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LOW FLOW MONITORING PILOT STUDY

An Assessment of Habitat, Water Quality, and Biological Responses to Low Flow Conditions in the Juniata River Subbasin in 2010 and 2011

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INTRODUCTION

Stream flow affects the physical structure of river ecosystems at every level, from the hydraulic conditions on the surface of an individual cobble, to the distribution of riffles and pools within a stretch of stream, to channel dimensions at the watershed scale (Hart and Finelli, 1999). Instream habitat is heavily influenced by flow-mediated physical 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 cover, soils, and geographic position within the stream network (Poff and Zimmerman, 2010). The magnitude, frequency, duration, seasonal timing, and predictability of major flow events, both low and high, are unique to individual river systems. Stream-dwelling organisms have developed adaptive strategies and behavioral mechanisms 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. Maintaining natural flow regimes is therefore critical to conserving the native biodiversity of freshwater systems.

Floods and droughts are natural features of river ecosystems that occur on a relatively predictable basis throughout much of the world (Lake, 2003). Naturally occurring seasonal low flows are common in areas where precipitation varies throughout the year and are generally benign in terms of ecological impacts (Boulton, 2003). On the other hand, artificial flow reductions resulting from human activities such as groundwater abstraction, water diversion, and surface water withdrawals can create low flow conditions out of season or extend the duration and severity of natural low flow events (Dewson and others, 2007a). Extended periods of drought, whether natural or human-influenced, that significantly reduce or completely eliminate instream habitat have the potential to negatively impact the distribution and abundance of fish, macroinvertebrates, and other organisms (Humphries and Baldwin, 2003).

Both flood damage reduction and low flow mitigation planning are ongoing priorities of the Susquehanna River Basin Commission (SRBC). In recent years, SRBC has been actively involved in a number of projects that explore the ecological implications of natural and human-influenced flow alterations. In 2010, The Nature Conservancy (TNC), in partnership with SRBC and the U.S. Army Corps of Engineers (USACE), published a report identifying seasonal ecosystem flow needs for the streams and rivers of the Susquehanna River Basin (DePhilip and Moberg, 2010). The outcome of this project was a set of flow recommendations intended to protect the biological communities and key ecological processes of the Susquehanna River Basin (i.e., ecological flows) throughout the year. In addition to ecosystem flow recommendations, the study partners also proposed a number of hypotheses regarding anticipated responses of species, groups of species, or physical habitat to changing conditions during high and low flows.

As the first step towards developing and implementing a basin-wide low flow monitoring plan, SRBC staff conducted a pilot study in the Juniata River Subbasin in 2010 and 2011. The purpose of this Low Flow Monitoring (LFM) Pilot Study was to provide preliminary data to guide development of a basin-wide low flow monitoring network and to begin testing some of the hypotheses outlined in TNC's ecosystem flows report. Much of the existing knowledge regarding the effects of reduced flows in unregulated, free-flowing systems has been gathered opportunistically or anecdotally (Boulton, 2003; Lake, 2003). Observational and experimental studies to investigate the ecological effects of water extraction and diversion are even more limited, although the body of literature on the definition and potential impacts of drought is large. Managing for ecological flows is still a relatively new concept in environmental science; therefore, the results of this pilot study can potentially provide valuable information not only to SRBC, but also to state and local environmental agencies and the scientific community as a whole.

Great Trough Creek, Huntingdon Co., Pa., during baseline flow (left) and low flow (right) in 2010.

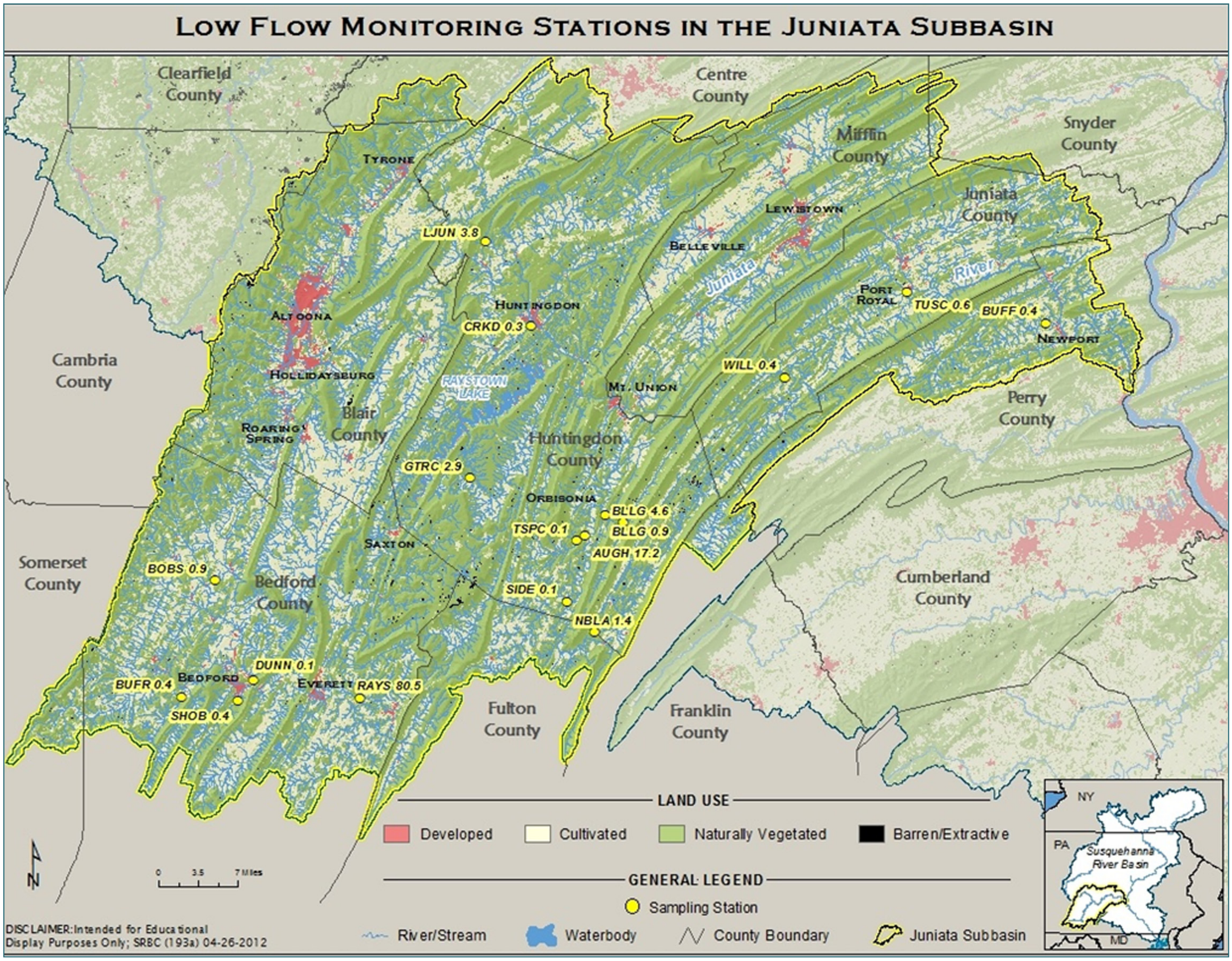

Figure 1. Location of the Low Flow Monitoring Pilot Study Stations in the Juniata River Subbasin

STUDY AREA AND MONITORING NETWORK

The Juniata River Subbasin drains an area of approximately 3,400 square miles from west of Bedford to Duncannon, Pennsylvania, which includes portions of Bedford, Blair, Fulton, Huntingdon, Perry, Juniata, and Mifflin Counties (Figure 1). Two ecoregions are found within this area: Central Appalachian Ridges and Valleys (Ecoregion 67) and Central Appalachians (Ecoregion 69) (Omernik, 1987). Ecoregion 67 is characterized by almost parallel ridges and valleys formed by folding and faulting events. The dominant geologic materials include sandstone, shale, limestone, dolomite, siltstone, chert, mudstone, and marble. The carbonate terrain characterizing this ecoregion commonly features subterranean springs and caves. Ecoregion 69 is a plateau formation typified by sandstone, shale, conglomerate, and coal geologic materials. Mining for bituminous coal has also occurred in this ecoregion, and there are some lands and streams affected by abandoned mine drainage.

Land use in the Juniata River Subbasin is mixed and includes forested areas concentrated in the ridges with agricultural and urban areas in the valleys. Many of the forested areas are managed as state forest or game lands. The largest urban center in the subbasin is Altoona; other notable developed areas include Bedford, Everett, Tyrone, Huntingdon, Mount Union, Lewistown, and Newport.

