SUMMARY OF WATER QUALITY MONITORING ACTIVITIES IN THE CHIQUES CREEK WATERSHED: 2015 – 2019

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TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

Chiques Creek is a medium-sized tributary of the Susquehanna River draining a 126-square-mile area in Lebanon and Lancaster Counties in southeastern Pennsylvania. Like many watersheds in this region, the dominant land uses in the Chiques Creek Watershed (CCW) include agricultural production (59%) and urban/suburban development (18%), a combination that has contributed to poor water quality in Chiques Creek and its tributaries. The Pennsylvania Department of Environmental Protection (PADEP) has designated over 95% of the 192 mapped stream miles in the CCW as impaired for aquatic life. An impaired aquatic life designation means that the biological community (e.g., fish, invertebrates, plants, and algae) found in the waterbody is not healthy due to the presence of pollution. PADEP has identified excess sediment (i.e., siltation) and nutrient enrichment as the primary causes of aquatic life impairment in the CCW.

Sediment is composed of the fine (<2 mm diameter) particles of sand, silt, and clay that form when rocks and soil erode. During storm events, overland runoff flushes sediments into streams where particles are suspended in the water column and moved downstream by the current. Siltation occurs when the supply of sediment in the water column exceeds the stream's transport capacity. Particles accumulate on the streambed, clogging the crevices between larger bed materials (e.g., gravel, cobbles, boulders) and reducing habitat availability for small animals like juvenile fish and aquatic insects.

The natural geologic process of sediment transport serves many important functions, such as the transfer of essential nutrients downstream and the modification of habitats both instream and on land (e.g., floodplains). The ability of a stream to transport its load of sediment is strongly dependent on the velocity of the water and the energy it generates to pick up and move particles. Water velocity varies throughout a stream and through time, and is influenced by gradient, channel characteristics such as width and depth, instream obstructions (e.g., rocks, logs, islands, bridge supports, etc.), and discharge. Discharge is the volume of water flowing past a point per unit of time, usually measured in cubic feet or meters per second. The volume of water flowing through a section of stream remains relatively constant over brief periods of time, but it can change dramatically over longer periods in response to changing weather and climate conditions. The difference in water volume between a drought and a flood can easily exceed a factor of 100 or even 1,000. In most watershed settings, it takes decades to centuries for streams to achieve a balance between the quantity and size of available sediment and the range of water velocity conditions that occur.[1]

Nutrient enrichment occurs when the availability of nitrogen and/or phosphorus exceed the nutrient needs of the natural stream community. Excess nutrients fuel the proliferation of aquatic plants, algae, and bacteria, resulting in alterations to physical habitat and changes in the food web and aquatic community composition.[2,3] The metabolic processes of plants and especially planktonic algae produce large daily swings in dissolved oxygen and pH that can, in extreme cases, fall outside the tolerable ranges for many aquatic organisms.[4,5] In addition to stimulating overgrowth of plants, algae, and other photosynthetic organisms, some forms of nitrogen also present a human health hazard. High levels of nitrate (> 10 mg/L) in drinking water can cause severe illness or even death in infants.[6]

Although streams have an amazing natural capacity for sediment transport, over the last several centuries human activities such as forest clearing, farming, damming of streams, mining, and urbanization have caused soil and streambank erosion rates to surge up to seven times higher than natural levels, resulting in siltation in many streams.[7] Human activities such as septic and wastewater discharge, fertilizer use, animal husbandry, and fossil fuel combustion contribute nutrients far in excess of natural aquatic community demand.

The Chesapeake Bay Connection

The Susquehanna River is the largest tributary to the Chesapeake Bay, accounting for approximately half of the Bay's freshwater inputs and playing a prominent role in the overall water quality and health of the Bay. Over the last several decades, chronic sedimentation and nutrient enrichment have wreaked havoc on the Bay ecosystem. High concentrations of suspended sediment reduce water quality and prevent sunlight from penetrating through the water column. Without adequate sunlight, the formerly expansive beds of submerged aquatic vegetation (SAV) found in shallow portions of the Bay are now limited to a much smaller area, resulting in reduced populations of the fish, crabs, and mollusks that rely on the SAV beds for habitat and nutrition. Sediment blanketing the floor of the Bay smothers sedentary bottom-dwelling species such as oysters. Burial of oyster beds also reduces habitat for various species that depend on the complex, hard structure provided by accumulations of oyster shells on the Bay floor. Severe blooms of algae and cyanobacteria caused by skyrocketing nutrient levels have resulted in fish kills and oxygen-depleted "dead zones" largely devoid of estuarine life. Over the last 30 years, reduced commercial harvests and loss of recreational fishing opportunities in the Chesapeake Bay due to excess sediment and nutrient enrichment have resulted in several billion dollars in economic losses.

Despite extensive restoration efforts in the 1990s and early 2000s, poor water quality has persisted in the Chesapeake Bay. In 2009, President Barack Obama signed an Executive Order recognizing the Bay as a national treasure and calling on the federal government to lead a renewed effort to restore and protect the nation's largest estuary and its watershed. In response to this decree, the U.S. Environmental Protection Agency (USEPA) released the Chesapeake Bay Total Maximum Daily Load (TMDL) in December 2010.

