Habitat	**Cameron-3**	**Cameron-4**	**Cameron-2**	**Quantico-3**	**Cameron-1**	**Quantico-2**	**Quantico-1**
Mean	3.219	5.093	7.302	10.249	12.834	14.471	23.144

F = 35.52, p>F = <.0001, df = 6

Variable = WIDTHAVG

Habitat	**Quantico-1**	**Quantico-2**	**Cameron-1**	**Cameron-2**	**Quantico-3**	**Cameron-4**	**Cameron-3**
Mean	1.5768	3.5104	4.3399	5.2173	8.1058	9.5552	12.8948

F = 92.15, p>F = <.0001, df = 6

Variable = WIDTHAVG

Habitat	**Quantico-1**	**Quantico-2**	**Cameron-1**	**Cameron-2**	**Quantico-3**	**Cameron-4**	**Cameron-3**
Mean	1.5768	3.5104	4.3399	5.2173	8.1058	9.5552	12.8948

F = 92.15, p>F = <.0001, df = 6

Table 9 (Cont'd).

Variable = DEPTHAVG

Habitat	**Quantico-1**	**Cameron-3**	**Cameron-2**	**Quantico-2**	**Cameron-4**	**Cameron-1**	**Quantico-3**
Mean	0.17177	0.19114	0.23547	0.23753	0.23856	0.25184	0.31671

F = 5.51, p>F = <.0001, df = 6

Variable = TEMP

Habitat	**Cameron-1**	**Cameron-2**	**Quantico-1**	**Quantico-2**	**Quantico-3**	**Cameron-3**	**Cameron-4**
Mean	11.014	11.316	11.580	12.051	12.804	13.857	14.019

F = 0.85, p>F = 0.5352, df = 6

Variable = CURAVG

Habitat	**Quantico-1**	**Cameron-1**	**Cameron-2**	**Quantico-2**	**Quantico-3**	**Cameron-4**	**Cameron-3**
Mean	0.1935	0.2244	0.2656	0.4484	0.5444	0.7400	0.9066

F = 7.30, p>F = <.0001, df = 6

Variable = FLOW

Habitat	**Quantico-1**	**Cameron-1**	**Cameron-2**	**Quantico-2**	**Cameron-4**	**Quantico-3**	**Cameron-3**
Mean	0.0796	0.2090	0.3186	0.5146	1.9444	2.0911	2.2780

F = 5.23
p>F = <.0001, df = 6

Variable = pH

Habitat	**Cameron-2**	**Quantico-2**	**Quantico-1**	**Cameron-1**	**Quantico-3**	**Cameron-4**	**Cameron-3**
Mean	6.5867	6.6150	6.6308	6.6310	6.6586	6.7095	7.0455

F = 1.54, p>F = 0.1644, df = 6

Table 10. Results of Duncan's Multiple Range Test (SAS, 2009) for % substrate composition and % riparian disturbance by stream order in Cameron Run and Quantico Creek watersheds. Underscored means do not differ at p=0.05.

			Stream Order				
Cobble	Cameron-2	Cameron-1	Cameron-4	Cameron-3	Quantico-1	Quantico-3	Quantico-2
Mean	5.0	5.0	10.0	15.0	22.5	27.0	34.0
F=9.92							
P>F=0.0002							
Gravel	Quantico-2	Quantico-3	Quantico-1	Cameron-2	Cameron-1	Cameron-3	Cameron-4
Mean	15.0	18.0	25.0	45.0	47.5	55.0	60.0
F=7.32							
P>F=0.0011							
Bedrock	Cameron-2	Cameron-3	Quantico-1	Quantico-2	Cameron-4	Cameron-1	Quantico-3
Mean	0.0	5.0	7.5	10.0	10.0	20.0	28.0
F=1.84							
P>F=0.1618							
Sand	Cameron-4	Cameron-3	Cameron-2	Cameron-1	Quantico-3	Quantico-1	Quantico-2
Mean	10.0	10.0	15.0	20.0	20.0	22.5	36.0
F=2.40							
P>F=0.0834							
Mud	Quantico-2	Quantico-3	Cameron-1	Cameron-4	Cameron-3	Cameron-2	Quantico-1
Mean	5	7.0	7.5	10.0	15.0	20.0	22.5
F=0.94							
p>F=0.4946							
Concrete	Quantico-1	Quantico-2	Quantico-3	Cameron-1	Cameron-3	Cameron-4	Cameron-2
Mean	0.0	0.0	0.0	0.0	0.0	0.0	15.0
F=2.11							
p>F=0.1170							
Riparian	Quantico-1	Quantico-2	Quantico-3	Cameron-2	Cameron-1	Cameron-3	Cameron-4
Mean	0.0	0.0	6.0	70.0	80.0	90.0	90.0
F=75.93							
p>F=0.0001							

Table 11. Mean, standard deviation (Std. Dev.), minimum and maximum values of watershed size (ha), human population, impervious cover (ha), undeveloped land cover (ha), and % undeveloped land cover in Quantico Creek and Cameron Run watersheds.

HABITAT	Variable	N	Mean	Std Dev	Minimum	Maximum
Quantico-1	WATERSHED SIZE	4	70.68	63.47	21.20	163.60
	POPULATION	4	0.00	0.00	0.00	0.00
	IMPERVIOUSIOUS	4	12.43	16.71	1.15	36.60
	UNDEVELOPED	4	67.77	62.55	19.78	159.35
	PERCENT UNDEVELOPED	4	94.39	3.88	89.40	97.53
Quantico-2	WATERSHED SIZE	5	580.78	704.85	17.40	1787.50
	POPULATION	5	240.00	336.15	0.00	700.00
	IMPERVIOUS	5	40.95	81.19	0.00	186.00
	UNDEVELOPED	5	550.28	696.82	8.26	1747.04
	PERCENT UNDEVELOPED	5	83.35	21.41	47.49	97.70
Quantico-3	WATERSHED SIZE	6	3370.95	1565.52	938.50	4777.80
	POPULATION	6	1250.00	1144.99	500.00	3500.00
	IMPERVIOUS	6	188.77	276.77	0.00	611.56
	UNDEVELOPED	6	3059.48	1311.84	938.50	4032.93
	PERCENT UNDEVELOPED	6	93.01	7.99	79.93	100.00
Cameron-1	WATERSHED SIZE	2	152.45	168.79	33.10	271.80
	POPULATION	2	2341.50	2782.47	374.00	4309.00
	IMPERVIOUS	2	91.33	89.17	28.27	154.38
	UNDEVELOPED	2	58.98	78.11	3.75	114.21
	PERCENT UNDEVELOPED	2	26.67	21.71	11.32	42.02
Cameron-2	WATERSHED SIZE	2	605.25	77.15	550.70	659.80
	POPULATION	2	10957.00	5412.20	7130.00	14784.00
	IMPERVIOUS	2	287.76	59.60	245.61	329.90
	UNDEVELOPED	2	291.24	27.68	271.66	310.81
	PERCENT UNDEVELOPED	2	48.22	1.57	47.11	49.33
Cameron-3	WATERSHED SIZE	2	2011.45	1782.69	750.90	3272.00
	POPULATION	2	44810.50	20342.75	30426.00	59195.00
	IMPERVIOUS	2	1412.18	1255.89	524.13	2300.22
	UNDEVELOPED	2	809.54	680.21	328.56	1290.52
	PERCENT UNDEVELOPED	2	41.60	3.05	39.44	43.76
Cameron-4	WATERSHED SIZE	1	4808.40	.	4808.40	4808.40
	POPULATION	1	103728.00	.	103728.00	103728.00
	IMPERVIOUS	1	3428.39	.	3428.39	3428.39
	UNDEVELOPED	1	1599.54	.	1599.54	1599.54
	PERCENT UNDEVELOPED	1	33.27	.	33.27	33.27

Table 12. Results of Duncan's Multiple Range Test (SAS, 2009) among watershed size (ha), human population, impervious cover (ha), undeveloped land cover (ha), and % undeveloped land cover in Quantico Creek and Cameron Run watersheds. Underscored means do not differ at p=0.05.

Variable = WATERSHED

Habitat	**Quantico-1**	**Cameron-1**	**Quantico-2**	**Cameron-2**	**Cameron-3**	**Quantico-3**	**Cameron-4**
Mean	71	152	581	605	2011	3371	4808

F = 7.17
p>F = 0.0009, df = 6

Variable = POPULATION

Habitat	**Quantico-1**	**Quantico-2**	**Quantico-3**	**Cameron-1**	**Cameron-2**	**Cameron-3**	**Cameron-4**
Mean	0	240	1250	2342	10957	44811	103728

F = 69.12, p>F = <.0001, df = 6

Variable = IMPERVIOUS

Habitat	**Quantico-1**	**Quantico-2**	**Cameron-1**	**Quantico-3**	**Cameron-2**	**Cameron-3**	**Cameron-4**
Mean	12.4	41.0	91.3	188.8	287.8	1412.2	3428.4

F = 16.19, p>F = <.0001, df = 6

Variable = UNDEVELOPED

Habitat	**Cameron-1**	**Quantico-1**	**Cameron-2**	**Quantico-2**	**Cameron-3**	**Cameron-4**	**Quantico-3**
Mean	59.0	67.8	291.2	550.3	809.5	1599.5	3059.5

F = 7.40, p>F = 0.0008, df = 6

Variable = PERCENT UNDEVELOPED

Habitat	**Cameron-1**	**Cameron-4**	**Cameron-3**	**Cameron-2**	**Quantico-2**	**Quantico-3**	**Quantico-1**
Mean	26.67	33.27	41.60	48.22	83.35	93.01	94.39

F = 12.90, p>F = <.0001, df = 6

Table 13. Frequency of occurrence of fishes by stream order in Cameron Run and Quantico Creek watersheds from November, 2008 - June, 2010.

Quantico Creek

SPECIES	**1**	**2**	**3**	**Total**
Cyprinidae	0	1	0	1
Clinostomus funduloides	8	46	38	92
Semotilus atromaculatus	12	38	27	77
Rhinichthys atratulus	42	58	56	156
Luxilus cornutus	2	15	19	36
Exoglossum maxillingua	1	26	46	73
Notropis procne	0	23	47	70
Semotilus corporalis	0	24	47	71
Cyprinella analostana	0	0	2	2
Notropis hudsonius	0	0	2	2
Notemigonus crysoleucas	0	1	7	8
Hybognathus regius	0	0	1	1
Catostomus commersoni	0	21	50	71
Erimyzon oblongus	6	21	37	64
Noturus insignis	0	19	51	70
Ameiurus natalis	0	0	3	3
Ameiurus nebulosus	0	0	4	4
Anguilla rostrata	2	10	45	57
Fundulus diaphanus	0	0	6	6
Lepomis auritus	4	44	66	114
Lepomis gibbosus	10	7	33	50
Lepomis cyanellus	8	21	42	71
Lepomis microlophus	0	3	1	4
Lepomis macrochirus	2	4	25	31
Micropterus salmoides	0	0	5	5
Etheostoma olmstedi	13	34	68	115
Channa argus	0	0	2	2
Lampetra aepyptera	0	0	1	1
Petromyzon marinus	0	0	3	3
Esox niger	0	1	9	10
Total	**110**	**417**	**743**	**1270**

Cameron Run

SPECIES	**1**	**2**	**3**	**4**	**Total**
Clinostomus funduloides	0	13	1	2	16
Semotilus atromaculatus	26	19	0	8	53
Rhinichthys atratulus	37	19	12	19	87
Notropis procne	0	0	12	21	33
Cyprinella analostana	0	0	12	22	34
Notropis hudsonius	0	0	0	1	1
Pimephales notatus	0	0	11	9	20
Catostomus commersoni	12	13	7	19	51
Erimyzon oblongus	0	1	0	1	2
Noturus insignis	0	0	1	0	1
Ameiurus natalis	0	12	9	16	37
Ameiurus nebulosus	0	4	0	5	9
Anguilla rostrata	0	0	3	16	19
Fundulus heteroclitus	0	0	7	9	16
Fundulus diaphanus	0	0	3	4	7
Lepomis auritus	0	0	11	21	32
Lepomis gibbosus	0	0	2	2	4
Lepomis cyanellus	0	1	0	0	1
Lepomis macrochirus	3	7	3	9	22
Micropterus salmoides	0	3	0	4	7
Etheostoma olmstedi	0	9	11	17	37
Total	**78**	**101**	**105**	**205**	**489**

Table 14. Frequency of occurrence of fishes by month in Quantico Creek watershed from November 2008 -- June, 2010.

SPECIES	**Jan.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Total**
Cyprinidae	1	0	0	0	0	0	0	0	0	0	0	1
Clinostomus funduloides	7	13	14	7	12	10	5	4	6	11	3	92
Semotilus atromaculatus	5	15	12	5	8	6	6	2	8	6	4	77
Rhinichthys atratulus	14	24	23	11	23	14	5	7	11	16	8	156
Luxilus cornutus	5	5	4	2	2	4	0	3	4	6	1	36
Exoglossum maxillingua	3	7	13	5	9	12	3	3	5	11	2	73
Notropis procne	6	11	9	5	8	8	5	1	7	7	3	70
Semotilus corporalis	4	13	8	6	8	6	3	4	7	11	1	71
Cyprinella analostana	0	0	1	0	0	1	0	0	0	0	0	2
Notropis hudsonius	0	0	1	1	0	0	0	0	0	0	0	2
Notemigonus crysoleucas	0	1	6	1	0	0	0	0	0	0	0	8
Hybognathus regius	0	0	1	0	0	0	0	0	0	0	0	1
Catostomus commersoni	6	13	12	4	6	7	3	2	6	8	4	71
Erimyzon oblongus	3	10	9	5	6	7	4	0	8	9	3	64
Noturus insignis	2	9	10	4	8	13	4	4	7	8	1	70
Ameiurus natalis	0	1	0	0	1	0	1	0	0	0	0	3
Ameiurus nebulosus	0	0	0	1	2	1	0	0	0	0	0	4
Anguilla rostrata	2	7	11	4	8	12	2	2	4	5	0	57
Fundulus diaphanus	2	1	0	0	0	0	0	0	0	3	0	6
Lepomis auritus	3	19	17	11	15	13	6	3	10	14	3	114
Lepomis gibbosus	4	10	9	2	3	3	5	2	4	6	2	50
Lepomis cyanellus	1	9	12	8	10	8	5	3	5	6	4	71
Lepomis microlophus	1	2	0	0	0	0	0	0	0	1	0	4
Lepomis macrochirus	0	7	4	2	4	4	2	2	2	4	0	31
Micropterus salmoides	0	2	0	0	0	1	1	0	0	1	0	5
Etheostoma olmstedi	6	18	18	9	14	13	7	3	9	13	5	115
Channa argus	1	0	0	0	0	1	0	0	0	0	0	2
Lampetra aepyptera	0	0	0	0	0	0	0	1	0	0	0	1
Petromyzon marinus	0	0	0	0	0	0	0	0	2	1	0	3
Esox niger	2	2	2	0	0	0	0	0	1	1	2	10
Total	**78**	**199**	**196**	**93**	**147**	**144**	**67**	**46**	**106**	**148**	**46**	**1270**

Table 15. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 1st order streams by month in Quantico Creek from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Semotilus atromaculatus	1	3.00	.	3	3
Rhinichthys atratulus	4	7.25	5.19	1	12
Erimyzon oblongus	1	1.00	.	1	1
Lepomis gibbosus	1	5.00	.	5	5
Etheostoma olmstedi	1	3.00	.	3	3

March

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	2.00	.	2	2
Semotilus atromaculatus	2	9.00	7.07	4	14
Rhinichthys atratulus	6	12.17	4.96	4	17
Erimyzon oblongus	2	1.00	0.00	1	1
Lepomis auritus	1	1.00	.	1	1
Lepomis gibbosus	2	12.00	11.31	4	20
Lepomis cyanellus	2	2.00	1.41	1	3
Lepomis macrochirus	1	6.00	.	6	6
Etheostoma olmstedi	2	5.50	0.71	5	6

April

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	2.00	1.41	1	3
Semotilus atromaculatus	2	5.00	1.41	4	6
Rhinichthys atratulus	6	13.83	8.47	1	24
Erimyzon oblongus	1	1.00	.	1	1
Anguilla rostrata	1	1.00	.	1	1
Lepomis gibbosus	2	5.50	0.71	5	6
Lepomis cyanellus	2	1.00	0.00	1	1
Etheostoma olmstedi	2	7.00	2.83	5	9

May

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Semotilus atromaculatus	1	3.00	.	3	3
Rhinichthys atratulus	3	19.00	9.54	9	28
Lepomis auritus	1	1.00	.	1	1
Lepomis gibbosus	1	2.00	.	2	2
Etheostoma olmstedi	1	5.00	.	5	5

Table 15. (continued)

June

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	1	1.00	.	1	1
Semotilus atromaculatus	2	2.00	0.00	2	2
Rhinichthys atratulus	7	10.43	6.83	1	21
Anguilla rostrata	1	1.00	.	1	1
Lepomis cyanellus	1	4.00	.	4	4
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	2	7.00	2.83	5	9

July

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Rhinichthys atratulus	3	18.33	12.90	4	29
Etheostoma olmstedi	1	5.00	.	5	5

August

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	1	2.00	.	2	2
Semotilus atromaculatus	1	4.00	.	4	4
Rhinichthys atratulus	1	5.00	.	5	5
Lepomis gibbosus	1	3.00	.	3	3
Lepomis cyanellus	1	1.00	.	1	1
Etheostoma olmstedi	1	4.00	.	4	4

September

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Rhinichthys atratulus	2	7.00	0.00	7	7

October

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	1	2.00	.	2	2
Semotilus atromaculatus	1	6.00	.	6	6
Rhinichthys atratulus	3	13.67	4.73	10	19
Erimyzon oblongus	1	1.00	.	1	1
Lepomis auritus	1	3.00	.	3	3
Lepomis gibbosus	1	7.00	.	7	7
Lepomis cyanellus	1	11.00	.	11	11
Etheostoma olmstedi	1	3.00	.	3	3

Table 15. (continued)

November

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	6.50	3.54	4	9
Semotilus atromaculatus	1	14.00	.	14	14
Rhinichthys atratulus	4	17.00	13.83	1	30
Luxilus cornutus	2	4.00	4.24	1	7
Exoglossum maxillingua	1	1.00	.	1	1
Lepomis auritus	1	2.00	.	2	2
Lepomis gibbosus	1	12.00	.	12	12
Etheostoma olmstedi	1	1.00	.	1	1

December

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Semotilus atromaculatus	1	5.00	.	5	5
Rhinichthys atratulus	3	12.67	6.66	5	17
Erimyzon oblongus	1	1.00	.	1	1
Lepomis gibbosus	1	4.00	.	4	4
Lepomis cyanellus	1	1.00	.	1	1
Etheostoma olmstedi	1	5.00	.	5	5

Table 16. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 2nd order streams by month in Quantico Creek from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Cyprinidae	1	1.00	.	1	1
Clinostomus funduloides	3	3.67	1.53	2	5
Semotilus atromaculatus	1	5.00	.	5	5
Rhinichthys atratulus	5	3.00	2.35	1	6
Luxilus cornutus	2	2.00	1.41	1	3
Exoglossum maxillingua	1	1.00	.	1	1
Notropis procne	2	3.00	2.83	1	5
Semotilus corporalis	1	3.00	.	3	3
Catostomus commersoni	2	1.50	0.71	1	2
Noturus insignis	1	1.00	.	1	1
Lepomis auritus	2	1.00	0.00	1	1
Lepomis microlophus	1	1.00	.	1	1
Etheostoma olmstedi	1	2.00	.	2	2

March

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	6	5.33	3.39	2	11
Semotilus atromaculatus	6	3.67	1.86	1	6
Rhinichthys atratulus	10	7.80	7.58	1	21
Luxilus cornutus	2	27.00	22.63	11	43
Exoglossum maxillingua	2	5.00	5.66	1	9
Notropis procne	3	3.00	2.00	1	5
Semotilus corporalis	4	4.50	1.29	3	6
Catostomus commersoni	3	2.67	1.53	1	4
Erimyzon oblongus	3	1.00	0.00	1	1
Noturus insignis	2	1.00	0.00	1	1
Anguilla rostrata	1	1.00	.	1	1
Lepomis auritus	8	2.88	2.17	1	7
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	2	2.00	1.41	1	3
Lepomis microlophus	2	1.00	0.00	1	1
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	4	5.50	4.12	2	10

Table 16. (continued)

April

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	8	4.13	1.64	2	6
Semotilus atromaculatus	6	4.50	2.43	1	8
Rhinichthys atratulus	7	5.00	3.87	2	12
Luxilus cornutus	2	6.50	2.12	5	8
Exoglossum maxillingua	5	2.40	2.07	1	6
Notropis procne	3	3.33	2.08	1	5
Semotilus corporalis	2	3.50	0.71	3	4
Notemigonus crysoleucas	1	1.00	.	1	1
Catostomus commersoni	4	1.50	1.00	1	3
Erimyzon oblongus	3	1.00	0.00	1	1
Noturus insignis	2	1.50	0.71	1	2
Anguilla rostrata	1	1.00	.	1	1
Lepomis auritus	7	2.86	2.19	1	7
Lepomis gibbosus	1	4.00	.	4	4
Lepomis cyanellus	4	2.25	0.96	1	3
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	6	2.33	1.21	1	4

May

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	4	6.25	2.5	3	9
Semotilus atromaculatus	3	3.67	3.79	1	8
Rhinichthys atratulus	4	7.25	3.77	2	10
Luxilus cornutus	1	17.00	.	17	17
Exoglossum maxillingua	2	1.50	0.71	1	2
Notropis procne	2	3.00	2.83	1	5
Semotilus corporalis	2	3.50	2.12	2	5
Catostomus commersoni	2	2.00	1.41	1	3
Erimyzon oblongus	2	1.00	0.00	1	1
Noturus insignis	1	3.00	.	3	3
Anguilla rostrata	1	2.00	.	2	2
Lepomis auritus	4	3.75	3.40	1	8
Lepomis cyanellus	3	1.67	1.15	1	3
Etheostoma olmstedi	3	2.33	1.53	1	4

Table 16. (continued)

June

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	7	6.86	3.29	2	11
Semotilus atromaculatus	6	2.67	1.51	1	4
Rhinichthys atratulus	8	5.00	3.12	2	11
Luxilus cornutus	2	4.50	0.71	4	5
Exoglossum maxillingua	6	3.50	3.02	1	9
Notropis procne	3	1.33	0.58	1	2
Semotilus corporalis	4	3.00	3.37	1	8
Catostomus commersoni	1	7.00	.	7	7
Erimyzon oblongus	3	3.67	3.06	1	7
Noturus insignis	2	1.00	0.00	1	1
Anguilla rostrata	1	5.00	.	5	5
Lepomis auritus	6	3.33	0.82	2	4
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	2	5.50	0.71	5	6
Etheostoma olmstedi	4	2.75	2.06	1	5

July

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	4	9.75	2.99	6	13
Semotilus atromaculatus	4	5.25	4.03	1	10
Rhinichthys atratulus	5	12.60	9.94	3	29
Luxilus cornutus	1	10.00	.	10	10
Exoglossum maxillingua	3	3.00	3.46	1	7
Notropis procne	2	3.00	2.83	1	5
Semotilus corporalis	2	1.50	0.71	1	2
Catostomus commersoni	2	2.00	1.41	1	3
Erimyzon oblongus	3	2.67	1.53	1	4
Noturus insignis	4	1.50	1.00	1	3
Anguilla rostrata	4	2.75	2.87	1	7
Lepomis auritus	4	3.25	2.87	1	7
Lepomis cyanellus	2	5.50	0.71	5	6
Etheostoma olmstedi	3	4.33	3.21	2	8

Table 16. (continued)

August

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	5.00	4.24	2	8
Semotilus atromaculatus	2	3.00	1.41	2	4
Rhinichthys atratulus	2	9.50	2.12	8	11
Notropis procne	2	8.00	7.07	3	13
Erimyzon oblongus	2	3.50	2.12	2	5
Noturus insignis	1	1.00	.	1	1
Lepomis auritus	2	4.00	4.24	1	7
Lepomis cyanellus	2	5.50	2.12	4	7
Etheostoma olmstedi	2	1.00	0.00	1	1

September

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	5.00	2.83	3	7
Semotilus atromaculatus	1	13.00	.	13	13
Rhinichthys atratulus	3	10.67	5.51	7	17
Luxilus cornutus	1	18.00	.	18	18
Exoglossum maxillingua	1	6.00	.	6	6
Semotilus corporalis	2	6.00	1.41	5	7
Catostomus commersoni	1	6.00	.	6	6
Noturus insignis	2	3.00	2.83	1	5
Lepomis auritus	1	12.00	.	12	12
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	1	2.00	.	2	2
Lepomis macrochirus	1	2.00	.	2	2
Etheostoma olmstedi	1	1.00	.	1	1

October

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	3	9.67	5.69	5	16
Semotilus atromaculatus	4	4.25	3.40	1	9
Rhinichthys atratulus	5	12.40	7.50	7	24
Luxilus cornutus	1	24.00	.	24	24
Exoglossum maxillingua	1	3.00	.	3	3
Notropis procne	2	10.00	12.73	1	19
Semotilus corporalis	3	4.33	3.51	1	8
Catostomus commersoni	1	13.00	.	13	13
Erimyzon oblongus	2	2.00	1.41	1	3
Noturus insignis	2	2.00	1.41	1	3
Anguilla rostrata	1	1.00	.	1	1

Lepomis auritus	3	7.00	1.00	6	8
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	1	1.00	.	1	1
Etheostoma olmstedi	3	3.67	4.62	1	9

Table 16. (continued)

November

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	4	10.25	4.50	4	14
Semotilus atromaculatus	3	5.67	6.43	1	13
Rhinichthys atratulus	5	7.80	4.55	3	15
Luxilus cornutus	2	10.00	12.73	1	19
Exoglossum maxillingua	3	4.67	5.51	1	11
Notropis procne	2	8.00	4.24	5	11
Semotilus corporalis	3	5.00	3.46	1	7
Catostomus commersoni	2	5.50	0.71	5	6
Erimyzon oblongus	2	2.00	1.41	1	3
Noturus insignis	1	1.00	.	1	1
Anguilla rostrata	1	1.00	.	1	1
Lepomis auritus	5	4.60	2.97	1	9
Lepomis gibbosus	1	3.00	.	3	3
Lepomis cyanellus	2	1.00	0.00	1	1
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	4	1.25	0.50	1	2

December

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	3	2.67	1.53	1	4
Semotilus atromaculatus	2	4.00	2.83	2	6
Rhinichthys atratulus	4	7.75	7.14	2	18
Luxilus cornutus	1	7.00	.	7	7
Exoglossum maxillingua	2	2.00	1.41	1	3
Notropis procne	2	6.50	3.54	4	9
Semotilus corporalis	1	2.00	.	2	2
Catostomus commersoni	3	1.67	1.15	1	3
Erimyzon oblongus	1	1.00	.	1	1
Noturus insignis	1	1.00	.	1	1
Lepomis auritus	2	3.50	0.71	3	4
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	2	3.00	0.00	3	3
Etheostoma olmstedi	3	4.00	1.73	3	6
Esox niger	1	1.00	.	1	1

Table 17. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 3rd order streams by month in Quantico Creek from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	4	7.00	5.23	2	12
Semotilus atromaculatus	3	1.33	0.58	1	2
Rhinichthys atratulus	5	2.20	1.64	1	5
Luxilus cornutus	3	1.33	0.58	1	2
Exoglossum maxillingua	2	1.50	0.71	1	2
Notropis procne	4	11.25	14.13	1	32
Semotilus corporalis	3	2.67	1.15	2	4
Catostomus commersoni	4	3.00	1.41	1	4
Erimyzon oblongus	2	2.00	1.41	1	3
Noturus insignis	1	1.00	.	1	1
Anguilla rostrata	2	3.00	1.41	2	4
Fundulus diaphanus	2	10.00	12.73	1	19
Lepomis auritus	1	1.00	.	1	1
Lepomis gibbosus	3	8.67	11.59	1	22
Lepomis cyanellus	1	1.00	.	1	1
Etheostoma olmstedi	4	6.00	5.23	1	11
Channa argus	1	1.00	.	1	1
Esox niger	2	1.00	0.00	1	1

March

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	6	8.50	6.57	2	18
Semotilus atromaculatus	7	2.43	2.94	1	9
Rhinichthys atratulus	8	2.88	2.17	1	6
Luxilus cornutus	3	3.33	1.53	2	5
Exoglossum maxillingua	5	4.20	2.39	2	8
Notropis procne	8	11.88	15.31	1	41
Semotilus corporalis	9	5.56	3.84	1	12
Notemigonus crysoleucas	1	1.00	.	1	1
Catostomus commersoni	10	2.50	1.18	1	5
Erimyzon oblongus	5	2.40	1.14	1	4
Noturus insignis	7	2.86	3.63	1	11
Ameiurus natalis	1	1.00	.	1	1
Anguilla rostrata	6	4.50	4.32	2	13
Fundulus diaphanus	1	12.00	.	12	12
Lepomis auritus	10	3.90	2.77	1	8
Lepomis gibbosus	7	15.71	22.97	1	60
Lepomis cyanellus	5	3.00	3.94	1	10
Lepomis macrochirus	5	2.60	1.52	1	4
Micropterus salmoides	2	1.00	0.00	1	1

Etheostoma olmstedi	12	7.00	10.05	1	34
Esox niger	2	1.50	0.71	1	2

Table 17. (continued)

April

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	4	4.50	2.38	1	6
Semotilus atromaculatus	4	2.50	1.29	1	4
Rhinichthys atratulus	10	2.90	1.91	1	6
Luxilus cornutus	2	2.50	0.71	2	3
Exoglossum maxillingua	8	3.63	2.83	1	9
Notropis procne	6	7.83	10.48	2	29
Semotilus corporalis	6	1.83	1.33	1	4
Cyprinella analostana	1	1.00	.	1	1
Notropis hudsonius	1	2.00	.	2	2
Notemigonus crysoleucas	5	18.00	17.26	1	41
Hybognathus regius	1	8.00	.	8	8
Catostomus commersoni	8	2.00	1.31	1	4
Erimyzon oblongus	5	3.20	1.48	1	5
Noturus insignis	8	3.63	3.16	1	8
Anguilla rostrata	9	4.11	4.31	1	14
Lepomis auritus	10	4.90	4.20	1	15
Lepomis gibbosus	6	2.67	3.14	1	9
Lepomis cyanellus	6	2.67	2.16	1	7
Lepomis macrochirus	3	2.33	1.53	1	4
Etheostoma olmstedi	10	9.90	14.00	2	49
Esox niger	2	2.00	1.41	1	3

May

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	3	3.67	3.79	1	8
Semotilus atromaculatus	1	2.00	.	2	2
Rhinichthys atratulus	4	4.50	4.43	1	11
Luxilus cornutus	1	3.00	.	3	3
Exoglossum maxillingua	3	4.00	1.00	3	5
Notropis procne	3	16.00	13.45	1	27
Semotilus corporalis	4	5.50	4.04	2	11
Notropis hudsonius	1	30.00	.	30	30
Notemigonus crysoleucas	1	3.00	.	3	3
Catostomus commersoni	2	1.50	0.71	1	2
Erimyzon oblongus	3	2.67	2.89	1	6
Noturus insignis	3	2.67	0.58	2	3
Ameiurus nebulosus	1	3.00	.	3	3
Anguilla rostrata	3	4.00	2.00	2	6
Lepomis auritus	6	6.00	5.44	1	14
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	5	1.60	0.89	1	3
Lepomis macrochirus	2	3.50	2.12	2	5

Etheostoma olmstedi	5	6.40	7.20	1	19

Table 17. (continued)

June

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	4	2.50	1.29	1	4
Rhinichthys atratulus	8	1.63	1.77	1	6
Exoglossum maxillingua	3	1.67	1.15	1	3
Notropis procne	5	3.80	1.92	2	7
Semotilus corporalis	4	1.75	0.96	1	3
Catostomus commersoni	5	2.80	0.84	2	4
Erimyzon oblongus	3	3.00	1.00	2	4
Noturus insignis	6	3.83	2.86	1	7
Ameiurus natalis	1	1.00	.	1	1
Ameiurus nebulosus	2	5.00	4.24	2	8
Anguilla rostrata	6	8.50	5.82	1	16
Lepomis auritus	9	5.00	3.24	1	10
Lepomis gibbosus	2	1.00	0.00	1	1
Lepomis cyanellus	7	6.43	5.06	1	14
Lepomis macrochirus	3	8.33	4.04	6	13
Etheostoma olmstedi	8	5.75	5.95	1	19

July

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	6	8.00	11.42	1	30
Semotilus atromaculatus	2	4.50	4.95	1	8
Rhinichthys atratulus	6	7.17	6.94	1	20
Luxilus cornutus	3	1.33	0.58	1	2
Exoglossum maxillingua	9	4.22	3.19	1	11
Notropis procne	6	3.17	3.37	1	8
Semotilus corporalis	4	3.00	2.71	1	7
Cyprinella analostana	1	1.00	.	1	1
Catostomus commersoni	5	2.60	3.05	1	8
Erimyzon oblongus	4	6.25	8.50	2	19
Noturus insignis	9	6.22	4.71	1	15
Ameiurus nebulosus	1	1.00	.	1	1
Anguilla rostrata	8	12.63	9.90	2	35
Lepomis auritus	9	5.78	3.07	2	12
Lepomis gibbosus	3	1.33	0.58	1	2
Lepomis cyanellus	6	4.33	4.93	1	14
Lepomis macrochirus	4	3.25	1.50	2	5
Micropterus salmoides	1	1.00	.	1	1
Etheostoma olmstedi	9	6.00	4.85	1	16
Channa argus	1	1.00	.	1	1

Table 17. (continued)

August

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	5.50	6.36	1	10
Semotilus atromaculatus	3	2.67	2.89	1	6
Rhinichthys atratulus	2	3.50	2.12	2	5
Exoglossum maxillingua	3	5.33	4.04	1	9
Notropis procne	3	4.33	2.52	2	7
Semotilus corporalis	3	3.33	2.08	1	5
Catostomus commersoni	3	4.67	3.21	1	7
Erimyzon oblongus	2	7.00	4.24	4	10
Noturus insignis	3	8.00	10.39	2	20
Ameiurus natalis	1	1.00	.	1	1
Anguilla rostrata	2	11.00	2.83	9	13
Lepomis auritus	4	8.50	4.43	5	15
Lepomis gibbosus	4	1.25	0.50	1	2
Lepomis cyanellus	2	10.00	0.00	10	10
Lepomis macrochirus	2	3.00	1.41	2	4
Micropterus salmoides	1	2.00	.	2	2
Etheostoma olmstedi	4	8.75	6.02	1	14

September

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	4.50	0.71	4	5
Semotilus atromaculatus	1	1.00	.	1	1
Rhinichthys atratulus	2	12.50	6.36	8	17
Luxilus cornutus	2	2.00	1.41	1	3
Exoglossum maxillingua	2	12.00	1.41	11	13
Notropis procne	1	5.00	.	5	5
Semotilus corporalis	2	5.50	3.54	3	8
Catostomus commersoni	1	3.00	.	3	3
Noturus insignis	2	8.50	0.71	8	9
Anguilla rostrata	2	3.50	2.12	2	5
Lepomis auritus	2	4.50	0.71	4	5
Lepomis gibbosus	1	1.00	.	1	1
Lepomis cyanellus	2	2.00	0.00	2	2
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	2	2.50	0.71	2	3
Lampetra aepyptera	1	1.00	.	1	1

Table 17. (continued)

October

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	2	2.50	2.12	1	4
Semotilus atromaculatus	3	5.33	5.86	1	12
Rhinichthys atratulus	3	29.33	27.79	9	61
Luxilus cornutus	3	2.00	1.00	1	3
Exoglossum maxillingua	4	9.00	4.24	6	15
Notropis procne	5	5.20	5.63	1	15
Semotilus corporalis	4	9.50	4.20	5	15
Catostomus commersoni	5	2.40	2.19	1	6
Erimyzon oblongus	5	2.60	3.05	1	8
Noturus insignis	5	6.00	4.53	1	11
Anguilla rostrata	3	7.33	9.29	1	18
Lepomis auritus	6	5.67	4.41	1	12
Lepomis gibbosus	2	2.50	2.12	1	4
Lepomis cyanellus	3	5.00	2.00	3	7
Lepomis macrochirus	2	10.50	2.12	9	12
Etheostoma olmstedi	5	7.60	5.22	1	14
Petromyzon marinus	2	5.00	5.66	1	9
Esox niger	1	2.00	.	2	2

November

SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Clinostomus funduloides	5	16.00	19.84	1	48
Semotilus atromaculatus	2	10.00	5.66	6	14
Rhinichthys atratulus	7	8.71	5.38	1	15
Luxilus cornutus	2	4.00	4.24	1	7
Exoglossum maxillingua	7	4.43	3.99	1	12
Notropis procne	5	31.80	34.88	1	83
Semotilus corporalis	8	4.25	3.06	1	11
Catostomus commersoni	6	4.33	3.83	1	10
Erimyzon oblongus	7	2.00	1.15	1	4
Noturus insignis	7	3.14	3.76	1	11
Anguilla rostrata	4	2.75	1.71	1	5
Fundulus diaphanus	3	12.00	14.80	2	29
Lepomis auritus	8	5.38	7.71	1	24
Lepomis gibbosus	4	19.75	18.52	4	42

Lepomis cyanellus	4	2.25	1.50	1	4
Lepomis microlophus	1	1.00	.	1	1
Lepomis macrochirus	3	7.00	7.81	2	16
Micropterus salmoides	1	1.00	.	1	1
Etheostoma olmstedi	8	5.75	4.20	2	14
Petromyzon marinus	1	1.00	.	1	1
Esox niger	1	2.00	.	2	2

Table 17. (continued)

		December			
SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Semotilus atromaculatus	1	1.00	.	1	1
Rhinichthys atratulus	1	1.00	.	1	1
Notropis procne	1	7.00	.	7	7
Catostomus commersoni	1	3.00	.	3	3
Erimyzon oblongus	1	10.00	.	10	10
Lepomis auritus	1	6.00	.	6	6
Lepomis cyanellus	1	6.00	.	6	6
Etheostoma olmstedi	1	3.00	.	3	3
Esox niger	1	2.00	.	2	2

Table 18. Mean, standard deviation (Std. Dev.), minimum, and maximum values of fish species richness and diversity indices (i.e., Shannon Weaver and Evenness) per stream order in Cameron Run and Quantico Creek satersheds from November, 2008 -- June, 2010.

Quantico Watershed

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	RICHNESS	43	2.53	2.54	0.00	9.00
	SHANNON	42	0.45	0.67	0.00	1.86
	EVENNESS	15	0.75	0.13	0.44	0.94
2	RICHNESS	66	6.30	2.60	0.00	11.00
	SHANNON	66	1.54	0.46	0.00	2.11
	EVENNESS	66	0.87	0.13	0.00	1.00
3	RICHNESS	77	9.65	2.58	0.00	14.00
	SHANNON	77	1.84	0.41	0.00	2.35
	EVENNESS	75	0.83	0.10	0.37	0.96

Cameron Run Watershed

ORDER	Variable	N	Mean	Std. Dev	Minimum	Maximum
1	RICHNESS	37	2.11	0.91	1.00	4.00
	SHANNON	37	0.45	0.36	0.00	1.19
	EVENNESS	27	0.69	0.21	0.23	0.99
2	RICHNESS	19	5.32	2.11	2.00	9.00
	SHANNON	19	1.07	0.48	0.17	1.77
	EVENNESS	19	0.65	0.17	0.24	0.95
3	RICHNESS	13	8.08	3.25	0.00	12.00
	SHANNON	13	1.54	0.61	0.00	2.04
	EVENNESS	13	0.72	0.25	0.00	0.93
4	RICHNESS	27	7.59	2.82	0.00	12.00
	SHANNON	27	1.36	0.44	0.00	1.86
	EVENNESS	27	0.68	0.19	0.00	0.96

Table 19. Results of Duncan's Multiple Range test (SAS, 2009) of mean values of species richness and diversity indices (i.e., Shannon Weaver and Evenness) by stream order in Cameron Run and Quantico Creek watersheds from November, 2008 – June, 2010. Underscored means do not differ significantly at p = 0.05.

Quantico Watershed

Variable = RICHNESS

Stream Order	1	2	3
Mean	2.5349	6.3030	9.6494
	______	______	______

F = 107.11
p>F = <.0001
df = 2

Variable = SHANNON

Stream Order	1	2	3
Mean	0.44795	1.53853	1.84016
	______	______	______

F = 110.29
p>F = <.0001
df = 2

Variable = EVENNESS

Stream Order	1	3	2
Mean	0.74790	0.83373	0.86745
	______	_____________	_____________

F = 6.62
p>F = 0.0018
df = 2

Cameron Run Watershed

Variable = RICHNESS

Stream Order	1	2	4	3
Mean	2.1081	5.3158	7.5926	8.0769
	______	______	_____________	_____________

F = 42.57, p>F = <.0001, df = 3

Variable = SHANNON

Stream Order	1	2	4	3
Mean	0.4481	1.0694	1.3601	1.5399
	______	______	_____________	_____________

F = 30.81, p>F = <.0001, df = 3

Variable = EVENNESS

Stream Order	2	4	1	3
Mean	0.65003	0.67945	0.68532	0.71548
	_____________	_____________	_____________	_____________

F = 0.27
p>F = 0.8447, df = 3

Table 20. Results of Duncan's Multiple Range test (SAS, 2009) of mean values of species richness and diversity indices (i.e., Shannon Weaver, HMAX, and Evenness) by month in Quantico Creek watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p=0.05.