The streams of the Juniata River Subbasin are largely unregulated except for a handful of small water supply reservoirs and Raystown Lake on the Raystown Branch Juniata River, which was dammed in 1968 for flood control, hydropower, and recreational purposes. This subbasin also has the fewest number of permitted withdrawals in the Susquehanna River Basin, making it an ideal location for the LFM Pilot Study. Because there are relatively few human impacts to flow regime in the Juniata River Subbasin, differences in abiotic and biotic factors observed between summer baseline flow and low flow conditions are likely natural rather than resulting from anthropogenic inputs.

METHODS

DATA COLLECTION

In June and July 2010, SRBC staff assessed water chemistry, stream discharge, and physical habitat, as well as macroinvertebrate, periphyton, and fish communities during summer baseline flow conditions at 27 stations in the Juniata River Subbasin. The stations sampled during the LFM Pilot Study were selected based on records of biologically non-impaired conditions from previous SRBC field surveys. In addition, stations were chosen to represent a variety of stream orders, subwatersheds, geology types, and drainage area sizes.

SRBC chose the exceedance probability flow of Annual P95 (the flow exceeded 95 percent of the time in any given year) as the trigger to initiate low flow sampling in 2010. Staff monitored flow conditions by accessing real-time streamflow data from the U.S. Geological Survey (USGS) web site (http://waterwatch.usgs.gov). Seventeen of the 27 stations were resampled between August and September 2010 when flows dropped below Annual P95 thresholds in an attempt to quantify any ecological, habitat, and water quality changes that may have occurred during low flow conditions. The remaining ten stations were not resampled because flows at these locations never dropped below Annual P95.

Water chemistry, stream discharge, physical habitat, macroinvertebrate, periphyton, and fish sampling were repeated the following year in June and July 2011 during summer baseline flow conditions. A seasonal August/September/October mean P95 (ASO P95) was designated as the trigger flow to initiate low flow sampling in 2011. Proponents of ecological flow management suggest that seasonal or even monthly exceedance values should be used to define low flow conditions and guide water management decisions (DePhilip and Moberg, 2010). The ASO P95 was chosen as the trigger flow in 2011 because the lowest average annual flows historically occurred during these months. However, Hurricane Irene and Tropical Storm

Table 1. Levels of Concern and Aquatic Life Tolerances for Measured Water Quality Parameters

Parameters	Limits	Reference Code	Reference
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	b	
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	> 0.6 mg/l	f	g. http://www.uky.edu/WaterResources/Watershed/KRB_AR/krww_ parameters.htm
Total Nitrite	> 1 mg/l	c	h. Hem (1970)
Total Phosphorus	> 0.1 mg/l	g	i. Based on archived data at SRBC
Total Orthophosphate	> 0.02 mg/l	f	
Total Organic Carbon	> 10 mg/l	h	
Total Hardness	> 300 mg/l	g	
Acidity	> 20 mg/l	i	
Calcium	> 100 mg/l	i	

Lee caused record precipitation and historic flooding in the Susquehanna River Basin in late August and early September 2011. As a result, flows in the Juniata subbasin never dropped below ASO P95, precluding low flow sampling. Consequently, for the purposes of this report, only results for the 17 stations that were sampled during low flow in 2010 will be discussed.

Figure 1 shows the extent of the Juniata River Subbasin and the locations of the 17 LFM Pilot Study sampling stations where Annual P95 occurred in 2010. Appendix A lists additional information about all stations sampled, including location descriptions, geographic coordinates, and drainage areas.

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 events, substrate material composition, surrounding land use, and any other relevant features of the surrounding landscape.

At stations with no USGS gage, staff took flow measurements using a FlowTracker and standard USGS procedures (Buchanan and Somers, 1969). For stations located at a USGS gage, the flow at the time of sampling was obtained from the USGS stream gage web site (http://waterwatch.usgs.gov). A second stream transect was characterized using the FlowTracker to record stream width and water depths across the channel. Additional habitat information was collected at each vertical location along the transects, including dominant substrate type, presence of sedimentation, and flow regime.

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 water quality standards based on current state or federal regulations, background levels for uninfluenced streams, or references for aquatic life tolerances. A handheld multi-probe YSI sonde was used to collect all field chemistry parameters (temperature, conductivity, pH, and dissolved oxygen) simultaneously. 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 – QA042). Water samples for laboratory analyses were collected using depth-integrated water sampling methods (Guy and Norman, 1969) and were kept on ice until delivery to the Pennsylvania Department of Environmental Protection (PADEP), Bureau of Laboratories in Harrisburg, Pa., (2010) or to ALS Environmental, in Middletown, Pa., (2011).

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 habitats at each station 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 immediately upstream of the net for approximately 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 PADEP's benthic macroinvertebrate index of biotic integrity (PADEP, 2012). Most insect taxa in the subsample were identified to genus level and enumerated. 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 manual (Barbour and others, 1999) and PADEP's draft index of biological integrity (IBI) protocols. 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,

Commisssion staff using a D-frame kick net to sample bugs at Tuscarora Creek, Juniata Co., Pa., during low flow in September 2010.

Commission staff using a backpack electrofishing unit to sample fish in September 2010 at Blacklog Creek, Huntingdon County, Pa.

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 fish species collected 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 returned to the laboratory and identified.

PERIPHYTON

Periphyton 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-ml aliquot of water from the rinse bottle was vacuum filtered onto a filter paper, chilled on ice, and shipped to the PADEP lab for analysis of periphyton chlorophyll-a concentration. A second 50-ml aliquot was preserved with 5 ml of formaldehyde and sent to EcoAnalysts, Inc., Moscow, Id., for identification of periphyton taxa.

DATA ANALYSIS

Water quality was assessed by comparing field and laboratory parameter data to current water quality standards (see Table 1). 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 of 116 to 170 indicated supporting conditions, scores between 61 to 115 designated partially supporting habitat, and a score of less than 60 was deemed non-supporting.

Streamflows during baseline flow and low flow periods were compared, and actual flow exceedance percentiles at the reference gages at the time of sampling were calculated for each time period. Using information from the second transect water depth/channel width profile, staff estimated the percentage of wetted area lost between baseline flow and low flow periods (Chow, 1959; Mecklenburg and Ward, 2005).

Macroinvertebrate, fish, and periphyton 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's benthic macroinvertebrate index of biotic integrity for freestone wadeable streams (PADEP, 2012), and from TNC's report outlining ecosystem flow requirements for the Susquehanna River Basin (DePhilip and Moberg, 2010). Periphyton metrics were based primarily on diatom taxa as this algal group is most often used in biomonitoring. Soft-bodied algae were identified to genus and enumerated only. A complete list and description of macroinvertebrate, fish, and periphyton metrics calculated can be found in Table 2.

Table 2. Description of Biological Metrics Calculated Using Low Flow Monitoring Pilot Study Data

Metrics	Description
Macroinvertebrates	
Taxa Richness	Total number of macroinvertebrate taxa identified
% Sensitive (PTV ≤ 3)	Percentage of individuals in the assemblage that have Pollution Tolerance Values (PTVs) 0 - 3
Shannon Diversity Index	Taxonomic composition metric measuring taxonomic richness and evenness of individuals across taxa of a subsample
Hilsenhoff Biotic Index	Taxonomic composition metric calculated as an average of the number of individuals in a subsample, weighted by PTVs
% EPT	Percentage of individuals from orders Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, caddisflies)
% Dominant	Percentage of subsample represented by the dominant taxon
% Multivoltine	Percentage of multivoltine (multiple generations per year) individuals in the subsample
% Desiccation Tolerant	Percentage of desiccation tolerant individuals in the subsample
% Strong Adult Flying Ability	Percentage of individuals in the subsample having strong adult flying ability
% Common/Abundant in Drift	Percentage of individuals in the subsample common or abundant in drift
% Strong Swimmers	Percentage of individuals in the subsample with strong swimming ability
% Small-bodied	Percentage of small-bodied individuals in the subsample
% Free-living	Percentage of free-living individuals (taxa not utilizing cases or other forms of substrate attachment) in the subsample
% Erosional	Percentage of erosional (riffle-dwelling) individuals in the subsample
% Obligate Depositional	Percentage of obligate depositional (pool-dwelling) individuals in the subsample
% Shredders	Percentage of shredder individuals in the subsample
% Herbivores	Percentage of herbivore taxa in the subsample
% Collector-Filterers	Percentage of collector-filterer individuals in the subsample
% Predators	Percentage of predator individuals in the subsample
% Eurythermal	Percentage of eurythermal (wide temperature range) individuals in the subsample
% Cold Stenothermal	Percentage of cold stenothermal (narrow temperature range) individuals in the subsample
% Burrowers	Percentage of burrower individuals in the subsample
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 coldwater individuals (brook trout, brown trout, rainbow trout, sculpin)
% Riffle Obligates	Percentage of riffle obligate individuals (margined madtom, longnose dace, central stoneroller, fantail darter)
% Riffle Associates	Percentage of riffle associate individuals (white sucker, shorthead redhorse, northern hogsucker, walleye)
Periphyton	
Diatom species richness	Total number of diatom species identified
Soft-bodied algae taxa richness	Total number of soft-bodied algae taxa identified
% Dominant (diatoms)	Percentage of assemblage represented by the dominant diatom species
Disturbance Index	Percentage of *Achnanthes minutissima* individuals in the sample; higher percentage indicates increased disturbance
Siltation Index	Percent relative abundance of individuals (*Navicula, Nitzschia, Surirella*) adapted to living on silty substrates
Diatom Model Affinity (DMA)	A percent similarity, reference-based community metric (Passy and Bode, 2004)
Chlorophyll-a Concentration	Chlorophyll-a (chl-a) concentration is a surrogate for algal biomass; biomass is at nuisance levels when chl-a > 10 µg/cm2