A TMDL is a scientific estimate of the maximum amount of pollution a body of water officially listed as "impaired" can accommodate and still meet water quality standards.[8] The Bay TMDL established legally enforceable limits for nitrogen, phosphorus, and sediment pollution, and gave USEPA the power to impose penalties for non-compliance. In 2014, representatives from each of the seven Bay jurisdictions (Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia) signed the Chesapeake Bay Watershed Agreement, officially committing to the "pollution diet" prescribed by the TMDL. Subsequently, each jurisdiction has developed a Watershed Implementation Plan (WIP) outlining its strategy for partnering with local and federal governments to achieve water quality standards for all impaired freshwater tributaries, tidal segments, and embayments by 2025.[9]

The Chiques Creek Watershed Alternative Restoration Plan

In 2014, PADEP selected the CCW as a "pilot" watershed for a novel adaptive management approach aimed at reducing sediment and nutrient loads in some of Pennsylvania's most degraded watersheds within the framework of the federal Clean Water Act. State and regional water management agencies and local stakeholders are working together to develop an Alternative Restoration Plan (ARP) to achieve water quality improvements in the CCW. The ARP approach involves a combination of focused support from a technical steering committee (PADEP, SRBC, and Penn State University's Agriculture and Environment Center (PSU-AEC)), and cooperation from local stakeholder groups reflecting a broad spectrum of interests. The Chiques Creek Watershed ARP demonstrates a combined agency and local commitment to pollution reduction aimed at recovering damaged aquatic resources. Although the primary goal for this ARP is restoration of local waterway integrity, improvements realized in the CCW will also add value in the larger context of Pennsylvania's WIP and the Chesapeake Bay TMDL.

Stressor effects associated with elevated sediment loads to streams (i.e., siltation, excess turbidity, and altered hydrology) tend to mask biological responses to other stressors, including nutrient pollution. Because of these potentially confounding effects, the ARP is being developed in phases with the first phase focusing on identifying and reducing suspended sediment inputs to Chiques Creek. Phase 1 of the ARP involves the following primary actions:

1) Defining causes and sources of aquatic life impairment in the CCW;
2) Estimating current sediment loads and deriving load reduction targets expected to foster recovery of healthy aquatic communities;
3) Developing and implementing Best Management Practices (BMPs) and projects to reduce sediment loads associated with previously identified sources; and
4) Monitoring effectiveness of BMPs and progress towards achieving load reduction targets.

The ARP steering committee has compiled a dynamic, stakeholder-vetted database of over 550 individual BMPs opportunities in the CCW with estimated sediment-reduction contributions and cost analysis. Agency partners have determined that the majority of excess sediment in the CCW originates from agricultural sources, with streambank erosion, croplands, and hay fields/pastures accounting for over 98% of the annual sediment load. Therefore, BMPs and projects will primarily focus on the agricultural sector and emphasize compliance with erosion and sediment control plans, livestock exclusion from stream corridors, adoption of healthy soil initiatives like conservation tillage and cover crop practices, and establishment of forested riparian buffers. Following agriculture, urban and suburban development is the second largest source of excess sediment in the CCW. BMPs to address urban sources will concentrate on establishing bioswales, stormwater basin retrofitting, and streambank stabilization. Other BMPs in the ARP database emphasize stream corridor projects to restore floodplain functions, and engineering the removal of unsafe or abandoned mill dams using designs that eliminate or stabilize legacy sediment accumulations.

MEASURING PROGRESS: CHIQUES CREEK WATERSHED MONITORING STRATEGY

Developing criteria by which to judge the effectiveness of BMPs and progress made towards sediment load reductions is a critical aspect of the ARP, which is intended to be a "living" document subject to revision based on the outcomes of various management decisions. In 2015, PADEP and SRBC began collecting data to characterize aquatic communities and water quality conditions in the CCW. These data were used to document aquatic life impairment status at the outset of the ARP process and will also function as a baseline for identifying changes and trends in the years to come. Over the past 4 years, monitoring efforts in the CCW have expanded to include a network of real-time remote water quality monitoring stations, as well as routine water quality monitoring at a sentinel station near the mouth of Chiques Creek (Figure 1). SRBC and local academic partners are also conducting targeted monitoring associated with BMPs, dam removals, and other restoration projects in the watershed. These and other monitoring activities will continue on a regular basis as part of a coordinated, long-term strategy to evaluate aquatic resource conditions and BMP effectiveness as prescribed by the ARP.

Monitoring Focus #1: Aquatic Life Surveys

PADEP assesses streams for aquatic life uses (ALUs) by surveying benthic macroinvertebrate communities. Macroinvertebrates are insects and other organisms such as worms, molluscs, and crustaceans that inhabit the bottom substrates (i.e., "benthos") of streams for at least part of their life cycles. Macroinvertebrates have been the focus of biomonitoring programs for several decades. Ubiquitous in streams both large and small, macroinvertebrates are a diverse group with varied abilities to tolerate pollution, and the presence or absence of certain species or groups of species (e.g., taxa) can signify good or poor water quality. Macroinvertebrates process organic materials in streams and are also the primary food source for many species of fish. Environmental impacts affecting macroinvertebrates can therefore influence both lower and higher levels of the food chain, making them particularly effective biological indicators of the overall health of aquatic systems.

SRBC collected benthic macroinvertebrate samples from 25 sites in the CCW (Figure 1) in April 2015 and February 2019 and calculated PADEP Index of Biotic Integrity (IBI) scores for each sample.[10] The IBI measures the degree of pollution in a stream based on overall assemblage composition, as well as the relative abundance and pollution tolerances of various taxa found in the sample. The IBI generates a single score from six individual metrics describing different aspects of the macroinvertebrate community, allowing for a quick assessment of the overall "health" of the system. The IBI is scored on a scale of 0 to 100, with 0 representing the worst ecological condition and 100 representing the best ecological condition. PADEP uses IBI score thresholds to formally assign ALU attainment/impairment status to stream reaches.

