Remote Water Quality Monitoring Network

Data Report of Baseline Conditions for 2010 - 2012
A SUMMARY

Susquehanna River Basin Commission

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Abstract

The Susquehanna River Basin Commission (SRBC) continuously monitors water chemistry in select watersheds in the Susquehanna River Basin undergoing shale gas drilling activity. Initiated in 2010, 58 monitoring stations are included in the Remote Water Quality Monitoring Network (RWQMN). Specific conductance, pH, turbidity, dissolved oxygen, and temperature are continuously monitored and additional water chemistry parameters (metals, nutrients, radionuclides, etc.) are collected at least four times a year. These data provide a baseline dataset for smaller streams in the basin, which previously had little or no data.

The two parameters most commonly used as indicators of shale gas drilling activities are specific conductance and turbidity. Any spills or leaks of flowback water from the drilling process can impact the specific conductance of a stream, while the infrastructure (roads and pipelines) needed to make drilling possible in remote watersheds may adversely impact stream sediment loads. The monitoring stations were grouped by Level III ecoregion with specific conductance and turbidity analyzed using box plots. Based on available data, land use, permitted dischargers, and geology appear to play the greatest role with influencing turbidity and specific conductance.

In order to determine if shale gas drilling and the associated development activities are impacting monitored streams, SRBC completed trend analyses on three stations with three years of continuous monitoring data. The analyses showed mixed results, with specific conductance and turbidity showing a decreasing trend at Choconut Creek, and pH and temperature showing an increasing trend at Hammond Creek. Dissolved oxygen did not show a trend at any of the stations and Meshoppen Creek did not show a trend with any parameters. The natural gas well density varies within the watersheds; Choconut Creek has no drilling activity, the Hammond Creek Watershed has less than one well per square mile, and the well density in the Meshoppen Creek Watershed is almost three times that of Hammond Creek. Although the analyses were only performed on three stations, the results show the importance of collecting enough data to properly characterize conditions in these previously unmonitored watersheds, recognizing the range of factors that can influence water quality conditions.

This publication is a summary of the full report, which is available on SRBC's web site at mdw.srbc.net/remotewaterquality/.

Photo: Little Pine Creek, Lycoming County, Pa.

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Introduction

In 2010, SRBC established a real-time, continuous water quality monitoring network called the Remote Water Quality Monitoring Network (RWQMN). The initial purpose of the project was to monitor small headwater streams for potential impacts from natural gas drilling as 85 percent of the Susquehanna River Basin is underlain with natural gas shales. Since 2008, unconventional gas drilling by means of hydraulic fracturing (fracking) has greatly increased throughout the basin. However, the applicability of a continuous, real-time data network is not limited to the impacts of gas drilling. The RWQMN allows SRBC and other agencies/groups to gain a better understanding of water quality conditions in headwater streams and monitor impacts from any activities in the watershed.

The RWQMN currently includes 58 continuous monitoring stations (Appendix A); this second annual report will focus on the 50 stations deployed long enough to have a sufficient amount of data for analysis (Figure 1). The stations were installed between January 2010 and September 2011. The data analyzed for this report are from installation date until June 30, 2012 (Appendix C).

Along with continuous monitoring at 58 stations, additional water chemistry parameters are collected on an eight- to nine-week interval. Macroinvertebrate samples are collected in October at every station and fish are sampled at select stations during the spring/summer season. The continuous and supplemental sampling data collected at each station have created a substantial baseline dataset for smaller streams in Pennsylvania and New York, where previously very little existed.

Equipment and Parameters

Each RWQMN station contains the following equipment: data sonde, data platform, and a power source – typically a solar panel. Recently, additional equipment has been added to select stations to record precipitation and water pressure data. Rain gages

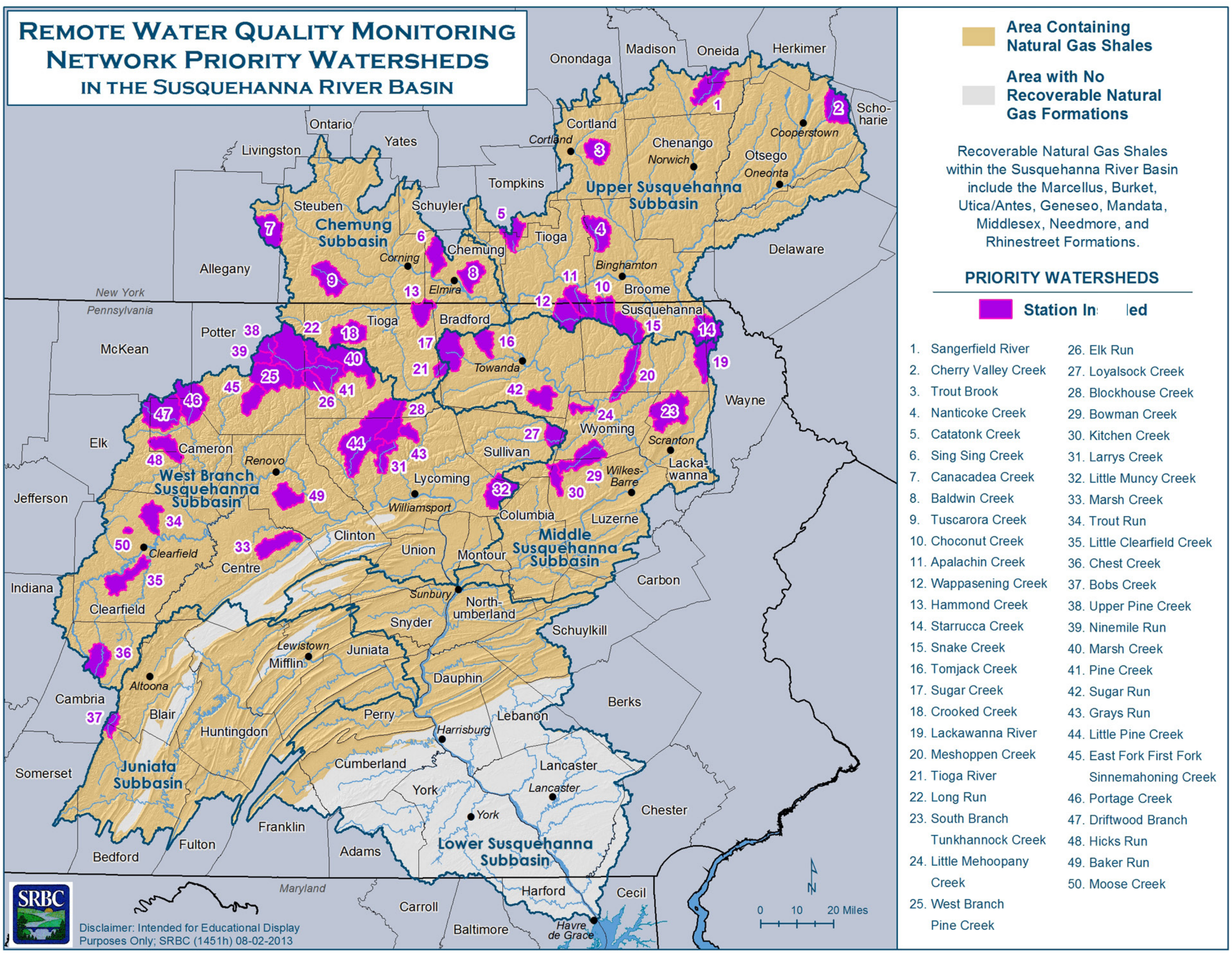


Figure 1. RWQMN Stations – Initial 50 Stations

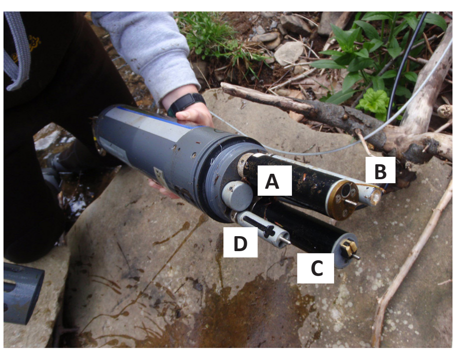
were installed at 11 stations and rainfall amounts are recorded at the same interval as the water quality data. The precipitation data will be correlated to turbidity and specific conductance; these two parameters are influenced by runoff and flow. Water stage data, along with actual flow measurements taken in the field, will be used to develop rating curves, which in time will allow for estimated flow measurements based on water stage. These data will be discussed in future reports.

The data sonde is a multi-parameter water quality sonde with optical dissolved oxygen and turbidity probes, a pH probe, and a conductance and temperature probe. The data sonde also includes a non-vented relative depth sensor. The entire unit is placed in protective housing and secured in free-flowing water at each site.

The data are uploaded to a public web site maintained by SRBC. The web site allows users to view, download, graph, and determine basic statistics from the raw data. General project information and maps are also found on the user-friendly web site at *http://mdw.srbc.net/remotewaterquality/*.

SRBC staff collects fish samples at select stations during the spring/summer season.

SRBC staff monitors flow along Long Run, Tioga County, Pa.
Photo credit: R. Szuch, PA DCNR



Each station is equipped with a data sonde (above) that measures dissolved oxygen, turbidity, pH, conductance and temperature. The data sonde also includes a non-vented relative depth sensor.

A – Dissolved Oxygen
B – pH
C – Turbidity
D – Conductance/Temperature

Results

In the Susquehanna River Basin, the majority of the shale gas region is located in the North Central Appalachian and Northern Appalachian Plateau and Uplands Level III ecoregions (Woods and others, 1996). For this reason, a majority of the RWQMN stations (52) are located in these two ecoregions. The shale gas region extends into the Central Appalachian Ridges and Valleys ecoregion, the ecoregion containing the remaining six RWQMN stations (Table 1).

