Susquehanna River Basin Flow Monitoring Network

Technical Summary – 2012

Publication No. 286 *September 30, 2013*

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INTRODUCTION

The Susquehanna River is the largest river in the Atlantic Ocean drainage that is entirely contained within the borders of the United States. The mainstem Susquehanna River and its tributaries constitute more than 49,000 river miles and drain an area of 27,150 square miles encompassing portions of New York, Pennsylvania, and Maryland. The Susquehanna River Basin (basin) is considered a largely water-rich area receiving an average of 40 inches of rainfall annually (SRBC, 2008). The groundwater and surface water resources of the basin are used to meet the demands of a diverse and sometimes conflicting group of users, including drinking water suppliers, wastewater treatment plants, electric power generators, resource extraction industries, recreation groups, and the flora and fauna native to the region.

Despite its abundant water resources, the Susquehanna River Basin is vulnerable to water shortages due to a rapidly increasing human population and threats from a changing climate. As water demands increase to satisfy the drinking water and energy production needs of a growing population, it becomes more challenging to manage water resources to avoid shortages and conflicts. Healthy, functional ecosystems are essential for supporting the basin's many water uses. Water quantity and quality are interdependent and equally important to the integrity of aquatic ecosystems which, when managed properly, are capable of providing adequate quantities of high quality water for both ecological and human uses.

Floods and droughts are natural features of river ecosystems and often occur on a relatively predictable basis (Lake, 2003). The Susquehanna River Basin is one of the country's most flood-prone areas, due in part to its moisture-rich climate, ample groundwater and surface water resources, and high degree of runoff from developed areas. Minor and moderate flooding generally occurs every year somewhere in the basin and major floods have been recorded in all seasons (SRBC, 2008). Major floods are most frequent in the early spring as a result of heavy rainfall on top of snowpack, and in the late summer when tropical storms or the remnants of hurricanes pass through the region. Significant droughts are also a feature of the basin, the most recent occurring in 2002. Many watersheds in the basin experience substantial surface runoff due to steep topography, complex geology, and/or impervious surfaces, and are highly dependent on aquifer storage to sustain streamflows during drought events. Climate change predictions include an increase in the frequency and severity of heavy rainfall with subsequent runoff and flooding, as well as an increase in the frequency of summer droughts. Current trends towards reduced snowfall and increased rainfall in the winter months may result in insufficient spring groundwater recharge and subsequent decreases in surface water availability heading into the dry summer months. Changing climatic conditions coupled with an ever-increasing demand for water pose a serious threat to the ecological integrity of the Susquehanna River and its tributaries.

Streamflow is often referred to as the “master” variable affecting river ecosystems at every level, from small-scale hydraulic conditions on the surface of an individual cobble to channel dimensions at the watershed scale (Hart and Finelli, 1999). Instream habitat is heavily influenced by flow-mediated processes, especially the movement of water and sediment within the stream channel and between the channel and floodplain (Poff and others, 1997). The natural flow regime of a stream varies in response to climate, topography, geology, land use, soils, and longitudinal position within the river network (Poff and Zimmerman, 2010). The magnitude, duration, seasonal timing, and predictability of major flow events, both low and high, are unique to individual river systems. Stream-dwelling organisms have adapted behavioral mechanisms and life history strategies in direct response to the natural flow regimes of their native rivers (Lytle and Poff, 2004). Important life cycle events such as reproduction and migration are often closely tied to seasonal low or high flows. Understanding and maintaining natural flow regimes is therefore critical to conserving the native biodiversity of freshwater systems, particularly in the face of the challenges posed by a changing climate.

FLOW MONITORING IN THE SUSQUEHANNA RIVER BASIN

Recently, The Nature Conservancy (TNC), in conjunction with the Susquehanna River Basin Commission (SRBC) and the U.S. Army Corps of Engineers, conducted an Ecosystem Flow Study that culminated in a set of flow recommendations intended to protect the biological communities and key ecological processes of the Susquehanna River and its tributaries (DePhilip and Moberg, 2010). A critical finding of this study is that ecosystem flow needs are naturally seasonal, and that water managers should impose restrictions on water withdrawals based upon seasonal rather than annual flow recommendations. This finding provided the impetus and context for revision of SRBC’s Policy No. 2003-01, *Guidelines for Using and Determining Passby Flows and Conservation Releases for Surface-Water and Ground-Water Withdrawal*

Approvals, previously adopted in 1993. SRBC Policy No. 2012-01, *Low Flow Protection Policy Related to Withdrawal Approvals*, was adopted in December 2012. Instead of a single annual passby flow/conservation release value for low protection, Policy No. 2012-01 outlines a series of seasonal or monthly flow values that more accurately reflect seasonal variability with respect to streamflow and associated ecosystem needs.

TNC's flow recommendations for the Susquehanna River Basin were developed through expert consultation supported by published literature and existing studies rather than quantitative analyses (DePhilip and Moberg, 2010). In addition to ecosystem flow recommendations, the study partners proposed a number of hypotheses regarding anticipated response of species, groups of species, or physical habitat to changing conditions during high and low flows. These hypotheses were intended to direct future quantitative analyses to confirm or revise their flow recommendations.

SRBC conducted a Low Flow Monitoring Pilot Study (Pilot Study) in the Juniata River subbasin in 2010 and 2011. Data collected during this Pilot Study were used to begin testing some of the hypotheses outlined in the TNC report. SRBC intended for the Pilot Study to document stream discharge, water quality, and physical habitat, as well as macroinvertebrate, fish, and periphyton communities during both summer baseline and low flow conditions in the Juniata River Subbasin in consecutive years. The exceedance probability flow of Annual P95 (the flow exceeded 95 percent of the time in any given year) was chosen to define low flow conditions during the first year of the Pilot Study. Annual P95 occurred at 17 of 27 monitoring stations between August and mid-September 2010. After reviewing the TNC report upon its release in September 2010, SRBC revised the sampling plan for the second year of the Pilot Study to reflect recommendations regarding use of seasonal rather than annual flow values for management purposes. In 2011, a seasonal August-September-October mean P95 (ASO P95) was chosen to define low flow conditions. The ASO P95 was chosen because the lowest average annual flows historically occurred during these months. SRBC staff completed baseline sampling in June and July 2011; however, record precipitation and historic flooding from Tropical Storm Lee in early September caused flows to remain well above ASO P95 through the fall. Although only one complete year of data were collected, the results of the Pilot Study provided initial support for TNC's hypothesis that compositional differences exist between the macroinvertebrate and fish communities associated with baseline and low flow conditions. For a full summary of the Pilot Study, see SRBC Publication 283 (Hutchison, 2012).

Guided by findings from the Pilot Study, SRBC established a basin-wide Flow Monitoring Network (FMN) in 2012. The purpose of the FMN is to document stream discharge, physical habitat, water quality, and biological communities during the natural low flow period, June 1 through September 30 (DePhilip and Moberg, 2010), in order to identify differences related to streamflow. SRBC staff will sample each station in the FMN twice annually: once during a period of higher baseline flow, with a target of sampling at June-July mean P50 flow (JJ P50), and again during a period of low flow (ASO P95). If in a given year ASO P95 does not occur, a second round of sampling will still be conducted in September to document conditions during a “normal” or “high” flow year. Data collected from the FMN stations will be used to characterize and compare water quality, habitat, and biological communities associated with different flows and to advise management decisions regarding low flow mitigation and passby flows associated with surface water withdrawals. The FMN will also provide sentinel stations for monitoring changes to flow regime, habitat, water quality, and biological communities that may occur throughout the Susquehanna River Basin as a result of climate change.

STUDY AREA AND MONITORING NETWORK

The FMN consists of 19 stations in the Pennsylvania and New York portions of the Susquehanna River Basin (Figure 1). The 19 stations are distributed across three Level III ecoregions: six stations are located in the Northern Appalachian Plateau and Uplands, six in the North Central Appalachians, and seven in the Central Appalachian Ridges and Valleys (Omernik, 1987).

The Central Appalachian Ridge and Valley ecoregion is comprised of parallel ridges and valleys formed by folding and faulting events. Land use in the Central Appalachian Ridges and Valleys is mixed and includes forested areas concentrated in the ridges with agricultural and urban areas in the valleys. The dominant geologic materials include sandstone, shale, limestone, dolomite, siltstone, chert, mudstone, and marble. Carbonate terrain is common in this ecoregion, which features many subterranean caves and springs.

The Northern Appalachian Plateau and Uplands ecoregion is characterized by open valleys and low mountains and is the largest of all ecoregions in the Susquehanna River Basin.

Land use in this ecoregion is primarily agricultural with some woodland and urban areas. The North Central Appalachian ecoregion is a densely forested upland typified by high hills and low mountains. Land use is primarily forested with numerous state forests and game lands located throughout the ecoregion. Resource extraction, including logging, mining, and oil and gas development, is common in the North Central Appalachians. Despite widespread detrimental impacts from abandoned mine drainage (AMD) and atmospheric deposition, some of the basin’s most pristine streams and forests are located in this ecoregion, making it a destination for tourists and outdoor enthusiasts. Both the Northern Appalachian Plateau and Uplands and the North Central Appalachians contain unglaciated and glaciated regions and have similar underlying geologic materials, including shale, siltstone, sandstone, and conglomerate.

The FMN focuses on streams in highly forested watersheds in an attempt to isolate natural from anthropogenic impacts to flow. Specific station selection criteria were identified for inclusion in the network, including:

- Land use – high percentage of forested lands (greater than 70 percent forested in the North Central Appalachian and Central Appalachian Ridge and Valley ecoregions and greater than 40 percent forested in the Northern Appalachian Plateau and Uplands);
- Non-impaired or minimally impaired waters with special consideration given to streams with High Quality (HQ) or Exceptional Value (EV) designations;
- Presence of non-impaired or minimally impaired biological communities (based on historic SRBC field surveys);
- Drainage area – per ecoregion, at least two stations each with drainage area less than 25 square miles, 25 – 49 square miles, and greater than 50 square miles.

Six stations, all located in the Central Appalachian Ridges and Valleys, were carried over from the Low Flow Monitoring Pilot study. Eleven of the FMN stations overlap with stations that are part of SRBC’s Remote Water Quality Monitoring Network (RWQMN). The RWQMN stations are equipped with real-time data sondes that continuously record and report temperature, pH, conductance, dissolved oxygen, turbidity, and water depth (at select stations only). For a list of FMN station names, location descriptions, geographic coordinates, drainage areas, percentage of forested and agricultural lands, and designated uses, see Appendix A.