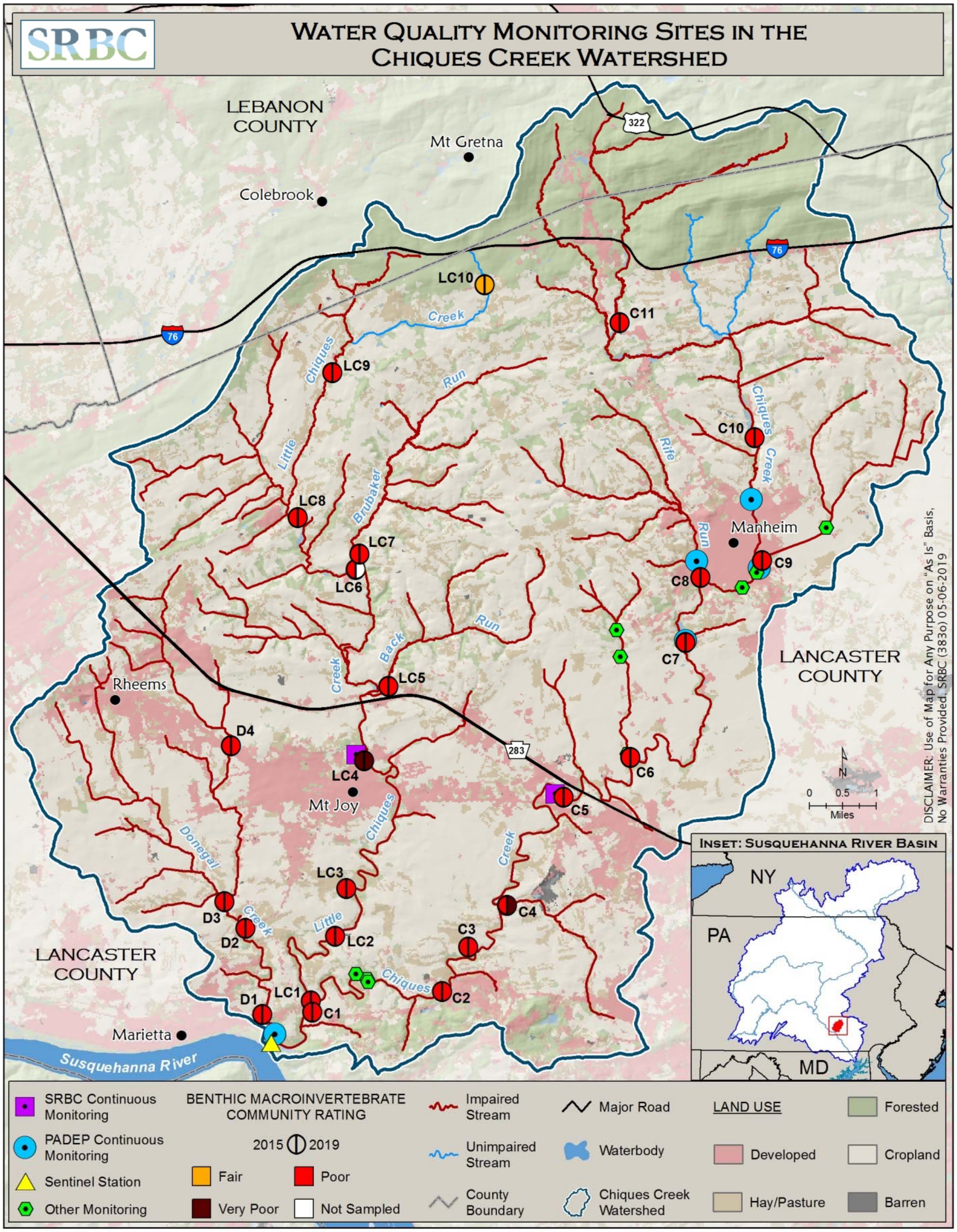

Figure 1. Locations of Monitoring Sites and Aquatic Life Use Impairment Status of Streams in the Chiques Creek Watershed

Based on the 2015 macroinvertebrate surveys, PADEP classified 183 miles of streams within the CCW as ALU impaired (Figure 1) due to nutrient enrichment and siltation. In addition to using IBI scores to determine ALU status, PADEP has also developed a categorical grading system for the IBI to allow for simplified comparisons across sites and through time (Table 1).[11] This grading system rates sites as Excellent, Good, Fair, or Poor based on IBI score. The IBI scores for the 2015 and 2019 CCW samples were graded according to this scoring system (Figure 2).

Unsurprisingly considering the high degree of impairment in the watershed, the majority of samples received Poor grades in both years. Site LC10, which is located within an unimpaired reach in the headwaters of Little Chiques Creek, was the only site to receive a "passing" grade of Fair. An IBI score was not calculated for site LC6 in 2019 because the sample did not contain the minimum number of organisms ($n \geq 160$) required for scoring. PADEP automatically grades samples with less than 160 organisms Very Poor. The IBI scores for 14 of the 25 sites did increase slightly between 2015 and 2019; however, these increases were not large enough to bump any sites rated Poor in 2015 up to the Fair category.

