Stream Health in the Upper Delaware River Basin Underlain by Marcellus Shale

Presented to the Delaware River Basin Commission

Considering Proposed Unconventional Gas Drilling Regulations

DELAWARE RIVERKEEPER NETWORK

March 29, 2018

Acknowledgements

Delaware Riverkeeper Network (DRN) has been partnering and training community volunteer monitors for over 25 years to address historic and emerging pollution threats to the Delaware River Basin. DRN would like to thank the dedicated Delaware Riverkeeper Network stream monitors and citizen science volunteers who collectively have volunteered thousands of hours streamside to collect stream data to monitor and protect the Delaware River from potential unconventional hydraulic fracturing natural gas drilling impacts.

Delaware Riverkeeper Network would like to thank Alliance for Aquatic Resource Monitoring (ALLARM) of Dickinson College and Pennsylvania Trout Unlimited (PATU) for providing partnership and collaboration to help ensure the volunteer monitoring community in the shale regions and potential shale regions had access to and were using equipment, protocols, and approved labs to document stream conditions that could detect water quality harms of gas drilling in the Marcellus shale while also helping to establish important baselines of stream health in areas where Marcellus shale is present. We would also like to thank the technical expertise of Stroud Water Research Center that provided macroinvertebrate training for volunteer monitors and Rider University and Dr. Hongbing for his assistance with specific metals and salt analysis for some of the streams that were part of this project. analysis for a select group of streams.

Thank you to Catskills Citizens for Safe Energy, Damascus Citizens for Sustainability, Lackawaxen River Conservancy, New York Water Sentinels, Pike-Wayne Trout Unlimited and other ally and community groups working to protect the Delaware River Basin from gas drilling and who helped recruit local volunteer monitors to participate.

Deep gratitude to Muhammad Sarwar, Delaware Riverkeeper Network, who helped compile, organize, and summarize the data for the shale gas monitoring effort that are outlined in this report.

Cover photo: Delaware River at Bushkill Access, by F.Zerbe, Delaware Riverkeeper Network

Project Description:

In anticipation of potential exploitation of Marcellus shale natural gas resources in the Delaware River Basin (DRB), the Delaware Riverkeeper Network (DRN) initiated a community-based citizen science monitoring initiative, to monitor and protect the water resources in the watershed. A volunteer monitor network was established, to document the baseline water quality in the Upper Delaware region in 2010. Volunteer monitors underwent extensive training by DRN. From February 2010 to June 2016, volunteer monitors collected 1,351 samples from 123 distinct stream stations, and analyzed samples for conductivity, temperature and chloride, utilizing equipment provided by DRN. In addition, the monitors collected 60 samples from 44 different sites, to be analyzed for barium and strontium (Ba/Sr). The locations of these sampling stations within the DRB can be seen in Figures 1 and 2. These samples were sent directly to Alliance for Aquatic Resource Monitoring (ALLARM), who coordinated Ba/Sr analysis through a DEP-approved laboratory. Several automatic water chemistry probes were also deployed and installed during this project to collect hourly stream data to compliment the volunteer monthly data collections. The monitoring stations can be found in Appendix A of this report.

To complement the water chemistry data, a DRN biologist collected macroinvertebrate data from multiple locations in the Upper Delaware. A total of 22 benthic samples were collected and analyzed, from 3 separate sampling events in 2011, 2012 and 2014. For site selection, DRN coordinated with the Delaware River Basin Commission (DRBC) to fill gaps in DRBC's natural gas baseline benthic surveys that were being conducted simultaneously.

Since 2010, there has been a de-facto moratorium on all gas drilling, hydraulic fracturing (fracking), water withdrawals for and wastewater treatment and discharges from fracking throughout the entire Delaware River Basin. The moratorium was put in place by the Delaware River Basin Commission (DRBC), the federal-interstate agency that manages the water resources of the Delaware River Watershed. The DRBC members – the Governors of Pennsylvania, New York, New Jersey, and Delaware, and the federal government – have the responsibility of protecting and managing the shared waters that provide 15-17 million people in all four of the Watershed states with drinking water, including New York City and Philadelphia.

The focus of this report is to present a summary of the data collected through this community-based DRN led monitoring initiative to better inform, characterize and recommend measures needed to protect the important water resources and headwater streams in the Delaware River watershed as it pertains to the potential development of unconventional gas drilling impacts. On September 13, 2017 the DRBC Commissioners by a Resolution directed the Executive Director to prepare and publish for public comment a revised set of draft regulations pertaining to gas drilling in the Basin. A public comment period was extended until March 30, 2017 on these proposed gas drilling regulations.

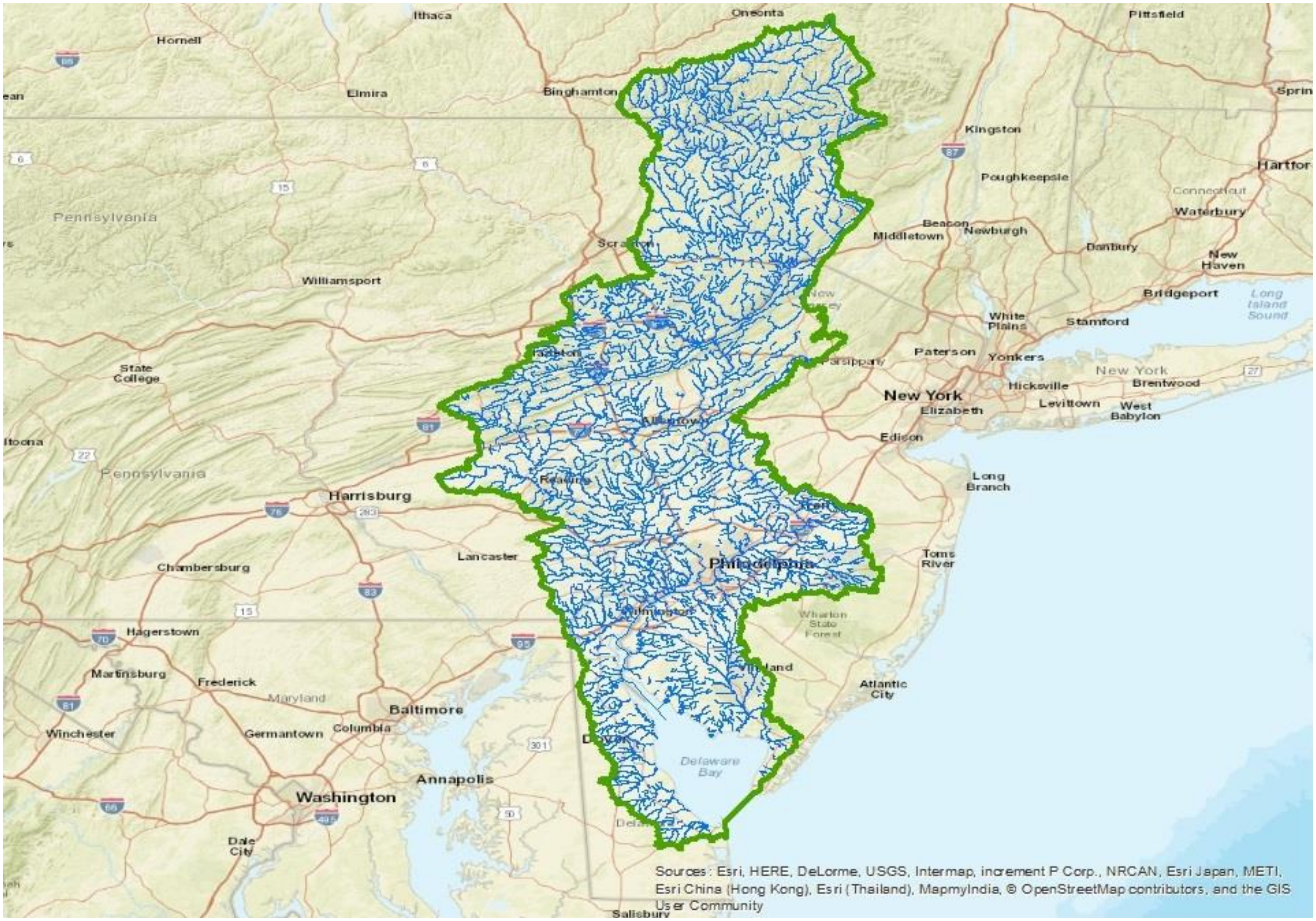

Figure 1. The Delaware River Watershed. Map by M. Sarwar

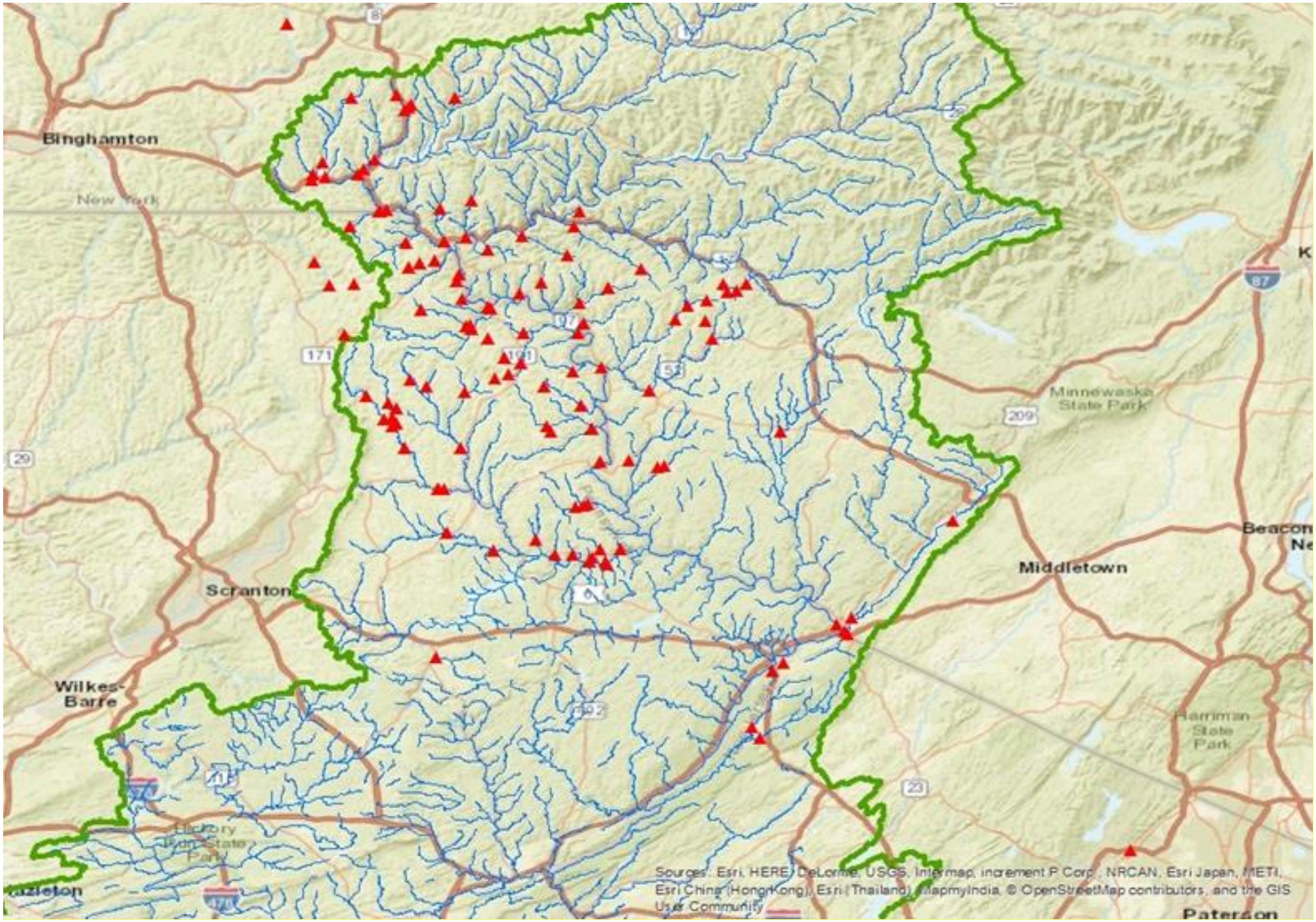

Figure 2. Sampling Stations in the Upper Delaware River Watershed. Map by M. Sarwar (Google Earth layer available upon request)