Table 1. RWQMN Station List with Basic Watershed Characteristics

Watershed Name	Dominant Landuse(s)	Watershed Size (mi^2)	Bedrock Geology	Impaired Miles[1]	% Impaired Stream Miles[1]	SRBC Well Pad Approvals*[2]	PADEP Horizontal Well Drilling Permits Issued*[2]
Northern Appalachian Plateau and Uplands							
Apalachin Creek	Forest (70%) Agriculture (26%)	43	Shale	0	0%	0	0
Baldwin Creek	Forest (73%) Agriculture (21%)	35	Shale	0	0%	0	0
Canacadea Creek	Forest (70%) Agriculture (23%)	47	Shale	0	0%	0	0
Cherry Valley Creek	Forest (67%) Agriculture (23%)	51	Shale	0	0%	0	0
Choconut Creek	Forest (73%) Agriculture (23%)	38	Shale	0	0%	0	0
Hammond Creek	Agriculture (51%) Forest (46%)	29	Shale	0	0%	12	19
Little Mehoopany Creek	Forest (68%) Agriculture (26%)	11	Sandstone	0	0%	4	3
Meshoppen Creek	Forest (48%) Agriculture (48%)	52	Sandstone	0	0%	59	97
Nanticoke Creek	Forest (62%) Agriculture (34%)	48	Shale	0	0%	0	0
Sangerfield River	Forest (35%) Agriculture (32%)	52	Shale	0	0%	0	0
Sing Sing Creek	Forest (60%) Agriculture (21%)	35	Shale	0	0%	0	0
Snake Creek	Forest (68%) Agriculture (28%)	45	Sandstone	0	0%	16	28
South Branch Tunkhannock Creek	Forest (55%) Agriculture (32%)	70	Sandstone	26.7	22%	3	0
Sugar Creek	Agriculture (51%) Forest (48%)	56	Sandstone	10.8	13%	44	109
Sugar Run	Forest (65%) Agriculture (31%)	33	Sandstone	0	0%	21	25
Tomjack Creek	Agriculture (55%) Forest (42%)	27	Shale	0	0%	25	20
Trout Brook	Forest (64%) Agriculture (31%)	36	Shale	0	0%	0	0
Upper Catatonk Creek	Forest (70%) Agriculture (16%)	30	Shale	0	0%	0	0
Upper Crooked Creek	Agriculture (53%) Forest (44%)	47	Shale	0	0%	19	21
Upper Tuscarora Creek	Agriculture (52%) Forest (42%)	53	Shale	0	0%	0	0
Wappasening Creek	Forest (64%) Agriculture (33%)	47	Shale	1.8	2%	22	15
North Central Appalachian							
Baker Run	Forest (99%)	35	Sandstone	0	0%	9	10
Blockhouse Creek	Forest (75%) Agriculture (21%)	38	Sandstone	0	0%	7	0

Watershed Name	Dominant Landuse(s)	Watershed Size (mi^2)	Bedrock Geology	Impaired Miles[1]	% Impaired Stream Miles[1]	SRBC Well Pad Approvals*[2]	PADEP Horizontal Well Drilling Permits Issued*[2]
Bowman Creek	Forest (90%)	54	Sandstone	0.3	1%	3	0
Driftwood Branch	Forest (93%) Grassland (5%)	83	Sandstone	0	0%	3	0
East Fork Sinnemahoning Creek	Forest (89%) Grassland (10%)	33	Sandstone	0	0%	2	4
Elk Run	Forest (82%) Agriculture (11%)	21	Sandstone	0	0%	22	13
Grays Run	Forest (95%)	16	Sandstone	5.1	21%	8	1
Hicks Run	Forest (92%)	34	Sandstone	0	0%	4	2
Kitchen Creek	Forest (88%)	20	Sandstone	1.8	5%	0	0
Lackawanna Creek	Forest (68%) Agriculture (23%)	38	Sandstone	4.3	6%	1	0
Larrys Creek	Forest (76%) Agriculture (22%)	29	Sandstone	1.9	4%	18	28
Little Pine Creek	Forest (83%) Agriculture (13%)	180	Sandstone	7.1	2%	28	55
Long Run	Forest (81%) Agriculture (14%)	21	Sandstone	0	0%	0	0
Loyalsock Creek	Forest (86%) Grassland (9%)	27	Sandstone	6.7	12%	0	0
Marsh Creek (Tioga County)	Forest (71%) Agriculture (22%)	78	Sandstone	14.8	12%	34	0
Moose Creek	Forest (95%)	3	Sandstone	0	0%	1	1
Ninemile Run	Forest (85%)	16	Sandstone	0	0%	6	0
Pine Creek	Forest (80%) Agriculture (11%)	385	Sandstone	23.8	3%	84	50
Portage Creek	Forest (92%) Grassland (4%)	71	Sandstone	0	0%	1	0
Starrucca Creek	Forest (74%) Agriculture (18%)	52	Sandstone	0	0%	7	0
Tioga River	Forest (88%) Grassland (9%)	14	Sandstone	4.2	18%	5	11
Trout Run	Forest (91%) Grassland (8%)	33	Sandstone	1.5	3%	24	18
Upper Pine Creek	Forest (75%) Agriculture (17%)	19	Sandstone	0	0%	0	0
West Branch Pine Creek	Forest (86%) Grassland (13%)	70	Sandstone	0	0%	1	0
Ridges and Valleys							
Bobs Creek	Forest (92%)	17	Sandstone	0	0%	1	2
Chest Creek	Forest (60%) Agriculture (35%)	44	Shale	29.6	24%	0	0
Little Clearfield Creek	Forest (74%) Agriculture (22%)	44	Sandstone	0	0%	2	1
Little Muncy Creek	Forest (57%) Agriculture (39%)	51	Sandstone	1.8	2%	31	33
Marsh Creek	Forest (88%) Agriculture (11%)	44	Sandstone	17.1	20%	1	0

As tracked by SRBC

[1] PA 2012 Integrated List and NY State 2011 Priority Waterbodies List

[2] Multiple wells can be located on one pad. Data last updated May 2013

North Central Appalachian Ecoregion

Twenty-four stations are found in the North Central Appalachian ecoregion (Figure 2). This ecoregion is a forested, sedimentary upland that has high hills and low mountains. Within this region of the Susquehanna River Basin, forested land use comprises 65 percent of the area. It is divided into two subecoregions, a glaciated eastern region and unglaciated western region. The stations are divided evenly between the two subecoregions.

There are a variety of designated uses on the streams monitored in this ecoregion. Designated uses include exceptional value (EV), cold water fisheries (CWF), high-quality cold water fisheries (HQ-CWF), high-quality trout stocked fisheries (HQ-TSF), trout stocked fisheries (TSF), and warm water fisheries (WWF). Exceptional value stream miles make up approximately 10 percent of the monitored stream miles. Twelve of the streams are meeting their designated uses. Bowman Creek, Kitchen Creek, Loyalsock Creek, and the Tioga River have short segments impaired by acid deposition and Larrys Creek, Little Pine Creek, and Trout Run are impaired by abandoned mine drainage (AMD). Marsh Creek and Pine Creek have segments impaired by urban runoff and the Lackawanna River has impairments from natural sources.

Forested land use is the dominant land use in each of the watersheds, ranging from 68 percent to 99 percent coverage. Generally, agriculture comprises less than 10 percent of the land use in the monitored watersheds with only a few watersheds exceeding 20 percent. Developed land use covers even less of the area, ranging from 0.01 percent to 2.89 percent. These land uses are reflected in the continuous water chemistry results seen at the stations.

Specific conductance is the ability of water to conduct electrical current and can be influenced by geology, AMD, and agricultural and urban runoff. A spill or leak of chemicals used to frack natural gas wells would show a spike in specific conductance. Specific conductance values range from 24 to 139 microsiemens (µS/cm) in the North Central Appalachian ecoregion. Chloride, sulfate, and total dissolved solids (TDS) concentrations were analyzed multiple times from grab samples throughout the monitoring period and showed values consistently below Pennsylvania water quality standards of 250 milligrams per liter (mg/l), 250 mg/l, and 500 mg/l, respectively. The range of