Table 1. Numeric Scores and Corresponding Categorical Grades for PADEP's Index of Biotic Integrity

Numeric IBI Score	Grade
90 - 100	**Excellent**
78 - 89	**Good**
53 - 77	**Fair**
Less than 52	**Poor**
Sample containing less than 160 organisms	**Very Poor**

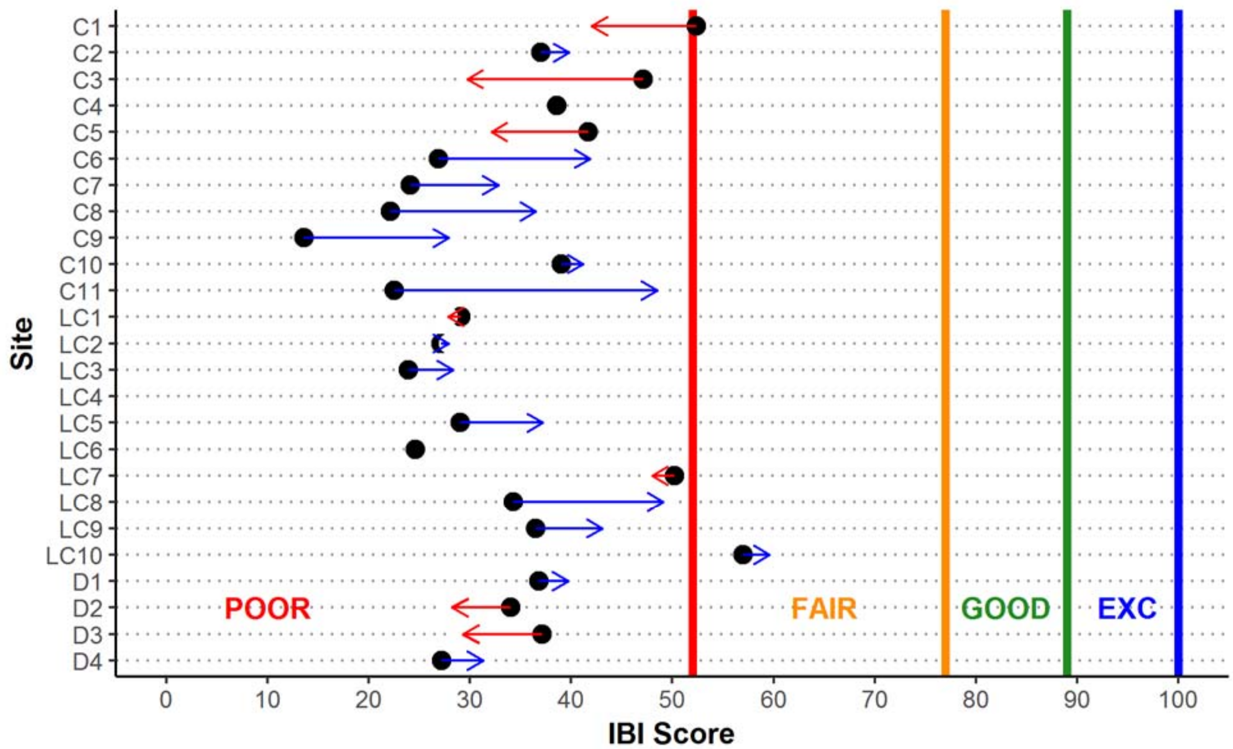

Figure 2. Index of Biotic Integrity (IBI) Scores and Categorical Grades for 25 Sites in the Chiques Creek Watershed Surveyed in 2015 and 2019 (Black dots mark 2015 scores and arrows point to 2019 scores; Blue arrows represent an increase/red arrows represent a decrease in IBI scores between 2015 and 2019; Site C4 was not sampled in 2019 due to high flows; Site LC6 was not scored due to having too few organisms (< 160) in the sample)

Macroinvertebrate community response depends on a multitude of dynamic and interactive factors including land use, instream habitat, species population dynamics, and climate conditions. For this reason, several data points will be necessary before any trends in IBI scores can reliably be detected. Changes in macroinvertebrate community structure, such as a shift from pollution-tolerant to sensitive taxa, as a result of new BMPs will likely not be evident for several years after implementation. Periodic reassessment of the macroinvertebrate community within this fixed network of 25 sites will therefore provide key information about the overall health of the CCW through time.

Monitoring Focus #2: Real-Time Water Quality Stations

Streams and rivers exist in a constant state of flux due to both natural and human-induced (e.g., dams, culverts, etc.) oscillations in flow, which in turn influences water quality and habitat. Recognizing the dynamic nature of aquatic systems, a growing number of water management agencies now incorporate continuous instream monitoring (CIM) into their assessment protocols. Unlike grab samples which only produce a snapshot of conditions at one moment in time, CIM data provide an integrated, long-term picture of water quality and allow managers to characterize baseline conditions, document seasonal fluctuations, and identify changes in water quality through time. CIM involves the passive deployment of automated data sondes programmed to record measurements at regular intervals. When paired with satellite stations, CIM data can be uploaded to the internet for real-time viewing by the public.

SRBC and PADEP first deployed CIM equipment in the CCW in 2015 (Figure 1). SRBC maintains CIM stations on Chiques Creek at the Lancaster Liederkranz and on Little Chiques Creek at Cove Road in Rapho Township. PADEP currently operates four CIM stations in the watershed: three on the mainstem of Chiques Creek and one each on the tributaries to Rife Run and Donegal Creek. A fifth PADEP-operated station, located on Chiques Creek downstream of Route 772 in Manheim, was deployed from April through November 2015. The data sondes at all of these stations record dissolved oxygen, pH, specific conductance, temperature, and turbidity at 15-minute intervals. Real-time data from the SRBC CIM stations are available for public viewing at: https://mdw.srbc.net/remotewaterquality/data_viewer.aspx.

CIM stations produce a record for each measured parameter that can be processed into a time series to highlight daily and seasonal patterns, allowing researchers to quickly and easily detect signals of changing or abnormal conditions in aquatic systems.

