Remote Water Quality Monitoring Network/
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SRBC
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Background

The Susquehanna River Basin Commission (SRBC) Remote Water Quality Monitoring Network (RWQMN) began continuously measuring and reporting water quality conditions in small streams that could potentially be impacted by the natural gas industry in January 2010. Eleven of these stations are located on Pennsylvania state forest lands and five others either drain significant portions of state forest lands or are heavily drilled watersheds that flow into and through state forest lands and are of interest to PADCNR (Table 1; Figure 1).

Table 1. PADCNR Priority Watersheds (Well densities represent 2018 densities from PADEP spud data: http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Spud_External_Data. Stations using satellite telemetry are indicated with a 1.)

Watershed	Percent State Forest Lands	Fractured Well Density (number of wells per mi^2)	Located on State Forest Lands
Baker Run[1]	86	0.45	Yes
East Fork Sinnemahoning Creek	94	0.13	Yes
Grays Run	34	1.83	Yes
Hicks Run[1]	34	0.15	Yes
Hunts Run[1]	74	0.00	No
Kettle Creek[1]	68	0.07	No
Little Pine Creek	13	0.98	Yes
Marsh Creek in Tioga County[1]	34	0.67	Yes
Moose Creek	98	0.13	Yes
Ninemile Run	73	0.12	Yes
Pine Creek	36	0.34	Yes
Pleasant Stream[1]	82	0.00	Yes
Sterling Run	11	0.37	No
Upper Pine Creek	28	0.00	Yes
West Pine Creek	67	0.01	No
Young Womans Creek	98	0.00	No

The initial 10 monitoring stations on state forest lands were installed in 2011; the station on Pleasant Stream was moved upstream from its original location onto state forest land in 2017. The other stations were installed between 2010 and 2014. The data sondes at each station monitor pH, temperature, dissolved oxygen (DO), specific conductance (SpCond), and turbidity at 15 minute intervals. Data are posted on a public website as provisional data (www.srbc.net/remotewaterquality/). Stations using satellite telemetry post a 4-hr average every four hours while stations using cellular telemetry post each 15-minute reading every two hours to the website. The telemetry method used is split 6 to 10 between the 16 stations, with the majority of sites using cellular telemetry. The continuously monitored parameters are supplemented by frequent discrete water quality sampling as well as biological community assessments, including fish and aquatic macroinvertebrates.

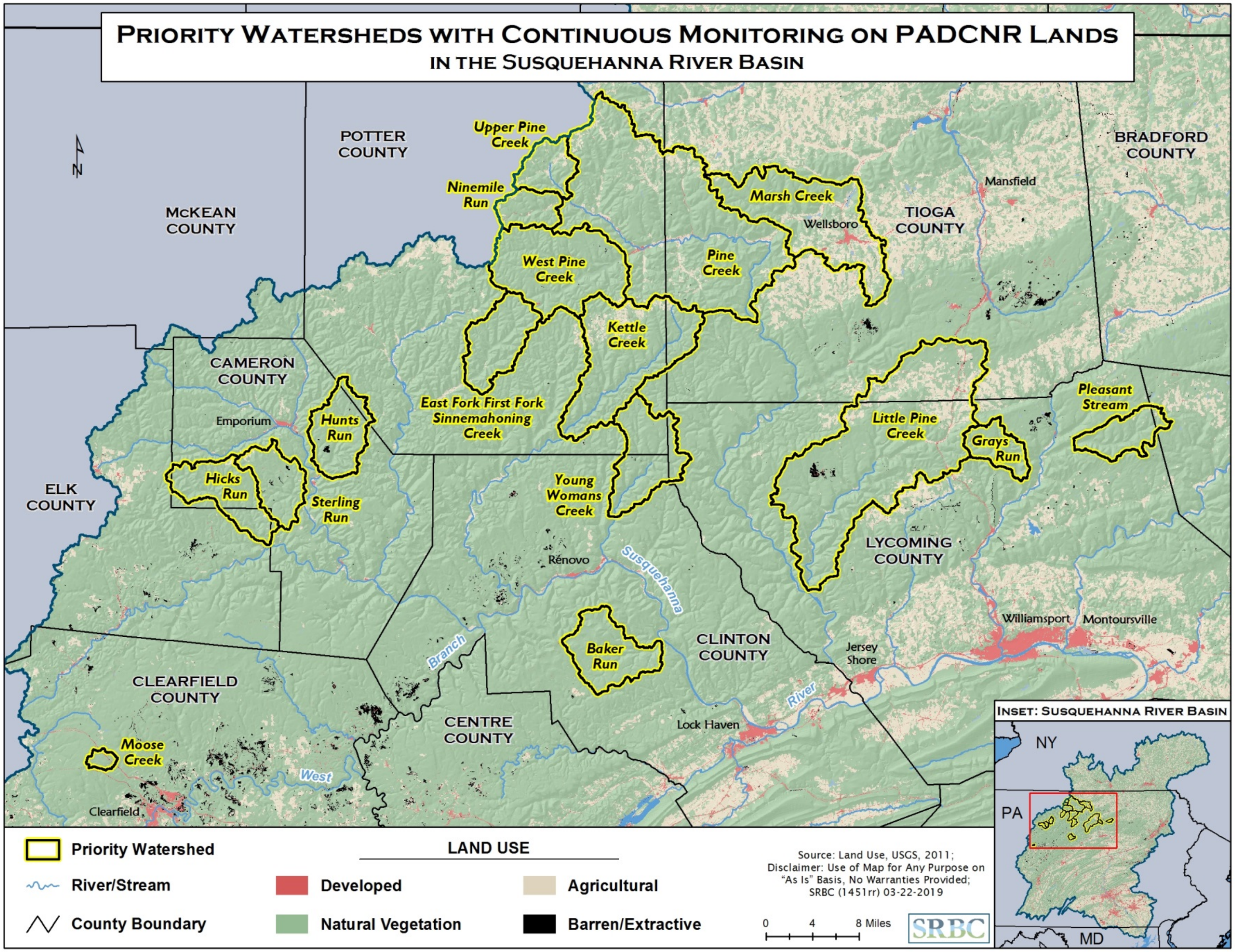

Figure 1. Priority Watersheds with Continuous Monitoring on PADCNR Lands

Continuous Water Chemistry Data

Specific conductivity, turbidity, and water temperature are the three continuous monitoring parameters that would likely show an immediate, real-time change if natural gas drilling activities in the Susquehanna River Basin (Basin) are leading to degraded stream conditions. Chemicals used in natural gas fracking typically have very high specific conductance and any spill or leak would raise the specific conductance of the stream. Infrastructure (roads, pipelines, well pads, etc.) have the potential to increase the volume of sediment in surface water systems. The increased sediment will increase turbidity. The final monitoring parameter is stream temperature. Canopy cover within a watershed shields streams from the sun and helps to maintain a cooler stream temperature. Unconventional natural gas wells are constructed on large cleared pads; in forested areas, trees must be removed to create the pad. Many stream organisms can only tolerate certain thermal regimes, so water temperature is an important parameter to track and see if temperature rises as the fragmentation of forested land continues due to natural gas development or other sources and percentage of forested lands decreases. Average continuous parameter values for specific conductivity, turbidity, and temperature from station installation date through 2018 are listed in Table 2.

Table 2. Average Continuous Parameter Values from Installation through December 31, 2018

Watershed	SpCond. (µS/cm)	Turbidity (NTU)	Temperature (˚C)
Baker Run	27	3.1	9.00
East Fork Sinnemahoning Creek	45	2.9	9.34
Grays Run	32	3.2	9.14
Hicks Run	53	7.5	10.12
Hunts Run	35	2.5	9.25
Kettle Creek	56	4.7	10.15
Little Pine Creek	119	4.2	11.37
Marsh Creek in Tioga County	169	15.8	10.36
Moose Creek	146	2.5	8.80
Ninemile Run	59	6.0	8.66
Pine Creek	89	16.0	11.39
Pleasant Stream	39	7.0	9.58
Sterling Run	74	4.4	9.77
Upper Pine Creek	77	4.7	9.04
West Pine Creek	47	6.6	10.11
Young Womans Creek	39	2.4	9.25

Overall, the 16 stations exhibit low specific conductivity; only three stations had concentrations greater than 100. Boxplots were used to show the monthly mean specific conductivity at each station (Figure 2). The boxplots indicate little variability in specific conductance concentrations at the majority of sites. Little Pine Creek, Marsh Creek in Tioga County, and Moose Creek were the three sites with the greatest range in their specific conductivities (Figure 2), but also had the highest average concentrations (Table 2). Little Pine Creek is a large watershed, and the station is downstream of a reservoir. The station on Marsh

Creek is downstream of Wellsboro, PA, which has numerous permitted dischargers. Moose Creek is a small watershed (3 mi^2) that is greatly impacted by Interstate Route 80. Road salt applied during the winter months enters the stream during snow melt and runoff, raising the specific conductivity.