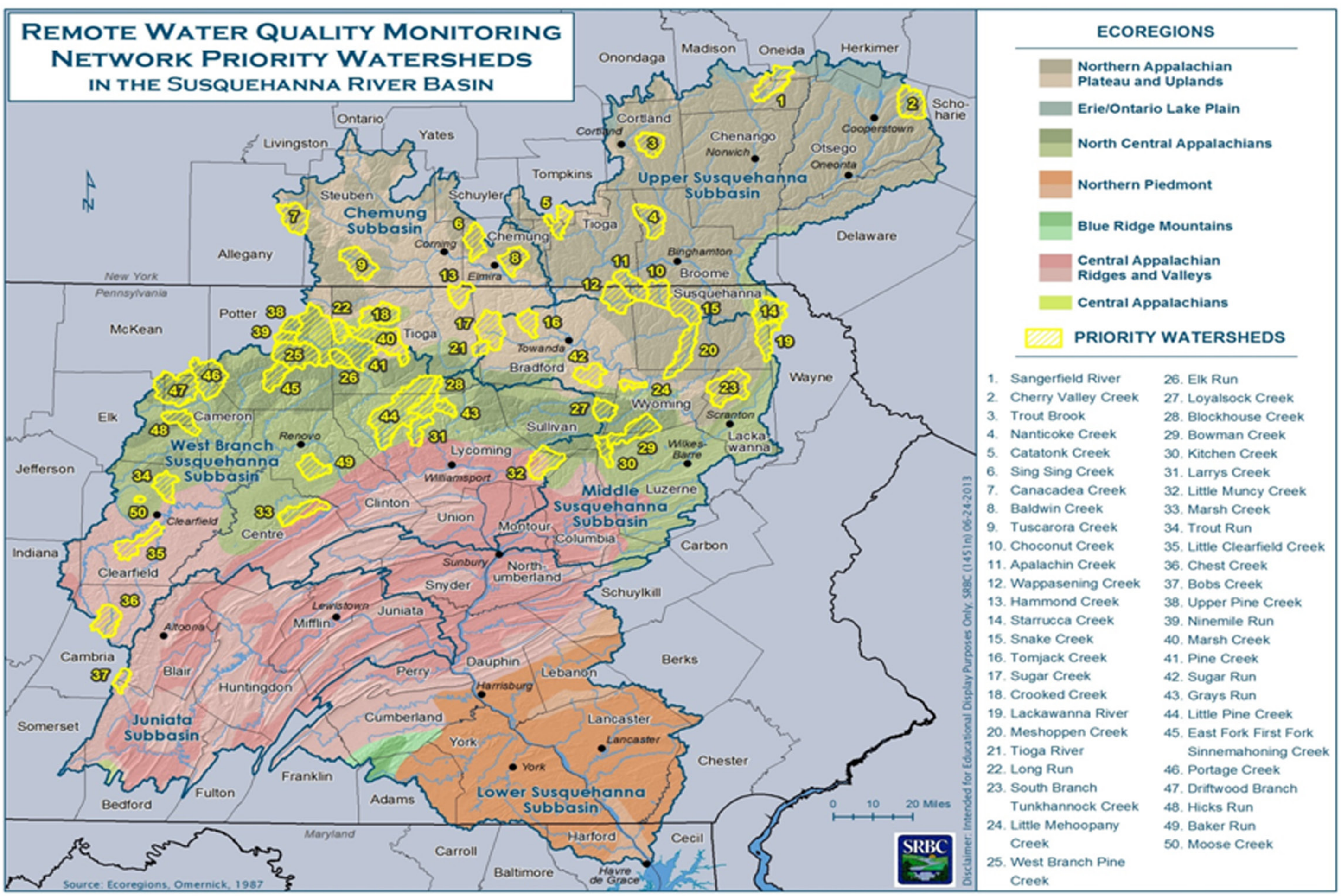


Figure 2. RWQMN Stations Shown with Level III Ecoregions

North Central Appalachian Ecoregion

The range of continuous specific conductance values and chloride, sulfate, and TDS concentrations show minimal influences from human impacts in the North Central Appalachian Ecoregion, where 24 monitoring stations are located.

Forested land use is the dominant land use in each of the watersheds, ranging from 68 percent to 99 percent coverage.

Kitchen Creek, Luzerne County, Pa., North Central Appalachian Ecoregion.

continuous specific conductance values and chloride, sulfate, and TDS concentrations show minimal influences from human impacts.

pH is another important parameter monitored continuously at the stations. pH ranges from 5.90 to 7.50 with the majority of the stations being fairly neutral. Four stations, Baker Run, Grays Run, Moose Creek, and Trout Run, have naturally acidic conditions while Blockhouse Creek, Elk Run, and Starrucca Creek are characterized as having natural basic conditions. The low alkalinity and calcium concentrations, seen in the lab chemistry sample analysis, indicate a low buffering capacity in these streams meaning that even a small introduction of acidic solutions could significantly alter the pH having adverse impacts on aquatic organisms.

The dissolved oxygen concentrations in the North Central Appalachian ecoregion continue to reflect the forested land use of the monitored watersheds. The average dissolved oxygen concentration ranges from 10.4 to 12.0 mg/l and only in rare occurrences in the summer months does the concentration drop below the water quality standard necessary to meet the streams' designated use. The forested land use provides canopy cover to help maintain the cool water temperatures to sustain higher dissolved oxygen levels.

Nineteen of the 24 stations in the ecoregion have median turbidity levels below 2.0 Nephelometric Turbidity Units (NTU), with only two stations, Marsh Creek near Ansonia Station, Pa., and Pine Creek, showing median turbidity levels above 5.0 NTU. These two watersheds have higher percentages of agricultural land (compared to other stations in the North Central Appalachian ecoregion) and have urban runoff impairments. The forested land use helps to control erosion leading to the lower turbidity levels in these systems.

Data analysis for the first baseline data report in April 2012 indicated the monitoring stations on Blockhouse and Starrucca Creeks exhibited water quality characteristics that differed from the other stations in the ecoregion. Data from 24 stations in the ecoregion were analyzed for this report and the stations no longer appear as outliers. Several of the additional stations in the ecoregion are similar to Blockhouse Creek in land use and number of permitted dischargers. These stations exhibit similar water chemistry to Blockhouse Creek. Starrucca Creek was incorrectly listed as being in the Northern Appalachian Plateau and Uplands ecoregion in the first report. Its water chemistry correlates with the stations in the North Central Appalachians ecoregion.

Northern Appalachian Plateau and Uplands Ecoregion

The Northern Appalachian Plateau and Uplands ecoregion spans the northern portion of the Susquehanna River Basin (Figure 2). It covers the majority of the New York portion of the basin and Pennsylvania counties along the NY/PA state border. It has experienced a significant amount of natural gas activity in recent years. Susquehanna, Bradford, and Tioga Counties, located along the PA/NY border in the Northern Appalachian Plateau and Uplands ecoregion, have the most gas well pad approvals and highest density of pad approvals (SRBC, 2013). Twenty-one of the RWQMN stations are located in this ecoregion.

Rolling hills and fertile valleys make this ecoregion conducive to agriculture and forested land uses. Forested land covers over 58 percent of the area and agricultural land uses cover almost 32 percent of the ecoregion in the Susquehanna River Basin. Two subecoregions make up the Northern Appalachian Plateau and Uplands ecoregion – the Glaciated Low Plateau and Northeastern Uplands. The two subecoregions share similar characteristics with the Northeastern Uplands having a greater lake and bog density and steeper stream gradient (Woods and others, 1999). Five stations are located in the

Northern Appalachian Plateau and Uplands Ecoregion

Land use and geology play a significant role in the water chemistry in the Northern Appalachian Plateau and Uplands ecoregion. Agricultural land use can lead to lower dissolved oxygen and higher nutrient levels. Leaching from glacial till geology can increase levels of sulfate, chloride, total dissolved solids, and specific conductance.

Twenty-one of the RWQMN stations are located in this ecoregion.

Wappasening Creek station, Bradford County, Pa.

Northeastern Uplands subecoregion: Apalachin Creek, Meshoppen Creek, Wappasening Creek, Snake Creek, and Choconut Creek — the remaining stations are located in the Glaciated Low Plateau subecoregion.

There is a range of designated uses for the monitored watersheds within the Northern Appalachian Plateau and Uplands. They include CWF, HQ-CWF, TSF, and WWF in Pa., and Class C, C(T), C(TS), B, and AA in NY. Class C indicates fisheries are supported by the waterbody and it is protected for non-contact activities. Classes C(T) and C(TS) are Class C water which may support a trout population and trout spawning, respectively. Class B supports contact activities and Class AA is a drinking water source. Only three stations in the ecoregion are not meeting their designated uses: South Branch Tunkhannock Creek is impaired by a municipal point source and Sugar and Wappasening Creeks have agricultural impairments.

When compared to the watersheds in the North Central Appalachian ecoregion, Northern Appalachian Plateau and Uplands watersheds have less forested land use (34 – 73 percent) and more agricultural land uses (16 – 55 percent). Development is also greater in this ecoregion, covering up to 10 percent in some watersheds. Land use and geology play a significant role in the water chemistry in the Northern Appalachian Plateau and Uplands ecoregion.

A substantial portion of the ecoregion is underlain with glacial till geology. Surficial glacial till geology consists of unconsolidated material deposited on bedrock by a continental glacier and can measure up to 50 meters in thickness (Rogers and others, 1999). Streams in this region are characterized as having highly mobile, unconsolidated substrate material, which can increase the turbidity concentrations. Sulfate, chloride, total dissolved solids, and specific conductance are typically found at higher ranges due to leaching from the glacial till geology (Missouri Department of Natural Resources, 2006).

The average level of specific conductance ranges from 83 to 422 µS/cm at the 21 monitoring locations in the ecoregion. Overall, the stations located in the Northeastern Uplands subecoregion had lower conductance values, range of 83 to 142 µS/cm, while the stations in the Glaciated Low Plateau had a wider range of values, 101 to 422 µS/cm. The highest levels of dissolved solids (TDS) in the water column were recorded at Sing Sing Creek and Canacadea Creek, the two stations with the highest mean continuous specific conductance. Sulfate and chloride concentrations follow the same pattern as the dissolved solid concentrations. Typically, when higher levels of specific conductance are found, TDS, sulfate, and chloride concentrations will also be elevated. Each of these parameters will influence conductance.

The median pH values followed the same pattern as specific conductance did in this ecoregion. The stations in the Northeastern Uplands ecoregion exhibited neutral water chemistry with the exception of Meshoppen Creek and Apalachin Creek, which are slightly basic streams. These two streams also showed the highest specific conductance values in the Northeastern Uplands region. The stations located in the Glaciated Low Plateau show basic water chemistry ranging from 7.22 to 8.07. Meshoppen Creek was identified in the first data report as needing further study due to its median pH level. Upon further study, it was noted that the Meshoppen Creek Watershed spans both subecoregions, and the recorded pH value does fit within the range of typical values.

Dissolved oxygen concentrations range from 9.6 to 12.1 mg/l within the ecoregion. Agriculture has a larger influence in the Northern Appalachian Plateau and Uplands region with almost 17 percent of the ecoregion having agricultural land uses. On average, 33 percent of the monitored watersheds are in agricultural land uses. Agriculture land uses can lead to lower dissolved oxygen levels with excess nutrients entering the waterbody and less canopy cover, which increases stream temperature. During the summer months, dissolved oxygen at several stations fell below the lowest water quality standard of 4.0 mg/l.

Overall, median turbidity values were higher in the Northern Appalachian Plateau and Uplands region when compared to the other two ecoregions. Values range from 0.8 to 9.0 NTU, while seven stations have a median value over 5 NTU. These stations are located in glacial till geology with mobile substrate contributing to the turbidity in the streams.

Central Appalachian Ridges and Valleys (Ridges and Valleys) Ecoregion

The Ridges and Valleys ecoregion is an area of parallel ridges and valleys with folded and faulted bedrock. Long, even ridges with long valleys in between dominate the landscape. Natural gas development pressure has been relatively low in this ecoregion; because of this, only five monitoring stations are located in this ecoregion.

The five stations share the same sandstone geology, with the exception of Chest Creek, which is underlain with shale. Forested land use covers the majority of each of the watersheds; however, Chest Creek and Little Muncy Creek have agriculture over one-third of their landscape. Designated uses range from CWF to HQ-CWF, and only Bobs Creek and Little Clearfield Creek are fully meeting their designated uses. Chest Creek, Little Muncy Creek, and Marsh Creek are impaired by agriculture and Chest Creek has AMD impairments.