CIM Data Applications

Identifying Streams with Nutrient Enrichment

In 2018, PADEP released a new assessment tool, called the Eutrophication Cause Determination Protocol (ECDP), which uses CIM data to identify streams where nutrient enrichment is causing ALU impairment.[12] The term eutrophication refers to the process by which elevated nutrient levels stimulate the growth of algae and/or plants in aquatic systems and alter stream metabolism. Eutrophication-related stressors to biological communities include elevated pH levels, low dissolved oxygen (DO) concentrations due to increased biochemical oxygen demand, and the potential for toxic algal blooms.

Algae and plants are known as primary producers, meaning they convert light energy into chemical energy and oxygen via photosynthesis. When large numbers of algae are present in a stream due to nutrient enrichment, their photosynthetic activity causes a marked increase in DO concentrations during daylight hours. After sunset, algae begin to respire, becoming users of oxygen rather than producers. This uptick in respiration also increases the level of carbon dioxide in the water, temporarily reducing the stream's buffering capacity and producing a diel (24-hour) pH swing mirroring the diel DO swing with elevated pH values during photosynthesis and lower pH values during respiration.

Diel DO swings will be strongly correlated with pH in streams where nutrient enrichment is problematic. In streams with low nutrient levels, water temperature is the primary driver of diel DO swings due to the influence of temperature on the solubility of oxygen in water. The magnitude of diel DO swings driven by the natural rise and fall of water temperatures over the course of the day tends to be less than those resulting from pH changes and, with the exception of extreme cases, these fluctuations do not have the same potential for ecosystem harm. Figure 3 illustrates patterns in DO, pH, and temperature in streams with (Rife Run in the CCW) and without nutrient enrichment (Grays Run in Lycoming County, PA) over a 24-hour period on March 10, 2016. Land cover in the Grays Run Watershed is 95% forested and the stream is relatively nutrient-poor. DO, pH, and temperature fluctuated less than one unit of measure over the course of the day in Grays Run. On the other hand, Rife Run experienced large fluctuations in DO (7.30 mg/L), pH (1.92 units), and temperature (6.09 °C). The watershed upstream of the

CIM station on Rife Run is only 11% forested, and the stream receives excess nutrients from both agricultural and urban/suburban sources (i.e., Manheim Borough).

PADEP's ECDP uses CIM data to examine the relative influences of diel pH and temperature swings on diel DO swings and identify stream reaches affected by eutrophication. Data from the seven CIM stations in the CCW were run through the ECDP tool, which looks at sites on a monthly basis during the March to October time period. The results indicate that nutrient enrichment is present at all seven CIM stations in the CCW (Table 2). Based on the available data, some areas in the watershed are more heavily impacted than others. Rife Run, which flows into the mainstem of Chiques Creek near Manheim, is the most affected of the 7 stations, with the ECDP signifying eutrophication in 16 of 18 months.

The ECDP is one tool the ARP partners can use to identify stream reaches in the CCW affected by eutrophication and prioritize these areas for BMP implementation. Moving forward, the ECDP can also be used to track BMP progress. Reduced nutrient inputs should likewise reduce the potential for algal overgrowth, subsequently stabilizing dissolved oxygen, pH, and temperature and resulting in fewer months with evidence of eutrophication.