Quantico Watershed

Variable = RICHNESS

Month	**Jan.**	**Dec.**	**June**	**April**	**Sept.**	**May**	**March**	**Oct.**	**Nov.**	**July**	**Aug.**
Mean	4.875	5.750	6.083	6.533	6.571	6.571	6.862	7.571	7.789	8.000	9.571

F = 1.36
p>F = 0.2026
df = 10

Variable = SHANNON

Month	**Jan.**	**Dec.**	**Sept.**	**June**	**April**	**May**	**March**	**Oct.**	**Nov.**	**July**	**Aug.**
Mean	1.0574	1.2610	1.2965	1.3616	1.3776	1.4123	1.4495	1.5079	1.5276	1.5334	1.9811

F = 0.99
p>F = 0.4523
df = 10

Variable = EVENNESS

Month	**Jan.**	**Nov.**	**July**	**Oct.**	**March**	**May**	**April**	**June**	**Dec.**	**Aug.**	**Sept.**
Mean	0.78877	0.79507	0.82748	0.83601	0.84540	0.84842	0.84935	0.86127	0.86508	0.88851	0.89228

F = 0.79
p>F = 0.6361
df = 10

Table 21. Frequency of occurrence of fishes by month in Cameron Run watershed from November 2008 -- June, 2010.

	Cameron Run Watershed										
SPECIES	**Jan.**	**March**	**April**	**May**	**June**	**July**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Total**
Clinostomus funduloides	1	2	2	1	4	1	1	2	1	1	16
Semotilus atromaculatus	4	6	9	3	10	6	4	4	4	3	53
Rhinichthys atratulus	11	12	13	7	14	6	6	6	6	6	87
Notropis procne	4	5	4	3	5	1	3	3	2	3	33
Cyprinella analostana	3	5	4	3	6	1	3	3	3	3	34
Notropis hudsonius	0	0	0	0	0	0	0	0	1	0	1
Pimephales notatus	2	3	4	2	3	0	2	1	1	2	20
Catostomus commersoni	5	6	8	2	10	4	4	4	4	4	51
Erimyzon oblongus	2	0	0	0	0	0	0	0	0	0	2
Noturus insignis	0	0	0	0	0	0	1	0	0	0	1
Ameiurus natalis	3	2	5	3	7	3	4	4	4	2	37
Ameiurus nebulosus	0	1	1	1	1	2	2	0	1	0	9
Anguilla rostrata	2	2	4	1	3	1	3	1	1	1	19
Fundulus heteroclitus	1	2	3	1	2	1	1	2	2	1	16
Fundulus diaphanus	0	2	0	1	0	0	2	2	0	0	7
Lepomis auritus	3	3	5	3	5	2	3	3	2	3	32
Lepomis gibbosus	1	0	1	0	0	0	0	0	2	0	4
Lepomis cyanellus	0	0	1	0	0	0	0	0	0	0	1
Lepomis macrochirus	1	4	5	1	5	0	3	1	2	0	22
Micropterus salmoides	0	1	0	0	2	3	0	1	0	0	7
Etheostoma olmstedi	3	3	7	2	6	3	4	4	2	3	37
Total	**46**	**59**	**76**	**34**	**83**	**34**	**46**	**41**	**38**	**32**	**489**

Table 22. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 1st order streams by month in Cameron Run from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	1	1.00	.	1	1
Rhinichthys atratulus	5	4.80	2.77	1	8

March

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	3	4.67	3.51	1	8
Rhinichthys atratulus	5	9.80	5.45	2	17
Catostomus commersoni	2	2.00	0	2	2
Lepomis macrochirus	1	2.00	.	2	2

April

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	4	5.50	6.35	2	15
Rhinichthys atratulus	5	18.20	9.31	9	30
Catostomus commersoni	2	5.50	6.36	1	10
Lepomis macrochirus	1	2.00	.	2	2

May

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	2	14.50	7.78	9	20
Rhinichthys atratulus	3	15.33	8.08	6	20
Catostomus commersoni	1	6.00	.	6	6

June

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	5	4.60	3.36	1	10
Rhinichthys atratulus	5	37.40	37.82	18	105
Catostomus commersoni	2	7.50	6.36	3	12
Lepomis macrochirus	1	1.00	.	1	1

July

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	3	4.33	2.89	1	6
Rhinichthys atratulus	3	29.00	20.30	7	47
Catostomus commersoni	1	3.00	.	3	3

Table 22. (continued)

September

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	2	9.50	9.19	3	16
Rhinichthys atratulus	3	11.67	2.31	9	13
Catostomus commersoni	1	7.00	.	7	7

October

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	2	16.00	9.90	9	23
Rhinichthys atratulus	3	17.00	17.35	6	37
Catostomus commersoni	1	7.00	.	7	7

November

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	2	6.50	3.54	4	9
Rhinichthys atratulus	2	25.50	26.16	7	44
Catostomus commersoni	1	3.00	.	3	3

December

SPECIES	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	2	8.50	0.71	8	9
Rhinichthys atratulus	3	10.67	8.50	1	17
Catostomus commersoni	1	4.00	.	4	4

Table 23. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 2nd order streams by month in Cameron Run from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Semotilus atromaculatus	3	3.67	2.08	2	6
Rhinichthys atratulus	3	14.00	7.21	8	22
Catostomus commersoni	3	2.33	1.53	1	4
Erimyzon oblongus	1	1.00	.	1	1
Ameiurus natalis	2	1.00	0	1	1
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	2	1.00	0	1	1

March

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	5.00	5.66	1	9
Semotilus atromaculatus	3	8.67	8.62	1	18
Rhinichthys atratulus	3	28.00	17.35	13	47
Catostomus commersoni	1	7.00	.	7	7
Ameiurus natalis	2	1.50	0.71	1	2
Ameiurus nebulosus	1	1.00	.	1	1
Lepomis macrochirus	2	1.00	0	1	1
Micropterus salmoides	1	1.00	.	1	1
Etheostoma olmstedi	1	5.00	.	5	5

April

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	3.50	2.12	2	5
Semotilus atromaculatus	3	12.67	4.51	8	17
Rhinichthys atratulus	3	37.67	6.51	31	44
Catostomus commersoni	2	7.50	9.19	1	14
Ameiurus natalis	1	1.00	.	1	1
Lepomis cyanellus	1	1.00	.	1	1
Lepomis macrochirus	2	1.00	0	1	1
Etheostoma olmstedi	2	2.00	1.41	1	3

May

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Semotilus atromaculatus	1	9.00	.	9	9
Rhinichthys atratulus	1	35.00	.	35	35
Ameiurus nebulosus	1	1.00	.	1	1

Table 23. (continued)

June

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	2	4.00	4.24	1	7
Semotilus atromaculatus	3	10.00	1.73	8	11
Rhinichthys atratulus	3	44.00	23.26	23	69
Catostomus commersoni	2	11.50	14.85	1	22
Ameiurus natalis	2	1.50	0.71	1	2
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	1	1.00	.	1	1

July

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	2.00	.	2	2
Semotilus atromaculatus	1	9.00	.	9	9
Rhinichthys atratulus	1	38.00	.	38	38
Catostomus commersoni	1	8.00	.	8	8
Ameiurus natalis	1	1.00	.	1	1
Ameiurus nebulosus	1	2.00	.	2	2
Micropterus salmoides	1	1.00	.	1	1
Etheostoma olmstedi	1	4.00	.	4	4

September

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	8.00	.	8	8
Semotilus atromaculatus	1	21.00	.	21	21
Rhinichthys atratulus	1	25.00	.	25	25
Catostomus commersoni	1	8.00	.	8	8
Ameiurus natalis	1	7.00	.	7	7
Ameiurus nebulosus	1	4.00	.	4	4
Lepomis macrochirus	1	3.00	.	3	3
Etheostoma olmstedi	1	2.00	.	2	2

October

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	4.00	.	4	4
Semotilus atromaculatus	1	12.00	.	12	12
Rhinichthys atratulus	1	11.00	.	11	11
Catostomus commersoni	1	8.00	.	8	8
Ameiurus natalis	1	3.00	.	3	3
Micropterus salmoides	1	1.00	.	1	1
Etheostoma olmstedi	1	7.00	.	7	7

Table 23. (continued)

November

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	7.00	.	7	7
Semotilus atromaculatus	2	7.00	4.24	4	10
Rhinichthys atratulus	2	13.50	7.78	8	19
Catostomus commersoni	1	16.00	.	16	16
Ameiurus natalis	1	5.00	.	5	5

December

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Semotilus atromaculatus	1	5.00	.	5	5
Rhinichthys atratulus	1	21.00	.	21	21
Catostomus commersoni	1	3.00	.	3	3
Ameiurus natalis	1	2.00	.	2	2

Table 24. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 3rd order streams by month in Cameron Run from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	1	2.00	.	2	2
Notropis procne	1	2.00	.	2	2
Cyprinella analostana	1	4.00	.	4	4
Pimephales notatus	1	1.00	.	1	1
Lepomis auritus	1	3.00	.	3	3
Etheostoma olmstedi	1	1.00	.	1	1

March

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	1	2.00	.	2	2
Notropis procne	1	16.00	.	16	16
Cyprinella analostana	1	15.00	.	15	15
Pimephales notatus	1	102.00	.	102	102
Catostomus commersoni	1	1.00	.	1	1
Lepomis auritus	1	1.00	.	1	1
Etheostoma olmstedi	1	1.00	.	1	1

April

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	2	8.00	4.24	5	11
Notropis procne	2	4.50	5.12	3	6
Cyprinella analostana	2	10.00	7.07	5	15
Pimephales notatus	2	37.50	31.82	15	60
Catostomus commersoni	2	5.50	2.12	4	7
Ameiurus natalis	1	1.00	.	1	1
Anguilla rostrata	1	2.00	.	2	2
Fundulus heteroclitus	1	1.00	.	1	1
Lepomis auritus	2	13.50	2.12	12	15
Lepomis gibbosus	1	1.00	.	1	1
Etheostoma olmstedi	2	7.50	0.71	7	8

May

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	1	18.00	.	18	18
Notropis procne	1	6.00	.	6	6
Cyprinella analostana	1	27.00	.	27	27
Pimephales notatus	1	20.00	.	20	20
Ameiurus natalis	1	2.00	.	2	2
Fundulus heteroclitus	1	2.00	.	2	2
Fundulus diaphanus	1	1.00	.	1	1
Lepomis auritus	1	21.00	.	21	21
Etheostoma olmstedi	1	3.00	.	3	3

Table 24. (continued)

June

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Rhinichthys atratulus	2	9.50	4.95	6	13
Notropis procne	2	14.00	1.41	13	15
Cyprinella analostana	2	14.00	5.66	10	18
Pimephales notatus	2	30.50	20.51	16	45
Catostomus commersoni	2	2.50	2.12	1	4
Ameiurus natalis	2	7.50	9.19	1	14
Anguilla rostrata	1	2.00	.	2	2
Fundulus heteroclitus	1	2.00	.	2	2
Lepomis auritus	2	13.50	0.71	13	14
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	2	7.50	4.95	4	11

September

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	1	44.00	.	44	44
Notropis procne	1	5.00	.	5	5
Cyprinella analostana	1	17.00	.	17	17
Pimephales notatus	1	27.00	.	27	27
Noturus insignis	1	1.00	.	1	1
Ameiurus natalis	1	13.00	.	13	13
Anguilla rostrata	1	2.00	.	2	2
Fundulus heteroclitus	1	2.00	.	2	2
Fundulus diaphanus	1	1.00	.	1	1
Lepomis auritus	1	38.00	.	38	38
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	1	19.00	.	19	19

October

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	1	32.00	.	32	32
Notropis procne	1	9.00	.	9	9
Cyprinella analostana	1	12.00	.	12	12
Pimephales notatus	1	7.00	.	7	7
Ameiurus natalis	1	4.00	.	4	4
Fundulus heteroclitus	1	4.00	.	4	4
Fundulus diaphanus	1	1.00	.	1	1
Lepomis auritus	1	21.00	.	21	21
Etheostoma olmstedi	1	12.00	.	12	12

Table 24. (continued)

November

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	2	15.50	2.12	14	17
Notropis procne	2	7.00	7.07	2	12
Cyprinella analostana	2	24.00	31.11	2	46
Pimephales notatus	1	15.00	.	15	15
Catostomus commersoni	1	9.00	.	9	9
Ameiurus natalis	2	6.50	7.78	1	12
Fundulus heteroclitus	1	15.00	.	15	15
Lepomis auritus	1	4.00	.	4	4
Lepomis gibbosus	1	1.00	.	1	1
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	1	10.00	.	10	10

December

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	1	9.00	.	9	9
Notropis procne	1	17.00	.	17	17
Cyprinella analostana	1	31.00	.	31	31
Pimephales notatus	1	30.00	.	30	30
Catostomus commersoni	1	4.00	.	4	4
Ameiurus natalis	1	2.00	.	2	2
Fundulus heteroclitus	1	1.00	.	1	1
Lepomis auritus	1	4.00	.	4	4
Etheostoma olmstedi	1	2.00	.	2	2

Table 25. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in 4th order streams by month in Cameron Run from November, 2008 to July, 2010.

January

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	2	8.00	9.90	1	15
Notropis procne	3	4.67	2.31	2	6
Cyprinella analostana	2	5.00	4.24	2	8
Pimephales notatus	1	1.00	.	1	1
Catostomus commersoni	2	1.50	0.71	1	2
Erimyzon oblongus	1	1.00	.	1	1
Ameiurus natalis	1	1.00	.	1	1
Anguilla rostrata	2	5.50	4.95	2	9
Fundulus heteroclitus	1	1.00	.	1	1
Lepomis auritus	2	4.00	4.24	1	7
Lepomis gibbosus	1	1.00	.	1	1

March

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	3	30.67	25.70	1	46
Notropis procne	4	10.75	9.67	3	23
Cyprinella analostana	4	8.00	3.37	4	12
Pimephales notatus	2	12.00	5.66	8	16
Catostomus commersoni	2	5.00	1.41	4	6
Anguilla rostrata	2	5.50	3.54	3	8
Fundulus heteroclitus	2	1.00	0.00	1	1
Fundulus diaphanus	2	1.00	0.00	1	1
Lepomis auritus	2	2.00	1.41	1	3
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	1	1.00	.	1	1

April

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Semotilus atromaculatus	2	1.00	0	1	1
Rhinichthys atratulus	3	18.33	16.56	1	34
Notropis procne	2	1.00	0.00	1	1
Cyprinella analostana	2	1.50	0.71	1	2
Pimephales notatus	2	4.00	4.24	1	7
Catostomus commersoni	2	8.50	9.19	2	15
Ameiurus natalis	3	2.00	1.00	1	3
Ameiurus nebulosus	1	1.00	.	1	1
Anguilla rostrata	3	6.00	5.00	1	11
Fundulus heteroclitus	2	3.00	2.83	1	5
Lepomis auritus	3	30.67	21.94	6	48
Lepomis macrochirus	2	1.50	0.71	1	2
Etheostoma olmstedi	3	4.00	2.65	2	7

Table 25. (continued)

May

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Rhinichthys atratulus	2	34.50	31.82	12	57
Notropis procne	2	1.50	0.71	1	2
Cyprinella analostana	2	7.50	4.95	4	11
Pimephales notatus	1	1.00	.	1	1
Catostomus commersoni	1	5.00	.	5	5
Ameiurus natalis	2	4.00	2.83	2	6
Anguilla rostrata	1	8.00	.	8	8
Lepomis auritus	2	26.00	33.94	2	50
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	1	1.00	.	1	1

June

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Semotilus atromaculatus	2	1.50	0.71	1	2
Rhinichthys atratulus	4	16.50	24.79	1	53
Notropis procne	3	2.33	1.15	1	3
Cyprinella analostana	4	13.75	13.07	1	32
Pimephales notatus	1	1.00	.	1	1
Catostomus commersoni	4	6.75	4.99	2	12
Ameiurus natalis	3	4.67	3.79	2	9
Ameiurus nebulosus	1	1.00	.	1	1
Anguilla rostrata	2	28.50	4.95	25	32
Fundulus heteroclitus	1	1.00	.	1	1
Lepomis auritus	3	16.67	10.97	8	29
Lepomis macrochirus	2	3.00	2.83	1	5
Micropterus salmoides	2	3.50	2.12	2	5
Etheostoma olmstedi	3	2.33	0.58	2	3

July

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Semotilus atromaculatus	2	2.00	1.41	1	3
Rhinichthys atratulus	2	8.00	9.90	1	15
Notropis procne	1	6.00	.	6	6
Cyprinella analostana	1	21.00	.	21	21
Catostomus commersoni	2	7.50	3.54	5	10
Ameiurus natalis	2	4.50	2.12	3	6
Ameiurus nebulosus	1	2.00	.	2	2
Anguilla rostrata	1	61.00	.	61	61
Fundulus heteroclitus	1	1.00	.	1	1
Lepomis auritus	2	12.50	13.44	3	22
Micropterus salmoides	2	5.00	0.00	5	5
Etheostoma olmstedi	2	1.50	0.71	1	2

Table 25. (continued)

September

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Semotilus atromaculatus	1	23.00	.	23	23
Rhinichthys atratulus	1	22.00	.	22	22
Notropis procne	2	4.00	2.83	2	6
Cyprinella analostana	2	20.50	20.51	6	35
Pimephales notatus	1	2.00	.	2	2
Catostomus commersoni	2	5.50	0.71	5	6
Ameiurus natalis	2	10.00	12.73	1	19
Ameiurus nebulosus	1	1.00	.	1	1
Anguilla rostrata	2	9.50	12.02	1	18
Fundulus diaphanus	1	1.00	.	1	1
Lepomis auritus	2	26.50	28.99	6	47
Lepomis macrochirus	1	2.00	.	2	2
Etheostoma olmstedi	2	3.00	2.83	1	5

October

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Semotilus atromaculatus	1	6.00	.	6	6
Rhinichthys atratulus	1	105.00	.	105	105
Notropis procne	2	3.50	3.54	1	6
Cyprinella analostana	2	29.50	31.82	7	52
Catostomus commersoni	2	2.50	0.71	2	3
Ameiurus natalis	2	4.50	4.95	1	8
Anguilla rostrata	1	10.00	.	10	10
Fundulus heteroclitus	1	4.00	.	4	4
Fundulus diaphanus	1	6.00	.	6	6
Lepomis auritus	2	26.50	31.82	4	49
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	2	2.50	0.71	2	3

November

SPECIES	N	Mean	Std Dev	Minimum	Maximum
Cyprinella analostana	1	26.00	.	26	26
Notropis hudsonius	1	5.00	.	5	5
Catostomus commersoni	1	1.00	.	1	1
Ameiurus natalis	1	1.00	.	1	1
Ameiurus nebulosus	1	1.00	.	1	1
Anguilla rostrata	1	36.00	.	36	36
Fundulus heteroclitus	1	9.00	.	9	9
Lepomis auritus	1	6.00	.	6	6
Lepomis gibbosus	1	3.00	.	3	3
Lepomis macrochirus	1	1.00	.	1	1
Etheostoma olmstedi	1	2.00	.	2	2

Table 25. (continued)

December					
SPECIES	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Rhinichthys atratulus	1	39.00	.	39	39
Notropis procne	2	8.00	4.24	5	11
Cyprinella analostana	2	22.00	2.83	20	24
Pimephales notatus	1	25.00	.	25	25
Catostomus commersoni	1	8.00	.	8	8
Anguilla rostrata	1	2.00	.	2	2
Lepomis auritus	2	9.00	11.31	1	17
Etheostoma olmstedi	2	1.50	0.71	1	2

Table 26. Results of Duncan's Multiple Range test (SAS, 2009) of mean values of species richness and diversity indices (i.e., Shannon Weaver, HMAX, and Evenness) by month in Cameron Run watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p=0.05.

Cameron Run Watershed

Variable = RICHNESS

Month	**Jan.**	**March**	**Dec.**	**May**	**Nov.**	**April**	**July**	**Oct.**	**June**	**Sept.**
Mean	3.286	4.538	4.571	4.857	5.429	5.429	5.667	5.857	5.929	6.571

F = 0.84
p>F = 0.5813
df = 9

Variable = SHANNON

Month	**Jan.**	**March**	**May**	**April**	**Dec.**	**July**	**Oct.**	**June**	**Nov.**	**Sept.**
Mean	0.6910	0.8679	0.9016	0.9482	1.0118	1.0189	1.0785	1.1110	1.1409	1.2587

F = 0.67
p>F = 0.7321
df = 9

Variable = EVENNESS

Month	**Jan.**	**April**	**March**	**July**	**June**	**May**	**Oct.**	**Nov.**	**Dec.**	**Sept.**
Mean	0.6112	0.6118	0.6415	0.6449	0.6576	0.6884	0.7403	0.7616	0.7925	0.8340

F = 1.19
p>F = 0.3139
df = 9

Table 27. Results of Duncan's Multiple Range Test (SAS, 2009) of fish species richness and diversity indices (Shannon Weiner Index and evenness) by stream order in Quantico Creek and Cameron Run watersheds from November, 2008 – June, 2010.

Variable = RICHNESS

Habitat	**Cameron-1**	**Quantico-1**	**Cameron-2**	**Quantico-2**	**Cameron-4**	**Cameron-3**	**Quantico-3**
Mean	2.1081	2.5349	5.3158	6.3030	7.5926	8.0769	9.6494

F = 61.51, p>F = <.0001, df = 6

Variable = SHANNON

Habitat	**Quantico-1**	**Cameron-1**	**Cameron-2**	**Cameron-4**	**Quantico-2**	**Cameron-3**	**Quantico-3**
Mean	0.4479	0.4481	1.0694	1.3601	1.5385	1.5399	1.8402

F = 61.46, p>F = <.0001, df = 6

Variable = EVENNESS

Habitat	**Cameron-2**	**Cameron-4**	**Cameron-1**	**Cameron-3**	**Quantico-1**	**Quantico-3**	**Quantico-2**
Mean	0.65003	0.67945	0.68532	0.71548	0.74790	0.83373	0.86745

F = 11.56, p>F = <.0001, df = 6

Table 28. Number of species per stream order, species in common and unique in stream orders, and Jaccard Coefficient of Similarity of Species in Quantico Creek and Cameron Run watersheds from November, 2008 – June, 2010.

Watershed	Stream Order	Total # Species	Stream Order Comparison	# Species in Common	Species unique to lower order	Species unique to higher order	Jaccard Coefficient of Similarity x 100
Quantico	1	12	1st & 2nd	12	0	8	60
	2	20	2nd and 3rd	19	1	10	63
	3	28					
Cameron	1	4	1st & 2nd	4	0	7	36
	2	11	2nd and 3rd	6	4	9	32
	3	15	3rd & 4th	14	1	5	70
	4	19					

Table 29. Results of stepwise multiple regression for fish species richness in Quantico Creek watershed, VA.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	0.51449	1.52377	0.42881	0.11	0.7361
Season	0.4346	0.12194	47.77655	12.7	0.0005
Stream Order	1.73006	0.42001	63.81895	16.97	<.0001
Elevation (m)	0.04152	0.00888	82.19455	21.85	<.0001
River Km	0.25609	0.04545	119.43246	31.75	<.0001
Stream Width (m)	0.23222	0.1274	12.49708	3.32	0.0703
Stream Depth (m)	2.00873	1.07362	13.16716	3.5	0.0633
Watershed Size (ha)	0.00081546	0.00027589	32.86265	8.74	0.0036
% Undeveloped Land Cover	-0.08121	0.01439	119.84079	31.86	<.0001

Table 30. Results of stepwise multiple regression for fish species diversity in Quantico Creek watershed, VA.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	1.82408	0.37076	3.06671	24.21	<.0001
Season	0.07887	0.0226	1.54237	12.17	0.0006
Stream order	0.14638	0.07747	0.45237	3.57	0.0607
River km	0.04835	0.00796	4.67192	36.87	<.0001
Stream gradient (m/km)	-0.0354	0.00446	7.99144	63.08	<.0001
Stream width (m)	0.08194	0.01939	2.26252	17.86	<.0001
Stream depth (m)	0.50794	0.19628	0.84845	6.7	0.0106
% Undeveloped land cover	-0.01902	0.0026	6.79646	53.64	<.0001

Table 31. Results of stepwise multiple regression for fish species richness in Cameron Run watershed, VA.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	10.10139	0.9337	258.54354	117.04	<.0001
Stream Gradient (m/km)	-0.62161	0.05149	321.99878	145.77	<.0001
Stream Flow (m3/sec)	0.18116	0.08929	9.09247	4.12	0.0463
Water temperature (C)	0.11283	0.02304	52.97471	23.98	<.0001
% Undeveloped Land Cover	-0.03953	0.01496	15.43041	6.99	0.0102

Table 32. Results of stepwise multiple regression for fish species diversity in Cameron Run watershed, VA.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	2.54731	0.33545	8.31995	57.67	<.0001
Season	0.05584	0.03583	0.35048	2.43	0.1236
Elevation (m)	-0.02945	0.00371	9.09569	63.04	<.0001
Water temperature (C)	0.01455	0.00703	0.61796	4.28	0.0422
Undeveloped land cover (ha)	-0.000286	0.00012443	0.76121	5.28	0.0246
% Undeveloped land cover	-0.00699	0.00376	0.50003	3.47	0.0669

Table 33. Results of multiple stepwise regression of differences in parameters accounting for decreased species richness in Cameron Run watershed.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	3.9176	0.60136	5.0799	42.44	0.0073
Impervious cover (ha)	-0.00071468	0.00017453	2.00718	16.77	0.0263
Mcroinvertebrate Functional Feed Group Richness	2.67075	0.29467	9.8325	82.15	0.0028
Stream flow (m^3/sec)	-4.57279	0.87578	3.26326	27.26	0.0137
Water temperature (C)	1.23308	0.47401	0.81	6.77	0.0803

Table 34. Macroinvertebrate taxa richness by order in Quantico Creek and Cameron Run watersheds from June-October 2009.

		Quantico Creek			Cameron Run			
	Stream Order	**1**	**2**	**3**	**1**	**2**	**3**	**4**
EPHEMEROPTERA	Ameletidae		X	X				
	Baetidae	X		X			X	X
	Caenidae			X				
	Caenis sp.							X
	Ephemerellidae		X	X				
	Ephemerella sp.			X				
	Heptageniidae	X	X	X				
	Maccaffertium sp.	X						
	Isonychiidae		X	X				
	Isonychia sp			X				
	Leptophlebiidae	X	X					
	Leptophlebia sp.	X						
	Paraleptophlebia sp.	X	X					
	Potamanthidae	X						
	Siphlonuridae		X	X				
Subtotal		**7**	**7**	**9**	**-**	**-**	**1**	**2**
PLECOPTERA	Capniidae	X						
	Chloroperlidae	X	X					
	Leuctridae	X	X	X				
	Nemouridae							
	Amphinemura sp.	X	X					
	Podmosta sp.	X						
	Peltoperlidae			X				
	Perlidae	X	X	X				
	Acroneuria sp.	X		X				
	Ecoptura sp.	X						
	Hexatoma sp.	X						
	Neoperla sp.			X				
	Paragnetina sp.			X				
	Perlesta sp.			X				
	Perlodidae		X					
	Pteronarcyidae							
	Pteronarcys sp.		X					
	Taenioptergidae	X						
Subtotal		**10**	**6**	**7**	**-**	**-**	**-**	**-**

Table 34 (cont'd)

TRICHOPTERA	Brachycentridae			X				
	Brachycentrus sp.		X					
	Calamoceratidae		X					
	Anisocentropus pyraioides	X						
	Glossomatidae	X		X				
	Hydropsychidae	X	X	X	X	X	X	X
	Cheumatopsyche ps.	X	X	X				
	Diplectrona sp.	X						
	Hydropsyche sp.		X	X		X		
	Hydropsychid Genus A			X				
	Potamyia sp.		X					
	Hydroptilidae			X				
	Lepidostomatidae	X						
	Leptoceridae							
	Oecetis sp.			X				
	Limnephilidae	X		X				
	Pycnopsyche sp.	X						
	Philopotamidae	X	X	X	X			
	Chimarra sp.	X						
	Phryganeidae		X	X				
	Polycentropodidae		X	X	X			
	Psychomyiidae	X	X					
	Rhyacophilidae	X	X					
Subtotal		**12**	**11**	**12**	**3**	**2**	**1**	**1**
COLEOPTERA	Chrysomelidae	X						
	Donacia sp.		X			X		
	Dytiscidae	X		X				
	Oreodytes sp.	X						
	Elmidae	X	X	X				
	Rhizelmis sp.			X				
	Stenelmis sp.		X					
	Georissidae		X					
	Heteroceridae							X
	Hydrophilidae		X	X		X		X
	Lampyridae							X
	Psephenidae			X				
	Ptilodactylidae							
	Anchytarsus bicolor	X						
	Anchycteis sp.	X						
	Staphylinidae		X	X				
Subtotal		**6**	**6**	**6**	**-**	**2**	**-**	**3**

Table 34 (cont’d)

DIPTERA	Athericidae			X		X		
	Ceratopogonidae	X		X				
	Chaoboridae			X				
	Chironomidae	X	X	X	X	X	X	X
	Brilla sp.		X					
	Chironomus sp.	X	X	X	X	X	X	
	Cricotopus sp.						X	
	Cryptochironomus sp.	X	X			X		
	Dicrotendipes sp.				X			
	Endochironomus sp.		X	X				
	Hexatoma sp.		X					
	Metriochemus sp.	X						
	Microtendipes sp.	X	X	X		X		
	Paralauterborniella sp.		X			X		
	Pedicia sp.	X						
	Pentaneura sp.	X	X					
	Polypedilum sp.	X	X	X	X	X	X	
	Procladius sp.	X	X	X	X	X	X	X
	Psectrocladius sp.			X				
	Smittia sp.						X	
	Tanypodinae Tribe Pentanurini		X	X				
	Corethrellidae		X					
	Culicidae		X	X			X	
	Dixidae	X						
	Empididae		X					
	Nymphomyiidae		X					
	Pediciidae		X					
	Psychodidae		X				X	
	Ptychopteridae	X						
	Simuliidae		X	X			X	X
	Stratiomyidae		X					
	Syrphidae		X		X			
	Tabanidae	X						
	Thaumaleidae			X				
	Tipulidae	X	X	X		X	X	
	Antocha sp.			X			X	
	Cryptolabis sp.		X				X	
	Dicranota sp.	X		X			X	
	Erioptera sp.		X					
	Limnophila sp.		X	X				
	Pedicia sp.				X			
	Phalacrocera sp.			X				

Table 34 (cont'd)

	Tipula sp.	X	X	X	X	X	X	X
Subtotal		**16**	**26**	**20**	**8**	**10**	**14**	**4**
MEGALOPTERA	Corydalidae	X	X	X			X	
	Corydalus cornutus	X	X	X				X
	Nigronia sp.	X						
	Sialidae	X	X	X				
Subtotal		**4**	**3**	**3**	**-**	**-**	**1**	**1**
ODONATA	Aeshnidae	X		X				
	Aeshna sp.			X				
	Anax junius					X		
	Boyeria sp.			X				
	Agrionidae							
	Amphiagrion sp.					X		
	Argia sp.		X			X		
	Calopterygidae							
	Calopteryx sp.							X
	Coenagrionidae							X
	Cordulegastridae	X						
	Cordulegaster sp.		X	X				
	Corduliidae			X				
	Gomphidae			X				
	Gomphus sp.		X	X				
	Hagenius sp.			X				
	Lestidae							
	Archilestes sp.					X		
	Lestes sp.							X
	Libelluidae	X						
	Macromiidae			X				
	Macromia sp.			X				
	Unidentified	X	X	X	X	X	X	X
Subtotal		**4**	**4**	**11**	**1**	**5**	**1**	**4**
GASTROPODA	Bithyniidae			X				
	Physidae		X	X	X	X	X	X
	Planorbidae		X	X		X		X
	Viviparidae			X				
Subtotal		**-**	**2**	**4**	**1**	**2**	**1**	**2**
VENEROIDA	Corbiculidae	X	X	X			X	
	Corbicula fluminea			X				

Table 34 (cont'd)

	Sphaeriidae	X	X	X			X	X
Subtotal		**2**	**2**	**3**	**-**	**-**	**2**	**1**
OTHER	Amphipoda	X	X	X	X	X	X	X
	Decapoda	X	X	X	X	X	X	X
	Isopoda	X			X	X		X
	Oligochaeta	X		X	X			
Subtotal		**4**	**2**	**3**	**4**	**3**	**2**	**3**
TOTAL		**65**	**69**	**78**	**17**	**24**	**23**	**21**

Table 35. Results of t-test (SAS, 2009) of macroinvertebrate taxa richness and functional feeding group (FFG) richness measured in Quantico Creek and Cameron Run watersheds from June-October 2009. Asterisk (*) indicates significant difference in means.

Taxa Richness

	Mean ± 1 Standard Deviation				
Stream Order	Quantico Creek	Cameron Run	F-value	Pr > F	
1	11.727 ± 4.403	6.375 ± 2.618	4.77	0.0096	*
2	16.869 ± 7.007	12.263 ± 4.733	2.65	0.1559	
3	15.101 ± 4.874	8.059 ± 2.204	5.54	0.0262	*
3&4	15.101 ± 4.874	10.854 ± 2.594	4.22	0.2604	

Functional Feeding Group Richness

	Mean ± 1 Standard Deviation				
Stream Order	Quantico Creek	Cameron Run	F value	Pr > F	
1	4.958 ± 6.843	2.118 ± 2.027	11.39	<.0001	*
2	5.106 ± 6.249	3.667 ± 4.747	1.73	0.1824	
3	6.152 ± 8.897	2.042 ± 1.654	28.92	<.0001	*
3&4	6.152 ± 8.897	2.176 ± 1.944	20.94	<.0001	*

Table 36. Macroinvertebrate functional feeding group (FFG) richness and composition in Quantico Creek and Cameron Run watersheds from June-October 2009. *S* denotes specialist and *G* denotes generalist feeding strategies.

Quantico Creek				Cameron Run			
Functional Feeding Group	Primary Strategy*	N		Functional Feeding Group	Primary Strategy*	N	
Predator	S	35	34.0%	Predator	S	16	34.0%
Gather-Collector	S	21	20.4%	Gather-Collector	S	10	21.3%
Filter-Collector	S	12	11.7%	Filter-Collector	S	6	12.8%
Shredder	S	10	9.7%	Shredder	S	3	6.4%
Scraper	S	7	6.8%	Scraper	S	3	6.4%
Shredder-Gatherer	G	6	5.8%	Shredder-Gatherer	G	3	6.4%
Gatherer-Scraper	G	4	3.9%	Filterer-Gatherer	G	3	6.4%
Filterer-Gatherer	G	3	2.9%	Gatherer-Scraper	G	1	2.1%
Gatherer-Predator	G	2	1.9%	Gatherer-Predator	G	1	2.1%
Filterer-Scraper	G	1	1.0%	Shredder-Gatherer-Predator	G	1	2.1%
Filterer-Predator	G	1	1.0%	Filterer-Scraper	G	0	0.0%
Shredder-Gatherer-Predator	G	1	1.0%	Filterer-Predator	G	0	0.0%
		103				47	

Table 37. Macroinvertebrate functional feeding group (FFG) richness and composition in Quantico Creek and Cameron Run watersheds from June-October 2009.

Quantico Creek			
FFG	**Order**	**Family**	**Lowest Taxon**
GATHER COLLECTOR: 21 (20.4%)	Amphipoda	Gammeridae	*Gammrus* sp.
		Talitridae	*Hyalella* sp.
	Coleoptera	Ptilodactylidae	*Anchycteis* sp.
			Anchytarsus bicolor
	Decapoda	Palaemonidae	*Palaemonetes* sp.
	Diptera	Chironomidae	*Paralauterborniella* sp.
		Psychodidae	Psychodidae
		Ptychopteridae	Ptychopteridae
		Thaumaleidae	Thaumaleidae
		Tipulidae	*Antocha* sp.
	Ephemeroptera	Baetidae	Baetidae
		Caenidae	*Caenis* sp.
		Ephemerellidae	*Ephemerella* sp.
		Heptageniidae	Heptageniidae
		Leptophlebiidae	*Leptophlebia* sp.
		Siphlonuridae	Siphlonuridae
	Oligochaeta		Oligochaeta
	Plecoptera	Capniidae	Capniidae
	Trichoptera	Hydropsychidae	Hydropsychidae
		Philopotamidae	Philopotamidae
		Psychomyiidae	Psychomyiidae
PREDATOR: 35 (34.0%)	Coleoptera	Dytiscidae	*Oreodytes* sp.
		Georissidae	Georissidae
		Hydrophillidae	Hydrophillidae
		Staphylinidae	Staphylinidae
	Diptera	Athericidae	Athericidae
		Chaoboridae	Chaoboridae
		Ceratopogonidae	Ceratopogonidae
		Chironomidae	*Cryptochironomus* sp.
			Pentaneura sp.
			Procladius sp.
			Tanypodinae Tribe Pentanurini
		Corethrellidae	Corethrellidae
		Pediciidae	*Pedicia* sp.
		Tabanidae	Tabanidae
		Tipulidae	*Dicranota* sp.
	Megaloptera	Corydalidae	*Corydalus cornutus*

		Sialidae	Sialidae
Table 37. (Cont'd.)	Odonata	Aeshnidae	*Aeshna* sp.
			Boyeria sp.
		Agrionidae	*Argia* sp.
		Cordulegastridae	*Cordulegaster*
		Corduliidae	Corduliidae
		Gomphidae	*Gomphus* sp.
			Hagenius sp.
		Libellulidae	*Dorocordulia*
		Macromiidae	*Macromia* sp.
	Plecoptera	Chloroperlidae	Chloroperlidae
		Perlidae	*Acroneuria* sp.
			Ecoptura sp.
			Neoperla sp.
			Paragnetina sp.
			Perlesta sp.
		Perlodidae	Perlodidae
	Trichoptera	Leptoceridae	*Oecetis* sp.
		Rhyacophilidae	Rhyacophilidae
SCRAPER:	Coleoptera	Psephenidae	Psephenidae
7 (6.8%)	Gastropoda	Bithyniidae	Bithyniidae
		Physidae	Physidae
		Planorbidae	Planorbidae
	Trichoptera	Calamoceratidae	*Anisocentropus pyraloides*
		Glossosomatidae	Glossosomatidae
FILTER COLLECTOR: 12 (11.7%)	Diptera	Simuliidae	Simuliidae
		Stratiomyidae	Stratiomyidae
	Ephemeroptera	Potamanthidae	Potamanthidae
	Trichoptera	Hydropsychidae	*Cheumatopsyche* sp.
			Diplectrona sp.
			Hydropsyche sp.
			Hydropsychid Genus A
			Potamyia sp.
		Philopotamidae	*Chimarra* sp.
		Polycentropidae	Polycentropidae
	Veneroida	Corbiculidae	*Corbicula fluminea*
		Sphaeriidae	Sphaeriidae
SHREDDER:	Coleoptera	Chrysomelidae	*Donacia* sp.
10 (9.7%)	Diptera	Tipulidae	*Cryptolabis* sp.
			Dicranota sp.
			Erioptera sp.
			Limnophila sp.
			Phalacrocera sp.

	Plecoptera	Leuctridae	Leuctridae
		Pteronarcyidae	*Pteronarcys* sp.

Table 37. (Cont'd.)

	Trichoptera	Limnephilidae	Limnephilidae
		Phrganeidae	Phrganeidae
SHREDDER GATHERER: 6 (5.8%)	Diptera	Tipulidae	*Tipula* sp.
		Chironomidae	*Brilla* sp.
			Chironomus sp.
			Psectrocladius sp.
		Dixidae	Dixidae
	Ephemeroptera	Leptophlebiidae	Leptophlebiidae
GATHERER SCRAPER: 4 (3.9%)	Coleoptera	Elmidae	Elmidae
	Ephemeroptera	Ameletidae	Ameletidae
		Heptageniidae	Heptageniidae
	Trichoptera	Hydropsychidae	Hydropsychidae
GATHERER PREDATOR: 2 (1.9%)	Diptera	Chironomidae	*Metriochemus* sp.
		Syrphidae	Syrphidae
FILTERER SCRAPER: (1.0%)	Diptera	Nymphomyiidae	Nymphomyiidae
FILTERER GATHERER: 3 (2.9%)	Diptera	Chironomidae	*Microtendipes* sp.
		Culicidae	Culicidae
	Ephemeroptera	Siphlonuridae	Siphlonuridae
FILTERER PREDATOR: 1 (1.0%)	Ephemeroptera	Isonychidae	*Isonychia* sp.
SHREDDER GATHERER PREDATOR: 1 (1.0%)	Diptera	Chironomidae	*Polypedilum* sp.
Total Taxa			103

Cameron Run

FFG	Order	Family	Lowest Taxon
GATHERER COLLECTOR: 10 (21.3%)	Amphipoda	Talitridae	*Hyalella* sp.
	Decapoda	Palaemonidae	*Palaemonetes* sp.
	Diptera	Chironomidae	*Paralauterborniella* sp.
			Smittia sp.
		Psychodidae	Psychodidae
		Tipulidae	*Antocha* sp.