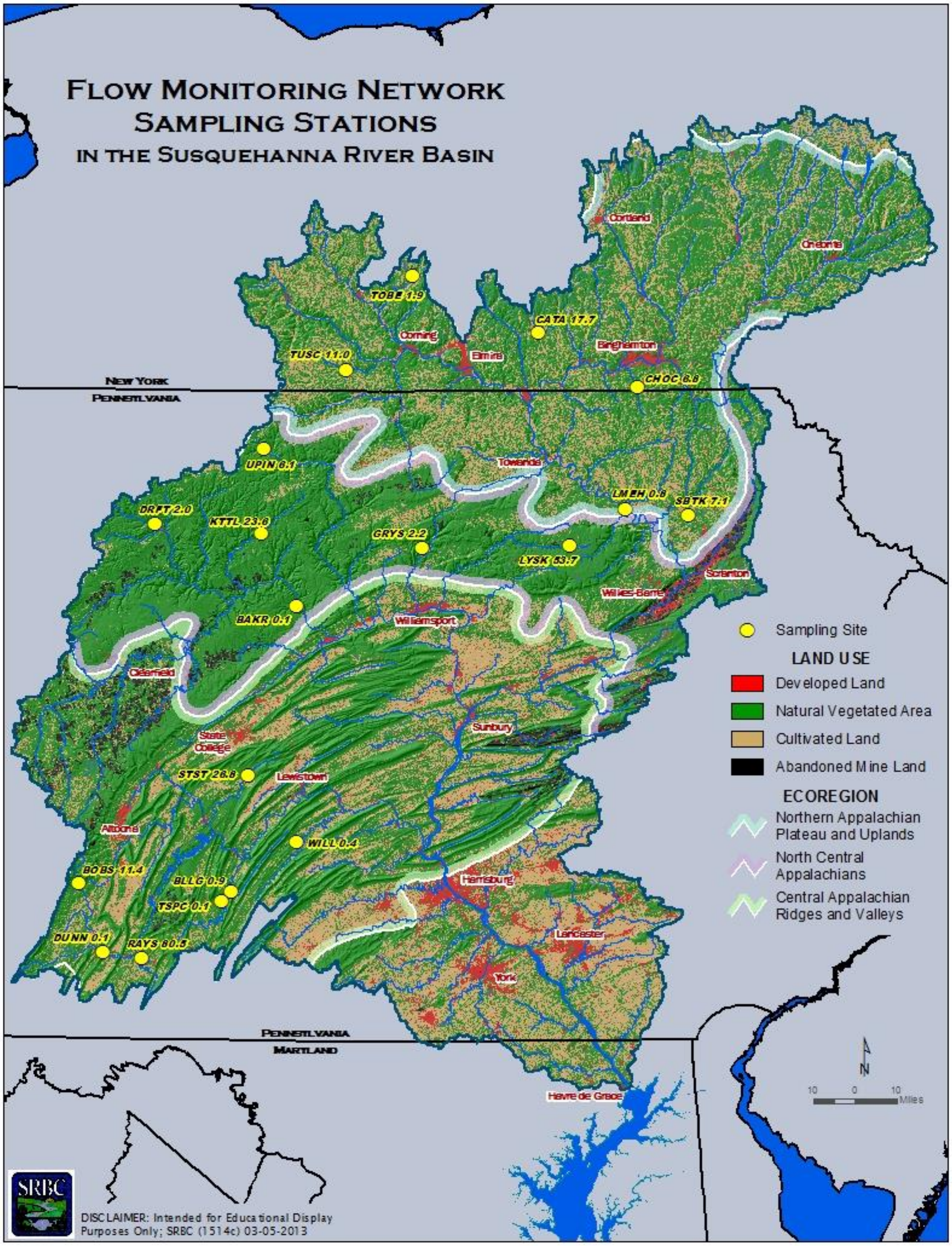

Figure 1. Location of the Flow Monitoring Network Sampling Stations in the Susquehanna River Basin

METHODS

Data Collection

Sampling design and methods employed for the FMN closely followed those outlined in the Low Flow Monitoring Pilot Study (Hutchison, 2012). SRBC staff completed two rounds of sampling at the 19 FMN stations in 2012 during the natural low flow period. The first round of sampling (Round 1) took place between June 28 and August 3 during summer baseline flow conditions. The exceedance probability flow of August-September-October P95 (ASO P95) was chosen to define low flow conditions and initiate a second round of sampling. No streams in the network experienced ASO P95 flows in 2012, so SRBC completed a second round of sampling (Round 2) between September 10 and October 4 at existing flows.

Staff monitored flow conditions prior to the start of the sampling period in June and between the sampling rounds by accessing real-time streamflow data from the U.S. Geological Survey (USGS) web site (http://waterwatch.usgs.gov). Parameters monitored during each sampling round included stream discharge, physical habitat, water quality, macroinvertebrate and fish communities, and periphyton biomass.

Stream Discharge

During each sampling round, SRBC staff measured stream discharge (flow) using a FlowTracker and standard USGS procedures (Buchanan and Somers, 1969). Additional habitat information was collected at each vertical location along the transect, including dominant substrate type and presence/absence of sedimentation. InSitu, Inc. Level TROLL pressure transducers were installed at all FMN stations in order to continuously record water depth. The pressure transducers at nine of the 19 stations report real-time data via the RWQMN satellite system. Data from the other ten pressure transducers are stored internally and downloaded at regular intervals by SRBC staff. Instantaneous discharge measurements will be paired with water depth measurements from the pressure transducers and used to build rating curves.

Habitat

Habitat conditions were assessed using a modified version of the U.S. Environmental Protection Agency's (USEPA's) Rapid Bioassessment Protocols for Use in Streams and

Wadeable Rivers (RBP III) (Plafkin and others, 1989; Barbour and others, 1999). Physical stream characteristics relating to substrate, pool, and riffle composition, flow status, shape of the channel, conditions of the banks, and the riparian zone were rated on a scale of 0 – 20, with 20 being optimal. Other observations were noted regarding recent precipitation, dominant substrate material composition, surrounding land use, and any other relevant features of the landscape.

Staff used surveying equipment to determine the change in water elevation from the top of the sampling reach to the bottom. A stream transect located in the dominant habitat type was characterized using the FlowTracker to record width and water depths across the channel. Additional habitat information was also collected at each of these vertical locations along the transect, including dominant substrate type and presence/absence of sedimentation. In years when ASO P95 occurs, these additional measurements would be to estimate loss of wetted area and specific habitat types.

Water Quality

Field chemistry parameters were measured at the time of sampling and water samples were collected for laboratory analyses. Table 1 lists all water quality parameters measured and their associated levels of concern based on current state or federal standards, background levels for uninfluenced streams, or references for aquatic life tolerances. A handheld multi-probe YSI sonde was used to simultaneously collect all field chemistry parameters (stream temperature, conductivity, pH, and dissolved oxygen). The probes were rinsed with distilled water and sample water prior to collection of water quality data, and calibrations were conducted as detailed in the Quality Assurance Project Plan (Quality Assurance/Work Plan, Document Control Number SRBC – QA049). Water samples for laboratory analyses were collected using depth-integrated sampling methods (Guy and Norman, 1969) and kept on ice until delivery to ALS Environmental in Middletown, Pa. SRBC staff collected one set of duplicate water samples per sampling round.

Macroinvertebrates

Benthic macroinvertebrates were collected using a modified version of RBP III (Barbour and others, 1999). Sampling was conducted in the best available riffle/run habitat using a D-frame kick net with 500-micron mesh. Samples consisted of a composite of six kicks with each kick disturbing approximately one square meter of substrate immediately upstream of the net for a period of one minute. Samples were preserved with 95-percent denatured ethyl alcohol and returned to SRBC's lab. The sample was then subsampled following procedures outlined in the Pennsylvania Department of Environmental Protection's (PADEP's) benthic macroinvertebrate index of biotic integrity (PADEP, 2012). Most insect taxa were identified to genus. Midges were identified to the family level of Chironomidae. Non-insect taxa (i.e., worms, mollusks, and mites) were identified to family, order, class, or phylum depending on available keys.

Fish

The fish community was sampled using methods adapted from the RBP III manual (Barbour and others, 1999) and PADEP's draft fish index of biological integrity. Electrofishing was conducted in wadeable reaches using either a backpack electroshocker or a tow barge unit, depending on the size of the stream. Reach length was equal to ten times the average wetted width of the stream channel, plus or minus 10 meters, with a minimum length of 100 meters and a maximum length of 400 meters. Three electrofishing passes were made per station, and all accessible habitats in the stream reach were sampled. All fish caught were identified to species and enumerated. The first 50 individuals of each game species were also weighed and measured. All fish were returned to the stream after processing unless there was a question regarding identification, in which case the specimen was preserved in 10-percent formalin and returned to the laboratory for identification.

Periphyton

Periphyton were collected for determination of chlorophyll-a (chl-a) concentration, which may be used a surrogate for biomass. Collection methods followed USEPA's National River and Stream Assessment Protocols (USEPA, 2007). Periphyton were sampled by removing natural rocks from the stream bed at each of 11 transects established throughout the sampling reach. Attached periphyton from a delimited area on the surface of each rock were scraped and rinsed into a bottle. A 50-milliliter aliquot of water from the rinse bottle was vacuum filtered onto a 4.7-centimeter, EPM 2000 filter paper, chilled on ice, and shipped to the PADEP lab in Harrisburg, Pa., for analysis of chl-a concentration.

Table 1. Water Quality Levels of Concern for Parameters Measured at Flow Monitoring Network Stations

Parameters	**Level of Concern**	**Reference Code**	**Reference**
Based on state water quality standards:			
Temperature	> 30.5 ºC	a	a. http://www.pacode.com/secure/data/025/chapter93/s93.7.html
Dissolved Oxygen	< 4 mg/l	a	b. http://www.pacode.com/secure/data/025/chapter93/s93.8c.html
pH	< 6.0	a	c. http://www.dec.ny.gov/regs/4590.html#16132
Alkalinity	< 20 mg/l	a	d. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03-3.htm
Total Chloride	> 250 mg/l	a	
Total Dissolved Solids	> 500 mg/l	c	
Total Sulfate	> 250 mg/l	a	
Total Iron	> 1500 µg/l	a	
Total Manganese	> 1000 µg/l	a	
Total Aluminum*	> 750 µg/l; > 100 µg/l	b; c	
Total Magnesium	> 35 mg/l	c	
Total Sodium	> 20 mg/l	c	
Total Suspended Solids	> 25 mg/l	a	
Turbidity	> 50 NTU	d	
Based on background levels or aquatic life tolerances:			
Conductivity	> 800 µmhos/cm	e	e. http://www.uky.edu/WaterResources/Watershed/KRB_AR/wq_standards.htm
Total Nitrogen	> 1 mg/l	f	f. http://water.usgs.gov/pubs/circ/circ1225/images/table.html
Total Nitrate/Nitrite-N	> 0.6 mg/l	f	g. http://www.uky.edu/WaterResources/Watershed/KRB_AR/krww_parameters.htm
Total Phosphorus	> 0.1 mg/l	g	h. Hem (1970)
Total Orthophosphate	> 0.02 mg/l	f	i. Based on archived data at SRBC
Total Organic Carbon	> 10 mg/l	h	
Total Hardness	> 300 mg/l	g	
Acidity	> 20 mg/l	i	
Calcium	> 100 mg/l	i	

*PA sites use > 750 µg/l standard for aluminum; NY sites use > 100 µg/l standard for aluminum

Data Analysis

Percent change in stream discharge between the two sampling rounds and ASO flow exceedance percentiles at the reference gages at the time of sampling were calculated. Habitat assessment scores from the modified RBP III were used to classify each station into a habitat condition category. Scores from 171 to 220 were designated excellent. A habitat score from 116 to 170 indicated supporting conditions, scores between 61 and 115 designated partially supporting habitat, and a score less than 60 was deemed non-supporting. Water quality was assessed by comparing field and laboratory parameter data to water quality levels of concern (see Table 1).