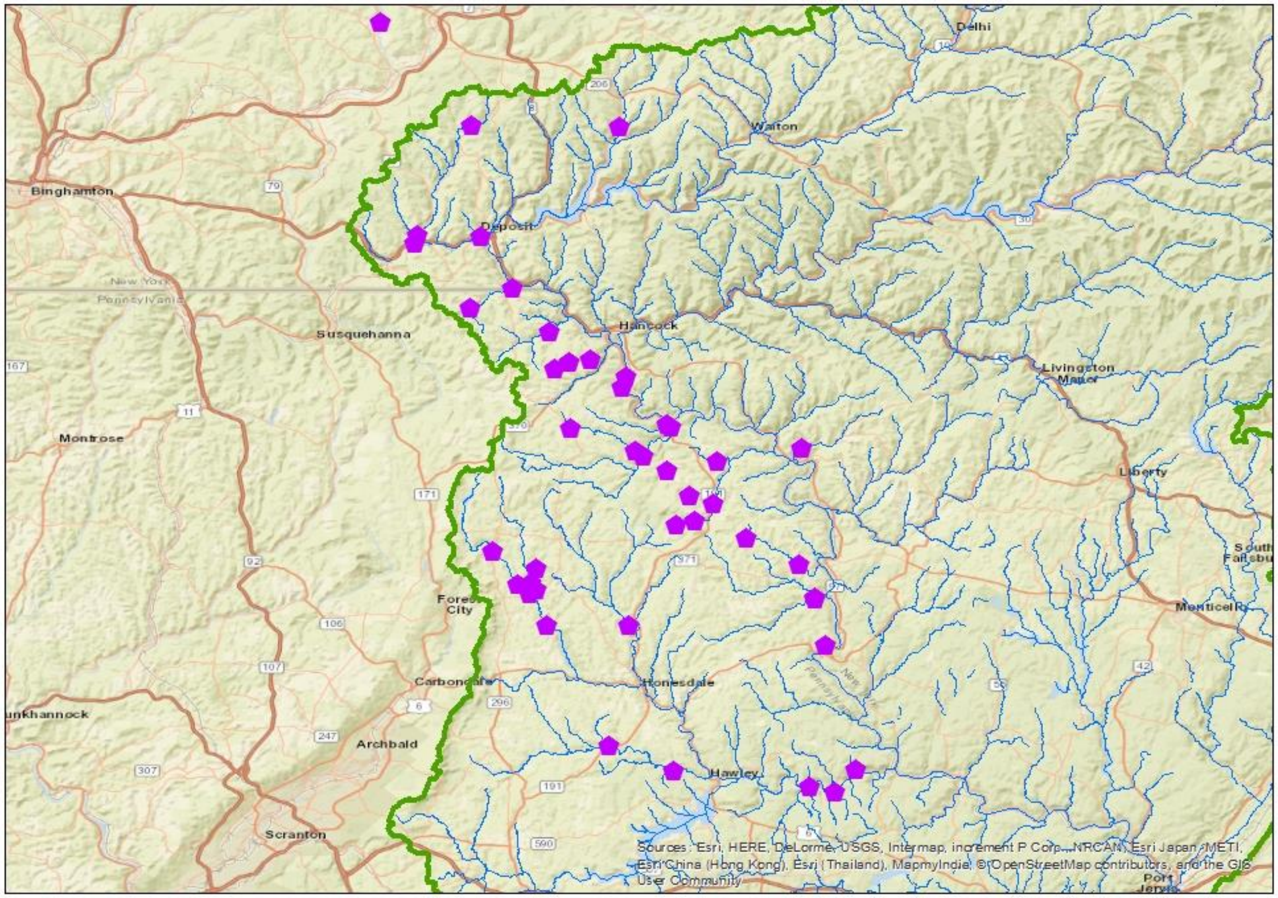

Figure 3. Barium and Strontium Stream Sampling Locations. Map by M. Sarwar (Google Earth layer available upon request)

The Impending Impacts of Unconventional Gas Drilling:

Community-based monitoring has been a critical component of Delaware Riverkeeper Network since its establishment in 1988. Trained community scientists have helped collect a variety of chemical, physical, biological, landscape, and other data that have been used by Delaware Riverkeeper Network and other agencies to better protect and enforce water quality regulations.

The Delaware River is a drinking water source to 17 million people (5% of the US population). Hydraulic fracturing (fracking) of Marcellus shale gas reserves poses a great threat to this water resource. Spills of fluid returned from the rock formation (brine), chemicals used during operations and other fuels/lubricants can stress the river basin. The waste water from drilling operations (flowback water) leaches salts and other minerals from the rock formations, and also contains high concentrations of chemical additives by the drilling operator. Therefore, flowback water has immensely high chloride and conductivity values. In addition to these ions, flowback water contains high concentrations of toxic metals, such as barium and strontium.

In August, 2015 CNA Analysis and Solutions (CNA) published a report that evaluated the environmental impacts of unconventional gas drilling in the DRB for select regions of the upper basin. One significant finding of this report was that 17-23 acres of land per well pad may be cleared to accommodate roads, pipeline, well pad, etc. Approximately 1-2% of forest cover in the DRB could be cleared, including a loss of 5-10% core forest area. This change in land use from forest to frack pad and infrastructure would significantly impact water resources in the DRB. This change in land use would affect multiple water quality parameters, including temperature and conductivity, as well as increased stormwater flow. To date there has been no other build out projection report conducted by the DRBC or others to fully assess the cumulative and overall impacts a gas drilling build out would bring to the Basin.

In areas where unconventional drilling is occurring outside the DRB, the scientific research is indicating significant harms even at the relatively low build out in the Marcellus shale to date. The most recent statistical analysis of the body of scientific literature by the Concerned Health Professionals of New York and Physicians for Social Responsibility, included 685 peer-reviewed papers examining gas drilling and/or hydraulic fracturing ("fracking") that were reviewed and the overwhelming majority of studies found evidence of or potential adverse impacts on water, air, and human health. Pennsylvania Department of Environmental Protection (PADEP) has determined that there are 301 cases of private water well contamination caused by oil and gas operations in the Commonwealth; over 4,400 water complaints related to oil and gas have been filed by the public with PADEP. Between 2004 and November 2016, PADEP lists 9,443 public complaints about environmental problems in shale gas drilling areas.

Stream Parameters Measured for this Study and Other Indicators of Concern:

The physical and chemical properties measured in this study included conductivity, stream temperature, chloride, barium and strontium. Each of these parameters can help establish water quality baselines in areas where drilling or other threats may occur, and can be used to track pollution from shale gas wells, especially if spills occur or projected build out were to happen.

One of the most apparent changes due to Marcellus shale exploration and development will be the change in land use to accommodate roads, well pads and pipelines. An expert report by Stroud Water Research Center examined the relationship between land use and stream conditions. The study showed that the percentage of upstream forest cover in any watershed is the best single indicator of changes in water chemistry. As land is converted to other land uses, e.g. well pads, roads and pipelines, higher values have been observed for parameters such as conductivity, which is a measure of the capability of water to pass electrical flow. In its pure form, water is a poor electrical conductor. The ability of water to transmit electric current is due to dissolved ions. Thus, conductivity is representative dissolved ions in water, and is closely linked to salinity and total dissolved solids (TDS). Normal conductivity readings for fresh water streams range from 50 µS/cm to 1500 µS/cm.

With Marcellus shale exploration and development, the conductivity of freshwater streams will not only be influenced due to the changes in land use but also due to extensive amounts of additives used for fracking, as well as the elements that flowback water picks up from the rock formation and brings to the surface. The conductivity of flowback wastewater from shale gas wells, has been found to be as high as 151,900 µS/cm. Thus, conductivity is an excellent parameter to establish baseline water quality, as well as to help detect pollution events that could come from natural gas drilling.

It is well known and long understood that the Marcellus Shale formation is radioactive. Wastewater contaminated with radioactivity is unavoidable. Exposure to these radioactive materials by the public will occur as a result of flowback produced by fracking through one pathway or another, increasing the likelihood of cancers. Radium-226 has a half-life of 1,600 years, so it will be present in the environment for thousands of years. It is also water soluble, meaning it easily travels with water. Radionuclides can also be trapped in drill cuttings and residual solids, providing another pathway for the release to the environment, increasing human exposure and a legacy of enduring environmental contamination. Interstitial or formation water (the brine in the shale formation) can be highly radioactive (as concentrated as 15,000 pCi/L), so each time the water is reused, the radium is concentrated.

Temperature is very crucial in determining the health of a stream, as it has an effect on other parameters. Warmer water is more soluble, and therefore leads to higher conductivity. In addition, warmer water has a lesser ability to hold dissolved oxygen (DO). The presence of harmful ions and a lack of DO poses danger for aquatic life. Also, many freshwater wildlife species require certain temperature ranges in order to sustain themselves and flourish. For example, mayflies and stoneflies thrive best in cool flowing streams and the diversity of these and other sensitive macroinvertebrates decrease with warming stream temperatures. Macroinvertebrates help cycle out nutrients in streams helping to clean the water with their daily biological actions and they also are important food for fish populations.

One significant impact will be stream temperature changes as natural gas development build out over time would reduce mature forests, and increase stormwater runoff from well pads and associated gas infrastructure. There are cascading and multiple impacts that will result. The development of natural gas, a fossil fuel, would itself also produce more methane gas which exacerbates climate change trends as methane is 86 times more heat trapping than carbon dioxide over a 20-year time frame and its effects persist for hundreds of years. Increased stream temperatures can also lead to increased algae blooms and decreased water clarity and lack of natural forest vegetation and riparian buffers to filter out nutrients could also lead to excess nutrients entering streams.

Chloride is the ionic form of chlorine, and is found in small concentrations in water naturally. Chloride exists in water due to the dissolution of natural salts in rock formations. Natural chloride levels are typically around 25mg/L. The reason this parameter was chosen to establish baseline water quality is that flowback water is very saline, i.e. it has been found to contain very high levels of chloride (up to over 151,000 mg/L). Shale gas wastewater has high chloride concentrations not only because of additives in the drilling fluid, but also from the materials in shale itself. Therefore, chloride is an ideal parameter to establish baseline conditions and detect pollution events. Another common anthropogenic source of chloride in surface waters is the use of winter de-icing road salts. With additional access roads, gas drilling activity and traffic, and rights of way (ROW), the use of deicing salts would also increase. This will have an even greater impact in chloride concentrations.

Two of the most abundant metals in Marcellus flowback water are barium and strontium. The wastewater picks up these metals from the formation itself. These metals in surface water pose a great threat to humans as well as animals. Numerous studies have shown that barium and strontium can cause malignant changes in the bronchial epithelial cells in the human body. In short, these compounds can cause cancer. The CNA report concluded that even if all flowback water was treated to effluent standards attainment, stream concentrations of barium and strontium could increase by up to 500 times the baseline, during periods of low flow. A study conducted by Pennsylvania State University evaluates the geochemistry of wastewater produced by unconventional gas drilling. The study found concentrations of barium of up to 13,600 mg/L, whereas strontium was found in concentrations of up to 5,350 mg/L. These metals can prove to be lethal, thus monitoring streams for these constituents was essential, in order to establish an appropriate baseline.

DRN's Shale Gas Monitoring Network Methods:

Recruitment and Training of Volunteer Monitors: With the threat of unconventional gas drilling emerging in the Upper Delaware River Basin, as well as a concerned and engaged community already involved in existing volunteer monitoring initiatives, DRN was able to advertise the community shale watch trainings and recruit many local volunteer monitors to assist with this project. In addition, a few other volunteer monitors who were located outside of the Basin and had concerns in the Susquehanna River Basin attended DRN trainings and collected data for several streams outside the DRB. As time elapsed and the drilling moratorium was put in place and secured by the DRBC in November 2011, many volunteer monitors reduced the sampling frequency for their stations after a solid baseline was established. If the moratorium were lifted and drilling commenced, DRN would work with the volunteer monitors to establish a more frequent monitoring effort to detect pollution threats and changes.

Interested volunteer monitors were trained by DRN staff, who conducted eight in person training workshops, between January 30, 2010 and November 7, 2013. These workshops were held in the Upper Delaware region, including towns of Hawley and Starlight in Pennsylvania, and Narrowsburg, Callicoon, and Hancock in New York. Over 109 volunteer monitors were trained during these workshops. Additional workshops were held on an as-needed basis.

In addition to providing trainings to facilitate water chemistry data collection, a two-day intensive Stream School Training was conducted to train volunteers on the importance of macroinvertebrates and benthic data collection and analysis. DRN collaborated with Stroud Water Research Center to conduct this training in Pike County, on April 26 and 27, 2013. DRN conducted smaller hands on field trainings in benthic collection with volunteer monitors whose stations were assessed for macroinvertebrates as part of DRN's more in-depth benthic analysis.