Specific conductance concentrations range from 75 to 397 µS/cm within the ecoregion. Bobs Creek has the lowest average conductance at 75 µS/cm and is located in the Northern Sandstone Ridge subecoregion. Little Muncy Creek and Marsh Creek are located in the Northern Dissected Ridges and Knobs subecoregion and have average specific conductance concentrations of 101 µS/cm and 106 µS/cm, respectively. The highest concentrations are seen in the Uplands and Valleys of Mixed Land Use subecoregion; Chest Creek and Little Clearfield Creek are located in this region. These are two streams impacted by AMD. Average conductance in Chest Creek is 232 µS/cm and Little Clearfield Creek's average conductance is 397 µS/cm. While these concentrations are significantly higher than the other stations in the Ridges and Valleys ecoregion, they are considerably less than severely impaired AMD streams.

The Ridges and Valleys ecoregion stations are characterized by neutral to slightly basic water chemistry. pH values range from 7.12 to 7.6. Bobs Creek exhibits the lowest median pH and Little Clearfield Creek has the highest median pH.

Overall, the median turbidity value (4.04 NTU) in the Ridges and Valleys ecoregion is comparable to the Northern Appalachian Plateau and Uplands ecoregion and they are both higher than the North Central Appalachian ecoregion. Chest Creek and Little Muncy Creek exhibit the highest median turbidity values within the ecoregion: these are the least forested watersheds. Tree and shrub roots along streambanks help reduce streambank erosion that contributes to turbidity.

Dissolved oxygen levels vary in the ecoregion from 9.98 mg/l to 11.29 mg/l. The Ridges and Valleys region has the lowest average dissolved oxygen level. Dissolved oxygen levels are influenced by water temperature, nutrients, and water velocity. Agriculture comprises over 53 percent of the land use in the Ridges and Valleys ecoregion and the monitored watersheds average about 23 percent agricultural land use.

Little Muncy Creek station, Lycoming County, Pa.

Ridges and Valleys Ecoregion

The Ridges and Valleys region has the lowest average dissolved oxygen level. Dissolved oxygen levels are influenced by water temperature, nutrients, and water velocity....the monitored watersheds average about 23 percent agricultural land use.

Natural gas development pressure has been relatively low in this ecoregion; because of this, only five monitoring stations are located in this ecoregion.

Specific Conductance and Turbidity by Ecoregion

Natural gas drilling in the Susquehanna River Basin has brought two continuous field parameters to the forefront: conductance and turbidity. The chemicals used in natural gas fracking produce flowback water with very high specific conductance concentrations. Any significant spill or leak into a waterbody will quickly influence the specific conductance of the stream adversely impacting water quality.

Turbidity is important because of the infrastructure changes involved with natural gas drilling. New roads, additional truck traffic on existing roads, and pipeline construction under and through streams can negatively impact the water quality with increased siltation, which will be seen with increased turbidity levels.

Box plots were created using the continuous records for specific conductance and turbidity by ecoregion. The box plots below show the median value and quartile ranges. The lower and upper edges of the box represent the lower and upper quartiles, respectively, and the line inside the box represents the median value. Twenty-five percent of the data are less than the lower quartile and 25 percent of the data are greater than the upper quartile. The lines (whiskers) extending from the box represent the maximum and minimum values excluding outliers.

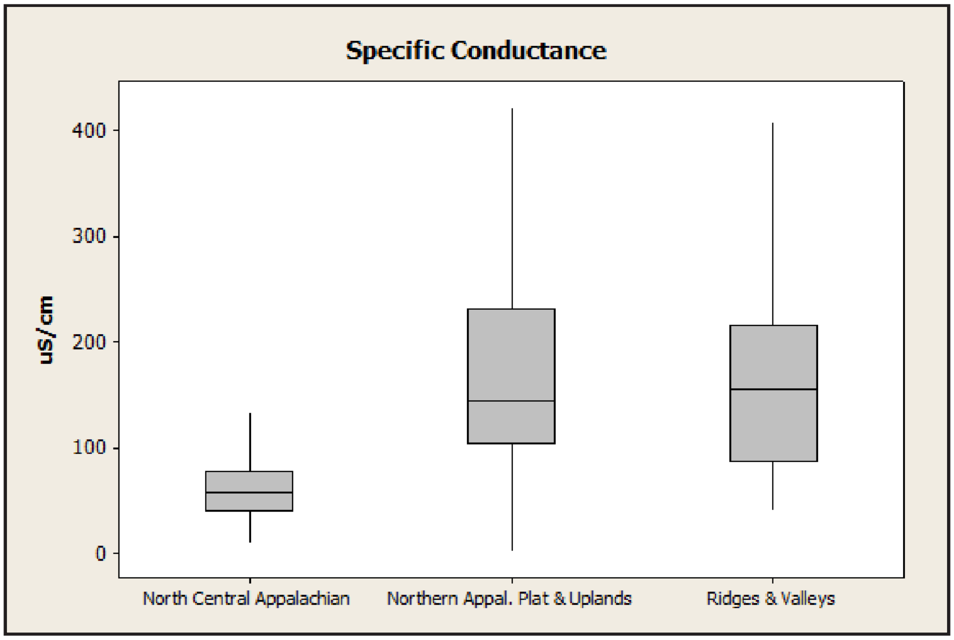


Figure 3. Box Plot for Specific Conductance by Ecoregion

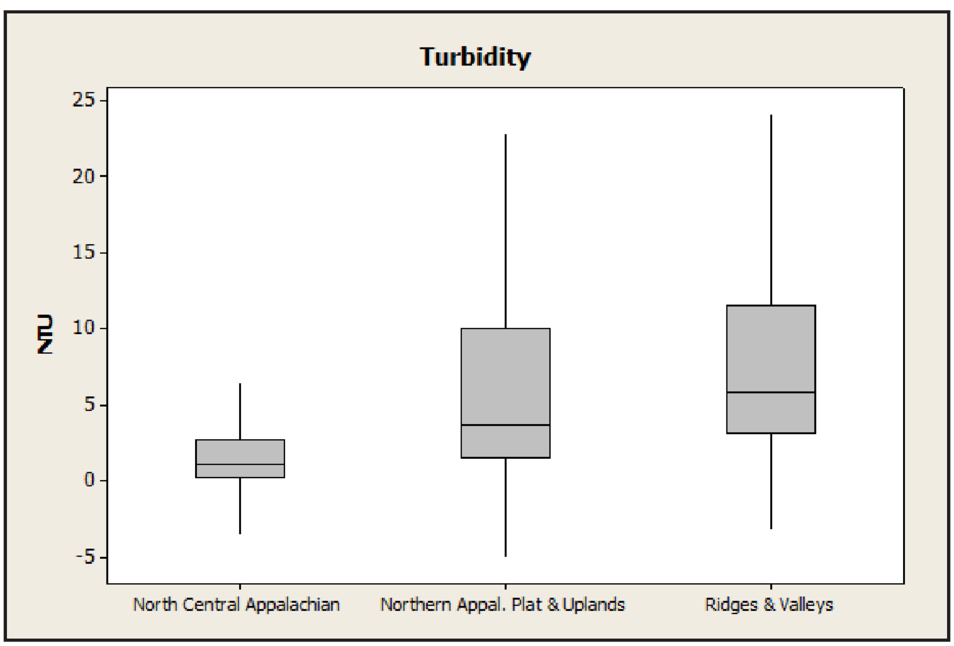


Figure 4. Box Plot for Turbidity by Ecoregion

A box plot with a compact box and short whiskers indicates a dataset with little variability. Conversely, a dataset with high variability will produce a longer box in the plot. When comparing more than one dataset on the same scale, parallel box plots are used. If the boxes in parallel box plots do not overlap, it indicates a significant difference between the datasets. Figures 3 and 4 provide a graphical representation of differences in specific conductance and turbidity across the ecoregions, respectively.

The box plot for specific conductance shows a significant difference between ecoregions, especially the North Central Appalachian ecoregion compared to the other two ecoregions. The North Central Appalachian ecoregion box plot shows the least variability, tightly grouped together with the lowest interquartile and outlier ranges (Figure 3). The Northern Appalachian Plateau and Uplands and Ridges and Valleys ecoregions are similar, with the Ridges and Valleys ecoregion having a slightly higher median specific conductance, but the Northern Appalachian Plateau and Uplands ecoregion having a greater quartile range.

The Northern Appalachian Plateau and Uplands ecoregion is underlain with glacial till geology. Glacial till geology can impact specific conductance in a stream, accounting for the higher upper range and larger variability. The Ridges and Valleys ecoregion has a small subset of stations and two are impacted by AMD. A greater variability is typical in box plots with less data.

Turbidity values for each station were grouped by ecoregion and represented in a box plot (Figure 4). Turbidity does not show a significant difference as specific conductance did by ecoregion as seen by the overlapping boxes. However, the North Central Appalachian ecoregion maintains the lowest variability indicating similar and consistent water chemistry. Forested land use covers the majority of the monitored watersheds in this ecoregion, helping to reduce erosion, leading to lower turbidity levels.

The Northern Appalachian Plateau and Uplands and Ridges and Valleys ecoregions show greater variability and higher median turbidity values. Interquartile and outlier ranges are wide indicating an extensive range of turbidity values in the two ecoregions. Land use and glacial till geology in the Northern Appalachian Plateau and Uplands ecoregion can impact turbidity as it does specific conductance. Streams underlain with glacial till geology typically will have higher turbidity (Cornell Cooperative Extension – Ulster County, 2007).

Land use and the small dataset are two factors that could be contributing to the large variability in turbidity in the Ridges and Valleys ecoregion. Agriculture covers a significant portion of several watersheds in the ecoregion and there are only five stations in this ecoregion.

Use of Continuous Water Chemistry Data

In general, continuous water quality data are not available for many watersheds around the country. The continuous water quality data collected through the RWQMN project have been useful in many applications. Simple uses for the data are determining the general health of streams that have historically lacked water quality data and to find out if current conditions of the streams support aquatic life and recreational uses.