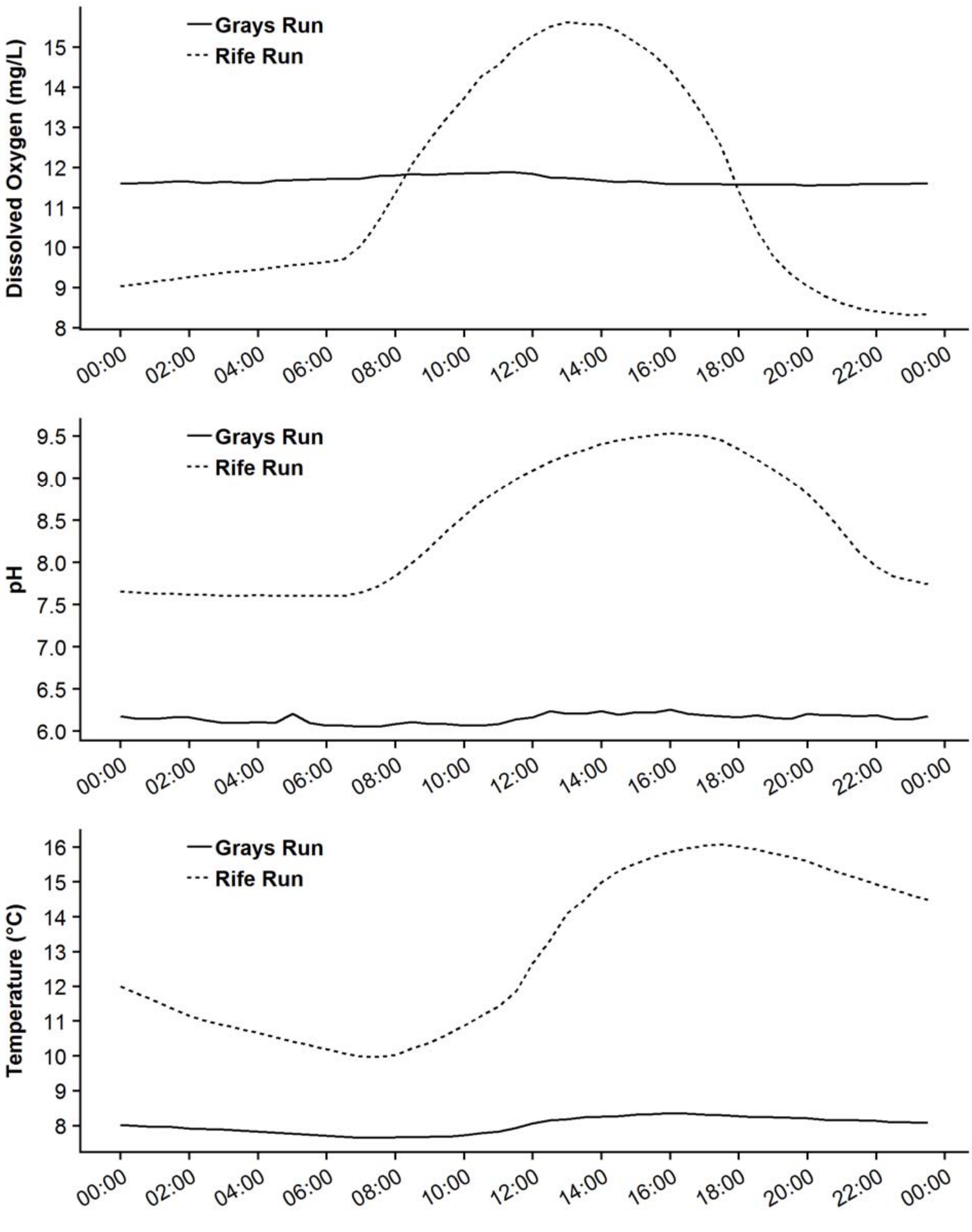

Figure 3. Dissolved Oxygen, pH, and Water Temperature CIM Data Collected Over a 24-hour Period on March 10, 2016 From Rife Run in the Chiques Creek Watershed (Dotted Line) and Grays Run in Lycoming County (Solid Line) (Diel DO swings in Rife Run are driven by pH swings (photosynthesis and respiration rates); Diel DO swings in Grays Run are driven by water temperature)

Table 2. Eutrophication Cause Determination Protocol (ECDP) Results for Continuous Instream Monitoring Stations in the Chiques Creek Watershed

Stream Name	Site Description	Agency	Drainage Area	ECDP Results		
				# Months	# Eutrophic	% Eutrophic
Rife Run	Upstream of Route 772 in Manheim	PADEP	5.9	18	16	88.9%
Donegal Creek	At Long Lane in Columbia	PADEP	17.1	14	2	14.3%
Chiques Creek	At the Manheim Farm Show	PADEP	22.1	8	3	37.5%
Chiques Creek	Downstream of Route 772 in Manheim	PADEP	28.8	2	1	50.0%
Little Chiques	At Cove Road in Rapho Township	SRBC	36.0	25	2	8.0%
Chiques Creek	At Mill Road in Penn Township	PADEP	37.2	8	4	50.0%
Chiques Creek	At the Lancaster Liederkranz	SRBC	49.2	24	1	4.2%

Examining Frequency and Duration of High Turbidity Events

Loss of ecological function in streams has been related to threshold levels of turbidity and suspended sediment concentrations.[13,14] High turbidity reduces light penetration and primary production, creating a cascade of negative impacts to growth rates and survival that reverberate up the food chain from invertebrate herbivores to predatory fish.[15] Many fish species also require clear water for successful nesting, and high levels of turbidity can lead to reduced reproductive success.[16]

The severity of impacts to aquatic organisms depends not only on turbidity levels, but also on the duration and frequency of high turbidity events. Frequency is important because organisms can potentially recover between exposure to stressors, provided they do not occur too close together.[17] In watersheds with a high degree of land disturbance (e.g., agriculture, urban development, resource extraction), chronic high levels of turbidity can develop as a function of excess sediment loads. Chronic high turbidity can cause out-migration from impacted reaches into unaffected areas and, in some cases, lead to mortality of resident fish and macroinvertebrates.[18] More commonly, elevated turbidity is episodic and occurs primarily during high streamflow events. As storms and flooding become more frequent and severe as a result of climate change, aquatic organisms will have less time to recover between events and mortality rates due to high turbidity, as well as other pollutants influenced by stormwater runoff, may increase.

Concentration-duration-frequency (CDF) plots provide a useful way to visualize patterns in high-resolution turbidity data collected using CIM technology. CDF plots are created by plotting the number of events for the time period of interest (frequency) where turbidity equaled or exceeded a specified level (measured in nephelometric turbidity units or NTU) versus the duration of the event. Figures 4 and 5 depict the frequency and duration of 7, 20, 55, 150, 400, and 1,100 NTU events occurring in 2016, 2017, and 2018 at the two SRBC-operated CIM stations (Chiques Creek at the Lancaster Liederkranz and Little Chiques Creek at Cove Road in Rapho Township). These NTU thresholds represent impairment levels for fishes (as a group) that require or prefer low turbidity.[19]

Turbidity values over 1100 NTUs were recorded in Little Chiques Creek following storm events in both 2017 and 2018 (Figure 5). Very high turbidity events (≥ 400 NTU) occurred more frequently in 2018 than in 2016 and 2017 at both SRBC-operated CIM stations (Figures 4 and 5). The increased frequency of these events in 2018 can be attributed to abnormally high flow conditions resulting from above average rainfall (Figure 6). Flows, and subsequently turbidity, were particularly high between late July and early October 2018 due to a series of strong storms that brought torrential rainfall and historic flooding to parts of the CCW.