RESULTS/DISCUSSION

SRBC's intent for the LFM Pilot Study was to document summer baseline flow and low flow conditions in the Juniata River Subbasin in consecutive years; however, low flow sampling could not be completed in 2011. Record precipitation and historic flooding from Hurricane Irene the week of August 26 and Tropical Storm Lee the week of September 9 caused flows to remain too high through the end of the monitoring period for SRBC staff to safely conduct sampling. Figure 2 depicts streamflow at the USGS gage on the Little Juniata River at Spruce Creek, Pa., from June 1, 2010 to September 30, 2011. Flows approached flood stage following Tropical Storm Lee and remained high through the end of September, particularly in comparison with flows from the same period in 2010. Streamflows throughout the Juniata River Subbasin exhibited a similar pattern. The pilot study stations were not sampled outside of the June through September time frame to avoid potentially introducing confounding factors due to seasonal changes in biological communities (PADEP, 2012). Because the focus of the pilot study was to document differences between baseline flow and low flow periods, this report primarily focuses on data from 2010. While data from 2011 are included in tables and figures for additional baseline documentation, they were not included in analyses.

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 (LeFevre, 2005; Campbell, 2011). All stations were categorized as having either excellent or supporting habitat during both baseline flow and low flow in 2010. Habitat condition category changed at only three stations, CRKD 0.3, GTRC 2.9, and TSPC 0.1, between baseline flow and low flow in 2010. All three stations scored excellent during baseline flow and supporting during low flow. The changes in the scores can primarily be attributed to decreased streamflow, which resulted in loss of riffle habitat and increased sediment deposition due to reduced capability of the streams to transport fine materials downstream. These three stations received lower scores for habitat condition factors related to flow status, velocity/depth regime, and sedimentation.

Table 3 lists flows at the 17 stations where baseline flow and low flow sampling occurred, as well as flows at the reference gages at the time of sampling, percent reduction in streamflow, percent loss of wetted area, and the actual annual flow exceedance percentile for the reference gages at the time of sampling. Percent reduction in streamflow between baseline flow and low flow periods ranged from 17 percent at LJUN 3.8 to 99 percent at GTRC 2.9. The median percent reduction in streamflow was 83 percent. The greatest loss of wetted area (78 percent) was also

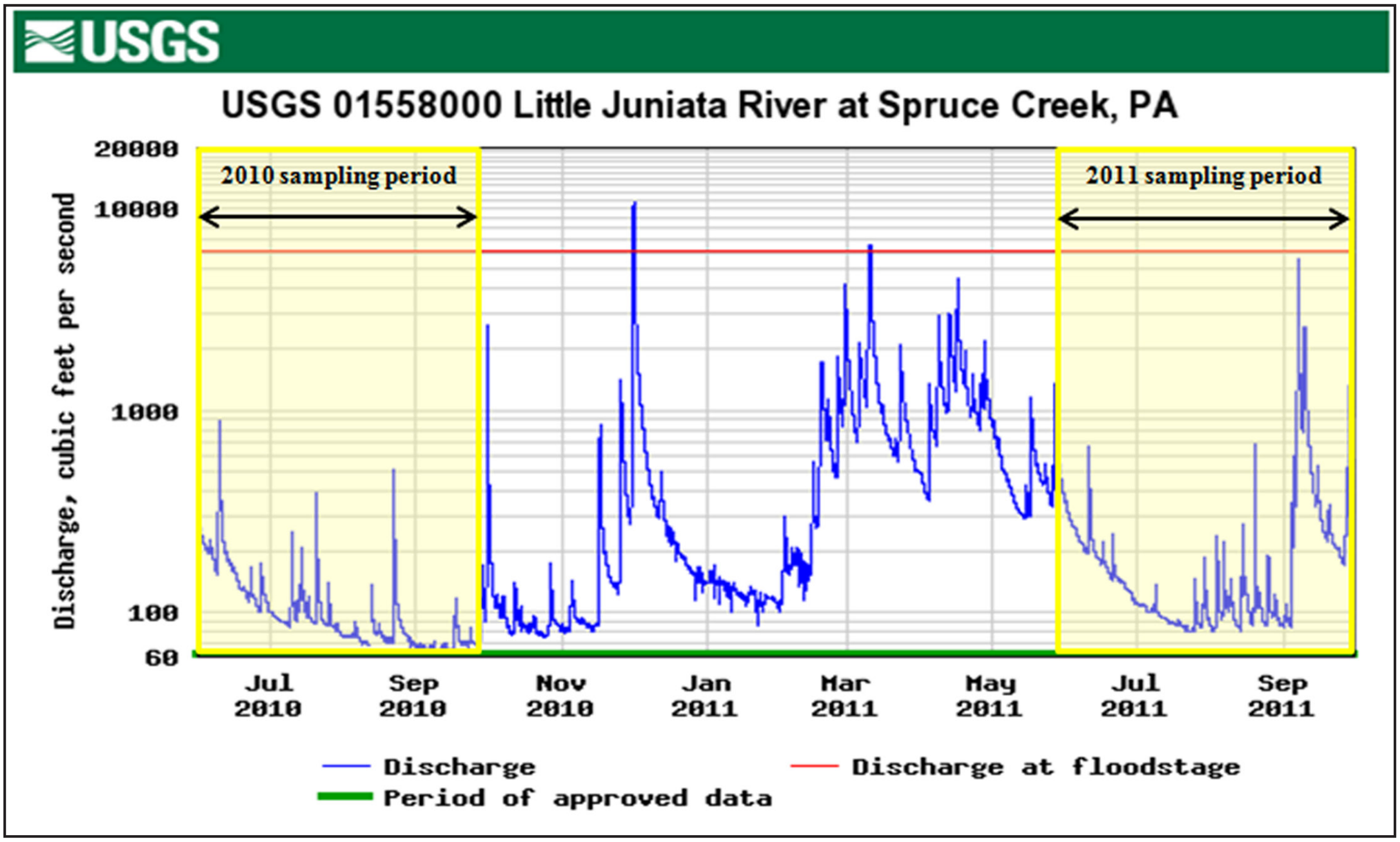

Figure 2. Streamflow at the USGS Gage on the Little Juniata River at Spruce Creek, Pa., from June 1, 2010 to September 30, 2011

Table 3. Measured Flow, Percent Flow Reduction, Percent Loss of Wetted Area, and Flow and Annual Exceedance Percentile at Reference Gages at Time of Sampling

Station Name	Date Sampled	Flow (cfs)	Percent Flow Reduction	Percent Loss of Wetted Area	Reference Gage	Flow at Reference Gage (cfs)	Annual Exceedance Percentile
AUGH 17.2	06/22/10 09/02/10	49.0 8.1	84	16	Aughwick Creek (1564500)	51.0 8.2	64 96
BLLG 0.9	06/22/10 09/07/10	19.9 4.1	79	51	Aughwick Creek (1564500)	51.0 6.8	64 98
BLLG 4.6	06/22/10 09/07/10	10.5 0.9	92	51	Aughwick Creek (1564500)	51.0 6.8	64 98
BOBS 0.9	06/08/10 09/09/10	60.9 6.1	90	31	Dunning Creek (01560000)	105.0 14.0	48 97
BUFF 0.4	06/01/10 09/01/10	28.7 3.2	89	38	Tuscarora Creek (01566000)	162.0 16.0	40 94
BUFR 0.4	06/07/10 09/09/10	6.7 0.2	96	72	Dunning Creek (01560000)	121.0 14.0	44 97
CRKD 0.3	06/16/10 09/07/10	9.3 1.7	82	14	Dunning Creek (01560000)	110.0 12.0	47 98
DUNN 0.1	06/08/10 09/08/10	115.7 17.3	85	37	Dunning Creek (01560000)	105.0 14.0	48 97
GTRC 2.9	06/09/10 09/09/10	35.5 0.4	99	78	Raystown Branch (01562000)	486.0 82.0	47 97
LJUN 3.8	07/06/10 08/04/10	89.0 74.0	17	6	Little Juniata River (01558000)	89.0 74.0	87 94
NBLA 1.4	06/21/10 09/02/10	8.8 1.8	80	27	Aughwick Creek (1564500)	57.0 8.2	62 96
RAYS 80.5	07/08/10 09/08/10	69.7 46.8	33	1	Raystown Branch (01562000)	127.0 84.0	87 97
SHOB 0.4	06/07/10 09/08/10	7.6 2.5	67	9	Dunning Creek (01560000)	121.0 14.0	44 97
SIDE 0.1	06/21/10 09/02/10	18.5 0.6	97	69	Aughwick Creek (1564500)	57.0 8.2	62 96
TSPC 0.1	06/21/10 09/02/10	4.4 0.8	83	50	Aughwick Creek (1564500)	57.0 8.2	62 96
TUSC 0.6	06/23/10 09/01/10	80.0 15.0	81	23	Tuscarora Creek (01566000)	80.0 16.0	61 94
WILL 0.4	06/23/10 9/1/2010	3.9 1.7	55	22	Tuscarora Creek (01566000)	80.0 16.0	61 94