Several agencies and organizations have made requests for the continuous monitoring data for more in-depth studies. Data requests have been made to follow up on spills and new infrastructure related to natural gas drilling and temperature data have been requested for climate change studies. As a database of continuous data is collected at each of the monitoring stations, SRBC will be able to build analyses to determine if any trends of water quality are occurring in the watersheds. Based on the short data record (less than three years), most in-depth data analysis is currently still in progress.

Trends

Water quality can be impacted by natural conditions and human activities on the landscape. Using consistent methods to collect water chemistry data allows for water quality trends to be analyzed for streams. Water quality trends are a method to indicate if water quality conditions are improving, degrading, or staying steady over time.

Sufficient continuous data have been collected at three of the RWQMN stations to look at water quality trends. Monthly means and medians for temperature, dissolved oxygen, specific conductance, pH, and turbidity were calculated for Choconut Creek, Hammond Creek, and Meshoppen Creek. Continuous data from January 2010 through December 2012 were used to calculate the means and medians. Natural gas drilling activity varies within the watersheds. Choconut Creek has no current drilling activity, Hammond Creek has 19 drilled wells, an average of less than one well per square mile, and Meshoppen Creek has 97 drilled wells, an average of almost two per square mile.

The Mann-Kendall trend analysis was run on the continuous water quality data. Mann-Kendall is a non-parametric test to detect if there is a positive or negative trend in a time series set of data. With the limited time series data available, a Mann-Kendall test was ran on the mean values for temperature, specific conductance, and dissolved oxygen and median values for turbidity and pH for each month. The p-values from the Mann-Kendall test for each station were analyzed to see if there was an overall trend in either direction. A p-value of 10 percent or less was determined to be significant to indicate a negative or positive trend. Trends were seen on two parameters at two of the stations (Table 2).

The results from the Mann-Kendall test show a decreasing trend for specific conductance and turbidity at the Choconut Creek monitoring location and an increasing trend for temperature and pH at Hammond Creek station. No trends were displayed at Meshoppen Creek during the initial three years of continuous monitoring. As additional continuous data are added to the Mann-Kendall trend test, the results may change.

Table 2. Mann-Kendall p-values for Select RWQMN Stations

	Choconut Creek		Hammond Creek		Meshoppen Creek	
Parameter	p-value	Trend	p-value	Trend	p-value	Trend
Dissolved Oxygen	17%	---	29%	---	22%	---
pH	17%	---	10%	Increase	65%	---
Specific Conductance	1%	Decrease	88%	---	45%	---
Temperature	65%	---	3%	Increase	88%	---
Turbidity	10%	Decrease	88%	---	88%	---

Water Chemistry – Lab Samples

Along with monitoring the 50 stations continuously, SRBC collected water samples for lab analysis at each station six times a year. Beginning in 2013, water sample collection was switched to seasonal sampling (4 times a year). The water samples are submitted to a certified lab for analysis of a set list of parameters (Table 3). These additional parameters provide point-in-time metal and nutrient concentrations among other parameters to supplement the continuous data.

Water quality lab samples indicated that some stations are impacted by a variety of pollutants (Table 3). Bobs Creek, Chest Creek, Little Muncy Creek, Sangerfield River, Sing Sing Creek, Sugar Creek, and Upper Pine Creek have nitrate concentrations that exceed natural background levels; concentrations of phosphorus in Sugar Creek are also above levels of concern. Sugar Creek and Sing Sing Creek show high levels of aluminum and Canacadea Creek, South Branch Tunkhannock Creek, and Sing Sing Creek have high concentrations of sodium. Several other stations had single occurrences of parameters exceeding water quality standards or levels of concern, but the average concentration met standards.

Chest Creek, Little Muncy Creek, and Sugar Creek are listed as impaired by agriculture on the PA 303(d) list (PADEP, 2012). They each have wastewater treatment plants upstream of the monitoring location and over one-third of the land use in the watershed is agriculture. Excess nutrients from these uses could be entering the waterbody impairing the stream. Sing Sing Creek and the Sangerfield River have no miles listed as impaired, but do contain industrial dischargers and over 20 percent of their land use is agriculture. Bobs Creek and Upper Pine Creek also have no impaired miles and have no dischargers located within the monitored watershed. Less than 20 percent of the watersheds are covered with agricultural land use, but elevated levels of nitrate are consistently observed. The levels range from 0.6 to 1.0 mg/l, which exceeds the level of concern for aquatic life, but is significantly below the drinking water standard of 10 mg/l. The high levels of aluminum in Sugar Creek and Sing Sing Creek were only observed once at each station during lower flow conditions.

Elevated concentrations of sodium at monitoring stations on Canacadea Creek, Sing Sing Creek, and South Branch Tunkhannock Creek indicate a source(s) of sodium to the waterbodies. Sources of sodium to surface water include road salt, waste water treatment plants, water treatment plants, and water softeners (USEPA, 2003). Wastewater treatment plants are located in Canacadea Creek and South Branch Tunkhannock Creek Watersheds and several state roads and/or an interstate bisect the watersheds. Salt mining or storage may be impacting both sodium and conductance concentrations in these watersheds.

In addition to human sodium sources, in the late 1800s, subsurface rock salt was discovered in New York in Wyoming County. Since that time, over 650 salt related wells have been drilled in the southern tier of New York. Salt thickness is over 500 feet in Chemung, Tioga, southern Tompkins and Schuyler and eastern Steuben Counties (Sanford, 1995). The Sing Sing Creek drainage area is located in Chemung County and the Canacadea Creek monitoring location is located in eastern Allegheny County, which borders Steuben County.

Bromide concentrations exceeded levels of concern at eight stations, but average bromide concentrations remained below levels of concern. Baldwin Creek, Canacadea Creek, Driftwood Branch, Hammond Creek, Portage Creek, Snake Creek, Sugar Run, and Tomjack Creek each recorded a single concentration of bromide above 50 µg/l. The higher bromide concentrations were recorded during low flow periods; bromide concentrations are typically higher during low flow in surface water systems. Each of these watersheds is listed as meeting its designated use.

Acidity and alkalinity concentrations were outside of water quality standards at several locations. Average acidity concentrations were below the water quality standard, but 12 stations recorded concentrations above 20 mg/l at least once. Bobs Creek, Meshoppen Creek, Moose Creek, Sing Sing Creek, Starrucca Creek, Trout Brook, and West Branch Pine Creek are meeting their designated uses. Bowman Creek and Kitchen Creek each have short stream segments listed as impaired by acid deposition and Trout Run has a segment listed for AMD. Acid deposition and AMD can adversely impact a stream's acidity. Little Muncy Creek and Sugar Creek have stream segments impaired by agriculture.

Many of the monitored watersheds in the network have naturally low alkalinity, below the water quality standard of 20 mg/l. Twenty-eight streams had at least one alkalinity value below the standard and 19 of these stations average alkalinity values under 20 mg/l. Seventeen of the stations are located in the North Central Appalachian ecoregion with Bobs Creek (Ridges and Valleys) and Choconut Creek (Northern Appalachian Plateau and Uplands) being the exceptions. The low alkalinity values in these systems indicate a low buffering capacity meaning even small introductions of acidic solutions can significantly alter the pH.

The major anion and cation structure in percentages was plotted for each

Table 3. Water Chemistry Parameters

Parameter	Water Quality Standard	Reference Code	Ecoregion Range			
			North Central Appalachian	Northern Appalachian Plateau & Uplands	Central Appalachian Ridges & Valleys	
Alkalinity (mg/l)	> 20 mg/l	a	< 5 – 63	12 - 205	7 - 111	a. http://www.pacode.com/secure/data/025/chapter93/s93.7.html
Aluminum (mg/l)	0.75 mg/l	b	< 0.11 – 1.0	< 0.11 – 5.2	< 0.11 – 0.18	b. http://www.pacode.com/secure/data/025/chapter93/s93.8c.html
Barium (mg/l)	2.0 mg/l	b	< 0.011 – 0.066	< 0.011 – 0.24	0.023 – 0.062	c. http://www.dec.ny.gov/regs/4590.html#16132
Chloride (mg/l)	250 mg/l	a	< 1 .0 – 67.5	3.6 – 105	3.8 – 21.5	
+Gross Alpha (pCi/L)	15 pCi/L	b	ND – 1.91	ND – 11.7	ND – 4.31	
+Gross Beta (pCi/L)	4 mrem/yr	b	ND – 4.21	ND – 14.6	ND – 7.38	
+Magnesium (mg/l)	35 mg/l	c	0.4 – 6.6	0.69 – 16.6	1.7 – 28.8	
pH	6.0 – 9.0	a	5.13 – 9.89	6.85 – 8.89	6.53 – 8.36	
+Sodium (mg/l)	20 mg/l	c	< 0.25 – 28.8	2.6 – 53.7	2.6 – 9.7	
Sulfate (mg/l)	250 mg/l	a	3.9 – 50.4	< 2 – 108	6.8 – 229	
Total Dissolved Solids (mg/l)	500 mg/l	c	< 5 – 180	9 – 457	< 5 – 491	
Levels of Concern* – Based on background levels, aquatic life tolerances, or recommendations						
+Alkalinity, Bicarbonate (mg/l)	**Related to pH	j	< 5 – 61	13-190	< 5 – 116	d. http://www.uky.edu/WaterResources/Watershed/KRB_AR/wq_standards.htm
+Alkalinity, Carbonate (mg/l)	**Related to pH	j	< 5	< 5 -12	< 5	e. http://water.usgs.gov/pubs/circ/circ1225/images/table.html
+Bromide (µg/l)	50 µg/l	l	< 10.0 – 62.2	< 10.0 – 87.3	< 10.0 – 34.8	f. http://www.uky.edu/WaterResources/Watershed/KRB_AR/krww_parameters.htm
+Calcium (mg/l)	100 mg/l	h	1.9 – 21.7	5.1 – 64.3	4.4 – 90.0	g. Hem (1970)
+Carbon Dioxide (mg/l)			< 1 - 55	11 – 170	7 – 104	h. Based on archived data at SRBC
Hot Acidity (mg/l)	20 mg/l	h	< 3 - 51	< 3 – 108	< 3- 29	i. http://www.pabulletin.com/secure/data/vol42/42-27/1292.html
+Lithium (mg/l)	0.70 mg/l	k	< 0.11	< 0.11	< 0.11	j. http://water.me.vccs.edu/courses/env211/lesson7_4.htm
+Nitrate (mg/l)	0.6 mg/l	e	< 0.2 – 1.1	< 0.2 – 4.6	< 0.2 – 1.6	k. https://www.vdh.virginia.gov/Epidemiology/DEE/publichealthtoxicology/documents/pdf/lithium.pdf
+Phosphorus (mg/l)	0.1 mg/l	f	< 0.01 – 0.14	< 0.1 – 0.19	< 0.1 – 0.048	l. Natural background levels for freshwater systems. http://wilkes.edu/include/waterresearch/pdfs/waterbooklet070610.pdf
+Potassium (mg/l)			< 0.25 – 2.9	0.42 – 4.3	0.84 – 2.5	
Specific Conductance (µS/cm)	800 µS/cm	d	22 – 248	53 – 694	62 – 697	
+Strontium (mg/l)	4.0 mg/l***	i	0.0082 – 0.18	0.019 – 0.11	0.024 – 0.35	
Total Organic Carbon (mg/l)	10 mg/l	g	< 1 – 5.1	< 1 – 9.2	< 1 – 3.2	