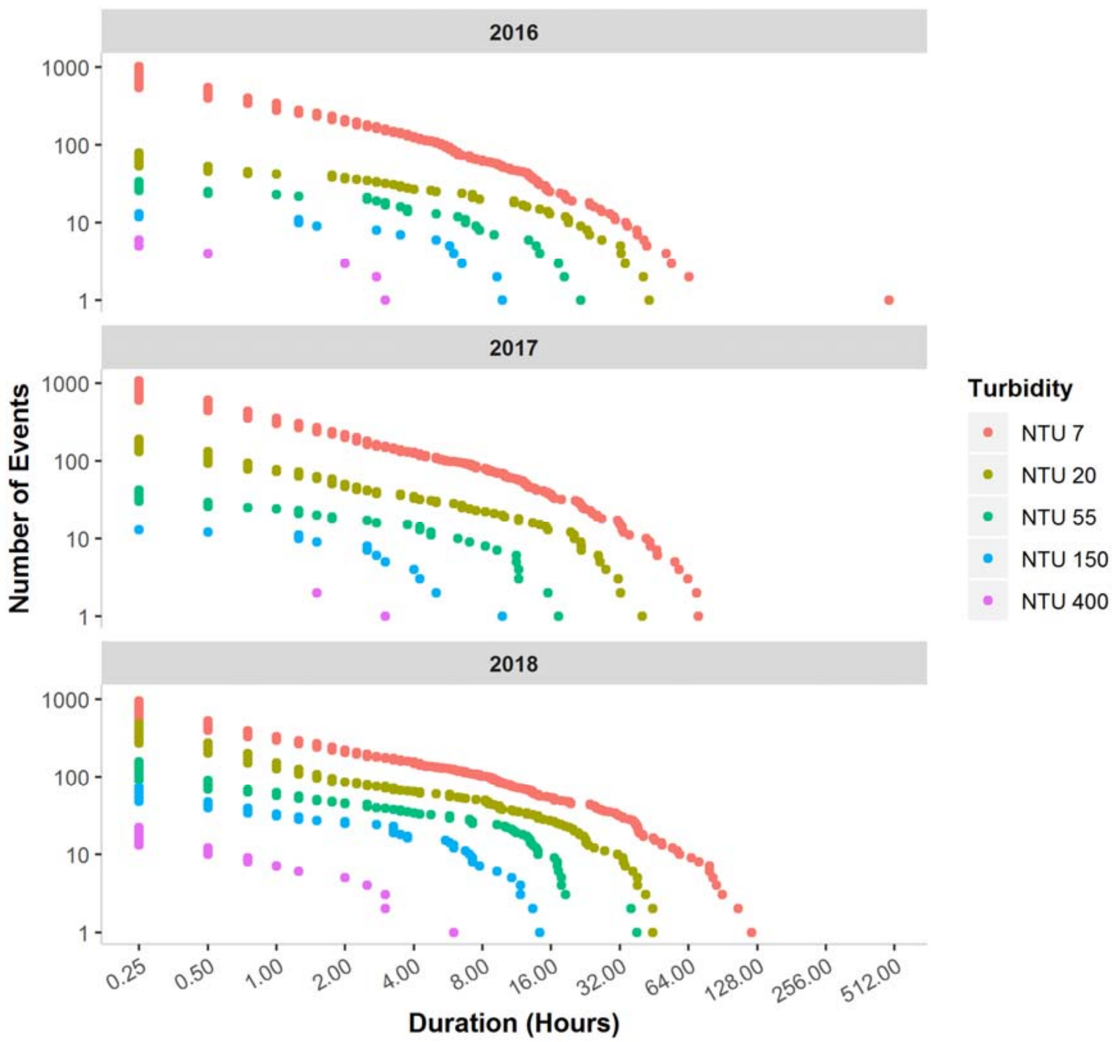

Figure 4. Number of Events Per Year With Turbidities Greater than Specified Turbidity Cutoff Versus Duration (Hours) of Event for the CIM Station on Chiques Creek at the Lancaster Liederkranz