	Ephemeroptera	Baetidae	Baetidae
		Caenidae	*Caenis* sp.
	Oligochaeta		Oligochaeta
Table 37. (Cont'd.)			
	Trichoptera	Hydropsychidae	Hydropsychidae
PREDATOR: 16 (34.0%)	Coleoptera	Hydrophillidae	Hydrophillidae
		Lampyridae	Lampyridae
	Diptera	Athericidae	Athericidae
		Chironomidae	*Cryptochironomus* sp.
			Procladius sp.
		Pediciidae	*Pedicia* sp.
		Tipulidae	*Dicranota* sp.
	Hirudinea		Hirudinea
	Megaloptera	Corydalidae	*Corydalus cornutus*
	Odonata	Aeshnidae	*Anax junius*
		Agrionidae	*Amphiagrion* sp.
			Argia sp.
		Calopterygidae	*Calopteryx* sp.
		Coenagrionidae	Coenagrionidae
		Lestidae	*Archilestes* sp.
			Lestes sp.
SCRAPER: 3 (6.4%)	Gastropoda	Bithyniidae	Bithyniidae
		Physidae	Physidae
		Planorbidae	Planorbidae
FILTER COLLECTOR: 6 (12.8%)	Diptera	Simuliidae	Simuliidae
	Trichoptera	Hydropsychidae	*Hydropsyche* sp.
		Philopotamidae	*Chimarra* sp.
		Polycentropidae	Polycentropidae
	Veneroida	Corbiculidae	*Corbicula fluminea*
		Sphaeriidae	Sphaeriidae
SHREDDER: 3 (6.4%)	Coleoptera	Chrysomelidae	*Donacia* sp.
	Diptera	Tipulidae	*Cryptolabis* sp.
	Isopoda		Isopoda
SHREDDER GATHERER: 3 (6.4%)	Diptera	Tipulidae	*Tipula* sp.
		Chironomidae	*Chironomus* sp.
			Cricotopus sp.
GATHERER SCRAPER: 1 (2.1%)	Coleoptera	Elmidae	Elmidae
GATHERER PREDATOR: 1 (2.1%)	Diptera	Syrphidae	Syrphidae
FILTERER SCRAPER: 0 (0%)			
FILTERER GATHERER: 3 (6.4%)	Diptera	Chironomidae	*Dicrotendipes* sp.

			Microtendipes sp.
		Culicidae	Culicidae

Table 37. (Cont'd.)

FILTERER PREDATOR: 0 (0%)			
SHREDDER GATHERER PREDATOR: 1 (2.1%)	Diptera	Chironomidae	*Polypedilum* sp.
Total Taxa			47

Table 38. Results of Duncan's Multiple Range test (SAS, 2009) of macroinvertebrate taxa richness, functional feeding group (FFG) richness, evenness and Shannon diversity index measured in Quantico Creek and Cameron Run watersheds from June-October 2009. Underscored means do not differ at p = 0.05.

Variable = Taxa Richness

Stream Order	Cameron 1	Cameron 4	Cameron 3	Cameron 2	Quantico 1	Quantico 2	Quantico 3
Mean	6	6.75	9.25	13.25	23	31.5	38
	—	—	—	—			
				—	—		
					—	—	
						—	—

F = 11.29
p>F = <0.0001

Variable = FFG Richness

Stream Order	Cameron 1	Cameron 4	Cameron 3	Cameron 2	Quantico 1	Quantico 2	Quantico 3
Mean	4.0	4.0	5.25	5.75	6.75	9.5	9.5
	—	—	—	—			
			—	—	—		
						—	—

F = 7.58
p>F = 0.0002

Variable = FFG Evenness

Stream Order	Cameron 1	Quantico 3	Quantico 1	Cameron 2	Quantico 2	Cameron 4	Cameron 3
Mean	0.7147	0.8788	0.8891	0.8925	0.8932	0.9171	0.9368
	—	—	—	—	—	—	—

F = 0.62
p>F = 0.7129

Variable = FFG Diversity

Stream Order	Cameron 1	Cameron 4	Cameron 3	Cameron 2	Quantico 1	Quantico 2	Quantico 3
Mean	1.1533	1.2593	1.5311	1.5318	1.6794	1.9761	1.9972
	—	—	—	—	—		
			—	—	—	—	—

F = 3.5
p>F = 0.0147

Table 39. Macroinvertebrate taxa richness and functional feeding group (FFG) richness by month in Quantico Creek and Cameron Run watersheds from June-October 2009.

		Quantico Creek			Cameron Run			
		Stream Order						
Month	Parameter	1	2	3	1	2	3	4
June	Taxa Richness	43	38	44	0	9	10	7
	FFG Richness	8	11	9	0	5	5	5
July	Taxa Richness	19	30	37	13	24	14	7
	FFG Richness	7	7	10	8	8	7	4
August	Taxa Richness	14	24	46	6	12	7	7
	FFG Richness	5	10	10	4	5	4	3
October	Taxa Richness	16	34	25	5	8	6	6
	FFG Richness	7	10	9	4	5	5	4

Table 40. Results of analysis of variance and multiple stepwise regression analysis (SAS, 2009) for macroinvertebrate taxa richness, functional feeding group (FFG) richness and Shannon diversity indices measured in Quantico Creek and Cameron Run watersheds from June-October 2009. All variables left in the model are significant at the 0.1000 level.

		Quantico Creek				
	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Taxa Richness	Intercept	12.57518	3.08899	370.25932	16.57	0.0002
	Stream Order	6.86044	2.12885	232.01982	10.39	0.0025
	River km	-0.4976	0.19868	140.14379	6.27	0.0163
	Watershed Size	0.01589	0.00875	73.6296	3.3	0.0768
	Population in the Sub-watershed	-0.00438	0.00257	64.9283	2.91	0.0958
	Undeveloped Land (ha)	-0.01994	0.0093	102.6349	4.59	0.0381
FFG Richness	Intercept	4.56929	0.79373	56.09605	33.14	<.0001
	Stream Order	1.30416	0.3843	19.49383	11.52	0.0015
	Elevation	-0.01705	0.00931	5.67646	3.35	0.074
	Forested Hectares	-0.00077	0.000207	23.4534	13.86	0.0006
FFG Diversity	Intercept	1.84658	0.26394	2.90436	48.95	<.0001
	Stream Order	0.17754	0.06836	0.40023	6.75	0.0128
	Average Width	-0.04009	0.01548	0.39825	6.71	0.013
	Percent Undeveloped Land (ha) s	-0.00581	0.00276	0.26252	4.42	0.0413

Table 40. (Continued).

	Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
	Cameron Run					
Taxa Richness	Intercept	-25.09794	9.20591	36.02912	7.43	0.0197
	Month	7.81614	1.49182	133.0654	27.45	0.0003
	Elevation	0.38474	0.20735	16.6892	3.44	0.0003
	Gradient	-2.17792	0.88229	29.53747	6.09	0.0312
	Average Width	0.76503	0.30658	30.18431	6.23	0.0298
	Water Temperature	-0.90849	0.47794	17.51509	3.61	0.0838
	Watershed Size	0.04868	0.01344	63.55417	13.11	0.004
	Amount of Impervious Surfaces	-0.06506	0.01825	61.62149	12.71	0.0044
	Percent Undeveloped Land (ha)	-0.32548	0.08784	66.56005	13.73	0.0035
FFG Richness	Intercept	5.69777	3.50691	1.11156	2.64	0.1325
	Month	3.37471	0.043451	25.40013	60.32	<.0001
	Stream Order	1.78262	0.42666	7.35062	17.46	0.0015
	Elevation	0.20657	0.04578	8.57487	20.36	0.0009
	Gradient	-1.55543	0.2239	20.32249	48.26	<.0001
	Average Width	0.47074	0.10341	8.72649	20.72	0.0008
	Average Current	-7.15292	1.91873	5.85203	13.9	0.0033
	Water Temperature	-0.98292	0.1476	18.67482	44.35	<.0001
	Percent Undeveloped Land (ha)	-0.16547	0.02292	21.94374	52.11	<.0001
FFG Diversity	Intercept	-2.15556	1.13343	0.31021	3.62	0.0766
	Month	0.54623	0.15958	1.00492	11.72	0.0038
	River km	0.07009	0.01709	1.44287	16.82	0.0009
	Gradient	-0.12109	0.02994	1.40328	16.36	0.0011
	Flow	0.49597	0.25126	0.33418	3.9	0.0671

Table 41: Stage-storage-discharge relationships at Lake Barcroft and Fairview Lake.

Lake Barcroft				**Fairview Lake**		
Elevation (ft)	Storage (ac-ft)	Flow (cfs)		Elevation (ft)	Storage (ac-ft)	Flow (cfs)
178.00	1500.00	0*		310	16.05	0
208.00	1932.36	1.1		312	20.65	131
208.25	1966.18	1.1		314	25.25	368
208.33	1977.00	2.8		316	30.26	661
208.50	2000.00	1,081.0		318	35.69	987
209.00	2067.64	4,219.0		320	41.11	2181
209.50	2135.28	7,956.0		322	60.83	4997
210.00	2202.92	11,693.0		324	80.54	8940
210.50	2270.56	18,086.0		326	97.98	13594
				328	113.14	18622

* A zero flow depth was added to allow some flow during dry weather period

Table 42. Monthly potential evapotranspiration used in the Cameron Run and the Quantico Creek watershed models.

Month	Potential Evapotranspiration		
	Reagan Washington National Airport*	Fredericksburg	Quantico Creek**
	(in/month)	(in/month)	(in/month)
January	0.07	0.07	0.07
February	0.16	0.13	0.15
March	0.80	0.84	0.82
April	2.13	2.11	2.12
May	3.87	3.8	3.84
June	5.5	5.23	5.37
July	6.51	6.11	6.31
August	5.84	5.46	5.65
September	4.06	3.83	3.95
October	2.15	2.04	2.10
November	0.88	0.82	0.85
December	0.22	0.20	0.21
Total	32.19	30.66	31.415

* Applied to Cameron Run watershed

** Interpolated between Regan Washington Airport and Fredericksburg measurements

Table 43. Mean, standard deviation (Std. dev.), minimum, and maximum values of survey questions for EcoLab at the Science Museum of Virginia. Classification for al categories is 5=Excellent; 4=Good; 3=Neutral; 2=Fair; and 1=Poor except for Familiarity with ecology principles where 0= no knowledge; 1=Some knowledge; 2=Good knowledge; and Comments provided: 0=no written comments; 1=written comments provided.

Individual					
Variable	N	Mean	Std Dev	Minimum	Maximum
Familiarity with ecology principles	2	2.00	0.00	2	2
EcoLab Atmosphere	2	5.00	0.00	5	5
Helpfulness of staff	2	5.00	0.00	5	5
Ecophoto experience	2	5.00	0.00	5	5
Sorting experience	2	5.00	0.00	5	5
Identification experience	2	5.00	0.00	5	5
Magnify experience	2	5.00	0.00	5	5
Water quality wrap=up	2	5.00	0.00	5	5
Overall children's opinion of EcoLab	2	5.00	0.00	5	5
Overall adult's opinion of EcoLab	2	5.00	0.00	5	5
Comments provided	2	1.00	0.00	1	1
Immediate Family					
Familiarity with ecology principles	17	1.24	0.97	0	2
EcoLab Atmosphere	17	4.71	0.47	4	5
Helpfulness of staff	17	4.94	0.24	4	5
Ecophoto experience	17	4.65	0.70	3	5
Sorting experience	17	4.76	0.44	4	5
Identification experience	17	4.76	0.44	4	5
Magnify experience	17	4.82	0.39	4	5
Water quality wrap=up	16	4.75	0.45	4	5
Overall children's opinion of EcoLab	17	4.88	0.33	4	5
Overall adult's opinion of EcoLab	17	4.88	0.33	4	5
Comments provided	17	0.41	0.51	0	1
Extended Family					
Familiarity with ecology principles	3	0.00	0.00	0	0
EcoLab Atmosphere	3	4.67	0.58	4	5
Helpfulness of staff	3	5.00	0.00	5	5
Ecophoto experience	3	4.67	0.58	4	5
Sorting experience	3	4.67	0.58	4	5
Identification experience	3	4.67	0.58	4	5
Magnify experience	3	4.67	0.58	4	5
Water quality wrap=up	3	5.00	0.00	5	5

Table 43 (cont'd)					
Overall children's opinion of EcoLab	3	5.00	0.00	5	5
Overall adult's opinion of EcoLab	3	5.00	0.00	5	5
Comments provided	3	0.67	0.58	0	1
School / Community Group					
Familiarity with ecology principles	3	0.67	1.15	0	2
EcoLab Atmosphere	4	4.75	0.50	4	5
Helpfulness of staff	4	4.75	0.50	4	5
Ecophoto experience	2	5.00	0.00	5	5
Sorting experience	1	5.00	.	5	5
Identification experience	1	5.00	.	5	5
Magnify experience	3	5.00	0.00	5	5
Water quality wrap=up	1	5.00	.	5	5
Overall children's opinion of EcoLab	1	5.00	.	5	5
Overall adult's opinion of EcoLab	1	5.00	.	5	5
Comments provided	4	0.75	0.50	0	1

Table 44. Frequency and percent of survey questions for EcoLab experiences at the Science Museum of Virginia from March 2010-August, 2010.

EcoLab Atmosphere					
	Good	Excellent	Total		
Individual	0	2	2	Frequency	
	0	7.69	7.69	%	
Immediate Family	5	12	17	Frequency	
	19.23	46.15	65.38	%	
Extended Family	1	2	3	Frequency	
	3.85	7.69	11.54	%	
School / Community Group	1	3	4	Frequency	
	3.85	11.54	15.38	%	
Total	7	19	26	Frequency	
%	26.92	73.08	100	%	
Helpfulness of Staff					
	Good	Excellent	Total		
Individual	0	2	2	Frequency	
	0	7.69	7.69	%	
Immediate Family	1	16	17	Frequency	
	3.85	61.54	65.38	%	
Extended Family	0	3	3	Frequency	
	0	11.54	11.54	%	
School / Community Group	1	3	4	Frequency	
	3.85	11.54	15.38	%	
Total	2	24	26	Frequency	
%	7.69	92.31	100	%	
Sort Activity	Good	Excellent	Total		
Individual	0	2	2	Frequency	
	0	8.7	8.7	%	
Immediate Family	4	13	17	Frequency	
	17.39	56.52	73.91	%	
Extended Family	1	2	3	Frequency	
	4.35	8.7	13.04	%	
School / Community Group	0	1	1	Frequency	
	0	4.35	4.35	%	
Total	5	18	23	Frequency	

%	21.74	78.26	100	%	
Table 44 (cont’d.)					
Identify Activity					
	Good	Excellent	Total		
Individual	0	2	2	Frequency	
	0	8.7	8.7	%	
Immediate Family	4	13	17	Frequency	
	17.39	56.52	73.91	%	
Extended Family	1	2	3	Frequency	
	4.35	8.7	13.04	%	
School / Community Group	0	1	1	Frequency	
	0	4.35	4.35	%	
Total	5	18	23	Frequency	
%	21.74	78.26	100	%	
Magnify Activity	Good	Excellent	Total		
Individual	0	2	2	Frequency	
	0	8	8	%	
Immediate Family	3	14	17	Frequency	
	12	56	68	%	
Extended Family	1	2	3	Frequency	
	4	8	12	%	
School / Community Group	0	3	3	Frequency	
	0	12	12	%	
Total	4	21	25	Frequency	
%	16	84	100	%	
Water Quality Wrap-up	Good	Excellent	Total		
Individual	0	2	2	Frequency	
	0	9.09	9.09	%	
Immediate Family	4	12	16	Frequency	
	18.18	54.55	72.73	%	
Extended Family	0	3	3	Frequency	
	0	13.64	13.64	%	
School / Community Group	0	1	1	Frequency	
	0	4.55	4.55	%	
Total	4	18	22	Frequency	
%	18.18	81.82	100	%	
Children's Opinion of Overall EcoLab Experience	Good	Excellent	Total		
Individual	0	2	2	Frequency	

	0	8.7	8.7	%	
Table 44 (cont'd.)					
Immediate Family	2	15	17	Frequency	
	8.7	65.22	73.91	%	
Extended Family	0	3	3	Frequency	
	0	13.04	13.04	%	
School / Community Group	0	1	1	Frequency	
	0	4.35	4.35	%	
Total	2	21	23	Frequency	
%	8.7	91.3	100	%	
Adult's Opinion of Overall EcoLab Experience	Good	Excellent	Total		
Individual	0.00	2.00	2.00	Frequency	
	0.00	8.70	8.70	%	
Immediate Family	2.00	15.00	17.00	Frequency	
	8.70	65.22	73.91	%	
Extended Family	0.00	3.00	3.00	Frequency	
	0.00	13.04	13.04	%	
School / Community Group	0.00	1.00	1.00	Frequency	
	0.00	4.35	4.35	%	
Total	2.00	21.00	23.00	Frequency	
%	8.70	91.30	100.00	%	
Knowledge of Ecology and Environmental Principles	None	Little	A Lot	Total	
Individual	0.00	0.00	2.00	2.00	Frequency
	0.00	0.00	8.00	8.00	%
Immediate Family	6.00	1.00	10.00	17.00	Frequency
	24.00	4.00	40.00	68.00	%
Extended Family	3.00	0.00	0.00	3.00	Frequency
	12.00	0.00	0.00	12.00	%
School / Community Group	2.00	0.00	1.00	3.00	Frequency
	8.00	0.00	4.00	12.00	%
Total	11.00	1.00	13.00	25.00	Frequency
%	44.00	4.00	52.00	100.00	%
Ecophoto Experience	Neutral	Good	Excellent	Total	
Individual	0.00	0.00	2.00	2.00	Frequency
	0.00	0.00	8.33	8.33	%
Immediate Family	2.00	2.00	13.00	17.00	Frequency

	8.33	8.33	54.17	70.83	%
Extended Family	0.00	1.00	2.00	3.00	Frequency
	0.00	4.17	8.33	12.50	%
Table 44 (cont'd.)					
School / Community Group	0.00	0.00	2.00	2.00	Frequency
	0.00	0.00	8.33	8.33	%
Total	2.00	3.00	19.00	24.00	Frequency
%	8.33	12.50	79.17	100.00	%

Table 45. Written comments from adults who visited EcoLab at the Science Museum of Virginia from March- August, 2010.

Group	Comment
Individual	Great - hard to gear comments at end to various ages, but did a great job.
100 % commented	Thoroughly enjoyed one on one contact and answers
Immediate Family	Awesome
41.2 % commented	Email address for follow-up
	Add microscopy for older students (i.e., dinoflagellates, algae, plankton, diatoms)
	Interesting - love the take home Instructor was very good with the kids
	Martha F. was supberb - Thank you
	Great interactive activity; Great for older kids; Volunteer was very helpful and informative
	Martha F. was excellent! Very friendly, very helpful, very patient
Extended Family	This lab was wonderful and very educational. The staff person was so patient and informative.
50 % commented	Awesome exhibit- staff worked so well with children on their level- great experience
School/Community Groups	Great information and answered many questions. Very interactive!
75 % commented	We loved this! Info was short and appropriate, many questions- high interest. Thanks
	She was great with all those bugs!

Figures

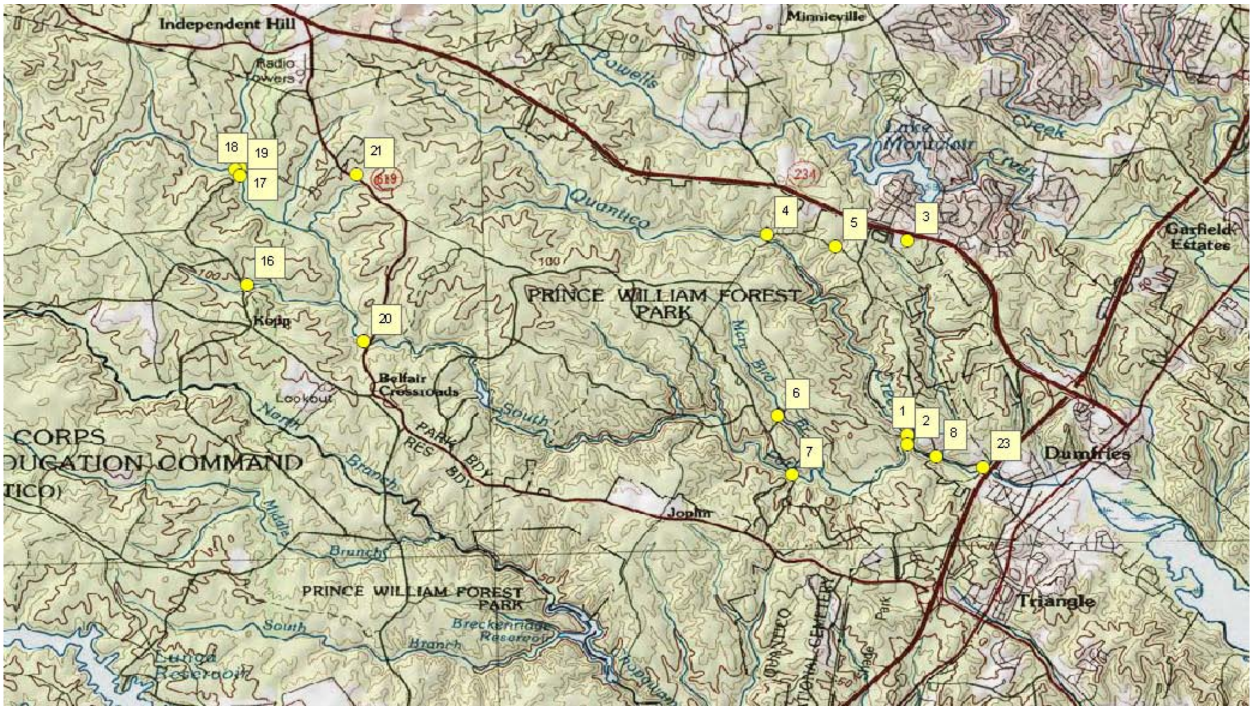


Figure 1. Map of study locations in the Quantico Creek watershed for the period November, 2008 – June, 2010.

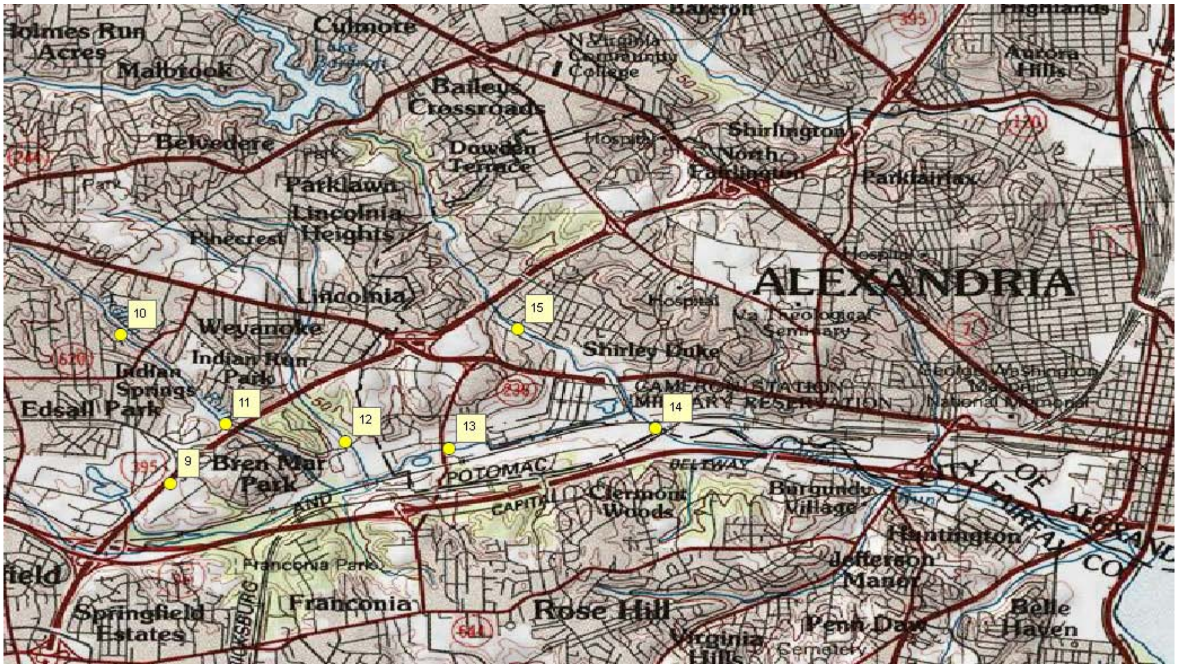


Figure 2. Map of study locations in the Quantico Creek watershed for the period November, 2008 – June, 2010.

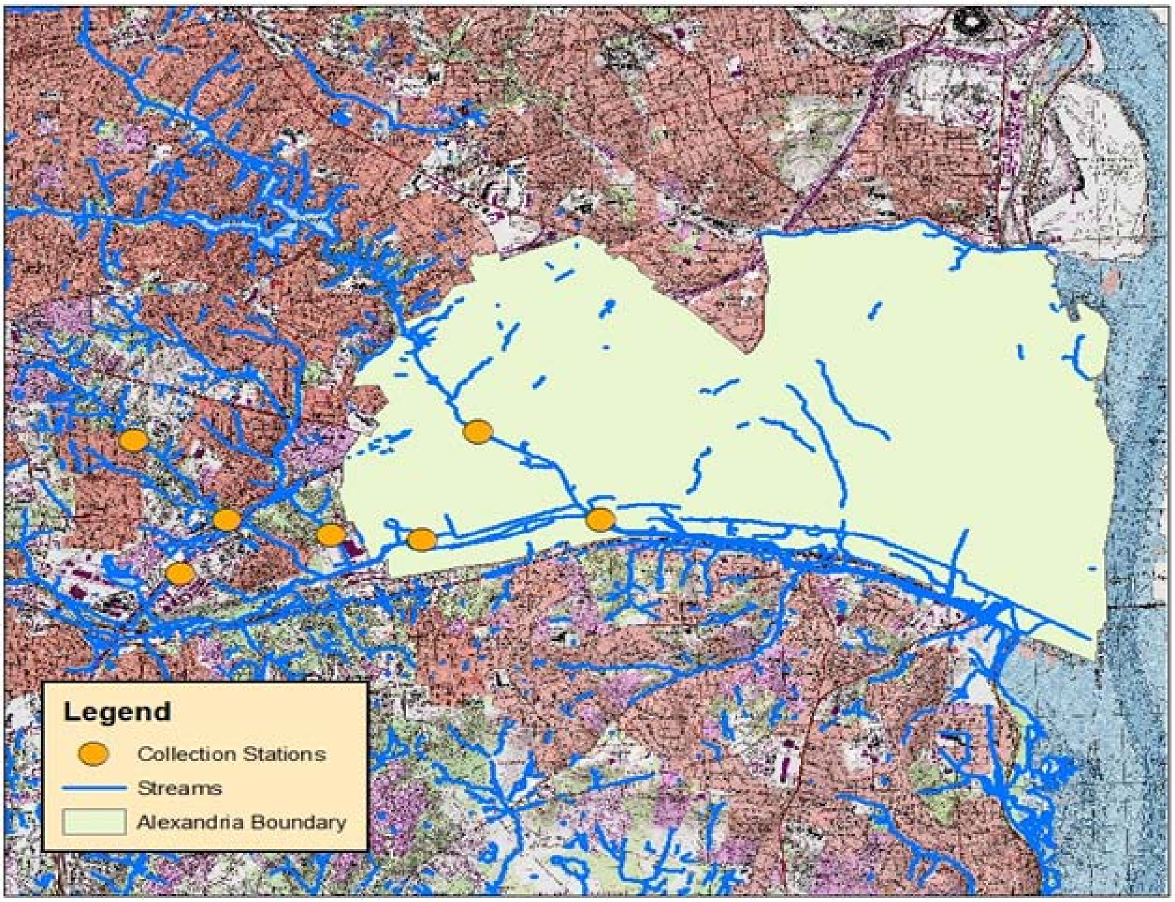


Figure 3. The base map for the GIS (ESRI's ArcView 9.3) analysis was developed by importing: jurisdictional boundaries; streams and 1:24k topographic maps of the study area into a project geodatabase.

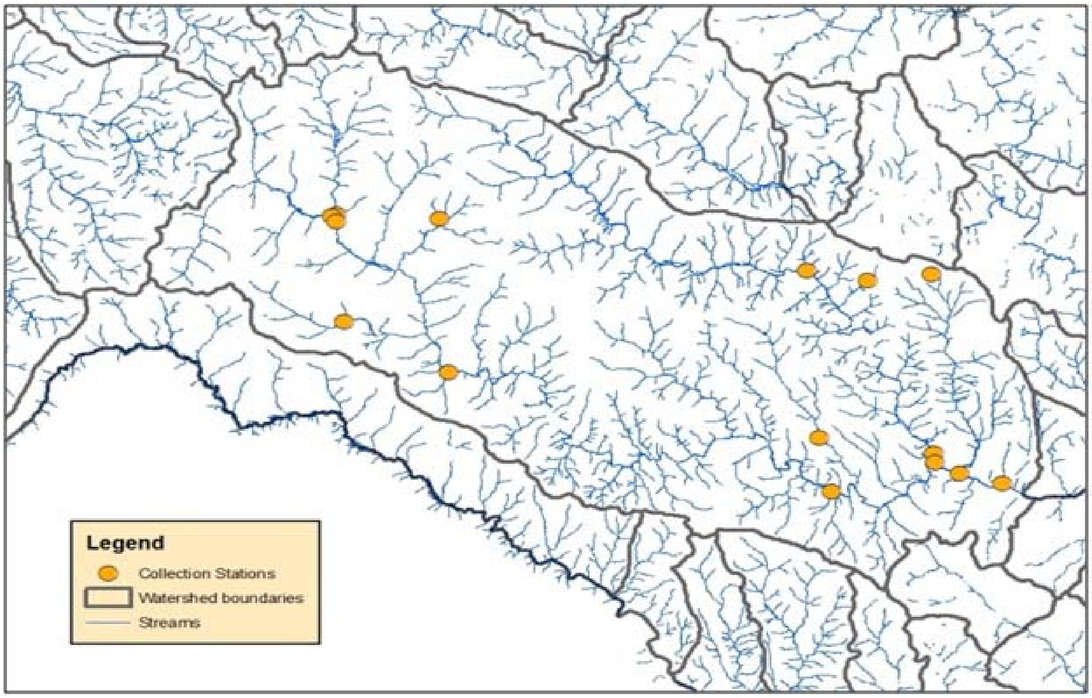


Figure 4. Collection stations for the Quantico Creek study area were imported to the base map as x, y data using latitudes and longitudes collected in the field using a Garmin Oregon 550t GPS receiver. The geographic coordinate system (GCS) for the GIS analysis was defined as Virginia State Plane North NAD83 (feet) and the projection was defined as Lambert Conformal Conic.

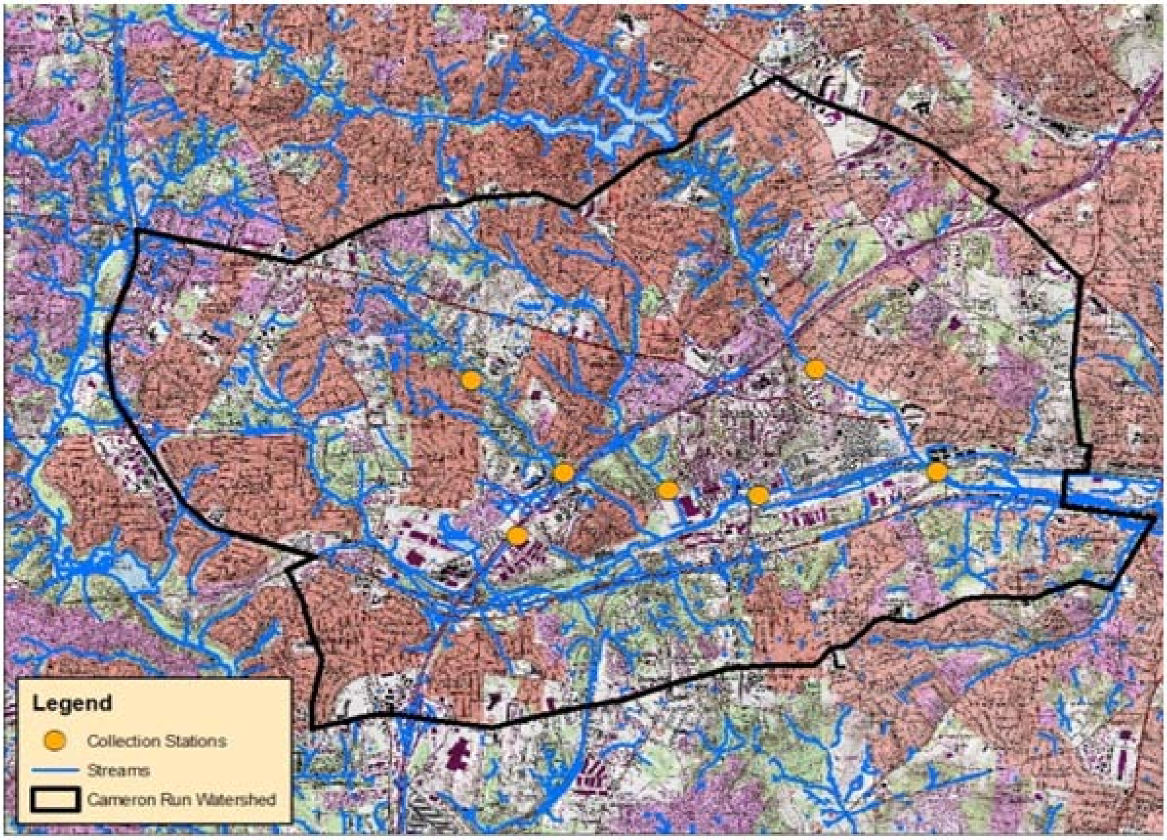


Figure 5. Collection stations for the Cameron Run study area were imported to the base map as x, y data using latitudes and longitudes collected in the field using a Garmin Oregon 550t GPS receiver. The geographic coordinate system (GCS) for the GIS analysis was defined as Virginia State Plane North NAD83 (feet) and the projection was defined as Lambert Conformal Conic.

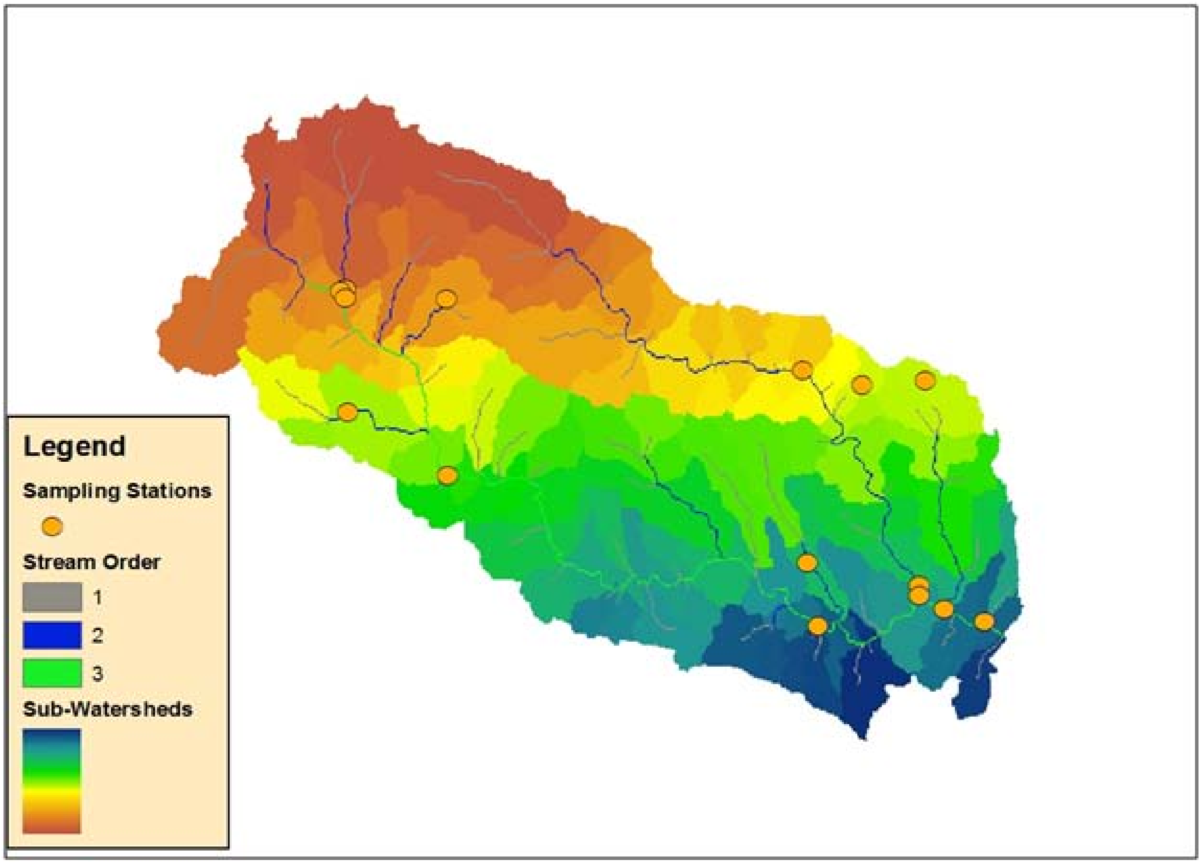


Figure 6. Sub-watersheds of Quantico Creek associated with each collection station were developed through a hydrology analysis of 30m gridded Digital Elevation Models (ESRI, USGS).

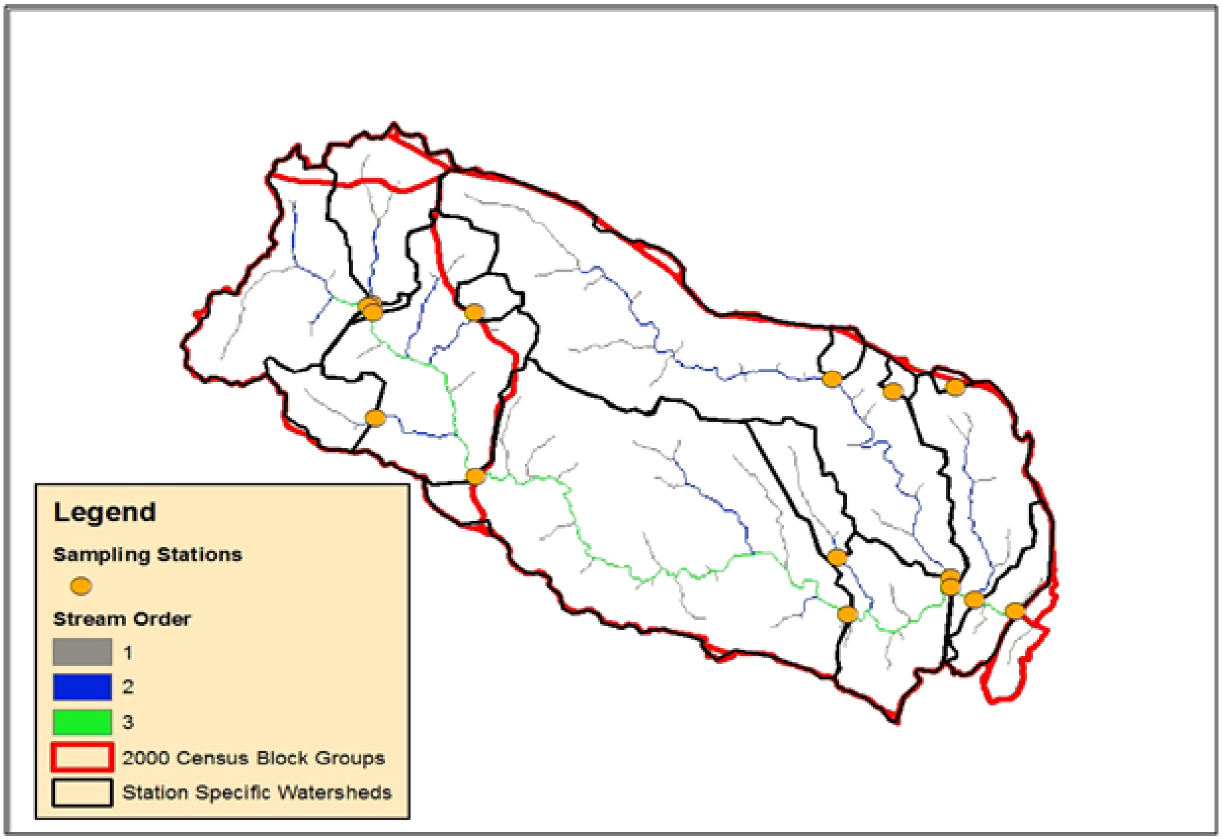


Figure 7. Sub-watershed polygons of Quantico Creek watershed. Sub-watershed polygons were layered onto a 2000 Census Block Group (CBG) layer (U.S. Census Bureau) to determine total population for each sub-watershed.