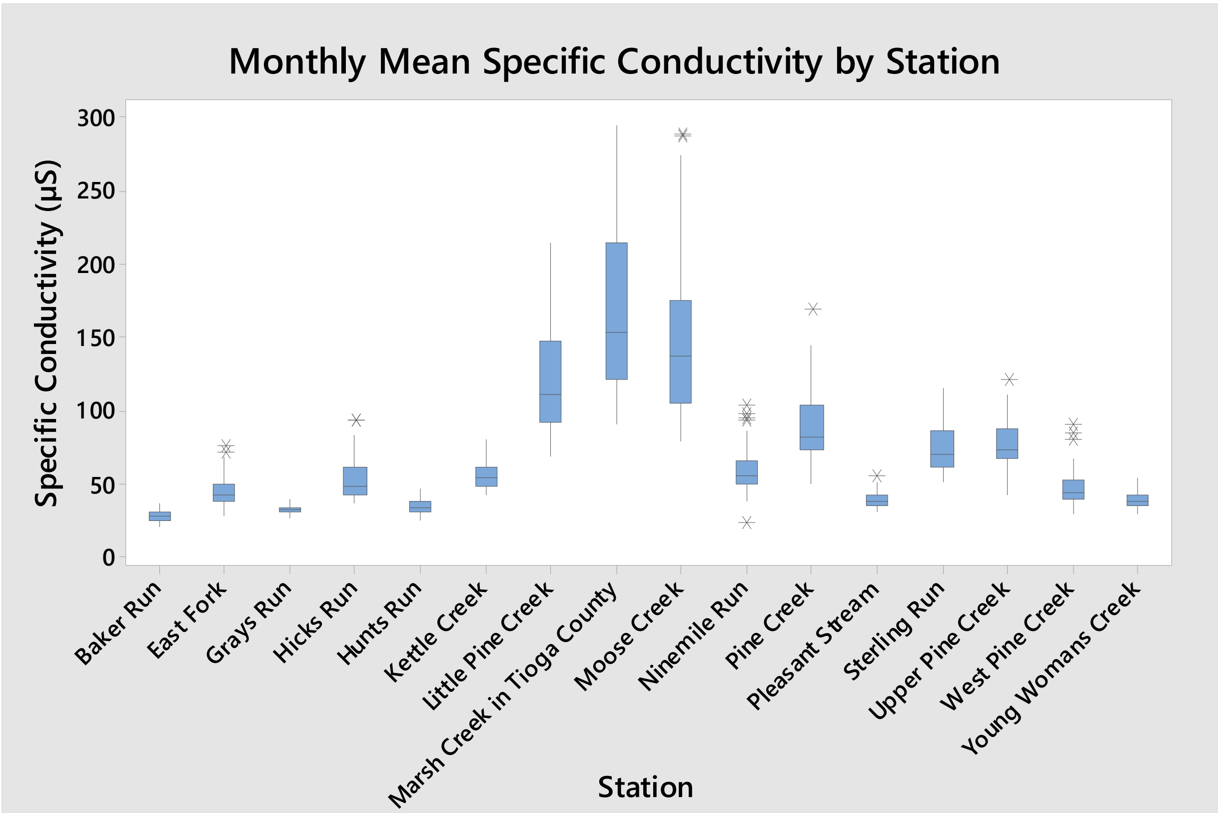

Figure 2. Boxplot of Average Monthly Specific Conductivity Concentrations for the Period of Record

Generally, turbidity concentrations are low across the sites and all but two sites have averages of less than 10 NTU. The highest average turbidity values are seen in Marsh Creek in Tioga County and Pine Creek (Table 2). Marsh Creek is a slow, meandering stream impacted by agriculture and urban influences. These characteristics mean that Marsh Creek takes longer to flush sediment and runoff related to a storm event. Pine Creek is a large stream, which tend to have higher turbidity values as it drains a larger area. Of the 16 stations, these two had the most variable turbidity concentrations (Figure 3). These two sites are also significantly different (α=0.05) from the other 14 sites.

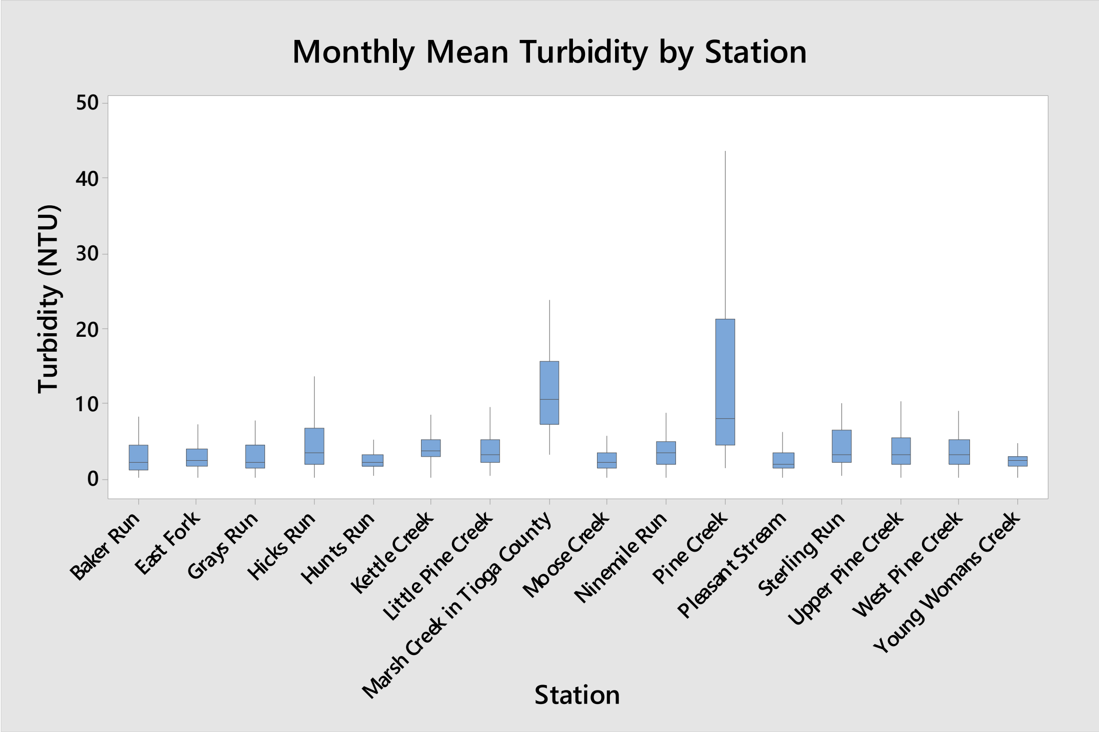

Figure 3. Boxplot of Average Monthly Turbidity Concentrations for the Period of Record

The majority of the PADCNR-RWQMN stations of interest are in highly forested watersheds with ample canopy cover. Average stream temperatures were cool (Table 2) and were not significantly different from each other (Figure 4).