Non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used to visually examine relative similarity of fish and macroinvertebrate communities between stations and sampling periods. NMDS functions by mapping community dissimilarities based on taxa abundances into *n*-dimensional ordination space (Clarke, 1993). All ordinations were two-dimensional and the distances between points on the plot approximated the degree of dissimilarity in communities. Samples that plotted distantly from one another may have had few taxa in common or abundances of shared taxa may have been substantially different. Samples plotting close together had more shared taxa with similar abundances. Stress values were obtained for each ordination. Stress values less than 0.05 indicate an excellent representation with no potential for misinterpretation, values between 0.05 and 0.1 correspond to a good representation with a small chance of misinterpretation, and values between 0.1 and 0.2 indicate a potentially useful representation but with potential for misinterpretation. Stress values greater than 0.3 indicate the points are close to being arbitrarily placed in the ordination space (Clarke and Warwick, 2001). The metaMDS function in the vegan package of the R software environment was used to complete NMDS ordination (Oksanen and others, 2011).

Macroinvertebrate and fish data were used to calculate biological metrics assessing various aspects of the assemblages. Fish and macroinvertebrate metrics were taken primarily from Barbour and others (1999), the PADEP benthic macroinvertebrate index of biotic integrity (PADEP, 2012), and from TNC's report outlining ecosystem flow requirements for the Susquehanna River Basin (DePhilip and Moberg, 2010). A complete list and description of macroinvertebrate and fish metrics calculated can be found in Table 2.

Table 2. ***Description of Biological Metrics Calculated Using Data Collected At the Flow Monitoring Network Stations in 2012***

Metrics	**Description**
Macroinvertebrates	
Index of Biotic Integrity (IBI)	Multimetric biotic index developed by PADEP (2012)
Taxa Richness*	Total number of macroinvertebrate taxa identified
EPT Taxa Richness*	Total number of individuals from orders Ephemeroptera, Plecoptera, and Trichoptera
% Sensitive (PTV ≤ 3)*	Percentage of individuals that have Pollution Tolerance Values (PTV) 0 – 3
Shannon Diversity Index*	Measures taxonomic richness and evenness of individuals across taxa of a subsample
Hilsenhoff Biotic Index*	Calculated as an average of the number of individuals in a subsample weighted by PTVs
Beck's Index (version 3)*	Taxonomic richness and tolerance metric weighted by PTVs
% Dominant	Percentage represented by the dominant taxon
% Multivoltine	Percentage of multivoltine (multiple generations per year) individuals
% Desiccation Tolerant	Percentage of desiccation tolerant individuals
% Strong Adult Flying Ability	Percentage of individuals having strong adult flying ability
% Common/Abundant in Drift	Percentage of individuals common or abundant in drift
% Strong Swimmers	Percentage of individuals with strong swimming ability
% Small-bodied	Percentage of small-bodied individuals
% Free-living	Percentage of taxa not utilizing cases or other forms of substrate attachment
% Erosional	Percentage of erosional individuals
% Obligate Depositional	Percentage of obligate depositional individuals
% Shredders	Percentage of shredder individuals
% Herbivores	Percentage of herbivore taxa
% Collector-Filterers	Percentage of collector-filterer individuals
% Predators	Percentage of predator individuals
% Eurythermal	Percentage of eurythermal (wide temperature range) individuals
% Cold Stenothermal	Percentage of cold stenothermal (narrow temperature range) individuals
% Burrowers	Percentage of burrower individuals
Fish	
Species Richness	Total number of fish species identified
% Tolerant	Percentage of tolerant individuals
% Intolerant	Percentage of intolerant individuals
% Dominant	Percentage of assemblage represented by the dominant species
% Cyprinids	Percentage of assemblage represented by Cyprinidae (minnows)
% Piscivores	Percentage of piscivorous individuals
% Insectivores	Percentage of insectivorous individuals
% Generalists	Percentage of generalist individuals
% Herbivores	Percentage of herbivorous individuals
% Coldwater	Percentage of brook trout, brown trout, rainbow trout, sculpin
% Riffle Obligates	Percentage of margined madtom, longnose dace, central stoneroller, fantail darter
% Riffle Associates	Percentage of white sucker, shorthead redhorse, northern hogsucker, walleye

*IBI component metric

Periphyton biomass was assessed using chl-a concentration as a surrogate. Chl-a concentrations greater than 10 µg/cm^2 are indicative of algal growth at nuisance levels (Welch and others, 1988) and chl-a greater than 20 µg/cm^2 indicates eutrophic conditions (Paul, 2012).

RESULTS AND DISCUSSION

SRBC intends for the FMN to be a long-term project with a primary objective of documenting habitat, water quality, and biological conditions associated with various streamflows at stations throughout the Susquehanna River Basin. Determining the degree of natural variation inherent to the streams being monitored will facilitate detection of alterations in the future, including those associated with climate change.

Stream Discharge

Water year is defined as the 12-month period from October 1 of a given year through September 30 of the following year and is designated by the calendar year in which it ends. Water year 2012 in the Susquehanna River Basin was average in terms of precipitation and came on the heels of one of the wettest years on record (NOAA, 2013). No streams in the FMN exhibited ASO P95 or lower flows during the June 1 to September 30 sampling period. Table 3 lists streamflows at the FMN stations, percent change in flow between Round 1 and Round 2, flows at the reference gages, and the ASO mean exceedance percentile for the reference gages at the time sampling. Most stations experienced a reduction in streamflow between sampling rounds; however, flows were higher during Round 2 at some stations in the northern part of the basin. Percent change in streamflow ranged from a 64 percent reduction at BLLG 0.9 to an 1361 percent increase at LYSK 53.7.

Conditions were driest during Round 2 in the Central Appalachian Ridge and Valley ecoregion, particularly in the Aughwick Creek subwatershed where TSPC 0.1 and BLLG 0.9 are located. Flows were lower during Round 2 at all seven stations in this ecoregion. The ASO mean exceedance percentile at the Aughwick Creek USGS gage was close to P95 when Round 2 sampling occurred at TSPC 0.1 and BLLG 0.9 (Table 3). Three stations in the Northern Appalachian Plateau and Uplands, including LMEH 0.8, TOBE 1.9, and CATA 17.7, were sampled at a lower flow during Round 2. Flows were higher during Round 2 at CHOC 6.8,

Table 3. Measured Flow, Percent Change in Flow, and Flow and August-September-October Mean Flow Exceedance Percentile at Reference Gages at Time of Sampling

Station Name	Date Sampled	Flow (cfs)	Percent Change in Flow	Reference Gage	Flow at Reference Gage (cfs)	ASO Mean Exceedance Percentile
Central Appalachian Ridges and Valleys						
WILL 0.4	08/03/12	3.4	-41%	Tuscarora Creek (01566000)	59.0	34
WILL 0.4	09/10/12	2.0		Tuscarora Creek (01566000)	28.0	69
BOBS 11.4	08/02/12	3.6	-61%	Dunning Creek (01560000)	31.0	49
BOBS 11.4	09/12/12	1.4		Dunning Creek (01560000)	24.0	62
TSPC 0.1	07/09/12	2.7	-56%	Aughwick Creek (01564500)	20.0	58
TSPC 0.1	09/17/12	1.2		Aughwick Creek (01564500)	7.3	92
STST 26.8	08/03/12	6.7	-15%	Kishacoquillas Creek (01565000)	61.0	42
STST 26.8	09/10/12	5.7		Kishacoquillas Creek (01565000)	46.0	60
BLLG 0.9	07/09/12	10.7	-64%	Aughwick Creek (01564500)	21.0	56
BLLG 0.9	09/17/12	3.8		Aughwick Creek (01564500)	7.7	91
DUNN 0.1	07/17/12	27.4	-39%	Dunning Creek (01560000)	36.0	42
DUNN 0.1	09/12/12	16.7		Dunning Creek (01560000)	24.0	62
RAYS 80.5	07/18/12	92.3	-32%	Raystown Branch (01562000)	174.0	52
RAYS 80.5	09/13/12	62.8		Raystown Branch (01562000)	116.0	78
Northern Appalachian Plateau and Uplands						
LMEH 0.8	07/23/12	0.6	-33%	Tunkhannock Creek (01534000)	99.0	44
LMEH 0.8	09/26/12	0.4		Tunkhannock Creek (01534000)	113.0	40
TOBE 1.9	06/28/12	0.8	-38%	Canisteo River (01521500)	2.9	45
TOBE 1.9	09/24/12	0.5		Canisteo River (01521500)	2.2	58
CATA 17.7	06/29/12	8.2	-59%	Fall Creek (04234000)	28.0	60
CATA 17.7	09/25/12	3.4		Fall Creek (04234000)	28.0	60
CHOC 6.8	07/24/12	4.9	90%	Tunkhannock Creek (01534000)	498.0	8
CHOC 6.8	09/25/12	9.3		Tunkhannock Creek (01534000)	120.0	38
TUSC 11.0	06/25/12	2.0	50%	Tuscarora Creek (01525981)	4.5	52
TUSC 11.0	09/24/12	3.0		Tuscarora Creek (01525981)	7.7	42
SBTK 7.1	07/23/12	15.6	26%	Tunkhannock Creek (01534000)	102.0	43
SBTK 7.1	09/26/12	19.6		Tunkhannock Creek (01534000)	113.0	40
North Central Appalachians						
GRYS 2.2	07/10/12	3.7	238%	Lycoming Creek (01550000)	32.0	63
GRYS 2.2	10/04/12	12.5		Lycoming Creek (01550000)	141.0	17
UPIN 6.1	07/19/12	2.0	-35%	Kettle Creek (01544500)	21.0	64
UPIN 6.1	10/02/12	1.3		Kettle Creek (01544500)	23.0	61
LYSK 53.7	07/10/12	1.8	1361%	Muncy Creek (01552500)	3.0	80
LYSK 53.7	10/04/12	26.3		Muncy Creek (01552500)	27.0	17
BAKR 0.1	07/13/12	6.6	100%	Kettle Creek (01544500)	11.0	50
BAKR 0.1	10/01/12	13.2		Kettle Creek (01544500)	35.0	19
DRFT 2.0	07/02/12	10.5	29%	Driftwood Branch (01543000)	39.0	58
DRFT 2.0	10/01/12	13.5		Driftwood Branch (01543000)	69.0	39
KTTL 23.6	07/16/12	14.7	-27%	Kettle Creek (01544500)	32.0	49
KTTL 23.6	10/02/12	10.8		Kettle Creek (01544500)	23.0	61

TUSC 11.0, and SBTK 7.1. Only two stations in the North Central Appalachians, UPIN 6.1 and KTTL 23.6, had lower flows during Round 2. Flows were much higher at GRYS 2.2, LYSK 53.7, and BAKR 0.1 during Round 2 due to rainfall in the days prior to sampling.