DRN biologists conducted focused and extensive technical benthic surveys and assisted agencies to install automatic data loggers at a select group of stations in the shale region during this study period.

Volunteer Monitoring Protocol:

In January 2010, stream monitoring protocols were developed by DRN. The document was intended to serve as a guide and standardized written protocol for the volunteer monitors to use streamside to ensure that each monitor was following the same sampling techniques. Partner organizations, including ALLARM, Trout Unlimited, United States Geological Survey (USGS) and Delaware River Basin Commission (DRBC), reviewed the protocols and provided technical assistance. The equipment manufacturer also reviewed and commented on the protocols. ALLARM had conducted the efficiency and accuracy of the Lamotte Pocket Tracer which was the meter that DRN utilized.

The first group of volunteer monitors were trained February 2010 and commenced monitoring immediately. These volunteers provided feedback on the protocols, which was utilized by DRN and the equipment manufacturer to make minor updates to the existing protocol document. Protocols can be downloaded from the Delaware Riverkeeper Network website.

Quality Assurance/Quality Control:

For the shale gas monitoring project, multiple Quality Assurance/Quality Control (QA/QC) measures were employed. All volunteers attended an in-person half day training conducted by DRN staff. These trainings included overall presentations on the protocols, basic water chemistry and stream monitoring techniques, basic watershed concepts, site station selection process, impacts expected with hydraulic fracturing development, and expectations of participants who would adopt a stream location. Every volunteer monitor worked through the hands on protocols with equipment and filled out a datasheet with results. At the trainings, a blind sample was also used to test accuracy of techniques. In addition, ALLARM assisted with an external QA/QC check that was required for all monitors who sent in a water sample to ALLARM, for analysis after they began stream testing. The ALLARM lab result was compared to the reading obtained by the volunteer for chloride and conductivity. If the relative percent difference (RPD) between the two readings was 20% or less, the volunteers passed QA/QC and their data were considered reliable. The QA/QC results were transmitted electronically to the volunteers and to DRN. This helped ensure that the volunteers were using the equipment properly, increased volunteer confidence and added to the validity and use of the data they collected.

As an added QA/QC measure, the volunteers were required to measure each parameter twice in the field, and then calculate the RPD between the two readings. If the RPD was greater than 20%, a third replicate was required. The two closest replicates were used to obtain mean measurements for all parameters. This method helped minimize error. A standard datasheet was used by all volunteers, and the data were reviewed by DRN staff before and after data entry into a standardized Excel database.

To assist with annual review of techniques, the DRN requested volunteer monitors to review protocols annually with online video tutorials, provided replacement reagents, and was available via phone and email for trouble shooting with volunteer monitors directly. The online tutorials can be found at: http://bit.ly/ShaleWatchMonitorModule.

Barium & Strontium Sampling:

In addition to the monthly conductivity, temperature & chloride testing, monitors also collected samples from their stations to be tested for barium and strontium (Ba/Sr). Volunteers sent these samples to ALLARM for testing by an independent Pennsylvania Department of Environmental Protection (PADEP) approved laboratory. Over the course of the six years, 60 samples were sent in from 44 different stations to be measured for Ba/Sr. The results were transmitted electronically to the volunteers and to the DRN by ALLARM.

Other Metals and Salt Sampling:

DRN is partnering with Rider University to sample streams for salinity impacts and other metals throughout the DRB. Three seasonal stream samples are collected and sent to Rider University for analysis for 18 analytes including salts and common metals and results are reported back to DRN. Four streams including Oquaga, Sherman, Atco, and Shehawken Creeks were sampled that overlap with this shale monitoring project and stations and the data are available upon request but not included in this report.

Water Chemistry Results:

Conductivity/Temperature/Chloride:

Volunteer datasheets were reviewed and processed by DRN staff. They were then entered into an Excel database. The data were organized by station code. Station codes can be found in Appendix A. In June 2016, all previously obtained data were consolidated. Summary statistics for each station can be found in Appendix B of this report. The appendix includes the number of samples from each station, as well as the mean, maximum and minimum measurement for each parameter in each station.

Conductivity is a measure of the capability of water to hold electrical current. Conductivity readings from the 1,351 samples, ranged from 2.36 µS/cm to 586.50 µS/cm, with a mean conductivity of 75.44 µS/cm. The conductivity measurements were within normal ranges for surface water and freshwater streams. A snapshot of the ranges of conductivity measurements in the 17 most sampled sites (with 24+ samples), can be seen in Figure 4 below.

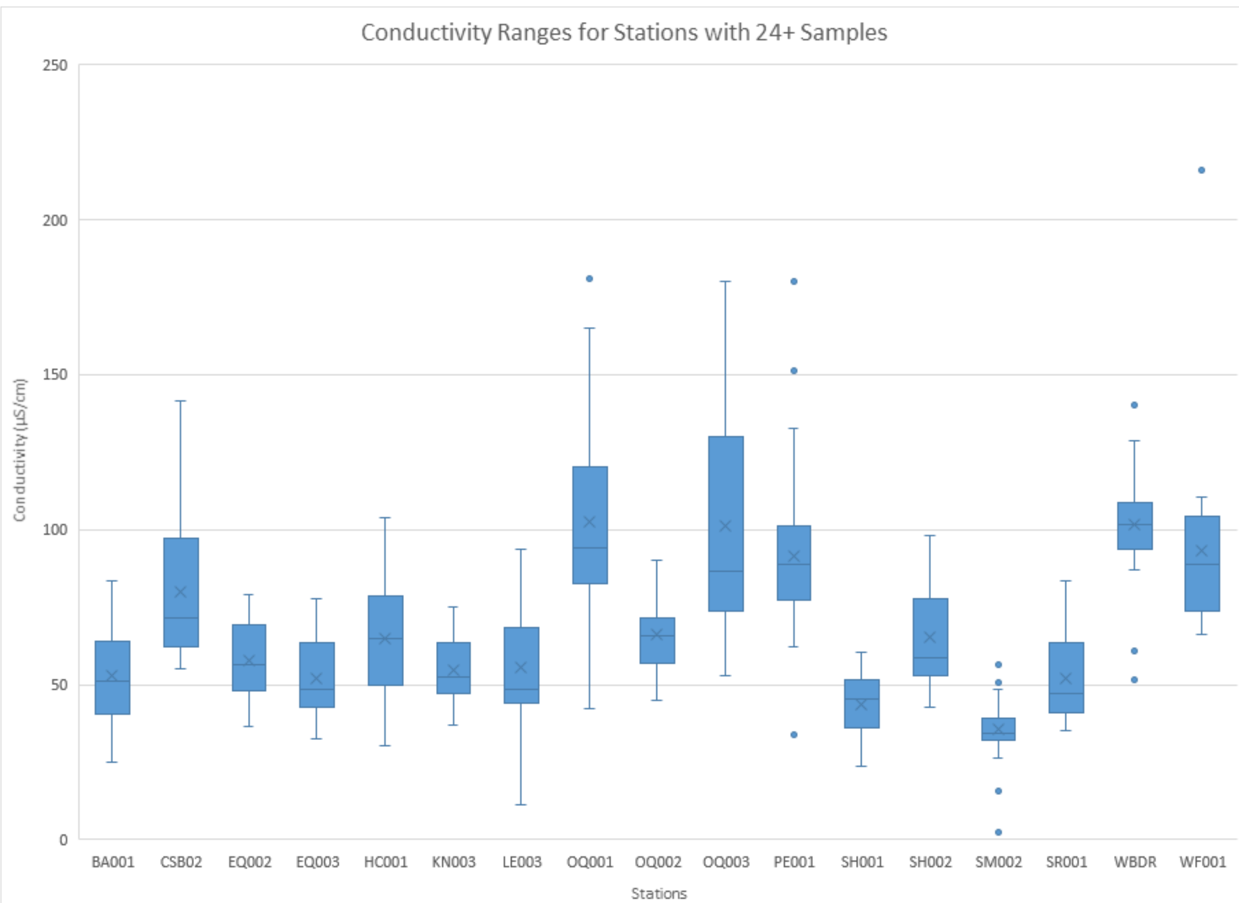

Figure 4: Conductivity ranges for the 17 most sampled sites

Water temperature is an important parameter to monitor, since it affects multiple chemical and biological aspects in stream water. Warmer water is more soluble and thus has higher conductivity and higher concentrations of chloride. Warmer water also holds lower amounts of dissolved oxygen (DO), which can be detrimental to freshwater species. In addition, many fresh water fish species require certain temperatures to be able to spawn and thrive. The temperatures recorded by the volunteer monitoring network range from 0.55°C to 31.65°C.

The DRB is host to many cold water species; one of the most sensitive of these is trout. According to the Pennsylvania Fish and Boat Commission, the maximum temperature that brown/rainbow trout can sustain is 25.6°C, whereas the maximum temperature that can be sustained by native brook trout is 22.2°C. The ideal average temperature range for trout, however, is between 10°C and 15.5°C. The average temperature recorded at all stations, along with the maximum temperature for brown/rainbow trout and ideal temperature range for trout, can be seen in Figure 5. In addition, the maximum temperatures observed at the site can be seen in Figure 6.

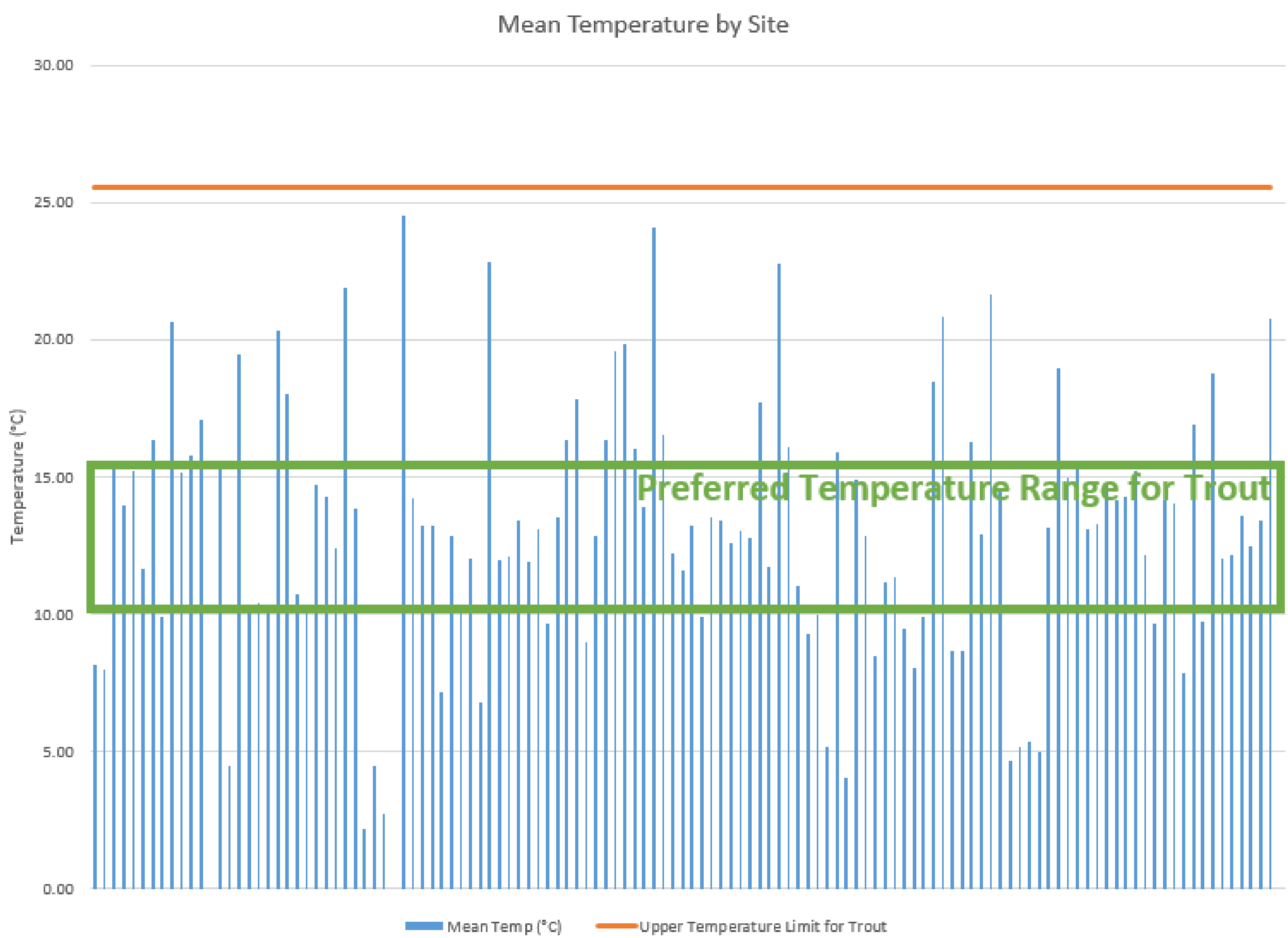

Figure 5: Mean temperatures observed at all sampling stations & the temperature ranges for trout