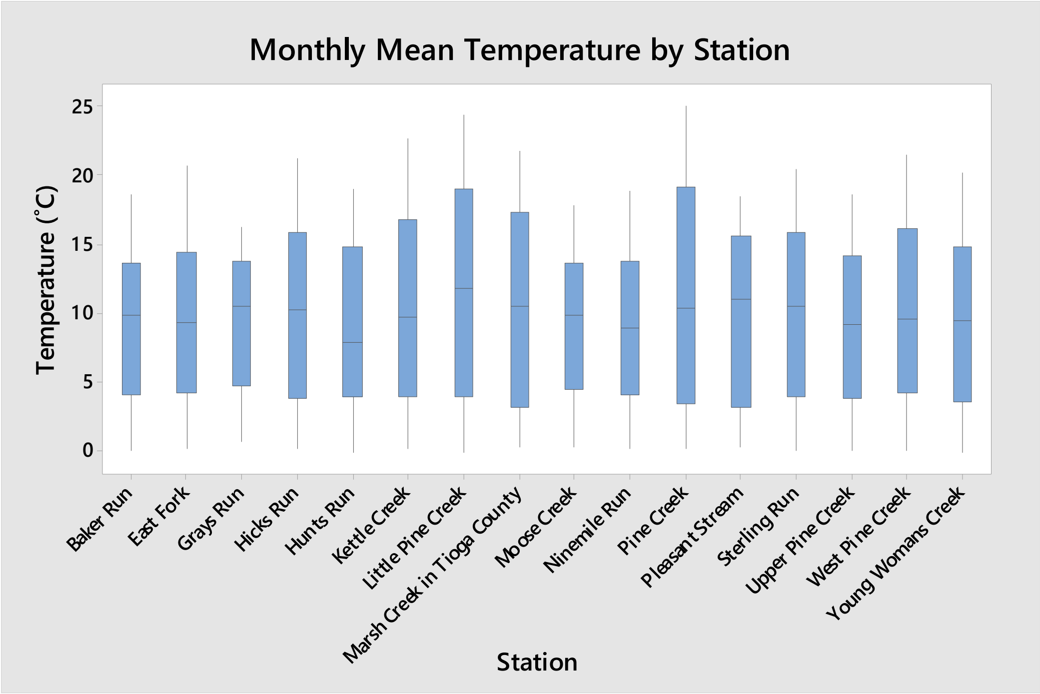

Figure 4. Boxplot of Average Monthly Temperature for the Period of Record

Discrete Water Chemistry Data

SRBC staff collects discrete samples on a quarterly basis to monitor additional water chemistry parameters of interest. Water chemistry impacts ecosystem health and the kinds of biota a stream can support. It also provides information on what pollutants may be entering the stream and in what concentrations over a long period of time. Baseline levels for some of the water chemistry parameters have been established and have not changed, so they have been dropped from the quarterly collection list. Twenty water chemistry parameters were collected and listed in Table 3. A newly-developed Water Quality Index (WQI) for the Basin allows for the synthesis of water quality data into a score that is comparable over time as well as between sites (Berry et al., 2019). The WQI score is based on a 0-100 scale where the greater the number, the better the water quality. The nine parameters used in the WQI are collected with each grab sample in addition to general chemistry parameters and metals associated with natural gas drilling (Table 3).

Table 3. Water Chemistry Parameters (The left column is made up of parameters that were previously part of the routine sampling, but are no longer collected. The middle column lists the nine parameters that are collected and used in the SRB Water Quality Index (WQI). The right column lists the remaining parameters that are collected quarterly. Parameters most often associated with UNG are indicated with ꞁ.)

Parameters No Longer Collected	Parameters Collected and Included in the SRB WQI	Additional Parameters Collected
Alkalinity, Bicarbonate	Aluminum	Alkalinity
Alkalinity, Carbonate	Chloride	Bariumꞁ
Carbon Dioxide	Iron	Bromideꞁ
Gross Alphaꞁ	Manganese	Calcium
Gross Betaꞁ	Nitrate	Hot Acidity
Lithiumꞁ	Phosphorus	Magnesium
	Sodium	pH
	Sulfate	Potassium
	Total Organic Carbon	Specific Conductance
		Strontiumꞁ
		Total Dissolved Solids

Of the 20 parameters currently being sampled, only three failed to meet water quality standards or levels of concern, on average. Fourteen stations had naturally low alkalinity below the water quality standard. Low alkalinity indicates a low buffering capacity, so these streams are more vulnerable to even small acidic inputs, which cause altered stream chemistry and are detrimental to aquatic life. Marsh Creek in Tioga County and Pine Creek at Blackwell were the only two sites to have average alkalinities above the 20 mg/l PA water quality standard, with 43.8 and 24.1 mg/l, respectively. Marsh Creek met the alkalinity standard 100 percent of the time while Pine Creek at Blackwell met it 57 percent of the time.

The average nitrate concentration exceeded the level of concern (0.6 mg/l) at Upper Pine Creek (0.76), and was close to the level of concern at Marsh Creek and Ninemile Creek (0.58 and 0.56 mg/l, respectively). Upper Pine Creek has no stream impairments and is designated as a high-quality cold water fisheries, but consistently exceeded the level of concern for nitrate (90 percent of samples). The last parameter, sodium, had one station exceeding its level of concern (20mg/l). The average sodium concentration at Moose Creek was 21.3 mg/l. As previously mentioned, Moose Creek's proximity to I-80 is likely the cause of elevated sodium levels. Overall, discrete water chemistry samples indicate that these 16 streams are meeting water quality standards and levels of concern with a few exceptions.

All but two sites had medians and averages in the good or excellent Tier I WQI categories. Marsh Creek in Tioga County had poor water quality and Moose Creek had fair water quality when compared to the Basin overall (Figure 45. The road salts from I-80 are elevating both chloride and sodium levels and are likely the reason this highly forested watershed falls into the fair category. Marsh Creek consistently had elevated metals and nutrient concentrations compared to the other sites on PADCNR lands. The monitoring site at Marsh Creek has the least forested lands of the state forest sites. The site drains 78 square miles, one quarter of which are agricultural lands. Additionally, inputs from 12 wastewater treatment plants and eight industrial discharges flow into Marsh Creek above the station.

Of the 16 RWQMN stations of interest to PADCNR, most are in largely forested watersheds (Table 1) and support excellent biological communities. A majority of sites (13 of 16) are located on stream segments that are designated by PADEP as Exceptional Value (EV) or High Quality (HQ). The three sites without EV/HQ designations are Little Pine Creek, Marsh Creek, and Sterling Run. Baker Run achieved the highest WQI score in the entire Basin. In addition to Baker Run, Young Womans Creek, Pleasant Stream, and Grays Run all consistently scored within the top 99th percentile of all sites in the Basin. Marsh Creek had the lowest mean WQI score of the 16 PADCNR RWQMN stations of interest and consistently fell into the poor category (Figure 5).

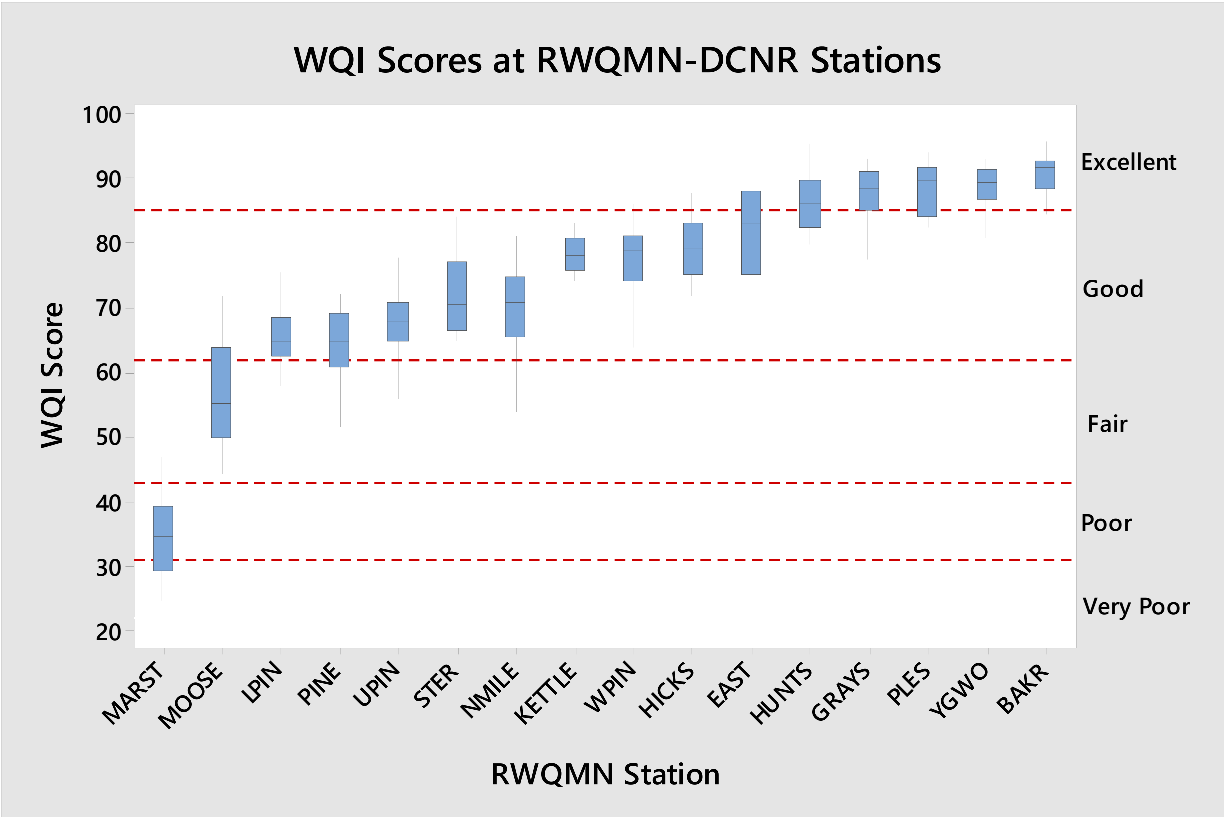

Figure 5. Boxplots of WQI Scores at the 16 RWQMN Stations of Interest (Categorical water quality classifications and cutoffs are on the right side of the plot. WQI category ranges are Excellent >85; Good 62-85; Fair 43-62; Poor 31-43; and Very Poor <31.)