There are fewer USGS stream gages located in the Northern Appalachian Plateau and Uplands ecoregion compared to the others sampled, which made selection of appropriate reference gages for the stations in this ecoregion difficult. Data collected in 2012 suggest that flows at the reference gages used for LMEH 0.8, CATA 17.7, and CHOC 6.8 correlate poorly with flows at the stations themselves. In order to better coordinate timing of sampling, SRBC installed InSitu, Inc. Level TROLL pressure transducers at all FMN stations in 2012 for the purpose of continuously recording water depth. The pressure transducers at nine of the 19 stations report real-time data via the RWQMN satellite system. Data stored internally by the other ten pressure transducers will be downloaded at regular intervals by SRBC staff for the duration of the FMN project. SRBC staff will also visit the FMN stations at least every six to eight weeks to take stream discharge measurements across a wide range of water depths. When paired with instantaneous discharge measurements, the water depth measurements from the pressure transducers can be used to build rating curves and provide a continuous streamflow record for each station. Once rating curves are developed, the nine real-time pressure transducers will act as reference gages for their associated FMN stations. Although the other ten transducers cannot act as real-time references, the continuous flow record they will provide can be used to develop correlations between flows at the stations and the best available USGS reference gage, which will improve timing of sampling rounds. Having a continuous flow record will also allow for better correlation between flow and the measured habitat, water quality, and biological parameters by providing a complete flow "history" between sampling rounds.

Habitat

Habitat conditions were generally very good at all stations. This was expected because the stations were selected based on historical records of non-impaired conditions from previous SRBC field surveys (Buda, 2007; Campbell, 2011; Hintz, 2012; Campbell, 2013). All stations were categorized as having either excellent or supporting habitat during both sampling rounds except for CATA 17.7, which was designated as partially supporting during Round 2.

All stations in the Central Appalachian Ridge and Valley ecoregion except for BOBS 11.4 were designated as having supporting habitat during both sampling rounds. Habitat at

BOBS 11.4 scored excellent during Round 1 and supporting during Round 2. Stream discharge was lower at BOBS 11.4 during Round 2, resulting in decreases in habitat condition factor scores related to flow, including epifaunal substrate, embeddedness, velocity/depth regimes, channel flow status, and frequency of riffles.

The Northern Appalachian Plateau and Uplands stations generally had lower habitat scores than stations in the Central Appalachian Ridges and Valleys and North Central Appalachians. Watersheds in this ecoregion have more agriculture and less forested lands (see Appendix A), as well as glacial geology that often creates shallow stream channels with highly mobile, unconsolidated substrate, and generally poor instream habitat (Rogers and others, 1999). All Northern Appalachian Plateau and Uplands stations were designated as supporting during both sampling rounds except for SBTK 7.1 and CATA 17.7. SBTK 7.1 scored excellent during both sampling rounds, while CATA 17.7 received a score of partially supporting during Round 2. Similar to the trend observed at BOBS 11.4, stream discharge was lower at CATA 17.7 during Round 2 with decreases in flow-dependent condition factors including velocity/depth regimes, sediment deposition, and channel flow status. Impacts from agriculture may have also contributed to low habitat scores at CATA 17.7. Although there is a narrow, mature forested buffer bordering the CATA 17.7 sampling reach, there are crops growing along the right bank and cattle pastured along the left bank, both of which could potentially increase sedimentation in the stream.

Stations located in the North Central Appalachians ecoregion tended to have better habitat than stations located in the other ecoregions, most likely due to the high percentage of forested lands in these watersheds (see Appendix A). All North Central Appalachian stations except for LYSK 53.7 and DRFT 2.0 scored excellent during both sampling rounds. LYSK 53.7 received scores in the supporting category during both sampling rounds, while DRFT 2.0 received a supporting score during Round 1 and an excellent score during Round 2. Stream discharge was slightly higher at DRFT 2.0 during Round 2, resulting in increases in scores for habitat condition factors closely tied to flow such as velocity/depth regime, sediment deposition, and channel flow status.

Water Quality

Water quality was generally good among the FMN stations. Although levels of concern were exceeded for some parameters, in most cases the exceeding values were only slightly higher than natural background levels. Table 4 lists stations where water quality levels of concern were exceeded. The parameters that most often exceeded levels of concern included total nitrogen (10 stations), total nitrate/nitrite-N (six stations), and total alkalinity (six stations). The only other parameters that exceeded levels of concern were total sodium (three stations) and total orthophosphate (two stations). Levels of concern for total nitrogen, total nitrate/nitrite-N, and total orthophosphate are based on natural background concentrations rather than state or federal water quality standards because neither Pennsylvania nor New York have developed numeric standards for nutrients. Total nitrogen greater than 1.0 mg/L, total nitrate/nitrite-N greater than 0.6 mg/L, and total orthophosphorus greater than 0.02 mg/L indicate enrichment above background levels. Pennsylvania has numeric water quality standards for total alkalinity and total sodium. Total alkalinity less than 20 mg/L and total sodium greater than 20 mg/L indicate possible impairment.

The highest levels of total nitrogen and total nitrate/nitrite-N were found at stations in the Central Appalachian Ridge and Valley ecoregion (Table 4). The highest total nitrogen value (5.12 mg/L) was observed at RAYS 80.5 during the first sampling round. Total nitrate/nitrite-N was highest (1.34 mg/L) at RAYS 80.5 during Round 2. Common sources of nitrogen compounds include fertilizers, livestock waste, wastewater treatment and septic systems, detergents, and industrial discharges. Major sources of water quality impairment in the Juniata River Subbasin, which encompasses all of the Central Appalachian Ridge and Valley stations, include agriculture (general, crop, and animal), AMD, combined sewer overflows, urban and residential runoff, industrial and municipal point sources, road runoff, and construction activities. Total alkalinity was less than 20 mg/L at BOBS 11.4 and was also low at STST 26.8 (29 mg/L during both sampling rounds). Total alkalinity averaged 110 mg/L across the other five stations in this ecoregion. The much lower total alkalinity values observed at BOBS 11.4 and STST 26.8 are most likely due to underlying geologic formations with poor buffering capacity. There are no obvious sources of acidity in either watershed. The BOBS 11.4 alkalinity data are consistent with data collected as part of the RWQMN. The continuous RWQMN data also show periodic spikes in specific conductance at BOBS 11.4 that are currently not attributable to any known causes (Hintz, 2012).

Based upon the parameters measured, stations located in the Northern Appalachian Plateau and Uplands ecoregion had slightly higher water quality than those located in the North Central Appalachian and Central Appalachian Ridge and Valley ecoregions (Table 4). Stations in this ecoregion had the fewest instances of parameters exceeding water quality levels of concern. Two stations, LMEH 0.8 and CHOC 6.8, did not have any parameters exceed water quality levels of concern during either sampling round. Total sodium levels were slightly higher than water quality levels of concern at TOBE 1.9, TUSC 11.0, and SBTK 7.1. Possible sources of sodium include urbanization, road salt runoff, and natural gas wells, as well as natural salt deposits which could be mobilized when stream banks erode. CATA 17.7 exhibited slightly elevated levels of total nitrogen and nitrate/nitrite-N, which is unremarkable given that immediate land use at this station is agricultural. Total nitrogen was also elevated at TUSC 11.0. Surrounding land use at this station is also agricultural. Water quality findings in this ecoregion are consistent with observations from previous (Buda, 2007) and concurrent SRBC surveys (Campbell, 2013).

The highest incidence of parameters exceeding water quality levels of concern occurred at stations in the North Central Appalachians ecoregion (Table 4). These stations are all situated in the West Branch Susquehanna River Subbasin, which has a long history of water quality degradation, primarily due to AMD. AMD typically impacts water quality by increasing acidity (decreasing pH and alkalinity) and metals, particularly iron, aluminum, manganese, and sulfate (Kimmel, 1983). Acidic atmospheric deposition, most often related to the burning of fossil fuels, is another common problem in the West Branch. Streams impacted by acid deposition tend to have low pH and elevated aluminum levels (Sharpe and others, 1984). Although pH and metals were within the acceptable range at all stations in the North Central Appalachians, alkalinity was less than 20 mg/L at all stations except UPIN 6.1. In addition to low alkalinity, all stations in this ecoregion had at least one instance of elevated total nitrogen (Table 4).

Table 4. *Flow Monitoring Stations with Water Quality Parameter Values Exceeding Levels of Concern (Most Extreme Value in Bold Print)*

Station Name	Date	Total Alkalinity (mg/L)	Total Nitrate/ Nitrite-N (mg/L)	Total Nitrogen (mg/L)	Total Ortho-phosphorus (mg/L)	Total Sodium (mg/L)
Central Appalachian Ridges and Valleys						
BOBS 11.4	08/02/12	16				
BOBS 11.4	09/12/12	18				
TSPC 0.1	07/09/12		1.06	1.06		
DUNN 0.1	07/17/12		0.94		**0.027**	
RAYS 80.5	07/18/12		1.22	**5.12**		
RAYS 80.5	09/13/12		**1.34**	1.34		
Northern Appalachian Plateau and Uplands						
TOBE 1.9	09/24/12					20.1
CATA 17.7	06/29/12		1.03	1.03		
CATA 17.7	09/25/12		0.77			
TUSC 11.0	06/28/12					**28.3**
TUSC 11.0	09/24/12			1.4		27
SBTK 7.1	07/23/12					20.6
SBTK 7.1	09/26/12					20.8
North Central Appalachians						
GRYS 2.2	07/10/12	7				
GRYS 2.2	10/04/12	6		1.24		
UPIN 6.1	07/19/12		0.76			
UPIN 6.1	10/02/12			1.69		
LYSK 53.7	07/10/12	15				
LYSK 53.7	10/04/12	5		1.5	0.023	
BAKR 0.1	07/13/12	**4**		1.87		
BAKR 0.1	10/01/12	5		1.1		
DRFT 2.0	07/02/12	13				
DRFT 2.0	10/01/12	15		1.1		
KTTL 23.6	07/16/12	18				
KTTL 23.6	10/02/12	18	1.19	2.39		

Macroinvertebrates

Non-metric multidimensional scaling (NMDS) using Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used to visually examine relative similarity of macroinvertebrate communities between stations and sampling rounds (Figure 2). The stress value for the ordination was 0.218, indicating that the placement of stations on the plot may be somewhat misleading and that interpretations made based on the plot should be regarded with caution. Stations from the Central Appalachian Ridge and Valley and Northern Appalachian Plateau and Uplands ecoregions broadly grouped together while the stations in the North Central Appalachians were more spread out. Five out of six stations in the Northern Appalachian Plateau and Uplands are loosely grouped together based on sampling round. SBTK 7.1 was the exception to this grouping. The sample from Round 1 plotted with the rest of the ecoregion's Round 2 samples. The samples from Rounds 1 and 2 plotted close together at several stations, including UPIN 6.1, LYSK 53.7, BAKR 0.1, WILL 0.4, and RAYS 80.5. Samples from DUNN 0.1 and RAYS 80.5 plotted close to one another, indicating that the communities inhabiting these much larger streams may be different. The River Continuum Concept (Vannote and others, 1980) suggests that a progressive shift in structural and functional attributes of the macroinvertebrate community occurs as stream size increases due to shifts in the type and location of food resources.

Twenty-five biological metrics were calculated using macroinvertebrate data collected at the FMN stations. These metrics were primarily taken from the TNC ecosystem flows report, which identified functional trait and general assemblage metrics that may potentially detect changes in the macroinvertebrate community resulting from lowered flows (DePhilip and Moberg, 2010). PADEP's benthic macroinvertebrate IBI was also calculated (PADEP, 2012).