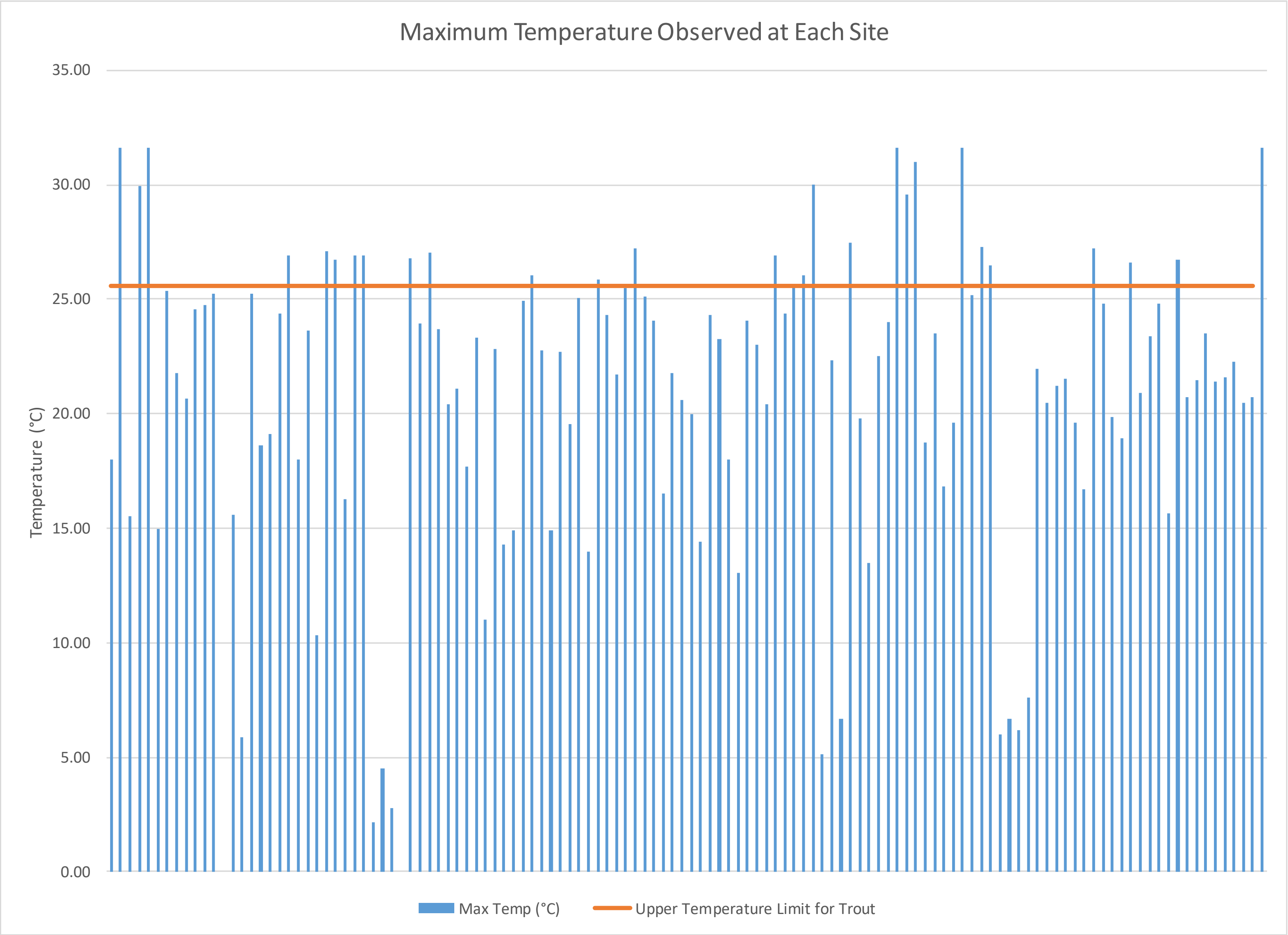

Figure 6: Maximum temperatures observed at sampling sites & maximum temperature for trout

The Pennsylvania Water Quality Standards (PA Code Chapter 93) reports maximum temperatures for warm water fisheries (WWF) and cold water fisheries (CWF), by month. To compare the temperature data obtained by the volunteers to these values, a monthly average was calculated for the entire dataset. These three datasets have been graphed on the same plot, and can be seen in Figure 7 below.

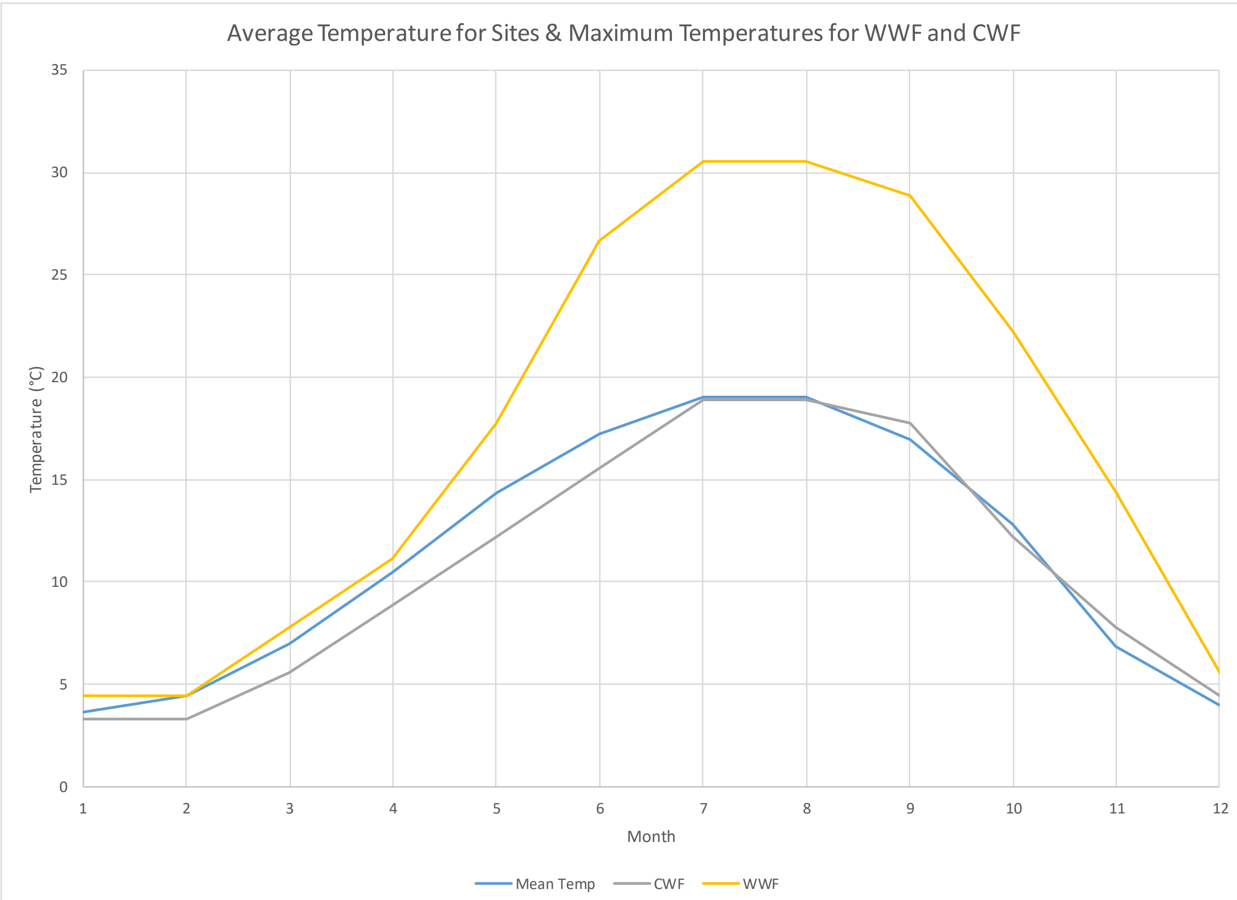

Figure 7: Maximum WWF and CWF temperatures, compared to mean DRB stream temperatures collected by volunteer monitors

Chloride (the ionic form of chlorine) is one of the most common chemicals found in water. When salts, such as sodium chloride (table salt) dissolve, the ions Na^+ and Cl^- enter solution. Depending on the underlying geology, a certain amount of chloride will naturally be present in groundwater and surface water. In Pennsylvania, groundwater typically has chloride concentrations lower than 25 mg/L. Concentrations in surface water can be higher than this amount, and can show wide seasonal variations. In the Upper Delaware, volunteer monitors have documented chloride levels in small headwater streams to be in the 20-50 mg/l range for most streams monitored year-round – indicating healthy freshwater conditions. Chloride measurements for all stream stations sampled ranged from 0.05 ppm to 140 ppm.

In contrast, gas well waste fluids (flowback water) can contain over 150,000 mg/L of chloride and other salts, often being up to five times saltier than seawater. Elevated chloride levels are not a direct indication of fracking fluid pollution but they are a good indicator to use to determine if drilling pollution may be present. High chlorides in streams can also be caused by road salt, community wastewater from water treatment, agricultural and stormwater runoff, or a variety of industrial pollutants.

Exposure to high concentrations of chloride is directly toxic to fish, macroinvertebrates and aquatic plants that live in streams as it disturbs their ability to regulate their body's normal functions and osmoregulation. Most freshwater life depends on a consistent ionic pressure as their bodies cannot adapt to significant changes or fluctuations in the salinity of their environment. Monitoring chloride levels is useful because it is a quick, low-cost test that can alert volunteers to possible contamination by other serious pollutants that might be present with the chloride.

PA DEP and EPA drinking water standard for chloride at the point of water intake is 250 mg/L. In 1988, EPA recommended an ambient chloride standard for streams to protect aquatic life as "except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if-the four-day average concentration of dissolved chloride, does not exceed 230 mg/L more than once every three years on the average and if the one-hour average concentration does not exceed 860 mg/L more than once every three years on the average." Due to projected gas drilling impacts from spills and flowback wastewater discharges, a chloride standard for streams was investigated and proposed by the Pennsylvania Dept. of Environmental Protection (PADEP) in 2010 but it was later withdrawn by PADEP and not adopted during the subsequent Triennial Review of water quality standards. Opposition of this chloride standard, sulfates, and molybdenum standards came from the coal and natural gas industry.

Barium/Strontium:

Barium and Strontium, along with many other heavy metals, are signature chemicals in fracking waste water. These elements may be found in water naturally, due to geologic factors, but the typical concentrations are in hundredths of parts per million. Fracking waste water picks up these, and many other, constituents from within the rock formations and brings them to the surface. Presently the drinking water quality standard, set by the U.S. Environmental Protection Agency (USEPA), for barium is 2.00 mg/L. There is no set drinking water quality standard for strontium, but the USEPA Office of Ground Water and Drinking Water has established a health advisory (acceptable safe levels of exposure) for strontium at 17 mg/L.

Concentrations of these elements in Marcellus shale flowback waters has been found to be hundreds of times higher than these standards. The PSU study evaluating geochemistry of flowback waters found concentrations of barium as high as 13,600 mg/L and strontium as high as 5,350 mg/L in flowback water from Marcellus shale gas wells. The median concentration of barium was 1,990 mg/L, whereas the median value for strontium was 2,330 mg/L.

The 60 water samples analyzed for barium and strontium over the course of this monitoring initiative, were found to contain very low concentrations of these elements. Barium concentrations ranged from 0.007 to 0.041 mg/L, while the strontium concentrations ranged from 0.009 to 0.050 mg/L. This data can be found in Appendix C of this report. Figure 8 presents these data relative to median flowback concentrations, as found in the PSU study. It should be noted that a logarithmic scale has been used, since the concentrations vary by multiple orders of magnitude.