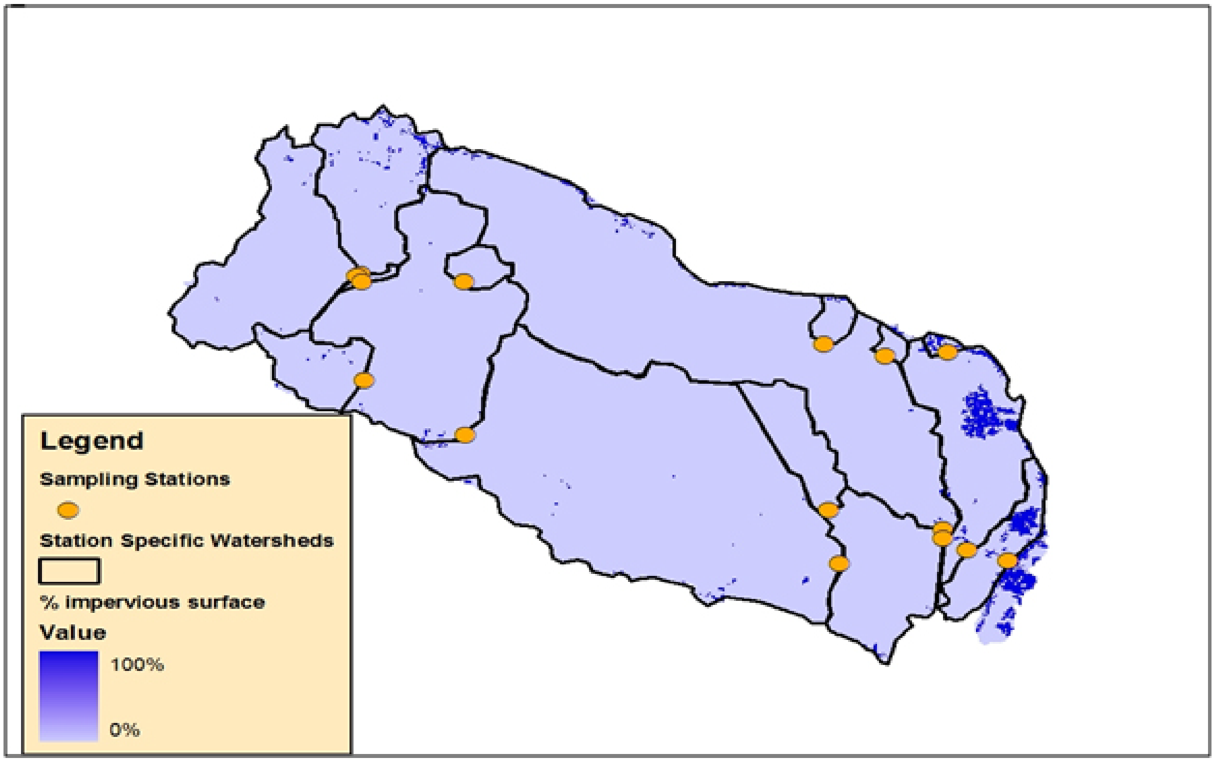


Figure 8. Station specific sub-watershed polygons of Quantico Creek were used to extract impervious surface areas from 30m gridded impervious surface rasters.

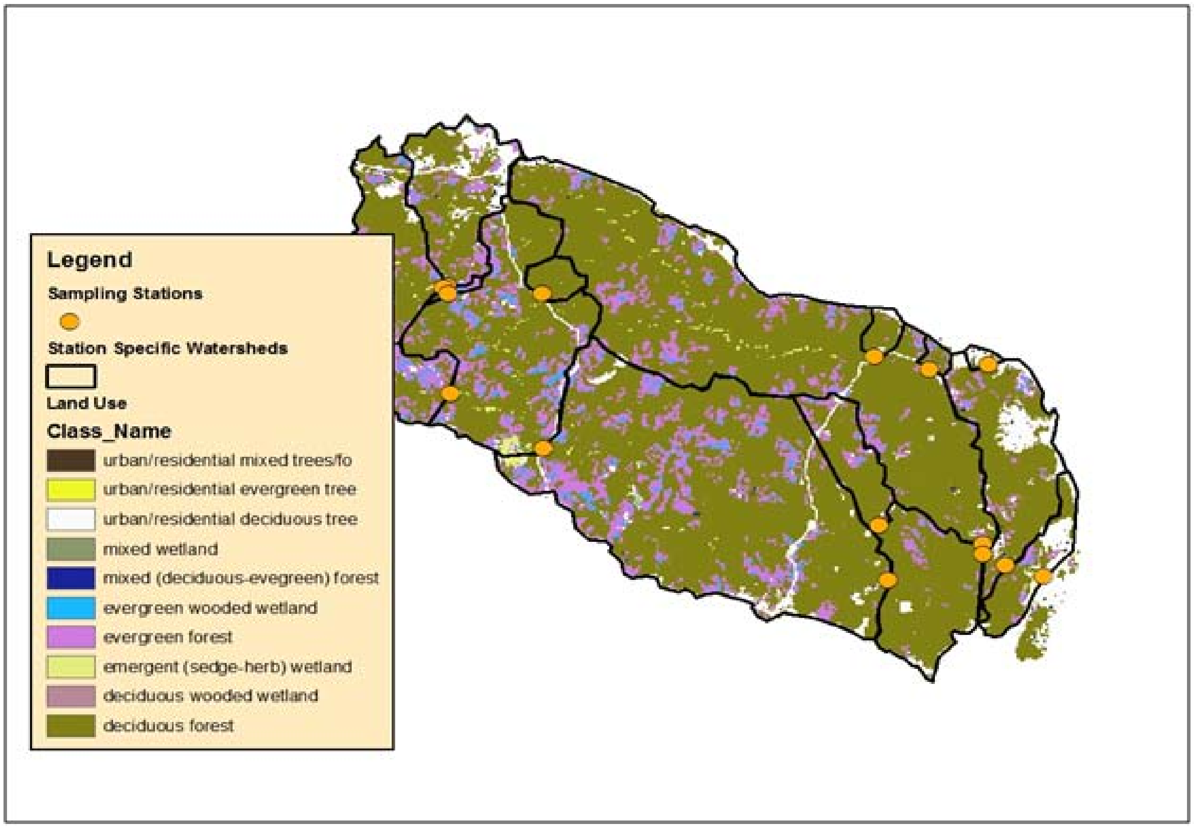


Figure 9. Station specific sub-watershed polygons of Quantico Creek were used to extract undeveloped land cover (=vegetated land cover) areas from 30m gridded vegetated land cover rasters.

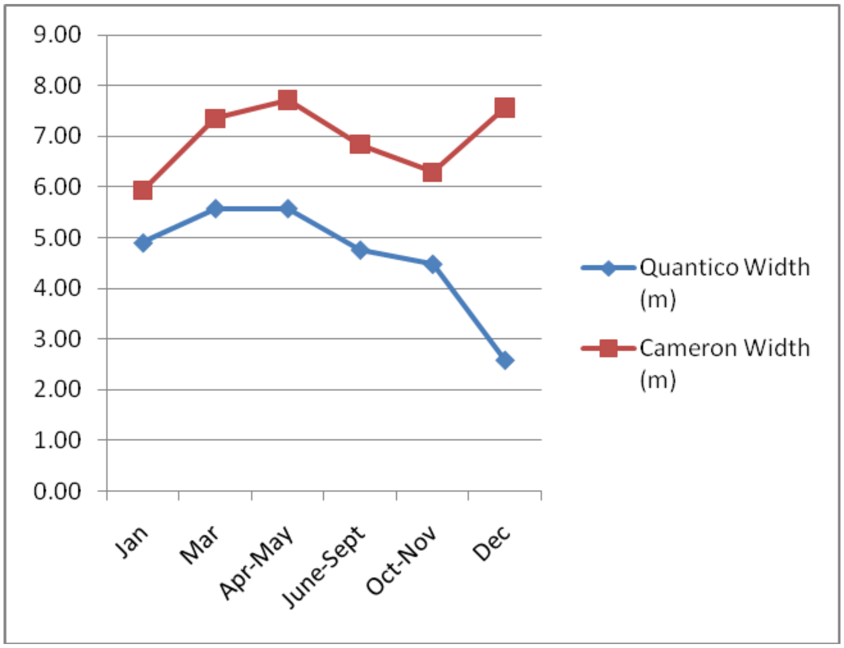


Figure 10. Average stream width (m) in Quantico Creek and Cameron Run watersheds by season from November, 2008 – June, 2010.

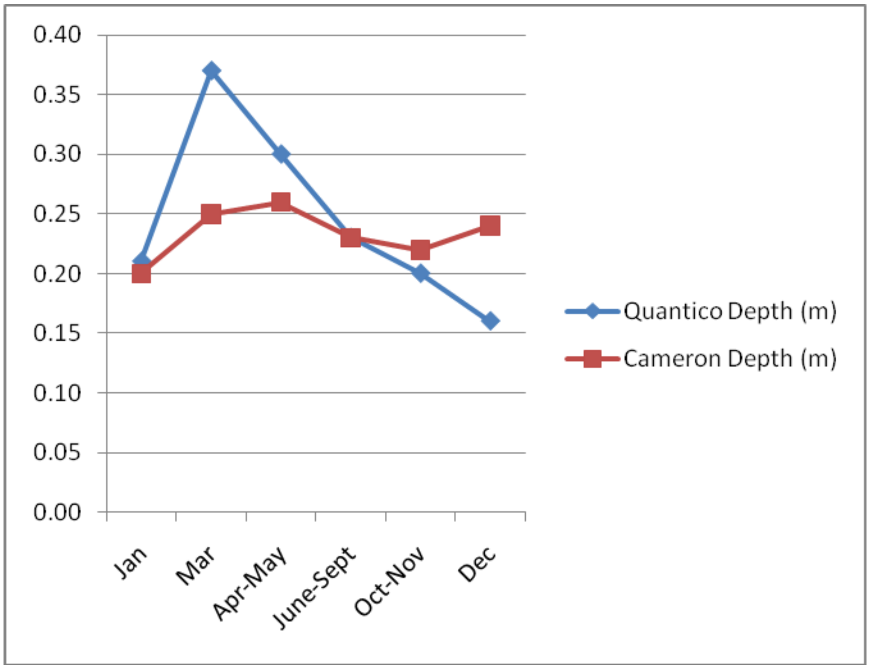


Figure 11. Average water depth (m) in Quantico Creek and Cameron Run watersheds by season from November, 2008 – June, 2010.

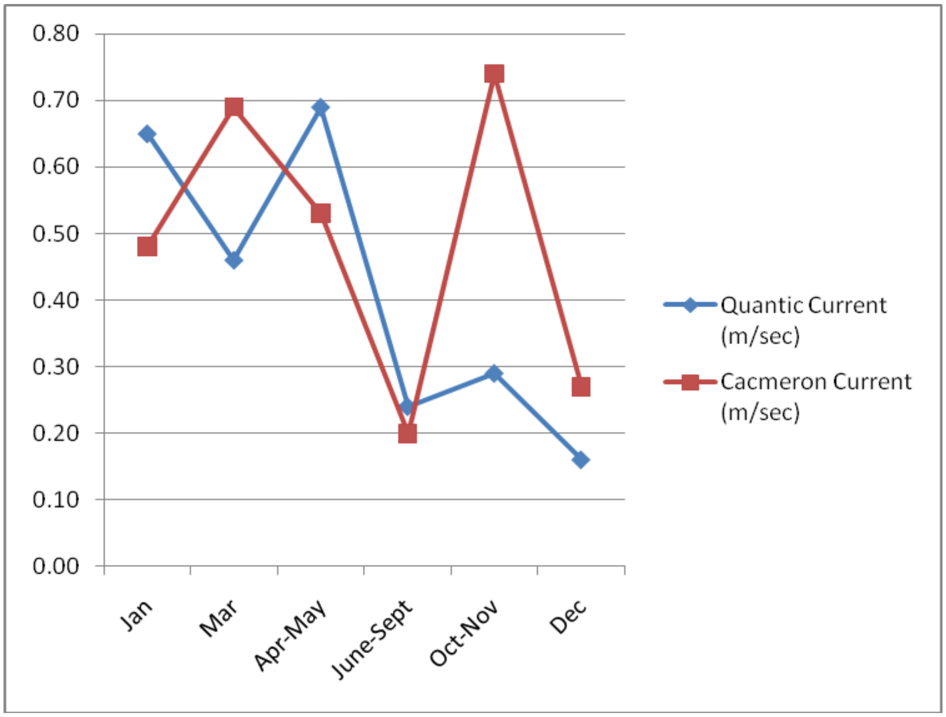


Figure 12. Average water current (m/sec) in Quantico Creek and Cameron Run watersheds by season from November, 2008 – June, 2010.

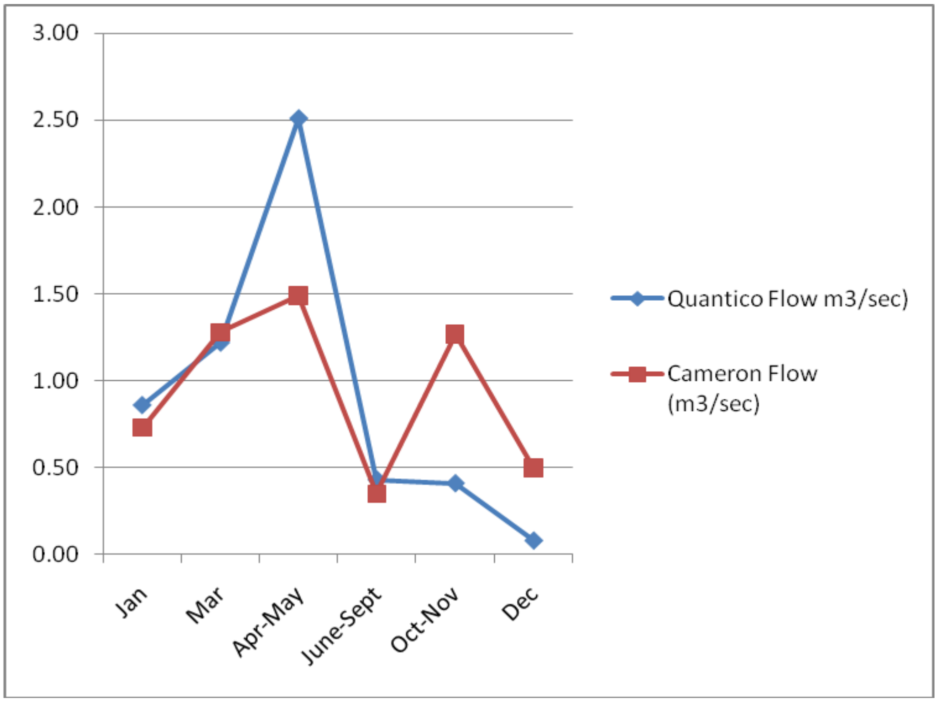


Figure 13. Average stream flow (m^3/sec) in Quantico Creek and Cameron Run watersheds by season from November, 2008 – June, 2010.

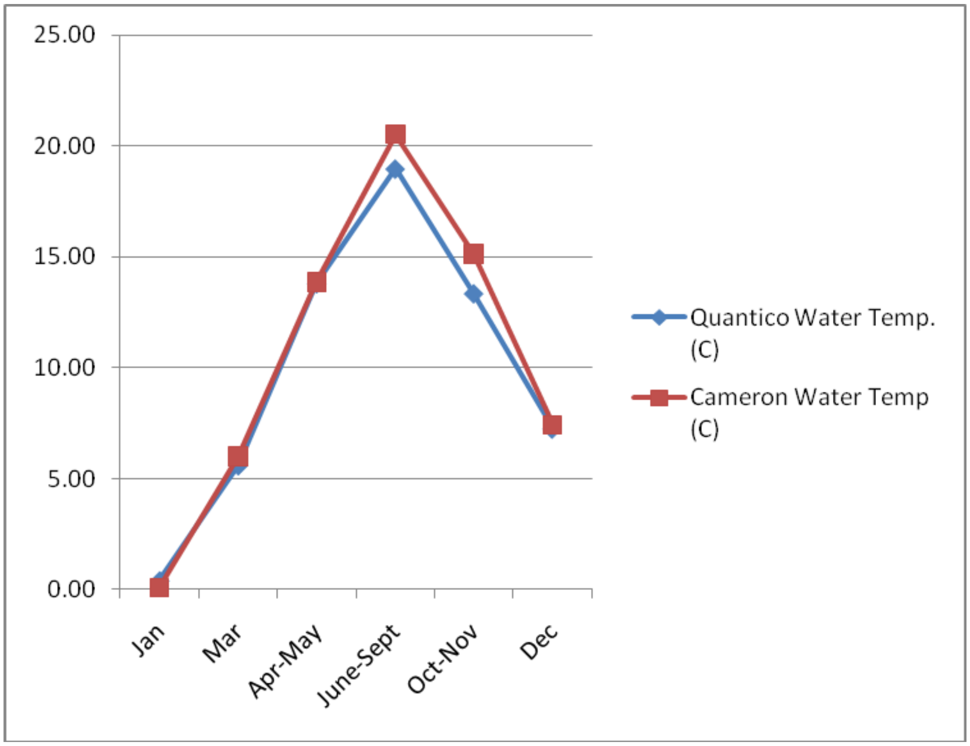


Figure 14. Average water temperature (C) in Quantico Creek and Cameron Run watersheds by season from November, 2008 – June, 2010.

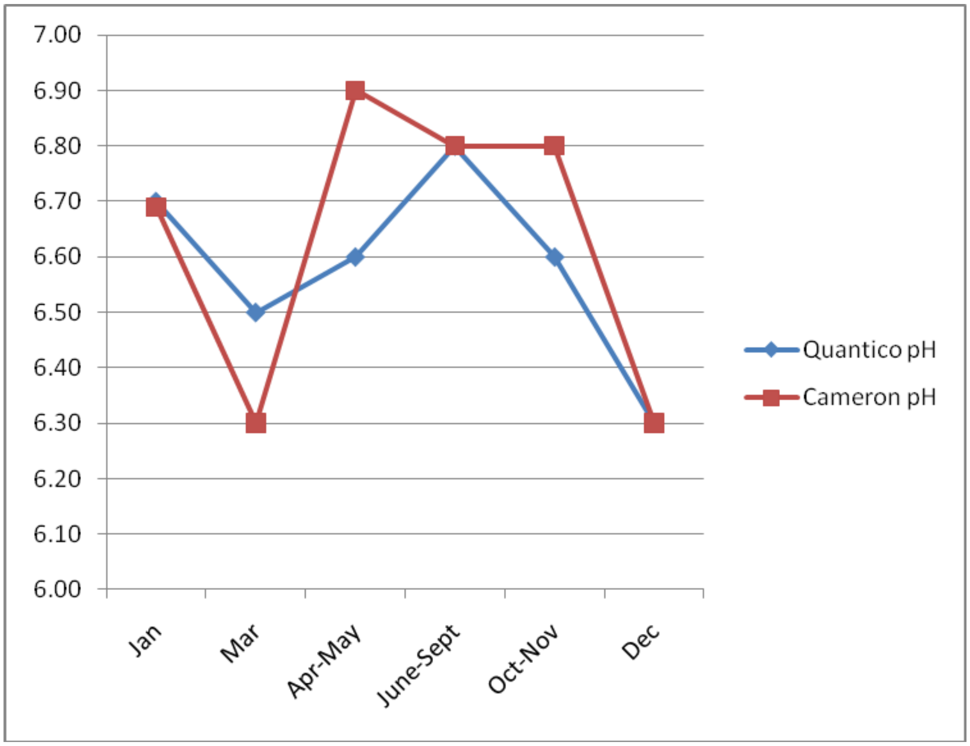


Figure 15. Average pH in Quantico Creek and Cameron Run watersheds by season from November, 2008 – June, 2010.

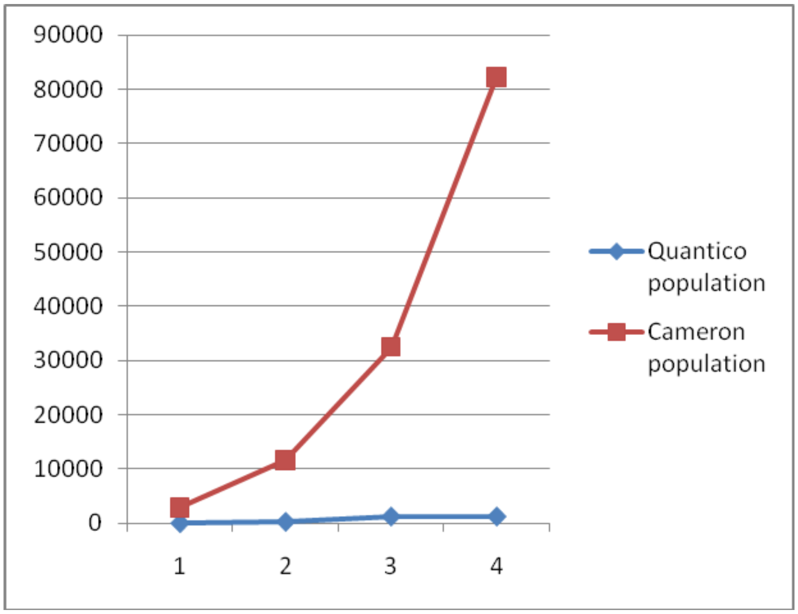


Figure 16. Average human population by stream order in Quantico Creek and Cameron Run watersheds. Cameron Run 4th order was compared to 3rd order Quantico Creek.

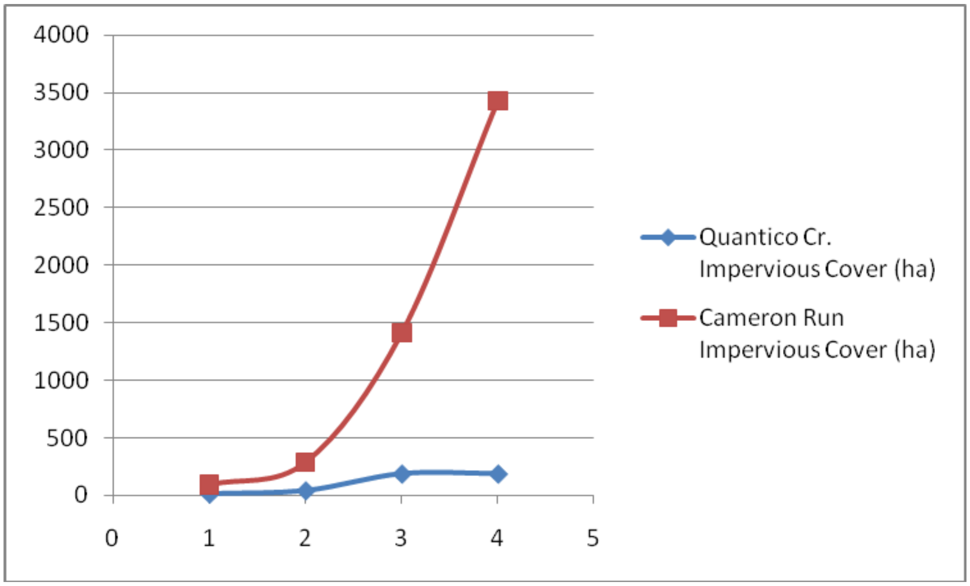


Figure 17. Average impervious cover (ha) by stream order in Quantico Creek and Cameron Run watersheds. Cameron Run 4th order was compared to 3rd order Quantico Creek.

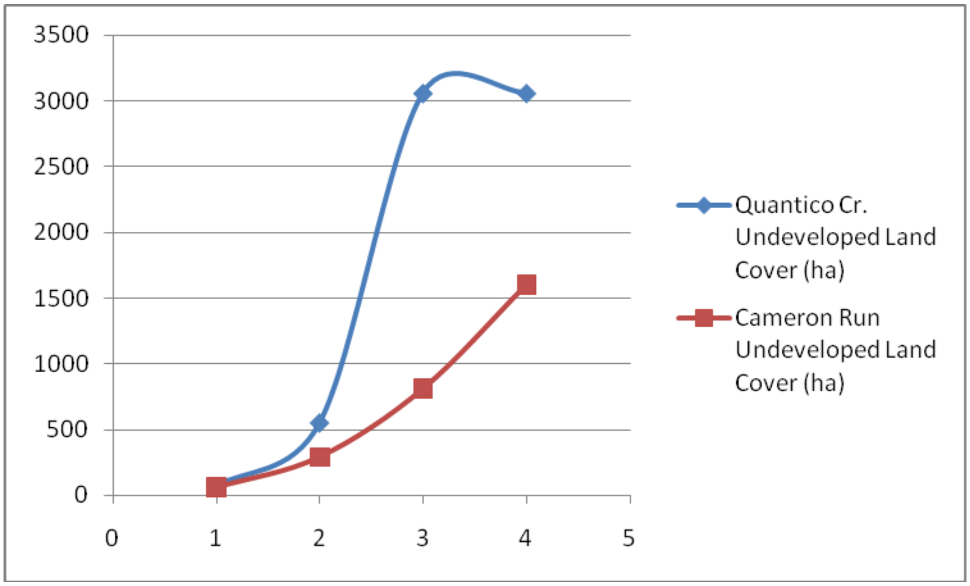


Figure 18. Average undeveloped land cover (ha) by stream order in Quantico Creek and Cameron Run watersheds. Cameron Run 4th order was compared to 3rd order Quantico Creek.

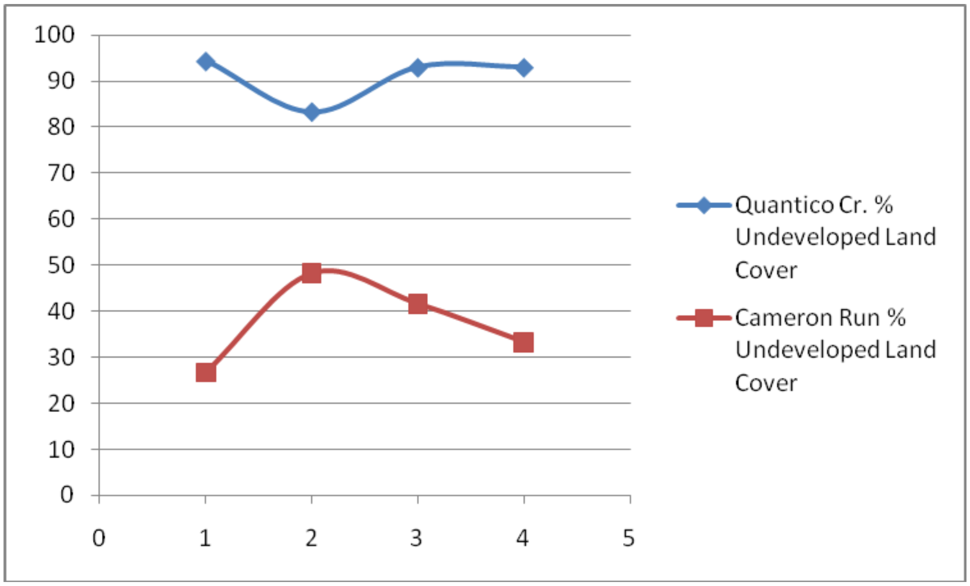


Figure 19. Average % undeveloped land cover (ha) by stream order in Quantico Creek and Cameron Run watersheds. Cameron Run 4th order was compared to 3rd order Quantico Creek.

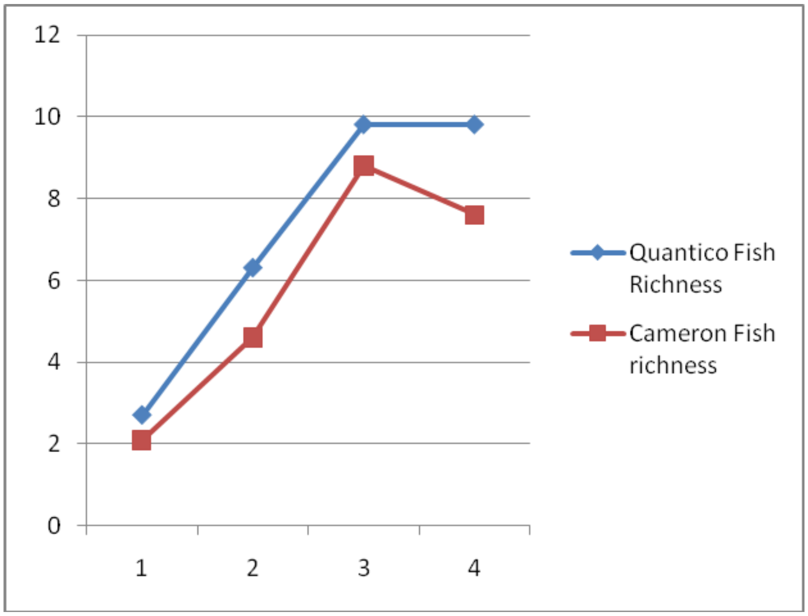


Figure 20. Average fish species richness by stream order in Quantico Creek and Cameron Run watersheds. Cameron Run 4th order was compared to 3rd order Quantico Creek.

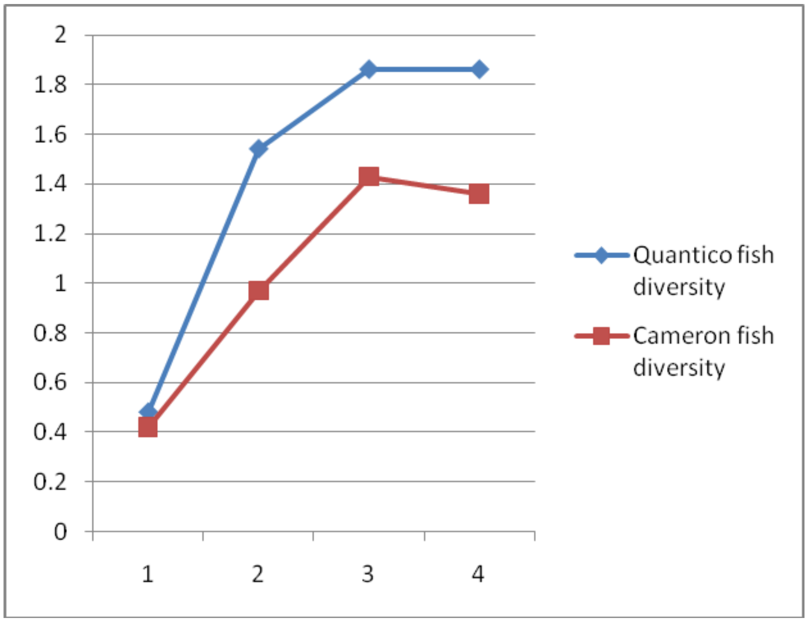
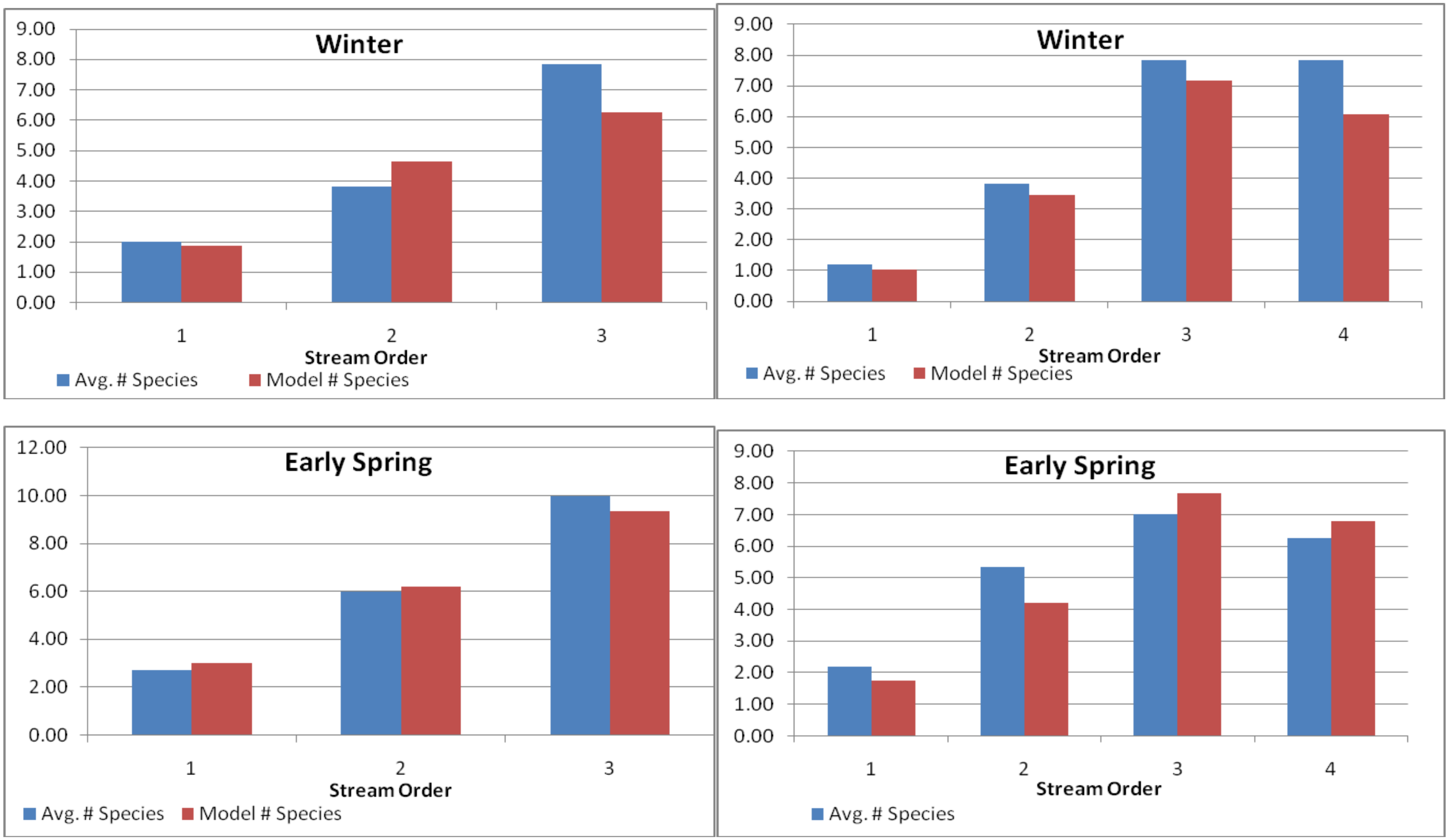


Figure 21. Average Shannon fish diversity by stream order in Quantico Creek and Cameron Run watersheds. Cameron Run 4th order was compared to 3rd order Quantico Creek.

Figure 22. Average and model species richness in Quantico Creek and Cameron Run by season (November 2008 – June 2010.



Quantico Creek

Cameron Run

Fig. 22 (Cont'd). Quantico Cameron

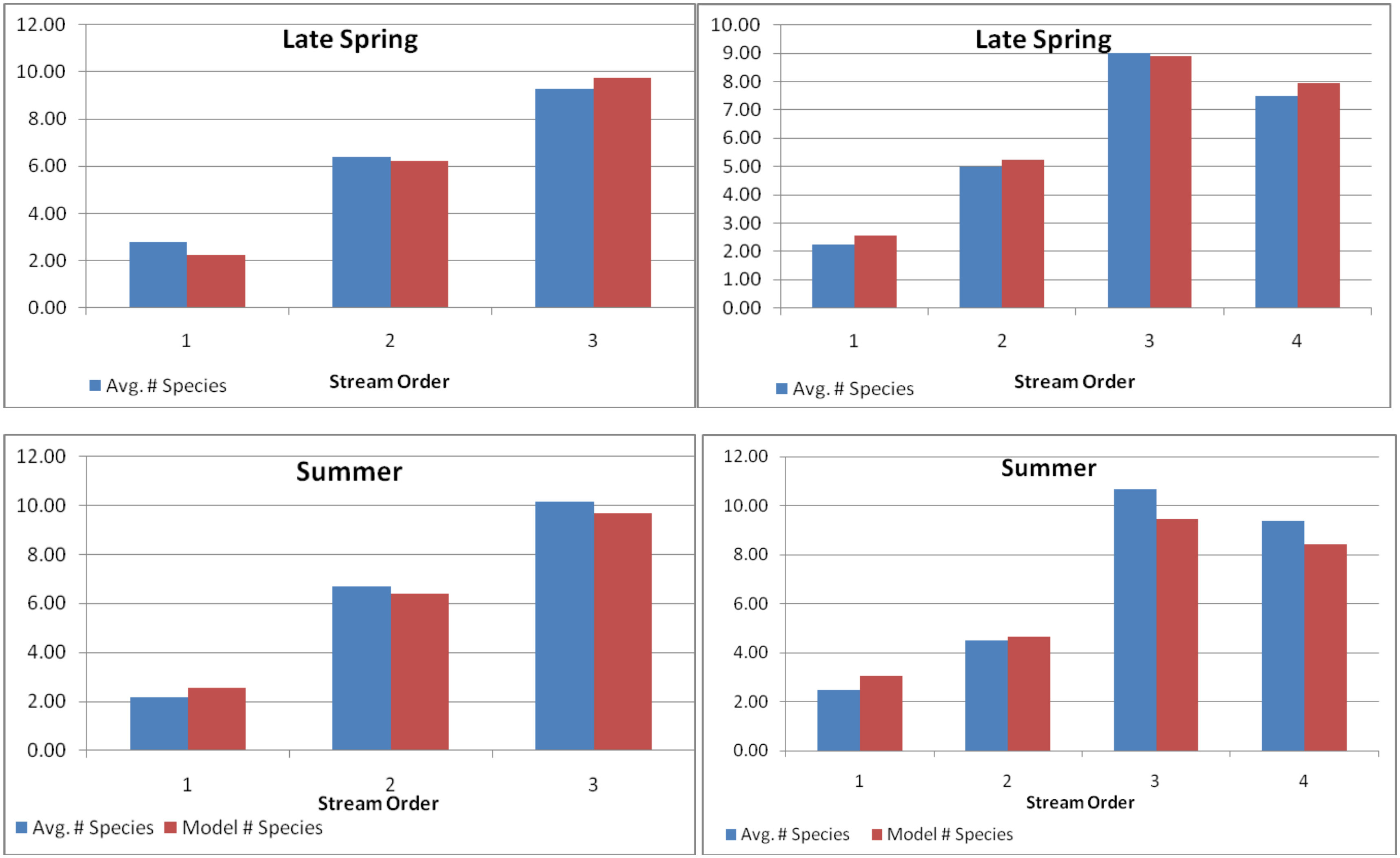


Fig. 22 (Cont'd). Quantico Cameron

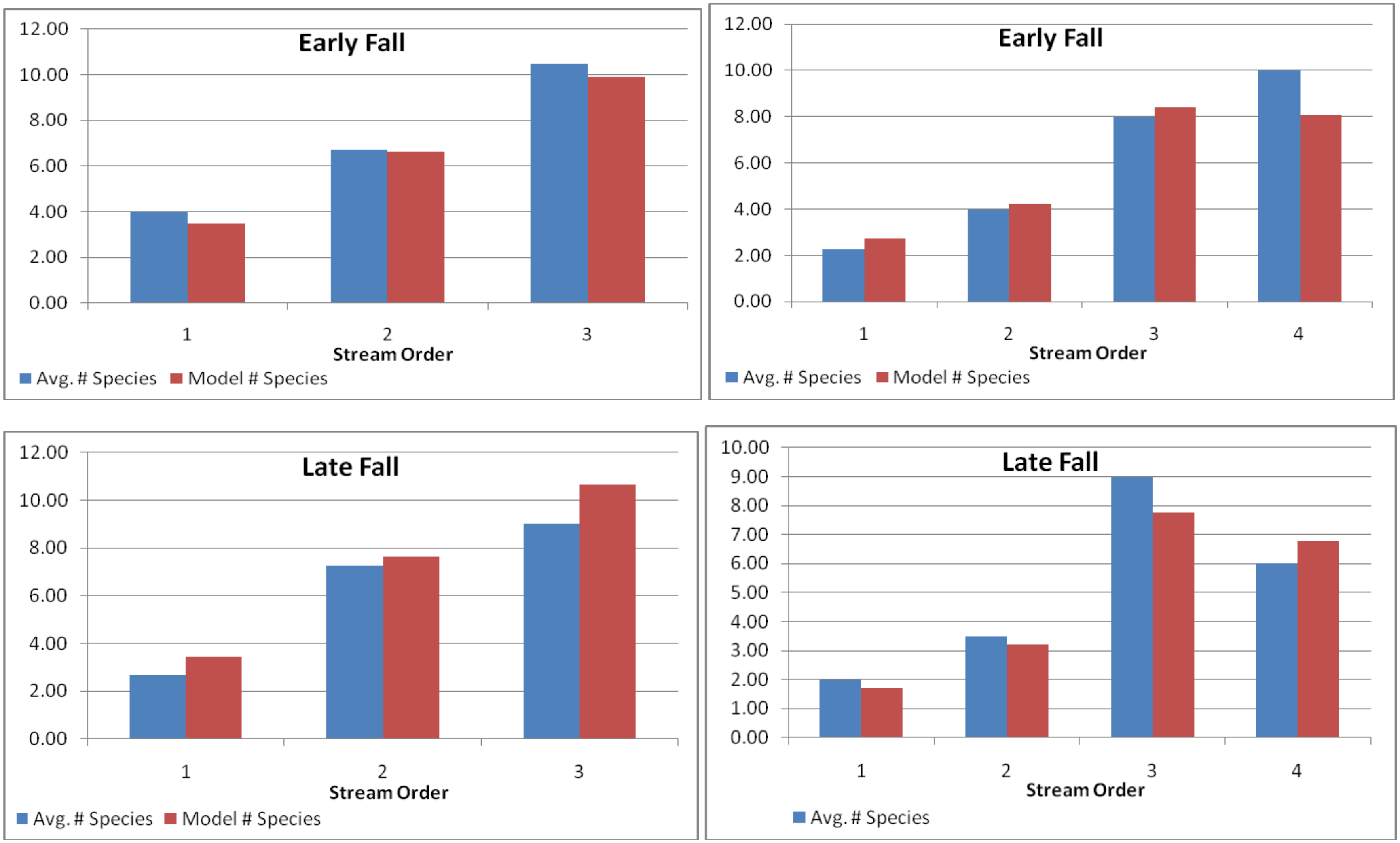


Figure 23. Actual and model species diversity in Quantico Creek and Cameron Run by season from November 2008 – June 2010.