Based upon the data collected in 2012, the majority of macroinvertebrate metrics exhibited patterns related to sampling round, with metric values consistently higher during either Round 1 or Round 2 (Table 5). These patterns were observed across ecoregions and drainage area sizes. Percent eurythermal, percent cold stenothermal, percent small-bodied, and percent erosional exhibited the strongest patterns (Figure 3). The percentage of cold stenothermal individuals was higher during Round 1 at 95 percent of stations while percentage of eurythermal individuals was higher during Round 2 at 95 percent of stations. RAYS 80.5 was the single exception, demonstrating opposite patterns for these metrics. The percentage of small-bodied individuals was higher during Round 1 at 84 percent of stations, with exceptions at WILL 0.4, CATA 17.7, and CHOC 6.8. Percent erosional was higher at 79 percent of stations during Round 2. CATA 17.7, SBTK 7.1, BAKR 0.1, and KTTL 23.6 exhibited the opposite pattern for percent erosional.

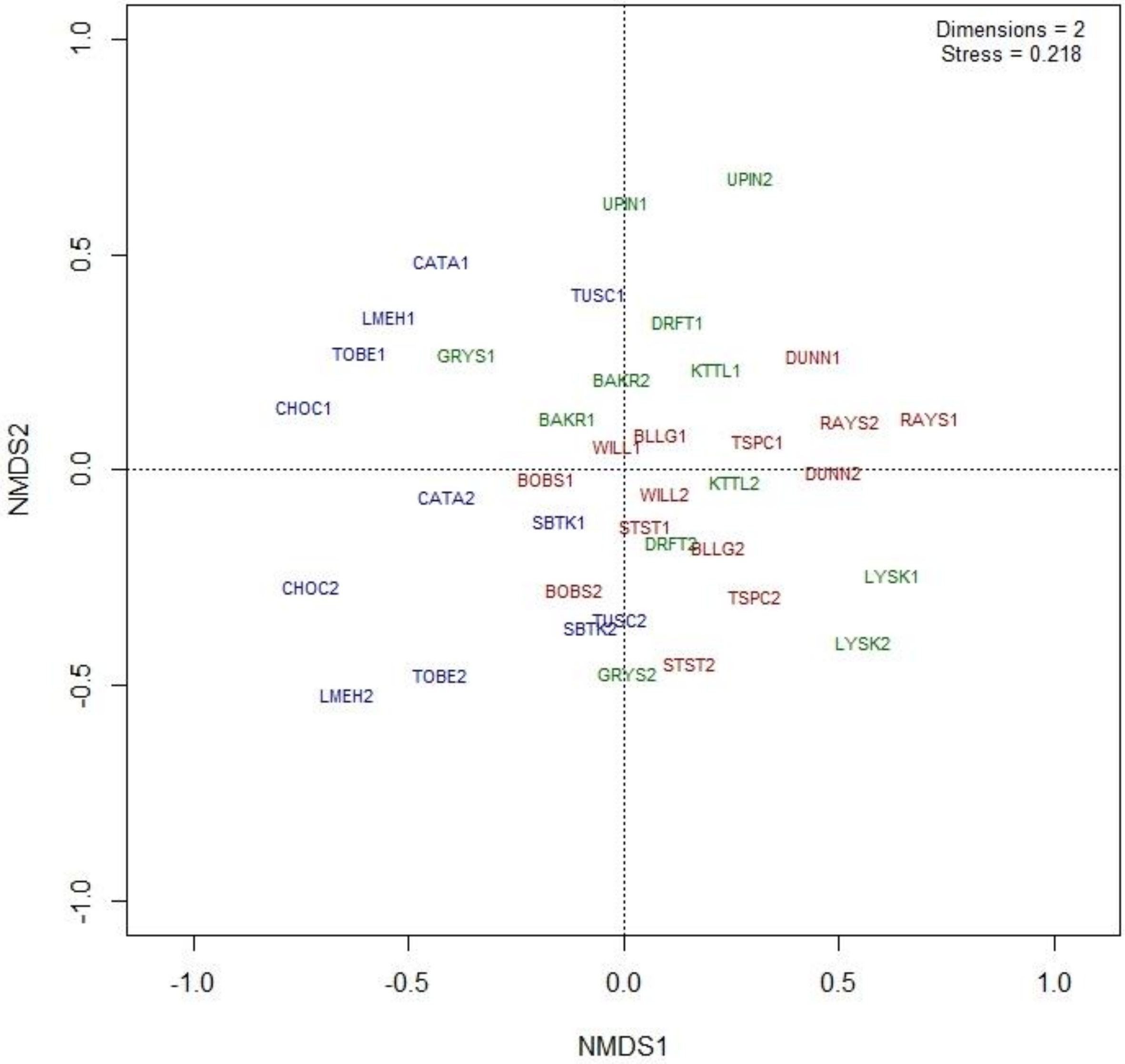

Figure 2. ***NMDS Ordination Plot Depicting Relative Similarity of Macroinvertebrate Communities Among FMN Stations (Central Appalachian Ridge and Valley stations shown in red text; Northern Appalachian Plateau and Uplands stations shown in blue text; North Central Appalachian stations shown in green text. Sampling round indicated by "1" or "2" following the four-letter stream name abbreviation.)***

Other metrics that demonstrated distinct sampling round trends (more than 60 percent of stations with values higher during one sampling round) included percent multivoltine, percent desiccation tolerant, percent strong adult flyers, percent free-living, percent shredders, percent collector-filterers, and percent burrowers (Table 5). Percent dominant, percent common/abundant in drift, percent strong swimmers, percent herbivores, and percent predators showed a sampling round trend at 50 to 60 percent of stations. The only metrics that had no apparent sampling round trend included percent obligate depositional and percent burrower taxa; however, these taxa made up only a small proportion of the taxa collected across stations (0 – 18 percent of sample). Shredder taxa were also infrequently collected (0 – 17 percent of sample).

The PADEP IBI measures the degree to which a set of community-level biological attributes differ at sites of interest compared to a "reference" condition. In this context, reference condition refers to a state of natural biotic structure and function in the absence of significant human disturbance or alteration (Stoddard and others, 2006). The IBI is a multimetric index that incorporates information from six individual metrics into a single measure of overall biological condition. PADEP's IBI considers streams with drainage area less than 25 square miles, between 25 and 50 square miles, and greater than 50 square miles separately when calculating IBI scores; however, score interpretation is the same across size classes. For macroinvertebrate samples collected between June and September, IBI scores less than 43 indicate aquatic life use (ALU) impairment. Samples scoring greater than or equal to 43 are subject to four screening questions before ALU attainment/impairment can be determined. The first screening question addresses absence of mayflies, stoneflies, and/or caddisflies, the second addresses scores for the individual metrics Beck's Index and Percent Sensitive Individuals, the third question deals with the ratios of tolerant to intolerant taxa, and the fourth flags signatures of acidification (i.e., low mayfly abundance and diversity, and high abundance of *Amphinemura* and *Leuctra* stoneflies). If a sample fails any of the screening questions, the sample may be considered impaired without compelling reason otherwise (PADEP, 2012).

Table 5. Summary of Macroinvertebrate Metric Trends For Flow Monitoring Network Station Samples (Red Bolded Text Indicates the Dominant Trend for Each Metric.)

	Higher Round 1		Higher Round 2		Same Both Rounds	
Metric	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**
% Dominant	10	**53%**	9	47%	0	0%
% Multivoltine	13	**68%**	6	32%	0	0%
% Desiccation Tolerant	14	**74%**	4	21%	1	5%
% Strong Adult Flyers	6	32%	13	**68%**	0	0%
% Common/Abundant in Drift	10	**53%**	8	42%	1	5%
% Strong Swimmers	8	42%	11	**58%**	0	0%
% Small-bodied	16	**84%**	3	16%	0	0%
% Free-living	12	**63%**	6	32%	1	5%
% Erosional	4	21%	15	**79%**	0	0%
% Obligate Depositional	6	32%	4	21%	9	**47%**
% Shredders	13	**68%**	3	16%	3	16%
% Herbivores	8	42%	10	**53%**	1	5%
% Collector-Filterers	4	21%	14	**74%**	1	5%
% Predators	10	**53%**	8	42%	1	5%
% Eurythermal	1	5%	18	**95%**	0	0%
% Cold Stenothermal	18	**95%**	1	5%	0	0%
% Burrowers	2	11%	5	26%	12	**63%**

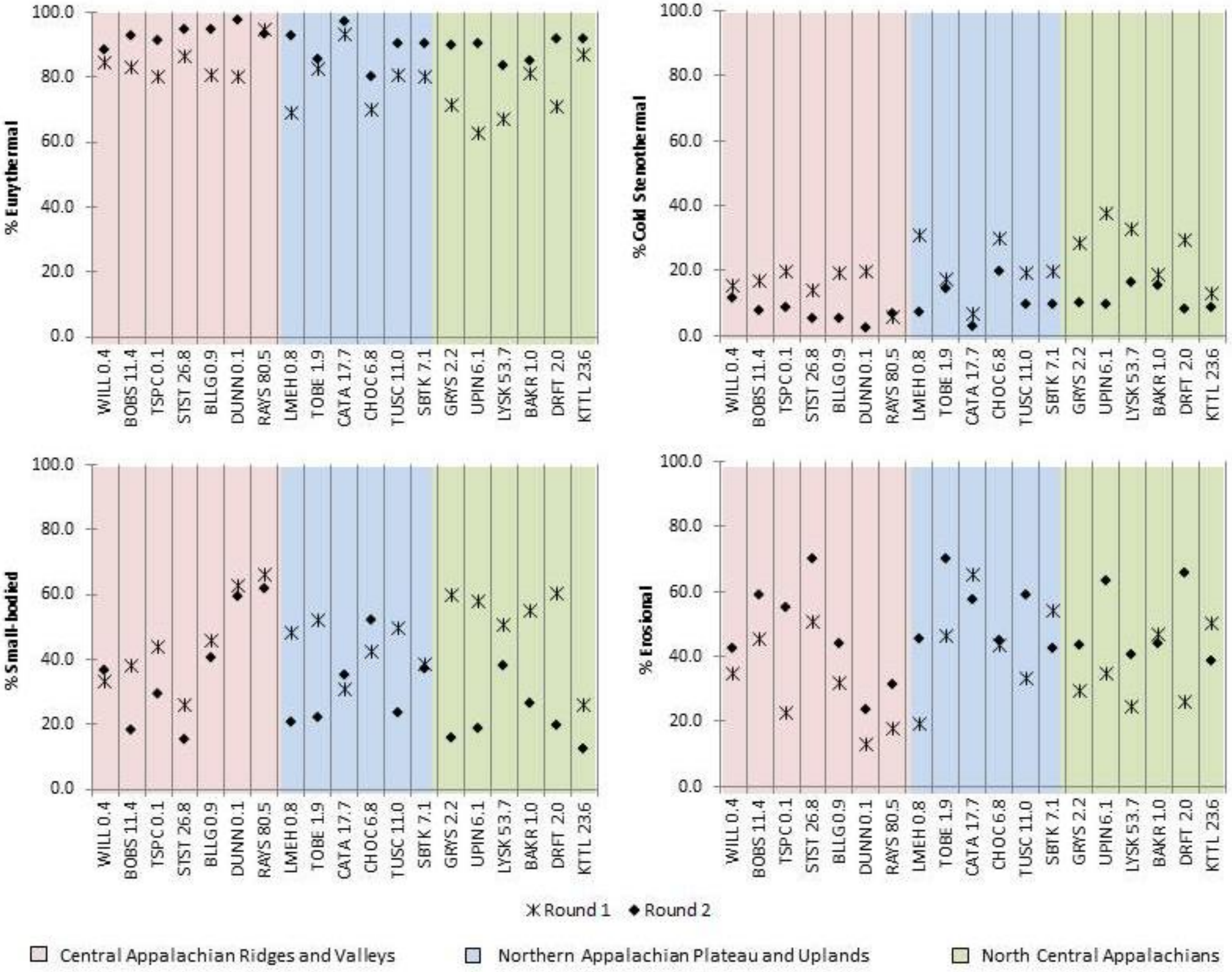

Figure 3. ***Percent Eurythermal, Percent Cold Stenothermal, Percent Small-Bodied, and Percent Erosional Individuals Found in Macroinvertebrate Samples Collected From the Flow Monitoring Network Stations***