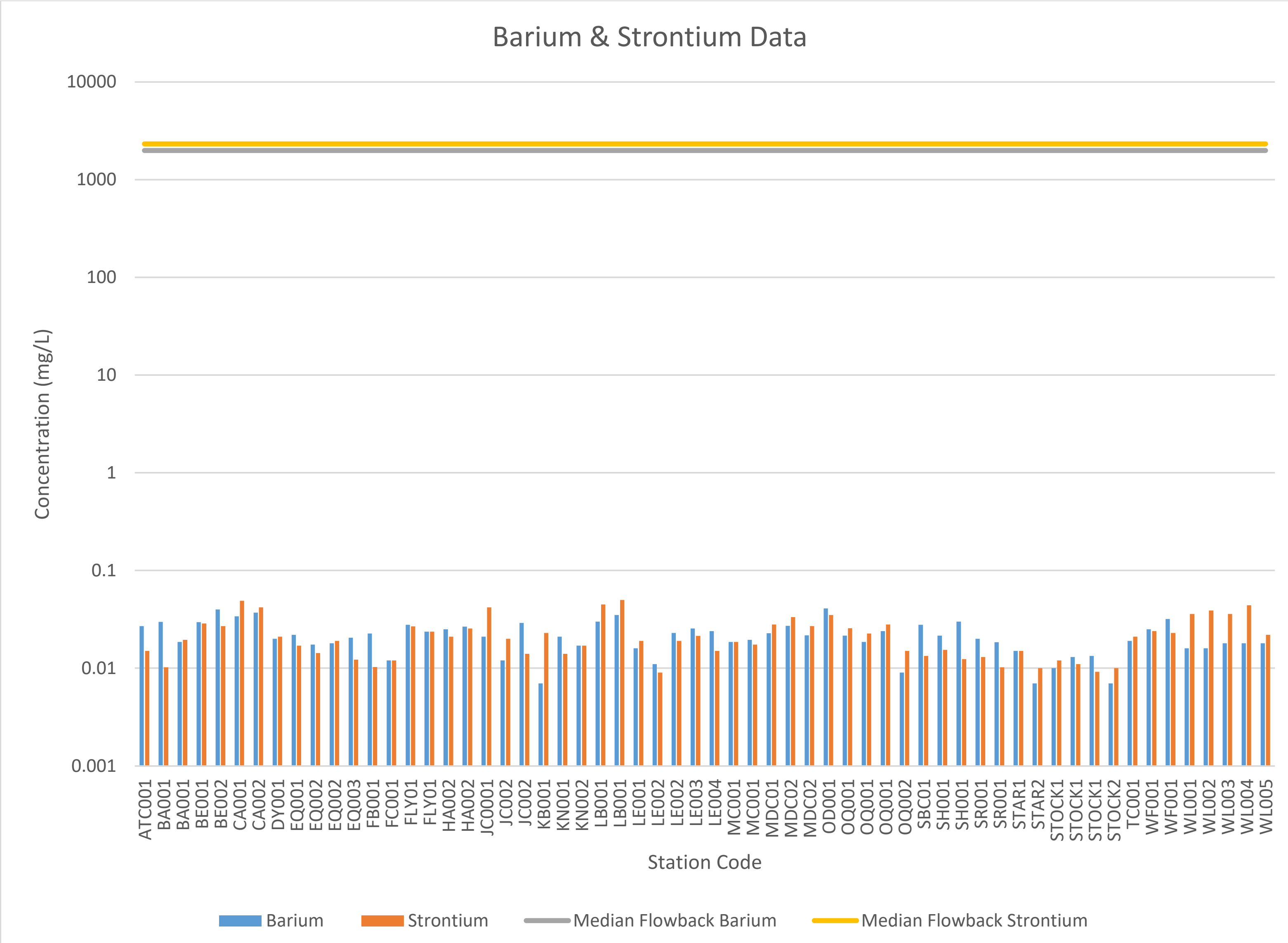

Figure 8: Barium and Strontium Concentrations in Streams with Comparison to Drilling Waste (logarithmic scale used)

Macroinvertebrate Data:

Sampling:

Macroinvertebrate sampling was conducted by DRN biologists using NY and PA approved rapid bio-assessment methodologies, based on each state's standard protocols. Trained volunteer monitors accompanied and assisted DRN's biologist for some of the field sampling but all kicks and collections of benthic invertebrates were conducted by the biologist for consistency from site to site.

The New York State Department of Environmental Conservation (NYSDEC) recommends several sampling methods, but the most commonly used one is kick sampling. Kick sampling involves disturbing stream bed sediments to dislodge organisms, which are then caught downstream utilizing an aquatic net. This was the method employed by DRN. Sampling was conducted for a duration of 5 minutes over a distance of 5 meters. The contents of the aquatic net, were sieved with an U.S. no. 30 sieve, and were preserved using 70-80% ethyl alcohol in a quart jar. The preserved samples were delivered to Watershed Assessment Associates (WAA), where the organisms were sorted and identified utilizing taxonomic references. WAA collected a subset of 300 organisms and analyzed this subset to calculate metrics. A smaller subset of 100 bugs was picked from this 300 bug sample to obtain another set of metrics.

The Pennsylvania Department of Environmental Protection (PADEP) utilizes a similar "kick" sampling method. However, their methods involve the collection of 6 samples from shallow, fast and slow riffle areas, at each station. These are collected using 500-micron mesh D-frame nets. For each of the benthic stations in Pennsylvania, the 6 samples were composited and preserved in 70-80% ethyl alcohol. The samples were then delivered to a PA DEP approved lab, where the organisms were sorted and identified utilizing taxonomic references.

Results:

The macroinvertebrate samples were analyzed for different parameters, based on the respective state's standard protocols. For the samples collected in New York, the parameters noted were taxa richness, EPT richness, biotic index, PMA and the BAP score. Taxa richness is the number of distinct species or taxa found in the 100 organism or 300 organism sub-sample. EPT richness is the number of species of mayflies (*Ephemeroptera*), stoneflies (*Plecoptera*), and caddisflies (*Trichoptera*) found in the subsample. The biotic index is a measure of the tolerance of the species in the subsample to organic waste pollution and low dissolved oxygen (DO) levels. The index ranges from 0 to 10, with 0 being the most intolerant to pollution and 10 being the most tolerant of these pollution conditions. The Percent Model Affinity (PMA) shows the similarity of the subsample to an ideal non-impacted community, based on the abundance of 7 major groups. Finally, the Biological Assessment Profile (BAP) score utilizes all of the above-mentioned parameters to assess the degree to which the stream has been impacted. The BAP score also ranges from 0 to 10, with 0 being severely impacted and 10 being pristine. All of these calculations for the 13 New York stream samples can be found in Appendix E.

The BAP score ranges from 7.28 to 9.01. A BAP score of 7.50 or higher is indicative of a non-impacted habitat. 12 out of the 13 samples have attained this score, and only 1 of the samples (Tar Hollow) shows a slight impact, being just below the threshold. These data show a largely undisturbed and healthy and diverse habitat. It should also be noted that the biotic index is very low for all of the samples. A biotic index of 0-4 is indicative of an abundance of pollution sensitive organisms, which are incapable of living under stressful conditions such as low levels of DO or influences of high conductivity levels.

Metrics calculated for the PA samples were slightly different than those calculated for the NY samples. These metrics have been developed through the PA Tiered Aquatic Life Uses IBI workshop. They include: total taxa richness, EPT taxa richness, Shannon Diversity Index, Beck's Index, Hilsenhoff Biotic Index and Percent Intolerant Individuals. These six metrics are then utilized to calculate an Index of Biotic Integrity (IBI) score. The IBI index integrates these metrics, in order to evaluate the overall health of the stream, with regard to biological conditions.

Total taxa richness, EPT richness and Hilsenhoff biotic index were calculated for both, NY and PA samples, and have been explained above. The Beck's Index is a weighted count of taxa with pollution tolerance levels (PTVs) of 0, 1 or 2. The index decreases with increasing anthropogenic stress to the stream, reflecting a loss of pollution-sensitive taxa. The Shannon Diversity Index takes into account the total taxa richness and the evenness of taxa in a subsample. This value decreases with increasing amounts of anthropogenic stress, since with increased anthropogenic stress, pollution tolerant taxa tend to survive. Finally, the percent sensitive individuals represent the percentage of individuals in a subsample with PTVs of 0 to 3, the taxa most sensitive to pollution. With increased amounts of anthropogenic stress, this percentage decreases, representing a loss of sensitive taxa. All six of these indices are coalesced into an IBI score, which represents overall stream quality. These metrics and results can be found in Appendix D for the macroinvertebrate samples collected in Pennsylvania.

Let's take a look at Equinunk Creek, one of the major tributaries of the river. It is 15.4 miles long, and meets the Delaware River at Equinunk, PA. There were 2 benthic stations located along the creek, in addition to 3 permanent monitoring stations. Additionally, data was obtained from the DRBC, from their monitoring stations for pH and alkalinity. The average measurements in the Equinunk Creek for each parameter, can be seen in the Table below.

Parameter	**Number of Readings**	**Average**
Conductivity	86	58.66 µS/cm
Chloride	86	25.88 ppm
Temperature	86	13.40°C
Barium (Ba)	4	$1.94*10^{-2}$ mg/L
Strontium (Sr)	4	$1.57*10^{-2}$ mg/L
pH*	52	7.55
Alkalinity*	52	17.50 mg/L

Furthermore, the macroinvertebrate data obtained for this stream are representative of a diverse and healthy habitat. There were 38 distinct taxa observed at one location, and 20 at the other. The Index of Biological Integrity (IBI) was calculated to be 84.68 for the more diverse sample, and 63.81 for the other. These data indicate aquatic life use attainment for Equinunk Creek.

The sampling stations were in 3rd, 4th, and 5th order streams. Even though sampling was conducted in higher order streams, the water quality is excellent.

Discussion:

From February 2010 to June 2016, volunteer monitors collected 1,351 samples from 123 distinct stream stations, and analyzed samples for conductivity, temperature and chloride, utilizing equipment provided by DRN. In addition, the monitors collected 60 samples from 44 different sites, to be analyzed for barium and strontium (Ba/Sr).

Stream data collected through this community based monitoring project indicates a very healthy network of Upper Delaware River streams. The data collected and the broad support from local monitors in this region show a strong stewardship and conservation ethic from the local community to protect these important streams of the Basin. According to the stream data collected, water chemistry is excellent, the biological integrity is intact and anthropogenic impacts are limited. Headwater streams sampled regulate multiple environmental factors in the Delaware River watershed and are critical to healthy drinking water downstream. According to PADEP, the DRB has approx. 843 miles of Exceptional Value (EV) streams in PA and another 258 miles of EV streams on the PADEP Existing Use list based on rigorous analysis and recent water quality data - meeting the highest Category 1 bar in the Commonwealth for stream health. Another 4,162 miles of streams in the DRB in Pennsylvania are designated High Quality (HQ) with an additional 95 miles of streams gaining HQ status on the Existing Use list. The DRB also has 1,995 miles of streams listed as Cold Water Fishery (CWF) with another 32 miles of streams on the existing use list for CWF. Existing use protection is to encourage interim protection until stream redesignations and upgrades work through the lengthy regulatory process. In December 2011, Delaware Riverkeeper Network and our local, regional and national allies submitted a petition to the PA DEP to upgrade the Upper and Middle Delaware region to Exceptional Value (EV) status because of this exceptional water quality and the local stewardship and conservation efforts active and on the ground in this critical region.

The Delaware River Basin is a vital resource for millions of people and wildlife in four states across the northeast. The 330-mile, protected river is the largest undammed river east of the Mississippi, is home to diverse wildlife and provides drinking water for over 17 million people. The waters of the river basin provide the region $22 billion in economic benefits from activities like hiking, hunting, fishing, boating, and farming and supports 600,000 jobs in the coastal, farm, ecotourism, water, ports, and recreation industries.

At the same time, the Delaware River Basin sits atop a sliver of the Marcellus Shale, the second largest natural gas field in the world. The exploration, development and build out of Marcellus shale in this region of study would cause cascading and detrimental impacts to a fragile system that is currently of very high and exceptional water quality. Impacts from shale development build out would strip the DRB of its vegetation and forests and important agricultural lands, changing landuse, posing a threat to small headwater streams, and causing long term degradation of overall surface water quality especially as build out expanded with cumulative impacts over time. Industry spills – both accidental or intentional - would also be a large threat if the industry were to expand into this rural region.