Biology

Macroinvertebrates

Macroinvertebrate community assemblage analysis takes both habitat and water quality conditions of a stream into consideration. A sensitivity gradient exists for macroinvertebrates that assigns/ranks their tolerance to pollution on a 0-10 scale, where the lower the number, the more sensitive or intolerant they are to pollution. Beginning in 2015, macroinvertebrates have been collected annually for EV/ HQ streams; data from the October 2015 sample of the three non-EV/HQ streams have been included to represent their communities although they are outside of the Index of Biotic Integrity (IBI) sample period (PADEP, 2013). Sampling was conducted using the PADEP Freestone Streams (PADEP, 2013) collection protocol of compositing six D-frame kicks into one sample and subsampling to a 200 (± 20) individual count. Subsampled organisms were identified by a certified taxonomist to genus when possible, with the exception of Chironomidae, which remained at the family level, and Oligochaeta, which was identified to class. The taxa identified in the subsample were scored through six different community metrics that were combined to determine an IBI score (PADEP, 2013). This score is based on a 0-100 scale and represents the quality of the macroinvertebrate assemblage.

WQI scores and IBI scores are strongly correlated (Berry et al., 2019). In this small 16 site sample, a significant relationship also existed (p= 0.011, α= 0.05) and accounted for ten percent of the variation (Figure 6).

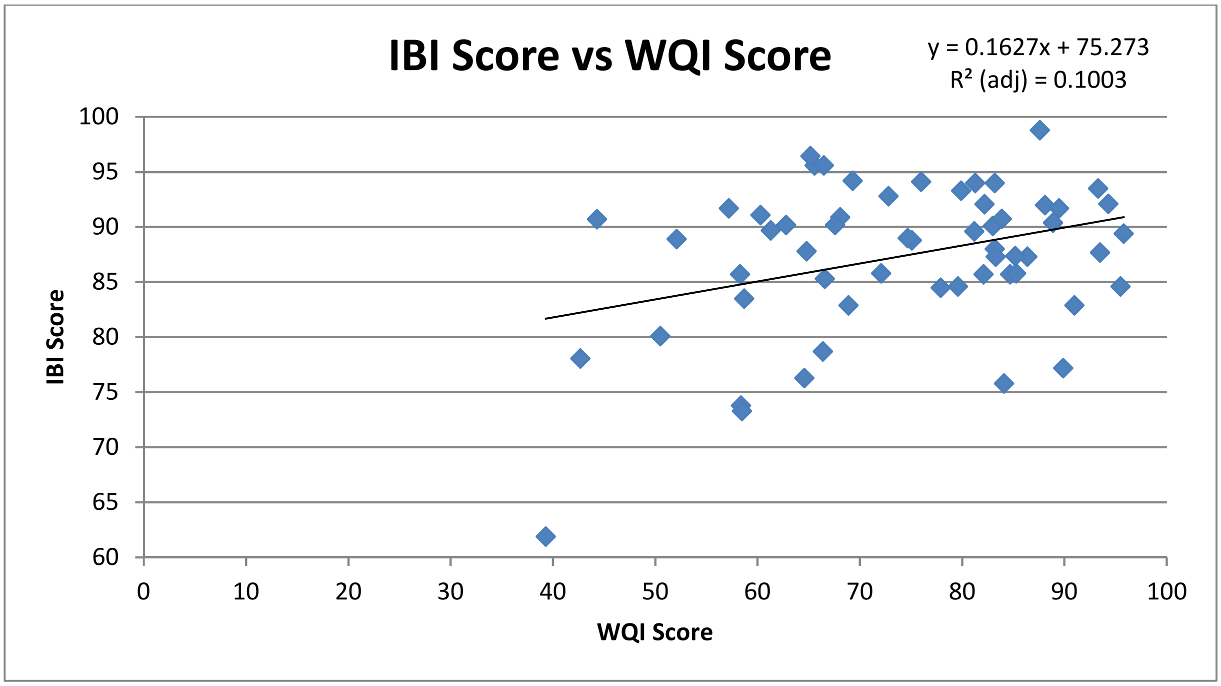

Figure 6. PADEP IBI Score vs. SRB WQI Score Shows a Strong Correlation for the 16 RWQMN Stations

Streams with IBIs greater than 78 are said to have excellent macroinvertebrate assemblages and streams with IBIs below 53 are considered poor (PADEP, 2013). All IBI scores for stream sampling locations from 2015-2018 were well above 53 and all sites except for Marsh Creek met the excellent benchmark. Marsh Creek consistently has had the lowest IBI scores of the 16 sites (Figure 7). The reach of Marsh Creek near the monitoring station has deep, slow moving pools with few riffles – poor habitat for macroinvertebrates.

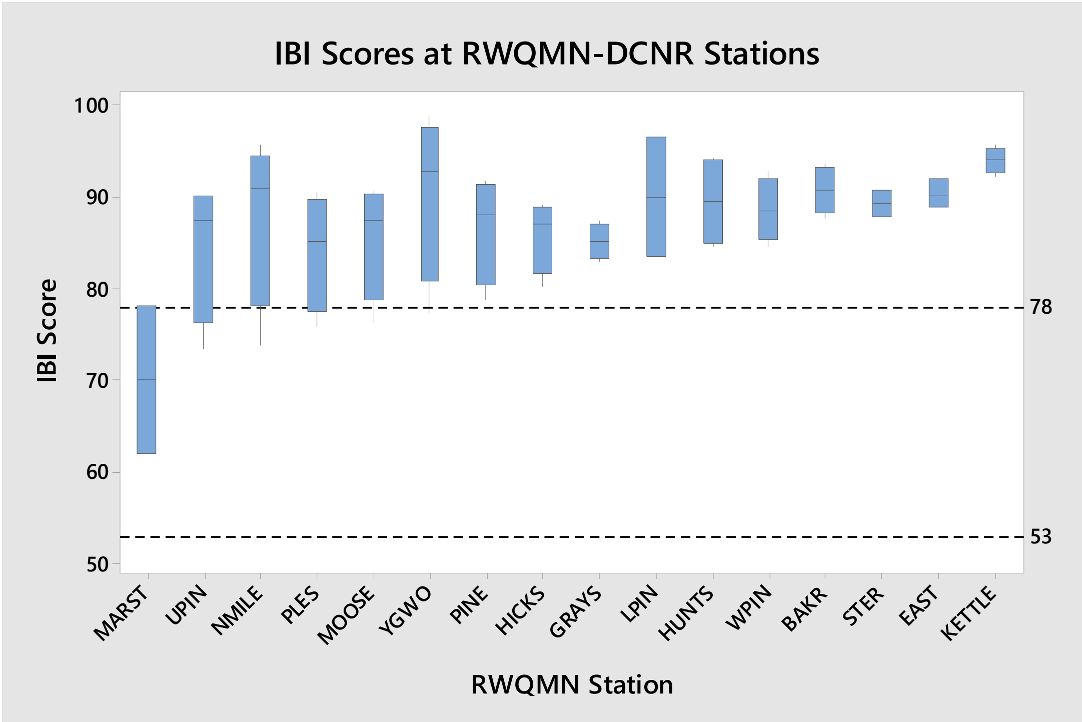

Figure 7. ***Boxplot of IBI Scores at 16 DCNR-RWQMN Sites (2015 IBI scores for these sites were collected in a different index period and thus have inherent differences. Little Pine Creek, Marsh Creek, and Sterling Run all had lower sample sizes because they are not EV/ HQ sites and are sampled on a less frequent rotational basis than the annual EV/ HQ survey. IBI scores less than 53 are considered poor; scores greater than 78 are said to have an excellent macroinvertebrate community (PADEP, 2013).)***

A non-metric multi-dimensional scaling (NMDS) ordination was run to spatially visualize similarities in macroinvertebrate community composition, where the closer the samples, the more similar their community compositions are. By assigning explanatory factors to each sample (e.g., year, size, ecoregion), plots can be used to assess groupings within all samples. Three macroinvertebrate samples from 2015 were collected outside of the November–May index period and were excluded from the NMDS plot as they have inherent seasonal differences from the rest of the samples. IBI scores from fall 2015 were included despite the difference in index period because these sites were not EV/HQ and so differences in overall IBI should be minimal. Samples from the same site generally clustered together. Some separation (e.g., samples from the same site not being directly on top of one another) is due to natural variation and slight differences in instream sample location. Moose Creek is further from the majority of sites, indicating differences in its community composition (Figure 8).