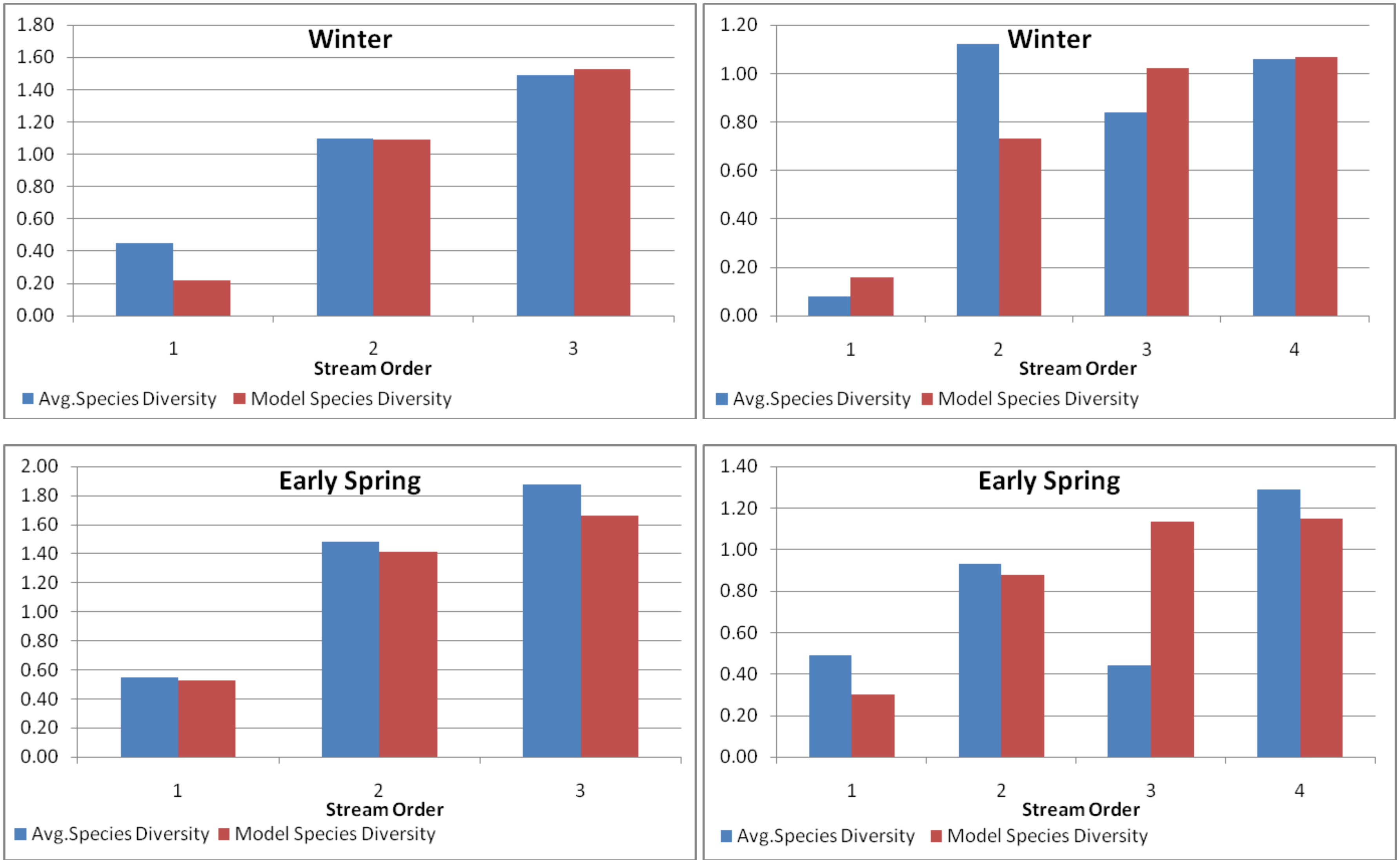
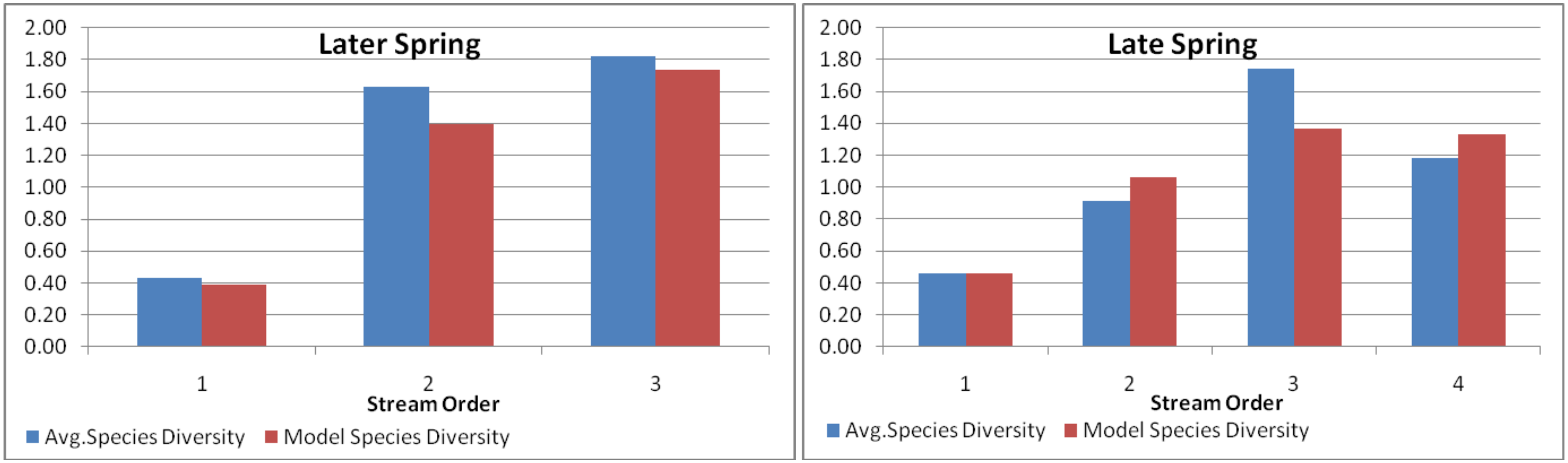


Fig. 23 (Cont'd).


Later Spring
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
Stream Order
Avg.Species Diversity
Model Species Diversity
Late Spring
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
Stream Order
Avg.Species Diversity
Model Species Diversity

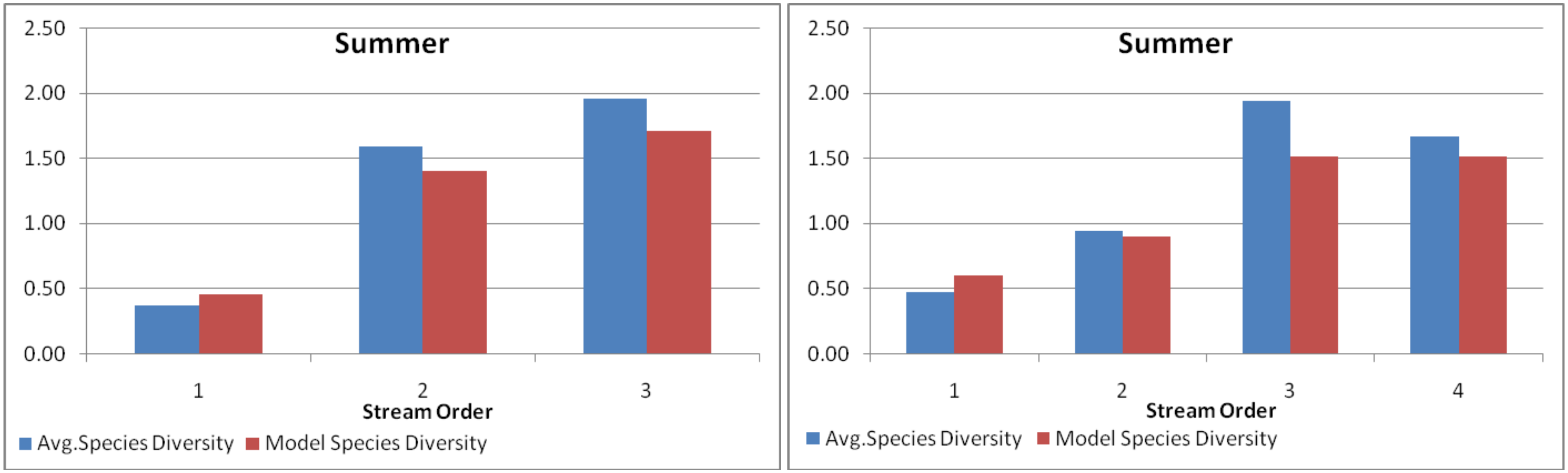
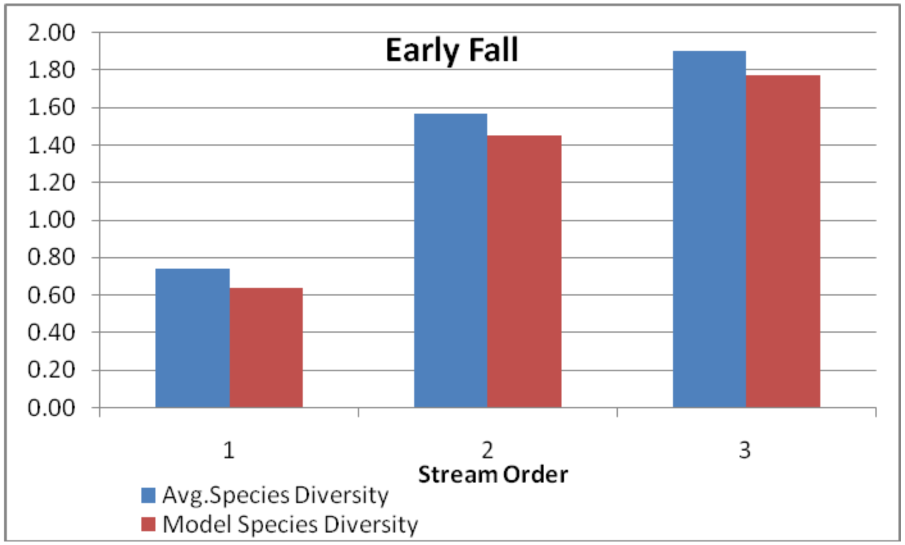
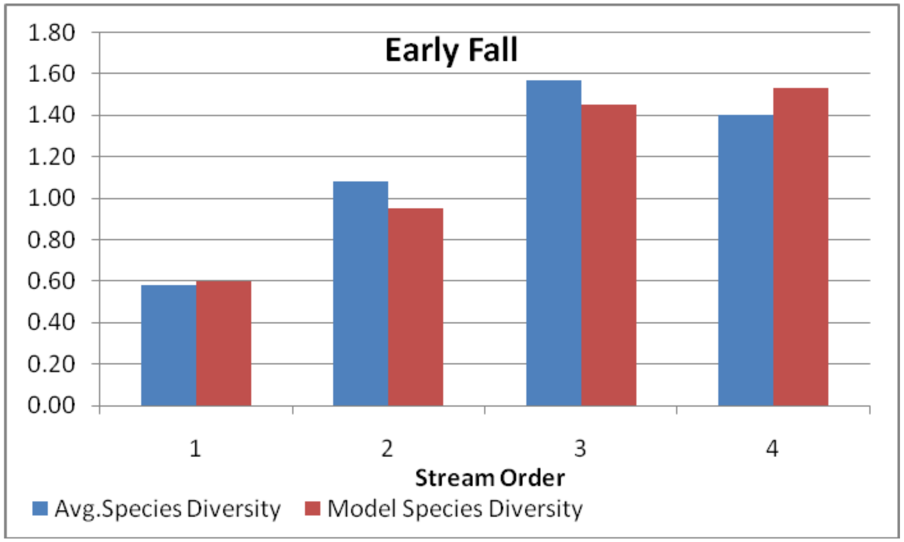
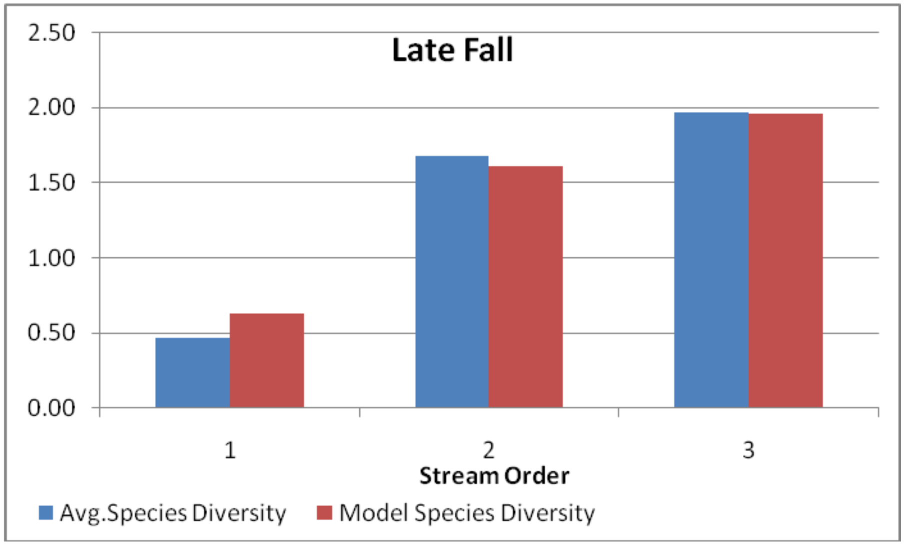

Summer
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
Stream Order
■ Avg.Species Diversity
■ Model Species Diversity
Summer
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
Stream Order
■ Avg.Species Diversity
■ Model Species Diversity

Fig. 23 (Cont'd).


Early Fall
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
Stream Order
🟦 Avg.Species Diversity
🟥 Model Species Diversity


Early Fall
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
Stream Order
🟦 Avg.Species Diversity
🟥 Model Species Diversity


Late Fall
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
Stream Order
🟦 Avg.Species Diversity
🟥 Model Species Diversity

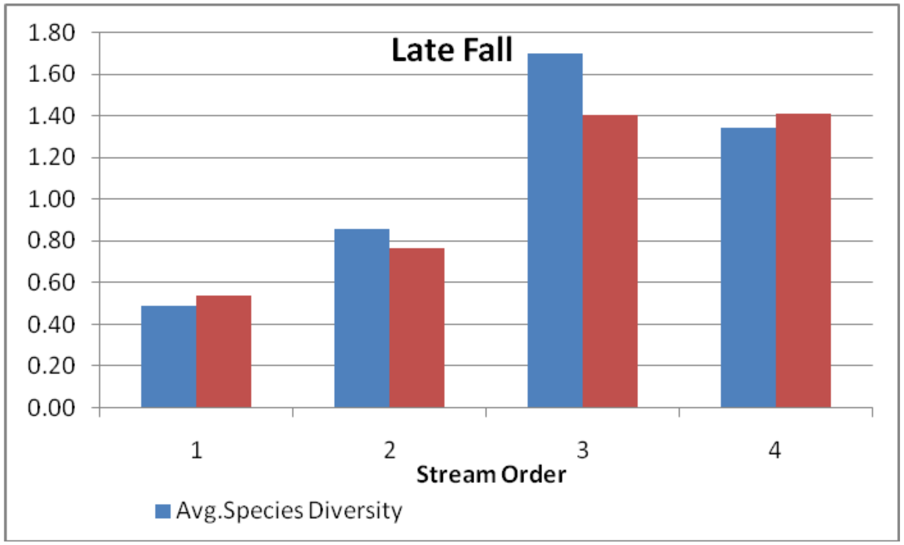
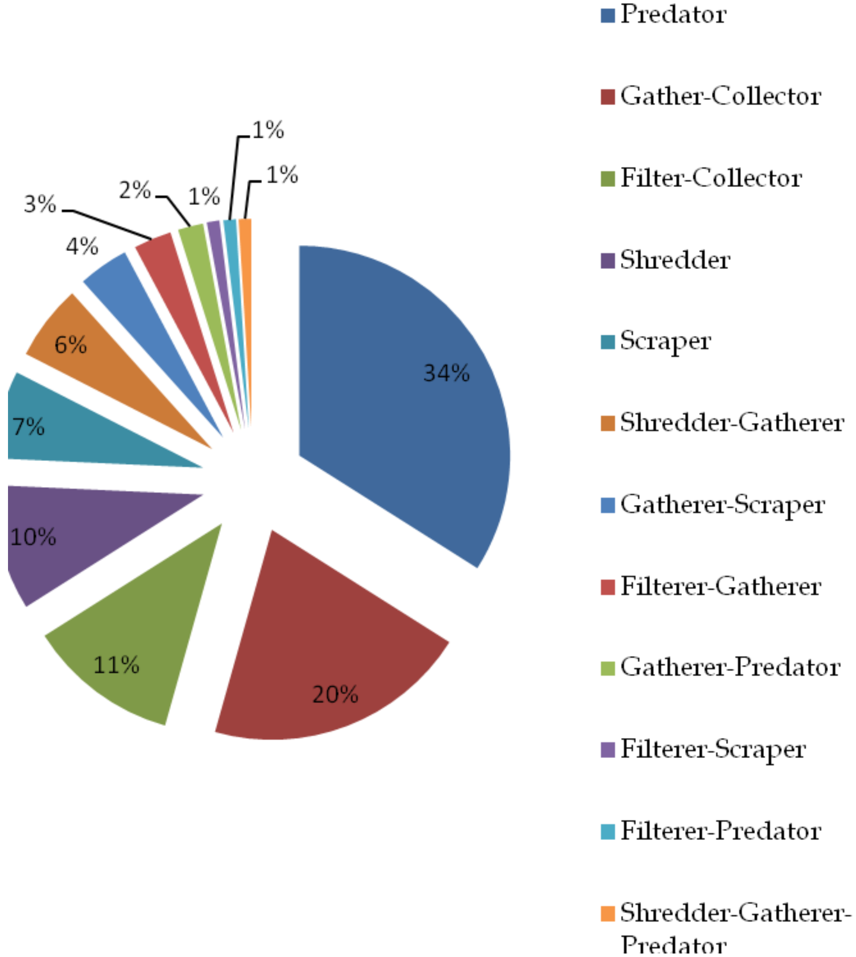

Late Fall
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
2
3
4
Stream Order
🟦 Avg.Species Diversity

Figure 24. Macroinvertebrate functional feeding group (FFG) composition of Quantico Creek and Cameron Run watersheds from June-October 2009.

Quantico Creek	Cameron Run



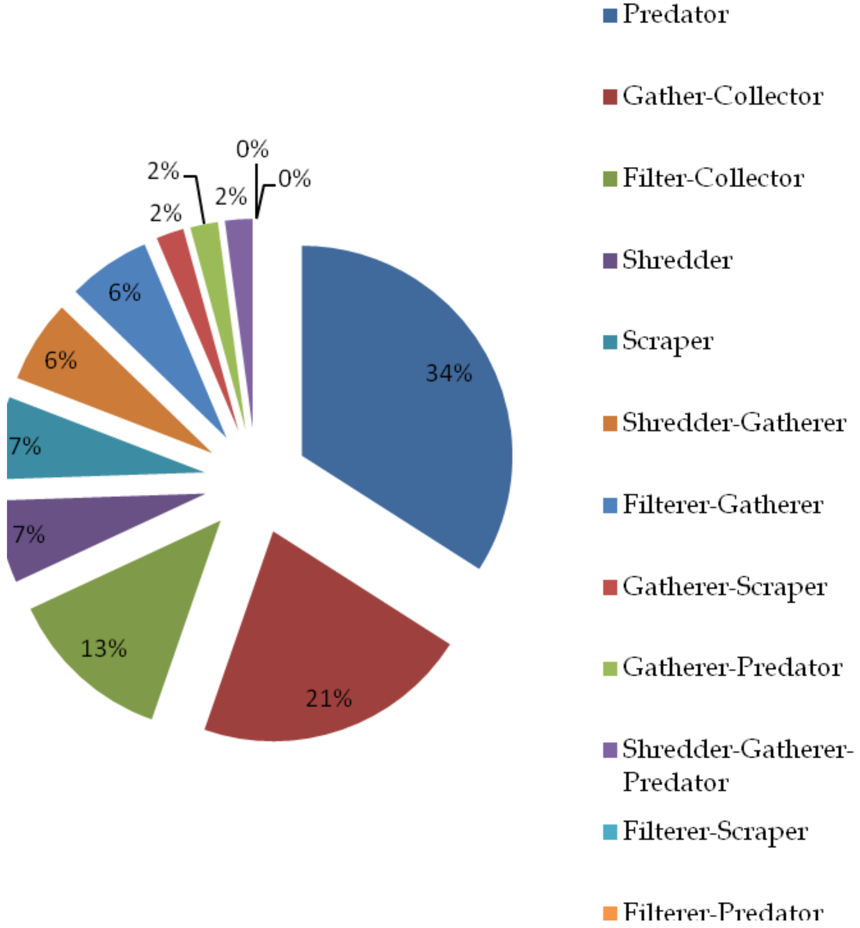


Figure 25. Macroinvertebrate functional feeding group (FFG) composition by stream order in Quantico Creek and Cameron Run watersheds from June-November 2009. Top graphs show the proportion of specialists and bottom graphs show the proportion of generalist feeding strategies.

Quantico Creek	Cameron Run

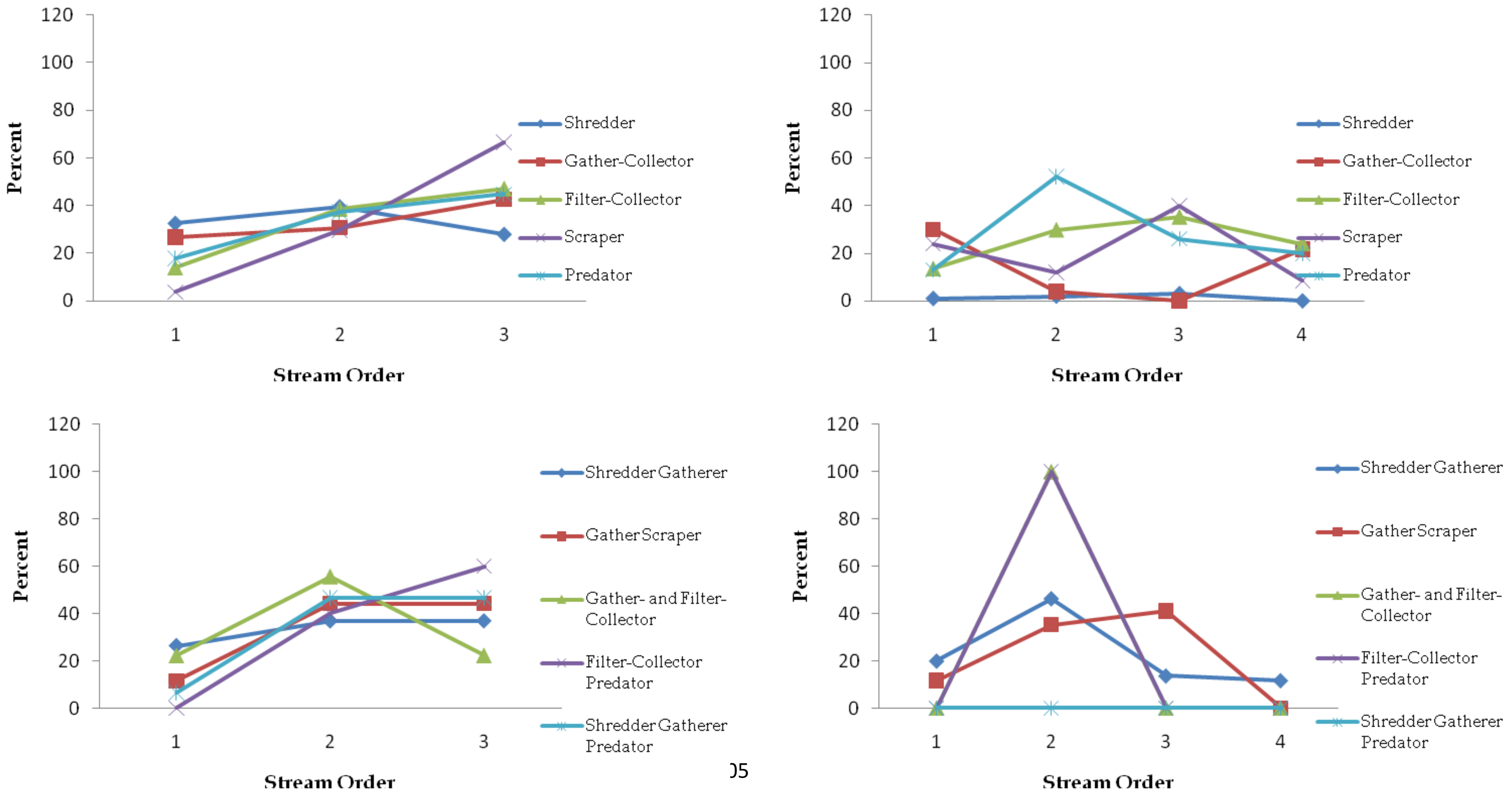
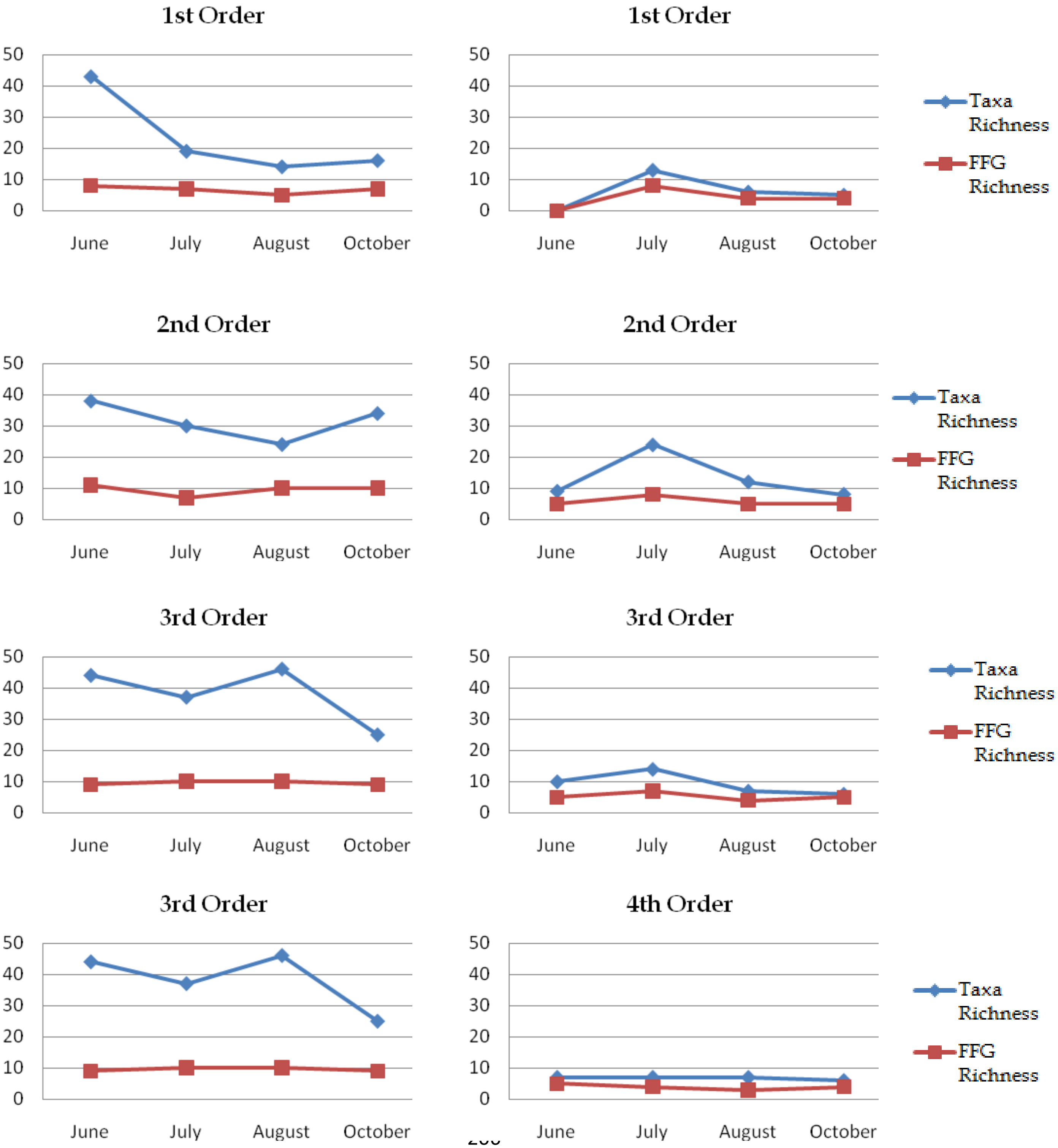


Figure 26. Macroinvertebrate taxa richness and functional feeding group (FFG) richness by month in Quantico Creek and Cameron Run watersheds from June-October 2009.

Quantico Creek	**Cameron Run**



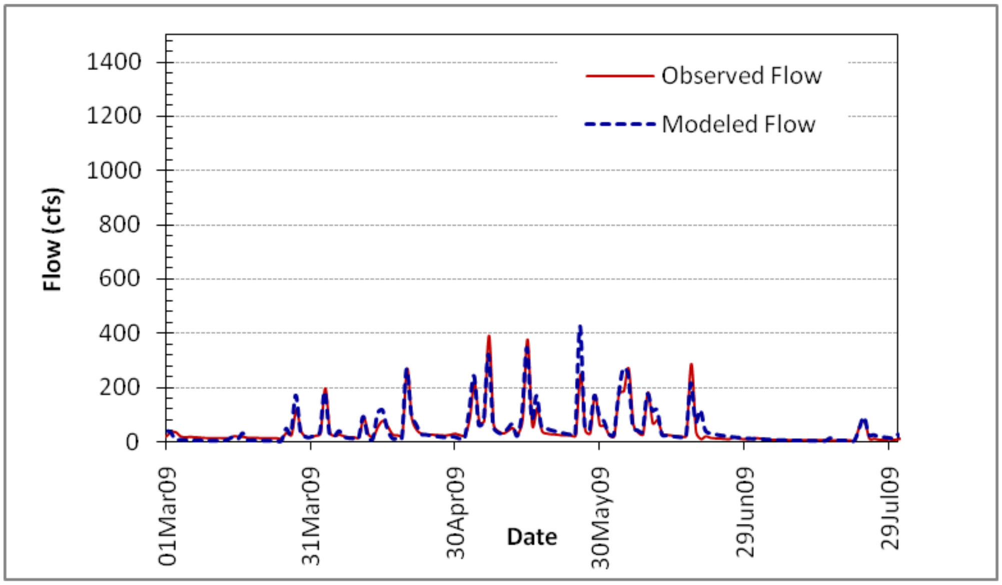


Figure 27. The Cameron Run model calibration results and the historic flows at the Cameron Run at Alexandria, VA gage.

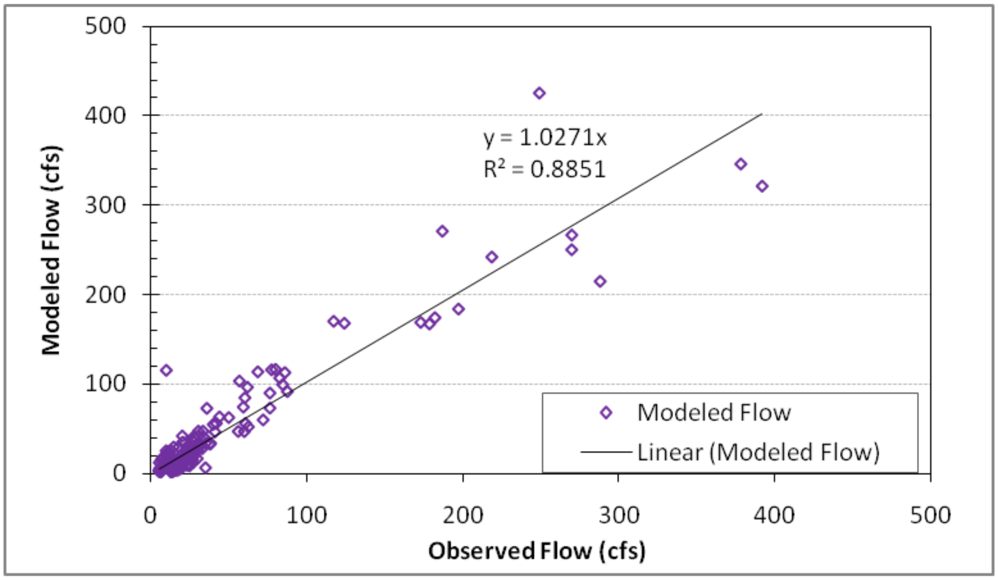


Figure 28. Correlation between the modeled and observed flows at the Cameron Run gage during the calibration period.

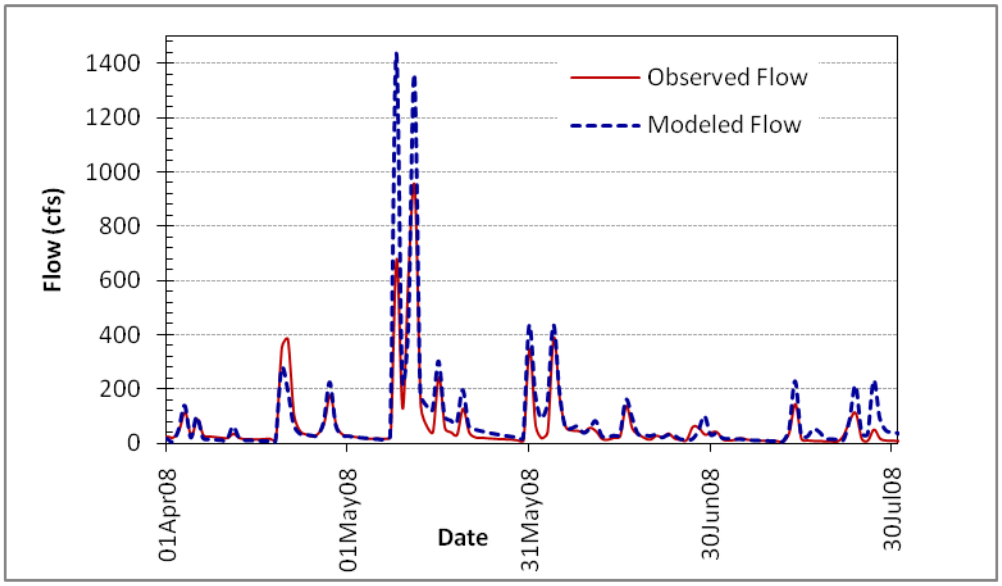


Figure 29. Modeled and observed flows at the Cameron Run at Alexandria, VA gage during the validation period.

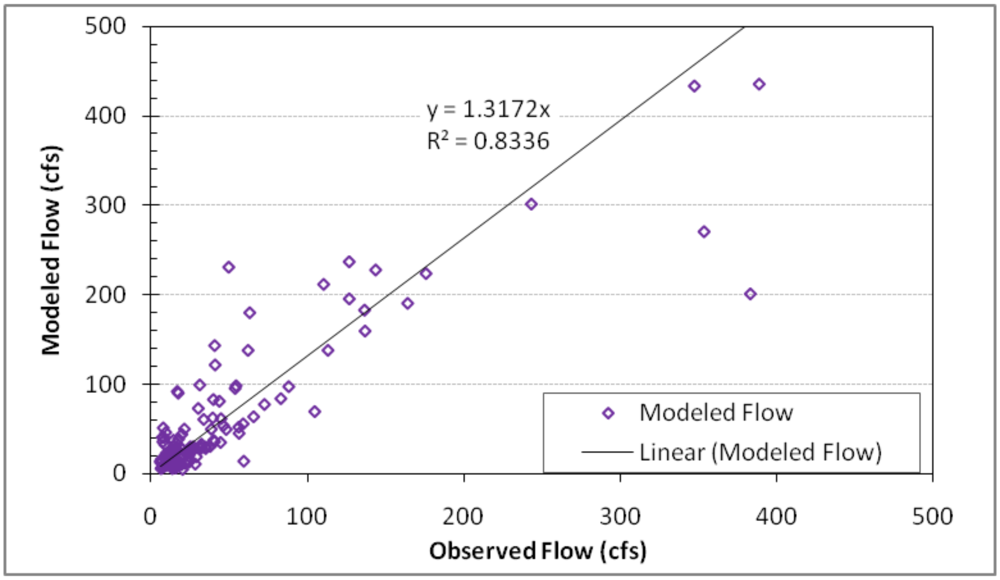


Figure 30. Correlation between the modeled and observed flows at the Cameron Run gage during the validation period.

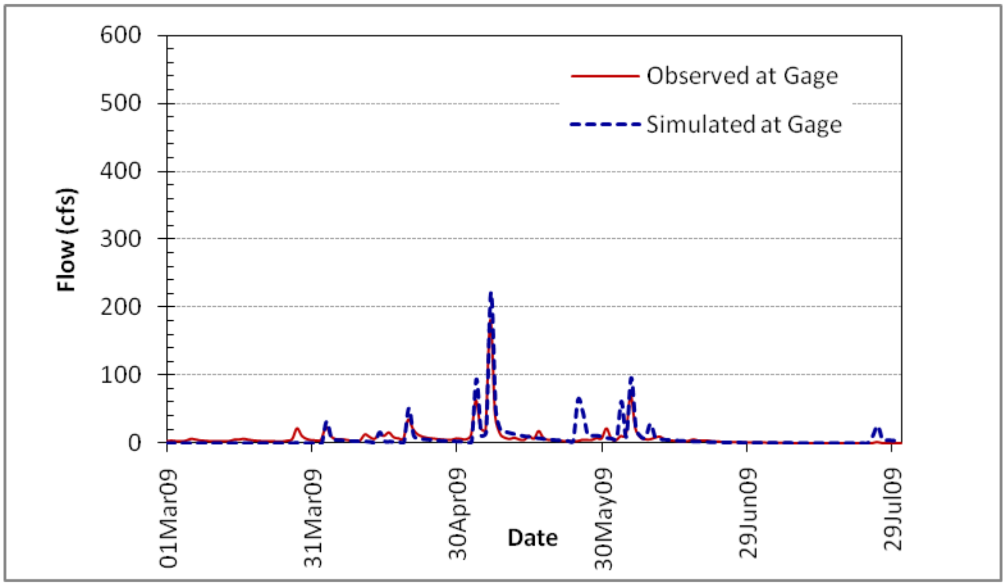


Figure 31. The Quantico Creek model calibration results and the historic flows at the Quantico Creek near Independent Hill, VA gage.

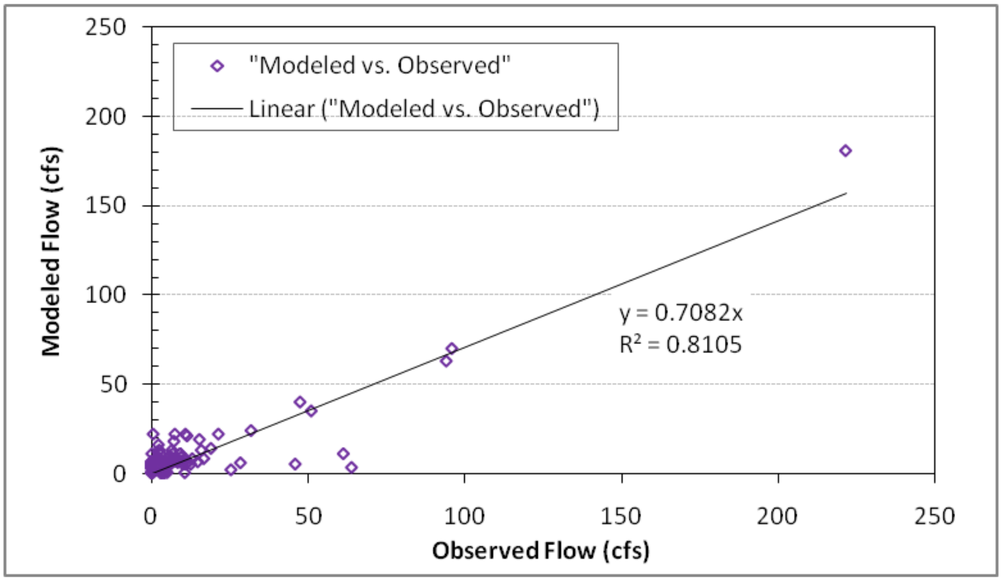


Figure 32. Correlation between the modeled and observed flows at the Quantico Creek gage during the calibration period.

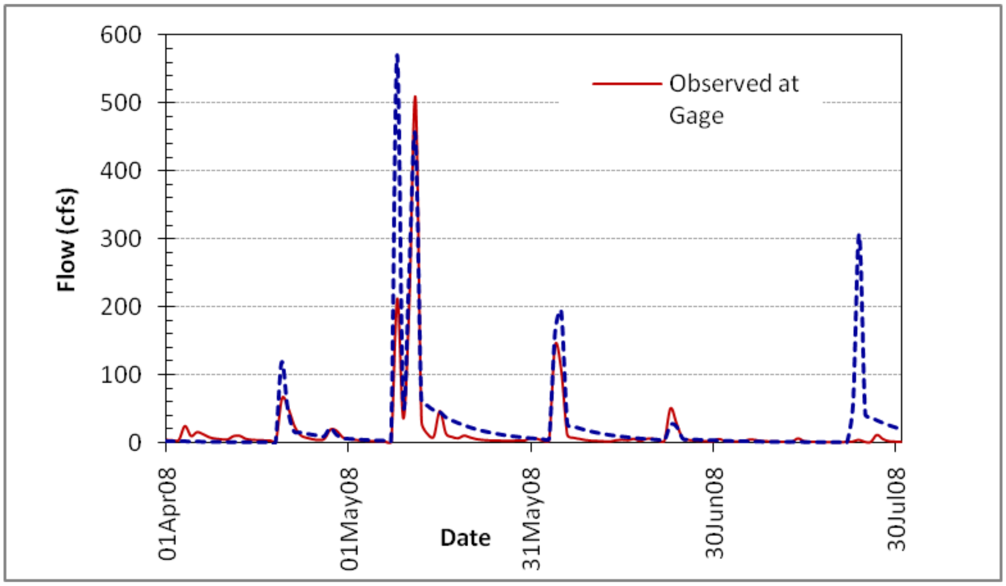


Figure 33. Modeled and observed flows at the Cameron Run at the Quantico Creek near Independent Hill, VA gage during the validation period.