Major threats caused by the exploration and development of unconventional shale gas wells in the Marcellus, would be created by the extensive deforestation and additional infrastructure needs (gathering pipelines, transmission pipelines, water pipelines, access roads, etc.) to support drilling activities. A USGS analysis of Washington and Bradford Counties outside of the DRB from 2004 to 2010 shows an increase in forest fragmentation and forest patches, largely due to gas pipelines, as well as an increase of edge forest which means more competition from edge species that flourish in more fragmented areas of the watershed. Take note this analysis was only conducted at the very beginning of the gas footprint build out that is projected for the state. The CNA Analysis and case study for DRB buildout projections indicated that 1-2% of forest cover would be cleared overall, with up to 10% of core forest area lost. Development of these 4,000 projected wells would require 18 to 26 square miles of land, the equivalent to building as many as 840 Walmart Supercenters. This forest and habitat loss would contribute to increased stream temperatures, increased stormwater impacts, and significantly deteriorate water quality in the DRB. Built out would also affect local ecosystems and lead to a decrease in the relative abundance of forest species. Vegetation, forests and natural meadows are a major contributor to the current high quality of the region's streams by reducing stormwater, increasing groundwater infiltration and base flow and as such helping alleviate stream erosion and sedimentation rates. With lesser forest cover replaced by gas infrastructure, erosion and sedimentation rates will increase and water temperatures will also increase with increased heated stormwater impacts and less shady streams. Already streams dependent on base flow, would be impacted with less groundwater infiltration, especially during hot summers and exacerbated with projected climate impacts predicted for the region. Sedimentation reduces the depth of light penetration in these streams and leads to decreases in oxygen levels and increases in water temperature. Sediment can clog gills of aquatic species including fish and benthic invertebrates. Sedimentation can be detrimental to aquatic plant and animal life, covering up benthic habitats and spawning areas for fish and physically smothering these animals.

The CNA report concluded the installation of multiple compressor stations to transport gas away from wells through pipelines in the DRB could as much as double nitrogen oxide emissions in the Upper Delaware basin. DRN monitored the addition of Hancock compressor station and upgrades to Milford compressor station that have already occurred with expansion of pipelines from shale exploration to the west and additional exploration in the DRB would add to this expansion. The presence of excess nitrogen in the atmosphere in the form of nitrogen oxides or ammonia is deposited back onto land or in the form of acid rain, where it washes into water bodies. These excess nutrients contribute to pollution, pH changes, harmful algal blooms and oxygen-deprived aquatic zones. Excess ammonia and low pH are toxic to aquatic organisms and affect their survival.

It is projected that up to 4,000 unconventional gas wells may be drilled in the DRB based on the CNA analysis case study and extrapolation of drilling elsewhere as a guide. Approximately 4.5 million gallons of water will be needed for each well, which amounts to 1.3 million gallons per day when averaged across 30 years. This would mean that fresh surface waters, such as those monitored for this project, would be withdrawn to support gas drilling activities. The CNA analysis indicated removal of up to 70 percent of water in small streams, permanently depleting crucial flows and increasing damaging runoff, turning some of the highest quality streams into ditches.

Barium and strontium levels in this study collected by volunteer monitors are at very low levels. The CNA analysis concluded an increase in in-stream concentrations of contaminants, including barium and strontium, up to 500 percent above the normal rate, an alarming increase in pollutants. Certain barium types can cause changes to heart rhythm, paralysis or death and radioactive strontium can cause cancer.

Recent studies by DRN, assessing the potential impacts of pipeline development in the Upper DRB, found that small intermittent headwater streams are already under stress due to impacts from large transmission pipelines that have been built to transport gas from shale development extraction occurring to the west of the DRB. Multiple high quality and exceptional value streams crossed by pipelines were found to have increased stream temperature impacts, increased sedimentation, and excess nutrients. Documentation by DRN of gas pipeline construction since 2011 (submitted to DRBC on past pipeline dockets) indicates time and time again - inadequate regulatory framework, inadequate oversight, inadequate fines and enforcement to discourage poor practices by the operators, and a system that systematically does not protect the special protection waters of the Basin and instead allows irreversible and avoidable repeated harm and stream cuts for multiple pipeline projects implemented, planned or currently underway. Invasive plant species have increased along pipeline corridors and the denuded streambank buffers allowed along stream and wetland cuts and lack of successful native tree and shrub buffer plantings or poor plantings post pipeline construction is a lasting harm that will have sustained stream and groundwater quality impacts – and this is only considering the transmission lines that have been allowed in the Basin to date. With fracking many more impacts would come. Water withdrawal from the DRB to drill or frack outside the basin as well as development of land and conversion into gas infrastructure, would pose a threat to these headwater streams. It could lead to the loss of many of these smaller headwater streams, which are crucial to the health of the entire watershed. Extensive water withdrawal will also lead to bank erosion and increased water temperatures. The threat of introduction of new and expanding aquatic invasive species in addition to plant invasive species as forest fragmentation increases along with industry traffic are also possible with the movement of water necessary for this industry and proposed out-of-basin transfers projected.

Another potential issue caused by the development of shale gas resources is the drill cuttings and radioactivity to both water and soils. A single 8,500-foot well could produce up to 200 cubic yards of material, which would be rich in heavy metals and naturally occurring radioactive material. It is well known that the Marcellus Shale formation is radioactive. Flowback wastewater contaminated with radioactivity is unavoidable. Exposure to these radioactive materials by the public will occur as a result of flowback produced by fracking through multiple pathways. Radium-226 has a half-life of 1,600 years, so it will be present in the environment for thousands of years. It is also water soluble, meaning it easily travels with water. Radionuclides can also be trapped in drill cuttings and residual solids, providing another pathway for the release to the environment, increasing human exposure and a legacy of enduring environmental contamination to soils and water. There is solid and ever- expanding science on these lasting wastewater harms that would come if wastewater were allowed to be imported in the Basin and the proposed regulations do not adequately protect the water resources from these harms.

The results of the study conducted by DRN volunteer monitors also shows excellent biological integrity in the DRB. Macroinvertebrates are healthy and diverse and they serve as a critical keystone to the health of the river downstream. These insects consume algae and other non-animal organic matter in streams, such as leaves. Thus, plant matter is converted to animal tissue, which is available for consumption by fish and birds. The macroinvertebrate communities in headwater streams provide food sources for aquatic life downstream. With higher stream temperatures, lower DO levels, and dried up streams from projected gas development impacts these macroinvertebrate communities will be threatened. This could mean that aquatic life species throughout the watershed would degrade as gas build out would occur over time. Drilling spills and legally permitted wastewater discharges from drill waste would also impact benthic life and potentially benthic habitat causing long term and irreversible damage and decreased diversity of a resilient freshwater system.

This is a clear indication that headwaters in the DRB are pristine, and gives stakeholders a reason to preserve these headwater streams and the freshwater that flows through them and to not allow any gas exploitation in this region.

Considerations Regarding the Proposed DRBC Gas Drilling Regulations

The tributaries and freshwater streams of the Delaware River Basin and the main stem Delaware River and DRBC Special Protection Waters (SPW) are a testament to decades of preservation and downstream clean up efforts and actions by a dedicated and diverse community made up of private residents, volunteer monitors, recreationists, conservationists, scientists, and the DRBC to keep the Delaware River Basin flowing clean and healthy to supply drinking water to over 17 million people. In addition to drinking water benefits, the watershed community recognizes fully that the Delaware River Basin, its forests and sustainable local farmlands, serve as a sustaining economic and ecologic system for numerous businesses, residents and visitors who flock to the DRB for long-term jobs, enjoyment, fishing, canoeing, hiking, birdwatching, hunting and other recreation that is dependent on a clean and healthy watershed. The tidal sections of the Basin are also undergoing a renaissance of clean water with improvements to water quality and better access to the main stem River with community parks and greenways that are bringing many people in urban areas closer to the River to enjoy and recreate along the tidal Delaware River and estuary. Endangered species like the Atlantic sturgeon, endangered freshwater mussels, imperiled horseshoe crabs, declining American eels, diamondback terrapins, and many shorebirds like the endangered red knot rufa and five other imperiled bird species that visit the

Delaware Bay during their migration, are still hanging on by relying on the main stem Delaware River and estuary. This area cannot become a gas hub nor a sacrifice zone for drill waste and treatment.

The grass-roots monitoring help that has made this multi-year long DRN monitoring project a success at a time when the community was facing gas drilling exploitation in 2010 before the DRBC de-facto moratorium was put in place, is an indication of the strong environmental ethic and deep roots in the region that continues to reside and recreate in the Delaware River Basin for the long term. Volunteer monitors will continue to assist in watershed protection, but the DRB community strongly believes as warranted by the extensive science that is available and the stream data that is included in this report, that it is absolutely critical that the DRBC and the Governors of the Basin states of PA, NJ, NY and DE and the President's federal representative solidly put forth a complete ban on any and all gas drilling activities and infrastructure in the DRB, including fracking, freshwater export to frack elsewhere or import of flowback wastewater to the basin.

Community volunteer monitors can play a role in watershed monitoring and protection but in a fiscally deprived environment with major cuts to environmental programs for decades, agency vacancies, and lack of regulatory oversight and enforcement, agencies are woefully under-staffed and do not have the resources available to adequately protect the Basin from fossil fuel corporations looking to exploit the resource for their own private gain and short-term interests. It is therefore critical that the DRBC employ the precautionary principle in full and not only ban fracking from the shale regions of the Basin as is proposed, but also ban import of frack waste and freshwater export to frack. This is the only available option if the science available is truly examined in full. In doing so and implementing a complete ban, the DRBC and the Governors and federal representatives each with a vote can focus on other uses and industries rather than allowing the natural gas industry to come in after having a strong gas moratorium in place since 2010.

Appendix A
Stream Monitoring Stations and Locations

Station Code	Stream Name	Latitude (°)	Longitude (°)
ATC001*	Atco Creek	41.6195222	-75.0594111
BA001*	Balls Creek	41.9540000	-75.3550000
BB001	Bouchoux Brook	41.8763350	-75.1806090
BC001	Basket Creek	41.8843320	-75.0464880
BC002	Basket Creek	41.8840830	-75.0459330
BC003	Basket Creek	41.8620070	-75.0896570
BC004	Basket Creek	41.8844250	-75.0458500
BE001*	Beaverdam Creek	41.7341528	-75.1446083
BE002*	Beaverdam Creek	41.7058667	-75.0874000
BF001	Big Flat Brook	41.2000000	-74.8155556
BH001	Big Hollow Creek	42.0668778	-75.4182611
CA001*	Calkins Creek	41.6696139	-75.0709111
CA002*	Calkins Creek	41.6692611	-75.0706722
CA003	Calkins Creek	41.6666667	-75.1333333
CA004	Calkins Creek	41.6745720	-75.1402260
CC001	Callicoon Creek	41.7284000	-74.9835917
CC002	Callicoon Creek	41.7646390	-75.0558520
CC003	Callicoon Creek	41.8375000	-74.9435000
CD001	Cadosia Creek	41.9626800	-75.2624500
CD002	Cadosia Creek	42.0177700	-75.2553500
CL001	Clove Brook	41.3571500	-74.6819100
CSB01	Cold Spring Brook	42.1552270	-75.3556860
CSB02	Cold Spring Brook	42.0808000	-75.4018167
CSB03	Cold Spring Brook	42.1790778	-75.3680722
CT001	Cattail Brook Upper	41.8790000	-74.8639000
CT002	Cattail Brook Lower	41.8919000	-74.8353000
DR001	Delaware River	41.3717795	-74.6972152
DY001*	Dyberry Creek	41.6399000	-75.2702833
DY002	Dyberry Creek, West Branch	41.7441850	-75.3479320
DY003	Dyberry Creek, East Branch	41.7270220	-75.2654630
DY004	Dyberry, Middle Branch	41.7350330	-75.3227380
EBC01	East Branch Callicoon Creek	41.7293140	-74.9826340
ED001	Delaware River, East Branch	41.9439470	-75.2303910
EQ001*	Equinunk Creek, Main Stem	41.8533167	-75.2249000
EQ002*	Equinunk Creek, North Branch	41.8213167	-75.2550139
EQ003*	Equinunk Creek, South Branch	41.8066472	-75.2290056
FB001*	Fall Brook	41.9255020	-75.3106190
FC001*	Factory Creek	41.8554333	-75.2283833
FI001	Fish Creek, Upper	41.9350600	-75.1078200
FI002	Fish Creek, Lower	41.9645500	-75.1777000