Seven stations in the FMN are designated high-quality (HQ) or exceptional value (EV) waters (25 Pa. Code § 93.9), including WILL 0.4, BOBS 11.4, STST 26.8, GRYS 2.2, UPIN 6.1, BAKR 0.1, and KTTL 23.6 (see Appendix A). The ALU assessment process for streams with special protection designated uses differs slightly from the standard process described above (PADEP, 2012). First, PADEP will only make assessment decisions for HQ and EV based on samples collected November to May because macroinvertebrate taxonomic richness is highest during this time period. Any sample from an HQ or EV stream that scores less than 63 on the IBI is considered impaired without compelling reason otherwise. Determination of ALU attainment for HQ and EV streams is made by comparing the current IBI score to a baseline score from previous surveys, when available. Samples scoring more than 10 points below the baseline score are considered impaired. Because the FMN stations were not sampled between November and May, ALU attainment cannot be reliably determined for HQ and EV stations. Therefore, IBI scores for these stations serve primarily as points of comparison between sampling rounds.

Figure 4 summarizes the benthic macroinvertebrate IBI scores from samples collected at the FMN stations in 2012. No samples were designated impaired based solely on IBI score during either sampling round, although some samples failed based on the subsequent screening questions. RAYS 80.5, CATA 17.7, TUSC 11.0, and SBTK 7.1 failed at least one screening question during Round 1 while TOBE 1.9, CHOC 6.8, and TUSC 11.0 failed at least one screening question during Round 2. DUNN 0.1 failed to meet the requirements of at least one screening question during both sampling rounds. This indicates that despite receiving numerical IBI scores ≥ 43, the macroinvertebrate communities at DUNN 0.1, RAYS 80.5, CATA 17.7, CHOC 6.8, TUSC 11.0, and SBTK 7.1 may be impaired. All of these stations except CHOC 6.8 had nutrients and/or sodium concentrations exceeding levels of concern during one or both sampling rounds (see Table 4).

Water pollution, especially nutrient inputs, can inhibit colonization by sensitive macroinvertebrate taxa. Other sources of impairment include poor habitat conditions, particularly in the Northern Appalachian Plateau and Uplands ecoregion. Sweeney (1993) proposed that the presence of a forested buffer may be the single most important factor affecting the diversity and function of stream macroinvertebrate communities. The forest canopy shades a stream during the hot summer months, helping to regulate water temperature and provide refugia for coldwater taxa. Fallen trees and branches, as well as the root structures of living riparian trees, provide complex instream habitat for colonizing macroinvertebrates. Finally, streamside vegetation provides an allochthonous source of nutrients in the form of particulate plant structures (i.e., leaves, fruits, woody debris). Of the three ecoregions sampled, the Northern Appalachian Plateau and Uplands stations were located in watersheds with the lowest average percentage of forested lands while the North Central Appalachian watersheds had the highest average percent forested. The stations located in the North Central Appalachians ecoregion had consistently high IBI scores despite all stations having at least one water quality parameter that exceeded levels of concern during both sampling rounds, supporting the hypothesis that the presence of a forested buffer positively influences the macroinvertebrate community.

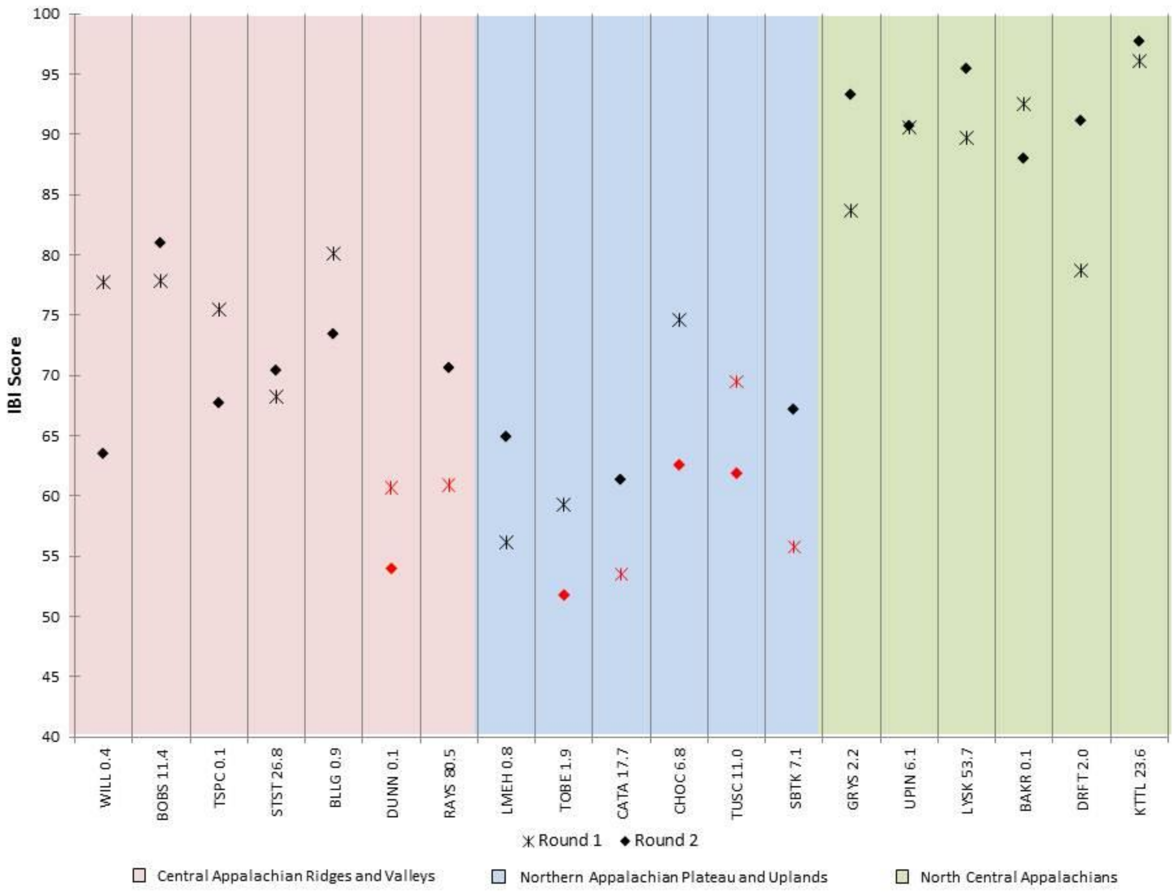

Figure 4. ***Index of Biotic Integrity Scores for Macroinvertebrate Samples Collected From the Flow Monitoring Network Stations in 2012 (Red Symbols Indicate Samples Failing At Least One Screening Question.)***

IBI scores were lower during Round 1 than Round 2 at 58 percent of stations (Table 6). Of the six IBI component metrics, taxa richness, Hilsenhoff Biotic Index (HBI), Shannon Diversity Index, and Beck's Index were higher during Round 1 at the majority (greater than 63 percent) of stations. Percent sensitive scores showed the opposite trend and were higher during Round 2 at 74 percent of stations. There was no distinct pattern in EPT taxa richness related to sampling round (Table 6).

Table 6. Summary of IBI Component Metric Trends For Flow Monitoring Network Station Samples (Red Bolded Text Indicates the Dominant Trend for Each Metric.)

	Higher Round 1		Higher Round 2		Same Both Rounds	
Metric	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**
Index of Biotic Integrity	8	42%	11	**58%**	0	0%
Taxa Richness*	13	**68%**	5	26%	1	5%
EPT Taxa Richness*	8	42%	8	42%	3	16%
Percent Sensitive (PTV ≤ 3)*	5	26%	14	**74%**	0	0%
Hilsenhoff Biotic Index*	15	**79%**	4	21%	0	0%
Shannon Diversity Index*	13	**68%**	6	32%	0	0%
Beck's Index (version 3)*	12	**63%**	7	37%	0	0%

The sampling round trends observed for the majority of the macroinvertebrate metrics calculated may be indicative of a seasonal difference in macroinvertebrate community composition. Lotic macroinvertebrate communities in most habitats exhibit a predictable temporal sequence of species replacement that is primarily driven by shifts in food sources (Cummins, 1974). Autotrophic production forms the major food base in the spring and summer months while detritus inputs from the riparian area support fall and winter communities (Coffman and others, 1971; Minshall, 1978). While developing the IBI, PADEP (2012) found that a transition occurs in Pennsylvania macroinvertebrate communities beginning in mid-October. This seasonal difference in community composition led the agency to outline separate IBI scoring systems for samples collected between November and May and June and September (PADEP, 2012). The agency also recommended that macroinvertebrate sampling in October be avoided due to the transitional nature of the community at this time of the year. Although both rounds of sampling at the FMN stations took place within the June to September timeframe, it is possible that changing climate trends could be causing the natural transition in the macroinvertebrate community to occur earlier. In that case, differences in macroinvertebrate communities detected between sampling rounds could be due to a seasonal shift in taxonomic composition.

Fish

NMDS using Bray-Curtis dissimilarity (Bray and Curtis, 1957) was used to visually examine relative similarity of fish communities between stations and sampling rounds (Figure 5). The stress value for the ordination was 0.163, indicating a potentially useful representation but with some potential for misinterpretation. The fish community NMDS plot showed a conspicuous pattern with samples from the same station plotting next to one another. There was also a pattern related to drainage area with the smallest stations (less than 25 square miles) appearing on the far left side of the plot, the medium-sized stations (25 – 50 square miles) plotting in the middle, and large stations (greater than 50 square miles) appearing on the far right. Ecoregion seemed to play a lesser role in fish community similarity compared to what was observed for the macroinvertebrate community (see Figure 2).

The TNC ecosystem flows report identified five groups of fish species that share life history strategies, habitat niches, or other characteristics that may make them sensitive to flow alterations (DePhilip and Moberg, 2010). Of these five groups, three are particularly sensitive to low flows, including riffle obligates, riffle associates, and coldwater species. Proportions of these three groups, as well as nine other metrics examining general assemblage composition or feeding guilds, were calculated.