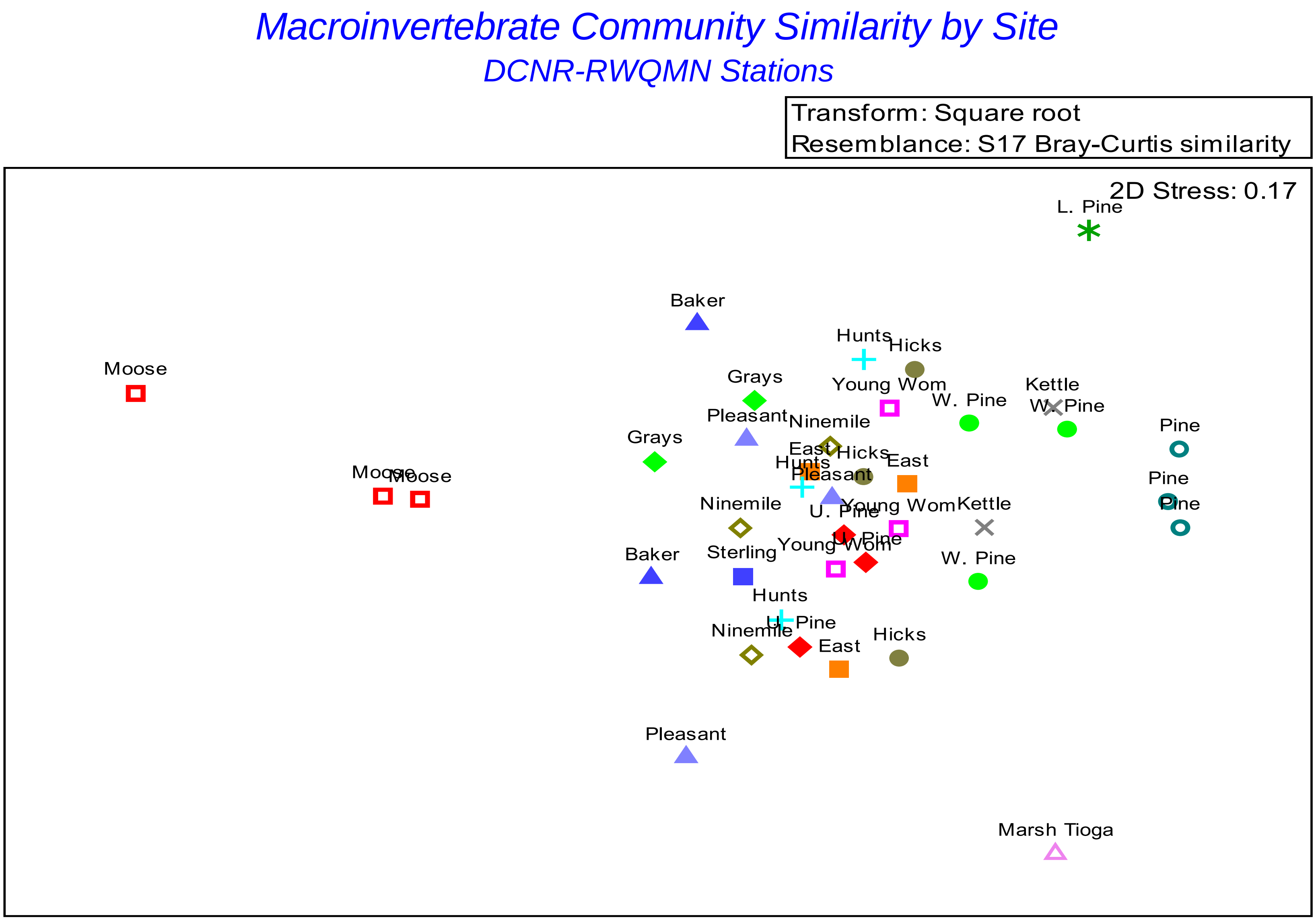

Figure 8. NMDS Plot of Macroinvertebrate Assemblage Similarity by Site (Sites closer together have similar macroinvertebrate communities.)

The symbology of the NMDS plot was changed to show the clustering of sites by drainage area and which category the mean WQI score fell into (Figure 6). With relatively good water quality across the majority of these sites, the availability of suitable habitat is likely determining macroinvertebrate assemblages. WQI category ranges are: >85, Excellent; 62-85, Good; 43-62, Fair; 31-43, Poor; and <31, Very Poor (Berry et al., 2019). Aquatic Resource Class (ARC) is a SRBC classification based on watershed drainage area: ARC 1, 0-10 mi^2; ARC 2, 10-50 mi^2; ARC 3, 50-200 mi^2; ARC 4, 200-1000 mi^2; ARC 5, 1000-5000 mi^2; ARC 6 greater than 5000 mi^2 (SRBC, 2012). Aside from Marsh Creek, water quality did not influence how macroinvertebrate communities clustered; sites with fair, good, and excellent water quality grouped together (Figure 9). Communities were significantly different and separated from left to right based on watershed size (ARC; p= 0.001) (Figure 8).

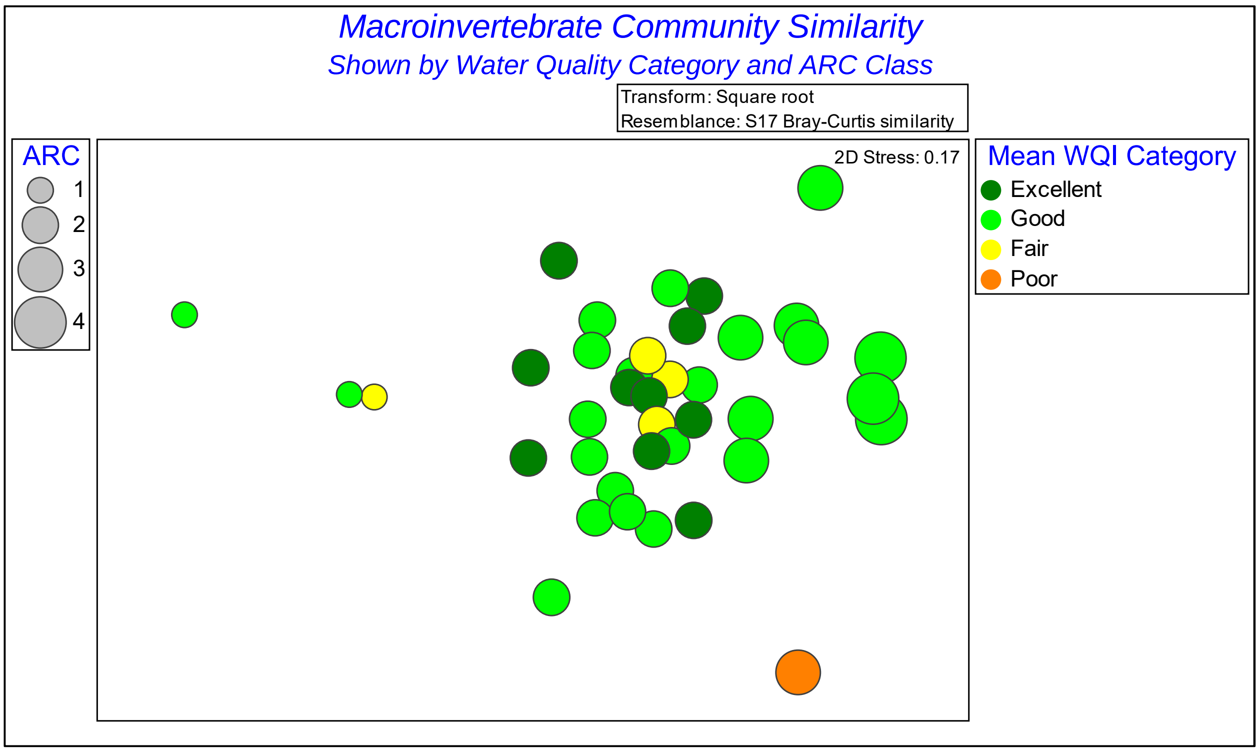

Figure 9. NMDS Plot Showing Similarity in Macroinvertebrate Assemblages from 39 Samples at 16 DCNR Priority RWQMN Stream Sites with Mean WQI Categories and ARC Classes (WQI category ranges are Excellent >85; Good 62-85; Fair 43-62; Poor 31-43; and Very Poor <31(Berry et al., 2019). Aquatic Resource Class (ARC) is a classification based on watershed area. ARC 1, 0-10 mi^2; ARC 2, 10-50 mi^2; ARC 3, 50-200 mi^2; ARC 4, 200-1000mi^2; ARC 5, 1000-5000 mi^2; ARC 6 greater than 5000mi^2 (SRBC, 2012).)