+ Analyzed four times a year
ND – Non-detect
*Levels of concern are not a water quality standard.
** Carbonate alkalinity is present below 4.3 and above 8.3 pH; bicarbonate alkalinity is present between 4.3 and 12.3 pH; forms carbonic acid, lowering the pH
*** Proposed water quality standard

monitoring location and grouped by ecoregion on a Piper Diagram. A Piper Diagram displays the chemical characteristics of each station on one diagram, allowing for visual comparison. The cations are plotted on the left triangle while anions are plotted on the right triangle. The points on the two triangles are projected upward into the diamond until they intersect to visually show difference of ion chemistry between stations and ecoregions (University of Idaho, 2001).

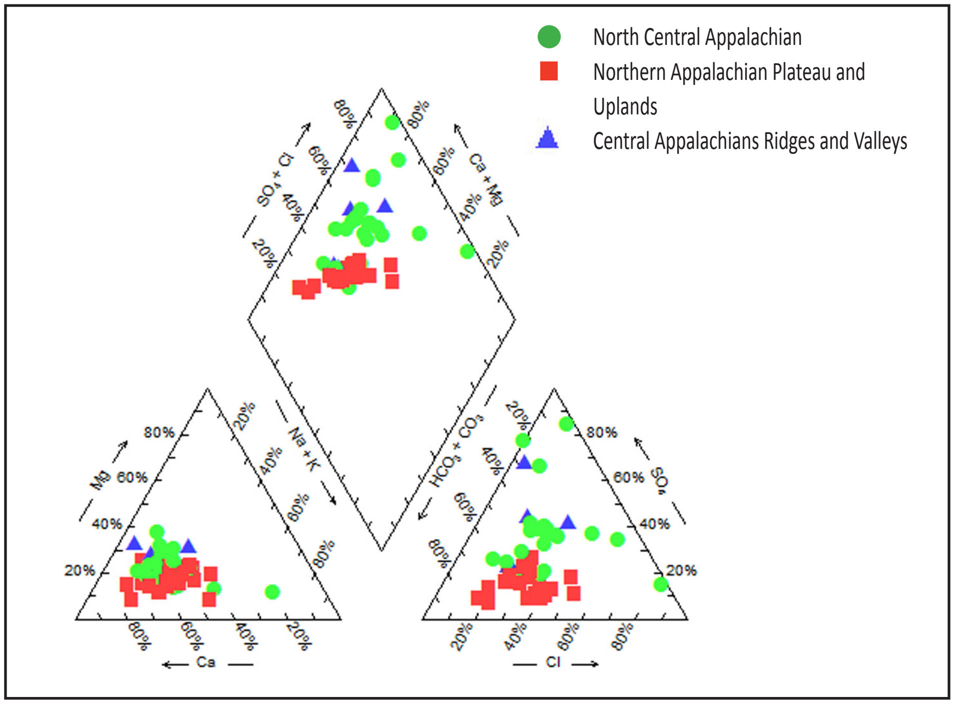


Figure 5. RWQMN Piper Diagram

Figure 5 shows the chemical diversity of the RWQMN stations. Overall, the cation structure for all stations is similar with the exception of Moose Creek indicated by the green circle located near 20 percent calcium. The anion structure shows a large diversity mostly within the North Central Appalachian ecoregion.

The Northern Appalachian Plateau and Uplands ecoregion shows the least diversity as seen by the red squares. The cations and anions are grouped together indicating similar water chemistry. The Ridges and Valleys ecoregion stations show some diversity in the water chemistry. The cations plot close together, but there is a range in the anion percentages. Little Muncy Creek and Marsh Creek show similar water chemistry and have comparable watershed characteristics. Once again, Bobs Creek exhibits similar water chemistry to Chest Creek and Little Clearfield Creek, both with AMD influences.

The North Central Appalachian ecoregion shows the greatest diversity of cation and anion composition. Six stations show significant differences in anion composition: Moose Creek, Baker Run, Kitchen Creek, Trout Run, Grays Run, and Little Pine Creek. These are represented by the three green circles located near the top of the right triangle and the three green circles located on the right side of the right triangle. Two of the stations, Kitchen Creek and Trout Run, were mentioned in the first data report as having different cation and anion percentages and still exhibit these differences. Baker Run, Grays Run, Little Pine Creek, and Moose Creek were not analyzed in the first report. The six stations have very good water chemistry and support excellent macroinvertebrate communities, but other stations in the ecoregion and other ecoregions show the same characteristics.

Biological Data

Macroinvertebrate data were collected at all stations in 2011. Data were collected at the majority of the stations in October 2011; however, several stations were collected in May – June 2011. These biological data will serve as a baseline for future collection efforts at the monitoring stations. All data were collected following PADEP's protocol (PADEP, 2006).

To characterize the biological health of the monitored streams, an Index of Biotic Integrity (IBI) is calculated. The pollution tolerance level varies between macroinvertebrates and the ratio of tolerant and sensitive species is the basis of the IBI score. Several indices are calculated in order to determine the IBI score. These indices include: taxa richness, EPT taxa, Beck's Index, Hilsenhoff Biotic Index, Shannon Diversity, and percent sensitive taxa. Streams with an IBI score of greater than 63 are rated as non-impacted.

Overall, the North Central Appalachian ecoregion scored the highest IBI scores, with scores in the 80-90 range. The two stations falling below this range are the Lackawanna River, where the station is located below two dams, and Marsh Creek in Tioga County, which is downstream of Wellsboro, Pa.

The majority of the monitoring stations in the Northern Appalachian Plateau and Uplands ecoregion have IBI scores in the 60-80 range. Several stations in the ecoregion fall below this range and score in the 40-50 range. Canacadea Creek, Cherry Valley Creek, and Tuscarora Creek have lower IBI scores and have some of the highest agriculture land use percentages in the ecoregion; however, no stream miles are listed as impaired.

In general, the stations located in the Ridges and Valleys ecoregion have IBI scores in the 80 range. Bobs Creek scores over 90 and is the most pristine watershed monitored in this ecoregion. Chest Creek scores in the 60 range; it is located downstream of Patton, Pa., and has AMD influences.

More in-depth biological analysis will be discussed in the next report when more data are available for analysis.

Only one macroinvertebrate sample for each station was available for analysis for the current report. The next report will have three macroinvertebrate samples from concurrent years and two fish samples to analyze.

Conclusions

SRBC began continuous water quality monitoring in January 2010 with the intent to monitor natural gas drilling impacts to small headwater streams in the Susquehanna River Basin. In addition to the continuous water quality monitoring, supplemental water chemistry samples are collected along with macroinvertebrate samples. Analyses have been conducted on the datasets with several preliminary findings:

- Continuously monitored water chemistry parameters (specific conductance, dissolved oxygen, pH, and turbidity) group together by ecoregion, with the North Central Appalachian ecoregion showing the tightest grouping;
- The results of supplemental lab analyses show water chemistry parameters group together by ecoregion, with the exception of six stations in the North Central Appalachian ecoregion;
- Trend analyses at select stations show a mix of positive, negative, or no trend for continuous monitored parameters; and
- Specific conductance has not shown a correlation to well pad density or consumptive water use approvals in the monitored watersheds.

The North Central Appalachian ecoregion stations exhibit good water quality, including the six stations that display variability in the Piper Diagram. For the stations shown as outliers, metal, nutrient, and macroinvertebrate data do not show differences from the other stations within the ecoregion. The anion results (and cation results at Moose Creek) seems to be the only significant difference in water chemistry at these stations.

To start to evaluate any potential impacts from natural gas drilling activities, trend analyses were conducted on three stations in the Northern Appalachian Plateau and Uplands ecoregion. The results of the analyses were mixed, with specific conductance and turbidity showing a decreasing trend at Choconut Creek, and pH and temperature showing an increasing trend at Hammond Creek. Meshoppen Creek did not show a trend with any parameters. With respect to the parameters, dissolved oxygen was the only parameter that did not show a trend at any of the stations.

Natural gas impacts are not the only potential influences for the streams analyzed. Construction, agricultural practices, development, and abnormal seasonal temperatures all have the potential for influencing the continuously monitored water quality parameters. The 2011/2012 winter season was very warm leading to warmer water temperatures and decreasing road salt use, which eventually makes its way into the streams which increases specific conductance. Changes in urban and agricultural practices can influence all of the parameters.

A few accidents have occurred as a result of drilling activities upstream of select monitoring stations. In those cases, Pennsylvania agencies have used the continuous water chemistry data to track the events and determine if any water quality impacts occurred. In addition to other agencies using the continuous water chemistry data to track events, SRBC staff collects supplemental lab water chemistry data if significant deviations are seen in the continuous data. While not utilized often, established plans outline protocols on where and how to collect water samples within the watershed. These data assist in determining the reason behind deviations in the continuous water chemistry data.