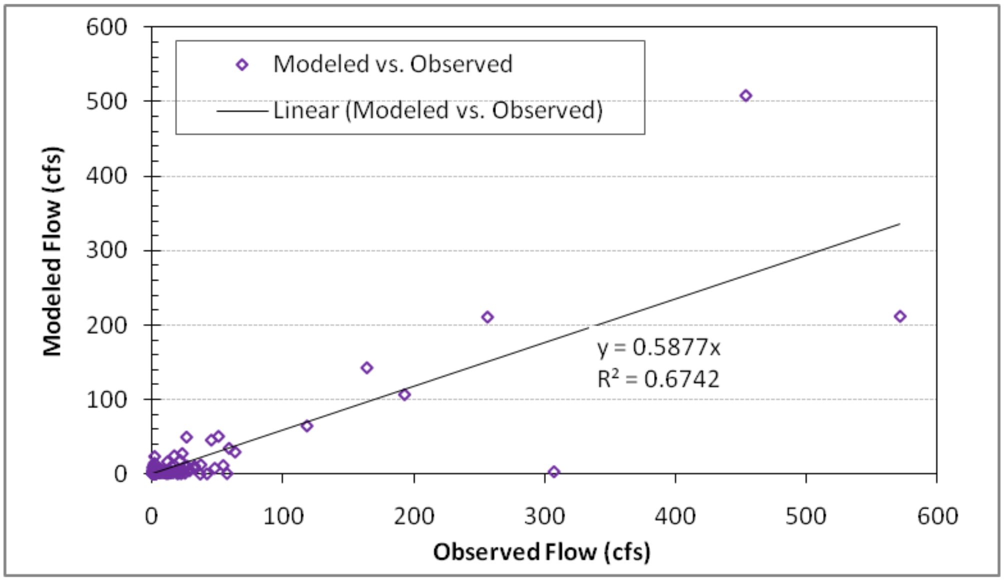


Figure 34. Correlation between the modeled and observed flows at the Quantico Creek gage during the validation period.

Appendices

Appendix 1. Mean, standard deviation (Std. Dev.), minimum and maximum values of physical variables by stream order and month for Quantico Creek drainage from November, 2008 -- June, 2010.

January

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	9	68.48	32.64	22.90	93.00
	RIVERKM	9	15.49	3.10	13.50	23.56
	GRADIENT	9	16.97	11.25	8.87	32.53
	WIDTHAVG	9	1.86	0.36	1.27	2.13
	DEPTHAVG	9	0.17	0.07	0.08	0.30
	CURAVG	9	0.82	0.42	0.33	1.26
	FLOW	9	0.29	0.21	0.05	0.51
	TEMP	9	1.22	0.44	1.00	2.00
	PH	9	6.87	0.23	6.30	7.00
2	ELEV	26	37.69	16.67	13.94	61.50
	RIVERKM	26	16.27	6.10	9.30	23.63
	GRADIENT	26	15.26	7.27	8.13	27.89
	WIDTHAVG	26	3.48	1.49	1.87	5.30
	DEPTHAVG	26	0.18	0.04	0.13	0.27
	CURAVG	26	0.75	0.29	0.05	1.15
	FLOW	26	0.43	0.20	0.04	0.76
	TEMP	26	0.00	0.63	-1.00	1.00
	PH	26	6.80	0.29	6.30	7.10
3	ELEV	49	31.53	21.00	6.10	60.00
	RIVERKM	49	13.72	6.76	7.13	23.25
	GRADIENT	49	11.77	6.56	3.05	20.00
	WIDTHAVG	49	7.90	3.19	3.87	11.59
	DEPTHAVG	49	0.27	0.08	0.20	0.42
	CURAVG	49	0.94	0.40	0.33	1.48
	FLOW	49	2.12	1.54	0.50	4.62
	TEMP	49	0.20	0.46	-1.00	1.00
	PH	49	6.76	0.26	6.30	7.00

March

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	20	78.46	27.74	22.90	93.00
	RIVERKM	20	15.15	2.06	13.50	23.56
	GRADIENT	20	13.60	9.24	8.87	32.53
	WIDTHAVG	20	1.85	0.16	1.31	2.06
	DEPTHAVG	20	0.76	0.65	0.08	1.46
	CURAVG	20	0.30	0.12	0.03	0.38
	FLOW	20	0.48	0.43	0.01	0.94
	TEMP	20	6.13	1.17	4.00	8.50
	PH	20	6.51	0.19	6.30	6.70
2	ELEV	60	36.20	14.54	13.94	61.50
	RIVERKM	60	17.12	5.90	9.30	23.63
	GRADIENT	60	16.42	8.09	8.13	27.89
	WIDTHAVG	60	4.15	1.85	2.33	8.39
	DEPTHAVG	60	0.37	0.27	0.13	1.10
	CURAVG	60	0.47	0.18	0.21	0.83
	FLOW	60	0.73	0.61	0.13	2.24
	TEMP	60	5.48	1.54	3.00	7.00
	PH	60	6.55	0.24	6.30	6.90

3	ELEV	120	31.24	18.36	6.10	60.00
	RIVERKM	120	12.92	6.22	7.13	23.25
	GRADIENT	120	10.43	6.22	3.05	20.00
	WIDTHAVG	120	9.17	2.90	4.67	13.09
	DEPTHAVG	120	0.33	0.08	0.22	0.46
	CURAVG	120	0.51	0.27	0.06	1.01
	FLOW	120	1.81	1.57	0.11	4.56
	TEMP	120	6.17	1.91	3.00	9.00
	PH	120	6.54	0.23	6.30	6.90

April

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	19	77.69	28.28	22.90	93.00
	RIVERKM	19	15.15	2.12	13.50	23.56
	GRADIENT	19	13.84	9.43	8.87	32.53
	WIDTHAVG	19	1.93	0.37	1.10	2.23
	DEPTHAVG	19	0.22	0.05	0.09	0.27
	CURAVG	19	0.35	0.20	0.11	0.67
	FLOW	19	0.16	0.11	0.01	0.40
	TEMP	19	12.84	2.34	10.00	18.00
	PH	19	6.34	0.08	6.10	6.50
2	ELEV	63	38.36	14.63	13.94	61.50
	RIVERKM	63	17.87	6.03	9.30	23.63
	GRADIENT	63	14.80	7.64	8.13	27.89
	WIDTHAVG	63	4.06	1.76	2.34	7.25
	DEPTHAVG	63	0.31	0.08	0.16	0.44
	CURAVG	63	0.89	0.71	0.24	2.83
	FLOW	63	1.33	1.57	0.10	6.45
	TEMP	63	14.27	3.38	10.00	19.00
	PH	63	6.39	0.21	6.00	6.80
3	ELEV	116	32.20	19.38	6.10	60.00
	RIVERKM	116	13.43	6.42	7.13	23.25
	GRADIENT	116	10.63	6.52	3.05	20.00
	WIDTHAVG	116	9.22	3.38	4.66	13.52
	DEPTHAVG	116	0.41	0.13	0.24	1.34
	CURAVG	116	1.16	0.63	0.35	2.50
	FLOW	116	4.95	4.77	0.60	37.88
	TEMP	116	13.92	3.43	10.00	20.00
	PH	116	6.42	0.21	6.00	6.80

May

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	7	73.59	33.18	22.90	93.00
	RIVERKM	7	14.60	0.69	13.50	15.00
	GRADIENT	7	15.34	11.06	8.87	32.53
	WIDTHAVG	7	1.72	0.32	1.23	1.91
	DEPTHAVG	7	0.16	0.05	0.08	0.19
	CURAVG	7	0.02	0.04	0.00	0.11
	FLOW	7	0.00	0.01	0.00	0.01
	TEMP	7	10.86	1.46	10.00	13.00
	PH	7	7.00	0.00	7.00	7.00
2	ELEV	34	36.11	14.74	13.94	61.50
	RIVERKM	34	17.40	6.12	9.30	23.63
	GRADIENT	34	15.66	7.69	8.13	27.89
	WIDTHAVG	34	3.61	2.45	1.56	7.82
	DEPTHAVG	34	0.18	0.06	0.10	0.27
	CURAVG	34	0.17	0.10	0.10	0.37

	FLOW	34	0.15	0.18	0.03	0.50
	TEMP	34	12.41	1.46	11.00	14.00
	PH	34	6.96	0.14	6.50	7.00
3	ELEV	52	31.96	19.08	6.10	60.00
	RIVERKM	52	13.30	6.40	7.13	23.25
	GRADIENT	52	10.50	6.56	3.05	20.00
	WIDTHAVG	52	7.94	2.50	4.53	10.15
	DEPTHAVG	52	0.28	0.04	0.22	0.36
	CURAVG	52	0.28	0.10	0.12	0.40
	FLOW	52	0.70	0.41	0.15	1.19
	TEMP	52	12.96	1.45	11.00	16.00
	PH	52	6.90	0.20	6.50	7.00

June

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	15	73.61	30.72	22.90	93.00
	RIVERKM	15	15.20	2.40	13.50	23.56
	GRADIENT	15	15.17	10.26	8.87	32.53
	WIDTHAVG	15	2.03	0.64	0.97	2.63
	DEPTHAVG	15	0.14	0.04	0.05	0.17
	CURAVG	15	0.18	0.15	0.00	0.33
	FLOW	15	0.06	0.06	0.00	0.13
	TEMP	15	16.67	1.54	15.00	19.00
	PH	15	7.05	0.25	6.60	7.80
2	ELEV	56	39.11	13.10	13.94	61.50
	RIVERKM	56	18.50	5.65	9.30	23.63
	GRADIENT	56	15.67	8.37	8.13	27.89
	WIDTHAVG	56	3.36	1.34	1.55	5.75
	DEPTHAVG	56	0.24	0.11	0.08	0.40
	CURAVG	56	0.63	0.71	0.08	2.15
	FLOW	56	0.51	0.50	0.01	1.40
	TEMP	56	17.14	1.69	15.00	19.00
	PH	56	6.94	0.39	6.50	7.70
3	ELEV	76	32.02	20.42	6.10	60.00
	RIVERKM	76	14.22	6.91	7.13	23.25
	GRADIENT	76	11.73	6.68	3.05	20.00
	WIDTHAVG	76	7.82	2.67	4.57	11.10
	DEPTHAVG	76	0.32	0.11	0.15	0.49
	CURAVG	76	0.44	0.35	0.04	1.27
	FLOW	76	1.12	0.99	0.08	3.08
	TEMP	76	18.84	2.57	15.00	24.00
	PH	76	6.85	0.34	6.20	7.40

July

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	4	59.03	39.27	22.90	93.00
	RIVERKM	4	14.30	0.81	13.50	15.00
	GRADIENT	4	20.19	13.10	8.87	32.53
	WIDTHAVG	4	1.60	0.50	1.17	2.03
	DEPTHAVG	4	0.14	0.04	0.08	0.17
	CURAVG	4	0.00	0.00	0.00	0.00
	FLOW	4	0.00	0.00	0.00	0.00
	TEMP	4	18.50	1.73	17.00	20.00
	PH	4	6.60	0.12	6.50	6.70
2	ELEV	43	35.32	15.21	13.94	61.50

	RIVERKM	43	17.37	6.35	9.30	23.63
	GRADIENT	43	14.65	7.19	8.13	27.89
	WIDTHAVG	43	3.14	1.58	0.68	5.73
	DEPTHAVG	43	0.23	0.12	0.06	0.35
	CURAVG	43	0.13	0.20	0.00	0.54
	FLOW	43	0.14	0.27	0.00	0.71
	TEMP	43	20.47	1.32	19.00	25.00
	PH	43	6.40	0.33	5.90	7.10
3	ELEV	97	29.58	17.72	6.10	60.00
	RIVERKM	97	12.21	5.90	7.13	23.25
	GRADIENT	97	10.60	6.18	3.05	20.00
	WIDTHAVG	97	8.37	3.10	4.18	12.87
	DEPTHAVG	97	0.30	0.07	0.14	0.39
	CURAVG	97	0.26	0.24	0.00	0.76
	FLOW	97	0.86	0.93	0.00	2.64
	TEMP	97	20.90	2.16	18.00	24.00
	PH	97	6.77	0.68	5.50	7.80

August

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	93.00	0.00	93.00	93.00
	RIVERKM	6	15.00	0.00	15.00	15.00
	GRADIENT	6	8.87	0.00	8.87	8.87
	WIDTHAVG	6	1.39	0.00	1.39	1.39
	DEPTHAVG	6	0.11	0.00	0.11	0.11
	CURAVG	6	0.00	0.00	0.00	0.00
	FLOW	6	0.00	0.00	0.00	0.00
	TEMP	6	20.00	0.00	20.00	20.00
	PH	6	7.60	0.00	7.60	7.60
2	ELEV	17	45.35	2.57	43.00	48.00
	RIVERKM	17	23.62	0.01	23.61	23.63
	GRADIENT	17	10.71	2.51	8.13	13.01
	WIDTHAVG	17	1.96	0.17	1.79	2.12
	DEPTHAVG	17	0.20	0.01	0.19	0.22
	CURAVG	17	0.00	0.00	0.00	0.01
	FLOW	17	0.00	0.00	0.00	0.00
	TEMP	17	20.00	0.00	20.00	20.00
	PH	17	6.99	0.21	6.80	7.20
3	ELEV	44	30.71	22.39	6.10	60.00
	RIVERKM	44	14.55	7.32	7.13	23.25
	GRADIENT	44	13.23	6.31	3.05	20.00
	WIDTHAVG	44	5.74	2.30	3.69	9.15
	DEPTHAVG	44	0.27	0.10	0.16	0.43
	CURAVG	44	0.09	0.08	0.00	0.19
	FLOW	44	0.19	0.19	0.00	0.38
	TEMP	44	21.30	1.13	20.00	23.00
	PH	32	7.31	0.69	6.40	8.00

September

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	2	25.05	3.04	22.90	27.20
	RIVERKM	2	13.60	0.13	13.50	13.69
	GRADIENT	2	31.51	1.45	30.48	32.53
	WIDTHAVG	2	1.40	0.23	1.23	1.56
	DEPTHAVG	2	0.11	0.02	0.09	0.12
	CURAVG	2	0.00	0.00	0.00	0.00

	FLOW	2	0.00	0.00	0.00	0.00
	TEMP	2	18.00	1.41	17.00	19.00
	PH	0	.	.	.	.
2	ELEV	18	28.05	16.41	13.94	61.50
	RIVERKM	18	11.87	1.99	9.30	13.63
	GRADIENT	18	19.91	8.29	9.76	27.89
	WIDTHAVG	18	3.91	0.90	2.39	4.70
	DEPTHAVG	18	0.21	0.07	0.12	0.28
	CURAVG	18	0.03	0.04	0.00	0.08
	FLOW	18	0.01	0.02	0.00	0.03
	TEMP	18	18.67	0.77	18.00	20.00
	PH	0	.	.	.	.
3	ELEV	26	32.00	8.16	24.00	40.00
	RIVERKM	26	10.07	1.34	8.75	11.38
	GRADIENT	26	5.30	0.00	5.30	5.30
	WIDTHAVG	26	7.50	0.88	6.64	8.36
	DEPTHAVG	26	0.27	0.05	0.22	0.32
	CURAVG	26	0.06	0.02	0.05	0.08
	FLOW	26	0.12	0.01	0.11	0.13
	TEMP	26	18.50	0.51	18.00	19.00
	PH	0	.	.	.	.

October

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	10	79.41	28.67	22.90	93.00
	RIVERKM	10	14.72	0.59	13.50	15.00
	GRADIENT	10	13.40	9.56	8.87	32.53
	WIDTHAVG	10	1.88	0.36	1.10	2.05
	DEPTHAVG	10	0.16	0.02	0.11	0.17
	CURAVG	10	0.00	0.00	0.00	0.00
	FLOW	10	0.00	0.00	0.00	0.00
	TEMP	10	14.60	1.35	14.00	18.00
	PH	0	.	.	.	.
2	ELEV	33	35.81	15.48	13.94	61.50
	RIVERKM	33	16.55	5.98	9.30	23.63
	GRADIENT	33	16.24	8.01	8.13	27.89
	WIDTHAVG	33	2.81	1.32	1.32	4.51
	DEPTHAVG	33	0.18	0.03	0.16	0.22
	CURAVG	33	0.02	0.02	0.00	0.04
	FLOW	33	0.01	0.02	0.00	0.04
	TEMP	33	15.24	1.62	13.00	18.00
	PH	0	.	.	.	.
3	ELEV	63	29.07	17.92	6.10	60.00
	RIVERKM	63	12.07	5.89	7.13	23.25
	GRADIENT	63	10.53	6.37	3.05	20.00
	WIDTHAVG	63	6.21	1.99	3.15	8.63
	DEPTHAVG	63	0.23	0.08	0.15	0.41
	CURAVG	63	0.06	0.02	0.02	0.09
	FLOW	63	0.09	0.07	0.01	0.24
	TEMP	63	15.33	1.18	13.00	17.00
	PH	0	.	.	.	.

November

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	13	65.57	33.41	22.90	93.00
	RIVERKM	13	15.13	2.63	13.50	23.56

	GRADIENT	13	17.96	11.38	8.87	32.53
	WIDTHAVG	13	1.62	0.90	0.09	2.37
	DEPTHAVG	13	0.16	0.06	0.02	0.19
	CURAVG	13	0.42	0.39	0.01	0.77
	FLOW	13	0.19	0.18	0.00	0.35
	TEMP	13	12.69	0.43	12.50	14.00
	PH	13	6.68	0.04	6.60	6.70
2	ELEV	41	34.73	16.03	13.94	61.50
	RIVERKM	41	16.67	6.40	9.30	23.63
	GRADIENT	41	14.64	6.88	8.13	27.89
	WIDTHAVG	41	3.54	1.56	1.99	5.51
	DEPTHAVG	41	0.21	0.05	0.16	0.32
	CURAVG	41	0.57	0.36	0.25	1.23
	FLOW	41	0.53	0.62	0.08	1.74
	TEMP	41	12.49	2.01	8.00	15.00
	PH	41	6.64	0.16	6.30	6.80
3	ELEV	94	35.14	18.26	6.10	60.00
	RIVERKM	94	13.71	6.17	7.13	23.25
	GRADIENT	94	8.93	6.04	3.05	20.00
	WIDTHAVG	94	7.37	3.05	4.22	12.12
	DEPTHAVG	94	0.25	0.12	0.14	0.55
	CURAVG	80	0.61	0.25	0.26	0.96
	FLOW	80	1.12	0.48	0.34	1.72
	TEMP	94	11.22	2.79	8.00	14.00
	PH	94	6.53	0.23	6.30	6.80

December

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	8	76.01	31.48	22.90	93.00
	RIVERKM	8	14.65	0.65	13.50	15.00
	GRADIENT	8	14.53	10.49	8.87	32.53
	WIDTHAVG	8	2.32	0.70	0.99	2.69
	DEPTHAVG	8	0.13	0.03	0.06	0.14
	CURAVG	8	0.11	0.01	0.08	0.12
	FLOW	8	0.04	0.02	0.01	0.04
	TEMP	8	7.75	0.46	7.00	8.00
	PH	8	6.30	0.00	6.30	6.30
2	ELEV	29	41.28	11.46	26.30	61.50
	RIVERKM	29	19.29	5.27	11.72	23.63
	GRADIENT	29	15.78	8.49	8.13	27.89
	WIDTHAVG	29	3.03	1.11	1.87	4.61
	DEPTHAVG	29	0.22	0.06	0.13	0.30
	CURAVG	29	0.22	0.08	0.11	0.33
	FLOW	29	0.14	0.05	0.03	0.20
	TEMP	29	7.17	1.71	5.00	9.00
	PH	29	6.30	0.00	6.30	6.30
3	ELEV	9	44.00	0.00	44.00	44.00
	RIVERKM	9	23.25	0.00	23.25	23.25
	GRADIENT	9	13.94	0.00	13.94	13.94
	WIDTHAVG	9	4.30	0.00	4.30	4.30
	DEPTHAVG	9	0.17	0.00	0.17	0.17
	CURAVG	9	0.20	0.00	0.20	0.20
	FLOW	9	0.15	0.00	0.15	0.15
	TEMP	9	8.00	0.00	8.00	8.00
	PH	9	6.30	0.00	6.30	6.30

Appendix 2. Mean, standard deviation (Std. Dev.), minimum and maximum values of physical variables by stream order and month for Cameron Run drainage from November, 2008 -- June, 2010.

January

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	75.50	1.64	74.00	77.00
	RIVERKM	6	17.61	6.52	11.66	23.56
	GRADIENT	6	12.84	0.01	12.83	12.84
	WIDTHAVG	6	3.37	1.50	2.14	5.77
	DEPTHAVG	6	0.18	0.10	0.09	0.33
	CURAVG	6	0.23	0.16	0.03	0.44
	FLOW	6	0.09	0.07	0.05	0.23
	TEMP	6	-0.67	0.52	-1.00	0.00
	PH	6	6.58	0.44	6.30	7.20
2	ELEV	16	47.44	5.24	45.00	58.00
	RIVERKM	16	9.11	0.50	8.88	10.11
	GRADIENT	16	6.89	2.21	5.86	11.34
	WIDTHAVG	16	5.34	0.52	4.70	5.90
	DEPTHAVG	16	0.14	0.08	0.07	0.28
	CURAVG	16	0.38	0.17	0.25	0.59
	FLOW	16	0.24	0.08	0.20	0.41
	TEMP	16	0.00	0.00	0.00	0.00
	PH	16	6.71	0.40	6.30	7.30
3	ELEV	7	37.00	0.00	37.00	37.00
	RIVERKM	7	5.97	0.00	5.97	5.97
	GRADIENT	7	3.05	0.00	3.05	3.05
	WIDTHAVG	7	15.36	2.23	10.30	16.20
	DEPTHAVG	7	0.21	0.02	0.17	0.22
	CURAVG	7	0.53	0.28	0.42	1.17
	FLOW	7	1.57	0.22	1.49	2.08
	TEMP	7	0.29	0.76	0.00	2.00
	PH	7	6.37	0.19	6.30	6.80
4	ELEV	19	30.05	6.09	25.00	37.00
	RIVERKM	19	6.14	1.22	5.13	7.54
	GRADIENT	19	5.06	0.32	4.79	5.42
	WIDTHAVG	19	9.82	0.88	7.03	10.50
	DEPTHAVG	19	0.25	0.07	0.17	0.32
	CURAVG	19	0.53	0.29	0.37	1.14
	FLOW	19	1.30	0.79	0.66	2.95
	TEMP	19	1.32	0.58	0.00	2.00
	PH	19	6.41	0.23	6.30	6.90

March

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	11	75.36	1.57	74.00	77.00
	RIVERKM	11	18.15	6.21	11.66	23.56
	GRADIENT	11	12.84	0.01	12.83	12.84
	WIDTHAVG	11	4.72	0.72	3.93	6.02
	DEPTHAVG	11	0.24	0.11	0.12	0.43
	CURAVG	11	0.46	0.23	0.11	0.70
	FLOW	11	0.40	0.07	0.29	0.49
	TEMP	11	6.00	2.32	3.00	8.00
	PH	5	6.30	0.00	6.30	6.30
2	ELEV	16	46.63	4.44	45.00	58.00

	RIVERKM	16	9.03	0.42	8.88	10.11
	GRADIENT	16	6.55	1.87	5.86	11.34
	WIDTHAVG	16	5.39	0.24	5.27	6.00
	DEPTHAVG	16	0.18	0.09	0.11	0.29
	CURAVG	16	0.51	0.21	0.07	0.66
	FLOW	16	0.41	0.15	0.13	0.59
	TEMP	16	6.63	1.86	4.00	8.00
	PH	5	6.30	0.00	6.30	6.30
3	ELEV	8	37.00	0.00	37.00	37.00
	RIVERKM	8	5.97	0.00	5.97	5.97
	GRADIENT	8	3.05	0.00	3.05	3.05
	WIDTHAVG	8	8.16	4.40	6.60	19.04
	DEPTHAVG	8	0.16	0.04	0.15	0.25
	CURAVG	8	1.00	0.09	0.78	1.03
	FLOW	8	1.36	0.95	1.02	3.71
	TEMP	8	7.50	1.41	4.00	8.00
	PH	1	6.30	.	6.30	6.30
4	ELEV	25	28.36	5.50	25.00	37.00
	RIVERKM	25	5.80	1.10	5.13	7.54
	GRADIENT	25	4.97	0.29	4.79	5.42
	WIDTHAVG	25	9.11	2.47	6.53	12.13
	DEPTHAVG	25	0.30	0.08	0.14	0.38
	CURAVG	25	1.21	0.67	0.63	2.11
	FLOW	25	2.81	1.00	1.25	4.04
	TEMP	25	6.36	2.31	4.00	9.00
	PH	13	6.30	0.00	6.30	6.30

April

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	12	75.25	1.54	74.00	77.00
	RIVERKM	12	18.60	6.13	11.66	23.56
	GRADIENT	12	12.84	0.01	12.83	12.84
	WIDTHAVG	12	4.58	1.40	2.58	6.37
	DEPTHAVG	12	0.27	0.07	0.12	0.37
	CURAVG	12	0.43	0.27	0.07	0.75
	FLOW	12	0.51	0.39	0.13	1.02
	TEMP	12	13.33	1.87	11.00	15.00
	PH	12	6.50	0.52	6.00	7.00
2	ELEV	16	48.25	5.81	45.00	58.00
	RIVERKM	16	9.19	0.55	8.88	10.11
	GRADIENT	16	7.23	2.45	5.86	11.34
	WIDTHAVG	16	5.15	0.40	4.65	5.52
	DEPTHAVG	16	0.30	0.17	0.19	0.59
	CURAVG	16	0.44	0.11	0.32	0.56
	FLOW	16	0.69	0.44	0.28	1.37
	TEMP	16	13.50	2.00	12.00	16.00
	PH	16	6.38	0.50	6.00	7.00
3	ELEV	18	37.00	0.00	37.00	37.00
	RIVERKM	18	5.97	0.00	5.97	5.97
	GRADIENT	18	3.05	0.00	3.05	3.05
	WIDTHAVG	18	17.73	0.42	17.27	18.10
	DEPTHAVG	18	0.29	0.08	0.20	0.36
	CURAVG	18	0.98	0.44	0.51	1.36
	FLOW	18	5.68	3.60	1.76	8.81
	TEMP	18	17.44	5.11	13.00	23.00
	PH	18	7.47	1.69	6.00	9.30

4	ELEV	30	30.20	6.05	25.00	37.00
	RIVERKM	30	6.17	1.21	5.13	7.54
	GRADIENT	30	5.06	0.32	4.79	5.42
	WIDTHAVG	30	11.35	0.97	10.28	12.94
	DEPTHAVG	30	0.31	0.08	0.21	0.42
	CURAVG	30	1.46	1.09	0.36	2.63
	FLOW	30	5.45	4.96	1.18	12.98
	TEMP	30	15.50	2.54	13.00	18.00
	PH	30	6.90	0.93	6.00	8.00

May

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	75.50	1.64	74.00	77.00
	RIVERKM	6	17.61	6.52	11.66	23.56
	GRADIENT	6	12.84	0.01	12.83	12.84
	WIDTHAVG	6	3.75	1.87	2.16	5.95
	DEPTHAVG	6	0.20	0.09	0.12	0.29
	CURAVG	6	0.18	0.17	0.00	0.34
	FLOW	6	0.06	0.04	0.00	0.09
	TEMP	6	11.00	1.10	10.00	12.00
	PH	6	7.00	0.00	7.00	7.00
2	ELEV	4	45.00	0.00	45.00	45.00
	RIVERKM	4	8.88	0.00	8.88	8.88
	GRADIENT	4	5.86	0.00	5.86	5.86
	WIDTHAVG	4	3.96	0.00	3.96	3.96
	DEPTHAVG	4	0.20	0.00	0.20	0.20
	CURAVG	4	0.04	0.00	0.04	0.04
	FLOW	4	0.03	0.00	0.03	0.03
	TEMP	4	11.00	0.00	11.00	11.00
	PH	4	7.00	0.00	7.00	7.00
3	ELEV	9	37.00	0.00	37.00	37.00
	RIVERKM	9	5.97	0.00	5.97	5.97
	GRADIENT	9	3.05	0.00	3.05	3.05
	WIDTHAVG	9	15.13	0.00	15.13	15.13
	DEPTHAVG	9	0.22	0.00	0.22	0.22
	CURAVG	9	0.48	0.00	0.48	0.48
	FLOW	9	1.59	0.00	1.59	1.59
	TEMP	9	13.00	0.00	13.00	13.00
	PH	9	7.50	0.00	7.50	7.50
4	ELEV	15	29.80	6.09	25.00	37.00
	RIVERKM	15	6.09	1.22	5.13	7.54
	GRADIENT	15	5.04	0.32	4.79	5.42
	WIDTHAVG	15	10.25	0.09	10.17	10.36
	DEPTHAVG	15	0.22	0.09	0.10	0.29
	CURAVG	15	0.18	0.05	0.15	0.24
	FLOW	15	0.36	0.09	0.26	0.43
	TEMP	15	13.60	0.51	13.00	14.00
	PH	15	7.00	0.00	7.00	7.00

June

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	13	75.38	1.56	74.00	77.00
	RIVERKM	13	18.07	6.17	11.66	23.56
	GRADIENT	13	12.84	0.01	12.83	12.84
	WIDTHAVG	13	3.55	0.88	2.63	4.97
	DEPTHAVG	13	0.22	0.03	0.20	0.27
	CURAVG	13	0.20	0.15	0.05	0.40
	FLOW	13	0.14	0.10	0.06	0.29
	TEMP	13	17.31	0.48	17.00	18.00

	PH	13	6.62	0.43	6.10	7.00
2	ELEV	14	46.86	4.72	45.00	58.00
	RIVERKM	14	9.06	0.45	8.88	10.11
	GRADIENT	14	6.64	1.99	5.86	11.34
	WIDTHAVG	14	5.09	1.37	3.84	7.96
	DEPTHAVG	14	0.28	0.08	0.25	0.46
	CURAVG	14	0.19	0.10	0.08	0.29
	FLOW	14	0.27	0.15	0.08	0.43
	TEMP	14	18.57	1.16	17.00	20.00
	PH	14	6.42	0.45	6.10	7.00
3	ELEV	20	37.00	0.00	37.00	37.00
	RIVERKM	20	5.97	0.00	5.97	5.97
	GRADIENT	20	3.05	0.00	3.05	3.05
	WIDTHAVG	20	13.80	2.71	10.88	16.20
	DEPTHAVG	20	0.14	0.03	0.11	0.17
	CURAVG	20	0.53	0.02	0.51	0.55
	FLOW	20	0.95	0.01	0.94	0.97
	TEMP	20	25.10	1.02	24.00	26.00
	PH	20	7.74	1.43	6.20	9.00
4	ELEV	36	30.67	6.08	25.00	37.00
	RIVERKM	36	6.27	1.22	5.13	7.54
	GRADIENT	36	5.09	0.32	4.79	5.42
	WIDTHAVG	36	10.23	1.21	8.27	11.42
	DEPTHAVG	36	0.23	0.04	0.17	0.26
	CURAVG	36	0.42	0.14	0.29	0.66
	FLOW	36	0.96	0.34	0.48	1.32
	TEMP	36	22.81	1.58	20.00	24.00
	PH	36	6.75	0.78	6.10	8.00

July

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	7	75.71	1.60	74.00	77.00
	RIVERKM	7	16.76	6.36	11.66	23.56
	GRADIENT	7	12.83	0.01	12.83	12.84
	WIDTHAVG	7	3.71	2.07	2.47	6.74
	DEPTHAVG	7	0.24	0.17	0.10	0.47
	CURAVG	7	0.06	0.01	0.04	0.06
	FLOW	7	0.06	0.06	0.01	0.14
	TEMP	7	18.29	0.49	18.00	19.00
	PH	7	6.80	0.19	6.60	7.00
2	ELEV	8	45.00	0.00	45.00	45.00
	RIVERKM	8	8.88	0.00	8.88	8.88
	GRADIENT	8	5.86	0.00	5.86	5.86
	WIDTHAVG	8	4.98	0.00	4.98	4.98
	DEPTHAVG	8	0.21	0.00	0.21	0.21
	CURAVG	8	0.03	0.00	0.03	0.03
	FLOW	8	0.03	0.00	0.03	0.03
	TEMP	8	20.00	0.00	20.00	20.00
	PH	8	6.90	0.00	6.90	6.90
4	ELEV	19	29.42	5.95	25.00	37.00
	RIVERKM	19	6.02	1.19	5.13	7.54
	GRADIENT	19	5.02	0.31	4.79	5.42
	WIDTHAVG	19	8.47	1.91	6.04	9.89
	DEPTHAVG	19	0.21	0.00	0.21	0.21
	CURAVG	19	0.24	0.04	0.21	0.29
	FLOW	19	0.41	0.04	0.36	0.44

	TEMP	19	26.53	1.98	24.00	28.00
	PH	19	7.03	0.10	6.90	7.10

September

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	75.50	1.64	74.00	77.00
	RIVERKM	6	17.61	6.52	11.66	23.56
	GRADIENT	6	12.84	0.01	12.83	12.84
	WIDTHAVG	6	4.87	2.09	2.97	6.93
	DEPTHAVG	6	0.32	0.10	0.23	0.45
	CURAVG	6	0.01	0.02	0.00	0.05
	FLOW	6	0.01	0.03	0.00	0.07
	TEMP	6	18.17	0.75	17.00	19.00
	PH	0	.	.	.	.
2	ELEV	8	45.00	0.00	45.00	45.00
	RIVERKM	8	8.88	0.00	8.88	8.88
	GRADIENT	8	5.86	0.00	5.86	5.86
	WIDTHAVG	8	3.66	0.00	3.66	3.66
	DEPTHAVG	8	0.19	0.00	0.19	0.19
	CURAVG	8	0.00	0.00	0.00	0.00
	FLOW	8	0.00	0.00	0.00	0.00
	TEMP	8	20.00	0.00	20.00	20.00
	PH	0	.	.	.	.
3	ELEV	12	37.00	0.00	37.00	37.00
	RIVERKM	12	5.97	0.00	5.97	5.97
	GRADIENT	12	3.05	0.00	3.05	3.05
	WIDTHAVG	12	11.98	0.00	11.98	11.98
	DEPTHAVG	12	0.16	0.00	0.16	0.16
	CURAVG	12	0.30	0.00	0.30	0.30
	FLOW	12	0.58	0.00	0.58	0.58
	TEMP	12	23.00	0.00	23.00	23.00
	PH	0	.	.	.	.
4	ELEV	20	30.40	6.13	25.00	37.00
	RIVERKM	20	6.21	1.23	5.13	7.54
	GRADIENT	20	5.07	0.32	4.79	5.42
	WIDTHAVG	20	8.47	0.69	7.73	9.08
	DEPTHAVG	20	0.20	0.04	0.15	0.23
	CURAVG	20	0.22	0.06	0.17	0.29
	FLOW	20	0.35	0.02	0.33	0.37
	TEMP	20	23.55	0.51	23.00	24.00
	PH	0	.	.	.	.

October

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	75.50	1.64	74.00	77.00
	RIVERKM	6	17.61	6.52	11.66	23.56
	GRADIENT	6	12.84	0.01	12.83	12.84
	WIDTHAVG	6	3.99	2.42	2.21	7.08
	DEPTHAVG	6	0.25	0.11	0.17	0.38
	CURAVG	6	0.01	0.01	0.00	0.02
	FLOW	6	0.01	0.01	0.00	0.02
	TEMP	6	14.50	0.55	14.00	15.00
	PH	0	.	.	.	.
2	ELEV	7	45.00	0.00	45.00	45.00
	RIVERKM	7	8.88	0.00	8.88	8.88
	GRADIENT	7	5.86	0.00	5.86	5.86
	WIDTHAVG	7	4.45	0.00	4.45	4.45
	DEPTHAVG	7	0.18	0.00	0.18	0.18

	CURAVG	7	0.01	0.00	0.01	0.01
	FLOW	7	0.01	0.00	0.01	0.01
	TEMP	7	15.00	0.00	15.00	15.00
	PH	0	.	.	.	.
3	ELEV	9	37.00	0.00	37.00	37.00
	RIVERKM	9	5.97	0.00	5.97	5.97
	GRADIENT	9	3.05	0.00	3.05	3.05
	WIDTHAVG	9	8.00	0.00	8.00	8.00
	DEPTHAVG	9	0.20	0.00	0.20	0.20
	CURAVG	9	0.18	0.00	0.18	0.18
	FLOW	9	0.29	0.00	0.29	0.29
	TEMP	9	20.00	0.00	20.00	20.00
	PH	0	.	.	.	.
4	ELEV	19	30.05	6.09	25.00	37.00
	RIVERKM	19	6.14	1.22	5.13	7.54
	GRADIENT	19	5.06	0.32	4.79	5.42
	WIDTHAVG	19	8.36	1.66	6.47	9.74
	DEPTHAVG	19	0.17	0.02	0.15	0.19
	CURAVG	19	0.19	0.12	0.09	0.32
	FLOW	19	0.23	0.07	0.17	0.31
	TEMP	19	18.00	0.00	18.00	18.00
	PH	0	.	.	.	.
			November			
ORDER	**Variable**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
1	ELEV	5	75.20	1.64	74.00	77.00
	RIVERKM	5	18.80	6.52	11.66	23.56
	GRADIENT	5	12.84	0.01	12.83	12.84
	WIDTHAVG	5	4.65	0.10	4.54	4.72
	DEPTHAVG	5	0.25	0.18	0.11	0.44
	CURAVG	5	0.78	0.16	0.61	0.90
	FLOW	5	0.78	0.41	0.48	1.23
	TEMP	5	13.20	0.27	13.00	13.50
	PH	5	6.72	0.16	6.60	6.90
2	ELEV	7	48.71	6.34	45.00	58.00
	RIVERKM	7	9.23	0.60	8.88	10.11
	GRADIENT	7	7.43	2.67	5.86	11.34
	WIDTHAVG	7	6.23	0.26	5.85	6.38
	DEPTHAVG	7	0.14	0.15	0.05	0.35
	CURAVG	7	0.41	0.08	0.29	0.45
	FLOW	7	0.28	0.23	0.14	0.61
	TEMP	7	13.50	0.00	13.50	13.50
	PH	7	6.80	0.00	6.80	6.80
3	ELEV	15	37.00	0.00	37.00	37.00
	RIVERKM	15	6.39	0.72	5.97	7.54
	GRADIENT	15	3.68	1.08	3.05	5.42
	WIDTHAVG	15	9.11	2.55	5.03	10.59
	DEPTHAVG	15	0.16	0.00	0.15	0.16
	CURAVG	15	3.34	1.65	0.69	4.30
	FLOW	15	5.38	3.03	0.52	7.15
	TEMP	15	14.50	0.00	14.50	14.50
	PH	15	6.90	0.00	6.90	6.90
4	ELEV	11	25.00	0.00	25.00	25.00
	RIVERKM	11	5.13	0.00	5.13	5.13
	GRADIENT	11	4.79	0.00	4.79	4.79
	WIDTHAVG	11	9.83	0.00	9.83	9.83

	DEPTHAVG	11	0.28	0.00	0.28	0.28
	CURAVG	11	2.49	0.00	2.49	2.49
	FLOW	11	6.85	0.00	6.85	6.85
	TEMP	11	15.50	0.00	15.50	15.50
	PH	11	6.90	0.00	6.90	6.90

December

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	75.50	1.64	74.00	77.00
	RIVERKM	6	17.61	6.52	11.66	23.56
	GRADIENT	6	12.84	0.01	12.83	12.84
	WIDTHAVG	6	4.28	2.58	2.25	7.50
	DEPTHAVG	6	0.27	0.08	0.20	0.37
	CURAVG	6	0.19	0.12	0.08	0.30
	FLOW	6	0.15	0.03	0.13	0.19
	TEMP	6	5.50	0.55	5.00	6.00
	PH	6	6.30	0.00	6.30	6.30
2	ELEV	5	45.00	0.00	45.00	45.00
	RIVERKM	5	8.88	0.00	8.88	8.88
	GRADIENT	5	5.86	0.00	5.86	5.86
	WIDTHAVG	5	4.50	0.00	4.50	4.50
	DEPTHAVG	5	0.18	0.00	0.18	0.18
	CURAVG	5	0.19	0.00	0.19	0.19
	FLOW	5	0.15	0.00	0.15	0.15
	TEMP	5	8.00	0.00	8.00	8.00
	PH	5	6.30	0.00	6.30	6.30
3	ELEV	9	37.00	0.00	37.00	37.00
	RIVERKM	9	5.97	0.00	5.97	5.97
	GRADIENT	9	3.05	0.00	3.05	3.05
	WIDTHAVG	9	15.21	0.00	15.21	15.21
	DEPTHAVG	9	0.16	0.00	0.16	0.16
	CURAVG	9	0.41	0.00	0.41	0.41
	FLOW	9	0.99	0.00	0.99	0.99
	TEMP	9	9.00	0.00	9.00	9.00
	PH	9	6.30	0.00	6.30	6.30
4	ELEV	12	30.00	6.18	25.00	37.00
	RIVERKM	12	6.13	1.24	5.13	7.54
	GRADIENT	12	5.05	0.32	4.79	5.42
	WIDTHAVG	12	9.82	0.31	9.47	10.07
	DEPTHAVG	12	0.25	0.09	0.14	0.32
	CURAVG	12	0.40	0.04	0.35	0.44
	FLOW	12	1.03	0.49	0.48	1.42
	TEMP	12	8.83	1.03	8.00	10.00
	PH	12	6.30	0.00	6.30	6.30

Appendix 3. Results of Duncan's Multiple Range test (SAS, 2009) of average stream width (m), stream depth (m), water temperature (C), water current velocity (m/sec), and total average abundance of fishes by month in Quantico Creek watershed from November, 2008 – June, 2010. Underscored means do not differ at p = 0.05.