Station Code	Stream Name	Latitude (°)	Longitude (°)
FLY01*	Fly Creek	42.0494361	-75.4988278
GC001	Gold Creek	41.3822618	-74.6741082
HA001	Hankins Creek	41.8162700	-75.0920600
HA002*	Hankins Creek	41.8307556	-75.0841694
HA002	Hollister Creek	41.7583667	-75.1011167
HT001	Hillview Tarn (Glacial Pond)	41.4863889	-75.0594444
JC001*	Johnson Creek trib. to West Branch	41.7013889	-75.3691667
JC002*	Unnamed trib. to Johnson Creek	41.6863889	-75.3750000
JC003	New Johnson Creek	41.7105556	-75.3825000
KB001***	Kelsey Brook	42.2861889	-75.5358333
KN001*	Kinneyville Creek	41.8273111	-75.2626361
KN002*	Kinneyville Creek	41.8510000	-75.3318100
KN003	Kinneyville Creek	41.8277944	-75.2567250
LB001*	Little Blooming Grove Creek	41.4679667	-75.0761500
LE001*	Little Equinunk Creek	41.7791000	-75.2050333
LE002*	Little Equinunk Creek	41.7474667	-75.2193667
LE003*	Little Equinunk Creek	41.7705500	-75.1789611
LE004*	Little Equinunk Creek	41.7527667	-75.1990667
LF001	Little Flat Brook	41.2159450	-74.8265621
LL001	Lily Brook	41.6108694	-74.9704667
LW001	Lackawaxen River	41.4744444	-75.0705556
MA001	Masthope Creek	41.5536111	-75.0825000
MA002	Masthope Creek	41.5559333	-75.0778833
MC001*	Marsh Creek	42.0586611	-75.4959583
MDC01*	Middle Creek / Wangum Creek	41.4848639	-75.2218083
MDC02*	Middle Creek	41.5117861	-75.2917222
NG001	Mongaup River	41.6665840	-74.7839210
NLT01	Nabbys Lake Tributary	41.8684000	-75.2684500
NN001	Unnamed	41.5787139	-75.3065083
NN002	Glass Pond Outlet Crossing	41.5788917	-75.2960028
NN003	Unnamed	41.5789556	-75.3052444
NV001	Neversink River	41.3608333	-74.6847222
OD001*	O'Donnell Brook	41.4867000	-75.0271280
OQ001*	Oquaga Creek	42.0569167	-75.4284000
OQ002*	Oquaga Creek	42.1747500	-75.4383667
OQ003	Oquaga Creek	42.0754694	-75.4807139
PA001	Panther Rock Brook Upper	41.5300000	-74.5200000
PA002	Panther Rock Brook Lower	41.8072000	-74.8867000
PB001	Pea Brook	41.8938222	-75.1486000
PE001	Perry Pond Brook	41.6230389	-75.0153944
RR001**	Ramapo River	41.0272846	-74.2501830
RSC01	Rattlesnake Creek	41.5508167	-75.0957833
SA001	Sands Creek	41.9560000	-75.2970000

Station Code	Stream Name	Latitude (°)	Longitude (°)
SA002	Sands Creek	42.0054400	-75.3022900
SA003	Sands Creek	41.9550000	-75.2963200
SBC01*	Starboard Creek	42.0017600	-75.3948100
SH001*	Sherman Creek	41.9795300	-75.4391700
SH002	Sherman Creek	42.0017820	-75.0896570
SH003	Sherman Brook	42.0012000	-75.3955667
SH004	Shimer's Brook	41.3127778	-74.7788889
SM001	Steam Mill Brook	42.1644528	-75.3462944
SM002	East Branch Steam Mill Brook	42.1605333	-75.3513000
SN001	Shandelee Lake Outlet Upper	41.8917000	-74.8706000
SN002	Shandelee Brook Lower	41.8812000	-74.8506000
SP001	Sand Pond Outlet Upper	41.8655000	-74.8953000
SP002	Sand Pond Outlet Lower	41.8581000	-74.9244000
SQ001**	Shadigee Creek	41.8916200	-75.4346000
SQ002**	Starrucca Creek	41.8896700	-75.4715600
SQ003**	Starrucca Creek trib	41.9240300	-75.4942700
SQ004**	Orson Pond Outlet	41.8136800	-75.4481400
SR001*	Salt River Brook	41.8165667	-75.1748000
ST001	Smith Mill Brook	41.6138917	-74.9595333
STAR1*	Travis Road Creek	41.9155000	-75.3499000
STAR2*	Danny's Creek	41.9224000	-75.3338000
STOCK1*	Stockport Creek	41.8953500	-75.2776200
STOCK2*	Shingle Hollow Creek	41.9060000	-75.2726500
SU001	Stump Pond Outlet Spillway	41.8350000	-74.8974000
SW001	Swamp Brook	41.5013667	-75.1568000
TA001	Tarbell Brook	42.0530750	-75.4765333
TC001*	Trout Creek	42.1736111	-75.2797222
TC002	Trout Creek, Upper	41.9134100	-74.9968400
TC003	Trout Creek, Lower	41.9792900	-75.0976300
TE001	Teedyuskung Creek	41.4783000	-75.0991833
TK001	Tinkwig Creek	41.4779850	-75.1282100
WBDR	West Branch Delaware River	42.0031500	-75.3838167
WF001*	West Falls Creek	41.4627667	-75.0489833
WF002	West Falls Creek	41.4688889	-75.0497222
WH001	White Brook	41.3008232	-74.7950598
WL001*	West Branch Lackawaxen	41.7191667	-75.4158333
WL002*	West Branch Lackawaxen	41.6841667	-75.3883333
WL003*	West Branch Lackawaxen	41.6744444	-75.3761111
WL004*	West Branch Lackawaxen	41.6411111	-75.3575000
WL005*	West Branch Lackawaxen	41.6780556	-75.3691667
WR001	East Branch Wallenpaupack River	41.3212722	-75.3077472

*Sampled for barium & strontium data, **Outside the Delaware River Basin, ***Sampled for barium & strontium AND outside the Delaware River Basin

Appendix B

Conductivity, Temperature & Chloride Summary Statistics

Station Code	Number of Samples	Mean Conductivity (µS/cm)	Min Conductivity (µS/cm)	Max Conductivity (µS/cm)	Mean Chloride (ppm)	Min Chloride (ppm)	Max Chloride (ppm)	Mean Temp (°C)	Min Temp (°C)	Max Temp (°C)
ATC001	16	43.87	30.65	56.55	19.16	12.50	28.00	8.17	0.80	18.00
BA001	24	53.11	24.90	83.25	24.45	15.00	51.00	7.95	0.72	31.65
BB001	2	79.68	77.35	82.00	2.00	2.00	2.00	15.50	15.50	15.50
BC001	12	37.82	20.10	50.95	2.51	0.05	8.00	13.94	1.03	29.95
BC002	12	41.86	22.85	56.95	2.26	0.05	8.00	15.24	2.11	31.65
BC003	3	70.00	53.30	91.85	20.00	20.00	20.00	11.63	8.61	15.00
BE001	15	75.72	50.30	121.20	32.43	19.50	40.00	16.31	1.95	25.35
BE002	12	75.65	58.90	105.20	33.08	28.00	38.50	9.90	1.10	21.78
BF001	1	137.45	137.45	137.45	26.50	26.50	26.50	20.65	20.65	20.65
BH001	6	91.50	75.55	108.25	30.58	16.50	38.00	15.16	3.45	24.55
CA001	21	81.86	56.30	116.45	27.88	20.00	42.00	15.79	1.10	24.75
CA002	16	72.92	50.85	90.10	27.89	18.00	42.00	17.11	3.60	25.25
CA003	1	67.55	67.55	67.55	11.60	11.60	11.60	-	-	-
CA004	1	88.45	88.45	88.45	22.00	22.00	22.00	15.60	15.60	15.60
CC001	7	118.59	85.65	169.20	43.43	34.00	51.00	4.45	3.60	5.90
CC002	3	94.67	81.70	118.30	25.67	20.00	35.00	19.48	12.06	25.28
CC003	10	78.89	56.00	99.00	20.80	10.00	26.00	10.25	1.05	18.65
CD001	12	90.77	63.95	118.85	47.00	30.00	60.00	10.41	1.50	19.10
CD002	10	80.49	52.30	126.80	41.90	30.50	66.00	10.05	1.50	24.40
CL001	5	335.85	179.75	473.50	57.10	40.00	80.00	20.35	14.85	26.90
CSB01	1	43.50	43.50	43.50	20.50	20.50	20.50	18.00	18.00	18.00
CSB02	34	80.08	55.20	141.40	23.03	15.50	33.50	10.71	1.14	23.61
CSB03	1	141.40	141.40	141.40	34.00	34.00	34.00	10.30	10.30	10.30
CT001	10	39.11	25.95	55.80	17.40	12.00	23.00	14.70	1.30	27.10
CT002	8	75.84	54.45	99.45	25.75	16.00	32.00	14.24	0.55	26.73
DG001	2	128.40	103.45	153.35	28.50	27.00	30.00	12.43	8.55	16.30
DR001	2	93.30	89.95	96.65	22.00	22.00	22.00	21.88	16.85	26.90
DY001	6	68.63	57.75	79.05	22.83	20.00	26.00	13.84	4.55	26.90
DY002	1	93.10	93.10	93.10	42.50	42.50	42.50	2.15	2.15	2.15
DY003	1	50.15	50.15	50.15	28.00	28.00	28.00	4.50	4.50	4.50
DY004	1	39.45	39.45	39.45	22.50	22.50	22.50	2.75	2.75	2.75
EBC01	1	123.50	123.50	123.50	49.00	49.00	49.00	-	-	-
ED001	2	114.48	68.60	160.35	15.10	4.20	26.00	24.50	22.22	26.78
EQ001	15	76.30	48.70	108.45	38.12	8.00	140.00	14.20	3.90	23.95
EQ002	37	57.56	36.70	79.05	22.96	17.50	36.00	13.24	1.05	27.05

Station Code	Number of Samples	Mean Conductivity (µS/cm)	Min Conductivity (µS/cm)	Max Conductivity (µS/cm)	Mean Chloride (ppm)	Min Chloride (ppm)	Max Chloride (ppm)	Mean Temp (°C)	Min Temp (°C)	Max Temp (°C)
EQ003	34	52.09	32.50	77.80	22.91	17.00	42.50	13.22	1.95	23.70
FB001	22	32.00	14.30	49.30	19.33	8.00	35.00	7.16	0.61	20.40
FC001	12	60.50	38.55	83.25	29.41	7.00	100.00	12.85	0.80	21.10
FI001	10	80.58	59.10	107.20	42.30	28.50	66.50	10.03	1.30	17.70
FI002	10	78.01	60.65	108.30	36.90	26.00	55.00	12.01	1.40	23.30
FLY01	4	104.85	83.95	140.00	32.38	23.00	49.50	6.75	2.00	11.00
GC001	1	250.50	250.50	250.50	21.00	21.00	21.00	22.85	22.85	22.85
HA001	3	62.57	53.10	70.75	18.67	16.00	24.00	11.97	7.40	14.30
HA002	2	83.05	68.40	97.70	20.00	16.00	24.00	12.10	9.30	14.90
HC001	42	64.74	30.15	103.60	24.79	18.00	43.00	13.42	0.90	24.95
HT001	9	172.71	139.95	197.80	61.56	50.00	72.00	11.93	3.35	26.05
JC001	8	69.22	57.45	107.10	18.93	15.00	21.00	13.06	1.20	22.80
JC002	8	46.14	38.60	63.65	19.00	15.00	21.00	9.66	0.90	14.90
JC003	9	91.52	73.60	116.20	20.28	13.50	23.00	13.52	1.60	22.70
KB001	4	94.49	74.60	112.25	23.25	22.00	24.00	16.31	11.70	19.54
KN001	8	59.29	46.90	79.75	31.19	24.00	36.00	17.83	10.30	25.05
KN002	3	58.27	52.40	65.75	24.83	20.00	28.00	8.97	4.92	14.00
KN003	29	54.74	36.95	75.25	21.84	18.00	30.00	12.85	1.85	25.85
LB001	21	71.51	54.05	112.10	23.24	20.00	29.00	16.33	9.95	24.33
LE001	4	38.99	35.55	45.05	19.75	10.00	23.50	19.58	16.05	21.70
LE002	3	38.17	24.25	56.30	23.67	22.00	26.00	19.82	15.55	25.50
LE003	30	55.82	11.45	93.60	22.39	17.50	36.50	16.04	2.35	27.25
LE004	6	43.18	38.30	45.60	23.79	21.00	28.00	13.93	5.00	25.10
LF001	1	357.50	357.50	357.50	40.00	40.00	40.00	24.10	24.10	24.10
LL001	2	69.45	68.50	70.40	21.50	21.00	22.00	16.50	16.50	16.50
LW001	11	69.25	50.40	84.80	29.27	22.00	39.00	12.21	1.90	21.80
MA001	16	50.75	37.00	70.00	33.85	20.00	39.00	11.59	2.00	20.60
MA002	3	49.03	45.50	54.60	43.67	40.00	49.00	13.21	9.78	19.97
MC001	5	45.13	39.55	49.60	18.10	16.00	20.00	9.91	6.00	14.39
MDC01	13	73.83	54.20	104.25	19.31	18.00	20.00	13.50	1.67	24.33
MDC02	13	77.30	47.10	116.70	19.23	16.00	21.00	13.38	2.50	23.28
NG001	5	150.70	130.55	180.65	39.00	28.00	48.00	12.60	5.60	18.00
NLT01	1	23.80	23.80	23.80	35.00	35.00	35.00	13.05	13.05	13.05
NN001	6	149.68	117.15	198.65	27.78	0.42	50.00	12.80	1.00	24.10
NN002	6	102.55	74.50	141.05	19.92	0.24	31.25	17.68	11.40	23.00
NN003	5	64.42	52.50	89.95	16.63	0.28	25.00	11.71	1.00	20.40
NV001	4	118.35	114.55	121.25	26.25	24.00	30.00	22.75	15.30	26.90
OD001	21	242.29	140.15	365.00	73.71	48.00	132.00	16.09	4.75	24.39
OQ001	46	102.69	42.25	180.85	29.22	18.00	44.00	11.05	1.50	25.60
OQ002	40	66.04	44.95	90.20	20.15	15.00	28.00	9.29	2.47	26.05
OQ003	24	101.12	53.10	180.00	-	-	-	9.98	1.00	30.00