Fish Communities

Like macroinvertebrates, fish taxa vary in sensitivity to pollutants. Fish data complement macroinvertebrate data as fish integrate wider scale conditions because they are more mobile and live longer than macroinvertebrates. Beginning in 2014, fish communities at RWQMN stations were surveyed to provide a baseline and document fish community data for these streams as many had no recent record of fish assemblage data. Sampling was conducted following the standard SRBC three-pass electrofishing methods of Shank et al., 2016. Game fish were also measured for total length (mm), weighed (g), and then released. General fish survey statistics are outlined in Table 4. Moose Creek represents the minimum species richness, fish abundance, percent tolerant individuals, and percent introduced individuals as well as the maximum intolerant and native individuals statistics because only 64 native brook trout were captured in the survey.

Table 4. General Fish Survey Statistics (The minimum species richness was found at Moose Creek where only 64 native brook trout were caught.)

Number of Fish Surveys		**22**
Number of Unique Sites		**16**
Species Richness	min	1
	max	33
	mean	13
	stdev	7.6
Fish Abundance	min	64
	max	1597
	mean	608
	stdev	348.7
Percent Tolerant Individuals	min	0
	max	57
	mean	25
	stdev	15.1
Percent Intolerant Individuals	min	34
	max	100
	mean	62
	stdev	16.3
Percent Native Individuals	min	50
	max	100
	mean	87
	stdev	14.0
Percent Introduced Individuals	min	0
	max	50
	mean	13
	stdev	13.9
Trout Species Biomass (g)	min	0
	max	52220
	mean	1315
	stdev	1453

A NMDS ordination was run to spatially visualize similarities in fish community composition, where the closer the samples, the more similar their community compositions are. By assigning explanatory factors to each sample (e.g., year, size, ecoregion), plots can be used to assess groupings within all samples. Moose Creek's position in Figure 10 indicates that its community is not very similar to the rest of the sites. Only one species was found at Moose

Creek, so the distance between it and other sites is not unexpected. Sites that were surveyed more than once (Baker Run, East Fork Sinnemahoning Creek, Grays Run, Kettle Creek, Little Pine Creek and Pleasant Creek) clustered close to each other (Figure 10). Some separation between samples from the same site can be explained by differences in sampling conditions and is expected.

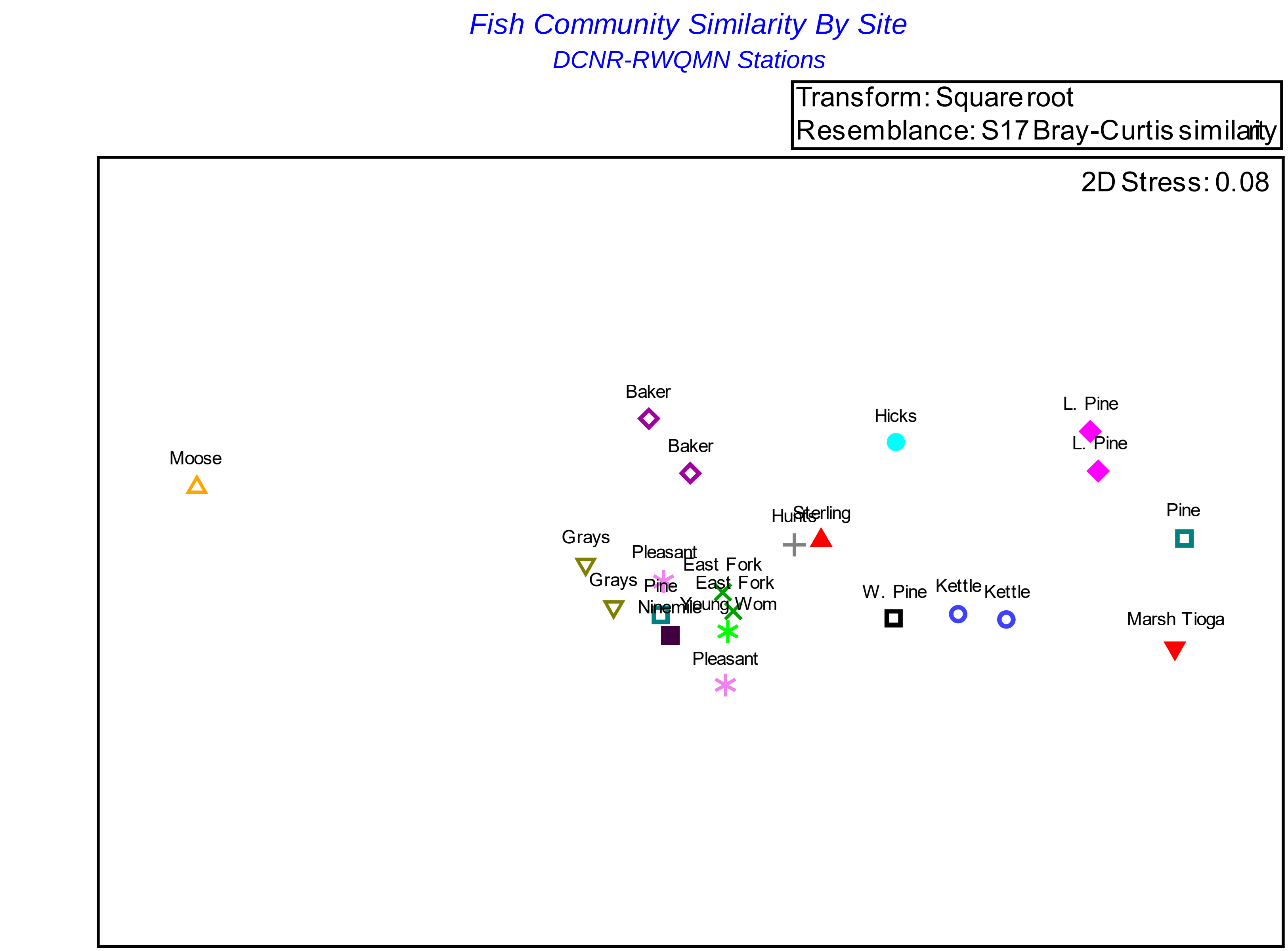

Figure 10. NMDS Plot of Fish Assemblage Similarity By Site (Sites closer together have similar fish communities.)

As in the macroinvertebrate plots, the symbology of the NMDS plot was changed to show the clustering of sites by drainage area and which category the mean WQI score fell into (Figure 11). Stream sites with Excellent water quality had very similar fish communities while stream sites with Good water quality appear to have more variation. This variation could be explained by ARC. Larger ARCs (3&4) cluster near each other on the right side while the ARC 2s are in the center and the ARC 1 (Moose Creek) is on the left side (Figure 11). Drainage area and stream size are known to impact fish communities (Vannote et al., 1980); it is well established that species richness increases along the stream continuum from small headwaters to large rivers (Altermatt, 2013).