As SRBC moves forward with monitoring the 58 watersheds in the Susquehanna River Basin, additional enhancements have been added to the network. Continuous precipitation data are collected at 11 stations and pressure transducers have been placed at 17 stations to monitor water levels to build rating curves. The rating curves will allow for staff to estimate streamflow at these stations. Precipitation gages will assist staff with correlating turbidity and specific conductance to precipitation events. In addition to these efforts already in place, autosamplers will be placed at select stations to collect water chemistry samples when triggered by significant changes in one of the continuously monitored parameters. Based on the remoteness of the monitoring stations, autosamplers will allow for a water chemistry sample to be collected at the time of a potential event in the stream.

SRBC will continue to monitor the 58 monitoring stations and provide a technical summary of all the data collected by the network, but future reports will begin to focus more on analysis of water chemistry in a subset of watersheds, trend analyses of the continuous data, and assessments of the biological data.

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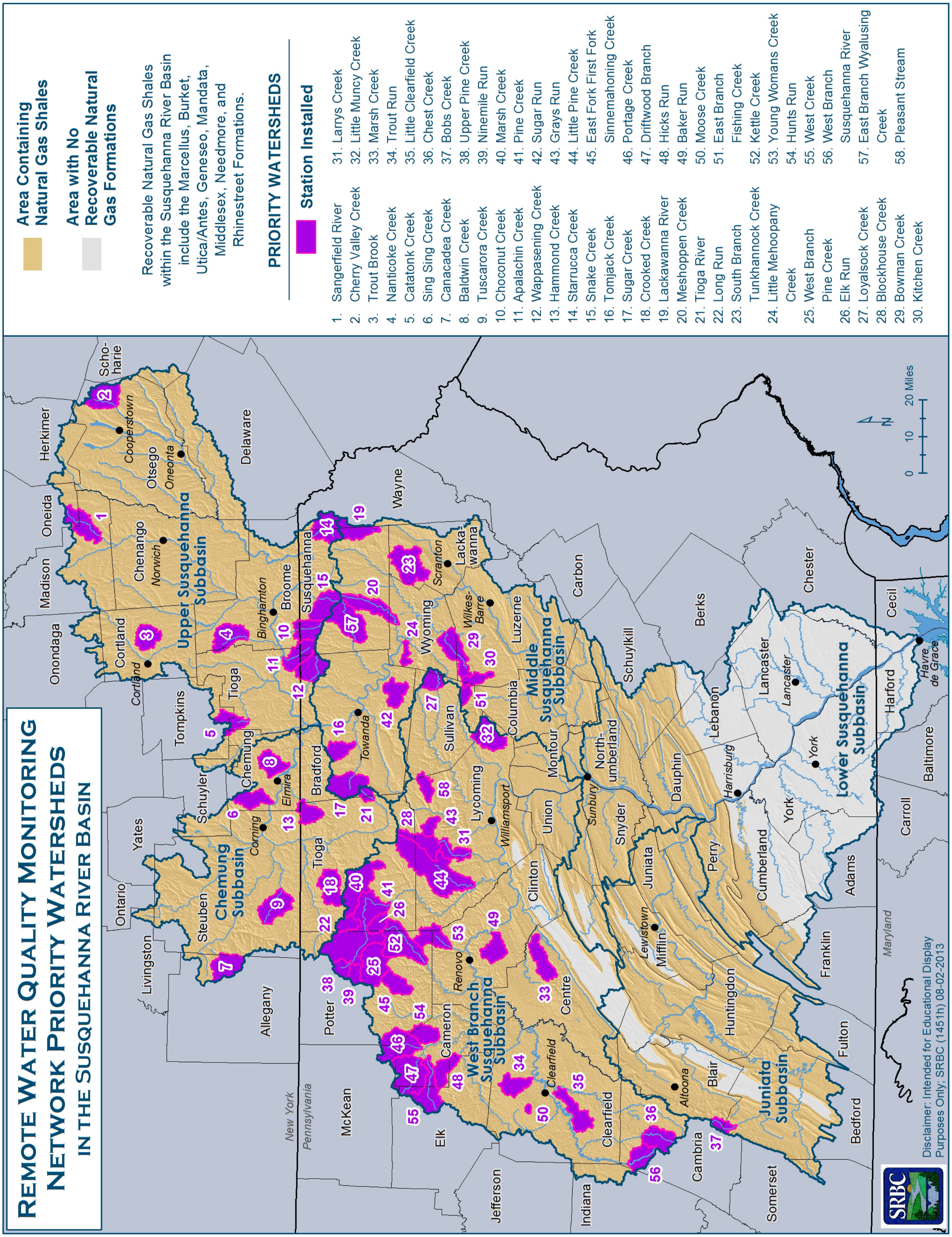
APPENDIX A

RWQMN Watersheds – 58 Stations



APPENDIX B

Continuous Water Chemistry Statistics

Site	Map ID	Number of Observations	Median SpCond µS/cm	Mean SpCond µS/cm	StDev SpCond µS/cm	Median DO mg/l	Mean DO mg/l	StDev DO mg/l	Median pH	Median Turb NTU	Mean Turb NTU	StDev Turb NTU
Apalachin Creek	11	139,166	136	142	37	11.759	11.1	2.882	7.193	4.138	26.564	105.859
Baker Run	49	1,459	24	24	3	12.101	12.025	0.964	6.313	0.7	12.117	82.105
Baldwin Creek	8	157,240	148	154	38	11.546	11.567	2.344	7.346	5.4	18.911	75.618
Blockhouse Creek	28	135,704	100	108	37	10.285	10.555	2.115	7.503	1.2	19.876	115.586
Bobs Creek	37	4,588	71	75	12	10.71	11.067	1.71	7.12	2.6	17.086	85.588
Bowman Creek	29	179,320	44	49	12	11.636	11.466	1.763	6.777	2.103	6.416	27.538
Canacadea Creek	7	130,609	383	422	166	12.509	11.904	2.702	8.066	2.3	38.508	153.38
Catatonk Creek	5	155,804	305	294	86	10.268	9.891	2.235	7.721	3.1	8.644	28.653
Cherry Valley Creek	2	2,864	196	199	38	12.1	11.324	2.022	7.703	9	27.033	102.951
Chest Creek	36	172,631	215	232	69	10.942	10.893	1.798	7.293	8.043	18.426	40.771
Choconut Creek	10	238,025	76	83	24	11.217	11.275	2.402	7.08	3.99	17.132	76.269
Crooked Creek	18	3,841	175	179	62	11.262	11.038	2.745	7.735	0.81	15.64	84.326
Driftwood Branch	47	83,272	52	52	8	11.699	11.623	1.867	6.914	1.4	3.568	39.28
East Fork Sinnemahoning	45	2,150	42	46	10	10.924	10.645	1.769	6.862	1.15	2.409	7.431
Elk Run	26	3,887	74	81	21	11.165	11.298	1.944	7.47	4.596	21.122	83.804
Grays Run	43	109,843	30	30	3	11.022	11.079	1.319	6.387	0	1.912	27.785
Hammond Creek	13	229,524	167	190	80	11.697	11.206	3.038	7.76	2.61	13.811	65.096
Hicks Run	48	1,852	46	51	15	11.661	11.482	1.766	6.719	1.27	2.227	9.527
Kitchen Creek	30	2,391	57	58	11	12.177	12.009	1.685	6.732	1.41	4.365	25.922
Lackawanna River	19	188,074	70	73	17	11.495	10.934	2.527	7.038	2.1	12.878	68.675
Larrys Creek	31	11,152	55	59	7	11.74	11.194	1.605	7.208	1.56	7.073	17.786
Little Clearfield Creek	35	4,480	316	397	187	9.85	9.975	1.314	7.6	2.7	18.723	37.877
Little Mehoopany Creek	24	172,781	105	108	29	11.727	11.85	1.802	7.434	1.532	5.093	23.417
Little Muncy Creek	32	3,394	97	101	21	11.006	11.292	1.984	7.205	3.52	15.754	73.608
Little Pine Creek	44	2,091	90	110	50	11.186	11.259	2.019	7.112	1.2	14.08	84.163
Long Run	22	113,498	79	83	19	10.819	11.482	1.85	7.29	1.2	15.186	77.405
Loyalsock Creek	27	190,233	29	33	13	10.924	11.072	2.25	6.531	0.8	2.341	8.509
Marsh Creek (Blanchard)	33	181,719	90	106	35	11.331	11.181	2.492	7.392	3.357	34.764	148.524
Marsh Creek (Ansonia Station)	40	2,152	131	139	45	10.603	10.409	2.016	7.308	6.72	17.396	33.204
Meshoppen Creek	20	231,098	112	111	27	11.06	11.104	2.327	7.57	2.7	13.035	49.296
Moose Creek	50	114,127	102	119	1018	10.98	11.103	1.425	6.472	0.7	1.661	21.37
Nanticoke Creek	4	154,906	124	129	35	11.813	11.511	2.234	7.216	7.6	50.139	151.8
Ninemile Creek	39	2,160	53	56	13	11.15	11.211	1.46	7.023	1.15	2.114	6.454
Pine Creek	41	1,824	73	82	26	11.694	11.438	2.009	7.13	26.47	151.693	276.267
Portage Creek	46	86,825	59	63	18	11.819	11.539	1.716	7.06	0.8	2.117	14.228
Sangerfield River	1	157,442	273	278	67	11.609	11.368	1.895	7.949	4.7	10.034	44.403
Sing Sing Creek	6	155,869	377	378	132	10.846	10.782	1.976	7.802	7.1	53	136.263
Snake Creek	15	178,032	86	89	20	10.56	10.86	2.605	7.02	3.1	13.9	42.044
South Branch Tunkhannock Creek	23	152,227	219	236	71	10.851	11.071	2.071	7.588	2.078	9.67	52.766
Starrucca Creek	14	153,584	74	78	17	10.98	11.301	2.075	7.465	1.271	3.932	19.178
Sugar Creek	17	165,624	197	242	105	10.695	10.582	2.566	7.666	6.6	20.787	85.645
Sugar Run	42	78,505	100	101	13	12.005	12.09	2.238	7.35	5.6	10.989	23.549
Tioga River	21	3,924	41	44	13	11.216	11.133	1.86	6.752	0.92	13.372	89.763
Tomjack Creek	16	129,005	183	182	43	9.604	9.61	2.064	7.838	5.9	18.625	64.554
Trout Brook	3	159,850	157	171	60	11.906	11.713	1.831	7.782	2.2	8.733	37.88
Trout Run	34	197,092	51	55	16	10.71	10.925	1.867	5.9	0.32	1.5	14.404
Tuscarora Creek	9	141,831	216	237	70	11.638	11.417	2.452	7.939	4.8	17.684	59.95
Upper Pine Creek	38	2,325	65	70	20	10.934	10.923	1.628	7.17	1.27	3.723	12.415
Wappasening Creek	12	193,529	89	95	25	10.473	10.382	2.725	7.024	3.2	18.735	82.19
West Branch Pine Creek	25	172,754	43	46	11	10.508	10.434	1.688	6.886	1.6	12.91	76.561