observed at GTRC 2.9, while the smallest loss was documented at RAYS 80.5 (1 percent). The median loss of wetted area was 31 percent. The two limestone-influenced streams that experienced annual P95 flows in 2010, SHOB 0.4 and LJUN 3.8, had small reductions in wetted area between sampling periods (9 percent and 6 percent, respectively) compared to most stations. Baseline flow in streams flowing through limestone geology is generally comprised of a greater proportion of groundwater than baseline flow in freestone streams, which allows limestone streams to maintain higher flows during dry periods (Apse and others, 2008).

WATER QUALITY

Water quality was generally good at all stations across sampling periods. Six stations did not exceed any water quality levels of concern for the parameters assessed during baseline flow 2010, and 11 stations had zero exceedances during low flow 2010. Parameters that most often exceeded levels of concern included total nitrate (71 percent of stations), total orthophosphorus (53 percent), and total nitrogen (41 percent). The levels of concern for these three parameters are based on natural background concentrations rather than water quality standards or aquatic life tolerances because Pennsylvania has not yet developed numeric standards for nutrients. Total nitrate greater than 0.6

mg/L, total orthophosphorus greater than 0.02 mg/L, and total nitrogen greater than 1.0 mg/L indicate potential enrichment above background levels. The highest levels of total nitrate and total orthophosphate were 2.87 mg/L and 0.078 mg/L, respectively, both of which were observed at LJUN 3.8. RAYS 80.5 had the highest total nitrogen value (3.41 mg/L). Total phosphorus was elevated at LJUN 3.8 in July 2010, and total sodium was elevated at SIDE 0.1 in September 2010.

These water quality findings are consistent with those from previous surveys of the Juniata River Subbasin (LeFevre, 2005; Campbell, 2011). Common sources of nitrogen and phosphorus compounds include fertilizers, livestock waste, wastewater treatment and septic systems, detergents, and industrial discharges. Major sources of impairment in the Juniata River Subbasin include agriculture (general, crop, and animal), abandoned mine drainage, combined sewer overflows, urban and residential runoff, industrial and municipal point source, road runoff, and construction activities.

MACROINVERTEBRATES

TNC hypothesized that decreased flows during the summer low flow period, whether brought on by natural or human causes, could reduce macroinvertebrate diversity and richness, particularly of sessile, rheophilic (i.e., preferring fast-flowing waters), large-bodied, pollutant-sensitive, filter feeding, and grazing taxa (DePhilip and Moberg, 2010). TNC's ecosystem flows report condensed the results from nearly two dozen studies into a list of 21 functional trait or general assemblage metrics that may potentially detect changes in the macroinvertebrate community resulting from lowered flows. These 21 metrics, as well as PADEP's benthic IBI, were calculated using macroinvertebrate data collected at the Low Flow Monitoring Pilot Study stations.

Table 4 lists the expected changes in metrics between baseline flow and low flow sampling periods and the percentages of stations where the expected changes were observed. Twelve macroinvertebrate metrics showed the expected change between baseline flow and low flow conditions at a majority (greater than 50 percent) of stations. These metrics included IBI, percent dominant, percent multivoltine, percent strong swimmers, percent shredders, percent herbivores, percent predators, percent eurythermal, and percent cold stenothermal.

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 which incorporates information from six individual metrics into a single measure of overall biological condition (Barbour et al., 1995). 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 also 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, 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).

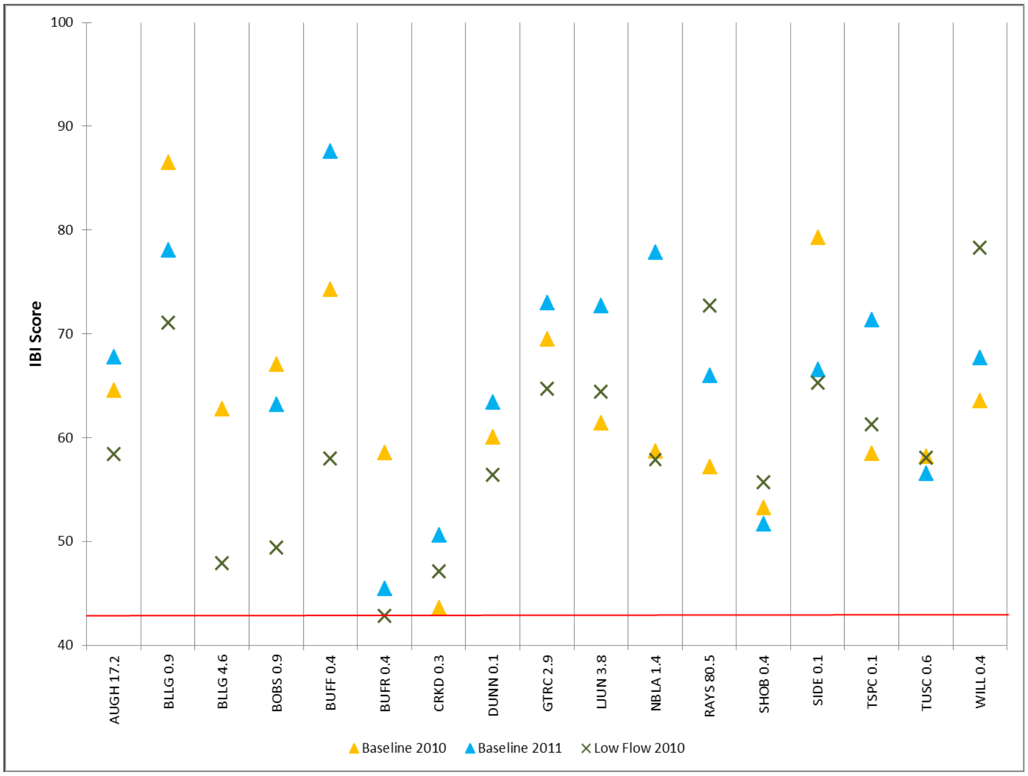

Figure 3. Index of Biotic Integrity Scores for the Low Flow Monitoring Pilot Study Stations. Scores Less than 43 Indicate Impaired Communities

Figure 3 summarizes the benthic macroinvertebrate IBI scores from samples collected at the Low Flow Monitoring Pilot Study stations during baseline flow 2010, low flow 2010, and baseline flow 2011. Seven stations had IBI scores indicating attainment of aquatic life use during baseline flow 2010. No samples were designated impaired

Table 4. List of Macroinvertebrate Metrics, Expected Metric Changes Between Baseline Flow and Low Flow, and the Percentage of Expected Changes Observed

Metrics	Expected Change	Percent of Stations with Expected Changes Observed
General Assemblage Metrics		
PADEP Index of Biotic Integrity (IBI)	decrease	65%
Taxa Richness*	decrease	53%
EPT Taxa Richness (PTV ≤ 3)*	decrease	71%
Beck's Index (Version 3)*	decrease	77%
Hilsenhoff Biotic Index (HBI)*	increase	82%
Shannon Diversity*	decrease	18%
Percent Sensitive (PTV ≤ 3)*	decrease	47%
Percent EPT Taxa	decrease	35%
Percent Dominant	increase	53%
Functional Traits (from Poff et al., 2006)		
Percent Multivoltine	increase	71%
Percent Dessication Tolerant	increase	47%
Percent Strong Adult Flyers	increase	41%
Percent Common/Abundant in Drift	increase	47%
Percent Strong Swimmers	increase	53%
Percent Small-Bodied	increase	47%
Percent Free-Living	increase	47%
Percent Erosional	decrease	47%
Percent Obligate Depositional	increase	41%
Percent Burrowers	increase	24%
Percent Shredders	decrease	53%
Percent Herbivores	decrease	53%
Percent Collector-Filterers	decrease	35%
Percent Predators	increase	59%
Percent Eurythermal	increase	65%
Percent Cold Stenothermal	decrease	65%

* denotes IBI component metric

based solely on IBI score during baseline flow 2010; however, BOBS 0.9, CRKD 0.3, DUNN 0.1, RAYS 80.5, SHOB 0.4, TSPC 0.1, and TUSC 0.6 failed at least one screening question. Only GTRC, TSPC 0.1, and WILL 0.4 scored as definitively attaining ALU during low flow in 2010. All other stations failed at least one screening question, and BUFR 0.4 was considered impaired on the basis of score alone.