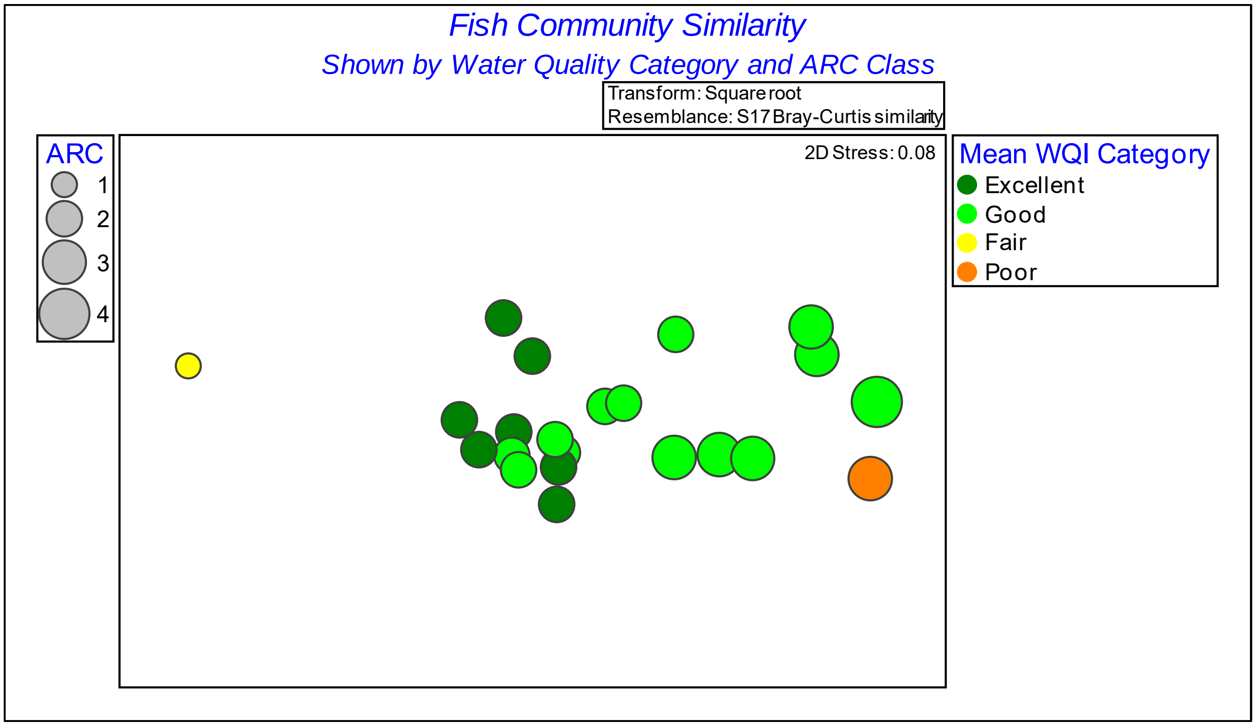

Figure 11. NMDS Plot Showing Similarity in Fish Assemblages at 16 DCNR Priority RWQMN Stream Sites with Mean WQI Categories and ARC Classes (WQI category ranges are Excellent >85; Good 62-85; Fair 43-62; Poor 31-43; and Very Poor <31 (Berry et al., 2019). Aquatic Resource Class (ARC) is a classification based on watershed area. ARC 1, 0-10 mi^2; ARC 2, 10-50 mi^2; ARC 3, 50-200 mi^2; ARC 4, 200-1000mi^2; ARC 5, 1000-5000 mi^2; ARC 6 greater than 5000mi^2 (SRBC, 2012).)

Relative abundances of cold water fish species were compared to mean temperatures. Sculpin and trout species were found at mean temperature ranges of 7.5°C - 11.5°C. Brook trout's optimal range was between 8.8°C and 9.6°C. Brown trout's range was slightly warmer, from 9.3°C to 10.2°C. Sculpin species had the greatest relative abundances between mean temperatures of 8.8°C to 9.7°C, with a second peak at 11.2°C where they made up over half of the abundance (Figure 12). Trout and sculpin species were rarely found at sites with mean temperatures >14°C across all RWQMN stations.

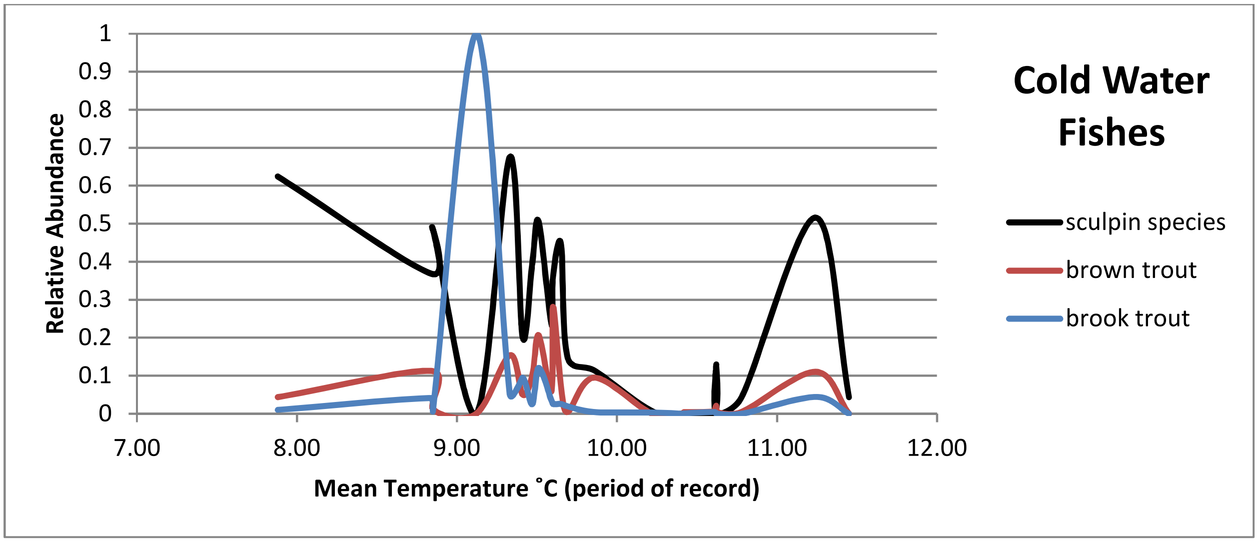

Figure 12. Relative Abundances of Cold Water Fishes at the 16 Stations (Mean temperature represents all data available from station installation up to the day prior to the fishing survey.)

Pine Creek at Blackwell was the only PADCNR station of interest that had none of the selected cold water fish specialists in its survey. The remaining 15 sites had either brook trout, brown trout, or both in their communities. Little Pine Creek had no sculpin species, but six brown trout were found in one of the surveys. Brook Trout comprised 100 percent of Moose Creek's fish assemblage. In addition to Pine Creek and Moose Creek, no sculpin were found at Kettle Creek or Marsh Creek (Figure 13).

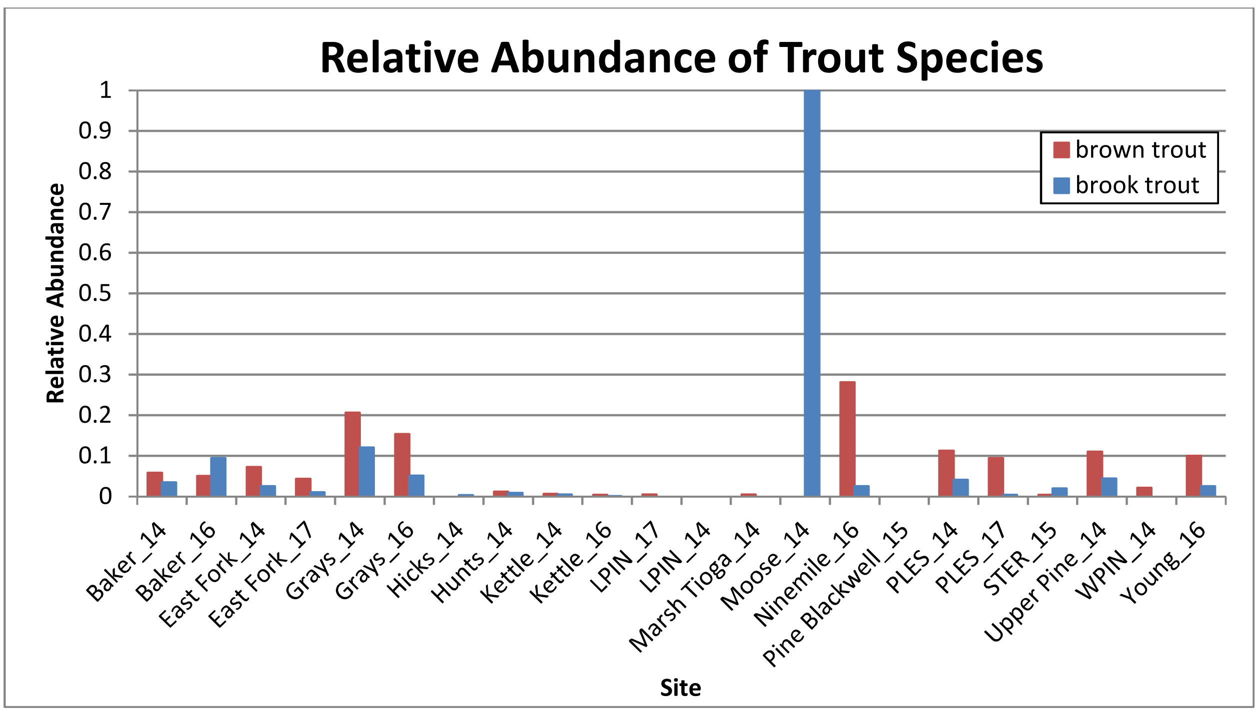

Figure 13. Relative Abundance of Brook and Brown Trout Across the 16 RWQMN Stations of Interest

East Fork Sinnemahoning Creek had the highest biomass of brown trout (Figure 14). Brown trout had higher total biomasses than brook trout at all stream sites where both species were found in sympatric populations. The biomass of both trout species increased at Baker Run and Grays Run from the 2014 to 2016 fish surveys, which could indicate a population growing to larger size classes. Biomass for both trout species decreased from 2014 to 2016/2017 at East Fork Sinnemahoning Creek, Kettle Creek, and Pleasant Stream (Figure 14).