Station Code	Number of Samples	Mean Conductivity (µS/cm)	Min Conductivity (µS/cm)	Max Conductivity (µS/cm)	Mean Chloride (ppm)	Min Chloride (ppm)	Max Chloride (ppm)	Mean Temp (°C)	Min Temp (°C)	Max Temp (°C)
PA001	1	42.20	42.20	42.20	44.00	44.00	44.00	5.15	5.15	5.15
PA002	8	111.37	90.80	127.35	29.69	20.00	34.00	15.92	1.19	22.35
PB001	9	95.44	71.05	148.35	40.17	34.00	52.00	4.06	1.00	6.70
PE001	45	91.31	34.00	180.00	31.40	20.00	46.00	14.91	1.00	27.45
RSC01	15	35.98	23.70	54.00	32.44	23.60	41.00	12.82	1.78	19.78
SA001	2	52.90	51.05	54.75	20.00	20.00	20.00	8.45	3.40	13.50
SA002	12	86.95	57.40	141.75	47.29	29.50	77.00	11.13	0.78	22.50
SA003	11	89.50	57.60	147.00	46.36	29.50	69.00	11.33	0.78	24.00
SBC01	20	40.83	26.20	62.30	18.78	10.00	42.00	9.47	0.75	31.65
SH001	25	43.80	23.75	60.25	20.86	11.00	45.00	8.01	0.83	29.55
SH002	24	65.49	42.80	98.00	-	-	-	9.90	0.56	31.00
SH003	2	82.50	76.35	88.65	17.75	16.50	19.00	18.47	18.17	18.78
SH004	3	371.33	223.00	456.00	39.50	28.00	47.50	20.85	15.80	23.50
SM001	8	38.03	33.10	55.45	14.38	11.50	18.50	8.65	1.64	16.83
SM002	25	35.42	2.36	56.50	13.42	9.50	16.00	8.68	0.69	19.64
SN001	12	55.96	42.80	73.55	22.23	15.00	28.50	16.26	1.05	31.65
SN002	10	59.65	41.15	84.75	24.20	19.00	28.00	12.91	1.00	25.20
SP001	2	55.63	55.40	55.85	20.00	16.00	24.00	21.64	16.00	27.28
SP002	10	71.27	58.00	94.15	21.80	15.00	30.00	14.59	0.60	26.50
SQ001	5	64.48	49.55	82.20	21.40	20.00	24.00	4.65	1.62	6.00
SQ002	3	92.88	78.90	107.20	33.33	20.50	44.00	5.14	3.39	6.65
SQ003	6	49.95	40.20	67.70	18.42	14.50	20.00	5.34	3.42	6.16
SQ004	4	58.68	49.50	64.55	22.63	19.50	25.00	4.95	3.03	7.60
SR001	36	52.50	35.10	83.60	24.46	17.00	44.50	13.13	1.75	21.95
ST001	2	45.48	44.45	46.50	20.00	20.00	20.00	18.94	17.39	20.50
STAR1	11	43.28	29.60	65.95	31.91	21.00	42.00	14.95	8.20	21.25
STAR2	13	39.20	31.50	48.25	29.35	23.00	37.00	15.51	7.55	21.55
STOCK1	10	36.39	21.30	60.15	37.39	25.00	121.42	13.06	1.90	19.60
STOCK2	9	28.36	23.10	36.45	31.11	22.50	40.00	13.26	7.95	16.70
SU001	7	60.40	55.60	71.05	22.50	18.00	30.00	14.76	0.86	27.20
SW001	13	36.30	24.95	43.50	22.00	18.00	32.00	14.12	5.70	24.80
TA001	6	44.87	35.80	50.85	25.67	13.50	35.50	14.25	3.60	19.85
TC001	4	92.56	75.05	117.20	28.25	22.00	44.00	15.24	8.40	18.95
TC002	10	80.01	28.85	113.00	46.40	30.50	78.00	12.16	3.40	26.60
TC003	10	63.48	51.60	97.25	39.05	25.00	65.00	9.67	0.89	20.90
TE001	10	144.06	48.70	205.00	42.10	20.00	57.00	14.14	5.70	23.40
TK001	13	70.09	44.20	111.45	30.08	24.00	40.00	14.00	2.50	24.80
WBDR	29	101.54	51.50	140.10	24.93	19.00	31.50	7.83	0.83	15.67
WF001	24	92.58	66.00	216.00	34.52	20.00	68.00	16.87	8.97	26.75
WF002	10	74.04	52.15	90.70	31.50	21.00	40.00	9.69	0.55	20.70
WH001	2	531.50	476.50	586.50	61.75	51.00	72.50	18.78	16.05	21.50

Station Code	Number of Samples	Mean Conductivity (µS/cm)	Min Conductivity (µS/cm)	Max Conductivity (µS/cm)	Mean Chloride (ppm)	Min Chloride (ppm)	Max Chloride (ppm)	Mean Temp (°C)	Min Temp (°C)	Max Temp (°C)
WL001	12	71.05	54.15	114.75	22.09	15.00	40.00	12.00	1.50	23.50
WL002	12	80.69	70.00	98.15	20.82	15.00	30.00	12.12	1.20	21.40
WL003	9	85.82	71.95	103.00	23.67	18.00	36.00	13.58	4.00	21.60
WL004	12	87.61	73.65	96.55	21.42	11.00	40.00	12.44	1.40	22.30
WL005	9	102.65	48.80	173.10	25.89	20.00	30.00	13.42	2.60	20.50
WR001	1	71.40	71.40	71.40	43.50	43.50	43.50	20.75	20.75	20.75

Appendix C
Barium & Strontium Data

Station Code	Date Collected	Barium (mg/L)	Strontium (mg/L)
ATC001	7/18/2012	0.027	0.015
BA001	3/17/2011	0.02972	0.010248
BA001	11/29/2011	0.018514	0.019542
BE001	5/12/2011	0.029649	0.028627
BE002	10/4/2010	0.04	0.027
CA001	9/26/2010	0.034	0.049
CA002	9/26/2010	0.037	0.042
DY001	10/22/2010	0.02	0.021
EQ001	10/4/2010	0.022	0.017
EQ002	4/29/2011	0.0174	0.014329
EQ002	10/4/2010	0.018	0.019
EQ003	4/29/2011	0.020452	0.012271
FB001	11/30/2011	0.022631	0.010287
FC001	10/19/2010	0.012	0.012
FLY01	11/9/2011	0.027824	0.026793
FLY01	11/19/2011	0.023622	0.023622
HA002	10/4/2010	0.025	0.021
HA002	5/12/2011	0.026599	0.025576
JC0001	9/17/2010	0.021	0.042
JC002	9/17/2010	0.012	0.02
JC002	9/17/2010	0.029	0.014
KB001	7/18/2012	0.007	0.023
KN001	4/29/2011	0.021	0.014
KN002	10/4/2010	0.017	0.017
LB001	7/18/2012	0.03	0.045
LB001	6/10/2013	0.035	0.05
LE001	10/19/2010	0.016	0.019
LE002	10/22/2010	0.011	0.009
LE002	10/4/2010	0.023	0.019
LE003	5/12/2011	0.025573	0.021481
LE004	10/22/2010	0.024	0.015
MC001	11/9/2011	0.018511	0.018511
MC001	11/19/2011	0.019541	0.017484
MDC01	11/7/2011	0.022749	0.027919
MDC02	10/18/2011	0.027118	0.033376
MDC02	11/7/2011	0.021733	0.026907
OD001	7/18/2012	0.041	0.035
OQ001	11/9/2011	0.021581	0.025692
OQ001	11/19/2011	0.018537	0.022657

Station Code	Date Collected	Barium (mg/L)	Strontium (mg/L)
OQ001	7/20/2012	0.024	0.028
OQ002	7/20/2012	0.009	0.015
SBC01	11/29/2011	0.027781	0.013376
SH001	3/17/2011	0.021529	0.015378
SH001	11/29/2011	0.029904	0.012374
SR001	10/4/2010	0.02	0.013
SR001	4/29/2011	0.018416	0.010231
STAR1	10/30/2010	0.015	0.015
STAR2	10/30/2010	0.007	0.01
STOCK1	10/30/2010	0.01	0.012
STOCK1	10/30/2010	0.013	0.011
STOCK1	3/9/2011	0.013313	0.009217
STOCK2	10/30/2010	0.007	0.01
TC001	7/18/2012	0.019	0.021
WF001	7/18/2012	0.025	0.024
WF001	6/10/2013	0.032	0.023
WL001	9/17/2010	0.016	0.036
WL002	9/17/2010	0.016	0.039
WL003	9/17/2010	0.018	0.036
WL004	9/17/2010	0.018	0.044
WL005	9/17/2010	0.018	0.022

Appendix D

Macroinvertebrate Data for Sampling Conducted in Pennsylvania in Proposed Shale Extraction Region of the Delaware River Basin

	EQ004	EQ005	FB001	LE002	NB001	CB001	DE001	DM001	PI001
Year	2011	2011	2011	2011	2011	2014	2014	2014	2014
Taxa Richness	38	20	34	18	28	32	23	25	27
EPT Taxa (Tol. = 0 - 4)	16	10	20	5	17	12	14	11	14
Becks Index	25	13	39	3	34	25	32	22	23
Hilsenhoff Biotic Index	3.035897	3.568075	3.537383	5.552764	3.286408	3.986111	4.07	3.37	3.74
(Water Quality Rating)	(excellent)	(very good)	(very good)	(fair)	(excellent)	(Very Good)	(Very Good)	(Excellent)	(very good)
Shannon Diversity	2.877298	2.081209	2.586986	2.021261	2.464493	2.563833	2.32	2.49	2.53
Percent Sensitive Individuals (Tol. = 0 - 3)	0.610256	0.704225	0.53271	0.165829	0.587379	0.430556	36.90%	55.90%	48.70%
Index of Biotic Integrity (IBI)	84.68171	63.81109	88.86395	38.98177	83.71014	73.4	70.9	71.1	73.2

Benthic sampling locations are available upon agency request.

Appendix E

Macroinvertebrate Data for Sampling Conducted in New York in Proposed Shale Extraction Region of the Delaware River Basin

	Telford Hollow	Fuller Hollow	Spring Brook	Campbell Brook	Tiffany Hollow	Downs Brook	Barney Hollow	Wilson Hollow Brook	Baxter Brook	Carcass Brook	Russell Brook	Horse Brook	Tar Hollow
Taxa Richness	22	32	29	24	27	30	25	27	20	26	25	22	21
EPT Richness	18	25	19	20	20	20	19	15	15	17	21	20	15
Biotic Index	3.51	2.99	2.59	2.69	2.79	3.03	3	3.55	3.26	4.03	2.71	2.41	3.52
PMA	54	50	70	45	63	74	53	60	60	72	64	57	48
BAP Score	7.62	8.33	8.96	7.59	8.56	9.01	7.93	8.25	7.78	8.4	8.44	8.01	7.28

Benthic sampling locations are available upon agency request.

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