Four stations – CRKD 0.3, DUNN 0.1, RAYS 80.5, and SHOB 0.4 – failed at least one screening question during all three collection periods. Despite receiving numerical IBI scores greater than or equal to 43, the macroinvertebrate communities at CRKD 0.3, DUNN 0.1, and RAYS 80.5 may be impaired. All three of these stations had high nitrate, total nitrogen, and orthophosphorus levels, which can inhibit colonization by sensitive macroinvertebrate taxa that cannot tolerate high levels of nutrients. Limestone influence at SHOB 0.4 may account for the consistent failure of this station to meet the requirements of the screening questions. Streams flowing through limestone geology tend to have uniform habitat, temperature, and water chemistry, which favor a high density but low diversity macroinvertebrate community (PADEP, 2009). No water quality parameters exceeded levels of concern at SHOB 0.4 during any sampling period.

IBI scores were lower during low flow than baseline flow at 65 percent of stations in 2010 (Figure 3). Of the six IBI component metrics, taxa richness, EPT taxa richness, Beck's Index, and Hilsenhoff Biotic Index (HBI) showed the expected change between baseline flow and low flow at more than 50 percent of stations (Table 4). All of these metrics except HBI measure aspects of taxonomic richness within the macroinvertebrate community. Numerous other studies conducted in a variety of stream settings in the United States and abroad have also documented reductions in total taxa and particularly EPT taxa richness following water diversion or abstraction (Englund and Malmqvist, 1996; Rader and Belish, 1999; McIntosh and others, 2002; McKay and King, 2006), indicating that lowered flows may result in reduced taxonomic richness of macroinvertebrate communities. Other studies failed to detect any changes in macroinvertebrate taxa richness in response to decreased streamflows (Armitage and Petts, 1992; Cortes and others, 2002; Dewson and others, 2003). Dewson and others (2007b) suggest that the initial composition of the macroinvertebrate community controls the magnitude and direction of response to flow reduction. Some taxa have specific water-velocity requirements (i.e., limited to riffles or pools), while others can utilize a variety of habitats. Changes in habitat related to flow reduction are highly variable and dependent upon characteristics such as channel morphology, substrate stability, degree of nutrient enrichment, stream size, and temperature regime. In other words, the macroinvertebrate community in an individual stream may or may not lose taxa when flows are reduced depending on local habitat and the taxa initially present prior to the drought or water withdrawal event.

HBI values increased as expected between baseline flow and low flow at 82 percent of stations (see Table 4). The HBI is a community composition and pollution tolerance metric calculated as an average of the number of individuals in the sample weighted by pollution tolerance values (Hilsenhoff, 1987). PADEP has assigned regionally specific pollution tolerance values (PTVs) to most macroinvertebrate taxa in the state of Pennsylvania, which are used in calculating the IBI component metrics. Although individual taxa respond differently to different types of pollution (Carlisle and others, 2007), most of the PTVs developed by PADEP reflect responses to nutrient enrichment and sedimentation. The HBI generally increases with increasing pollution levels due to a shift in community composition from pollution-sensitive to pollution-tolerant taxa. Although 12 of the 17 stations had elevated nutrient levels throughout the study period, nutrient levels were not always higher during low flow compared to baseline flow, making it unlikely that the increases in HBI values were due to increasing pollution.

While developing the IBI, PADEP (2012) found that HBI scores begin increasing in June through September or October when they start to drop back to their minimum potential. Likewise, the metrics based on taxonomic richness begin dropping in June through September before rising again to their maximum potential in November. These seasonal patterns may be explained by macroinvertebrate life cycles (Merritt and Cummins, 2008). Many taxa are in egg stages or very early (i.e., very small) instars throughout the summer months and are often overlooked in samples. This can lead to artificially low taxa counts for samples collected during this time period. Although the IBI and its component metrics showed a large number of expected changes between baseline flow and low flow sampling periods, they may not be the best indicators for flow-related responses due to the seasonal patterns in their scores.

Voltinism (the number of generations produced per year) is a macroinvertebrate life history trait that may be sensitive to decreases in streamflow. Studies have demonstrated that multivoltine taxa (those that produce several generations per year) become more abundant during times of lowered flows while univoltine (one generation per year) and semivoltine (less than one generation per year) taxa decrease in abundance (Richards and others, 1997). The proportion of multivoltine taxa increased at 71 percent of the LFM Pilot Study stations between baseline flow and low flow sampling in 2010 (see Table 4).

Mobility is a functional trait that other studies have demonstrated affects the ability of macroinvertebrate taxa to persist during periods of decreased streamflow. Taxa with limited ability to drift, fly, or swim are more likely to suffer reduced abundance due to low flows than highly mobile taxa (Boulton, 2003; Walters and Post, 2011). Walters and Post (2011) found that taxa with strong swimming ability, such as Gomphid dragonflies, increased in abundance following artificial flow reductions in streams in the Yale Myers Experimental Forest, Connecticut. Fifty-three percent of LFM Pilot Study stations had a higher proportion of strong swimmers during low flow than baseline flow (see Table 4).

Decreases in baseline flows required to maintain riffle and pool habitat, particularly during naturally dry seasons, can alter trophic composition of the macroinvertebrate assemblage (DePhilip and Moberg, 2010). As flows decrease and wetted width contracts, macroinvertebrate density increases in remaining wetted areas may lead to increased competition and predator-prey interactions. Walters and Post (2011) observed that predators became concentrated in high densities in pools that remained during low flows, subsequently increasing predation rates. Boulton and Lake (1990) found that predators dominated the trophic structure of the macroinvertebrate communities in Australian streams during drought years. The proportion of predatory macroinvertebrate taxa was higher during low flow than baseline flow at 59 percent of the pilot study stations (see Table 4). Water velocity also influences the foraging behavior and efficiency of herbivorous (grazing) macroinvertebrate taxa. As flow decreases and riffles disappear, the algal community shifts from the diatom-dominated assemblage preferred by most grazing macroinvertebrates to one characterized by filamentous algae (Suren and others, 2003a), thus reducing richness and abundance of herbivores (McKay and King, 2006; Wills and others, 2006). Proportion of herbivores was lower during low flow than baseline flow at 53 percent of stations (see Table 4). Shredder taxa were also less abundant during low flow (53 percent of stations); however, this trophic class made up a very small proportion (3 percent on average) of the assemblage across all stations.

Reductions in streamflow and water volume, along with the higher air temperatures that generally accompany natural droughts, can cause water temperatures to rise and subsequently dissolved oxygen levels to decline, particularly in pools and slow-moving reaches (Lake, 2003; Dewson and others, 2007a). Reductions in dissolved oxygen in particular can negatively impact macroinvertebrate assemblages. Coldwater taxa, such as many stoneflies, require high dissolved oxygen levels and may experience higher mortality when water temperatures rise. The proportion of coldwater macroinvertebrate taxa was lower at 65 percent of pilot study stations during low flow than during baseline flow (see Table 4). Eurythermal taxa, which have less stringent temperature and dissolved oxygen requirements, made up a larger proportion of the assemblage during low flow than baseline flow at 65 percent of stations (see Table 4).

FISH

TNC's 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 using data collected from the Low Flow Monitoring Pilot Study stations.

Table 5 lists the expected changes in metrics between baseline flow and low flow sampling periods and the percentages of stations where the expected changes were observed. Nine fish metrics showed the expected change between baseline flow and low flow conditions at a majority (greater than 50 percent) of stations. These metrics included percent riffle obligates, percent riffle associates, percent dominant, percent cyprinids, percent tolerant, percent intolerant, percent insectivores, percent feeding generalists, and percent herbivores.

TNC identified riffle obligate and riffle associate species as the group most sensitive to alterations in flow regime.