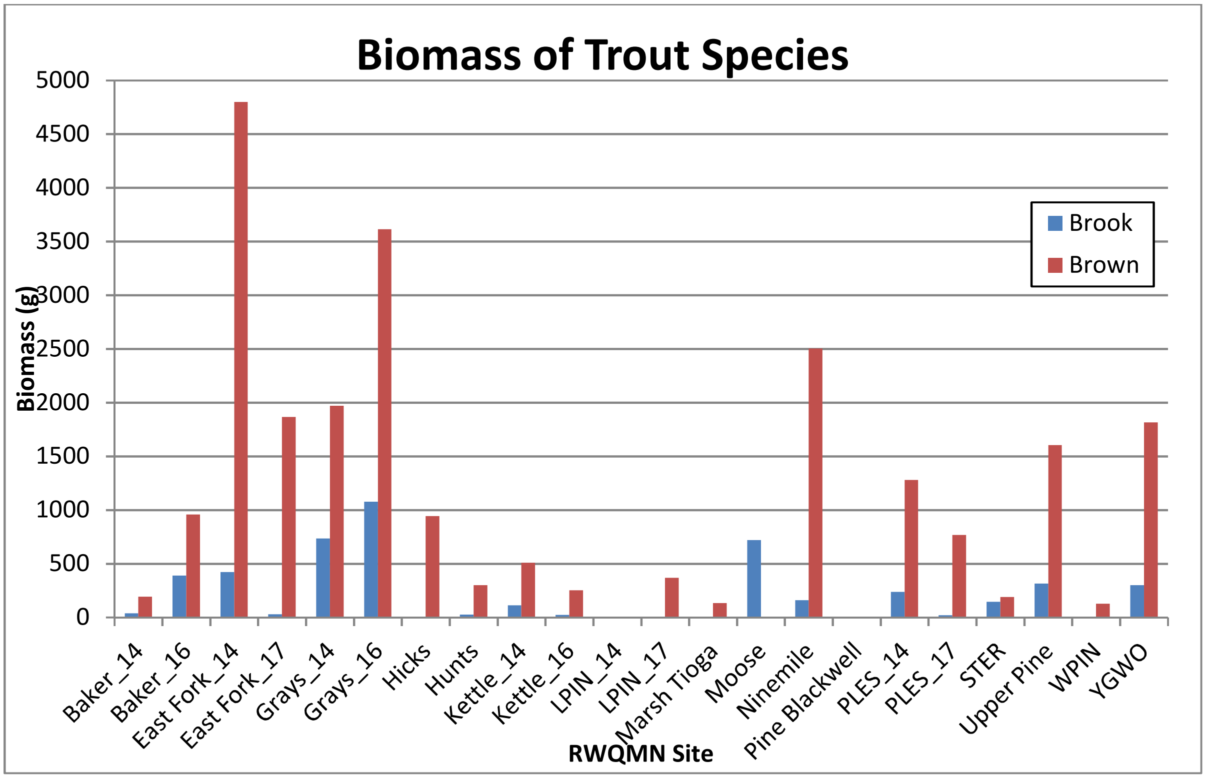

Figure 14. Total Biomass of Brook and Brown Trout at the 16 RWQMN Stations of Interest (Pine Creek at Blackwell had no trout of any kind. No brook trout were found at Little Pine Creek in either of the surveys; brown trout were found only in the 2017 survey.)

All PADCNR RWQMN stations are located on or near stream reaches where the Pennsylvania Fish and Boat Commission (PFBC) stocks brown trout, with the exception of Moose Creek. Stocked brown trout were not differentiated from wild brown trout in all of the fish surveys, so stocked brown trout (typically larger fish) are contributing to and elevating the biomass at some stations. The few rainbow trout collected were all stocked, so they were not included in the biomass analysis.

Interestingly, although trout biomass was high at East Fork Sinnemahoning Creek, Grays Run, and Ninemile Run (Figure 10), the relative abundance of trout was below 30 percent (Figure 13). Species richness is expected to increase from small headwater streams like Moose Creek to larger streams like Young Womans Creek and Pine Creek according to the stream continuum concept (Vannote et al., 1980). A high trout biomass and low proportional abundance at many of the stations indicates that the fish community is diverse and healthy and able to support multiple trophic levels.

Pine Creek had the highest mean temperature for the period of record (11.39°C). West Pine Creek, Marsh Creek, Kettle Creek, Hicks Run, and Little Pine Creek all had mean temperatures above 10°C (Table 2). These mean temperatures hint at some of the reasons for low numbers or no trout at sites despite stocking (Figure 14), but maximum temperatures provide more compelling evidence. Daily maximum temperatures exceeding brook trout (24°C; Raleigh, 1982) and brown trout (27°C; Raleigh et al., 1986) temperature thresholds were calculated per year. Infrequent exceedances of these limits represent an acute stress that trout will be able to tolerate for a short amount of time. Fish cannot tolerate extended periods of high temperatures and will move to areas of thermal refugia, i.e., cooler reaches or headwater tributaries, in attempts to flee the chronic stress.

Baker Run, Grays Run, Hunts Run, Moose Creek, Pleasant Stream, Sterling Run, Upper Pine Creek, and Young Womans Creek never exceeded the brook or brown trout maximum temperatures. Ninemile Run and East Fork Sinnemahoning Creek rarely exceeded 24°C (less than 5 and 7 days a year, respectively) and never exceeded 27°C. These streams experienced the lowest and least frequent temperature stress on trout species; intuitively, these streams had the highest biomass of trout species (Figure 14).

Hicks Run and Marsh Creek had relatively frequent (>20 days) daily maximum temperatures above the brook trout threshold of 24°C, but never exceeded the brown trout threshold of 27°C. Kettle Creek was slightly warmer, with daily maximum temperatures above 24°C observed in greater than 10 percent of days in some years from 2011 to 2018. However, Kettle Creek had a total of only three days from 2011 to 2018 that were above 27°C, so brown trout were continually supported. West Pine Creek averaged about eight days per year above the brook trout maximum between 2011 and 2018. Only two individual days during the entire time period ever exceeded the brown trout maximum temperature. These four streams support lower biomasses of brown trout (Figure 14).

Little Pine Creek and Pine Creek at Blackwell both exceeded brook and brown trout maximum temperatures. From 2011 to 2018, Little Pine Creek had temperatures above the brook trout threshold between 31 and 120 days per year and an average exceedance of 61 days per year. Pine Creek's maximum temperature exceedances ranged from 2-118 days per year and averaged 54 days above 24°C. Temperatures are clearly too high to support a native brook trout population. Over the same time period, Little Pine Creek exceeded 27°C on average 22 days per year while Pine Creek averaged 23 days per year. Depending on stocking location and time, it is possible to find brown trout within the station reach (see Little Pine Creek 2017 sample within Figure 14). However, these streams are too warm to maintain a wild trout population.

Future Analysis

The station on Kettle Creek was removed in spring 2019. SRBC will continue to monitor the water chemistry and biological health of the other 15 stations. As further data are collected, they will be added to existing analyses and used in future analyses. SRBC appreciates the opportunity to partner with PADCNR to ensure the preservation of some of the best streams in the Susquehanna River Basin.

References

Altermatt, F. 2013. Diversity in riverine metacommunities: a network perspective. *Aquatic Ecology,* 47:365-377.

Berry, J.L., L.Y. Steffy, and M.K. Shank. 2019. Development of a water quality index (WQI) for the Susquehanna River Basin. Susquehanna River Basin Commission, Harrisburg, Pennsylvania. *In preparation.*

Pennsylvania Department of Environmental Protection. 2013. A benthic macroinvertebrate index of biotic integrity for wadeable freestone riffle-run streams in Pennsylvania. Pennsylvania Department of Environmental Protection. Division of Water Quality Standards. Harrisburg, Pennsylvania.

Raleigh, R.F. 1982. Habitat suitability index models: Brook trout. United States Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.24. p. 24.

Raleigh, R.F., L.D. Zuckerman, and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Brown trout, revised. United States Fish and Wildlife Service Biological Report 82(10.124). p. 65.

Shank, M.K., A.M. Henning, and A.S. Leakey. 2016. Examination of a single-unit, multiple-pass electrofishing protocol to reliably estimate fish assemblage composition in wadeable streams of the Mid-Atlantic region of the USA. *North American Journal of Fisheries Management,* 36:3,497-505.

Susquehanna River Basin Commission. 2012. Technical guidance for low flow protection related to withdrawal approvals. FileSite #170,477. Harrisburg, Pennsylvania.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences,* 37(1):130-137.