Based upon the data collected in 2012, the majority of fish metrics exhibited patterns related to sampling round, with metric values higher during either Round 1 or Round 2 (Table 7). Unlike what was observed for the macroinvertebrate metrics, these patterns were not always consistent across ecoregions and drainage area sizes. The percent dominant and percent insectivores metrics exhibited the strongest sampling round patterns (Figure 6). Both percent dominant and percent insectivores were higher during Round 1 (84 percent and 74 percent of stations, respectively).

Other metrics that demonstrated distinct trends (more than 60 percent of stations with values higher during one sampling round) included percent cyprinids, percent coldwater species, and percent riffle associates (Table 7). Percent tolerant, percent intolerant, percent feeding generalists and percent riffle obligates showed a sampling round trend at more than 50 percent of stations. Two metrics, species richness and percent piscivores, had no apparent sampling round trends. Percent tolerant, percent intolerant, percent cyprinids, percent insectivores, percent feeding generalists, percent herbivores, and percent coldwater demonstrated patterns similar to what was observed between baseline (June/July) flow and low flow (August/September) sampling periods during the Low Flow Monitoring Pilot Study (Hutchison, 2012). This suggests that these metrics may exhibit a seasonal pattern and that differences observed during the Pilot Study were not necessarily attributable to differences in flow.

Although stream fish assemblages tend to be relatively stable in terms of species composition and relative abundance, they sometimes show considerable unpredictable temporal variation (Schlosser, 1990). Taylor and others (1996) found that spring and fall fish assemblages in the upper Red River basin of Oklahoma differed from one another in terms of species composition, relative abundance, and habitat usage. In the spring, the fish assemblage underwent a series of rapid shifts corresponding to a series of high flow events. In the fall, flows were much lower and more stable, and the fish assemblage was less variable. Taylor and others (1996) also noted strong spatial aggregations of minnow species in pools during the fall while no such aggregations occurred in the spring. Matthews and Hill (1980) reported similar large aggregations of minnows during fall surveys of the South Canadian River in Oklahoma. Percentage of minnows was higher during low flow than baseline flow at 94 percent of stations sampled for the Low Flow Monitoring Pilot Study in 2010 (Hutchison, 2012). In the Pilot Study report, this difference was attributed to sampling bias associated with small fish being easier to see and capture when flows are lower, and to the migration of more mobile larger fish into more suitable habitats as wetted area in the sampling reach decreased. However, a similar pattern was observed for this metric in 2012 despite it being a “normal” flow year. Percentage of minnows was higher during Round 2 (analogous to the low flow sampling in 2010) than Round 1 (analogous to the baseline sampling period in 2010) at 68 percent of FMN stations sampled in 2012 (Table 7). Studies by Taylor and others (1996) and Matthews and Hill (1980) indicate that certain minnow species may exhibit this fall aggregative behavior regardless of flow.

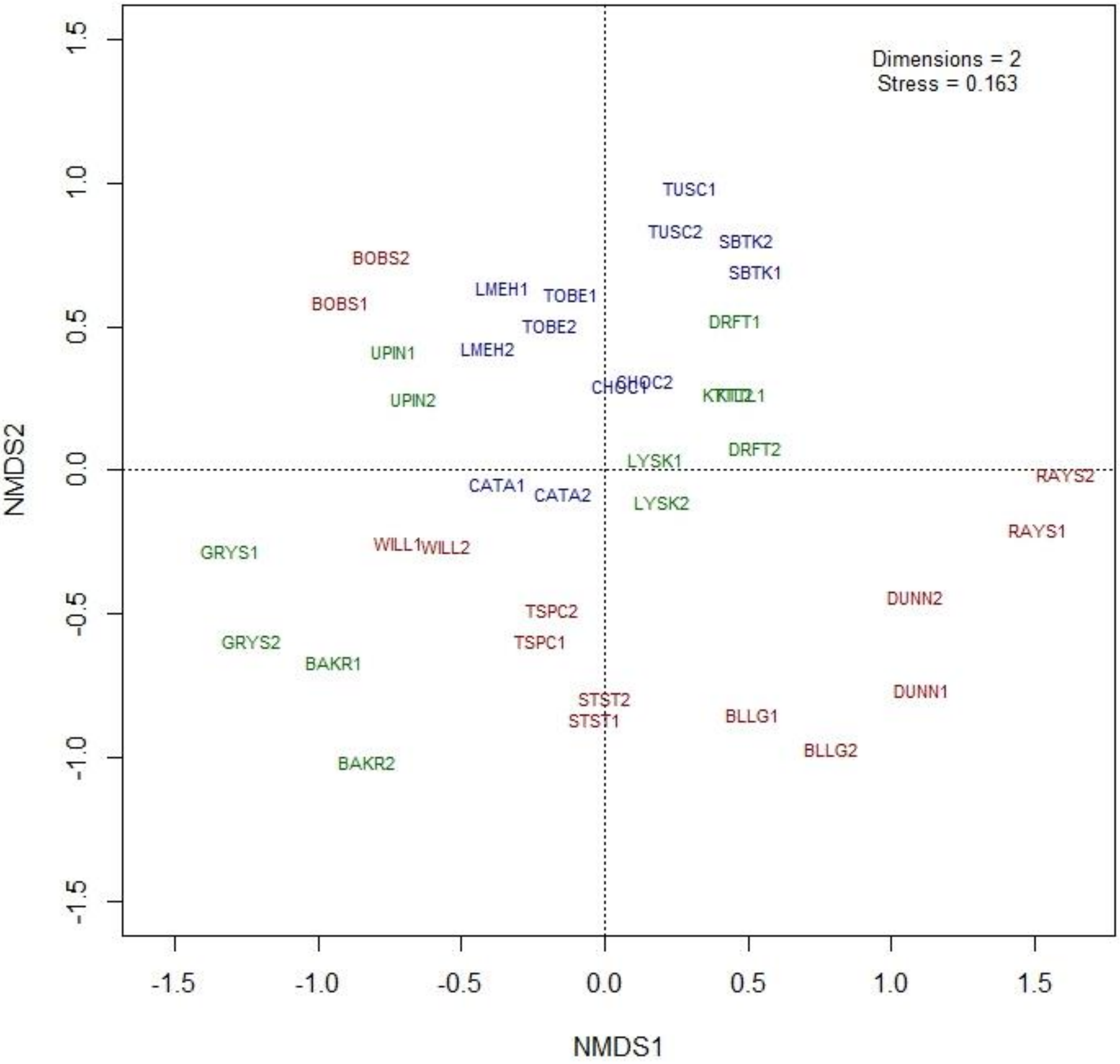

Figure 5. ***NMDS Ordination Plot Depicting Relative Similarity of Fish Communities Among FMN Stations (Central Appalachian Ridge and Valley stations shown in red text; Northern Appalachian Plateau and Uplands stations shown in blue text; North Central Appalachian stations shown in green text. Sampling round indicated by "1" or "2" following the four-letter stream name abbreviation.)***

Table 7. Summary of Fish General Assemblage and Functional Trait Metric Trends For Flow Monitoring Network Station Samples (Red Bolded Text Indicates the Dominant Trend for Each Metric.)

	Higher Round 1		Higher Round 2		Same Both Rounds	
Metric	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**	**Number of Stations**	**Percentage of Stations**
Species Richness	9	47%	6	32%	4	21%
% Tolerant	8	42%	11	**58%**	0	0%
% Intolerant	11	**58%**	8	42%	0	0%
% Dominant	16	**84%**	3	16%	0	0%
% Cyprinids	4	21%	13	**68%**	2	11%
% Piscivores	6	32%	9	47%	3	16%
% Insectivores	14	**74%**	5	26%	0	0%
% Feeding Generalists	8	42%	10	**53%**	1	5%
% Herbivores	2	11%	11	**58%**	6	32%
% Coldwater	12	**63%**	2	11%	5	26%
% Riffle Obligates	8	42%	11	**58%**	0	0%
% Riffle Associates	3	16%	13	**68%**	3	16%

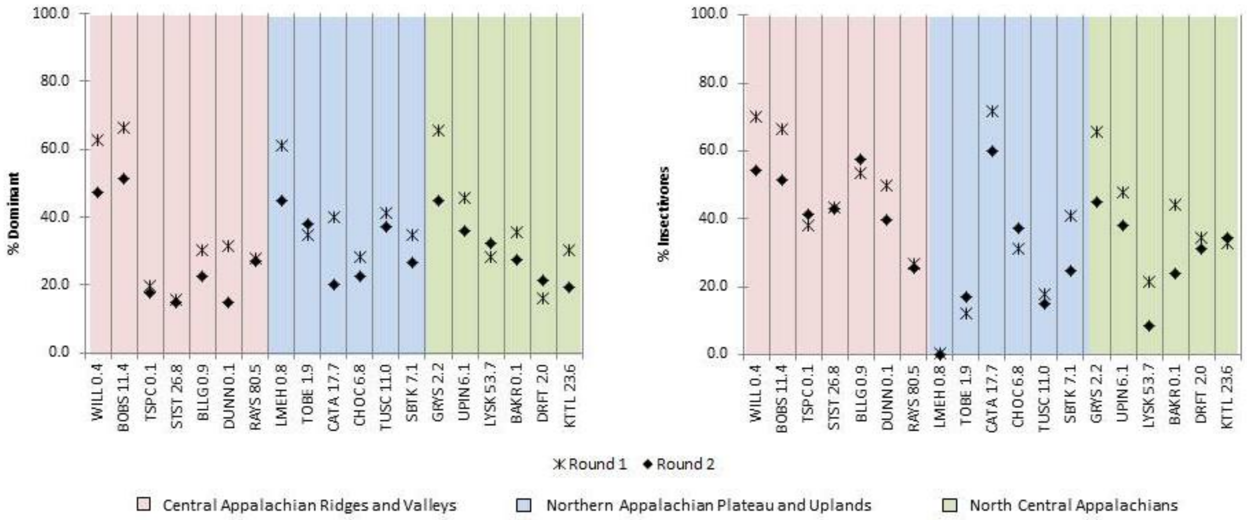

Figure 6. Percent Dominant Species and Percent Insectivores Found in Fish Samples Collected From the Flow Monitoring Network Stations

Periphyton Biomass

Chl-a concentration is widely used as a surrogate for live periphyton biomass because it is the most common pigment in oxygenic photosynthesis. It is found in higher plants as well as algae. Periphyton chl-a concentrations greater than 10 μg/cm^2 in streams are indicative of algal growth at nuisance levels (Welch, 1988) and chl-a greater than 20 μg/cm^2 indicates eutrophic conditions (Paul, 2012). Stream discharge, disturbance events, level of nutrient enrichment, light availability, and abundance of herbivores are the primary factors influencing algal biomass in lotic systems. Previous studies demonstrated seasonal changes in algal biomass ranging from many-fold to several orders of magnitude (Duncan and Blinn, 1989; Fisher and Grimm, 1988).