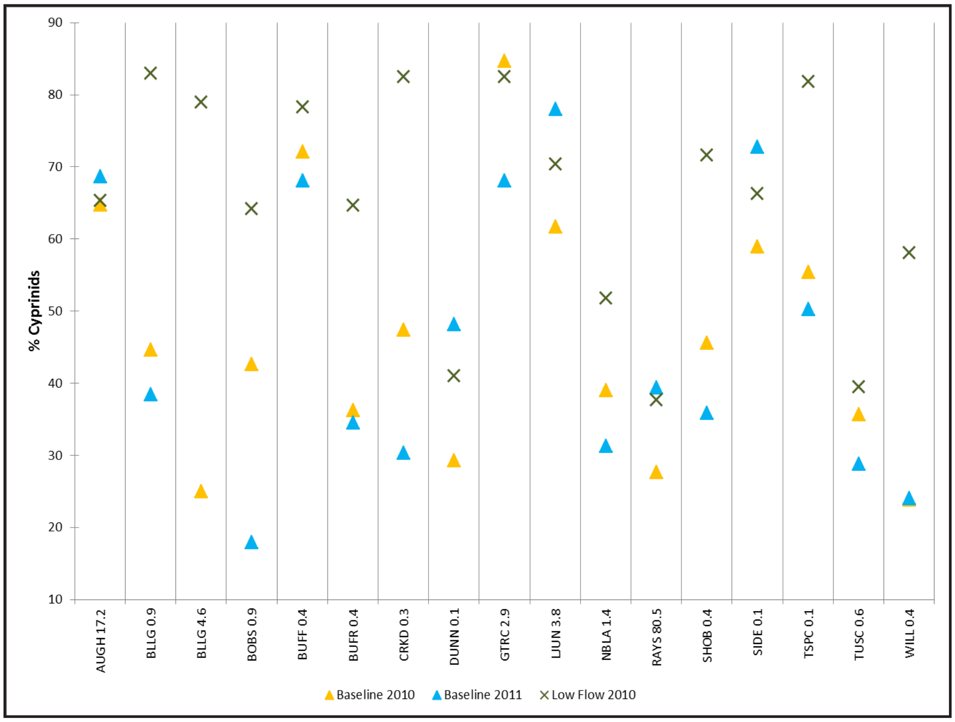

Figure 4. Percentage of the Fish Assemblage Represented by Minnow Species (Family Cyprinidae) at the Low Flow Monitoring Pilot Study Stations

Shallow riffle habitats are among the first to change velocity and depth as stream stage changes (DePhilip and Moberg, 2010). Riffle obligates, including longnose dace (*Rhinichthys cataractae*), margined madtom (*Notorus insignis*), central stoneroller (*Campostoma anomalum*), and fantail darter (*Etheostoma flabellare*), are dependent upon the presence of year-round, stable riffle habitat. Riffle associates, including white sucker (*Catostomus commersoni*), shorthead redhorse (*Moxostoma macrolepidotum*), northern hogsucker (*Hypentelium nigricans*), and walleye (*Sander vitreus*), are resident species with moderately sized home ranges that migrate to spawn and therefore rely on connectivity between riffle habitats in order to complete their life cycles. Freeman and Marcinek (2006) found that the number of riffle specialist fish species increased with increasing velocity and depth of riffle habitats in Piedmont streams. Percentage of riffle obligates was lower during low flow than baseline flow at 53 percent of LFM Pilot Study stations, while percentage of riffle associates was lower at 59 percent of stations (see Table 5).

Another group that may potentially be sensitive to low flows is coldwater species, particularly salmonid (trout) species. Although temperature is the primary limiting factor determining occurrence and distribution of trout, reduced stream discharge and increased sedimentation during major growth periods can negatively impact the size of adult brook trout (Hakala and Hartman, 2004). James and others (2010) found that biomass of adult brown trout was lower near the end of a prolonged drought than at the beginning. The only station with a self-sustaining (i.e., naturally reproducing) wild trout population was LJUN 3.8. Sixty-one fewer brown trout were collected during low flow (128 individuals) than baseline flow (189 individuals). The first 50 individuals collected were measured and weighed but not tagged so no assertions regarding growth or biomass can be made from the pilot study data.

Fish assemblage diversity is often positively correlated with the complexity of instream habitat. Velocity-depth regimes and availability of cover, such as boulders, fallen trees, and submerged aquatic vegetation, are the most important habitat variables determining fish species diversity (Gorman and Karr, 1978; Schlosser, 1982). Flow is a major determinant of physical habitat in streams, governing channel shape and size, distribution of riffle and pool habitats, and substrate stability (Bunn and Arthington, 2002). Although habitat assessment scores showed reductions in some condition factors due to decreased flows, loss of riffle habitat, and increased sedimentation, fish species richness was actually higher during low flow than baseline flow at 71 percent of LFM Pilot Study stations (see Table 5). This increase in fish species richness can be attributed to increases in the number of minnow species collected during low flow compared to baseline flow. Minnow species also made up a larger proportion of the fish assemblage during low flow than baseline flow at 94 percent of sampling stations in 2010 (Figure 4). The percentage of the assemblage represented by the dominant species was higher during low flow at 71 percent of the stations (see Table 5). The dominant species was a minnow at 77 percent of the stations during low flow compared to only 41 percent of the stations during baseline flow in 2010 and 2011.

Table 5. List of Fish Metrics, Expected Metric Changes Between Baseline Flow and Low Flow, and the Percentage of Expected Changes Observed

Metrics	Expected Change	Percent of Stations with Expected Changes Observed
General Assemblage Metrics		
Species Richness	decrease	29%
Percent Tolerant	increase	59%
Percent Intolerant	decrease	65%
Percent Dominant	increase	71%
Percent Cyprinids	increase	94%
Functional Traits		
Percent Piscivores	increase	24%
Percent Insectivores	decrease	65%
Percent Feeding Generalists	increase	53%
Percent Herbivores	increase	65%
Percent Coldwater	decrease	47%
Percent Riffle Obligates	decrease	53%
Percent Riffle Associates	decrease	59%

Commission staff collecting fish samples by electrofishing at Canoe Creek, Blair County, Pa.

At least some of the differences in numbers of minnows collected during the Low Flow Monitoring Pilot Study can be attributed to increased sampling effectiveness during low flow. Small fish are less susceptible to the electric current generated by electrofishing gear, and although they may become stunned, they often do not exhibit strong electrotaxis. Slower stream velocities make netting fish easier and decrease the likelihood that stunned fish will be swept downstream before being netted. Small fish are more likely to go unnoticed by netters and get swept away by the current when stream velocity is high and water is deep. Walters and Post (2008) observed a shift in the average length of fish towards smaller individuals following experimental water diversion in streams in the Yale Myers Experimental Forest, Connecticut. These authors attributed this phenomenon to outmigration by large individuals to unaffected reaches when food and other resources became increasingly scarce. In addition, body size is generally correlated with size of home range and increasing flow-velocity tolerance (Winemiller and Rose, 1992). Larger fish tend to have larger home ranges and are more apt to migrate to stream reaches with more suitable habitat when local conditions are compromised than small fish.

Modifications to flow regime, whether natural (i.e., drought) or human-induced (i.e., water withdrawal or diversion), can also affect the functional organization of the fish community (Bunn and Arthington, 2002). Pusey and others (1993) found that the fish assemblages in streams that experienced extended periods of low flow became dominated by small, physiologically tolerant, and feeding generalist species. Among the LFM stations, the proportion of tolerant species was higher at low flow than baseline flow at 59 percent of the stations and the proportion of intolerant species was lower at 65 percent of the stations (see Table 5). Feeding generalists were more common during low flow than baseline flow at 53 percent of the stations, while specialist insectivores were less common at 65 percent of the stations (see Table 5). The percentage of herbivores was higher during low flow than baseline flow at 65 percent of the stations (see Table 5). The only herbivorous fish found at the pilot study stations was the central stoneroller, which is also a riffle obligate. It is possible that increased food supply during low flow in the form of filamentous algae, which prefers slower water velocities (Suren and others, 2003a) allowed stonerollers to proliferate despite reductions in their preferred higher velocity habitat type. Evans-White and others (2003) found that algae constituted 47 percent of the diet of stonerollers in Kansas streams.

PERIPHYTON

Although studies addressing the effects of flow on macroinvertebrates and fish have become more common in recent years, the body of literature regarding responses of periphyton communities to changes in flow is limited. Most studies examining the effects of flow on periphyton communities have been in the context of how changes in algal communities affect higher trophic levels (Suren and others, 2003b; Riseng and others, 2004; McKay and King, 2006; Dewson and others, 2007b). Table 6 lists the expected changes in metrics between baseline flow and low flow sampling periods and the percentages of stations where the expected changes were observed. Five periphyton metrics showed the expected change between baseline flow and low flow conditions at a majority (greater than 65 percent) of stations. These metrics included diatom species richness, soft-bodied algae species richness, percent dominant, the disturbance index, and chlorophyll-a concentration.