Quantico Watershed

Variable = WIDTHAVG

Month	**Dec.**	**Aug.**	**Oct.**	**June**	**Nov.**	**Sept.**	**Jan.**	**May**	**July**	**April**	**March**
Mean	3.1508	4.3891	4.7434	5.5295	5.8053	5.8312	5.8866	5.8908	6.6218	6.8761	6.9340
	—	—	—	—	—	—	—	—	—		
			—	—	—	—	—	—	—	—	—

F = 9.99, p>F = <.0001, df = 10

Variable = DEPTHAVG

Month	**Dec.**	**Oct.**	**Nov.**	**Jan.**	**May**	**Aug.**	**Sept.**	**June**	**July**	**April**	**March**
Mean	0.19559	0.20684	0.22828	0.23304	0.23375	0.23718	0.24013	0.27324	0.27530	0.35641	0.38518
	—	—	—	—	—	—	—			—	—
			—	—	—	—	—	—	—		

F = 24.69, p>F = <.0001, df = 10

Variable = TEMP

Month	**Jan.**	**March**	**Dec.**	**Nov.**	**May**	**April**	**Oct.**	**June**	**Sept.**	**July**	**Aug.**
Mean	0.2500	5.9575	7.4348	11.7027	12.6022	13.9293	15.2358	17.9728	18.5435	20.7014	20.8507
	—	—	—	—	—	—	—	—	—	—	—

F = 963.92, p>F = <.0001, df = 10

Variable = CURAVG

Month	**Oct.**	**Sept.**	**Aug.**	**Dec.**	**July**	**May**	**March**	**June**	**Nov.**	**Jan.**	**April**
Mean	0.03966	0.04630	0.05999	0.19557	0.21615	0.22010	0.47662	0.48398	0.57928	0.86670	0.99482
	—	—	—	—	—	—	—	—	—	—	—

F = 91.20
p>F = <.0001, df = 10

Variable = FLOW

Month	**Oct.**	**Sept.**	**Dec.**	**Aug.**	**May**	**July**	**June**	**Nov.**	**March**	**Jan.**	**April**
Mean	0.0583	0.0721	0.1219	0.1245	0.4463	0.6212	0.7778	0.8533	1.3549	1.4040	3.3397
	—	—	—	—	—	—		—	—	—	—
					—	—	—	—			

F = 39.75, p>F = <.0001, df = 10

Variable = pH

Month	**Dec.**	**April**	**March**	**Nov.**	**July**	**Jan.**	**June**	**May**	**Aug.**
Mean	6.30000	6.40152	6.54050	6.57432	6.65764	6.78333	6.90544	6.93011	7.24364
	—	—	—	—		—	—	—	—
				—	—				

F = 66.74, p>F = <.0001, df = 8

Variable = ABUND

Month	**Jan.**	**Dec.**	**June**	**April**	**May**	**Aug.**	**March**	**July**	**Sept.**	**Oct.**	**Nov.**
Mean	3.808	4.348	4.361	4.408	5.065	5.090	5.337	5.542	5.696	6.745	7.007
	—	—	—	—	—	—	—	—	—		
					—	—	—	—	—	—	—

$F = 2.59$, $p>F = 0.0041$, $df = 10$

Appendix 4 . Results of Duncan's Multiple Range test (SAS, 2009) of sampling location elevation (m), river kilometer (km), and gradient (m/km) per stream order and month measured in Quantico Creek watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p = 0.05.

FIRST ORDER STREAMS

Variable = ELEV

Month	**Sept.**	**July**	**Nov.**	**Jan.**	**May**	**June**	**Dec.**	**April**	**March**	**Oct.**	**Aug.**
Mean	25.05	59.03	65.57	68.48	73.59	73.61	76.01	77.69	78.46	79.41	93.00

F = 1.14, p>F = 0.3397, df = 10

Variable = RIVERKM

Month	**Sept.**	**July**	**May**	**Dec.**	**Oct.**	**Aug.**	**Nov.**	**March**	**April**	**June**	**Jan.**
Mean	13.595	14.298	14.599	14.649	14.719	15.000	15.125	15.147	15.155	15.196	15.493

F = 0.31, p>F = 0.9761, df = 10

Variable = GRADIENT

Month	**Aug.**	**Oct.**	**March**	**April**	**Dec.**	**June**	**May**	**Jan.**	**Nov.**	**July**	**Sept.**
Mean	8.870	13.397	13.596	13.844	14.529	15.171	15.337	16.970	17.960	20.188	31.505

F = 1.13, p>F = 0.3474, df = 10

SECOND ORDER STREAMS

Variable = ELEV

Month	**Sept.**	**Nov.**	**July**	**Oct.**	**May**	**March**	**Jan.**	**April**	**June**	**Dec.**	**Aug.**
Mean	28.047	34.725	35.316	35.807	36.113	36.203	37.692	38.357	39.114	41.283	45.353

F = 1.91
p>F = 0.0425, df = 10

Variable = RIVERKM

Month	**Sept.**	**Jan.**	**Oct.**	**Nov.**	**March**	**July**	**May**	**April**	**June**	**Dec.**	**Aug.**
Mean	11.868	16.274	16.547	16.668	17.119	17.368	17.399	17.873	18.501	19.288	23.621

F = 4.44, p>F = <.0001, df = 10

Variable = GRADIENT

Month	**Aug.**	**Nov.**	**July**	**April**	**Jan.**	**May**	**June**	**Dec.**	**Oct.**	**March**	**Sept.**
Mean	10.714	14.644	14.649	14.797	15.256	15.657	15.668	15.777	16.238	16.421	19.908

F = 1.54

p>F = 0.1219, df = 10

THIRD ORDER STREAMS

Variable = ELEV

Month	**Oct.**	**July**	**Aug.**	**March**	**Jan.**	**May**	**Sept.**	**June**	**April**	**Nov.**	**Dec.**
Mean	29.068	29.583	30.711	31.235	31.534	31.964	32.000	32.019	32.201	35.139	44.000

F = 0.98, p>F = 0.4580, df = 10

Variable = RIVERKM

Month	**Sept.**	**Oct.**	**July**	**March**	**May**	**April**	**Nov.**	**Jan.**	**June**	**Aug.**	**Dec.**
Mean	10.065	12.071	12.208	12.921	13.299	13.433	13.715	13.725	14.225	14.554	23.250

F = 3.99, p>F = <.0001, df = 10

Variable = GRADIENT

Month	**Sept.**	**Nov.**	**March**	**May**	**Oct.**	**July**	**April**	**June**	**Jan.**	**Aug.**	**Dec.**
Mean	5.300	8.931	10.433	10.497	10.532	10.597	10.630	11.731	11.766	13.227	13.940

F = 4.05, p>F = <.0001, df = 10

Appendix 5. Mean, standard deviation, minimum and maximum values for physical parameters measured in Quantico Creek by season and stream order from November, 2008-June, 2010.

Quantico Creek, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	5	48.86	32.38	22.90	93.00
	RIVERKM	5	15.89	4.33	13.50	23.56
	GRADIENT	5	23.45	11.61	8.87	32.53
	WIDTHAVG	5	1.65	0.36	1.27	2.13
	DEPTHAVG	5	0.16	0.09	0.08	0.30
	CURAVG	5	0.48	0.11	0.33	0.60
	FLOW	5	0.12	0.07	0.05	0.24
	TEMP	5	1.40	0.55	1.00	2.00
	PH	5	6.76	0.27	6.30	7.00

Quantico Creek, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	6	55.50	34.87	22.90	93.00
	RIVERKM	6	15.71	3.91	13.50	23.56
	GRADIENT	6	20.68	11.60	8.87	32.53
	WIDTHAVG	6	1.79	0.27	1.31	2.06
	DEPTHAVG	6	0.38	0.53	0.08	1.46
	CURAVG	6	0.22	0.15	0.05	0.38
	FLOW	6	0.21	0.36	0.01	0.94
	TEMP	6	5.92	1.63	4.00	8.50
	PH	6	6.42	0.16	6.30	6.70

Quantico Creek, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	9	47.70	34.03	22.90	93.00
	RIVERKM	9	14.06	0.71	13.50	15.00
	GRADIENT	9	23.96	11.35	8.87	32.53
	WIDTHAVG	9	1.65	0.46	1.10	2.23
	DEPTHAVG	9	0.17	0.07	0.08	0.27
	CURAVG	9	0.25	0.23	0.00	0.67
	FLOW	9	0.10	0.14	0.00	0.40
	TEMP	9	13.44	3.00	10.00	18.00
	PH	9	6.52	0.37	6.10	7.00

Quantico Creek, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	12	47.70	33.51	22.90	93.00
	RIVERKM	12	14.06	0.70	13.50	15.00

	GRADIENT	12	23.96	11.18	8.87	32.53
	WIDTHAVG	12	1.51	0.51	0.97	2.63
	DEPTHAVG	12	0.12	0.04	0.05	0.17
	CURAVG	12	0.08	0.12	0.00	0.33
	FLOW	12	0.02	0.04	0.00	0.13
	TEMP	12	17.17	1.90	15.00	20.00
	PH	10	6.90	0.32	6.50	7.60

Quantico Creek, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	7	51.46	33.58	22.90	93.00
	RIVERKM	7	15.42	3.65	13.50	23.56
	GRADIENT	7	22.37	11.50	8.87	32.53
	WIDTHAVG	7	1.31	0.74	0.09	2.37
	DEPTHAVG	7	0.13	0.06	0.02	0.19
	CURAVG	7	0.12	0.29	0.00	0.77
	FLOW	7	0.05	0.13	0.00	0.35
	TEMP	7	14.29	2.04	12.50	18.00
	PH	4	6.68	0.05	6.60	6.70

Quantico Creek, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	3	47.70	39.29	22.90	93.00
	RIVERKM	3	14.06	0.82	13.50	15.00
	GRADIENT	3	23.96	13.11	8.87	32.53
	WIDTHAVG	3	1.70	0.89	0.99	2.69
	DEPTHAVG	3	0.11	0.04	0.06	0.14
	CURAVG	3	0.11	0.02	0.08	0.12
	FLOW	3	0.02	0.02	0.01	0.04
	TEMP	3	7.33	0.58	7.00	8.00
	PH	3	6.30	0.00	6.30	6.30

Quantico Creek, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	7	40.08	18.49	13.94	61.50
	RIVERKM	7	15.32	5.85	9.30	23.63
	GRADIENT	7	15.64	8.56	8.13	27.89
	WIDTHAVG	7	3.44	1.47	1.87	5.30
	DEPTHAVG	7	0.20	0.04	0.13	0.27
	CURAVG	7	0.62	0.36	0.05	1.15
	FLOW	7	0.37	0.26	0.04	0.76
	TEMP	7	0.14	0.69	-1.00	1.00
	PH	7	6.76	0.32	6.30	7.10

Quantico Creek, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	8	37.21	17.29	13.94	61.50
	RIVERKM	8	17.30	6.89	9.30	23.63
	GRADIENT	8	13.24	6.32	8.13	27.89
	WIDTHAVG	8	4.06	2.22	2.33	8.39
	DEPTHAVG	8	0.37	0.30	0.13	1.10
	CURAVG	8	0.54	0.18	0.21	0.83
	FLOW	8	0.83	0.73	0.13	2.24
	TEMP	8	5.06	1.57	3.00	7.00
	PH	8	6.46	0.25	6.30	6.90

Quantico Creek, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	15	38.55	17.27	13.94	61.50
	RIVERKM	15	16.38	6.28	9.30	23.63
	GRADIENT	15	14.36	7.27	8.13	27.89
	WIDTHAVG	15	4.00	2.19	1.56	7.82
	DEPTHAVG	15	0.25	0.10	0.10	0.44
	CURAVG	15	0.70	0.76	0.10	2.83
	FLOW	15	1.07	1.69	0.03	6.45
	TEMP	15	13.93	3.10	10.00	19.00
	PH	15	6.53	0.34	6.00	7.00

Quantico Creek, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	20	38.55	17.12	13.94	61.50
	RIVERKM	20	16.38	6.23	9.30	23.63
	GRADIENT	20	14.36	7.21	8.13	27.89
	WIDTHAVG	20	3.15	1.50	0.68	5.75
	DEPTHAVG	20	0.22	0.10	0.06	0.40
	CURAVG	20	0.28	0.50	0.00	2.15
	FLOW	20	0.23	0.39	0.00	1.40
	TEMP	20	18.85	2.30	15.00	25.00
	PH	17	6.78	0.40	5.90	7.70

Quantico Creek, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	11	36.31	18.26	13.94	61.50
	RIVERKM	11	15.73	6.43	9.30	23.63
	GRADIENT	11	14.24	7.04	8.13	27.89
	WIDTHAVG	11	3.14	1.56	1.32	5.51
	DEPTHAVG	11	0.20	0.05	0.16	0.32
	CURAVG	11	0.30	0.38	0.00	1.23
	FLOW	11	0.29	0.51	0.00	1.74
	TEMP	11	13.86	2.57	8.00	18.00

	PH	6	6.65	0.19	6.30	6.80

Quantico Creek, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	4	44.70	14.54	26.30	61.50
	RIVERKM	4	18.15	6.37	11.72	23.63
	GRADIENT	4	14.70	9.03	8.13	27.89
	WIDTHAVG	4	2.82	1.23	1.87	4.61
	DEPTHAVG	4	0.21	0.07	0.13	0.30
	CURAVG	4	0.20	0.10	0.11	0.33
	FLOW	4	0.12	0.07	0.03	0.20
	TEMP	4	7.00	1.83	5.00	9.00
	PH	4	6.30	0.00	6.30	6.30

Quantico Creek, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	8	31.29	17.90	6.10	60.00
	RIVERKM	8	12.30	6.06	7.13	23.25
	GRADIENT	8	9.31	6.41	3.05	20.00
	WIDTHAVG	8	8.22	3.06	3.87	11.59
	DEPTHAVG	8	0.27	0.08	0.20	0.42
	CURAVG	8	0.79	0.40	0.33	1.48
	FLOW	8	1.74	1.31	0.50	4.62
	TEMP	8	0.00	0.53	-1.00	1.00
	PH	8	6.68	0.32	6.30	7.00

Quantico Creek, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	10	30.86	21.34	6.10	60.00
	RIVERKM	10	13.65	7.12	7.13	23.25
	GRADIENT	10	11.71	6.84	3.05	20.00
	WIDTHAVG	10	9.08	3.29	4.67	13.09
	DEPTHAVG	10	0.35	0.08	0.23	0.46
	CURAVG	10	0.55	0.31	0.06	1.01
	FLOW	10	2.13	1.82	0.11	4.56
	TEMP	10	5.90	2.22	3.00	9.00
	PH	10	6.49	0.25	6.30	6.90

Quantico Creek, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	18	31.05	19.31	6.10	60.00
	RIVERKM	18	13.05	6.51	7.13	23.25
	GRADIENT	18	10.64	6.57	3.05	20.00
	WIDTHAVG	18	8.87	3.16	4.53	13.52
	DEPTHAVG	18	0.41	0.25	0.22	1.34

	CURAVG	18	0.89	0.74	0.12	2.50
	FLOW	18	4.92	8.84	0.15	37.88
	TEMP	18	13.89	3.07	10.00	20.00
	PH	18	6.58	0.31	6.00	7.00

Quantico Creek, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	24	31.05	19.17	6.10	60.00
	RIVERKM	24	13.05	6.46	7.13	23.25
	GRADIENT	24	10.64	6.52	3.05	20.00
	WIDTHAVG	24	7.72	2.88	3.69	12.87
	DEPTHAVG	24	0.30	0.09	0.14	0.49
	CURAVG	24	0.29	0.30	0.00	1.27
	FLOW	24	0.79	0.93	0.00	3.08
	TEMP	24	20.00	2.45	15.00	24.00
	PH	21	6.90	0.58	5.50	8.00

Quantico Creek, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	15	33.11	19.15	6.10	60.00
	RIVERKM	15	13.13	6.28	7.13	23.25
	GRADIENT	15	9.42	6.45	3.05	20.00
	WIDTHAVG	15	6.95	2.89	3.15	12.12
	DEPTHAVG	15	0.24	0.11	0.14	0.55
	CURAVG	14	0.36	0.33	0.02	0.96
	FLOW	14	0.68	0.66	0.01	1.72
	TEMP	15	12.57	3.21	8.00	17.00
	PH	9	6.50	0.24	6.30	6.80

Quantico Creek, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	1	44.00	.	44.00	44.00
	RIVERKM	1	23.25	.	23.25	23.25
	GRADIENT	1	13.94	.	13.94	13.94
	WIDTHAVG	1	4.30	.	4.30	4.30
	DEPTHAVG	1	0.17	.	0.17	0.17
	CURAVG	1	0.20	.	0.20	0.20
	FLOW	1	0.15	.	0.15	0.15
	TEMP	1	8.00	.	8.00	8.00
	PH	1	6.30	.	6.30	6.30

Appendix 6. Results of Duncan's Multiple Range test (SAS, 2009) of average stream width (m), stream depth (m), water temperature (C), water current velocity (m/sec), and total average abundance of fishes by month in Cameron Run watershed from November, 2008 – June, 2010. Underscored means do not differ at p = 0.05.

Cameron Run Watershed

Variable = WIDTHAVG

Month	**July**	**Oct.**	**March**	**Sept.**	**Nov.**	**Jan.**	**June**	**Dec.**	**May**	**April**
Mean	6.6689	6.9754	7.1863	8.0790	8.1995	8.3279	9.1759	9.4659	9.6532	10.4845

F = 5.76, p>F = <.0001, df = 9

Variable = DEPTHAVG

Month	**Oct.**	**Nov.**	**Jan.**	**Sept.**	**May**	**June**	**July**	**Dec.**	**March**	**April**
Mean	0.19149	0.19968	0.20013	0.20183	0.21194	0.21212	0.21618	0.21622	0.23970	0.29768

F = 9.03, p>F = <.0001, df = 9

Variable = CURAVG

Month	**Oct.**	**July**	**Sept.**	**May**	**Dec.**	**June**	**Jan.**	**March**	**April**	**Nov.**
Mean	0.1306	0.1516	0.1764	0.2440	0.3321	0.3734	0.4430	0.8573	0.9682	2.2159

F = 46.44, p>F = <.0001, df = 9

Variable = FLOW

Month	**Oct.**	**July**	**Sept.**	**May**	**June**	**Dec.**	**Jan.**	**March**	**April**	**Nov.**
Mean	0.1736	0.2497	0.3058	0.5938	0.7148	0.7158	0.8351	1.5370	3.7206	4.2614

F = 26.94, p>F = <.0001, df = 9

Variable = TEMP

Month	**Jan.**	**March**	**Dec.**	**May**	**Nov.**	**April**	**Oct.**	**June**	**Sept.**	**July**
Mean	0.4792	6.5167	8.1250	12.6765	14.4342	15.1974	17.4146	21.7831	22.0870	23.2941

F = 438.23, p>F = <.0001, df = 9

Variable = pH

Month	**March**	**Dec.**	**Jan.**	**Nov.**	**April**	**June**	**July**	**May**
Mean	6.3000	6.3000	6.5271	6.8579	6.8605	6.9108	6.9500	7.1324

F = 6.52, p>F = <.0001, df = 7

Variable = ABUND

Month	**Jan.**	**April**	**March**	**July**	**Nov.**	**Dec.**	**June**	**Sept.**	**May**	**Oct.**
Mean	3.739	9.342	9.627	10.029	10.211	10.625	11.217	11.261	11.471	12.415

F = 1.37, p>F = 0.1970, df = 9

Appendix 7. Results of Duncan's Multiple Range test (SAS, 2009) of sampling location elevation (m), river kilometer (km), and gradient (m/km) per stream order and month in Cameron Run watershed from November, 2008 – June, 2010. Underscored means do not differ significantly at p = 0.05.

FIRST ORDER STREAMS

Variable = ELEV

Month	**Nov.**	**April**	**March**	**June**	**Sept.**	**May**	**Dec.**	**Jan.**	**Oct.**	**July**
Mean	75.2000	75.2500	75.3636	75.3846	75.5000	75.5000	75.5000	75.5000	75.5000	75.7143

F = 0.06, p>F = 0.9999, df = 9

Variable = RIVERKM

Month	**July**	**Oct.**	**Sept.**	**May**	**Dec.**	**Jan.**	**June**	**March**	**April**	**Nov.**
Mean	16.760	17.610	17.610	17.610	17.610	17.610	18.068	18.151	18.602	18.800

F = 0.06, p>F = 0.9999, df = 9

Variable = GRADIENT

Month	**July**	**Oct.**	**Sept.**	**May**	**Dec.**	**Jan.**	**June**	**March**	**April**	**Nov.**
Mean	12.834286	12.835000	12.835000	12.835000	12.835000	12.835000	12.835385	12.835455	12.835833	12.836000

F = 0.06, p>F = 0.9999, df = 9

SECOND ORDER STREAMS

Variable = ELEV

Month	**Sept.**	**Oct.**	**July**	**May**	**Dec.**	**March**	**June**	**Jan.**	**April**	**Nov.**
Mean	45.000	45.000	45.000	45.000	45.000	46.625	46.857	47.438	48.250	48.714

F = 0.98, p>F = 0.4658, df = 9

Variable = RIVERKM

Month	**Sept.**	**Oct.**	**July**	**May**	**Dec.**	**March**	**June**	**Jan.**	**April**	**Nov.**
Mean	8.8800	8.8800	8.8800	8.8800	8.8800	9.0337	9.0557	9.1106	9.1875	9.2314

F = 0.98, p>F = 0.4658, df = 9

Variable = GRADIENT

Month	**Sept.**	**Oct.**	**July**	**May**	**Dec.**	**March**	**June**	**Jan.**	**April**	**Nov.**
Mean	5.8600	5.8600	5.8600	5.8600	5.8600	6.5450	6.6429	6.8875	7.2300	7.4257

F = 0.98, p>F = 0.4658, df = 9

Appendix 7 (continued).

THIRD ORDER STREAMS

Variable = ELEV

Month	**Sept.**	**Oct.**	**Nov.**	**May**	**March**	**June**	**Jan.**	**Dec.**	**April**
Mean	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00

F = 0.06,p>F = 0.9999, df = 8

Variable = RIVERKM

Month	**Sept.**	**Oct.**	**Jan.**	**May**	**March**	**June**	**April**	**Dec.**	**Nov.**
Mean	5.9700	5.9700	5.9700	5.9700	5.9700	5.9700	5.9700	5.9700	6.3887

F = 3.83, p>F = 0.0006, df = 8

Variable = GRADIENT

Month	**April**	**June**	**Jan.**	**May**	**March**	**Oct.**	**Sept.**	**Dec.**	**Nov.**
Mean	3.0500	3.0500	3.0500	3.0500	3.0500	3.0500	3.0500	3.0500	3.6820

F = 3.83, p>F = 0.0006, df = 8

Table . (continued)

FOURTH ORDER STREAMS

Variable = ELEV

Month	**Nov.**	**March**	**July**	**May**	**Dec.**	**Oct.**	**Jan.**	**April**	**Sept.**	**June**
Mean	25.000	28.360	29.421	29.800	30.000	30.053	30.053	30.200	30.400	30.667

F = 1.12
p>F = 0.3472, df = 9

Variable = RIVERKM

Month	**Nov.**	**March**	**July**	**May**	**Dec.**	**Oct.**	**Jan.**	**April**	**Sept.**	**June**
Mean	5.1300	5.8048	6.0179	6.0940	6.1342	6.1447	6.1447	6.1743	6.2145	6.2681

F = 1.12
p>F = 0.3472, df = 9

Variable = GRADIENT

Month	**Nov.**	**March**	**July**	**May**	**Dec.**	**Oct.**	**Jan.**	**April**	**Sept.**	**June**
Mean	4.7900	4.9664	5.0221	5.0420	5.0525	5.0553	5.0553	5.0630	5.0735	5.0875

F = 1.12
p>F = 0.3472

df = 9

Appendix 8. Mean, standard deviation, minimum and maximum values for physical parameters measured in Quantico Creek by season from November, 2008-June, 2010.

Cameron Run, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	5	75.80	1.64	74.00	77.00
	RIVERKM	5	16.42	6.52	11.66	23.56
	GRADIENT	5	12.83	0.01	12.83	12.84
	WIDTHAVG	5	3.62	1.53	2.14	5.77
	DEPTHAVG	5	0.20	0.10	0.09	0.33
	CURAVG	5	0.22	0.18	0.03	0.44
	FLOW	5	0.10	0.07	0.05	0.23
	TEMP	5	-0.60	0.55	-1.00	0.00
	PH	5	6.64	0.47	6.30	7.20

Cameron Run, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	5	75.80	1.64	74.00	77.00
	RIVERKM	5	16.42	6.52	11.66	23.56
	GRADIENT	5	12.83	0.01	12.83	12.84
	WIDTHAVG	5	4.81	0.81	3.93	6.02
	DEPTHAVG	5	0.27	0.11	0.12	0.43
	CURAVG	5	0.40	0.21	0.11	0.70
	FLOW	5	0.41	0.07	0.29	0.49
	TEMP	5	5.40	2.41	3.00	8.00
	PH	3	6.30	0.00	6.30	6.30

Cameron Run, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	8	75.88	1.55	74.00	77.00
	RIVERKM	8	16.12	6.16	11.66	23.56
	GRADIENT	8	12.83	0.01	12.83	12.84
	WIDTHAVG	8	4.54	1.59	2.16	6.37
	DEPTHAVG	8	0.25	0.09	0.12	0.37
	CURAVG	8	0.27	0.24	0.00	0.75
	FLOW	8	0.27	0.33	0.00	1.02
	TEMP	8	12.63	2.20	10.00	15.00
	PH	8	6.75	0.46	6.00	7.00

Cameron Run, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	8	75.50	1.60	74.00	77.00
	RIVERKM	8	17.61	6.36	11.66	23.56
	GRADIENT	8	12.84	0.01	12.83	12.84
	WIDTHAVG	8	3.51	1.36	2.47	6.45
	DEPTHAVG	8	0.20	0.05	0.10	0.26
	CURAVG	8	0.12	0.13	0.00	0.40
	FLOW	8	0.08	0.09	0.00	0.29
	TEMP	8	17.50	0.53	17.00	18.00
	PH	6	6.65	0.42	6.10	7.00

Cameron Run, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	4	75.50	1.73	74.00	77.00
	RIVERKM	4	17.61	6.87	11.66	23.56
	GRADIENT	4	12.84	0.01	12.83	12.84
	WIDTHAVG	4	3.66	1.19	2.21	4.72
	DEPTHAVG	4	0.23	0.15	0.11	0.44
	CURAVG	4	0.38	0.45	0.00	0.90
	FLOW	4	0.43	0.58	0.00	1.23
	TEMP	4	13.88	0.85	13.00	15.00

	PH	2	6.75	0.21	6.60	6.90

Cameron Run, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
1	ELEV	2	75.50	2.12	74.00	77.00
	RIVERKM	2	17.61	8.41	11.66	23.56
	GRADIENT	2	12.84	0.01	12.83	12.84
	WIDTHAVG	2	3.08	1.17	2.25	3.90
	DEPTHAVG	2	0.28	0.12	0.20	0.37
	CURAVG	2	0.20	0.14	0.10	0.30
	FLOW	2	0.14	0.01	0.13	0.14
	TEMP	2	5.50	0.71	5.00	6.00
	PH	2	6.30	0.00	6.30	6.30

Cameron Run, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	3	49.33	7.51	45.00	58.00
	RIVERKM	3	9.29	0.71	8.88	10.11
	GRADIENT	3	7.69	3.16	5.86	11.34
	WIDTHAVG	3	5.42	0.63	4.70	5.90
	DEPTHAVG	3	0.16	0.10	0.07	0.28
	CURAVG	3	0.37	0.20	0.25	0.59
	FLOW	3	0.27	0.12	0.20	0.41
	TEMP	3	0.00	0.00	0.00	0.00
	PH	3	6.83	0.50	6.30	7.30

Cameron Run, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	3	49.33	7.51	45.00	58.00
	RIVERKM	3	9.29	0.71	8.88	10.11
	GRADIENT	3	7.69	3.16	5.86	11.34
	WIDTHAVG	3	5.54	0.40	5.27	6.00
	DEPTHAVG	3	0.22	0.10	0.11	0.29
	CURAVG	3	0.38	0.29	0.07	0.66
	FLOW	3	0.37	0.23	0.13	0.59
	TEMP	3	6.33	2.08	4.00	8.00
	PH	1	6.30	.	6.30	6.30

Cameron Run, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	4	48.25	6.50	45.00	58.00
	RIVERKM	4	9.19	0.62	8.88	10.11
	GRADIENT	4	7.23	2.74	5.86	11.34
	WIDTHAVG	4	4.87	0.71	3.96	5.52
	DEPTHAVG	4	0.30	0.19	0.19	0.59
	CURAVG	4	0.34	0.22	0.04	0.56
	FLOW	4	0.58	0.58	0.03	1.37
	TEMP	4	12.75	2.22	11.00	16.00
	PH	4	6.50	0.58	6.00	7.00

Cameron Run, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	8	58.63	15.84	45.00	77.00
	RIVERKM	8	10.08	1.38	8.88	11.66
	GRADIENT	8	9.16	3.56	5.86	12.83
	WIDTHAVG	8	5.53	1.53	3.66	7.96
	DEPTHAVG	8	0.32	0.12	0.19	0.47
	CURAVG	8	0.08	0.09	0.00	0.29
	FLOW	8	0.14	0.17	0.00	0.43
	TEMP	8	18.88	1.13	17.00	20.00
	PH	6	6.67	0.44	6.10	7.00

Cameron Run, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum

2	ELEV	4	56.25	15.13	45.00	77.00
	RIVERKM	4	9.88	1.32	8.88	11.66
	GRADIENT	4	8.97	3.65	5.86	12.83
	WIDTHAVG	4	5.94	1.12	4.45	7.08
	DEPTHAVG	4	0.24	0.16	0.05	0.38
	CURAVG	4	0.19	0.22	0.01	0.45
	FLOW	4	0.19	0.28	0.01	0.61
	TEMP	4	14.00	0.71	13.50	15.00
	PH	2	6.80	0.00	6.80	6.80

Cameron Run, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
2	ELEV	2	61.00	22.63	45.00	77.00
	RIVERKM	2	10.27	1.97	8.88	11.66
	GRADIENT	2	9.35	4.93	5.86	12.83
	WIDTHAVG	2	6.00	2.12	4.50	7.50
	DEPTHAVG	2	0.26	0.10	0.18	0.33
	CURAVG	2	0.13	0.08	0.08	0.19
	FLOW	2	0.17	0.02	0.15	0.19
	TEMP	2	7.00	1.41	6.00	8.00
	PH	2	6.30	0.00	6.30	6.30

Cameron Run, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	1	37.00	.	37.00	37.00
	RIVERKM	1	5.97	.	5.97	5.97
	GRADIENT	1	3.05	.	3.05	3.05
	WIDTHAVG	1	10.30	.	10.30	10.30
	DEPTHAVG	1	0.17	.	0.17	0.17
	CURAVG	1	1.17	.	1.17	1.17
	FLOW	1	2.08	.	2.08	2.08
	TEMP	1	2.00	.	2.00	2.00
	PH	1	6.80	.	6.80	6.80

Cameron Run, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	2	37.00	0.00	37.00	37.00
	RIVERKM	2	5.97	0.00	5.97	5.97
	GRADIENT	2	3.05	0.00	3.05	3.05
	WIDTHAVG	2	12.82	8.80	6.60	19.04
	DEPTHAVG	2	0.20	0.07	0.15	0.25
	CURAVG	2	0.91	0.18	0.78	1.03
	FLOW	2	2.37	1.90	1.02	3.71
	TEMP	2	6.00	2.83	4.00	8.00
	PH	1	6.30	.	6.30	6.30

Cameron Run, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	2	37.00	0.00	37.00	37.00
	RIVERKM	2	5.97	0.00	5.97	5.97
	GRADIENT	2	3.05	0.00	3.05	3.05
	WIDTHAVG	2	16.20	1.52	15.13	17.27
	DEPTHAVG	2	0.21	0.01	0.20	0.22
	CURAVG	2	0.49	0.02	0.48	0.51
	FLOW	2	1.67	0.12	1.59	1.76
	TEMP	2	18.00	7.07	13.00	23.00
	PH	2	8.40	1.27	7.50	9.30

Cameron Run, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	3	37.00	0.00	37.00	37.00
	RIVERKM	3	5.97	0.00	5.97	5.97
	GRADIENT	3	3.05	0.00	3.05	3.05
	WIDTHAVG	3	13.02	2.81	10.88	16.20

	DEPTHAVG	3	0.15	0.04	0.11	0.17
	CURAVG	3	0.45	0.14	0.30	0.55
	FLOW	3	0.83	0.22	0.58	0.97
	TEMP	3	24.33	1.53	23.00	26.00
	PH	2	7.60	1.98	6.20	9.00

Cameron Run, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	3	37.00	0.00	37.00	37.00
	RIVERKM	3	6.49	0.91	5.97	7.54
	GRADIENT	3	3.84	1.37	3.05	5.42
	WIDTHAVG	3	7.87	2.78	5.03	10.59
	DEPTHAVG	3	0.17	0.03	0.15	0.20
	CURAVG	3	1.72	2.25	0.18	4.30
	FLOW	3	2.65	3.89	0.29	7.15
	TEMP	3	16.33	3.18	14.50	20.00
	PH	2	6.90	0.00	6.90	6.90

Cameron Run, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
3	ELEV	1	37.00	.	37.00	37.00
	RIVERKM	1	5.97	.	5.97	5.97
	GRADIENT	1	3.05	.	3.05	3.05
	WIDTHAVG	1	15.21	.	15.21	15.21
	DEPTHAVG	1	0.16	.	0.16	0.16
	CURAVG	1	0.41	.	0.41	0.41
	FLOW	1	0.99	.	0.99	0.99
	TEMP	1	9.00	.	9.00	9.00
	PH	1	6.30	.	6.30	6.30

Cameron Run, Winter

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
4	ELEV	3	29.00	6.93	25.00	37.00
	RIVERKM	3	5.93	1.39	5.13	7.54
	GRADIENT	3	5.00	0.36	4.79	5.42
	WIDTHAVG	3	8.82	1.74	7.03	10.50
	DEPTHAVG	3	0.27	0.07	0.19	0.32
	CURAVG	3	0.79	0.39	0.37	1.14
	FLOW	3	1.78	1.02	1.14	2.95
	TEMP	3	0.67	0.58	0.00	1.00
	PH	3	6.60	0.30	6.30	6.90

Cameron Run, Early Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
4	ELEV	4	31.00	6.93	25.00	37.00
	RIVERKM	4	6.34	1.39	5.13	7.54
	GRADIENT	4	5.11	0.36	4.79	5.42
	WIDTHAVG	4	9.16	2.92	6.53	12.13
	DEPTHAVG	4	0.27	0.10	0.14	0.38
	CURAVG	4	1.17	0.70	0.63	2.11
	FLOW	4	2.51	1.18	1.25	4.04
	TEMP	4	6.50	2.38	4.00	9.00
	PH	2	6.30	0.00	6.30	6.30

Cameron Run, Late Spring

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
4	ELEV	6	31.00	6.57	25.00	37.00
	RIVERKM	6	6.34	1.32	5.13	7.54
	GRADIENT	6	5.11	0.35	4.79	5.42
	WIDTHAVG	6	11.04	1.09	10.17	12.94
	DEPTHAVG	6	0.27	0.11	0.10	0.42
	CURAVG	6	1.04	1.15	0.15	2.63
	FLOW	6	3.66	4.99	0.26	12.98
	TEMP	6	14.83	2.48	13.00	18.00

	PH	6	6.92	0.80	6.00	8.00

Cameron Run, Summer

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
4	ELEV	8	31.00	6.41	25.00	37.00
	RIVERKM	8	6.34	1.29	5.13	7.54
	GRADIENT	8	5.11	0.34	4.79	5.42
	WIDTHAVG	8	9.15	1.76	6.04	11.42
	DEPTHAVG	8	0.21	0.04	0.15	0.26
	CURAVG	8	0.33	0.15	0.17	0.66
	FLOW	8	0.66	0.39	0.33	1.32
	TEMP	8	23.75	2.19	20.00	28.00
	PH	6	6.87	0.71	6.10	8.00

Cameron Run, Early Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
4	ELEV	3	29.00	6.93	25.00	37.00
	RIVERKM	3	5.93	1.39	5.13	7.54
	GRADIENT	3	5.00	0.36	4.79	5.42
	WIDTHAVG	3	8.68	1.91	6.47	9.83
	DEPTHAVG	3	0.21	0.07	0.15	0.28
	CURAVG	3	0.97	1.32	0.09	2.49
	FLOW	3	2.44	3.82	0.17	6.85
	TEMP	3	17.17	1.44	15.50	18.00
	PH	1	6.90	.	6.90	6.90

Cameron Run, Late Fall

ORDER	Variable	N	Mean	Std Dev	Minimum	Maximum
4	ELEV	2	31.00	8.49	25.00	37.00
	RIVERKM	2	6.34	1.70	5.13	7.54
	GRADIENT	2	5.11	0.45	4.79	5.42
	WIDTHAVG	2	9.77	0.43	9.47	10.07
	DEPTHAVG	2	0.23	0.13	0.14	0.32
	CURAVG	2	0.40	0.06	0.35	0.44
	FLOW	2	0.95	0.67	0.48	1.42
	TEMP	2	9.00	1.41	8.00	10.00
	PH	2	6.30	0.00	6.30	6.30

Appendix 9. Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in streams per stream order in Quantico Creek from November, 2008 to July, 2010.

First Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Clinostomus funduloides	8	3.00	2.62	1	9
Semotilus atromaculatus	12	5.58	4.14	2	14
Rhinichthys atratulus	42	12.76	8.03	1	30
Luxilus cornutus	2	4.00	4.24	1	7
Exoglossum maxillingua	1	1.00	.	1	1
Erimyzon oblongus	6	1.00	0.00	1	1
Anguilla rostrata	2	1.00	0.00	1	1
Lepomis auritus	4	1.75	0.96	1	3
Lepomis gibbosus	10	6.80	5.39	2	20
Lepomis cyanellus	8	2.88	3.48	1	11
Lepomis macrochirus	2	3.50	3.54	1	6
Etheostoma olmstedi	13	5.00	2.20	1	9

Second Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Cyprinidae	1	1.00	.	1	1
Clinostomus funduloides	46	6.22	3.66	1	16
Semotilus atromaculatus	38	4.29	3.17	1	13
Rhinichthys atratulus	58	7.64	6.14	1	29
Luxilus cornutus	15	11.73	11.16	1	43
Exoglossum maxillingua	26	3.19	2.97	1	11
Notropis procne	23	4.61	4.55	1	19
Semotilus corporalis	24	3.83	2.37	1	8
Notemigonus crysoleucas	1	1.00	.	1	1
Catostomus commersoni	21	3.19	2.96	1	13
Erimyzon oblongus	21	2.05	1.66	1	7
Noturus insignis	19	1.58	1.12	1	5
Anguilla rostrata	10	2.20	2.10	1	7
Lepomis auritus	44	3.73	2.70	1	12
Lepomis gibbosus	7	1.71	1.25	1	4
Lepomis cyanellus	21	2.95	1.91	1	7
Lepomis microlophus	3	1.00	0.00	1	1
Lepomis macrochirus	4	1.25	0.50	1	2
Etheostoma olmstedi	34	2.94	2.52	1	10
Esox niger	1	1.00	.	1	1

Appendix 9 (continued).

Third Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Clinostomus funduloides	38	7.13	9.36	1	48
Semotilus atromaculatus	27	3.26	3.60	1	14
Rhinichthys atratulus	56	5.70	8.92	1	61
Luxilus cornutus	19	2.32	1.57	1	7
Exoglossum maxillingua	46	4.67	3.63	1	15
Notropis procne	47	10.28	15.80	1	83
Semotilus corporalis	47	4.32	3.47	1	15
Cyprinella analostana	2	1.00	0.00	1	1
Notropis hudsonius	2	16.00	19.80	2	30
Notemigonus crysoleucas	7	13.43	16.12	1	41
Hybognathus regius	1	8.00	.	8	8
Catostomus commersoni	50	2.82	2.12	1	10
Erimyzon oblongus	37	3.38	3.51	1	19
Noturus insignis	51	4.51	4.29	1	20
Ameiurus natalis	3	1.00	0.00	1	1
Ameiurus nebulosus	4	3.50	3.11	1	8
Anguilla rostrata	45	6.58	6.50	1	35
Fundulus diaphanus	6	11.33	11.00	1	29
Lepomis auritus	66	5.27	4.29	1	24
Lepomis gibbosus	33	7.55	13.95	1	60
Lepomis cyanellus	42	3.93	3.74	1	14
Lepomis microlophus	1	1.00	.	1	1
Lepomis macrochirus	25	4.56	3.97	1	16
Micropterus salmoides	5	1.20	0.45	1	2
Etheostoma olmstedi	68	6.85	7.86	1	49
Channa argus	2	1.00	0.00	1	1
Lampetra aepyptera	1	1.00	.	1	1
Petromyzon marinus	3	3.67	4.62	1	9
Esox niger	9	1.67	0.71	1	3

Appendix 10 . Mean, standard deviation (s.d.), minimum and maximum numbers of individuals of fishes collected in streams per stream order in Cameron Run from November, 2008 to July, 2010.

First Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Semotilus atromaculatus	26	7.04	5.89	1	23
Rhinichthys atratulus	37	17.65	18.62	1	105
Catostomus commersoni	12	5.00	3.44	1	12
Lepomis macrochirus	3	1.67	0.58	1	2

Second Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Clinostomus funduloides	13	3.77	3.06	1	9
Semotilus atromaculatus	19	9.21	5.41	1	21
Rhinichthys atratulus	19	27.79	15.79	8	69
Catostomus commersoni	13	7.31	6.55	1	22
Erimyzon oblongus	1	1.00	.	1	1
Ameiurus natalis	12	2.25	1.91	1	7
Ameiurus nebulosus	4	2.00	1.41	1	4
Lepomis cyanellus	1	1.00	.	1	1
Lepomis macrochirus	7	1.29	0.76	1	3
Micropterus salmoides	3	1.00	0.00	1	1
Etheostoma olmstedi	9	2.78	2.17	1	7

Third Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Clinostomus funduloides	1	1.00	.	1	1
Rhinichthys atratulus	12	14.42	12.49	2	44
Notropis procne	12	8.83	5.57	2	17
Cyprinella analostana	12	16.83	12.64	2	46
Pimephales notatus	11	30.73	29.03	1	102
Catostomus commersoni	7	4.29	2.93	1	9
Noturus insignis	1	1.00	.	1	1
Ameiurus natalis	9	5.56	5.68	1	14
Anguilla rostrata	3	2.00	0.00	2	2
Fundulus heteroclitus	7	3.86	5.01	1	15
Fundulus diaphanus	3	1.00	0.00	1	1
Lepomis auritus	11	13.27	10.79	1	38
Lepomis gibbosus	2	1.00	0.00	1	1
Lepomis macrochirus	3	1.00	0.00	1	1
Etheostoma olmstedi	11	7.09	5.63	1	19

Appendix 10 (continued).

Fourth Order Streams

SPECCODE	N	Mean	Std. Dev	Minimum	Maximum
Clinostomus funduloides	2	1.00	0.00	1	1
Semotilus atromaculatus	8	4.75	7.57	1	23
Rhinichthys atratulus	19	25.26	27.26	1	105
Notropis procne	21	5.05	5.33	1	23
Cyprinella analostana	22	13.91	13.13	1	52
Notropis hudsonius	1	5.00	.	5	5
Pimephales notatus	9	6.89	8.48	1	25
Catostomus commersoni	19	5.37	3.98	1	15
Erimyzon oblongus	1	1.00	.	1	1
Ameiurus natalis	16	4.25	4.71	1	19
Ameiurus nebulosus	5	1.20	0.45	1	2
Anguilla rostrata	16	14.56	16.50	1	61
Fundulus heteroclitus	9	2.67	2.83	1	9
Fundulus diaphanus	4	2.25	2.50	1	6
Lepomis auritus	21	17.19	18.30	1	50
Lepomis gibbosus	2	2.00	1.41	1	3
Lepomis macrochirus	9	1.67	1.32	1	5
Micropterus salmoides	4	4.25	1.50	2	5
Etheostoma olmstedi	27	2.35	1.58	1	7

Table 5 . Results of correlation analysis (SAS, 2009) among physical, chemical and biological parameters in Quantico Creek, VA watershed based on sample data collected from November, 2008 -- June 2010.

	MONTH	ORDER	ELEVATION	RIVERKM	GRADIENT	WIDTH AVG	DEPTH AVG	CURAVG	TEMP	PH	RICHNESS	ABUND	SHANNON	EVENNESS	WATERSHED SIZE	POPULATION	IMPERVIOUS	UN-DEVELOPED	% UN-DEVELOPED	MACRICH	FFGRICH	MACDIV	MACEVEN	FLOW	SEASON
MONTH	1 190	-0.02359 0.7467 190	0.01426 0.8452 190	0.03052 0.676 190	0.01519 0.8353 190	-0.14956 0.0394 190	-0.2162 0.0027 190	-0.3402 <.0001 189	0.48351 <.0001 190	0.01748 0.8221 168	0.14085 0.0565 184	0.12402 0.0953 182	0.09301 0.213 181	-0.08798 0.2763 155	-0.03708 0.6115 190	-0.03005 0.6806 190	-0.02728 0.7087 190	-0.03616 0.6204 190	0.00832 0.9093 190	-0.38445 0.0011 69	-0.1779 0.1436 69	-0.21218 0.0801 69	0.16759 0.1687 69	-0.16361 0.0245 189	0.96298 <.0001 190
ORDER	-0.02359 0.7467 190	1 190	-0.30889 <.0001 190	-0.16032 0.0271 190	-0.51864 <.0001 190	0.75577 <.0001 190	0.32984 <.0001 190	0.27156 0.0002 189	0.06317 0.3866 190	0.02817 0.717 168	0.74335 <.0001 184	-0.22895 0.0019 182	0.70204 <.0001 181	0.05914 0.4648 155	0.77554 <.0001 190	0.58094 <.0001 190	0.38446 <.0001 190	0.78757 <.0001 190	0.05715 0.4335 190	0.18349 0.1313 69	0.16495 0.1756 69	0.13028 0.286 69	-0.12933 0.2896 69	0.26505 0.0002 189	-0.02834 0.6979 190
ELEV	0.01426 0.8452 190	-0.30889 <.0001 190	1 190	0.52732 <.0001 190	-0.46496 <.0001 190	-0.51946 <.0001 190	-0.06568 0.3679 190	-0.1339 0.0662 189	-0.04421 0.5447 190	0.07327 0.3452 168	-0.05843 0.4308 184	-0.11945 0.1082 182	0.07693 0.3033 181	0.00638 0.9372 155	-0.49414 <.0001 190	-0.46742 <.0001 190	-0.46858 <.0001 190	-0.46777 <.0001 190	0.30391 <.0001 190	0.0023 0.985 69	0.05301 0.6653 69	0.04196 0.7321 69	0.00545 0.9645 69	-0.18321 0.0116 189	0.02019 0.7821 190
RIVERKM	0.03052 0.676 190	-0.16032 0.0271 190	0.52732 <.0001 190	1 190	-0.16405 0.0237 190	-0.58368 <.0001 190	-0.08702 0.2326 190	-0.10749 0.1409 189	-0.05885 0.42 190	0.01427 0.8544 168	0.06192 0.4037 184	-0.09925 0.1825 182	0.16382 0.0276 181	0.19162 0.0169 155	-0.58319 <.0001 190	-0.39312 <.0001 190	-0.38136 <.0001 190	-0.56804 <.0001 190	0.10014 0.1692 190	0.0678 0.5799 69	0.29651 0.0134 69	0.28608 0.0172 69	0.04697 0.7015 69	-0.21818 0.0026 189	0.04499 0.5377 190
GRADIENT	0.01519 0.8353 190	-0.51864 <.0001 190	-0.46496 <.0001 190	-0.16405 0.0237 190	1 190	-0.25519 0.0004 190	-0.18858 0.0092 190	-0.20649 0.0044 189	-0.0251 0.731 190	-0.05952 0.4434 168	-0.44764 <.0001 184	0.37827 <.0001 182	-0.5799 <.0001 181	-0.13788 0.0871 155	-0.34572 <.0001 190	0.02778 0.7036 190	0.09245 0.2046 190	-0.39627 <.0001 190	-0.49619 <.0001 190	-0.03781 0.7578 69	-0.08509 0.487 69	-0.08824 0.4709 69	0.08884 0.4679 69	-0.12777 0.0797 189	0.0239 0.7434 190
WIDTHAVG	-0.14956 0.0394 190	0.75577 <.0001 190	-0.51946 <.0001 190	-0.58368 <.0001 190	-0.25519 0.0004 190	1 190	0.37227 <.0001 190	0.38887 <.0001 189	-0.00589 0.9357 190	-0.08185 0.2915 168	0.54413 <.0001 184	-0.19969 0.0069 182	0.47868 <.0001 181	-0.05729 0.4789 155	0.90122 <.0001 190	0.63689 <.0001 190	0.53729 <.0001 190	0.90002 <.0001 190	-0.05848 0.4229 190	0.07697 0.5296 69	-0.07225 0.5552 69	-0.09324 0.4461 69	-0.17415 0.1524 69	0.42564 <.0001 189	-0.14151 0.0515 190
DEPTHAVG	-0.2162 0.0027 190	0.32984 <.0001 190	-0.06568 0.3679 190	-0.08702 0.2326 190	-0.18858 0.0092 190	0.37227 <.0001 190	1 190	0.39062 <.0001 189	-0.07389 0.311 190	-0.10879 0.1604 168	0.36416 <.0001 184	-0.02818 0.7057 182	0.39388 <.0001 181	0.035 0.6655 155	0.29763 <.0001 190	0.33215 <.0001 190	0.23157 0.0013 190	0.29043 <.0001 190	-0.10976 0.1317 190	0.16282 0.1813 69	0.14488 0.2349 69	0.11219 0.3587 69	-0.06048 0.6215 69	0.58826 <.0001 189	-0.18926 0.0089 190
CURAVG	-0.3402 <.0001 189	0.27156 0.0002 189	-0.1339 0.0662 189	-0.10749 0.1409 189	-0.20649 0.0044 189	0.38887 <.0001 189	0.39062 <.0001 189	1 189	-0.26027 0.0003 189	-0.21907 0.0045 167	0.14939 0.0435 183	-0.15546 0.0366 181	0.19936 0.0073 180	0.1078 0.1833 154	0.2663 0.0002 189	0.11379 0.119 189	0.09727 0.183 189	0.27784 0.0001 189	0.02471 0.7357 189	0.10343 0.3977 69	0.15009 0.2184 69	0.19943 0.1004 69	0.04816 0.6944 69	0.64029 <.0001 189	-0.2945 <.0001 189
TEMP	0.48351 <.0001 190	0.06317 0.3866 190	-0.04421 0.5447 190	-0.05885 0.42 190	-0.0251 0.731 190	-0.00589 0.9357 190	-0.07389 0.311 190	-0.26027 0.0003 189	1 190	0.25615 0.0008 168	0.1647 0.0255 184	0.17113 0.0209 182	0.12139 0.1036 181	-0.03329 0.6809 155	0.07956 0.2752 190	0.05837 0.4237 190	0.06882 0.3454 190	0.07671 0.2928 190	0.01923 0.7923 190	0.10369 0.3965 69	-0.00058 0.9962 69	0.03207 0.7936 69	-0.091 0.4571 69	-0.04538 0.5352 189	0.603 <.0001 190
PH	0.01748 0.8221 168	0.02817 0.717 168	0.07327 0.3452 168	0.01427 0.8544 168	-0.05952 0.4434 168	-0.08185 0.2915 168	-0.10879 0.1604 168	-0.21907 0.0045 167	0.25615 0.0008 168	1 168	0.05068 0.5218 162	0.22125 0.0049 160	0.04584 0.5662 159	-0.02792 0.7461 137	0.02743 0.7242 168	0.07892 0.3092 168	0.04109 0.5969 168	0.02354 0.762 168	-0.06265 0.4198 168	0.07566 0.6132 47	-0.04833 0.747 47	-0.16716 0.2614 47	-0.32851 0.0242 47	-0.18431 0.0171 167	0.01597 0.8372 168
RICHNESS	0.14085 0.0565 184	0.74335 <.0001 184	-0.05843 0.4308 184	0.06192 0.4037 184	-0.44764 <.0001 184	0.54413 <.0001 184	0.36416 <.0001 184	0.14939 0.0435 183	0.1647 0.0255 184	0.05068 0.5218 162	1 184	-0.17668 0.017 182	0.90952 <.0001 181	0.04765 0.556 155	0.54093 <.0001 184	0.48343 <.0001 184	0.33866 <.0001 184	0.54303 <.0001 184	-0.1315 0.0752 184	0.06048 0.6216 69	0.08843 0.4699 69	0.04754 0.6981 69	-0.05121 0.676 69	0.25404 0.0005 183	0.13059 0.0772 184
ABUND	0.12402 0.0953 182	-0.22895 0.0019 182	-0.11945 0.1082 182	-0.09925 0.1825 182	0.37827 <.0001 182	-0.19969 0.0069 182	-0.02818 0.7057 182	-0.15546 0.0366 181	0.17113 0.0209 182	0.22125 0.0049 160	-0.17668 0.017 182	1 182	-0.32123 <.0001 180	-0.20665 0.0099 155	-0.10402 0.1623 182	0.04414 0.5541 182	0.0401 0.5909 182	-0.12582 0.0906 182	-0.08169 0.273 182	0.05435 0.6574 69	-0.11041 0.3665 69	-0.12509 0.3058 69	-0.07113 0.5614 69	-0.17799 0.0165 181	0.11669 0.1167 182
SHANNON	0.09301 0.213 181	0.70204 <.0001 181	0.07693 0.3033 181	0.16382 0.0276 181	-0.5799 <.0001 181	0.47868 <.0001 181	0.39388 <.0001 181	0.19936 0.0073 180	0.12139 0.1036 181	0.04584 0.5662 159	0.90952 <.0001 181	-0.32123 <.0001 180	1 181	0.51249 <.0001 155	0.43139 <.0001 181	0.34504 <.0001 181	0.22191 0.0027 181	0.44321 <.0001 181	-0.13435 0.0714 181	0.09844 0.421 69	0.17332 0.1544 69	0.12587 0.3027 69	-0.09551 0.435 69	0.25769 0.0005 180	0.08939 0.2314 181
EVENNESS	-0.08798 0.2763 155	0.05914 0.4648 155	0.00638 0.9372 155	0.19162 0.0169 155	-0.13788 0.0871 155	-0.05729 0.4789 155	0.035 0.6655 155	0.1078 0.1833 154	-0.03329 0.6809 155	-0.02792 0.7461 137	0.04765 0.556 155	-0.20665 0.0099 155	0.51249 <.0001 155	1 155	-0.12893 0.1099 155	-0.2574 0.0012 155	-0.24823 0.0018 155	-0.09576 0.2359 155	-0.05658 0.4844 155	0.07777 0.5582 59	0.22168 0.0915 59	0.20857 0.1129 59	-0.03332 0.8022 59	0.05879 0.4689 154	-0.07274 0.3684 155
WATERSHED SIZE	-0.03708 0.6115 190	0.77554 <.0001 190	-0.49414 <.0001 190	-0.58319 <.0001 190	-0.34572 <.0001 190	0.90122 <.0001 190	0.29763 <.0001 190	0.2663 0.0002 189	0.07956 0.2752 190	0.02743 0.7242 168	0.54093 <.0001 184	-0.10402 0.1623 182	0.43139 <.0001 181	-0.12893 0.1099 155	1 190	0.70822 <.0001 190	0.62461 <.0001 190	0.99383 <.0001 190	0.13414 0.065 190	-0.01332 0.9135 69	-0.16946 0.1639 69	-0.1883 0.1213 69	-0.16048 0.1878 69	0.33353 <.0001 189	-0.04729 0.517 190
POP	-0.03005 0.6806 190	0.58094 <.0001 190	-0.46742 <.0001 190	-0.39312 <.0001 190	0.02778 0.7036 190	0.63689 <.0001 190	0.33215 <.0001 190	0.11379 0.119 189	0.05837 0.4237 190	0.07892 0.3092 168	0.48343 <.0001 184	0.04414 0.5541 182	0.34504 <.0001 181	-0.2574 0.0012 155	0.70822 <.0001 190	1 190	0.8738 <.0001 190	0.63735 <.0001 190	-0.3071 <.0001 190	0.00426 0.9723 69	-0.07417 0.5447 69	-0.12682 0.2991 69	-0.13268 0.2771 69	0.18999 0.0088 189	-0.02341 0.7485 190
IMPERV	-0.02728 0.7087 190	0.38446 <.0001 190	-0.46858 <.0001 190	-0.38136 <.0001 190	0.09245 0.2046 190	0.53729 <.0001 190	0.23157 0.0013 190	0.09727 0.183 189	0.06882 0.3454 190	0.04109 0.5969 168	0.33866 <.0001 184	0.0401 0.5909 182	0.22191 0.0027 181	-0.24823 0.0018 155	0.62461 <.0001 190	0.8738 <.0001 190	1 190	0.53762 <.0001 190	-0.24535 0.0006 190	-0.01615 0.8952 69	-0.15315 0.209 69	-0.18152 0.1355 69	-0.11131 0.3625 69	0.14874 0.0411 189	-0.01729 0.8128 190
UNDEVELOPED	-0.03616 0.6204 190	0.78757 <.0001 190	-0.46777 <.0001 190	-0.56804 <.0001 190	-0.39627 <.0001 190	0.90002 <.0001 190	0.29043 <.0001 190	0.27784 0.0001 189	0.07671 0.2928 190	0.02354 0.762 168	0.54303 <.0001 184	-0.12582 0.0906 182	0.44321 <.0001 181	-0.09576 0.2359 155	0.99383 <.0001 190	0.63735 <.0001 190	0.53762 <.0001 190	1 190	0.17891 0.0135 190	-0.01319 0.9144 69	-0.15879 0.1925 69	-0.1731 0.1549 69	-0.15406 0.2063 69	0.34172 <.0001 189	-0.04857 0.5058 190
% UN-DEVELOPED	0.00832 0.9093 190	0.05715 0.4335 190	0.30391 <.0001 190	0.10014 0.1692 190	-0.49619 <.0001 190	-0.05848 0.4229 190	-0.10976 0.1317 190	0.02471 0.7357 189	0.01923 0.7923 190	-0.06265 0.4198 168	-0.1315 0.0752 184	-0.08169 0.273 182	-0.13435 0.0714 181	-0.05658 0.4844 155	0.13414 0.065 190	-0.3071 <.0001 190	-0.24535 0.0006 190	0.17891 0.0135 190	1 190	-0.06971 0.5692 69	-0.13456 0.2703 69	-0.09674 0.4291 69	-0.02124 0.8625 69	0.02241 0.7595 189	0.00302 0.967 190
MACRICH	-0.38445 0.0011 69	0.18349 0.1313 69	0.0023 0.985 69	0.0678 0.5799 69	-0.03781 0.7578 69	0.07697 0.5296 69	0.16282 0.1813 69	0.10343 0.3977 69	0.10369 0.3965 69	0.07566 0.6132 47	0.06048 0.6216 69	0.05435 0.6574 69	0.09844 0.421 69	0.07777 0.5582 59	-0.01332 0.9135 69	0.00426 0.9723 69	-0.01615 0.8952 69	-0.01319 0.9144 69	-0.06971 0.5692 69	1 69	0.68845 <.0001 69	0.57505 <.0001 69	-0.45785 <.0001 69	0.16651 0.1715 69	-0.35467 0.0028 69
FFGRICH	-0.1779 0.1436 69	0.16495 0.1756 69	0.05301 0.6653 69	0.29651 0.0134 69	-0.08509 0.487 69	-0.07225 0.5552 69	0.14488 0.2349 69	0.15009 0.2184 69	-0.00058 0.9962 69	-0.04833 0.747 47	0.08843 0.4699 69	-0.11041 0.3665 69	0.17332 0.1544 69	0.22168 0.0915 59	-0.16946 0.1639 69	-0.07417 0.5447 69	-0.15315 0.209 69	-0.15879 0.1925 69	-0.13456 0.2703 69	0.68845 <.0001 69	1 69	0.95638 <.0001 69	-0.04914 0.6885 69	0.09783 0.4239 69	-0.19419 0.1098 69
MACDIV	-0.21218 0.0801 69	0.13028 0.286 69	0.04196 0.7321 69	0.28608 0.0172 69	-0.08824 0.4709 69	-0.09324 0.4461 69	0.11219 0.3587 69	0.19943 0.1004 69	0.03207 0.7936 69	-0.16716 0.2614 47	0.04754 0.6981 69	-0.12509 0.3058 69	0.12587 0.3027 69	0.20857 0.1129 59	-0.1883 0.1213 69	-0.12682 0.2991 69	-0.18152 0.1355 69	-0.1731 0.1549 69	-0.09674 0.4291 69	0.57505 <.0001 69	0.95638 <.0001 69	1 69	0.17664 0.1465 69	0.11057 0.3658 69	-0.21701 0.0733 69
MACEVEN	0.16759 0.1687 69	-0.12933 0.2896 69	0.00545 0.9645 69	0.04697 0.7015 69	0.08884 0.4679 69	-0.17415 0.1524 69	-0.06048 0.6215 69	0.04816 0.6944 69	-0.091 0.4571 69	-0.32851 0.0242 47	-0.05121 0.676 69	-0.07113 0.5614 69	-0.09551 0.435 69	-0.03332 0.8022 59	-0.16048 0.1878 69	-0.13268 0.2771 69	-0.11131 0.3625 69	-0.15406 0.2063 69	-0.02124 0.8625 69	-0.45785 <.0001 69	-0.04914 0.6885 69	0.17664 0.1465 69	1 69	-0.09503 0.4373 69	0.19252 0.113 69
FLOW	-0.16361 0.0245 189	0.26505 0.0002 189	-0.18321 0.0116 189	-0.21818 0.0026 189	-0.12777 0.0797 189	0.42564 <.0001 189	0.58826 <.0001 189	0.64029 <.0001 189	-0.04538 0.5352 189	-0.18431 0.0171 167	0.25404 0.0005 183	-0.17799 0.0165 181	0.25769 0.0005 180	0.05879 0.4689 154	0.33353 <.0001 189	0.18999 0.0088 189	0.14874 0.0411 189	0.34172 <.0001 189	0.02241 0.7595 189	0.16651 0.1715 69	0.09783 0.4239 69	0.11057 0.3658 69	-0.09503 0.4373 69	1 189	-0.12089 0.0975 189
SEASON	0.96298 <.0001 190	-0.02834 0.6979 190	0.02019 0.7821 190	0.04499 0.5377 190	0.0239 0.7434 190	-0.14151 0.0515 190	-0.18926 0.0089 190	-0.2945 <.0001 189	0.603 <.0001 190	0.01597 0.8372 168	0.13059 0.0772 184	0.11669 0.1167 182	0.08939 0.2314 181	-0.07274 0.3684 155	-0.04729 0.517 190	-0.02341 0.7485 190	-0.01729 0.8128 190	-0.04857 0.5058 190	0.00302 0.967 190	-0.35467 0.0028 69	-0.19419 0.1098 69	-0.21701 0.0733 69	0.19252 0.113 69	-0.12089 0.097 189	1 190

Table 8. Results of correlation analysis (SAS, 2009) among physical, chemical and biological parameters in Cameron Run, VA watershed based on sample data collected from November, 2008 -- June 2010.

	MONTH	ORDER	ELEVATION	RIVERKM	GRADIENT	WIDTH AVG	DEPTH AVG	CURRENT AVG	TEMP	PH	RICHNESS	ABUND	SHANNON	EVENNESS	WATERSHED SIZE	POPULATION	IMPERVIOUS	UN- DEVELOPED	% UN- DEVELOPED	MACRICH	FFGRICH	MACDIV	MACEVEN	FLOW	SEASON
MONTH	1 97	0.01138 0.9119 97	0.01495 0.8845 97	0.00619 0.952 97	0.00926 0.9283 97	-0.06553 0.5237 97	-0.0124 0.904 97	-0.05564 0.5883 97	0.49983 <.0001 97	-0.01654 0.8872 76	0.15029 0.146 95	0.0243 0.8161 94	0.21361 0.0357 97	0.21909 0.0453 84	0.00149 0.9885 97	0.0001 0.9992 97	0.00135 0.9896 97	0.00139 0.9893 97	-0.00166 0.9872 97	-0.05101 0.7745 34	-0.15079 0.3946 34	-0.14858 0.4017 34	0.00272 0.9878 34	-0.08217 0.4236 97	0.96468 <.0001 97
ORDER	0.01138 0.9119 97	1 97	-0.91613 <.0001 97	-0.73436 <.0001 97	-0.83062 <.0001 97	0.68953 <.0001 97	-0.03212 0.7548 97	0.36815 0.0002 97	0.20275 0.0464 97	0.10974 0.3453 76	0.71602 <.0001 95	-0.03538 0.7349 94	0.61681 <.0001 97	0.1484 0.1779 84	0.87351 <.0001 97	0.89424 <.0001 97	0.87138 <.0001 97	0.90192 <.0001 97	0.18156 0.0751 97	0.3616 0.0356 34	0.36398 0.0343 34	0.44087 0.0091 34	0.30687 0.0775 34	0.40939 <.0001 97	0.01406 0.8913 97
ELEV	0.01495 0.8845 97	-0.91613 <.0001 97	1 97	0.75034 <.0001 97	0.95077 <.0001 97	-0.66128 <.0001 97	0.14019 0.1708 97	-0.38329 0.0001 97	-0.17558 0.0854 97	-0.12582 0.2788 76	-0.83125 <.0001 95	0.07458 0.475 94	-0.72446 <.0001 97	-0.13952 0.2056 84	-0.77137 <.0001 97	-0.83506 <.0001 97	-0.76822 <.0001 97	-0.78756 <.0001 97	-0.19277 0.0585 97	-0.37045 0.031 34	-0.42098 0.0132 34	-0.48337 0.0038 34	-0.37576 0.0285 34	-0.41673 <.0001 97	0.01566 0.879 97
RIVERKM	0.00619 0.952 97	-0.73436 <.0001 97	0.75034 <.0001 97	1 97	0.75814 <.0001 97	-0.644 <.0001 97	-0.13505 0.1872 97	-0.23607 0.0199 97	-0.14214 0.1649 97	-0.1341 0.2481 76	-0.57407 <.0001 95	-0.05598 0.592 94	-0.4366 <.0001 97	-0.10421 0.3455 84	-0.58386 <.0001 97	-0.63198 <.0001 97	-0.56662 <.0001 97	-0.61777 <.0001 97	-0.73842 <.0001 97	-0.19345 0.273 34	-0.10471 0.5556 34	-0.13148 0.4586 34	-0.07059 0.6916 34	-0.32443 0.0012 97	0.00705 0.9453 97
GRADIENT	0.00926 0.9283 97	-0.83062 <.0001 97	0.95077 <.0001 97	0.75814 <.0001 97	1 97	-0.70476 <.0001 97	0.24962 0.0137 97	-0.38083 0.0001 97	-0.17306 0.09 97	-0.15653 0.1769 76	-0.84193 <.0001 95	0.0462 0.6584 94	-0.72684 <.0001 97	-0.19212 0.08 84	-0.57909 <.0001 97	-0.66962 <.0001 97	-0.57716 <.0001 97	-0.60908 <.0001 97	-0.28905 0.0041 97	-0.32755 0.0586 34	-0.4384 0.0095 34	-0.50178 0.0025 34	-0.36869 0.0319 34	-0.39283 <.0001 97	0.01067 0.9174 97
WIDTHAVG	-0.06553 0.5237 97	0.68953 <.0001 97	-0.66128 <.0001 97	-0.644 <.0001 97	-0.70476 <.0001 97	1 97	0.07258 0.4799 97	0.31497 0.0017 97	0.13058 0.2023 97	0.20647 0.0735 76	0.64003 <.0001 95	0.06707 0.5207 94	0.49398 <.0001 97	0.25834 0.0177 84	0.44654 <.0001 97	0.54374 <.0001 97	0.45208 <.0001 97	0.46322 <.0001 97	0.27183 0.0071 97	0.17561 0.3205 34	0.22742 0.1958 34	0.31531 0.0693 34	0.1974 0.2631 34	0.49489 <.0001 97	-0.04146 0.6868 97
DEPTHAVG	-0.0124 0.904 97	-0.03212 0.7548 97	0.14019 0.1708 97	-0.13505 0.1872 97	0.24962 0.0137 97	0.07258 0.4799 97	1 97	-0.0234 0.82 97	-0.02601 0.8003 97	-0.25016 0.0293 76	-0.19327 0.0606 95	0.23983 0.0199 94	-0.18609 0.068 97	-0.05847 0.5973 84	0.08136 0.4282 97	0.05969 0.5614 97	0.06681 0.5156 97	0.06154 0.5493 97	0.25839 0.0106 97	0.03118 0.861 34	-0.2195 0.2123 34	-0.2777 0.1118 34	-0.1639 0.3543 34	0.22831 0.0245 97	0.0219 0.8314 97
CURAVG	-0.05564 0.5883 97	0.36815 0.0002 97	-0.38329 0.0001 97	-0.23607 0.0199 97	-0.38083 0.0001 97	0.31497 0.0017 97	-0.0234 0.82 97	1 97	-0.09312 0.3643 97	-0.08538 0.4634 76	0.34622 0.0006 95	0.12729 0.2215 94	0.28149 0.0052 97	0.07788 0.4813 84	0.28945 0.004 97	0.33919 0.0007 97	0.29912 0.0029 97	0.28706 0.0044 97	-0.05669 0.5813 97	0.06593 0.711 34	0.34028 0.0489 34	0.49318 0.003 34	0.32328 0.0622 34	0.8285 <.0001 97	-0.07789 0.4482 97
TEMP	0.49983 <.0001 97	0.20275 0.0464 97	-0.17558 0.0854 97	-0.14214 0.1649 97	-0.17306 0.09 97	0.13058 0.2023 97	-0.02601 0.8003 97	-0.09312 0.3643 97	1 97	0.37121 0.001 76	0.43791 <.0001 95	0.03515 0.7366 94	0.39209 <.0001 97	-0.00556 0.96 84	0.15882 0.1202 97	0.17166 0.0927 97	0.15989 0.1177 97	0.16191 0.1131 97	0.02653 0.7965 97	0.32662 0.0594 34	0.4308 0.011 34	0.47572 0.0045 34	0.30388 0.0806 34	-0.03844 0.7085 97	0.59784 <.0001 97
PH	-0.01654 0.8872 76	0.10974 0.3453 76	-0.12582 0.2788 76	-0.1341 0.2481 76	-0.15653 0.1769 76	0.20647 0.0735 76	-0.25016 0.0293 76	-0.08538 0.4634 76	0.37121 0.001 76	1 76	0.17538 0.135 74	-0.20176 0.087 73	0.13775 0.2354 76	0.02192 0.8624 65	0.05178 0.6569 76	0.09315 0.4235 76	0.05567 0.6329 76	0.048 0.6805 76	0.05051 0.6648 76	0.06343 0.7905 20	0.17053 0.4723 20	0.19448 0.4113 20	0.12903 0.5877 20	-0.14654 0.2065 76	0.00318 0.9782 76
RICHNESS	0.15029 0.146 95	0.71602 <.0001 95	-0.83125 <.0001 95	-0.57407 <.0001 95	-0.84193 <.0001 95	0.64003 <.0001 95	-0.19327 0.0606 95	0.34622 0.0006 95	0.43791 <.0001 95	0.17538 0.135 74	1 95	-0.06577 0.5288 94	0.9096 <.0001 95	0.2125 0.0523 84	0.56219 <.0001 95	0.6555 <.0001 95	0.56476 <.0001 95	0.56079 <.0001 95	0.08048 0.4382 95	0.37901 0.0271 34	0.42529 0.0122 34	0.473 0.0047 34	0.33058 0.0562 34	0.37216 0.0002 95	0.16773 0.1042 95
ABUND	0.0243 0.8161 94	-0.03538 0.7349 94	0.07458 0.475 94	-0.05598 0.592 94	0.0462 0.6584 94	0.06707 0.5207 94	0.23983 0.0199 94	0.12729 0.2215 94	0.03515 0.7366 94	-0.20176 0.087 73	-0.06577 0.5288 94	1 94	-0.12759 0.2204 94	-0.18657 0.0893 84	-0.14238 0.171 94	-0.12022 0.2484 94	-0.14247 0.1707 94	-0.13572 0.1921 94	0.15258 0.1421 94	-0.16154 0.3614 34	-0.33099 0.0559 34	-0.35491 0.0394 34	-0.15251 0.3892 34	0.2007 0.0524 94	0.03445 0.7417 94
SHANNON	0.21361 0.0357 97	0.61681 <.0001 97	-0.72446 <.0001 97	-0.4366 <.0001 97	-0.72684 <.0001 97	0.49398 <.0001 97	-0.18609 0.068 97	0.28149 0.0052 97	0.39209 <.0001 97	0.13775 0.2354 76	0.9096 <.0001 95	-0.12759 0.2204 94	1 97	0.58185 <.0001 84	0.47174 <.0001 97	0.55006 <.0001 97	0.47233 <.0001 97	0.47249 <.0001 97	0.01967 0.8483 97	0.35932 0.0369 34	0.45532 0.0068 34	0.50656 0.0022 34	0.35294 0.0406 34	0.27966 0.0055 97	0.21956 0.0307 97
EVENNESS	0.21909 0.0453 84	0.1484 0.1779 84	-0.13952 0.2056 84	-0.10421 0.3455 84	-0.19212 0.08 84	0.25834 0.0177 84	-0.05847 0.5973 84	0.07788 0.4813 84	-0.00556 0.96 84	0.02192 0.8624 65	0.2125 0.0523 84	-0.18657 0.0893 84	0.58185 <.0001 84	1 84	0.07237 0.513 84	0.12275 0.266 84	0.07535 0.4957 84	0.06192 0.5758 84	0.00154 0.9889 84	0.11786 0.5206 32	0.15495 0.3971 32	0.19235 0.2916 32	0.24384 0.1787 32	0.07217 0.5141 84	0.13774 0.2115 84
WATERSHED SIZE	0.00149 0.9885 97	0.87351 <.0001 97	-0.77137 <.0001 97	-0.58386 <.0001 97	-0.57909 <.0001 97	0.44654 <.0001 97	0.08136 0.4282 97	0.28945 0.004 97	0.15882 0.1202 97	0.05178 0.6569 76	0.56219 <.0001 95	-0.14238 0.171 94	0.47174 <.0001 97	0.07237 0.513 84	1 97	0.98161 <.0001 97	0.99896 <.0001 97	0.99341 <.0001 97	-0.00936 0.9275 97	0.33565 0.0523 34	0.25237 0.1499 34	0.30723 0.0772 34	0.20411 0.2469 34	0.35428 0.0004 97	0.00198 0.9846 97
POP	0.0001 0.9992 97	0.89424 <.0001 97	-0.83506 <.0001 97	-0.63198 <.0001 97	-0.66962 <.0001 97	0.54374 <.0001 97	0.05969 0.5614 97	0.33919 0.0007 97	0.17166 0.0927 97	0.09315 0.4235 76	0.6555 <.0001 95	-0.12022 0.2484 94	0.55006 <.0001 97	0.12275 0.266 84	0.98161 <.0001 97	1 97	0.98382 <.0001 97	0.96649 <.0001 97	-0.00506 0.9608 97	0.32354 0.062 34	0.26828 0.125 34	0.33205 0.055 34	0.22755 0.1956 34	0.4136 <.0001 97	0.00013 0.999 97
IMPERV	0.00135 0.9896 97	0.87138 <.0001 97	-0.76822 <.0001 97	-0.56662 <.0001 97	-0.57716 <.0001 97	0.45208 <.0001 97	0.06681 0.5156 97	0.29912 0.0029 97	0.15989 0.1177 97	0.05567 0.6329 76	0.56476 <.0001 95	-0.14247 0.1707 94	0.47233 <.0001 97	0.07535 0.4957 84	0.99896 <.0001 97	0.98382 <.0001 97	1 97	0.99015 <.0001 97	-0.04197 0.6832 97	0.32447 0.0612 34	0.25373 0.1476 34	0.31441 0.0701 34	0.20895 0.2356 34	0.36162 0.0003 97	0.00179 0.9861 97
UNDEVELOPED	0.00139 0.9893 97	0.90192 <.0001 97	-0.78756 <.0001 97	-0.61777 <.0001 97	-0.60908 <.0001 97	0.46322 <.0001 97	0.06154 0.5493 97	0.28706 0.0044 97	0.16191 0.1131 97	0.048 0.6805 76	0.56079 <.0001 95	-0.13572 0.1921 94	0.47249 <.0001 97	0.06192 0.5758 84	0.99341 <.0001 97	0.96649 <.0001 97	0.99015 <.0001 97	1 97	0.05018 0.6255 97	0.34885 0.0432 34	0.27379 0.1171 34	0.33025 0.0564 34	0.21748 0.2166 34	0.3423 0.0006 97	0.00185 0.9857 97
% UNDEVELOPED	-0.00166 0.9872 97	0.18156 0.0751 97	-0.19277 0.0585 97	-0.73842 <.0001 97	-0.28905 0.0041 97	0.27183 0.0071 97	0.25839 0.0106 97	-0.05669 0.5813 97	0.02653 0.7965 97	0.05051 0.6648 76	0.08048 0.4382 95	0.15258 0.1421 94	0.01967 0.8483 97	0.00154 0.9889 84	-0.00936 0.9275 97	-0.00506 0.9608 97	-0.04197 0.6832 97	0.05018 0.6255 97	1 97	0.0255 0.8862 34	-0.13542 0.4451 34	-0.18409 0.2973 34	-0.1622 0.3594 34	0.01132 0.9124 97	-0.00221 0.9829 97
MACRICH	-0.05101 0.7745 34	0.3616 0.0356 34	-0.37045 0.031 34	-0.19345 0.273 34	-0.32755 0.0586 34	0.17561 0.3205 34	0.03118 0.861 34	0.06593 0.711 34	0.32662 0.0594 34	0.06343 0.7905 20	0.37901 0.0271 34	-0.16154 0.3614 34	0.35932 0.0369 34	0.11786 0.5206 32	0.33565 0.0523 34	0.32354 0.062 34	0.32447 0.0612 34	0.34885 0.0432 34	0.0255 0.8862 34	1 34	0.8252 <.0001 34	0.65985 <.0001 34	0.38713 0.0237 34	0.11576 0.5145 34	-0.14213 0.4226 34
FFGRICH	-0.15079 0.3946 34	0.36398 0.0343 34	-0.42098 0.0132 34	-0.10471 0.5556 34	-0.4384 0.0095 34	0.22742 0.1958 34	-0.2195 0.2123 34	0.34028 0.0489 34	0.4308 0.011 34	0.17053 0.4723 20	0.42529 0.0122 34	-0.33099 0.0559 34	0.45532 0.0068 34	0.15495 0.3971 32	0.25237 0.1499 34	0.26828 0.125 34	0.25373 0.1476 34	0.27379 0.1171 34	-0.13542 0.4451 34	0.8252 <.0001 34	1 34	0.94257 <.0001 34	0.62048 <.0001 34	0.30786 0.0765 34	-0.20451 0.246 34
MACDIV	-0.14858 0.4017 34	0.44087 0.0091 34	-0.48337 0.0038 34	-0.13148 0.4586 34	-0.50178 0.0025 34	0.31531 0.0693 34	-0.2777 0.1118 34	0.49318 0.003 34	0.47572 0.0045 34	0.19448 0.4113 20	0.473 0.0047 34	-0.35491 0.0394 34	0.50656 0.0022 34	0.19235 0.2916 32	0.30723 0.0772 34	0.33205 0.055 34	0.31441 0.0701 34	0.33025 0.0564 34	-0.18409 0.2973 34	0.65985 <.0001 34	0.94257 <.0001 34	1 34	0.76512 <.0001 34	0.44194 0.0089 34	-0.19419 0.2711 34
MACEVEN	0.00272 0.9878 34	0.30687 0.0775 34	-0.37576 0.0285 34	-0.07059 0.6916 34	-0.36869 0.0319 34	0.1974 0.2631 34	-0.1639 0.3543 34	0.32328 0.0622 34	0.30388 0.0806 34	0.12903 0.5877 20	0.33058 0.0562 34	-0.15251 0.3892 34	0.35294 0.0406 34	0.24384 0.1787 32	0.20411 0.2469 34	0.22755 0.1956 34	0.20895 0.2356 34	0.21748 0.2166 34	-0.1622 0.3594 34	0.38713 0.0237 34	0.62048 <.0001 34	0.76512 <.0001 34	1 34	0.31708 0.0677 34	-0.11855 0.5043 34
FLOW	-0.08217 0.4236 97	0.40939 <.0001 97	-0.41673 <.0001 97	-0.32443 0.0012 97	-0.39283 <.0001 97	0.49489 <.0001 97	0.22831 0.0245 97	0.8285 <.0001 97	-0.03844 0.7085 97	-0.14654 0.2065 76	0.37216 0.0002 95	0.2007 0.0524 94	0.27966 0.0055 97	0.07217 0.5141 84	0.35428 0.0004 97	0.4136 <.0001 97	0.36162 0.0003 97	0.3423 0.0006 97	0.01132 0.9124 97	0.11576 0.5145 34	0.30786 0.0765 34	0.44194 0.0089 34	0.31708 0.0677 34	1 97	-0.06732 0.5124 97
SEASON	0.96468 <.0001 97	0.01406 0.8913 97	0.01566 0.879 97	0.00705 0.9453 97	0.01067 0.9174 97	-0.04146 0.6868 97	0.0219 0.8314 97	-0.07789 0.4482 97	0.59784 <.0001 97	0.00318 0.9782 76	0.16773 0.1042 95	0.03445 0.7417 94	0.21956 0.0307 97	0.13774 0.2115 84	0.00198 0.9846 97	0.00013 0.999 97	0.00179 0.9861 97	0.00185 0.9857 97	-0.00221 0.9829 97	-0.14213 0.4226 34	-0.20451 0.246 34	-0.19419 0.2711 34	-0.11855 0.5043 34	-0.06732 0.5124 97	1 97