Periphyton biomass was higher during Round 2 at 90 percent of stations, often by several orders of magnitude (Figure 7). Only STST 26.8, RAYS 80.5, and LYSK 53.7 had chl-a concentrations that did not exceed the nuisance level. Concentrations occurred above nuisance levels at LMEH 0.8 and CHOC 6.8, and occurred above the eutrophic level at TSPC 0.1 during Round 1. During Round 2, WILL 0.4, BOBS 11.4, BLLG 0.9, DUNN 0.1, TOBE 1.9, CATA 17.7, TUSC 11.0, BAKR 0.1, and KTTL 23.6 had chl-a concentrations above 10 µg/cm^2. TSPC 0.1, LMEH 0.8, CHOC 6.8, SBTK 7.1, UPIN 6.1, and DRFT 2.0 had chl-a concentrations above the eutrophic level during Round 2.

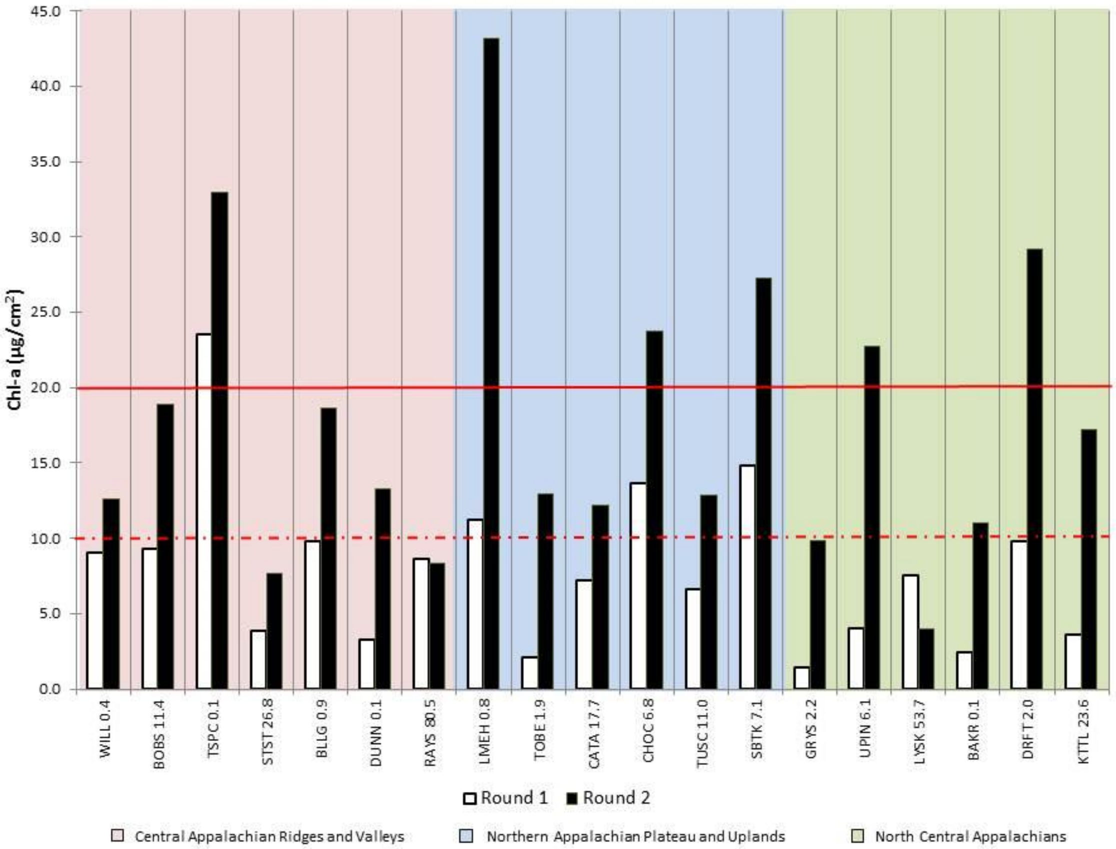

Figure 7. ***Chlorophyll-a Concentrations at the Flow Monitoring Network Stations (Dashed Red Line Indicates Nuisance Level of Algal Growth. Solid Red Line Indicates Eutrophic Conditions.)***

The very high chl-a concentrations observed at many of the FMN stations in 2012 seem counterintuitive. For example, the highest observed chl-a concentration (43 µg/cm^2) occurred at LMEH 0.8 during Round 2. The sampling reach for this station is located within a mature riparian buffer with dense canopy cover, the stream has good water quality with no evidence of nutrient enrichment, and 34 percent of the macroinvertebrate subsample consisted of herbivorous individuals (Appendix B). All of these factors should contribute to low periphyton biomass. In contrast, RAYS 80.5 is a large stream with all but the margins of the channel openly exposed to full sun, elevated concentrations of nitrogen compounds, and low proportions of herbivorous macroinvertebrates. These factors should contribute to high periphyton biomass, but chl-a concentrations were below the nuisance level during both sampling rounds (Figure 7). More data collection at the FMN stations will be necessary in order to identify and adequately explain trends in chl-a concentration.

SUMMARY

No streams in the FMN experienced ASO 95 or lower flows during the June 1 to September 30 sampling period in 2012. Data collected in 2012 provided useful baseline information about habitat, water quality, and biological conditions at the FMN stations. Without these baseline data, there would be no way to discern “normal” variations from those resulting from changing flow conditions.

A number of stations in the network have existing water quality issues, primarily associated with nutrient enrichment, road runoff, acid inputs, and resource extraction. The FMN will allow SRBC to track changes in water quality through time, allowing for the quick identification of new or escalating problems. This will be particularly important in areas where natural gas development is planned or ongoing.

Trends observed in the majority of macroinvertebrate and fish metrics calculated suggest that these biological communities may experience natural, seasonal shifts in composition over the course of the June 1 to September 30 sampling period. Additional data collected during this time frame across a number of years and flow conditions must be collected before the true effect of seasonality can be determined. If after several years of data collection it becomes apparent that early summer and late summer/early fall biological communities clearly differ, regardless of flow conditions, sampling design and/or data analyses employed for the FMN may need to be altered.

Periphyton chlorophyll-a concentrations exceeded nuisance or eutrophic levels at the majority of stations, even at locations where conditions do not seem favorable for algal overgrowth. This phenomenon warrants further investigation to determine whether the concentrations observed in 2012 are the result of a sampling or lab error, or if they can be attributed to natural or anthropogenic factors in the environment.

FUTURE DIRECTIONS

SRBC is working to establish rating curves for the 17 FMN stations located far from an appropriate USGS stream gage. Once rating curves are established, the nine real-time pressure transducers located at joint RWQMN/FMN stations will act as real-time reference gages. The continuous flow record that will be provided by the other eight pressure transducers will allow for better correlation between flows at the stations and the best available USGS real-time gage. Having a continuous flow record for each FMN station will not only improve timing of sampling rounds, it will also allow for better correlation between flow and measured habitat, water quality, and biological parameters.

Both flood control and low flow mitigation planning are ongoing priorities of the SRBC. SRBC intends for the Flow Monitoring Network to be a long-term project with a primary objective of documenting habitat, water quality, and biological conditions associated with various stream flows at stations throughout the Susquehanna River Basin. Data collected from the FMN will help advise management decisions regarding low flow mitigation and passby flows associated with surface water withdrawals. The network also provides sentinel stations for monitoring changes to the flow regime, habitat, water quality, and biological communities of the Susquehanna River Basin that may occur over the next several years as a result of changing climate conditions.

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APPENDIX A

Station Name	**Location Description**	**Latitude**	**Longitude**	**Drainage Area (m^2)**	**Percent Forested**	**Designated Use**
Central Appalachian Ridges and Valleys						
WILL 0.4	Willow Run near mouth at T305 bridge near McCullochs Mills, Juniata Co., Pa.	40.41852	-77.59602	11	93	HQ-CWF[1]
BOBS 11.4*	Bobs Creek in headwaters near Pavia, Bedford Co., Pa.	40.26388	-78.59258	17	92	HQ-CWF
TSPC 0.1	Three Springs Creek upstream of T341 near Pogue, Huntingdon Co., Pa.	40.20794	-77.94091	31	86	CWF[2]
STST 26.8	Standing Stone Creek at SR 1023 bridge near McAlevys Fort, Huntingdon Co., Pa.	40.65185	-77.82278	34	86	HQ-CWF
BLLG 0.9	Blacklog Creek along T599 upstream of Rockhill and Orbisonia, Huntingdon Co., Pa.	40.24054	-77.89502	66	88	CWF
DUNN 0.1	Dunning Creek near mouth upstream of SR 1001, near Bedford, Bedford Co., Pa.	40.02433	-78.47794	196	69	WWF[3]
RAYS 80.5	Raystown Branch Juniata River upstream of Greys Run east of Everett, Bedford Co., Pa.	40.00466	-78.30017	546	70	TSF[4]
Northern Appalachian Plateau and Uplands						
LMEH 0.8*	Little Mehoopany Creek near confluence with the Susquehanna River, Wyoming Co., Pa.	41.58155	-76.07095	11	68	CWF
TOBE 1.9	Tobehanna Creek on Lamoka Lake Road near Tyrone, Schulyer Co., N.Y.	42.40430	-77.06656	17	52	C[5]
CATA 17.7*	Upper Catatonk Creek near Spencer, Tioga Co., N.Y.	42.20472	-76.47508	30	70	C
CHOC 6.8*	Choconut Creek south of Vestal, NY, Susquehanna Co., Pa.	42.01077	-76.00703	38	73	CWF
TUSC 11.0*	Upper Tuscarora Creek near Woodhull, Steuben Co., N.Y.	42.07458	-77.37898	53	42	C
SBTK 7.1*	South Branch Tunkhannock Creek near La Plume, Lackawanna Co., Pa.	41.55761	-75.77664	70	55	TSF
North Central Appalachians						
GRYS 2.2*	Grays Run near Gray, Lycoming Co., Pa.	41.44997	-77.01979	16	95	HQ-CWF
UPIN 6.1*	Upper Pine Creek upstream of confluence with Ninemile Run near Telescope, Potter Co., Pa.	41.79573	-77.76546	19	75	HQ-CWF
LYSK 53.7*	Loyalsock Creek east of Ringdale, Sullivan Co., Pa.	41.45853	-76.33172	27	86	CWF
BAKR 0.1*	Baker Run in Sproul State Forest near Glen Union, Clinton Co., Pa.	41.24566	-77.60816	35	99	HQ-CWF
DRFT 2.0*	Driftwood Branch Sinnemahoning Creek near Lockwood, Cameron Co., Pa.	41.52649	-78.27008	83	90	TSF
KTTL 23.6*	Kettle Creek at PA Fish & Boat Commission Access along PA 144, Potter Co., Pa.	41.49972	-77.77085	84	95	EV[6]

[*] Denotes RWQMN station

[1] High-Quality Cold Water Fishery (25 Pa. Code § 93.3)

[2] Cold Water Fishery (25 Pa. Code § 93.3)

[3] Warm Water Fishery (25 Pa. Code § 93.3)

[4] Trout Stocked Fishery (25 Pa. Code § 93.3)

[5] Supports Fisheries and Non-Contact Sports (5 NY Code § 608.15)

[6] Exceptional Value Waters (25 Pa. Code § 93.3)