Diatom species richness was lower during low flow than baseline flow at 65 percent of stations and soft-bodied algae species richness was higher during low flow at 82 percent of the stations (see Table 6). Biggs and Close (1989) found that flow regime, particularly water velocity, plays an important role in periphyton development in cobble-bed streams and can affect colonization, production, and mortality rates. Periphyton assemblages in riffle-dominated streams are characterized by prostrate diatoms, which benefit from increased nutrient delivery rates at high velocities, whereas streams with slow velocities have communities dominated by soft-bodied filamentous algae, which can be damaged by high flows (Biggs and others, 1998). Suren and others (2003b) found that low flow conditions can bring about proliferation of certain types of filamentous algae that cause habitat degradation through reduced oxygen levels, high pH, and clogging of interstitial spaces used by macroinvertebrates and small fish. Streams with a high degree of nutrient enrichment (i.e., high levels of nitrogen, phosphorus, and their compounds) may be particularly prone to algal overgrowth during low flows. Nutrient enrichment is prevalent in the Juniata River Subbasin (LeFevre, 2005; Campbell, 2011), although not to the degree that it occurs in the heavily agricultural and urbanized Lower Susquehanna River Subbasin (Campbell, 2012).

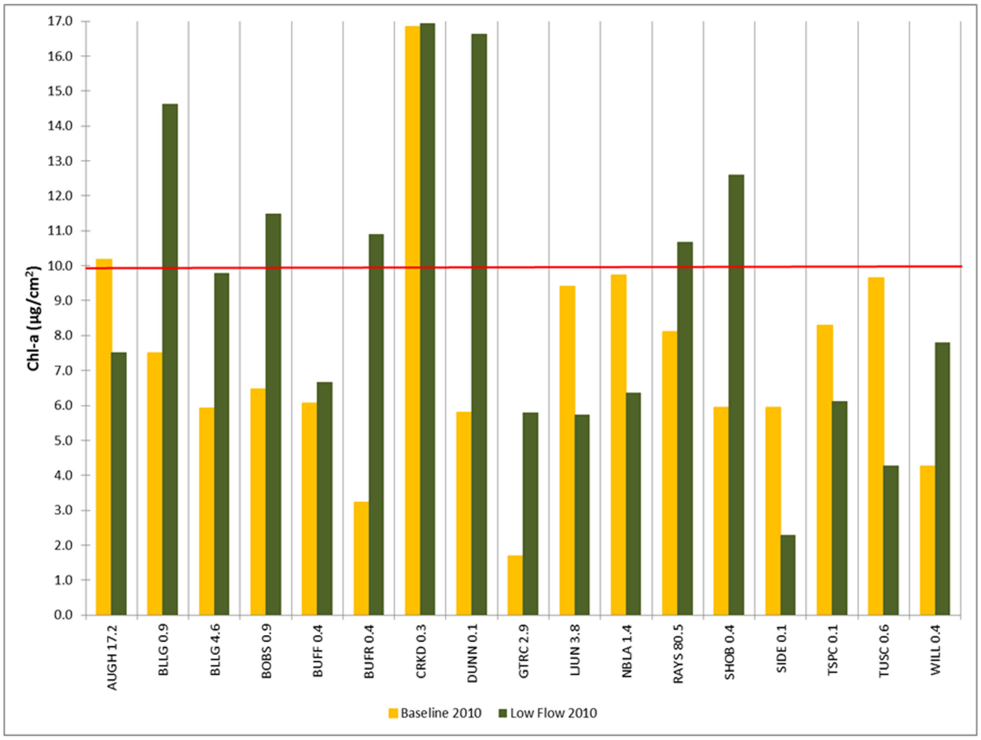

Figure 5. Chlorophyll-a Concentrations (µg/cm²) at the Low Flow Monitoring Pilot Study Stations in 2010

The percentage of the assemblage represented by the dominant diatom taxon was higher during low flow than baseline flow at 76 percent of the stations (see Table 6). This finding, combined with the decreased diatom taxa richness during low flow, supports the hypothesis that diatom communities are negatively impacted by reduced flows. The dominance metric was influenced by the disturbance index, which measures the percentage of the assemblage comprised of the pioneer diatom species *Achnanthidium minutissimum*. The disturbance index was higher during low flow at 82 percent of the stations (see Table 6). This is an expected result because this species becomes increasingly abundant with increasing temporal distance from a scour (i.e., high flow) event (Barbour et al., 1999).

Table 6. List of Periphyton Metrics, Expected Metric Changes Between Baseline Flow and Low Flow, and the Percentage of Expected Changes Observed

Metrics	Expected Change	Percent of Stations with Expected Changes Observed
Diatom Species Richness	decrease	65%
Soft Bodied Algae Species Richness	increase	82%
Percent Dominant	increase	76%
Disturbance Index (% *A. minutissima*)	increase	82%
Siltation Index	increase	35%
Diatom Model Affinity	decrease	29%
Chlorophyll-a Concentration	increase	65%

Chlorophyll-a (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 are indicative of algal growth at nuisance levels (Welch and others, 1988) and chl-a greater than 20 µg/cm^2 indicate eutrophic conditions (Paul, 2012). Periphyton chl-a was higher during low flow than baseline flow at 65 percent of the stations (Figure 5). Concentrations occurred at nuisance levels at two stations during baseline flow and seven stations during low flow, although no stations had chl-a concentrations greater than 20 µg/cm^2. McKay and King (2006) also found increases in chl-a concentration following water extraction from streams in Australia. Suren and others (2003a) found that chl-a concentration increased during a drought in a river with high nutrient enrichment but remained constant in a river with low nutrient enrichment.

A Northern Pike (*Esox lucius*) collected from Dunning Creek, Bedford County, Pa., in June 2011.

CONCLUSIONS

Despite the fact that flooding in fall 2011 prevented SRBC staff from collecting a second year of P95 data, the results of the Low Flow Monitoring Pilot Study provided useful information to guide future low flow monitoring efforts in the Susquehanna River Basin. Several biological metrics for macroinvertebrates, fish, and periphyton showed potential sensitivity to changes in flow. However, it is important to remember that this study compared only two points in time, making it impossible to separate seasonal and other factors as possible drivers for observed differences. It will require several years of sampling in both drought and normal flow years before relationships between flow and biological communities can be established.

FUTURE OF LOW FLOW MONITORING IN THE SUSQUEHANNA BASIN

SRBC established a basin-wide Low Flow Monitoring Network in 2012. The network consists of 19 stations in the Pennsylvania and New York portions of the Susquehanna River Basin (Figure 6). There are six stations located in the Northern Appalachian Plateau and Uplands, six in the North Central Appalachians ecoregions, and seven stations located in the Central Appalachian Ridges and Valleys ecoregion. The network focuses on forested streams in an attempt to isolate effects related to flow from anthropogenic impacts.

Eleven of the Low Flow Monitoring Network 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 temperature, pH, conductance, dissolved oxygen, turbidity, and water depth. Water depth measurements can be used to establish a relationship with streamflow. SRBC staff installed InSitu, Inc. Level TROLL loggers to record temperature and water-depth at the other eight Low Flow Monitoring Network stations in June 2012. Having a continuous temperature and flow record will allow for a better correlation between these factors and biological communities.

SRBC staff will sample each station in the Low Flow Monitoring Network twice annually during the natural low flow period (June – September): once during a period of higher baseline flow (seasonal P50 or median flow) and again during a period of low flow characterized by the seasonal P95 flow. If streams never reach seasonal P95 flows, a second sampling round will still be conducted in September to document conditions during a "normal" baseline flow year. Should a prolonged drought occur in a given year, staff may conduct additional sampling to document potential impacts of extreme and sustained low flows on water quality and biological communities.

Data collection will closely follow the procedures outlined in the Low Flow Monitoring Pilot Study, including:

- Field water chemistry analysis, including temperature, pH, dissolved oxygen, and specific conductivity;
- Laboratory water quality analysis;
- Biological community data, including fish, macroinvertebrates, periphyton (algae), and the presence of any invasive species;
- Physical habitat data, including stream channel, stream bank, and riparian area conditions; and
- Streamflow measurements.