APPENDIX C

Data Collection Timeframe

Site	Stream Name	Site ID	Period of Data Collection
Apalachin Creek near Apalachin, NY	Apalachin Creek	11	12/14/2010 – 6/28/2012
Baker Run near Glen Union, PA	Baker Run	49	9/19/2011 – 6/25/2012
Baldwin Creek near Loman, NY	Baldwin Creek	8	12/7/2010 – 6/28/2012
Blockhouse Creek near English Center, PA	Blockhouse Creek	28	6/4/2010 – 6/30/2012
Bobs Creek near Pavia, PA	Bobs Creek	37	3/30/2010 – 6/30/2012
Bowman Creek near Noxen, PA	Bowman Creek	29	4/1/2010 – 6/21/2012
Canacadea Creek near Almond, NY	Canacadea Creek	7	12/17/2010 – 6/30/2012
Upper Catatonk Creek near Spencer, NY	Catatonk Creek	5	12/16/2010 – 6/30/2012
Cherry Valley Creek near Middlefield, NY	Cherry Valley Creek	2	12/2/2010 – 6/30/2012
Chest Creek near Patton, PA	Chest Creek	36	9/21/2010 – 6/30/2012
Choconut Creek near Vestal Center, NY	Choconut Creek	10	1/27/2010 – 6/28/2012
Upper Crooked Creek near Keeneyville, PA	Crooked Creek	18	6/16/2010 – 6/30/2012
Driftwood Branch near Lockwood, PA	Driftwood Branch	47	5/19/2011 – 6/19/2012
East Fork Sinnemahoning Creek near Logue, PA	East Fork Sinnemahoning Creek	45	5/25/2011 – 6/30/2012
Elk Run near Watrous, PA	Elk Run	26	6/23/2010 – 6/20/2012
Grays Run near Gray, PA	Grays Run	43	5/5/2011 – 6/20/2012
Hammond Creek near Millerton, PA	Hammond Creek	13	1/27/2010 – 6/28/2012
Hicks Run near Hicks Run, PA	Hicks Run	48	6/16/2011 – 6/20/2012
Kitchen Creek near Huntington Mills, PA	Kitchen Creek	30	10/30/2010 – 5/12/2012
Lackawanna River near Forest City, PA	Lackawanna River	19	7/14/2010 – 6/30/2012
Larrys Creek near Salladasburg, PA	Larrys Creek	31	3/30/2010 – 6/27/2012
Little Clearfield Creek near Dimeling, PA	Little Clearfield Creek	35	4/28/2010 – 6/30/2012
Little Mehoopany Creek near North Mehoopany, PA	Little Mehoopany Creek	24	9/8/2010 – 6/21/2012
Little Muncy Creek near Moreland, PA	Little Muncy Creek	32	8/6/2010 – 6/30/2012
Long Run near Gaines, PA	Long Run	22	12/17/2010 – 6/1/2012
Loyalsock Creek near Ringdale, PA	Loyalsock Creek	27	6/3/2010 – 6/21/2012
Little Pine Creek near Waterville, PA	Little Pine Creek	44	7/1/2010 – 6/19/2012
Marsh Creek near Ansonia Station, PA	Marsh Creek	40	6/9/2011 – 6/20/2012
Marsh Creek near Blanchard, PA	Marsh Creek	33	6/30/2010 – 6/18/2012
Meshoppen Creek near Kaiserville, PA	Meshoppen Creek	20	1/27/2010 – 6/30/2012
Nanticoke Creek near Maine, NY	Nanticoke Creek	4	12/16/2010 – 6/30/2012
Ninemile Run near Walton, PA	Ninemile Run	39	5/25/2011 – 6/30/2012
Pine Creek near Blackwell, PA	Pine Creek	41	8/8/2011 – 6/30/2012
Portage Creek near Emporium, PA	Portage Creek	46	8/22/2011 – 6/19/2012
Sangerfield River near Poolville, NY	Sangerfield River	1	12/2/2010 – 6/30/2012
Sing Sing Creek near Big Flats, NY	Sing Sing Creek	6	12/1/2010 – 6/30/2012
Snake Creek near Lawsville Center, PA	Snake Creek	15	6/2/2010 – 6/28/2012
South Branch Tunkhannock Creek near La Plume, PA	South Branch Tunkhannock Creek	23	7/1/2010 – 6/30/2012
Starrucca Creek near Stevens Point, PA	Starrucca Creek	14	7/1/2010 – 6/30/2012
Sugar Creek near Troy, PA	Sugar Creek	17	4/27/2010 – 6/20/2012
Sugar Run near Sugar Run, PA	Sugar Run	42	9/21/2011 – 6/21/2012
Tioga River near Fall Brook, PA	Tioga River	21	6/23/2010 – 6/21/2012
Tomjack Creek near Burlington, PA	Tomjack Creek	16	4/27/2010 – 6/30/2012
Upper Tuscarora Creek near Woodhull, NY	Tuscarora Creek	9	12/16/2010 – 6/20/2012
Upper Pine Creek near Telescope, PA	Pine Creek	38	5/25/2011 – 6/27/2012
Wappasening Creek near Windham Center, PA	Wappasening Creek	12	6/2/2010 – 6/28/2012
West Branch Pine Creek near Galeton, PA	West Branch Pine Creek	25	6/3/2010 – 6/30/2012

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ACKNOWLEDGEMENTS

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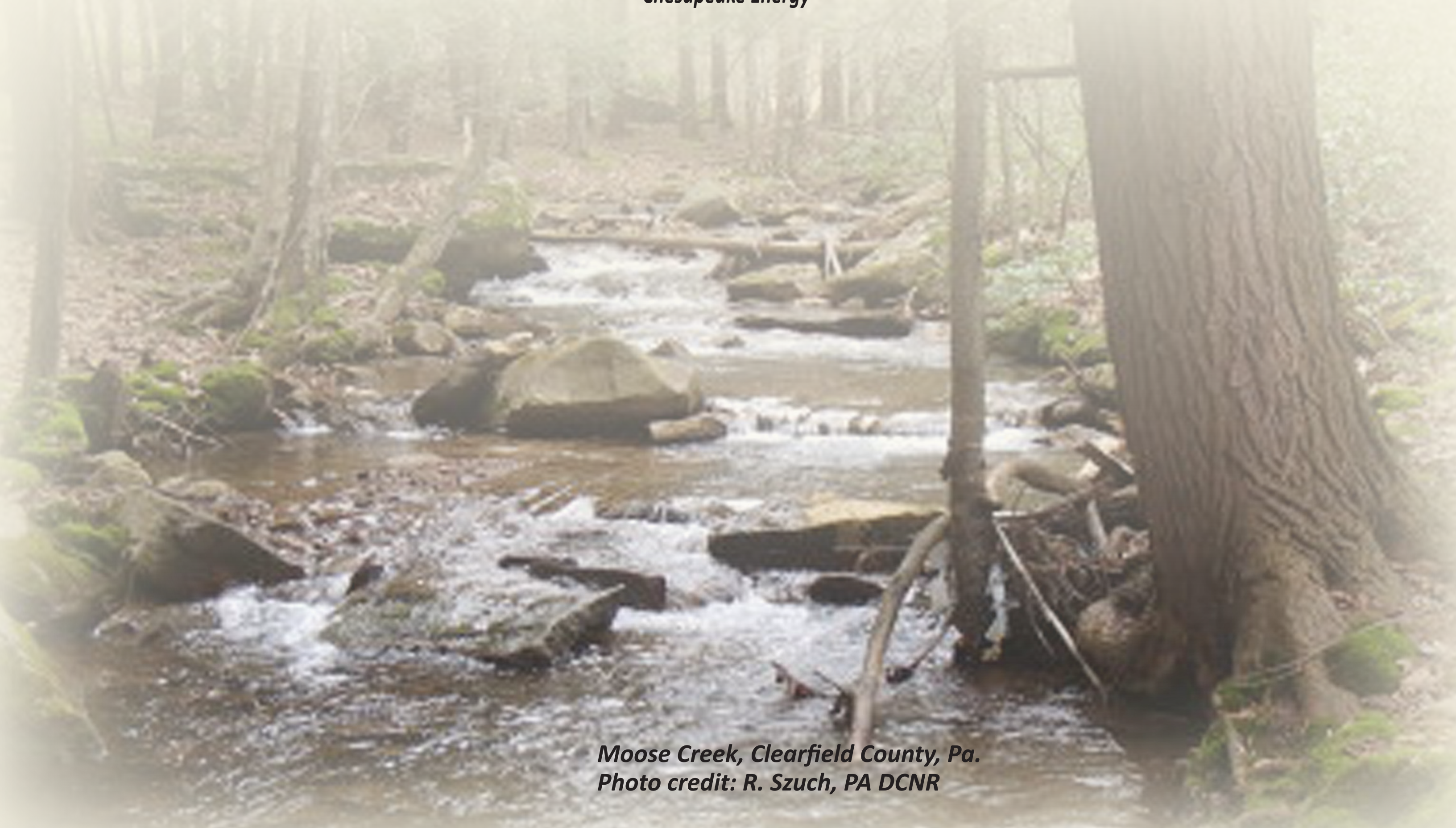
East Resources, Inc.

New York State Energy Research and Development Authority

Pennsylvania Department of Conservation and Natural Resources

Headwaters Resource Conservation & Development Council Sinnemahoning Stakeholders Committee

Chesapeake Energy



Moose Creek, Clearfield County, Pa.
Photo credit: R. Szuch, PA DCNR