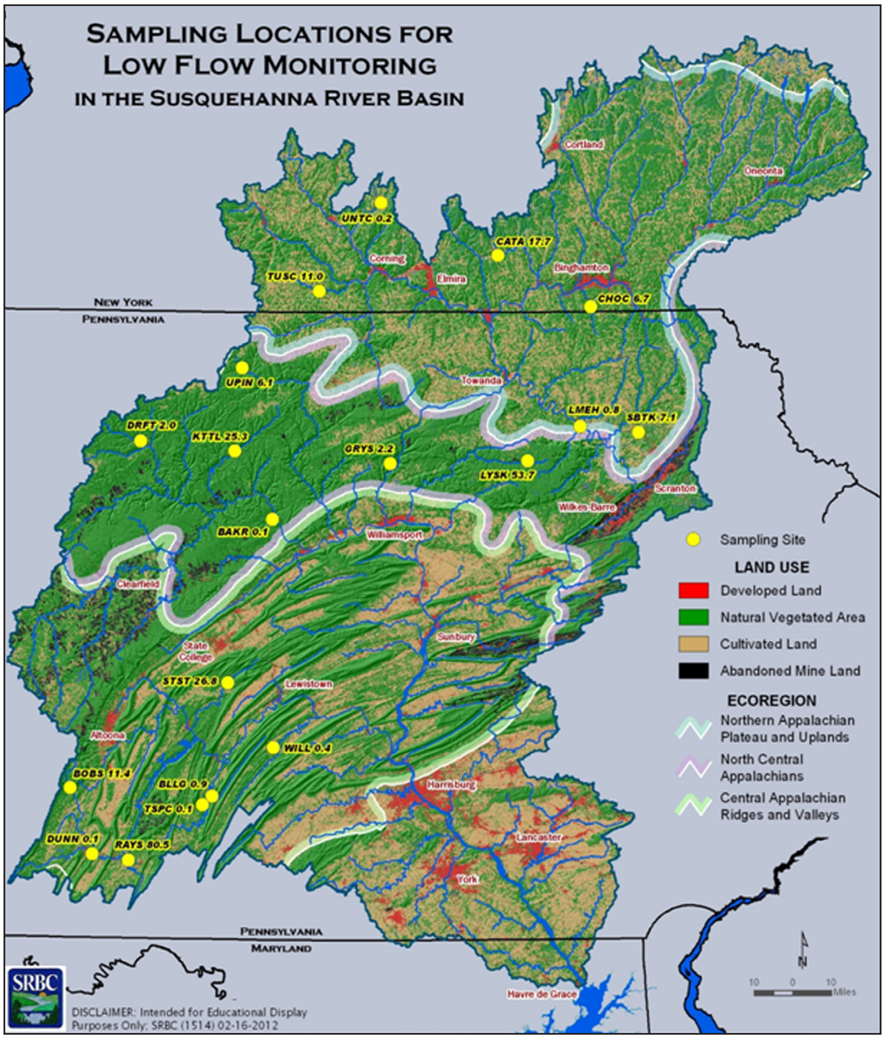

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Figure 6. Location of the Low Flow Monitoring Network Stations in the Susquehanna River Subbasin


Commission staff measuring flow at Buffalo Creek, Perry, Co., Pa., during baseline flow in 2010.

These data will be used to characterize "normal" conditions during baseline flow and low flow, as well as to compare water quality and biological communities associated with different flows. Data collected as part of the newly established Low Flow Monitoring Network will be used to advise management decisions regarding low flow mitigation and passby flows associated with surface water withdrawals, and to improve knowledge of changes associated with naturally occurring low flow conditions.

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APPENDIX A

Station Names, Location Descriptions, Geographic Coordinates, and Drainage Areas for Low Flow Monitoring Pilot Study Stations

Station Name	Location Description	Latitude	Longitude	Drainage Area (m^2)
AUGH 17.2	Aughwick Creek downstream of Three Springs Creek and Rt. 994 near Pogue, Huntingdon Co.	40.21542	-77.92717	203.9
BLLG 0.9	Blacklog Creek along T599 upstream of Rockhill and Orbisonia, Huntingdon Co.	40.24054	-77.89502	66.4
BLLG 4.6	Blacklog Creek upstream of Peterson Road Bridge, upstream of Shade Creek, Huntingdon Co.	40.23172	-77.8633	34.1
BOBS 0.9	Bobs Creek at tractor crossing, near Reynoldsdale, Bedford Co.	40.15096	-78.54532	64.1
BUFF 0.4	Buffalo Creek upstream of SR 1007 (Fairground Road) covered bridge, near Newport, Perry Co.	40.48906	-77.15807	67.3
BUFR 0.4	Buffalo Run upstream of Route 31/96 bridge in Manns Choice, Bedford Co.	40.00201	-78.59735	24.2
CANO 5.1	Canoe Creek, upstream of Canoe Creek State Park, along SR 1011, Blair Co.	40.52815	-78.25041	8.6
CRKD 0.3	Crooked Creek upstream of SR 3033 bridge in Huntingdon, Huntingdon. Co.	40.48039	-78.02143	26.9
DUNN 0.1	Dunning Creek near mouth upstream SR 1001, near Bedford, Bedford Co.	40.02433	-78.47794	196.4
FRNK 18.9	Frankstown Branch Juniata River at USGS gage in Williamsburg, Blair Co.	40.46309	-78.20009	289.3
GTRC 2.9	Great Trough Creek upstream of T370 bridge near Newburg, Huntingdon Co.	40.28637	-78.12104	71.5
HONY 0.2	Honey Creek near mouth in Reedsville, Mifflin Co.	40.66347	-77.59253	93.6
JACK 2.9	Jacks Creek upstream SR 2004 east of Lewistown, Mifflin Co.	40.61305	-77.53219	57
JUNR 34.0	Juniata River at Route 35 bridge in Mifflintown, Juniata Co.	40.56889	-77.40067	2838
JUNR 47.0	Juniata River at Route 103 bridge upstream of Kishacoquillas Creek in Lewistown, Mifflin Co.	40.59352	-77.57842	2518.4
JUNR 63.6	Juniata River on both sides of the island at bridge in McVeytown, Mifflin Co.	40.49817	-77.73621	2454.8
JUNR 84.6	Juniata River at bridge in Mapleton, Huntingdon Co.	40.3946	-77.93979	2026.8
JUNR 94.9	Juniata River at 4th Street bridge in Huntingdon, Huntingdon Co.	40.48258	-78.01178	846.2
KISH 5.5	Kishacoquillas Creek in Jacks Mountain gap near Burnham, Mifflin Co.	40.65472	-77.58333	163
LJUN 3.8	Little Juniata River at SR 4004 bridge in Barree, Huntingdon Co.	40.58703	-78.10042	335.2
NBLA 1.4	North Branch Little Aughwick Creek upstream T457 bridge near Burnt Cabins, Fulton Co.	40.09193	-77.90921	18
RAYS 80.5	Raystown Branch Juniata River upstream of Greys Run east of Everett, Bedford Co.	40.00466	-78.30017	546
SHAV 17.0	Shaver's Creek downstream of Route 26 in Penn State Experimental Forest, Huntingdon Co.	40.69245	-77.8949	3.9
SHOB 0.4	Shobers Run along Business Route 220 downstream of Bedford Springs, Bedford Co.	39.99889	-78.50361	16.3
SIDE 0.1	Sideling Hill Creek at mouth near Maddensville, Huntingdon Co.	40.13057	-77.95726	96.7
STST 26.8	Standing Stone Creek at SR 1023 bridge near McAlevys Fort, Huntingdon Co.	40.65185	-77.82278	34
TIPT 3.0	Tipton Run along SR 4023 near Tyrone, Blair Co.	40.65534	-78.3281	15.6
TSPC 0.1	Three Springs Creek upstream of T341 near Pogue, Huntingdon Co.	40.20794	-77.94091	30.9
TUSC 0.6	Tuscarora Creek near mouth at Route 75/Route 333 bridge in Port Royal, Juniata Co.	40.52816	-77.39193	269.5
WILL 0.4	Willow Run near mouth at T305 bridge near McCullochs Mills, Juniata Co.	40.41852	-77.59602	10.5

SUSQUEHANNA RIVER BASIN COMMISSION

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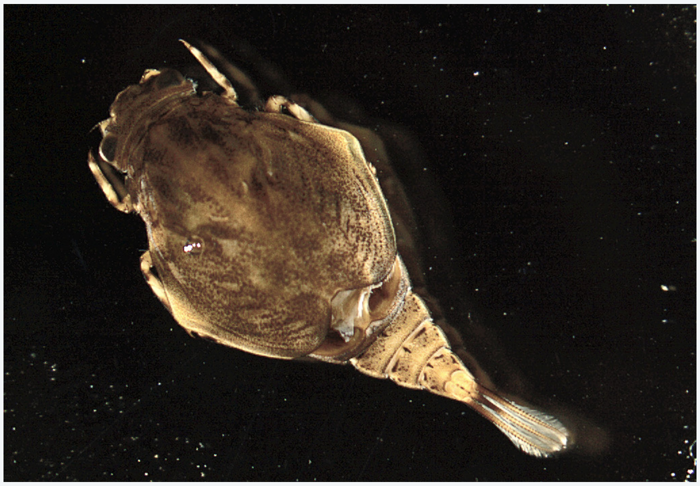

Maintaining natural flow regimes is critical to conserving the native biodiversity of freshwater systems.

Flood damage reduction and low flow mitigation planning are ongoing priorities of the Susquehanna River Basin Commission.

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