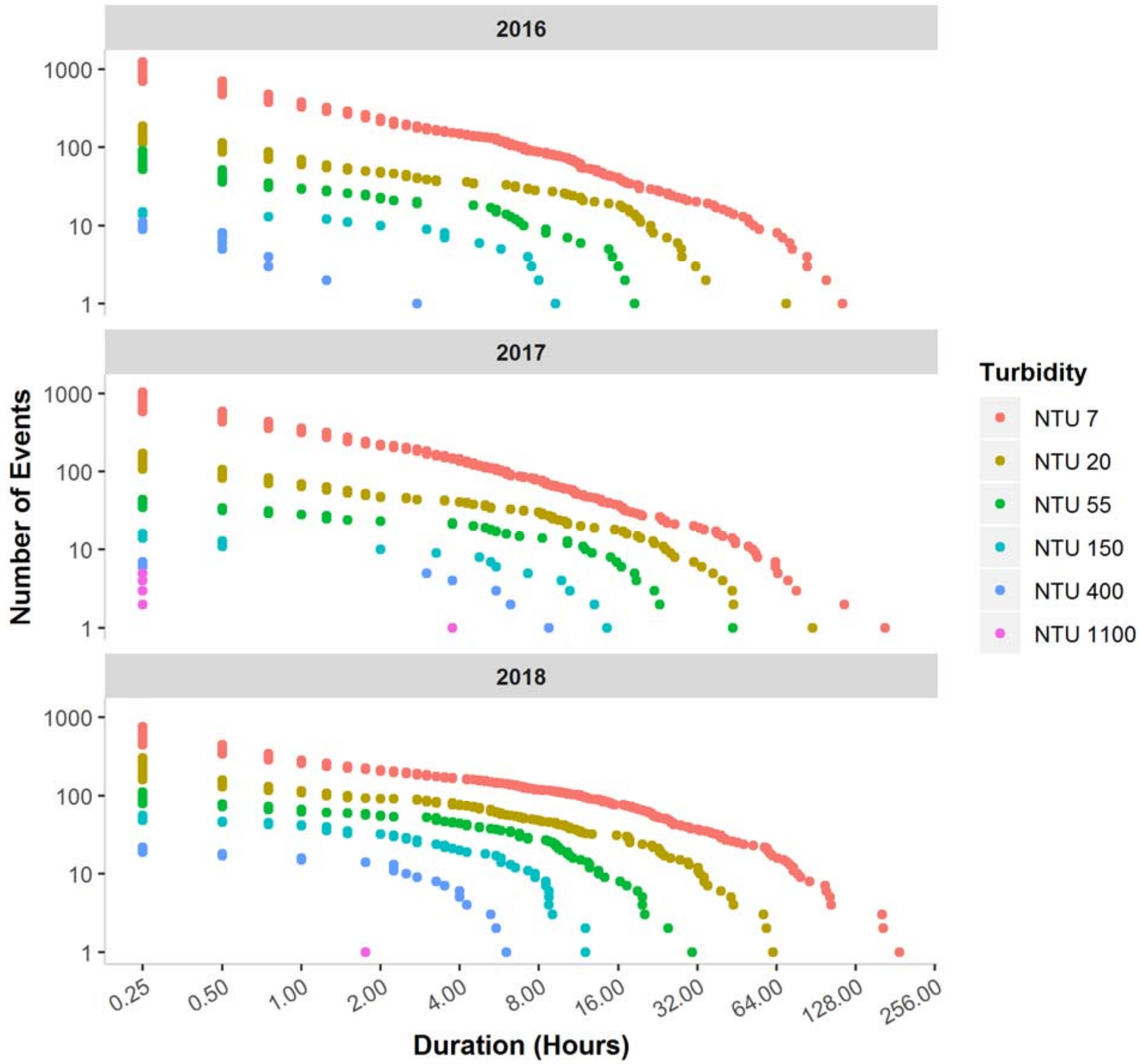

Figure 5. Number of Events Per Year With Turbidities Greater than Specified Turbidity Cutoff Versus Duration (Hours) of Event for the CIM Station on Little Chiques Creek at Cove Road in Rapho Township

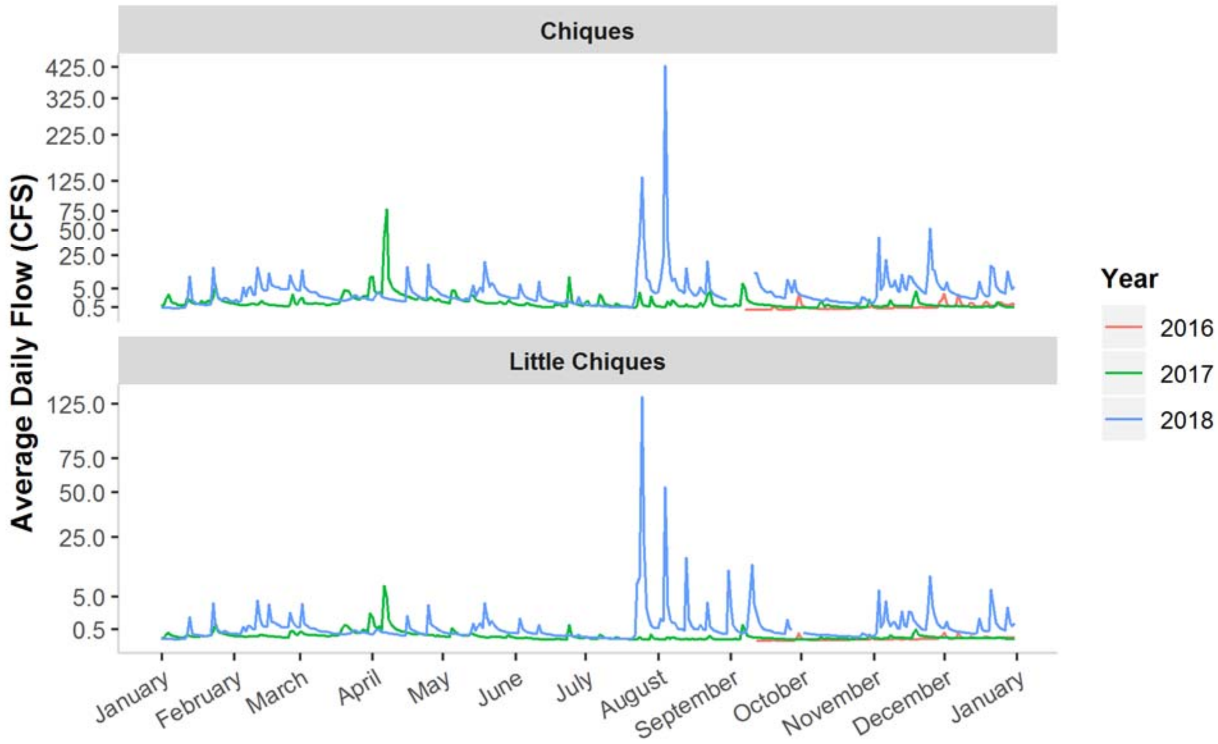

Figure 6. Average Daily Streamflow By Year at the CIM Stations on Chiques Creek at the Lancaster Liederkranz and Little Chiques Creek at Cove Road in Rapho Township

Studies have demonstrated that turbidity can be a useful surrogate for estimating suspended sediment concentrations in streams.[20,21,22] Turbidity CDF curves can therefore be used to track the effectiveness of the sediment and erosion control measures through time. Improvement would be indicated by reduced frequency and shorter duration of higher turbidity (e.g., 150, 400, and 1,100 NTU) episodes, particularly following storm events.

Monitoring Focus #3: Watershed Level Pollutant Loads and Water Quality Trends

In April 2018, SRBC established a Sentinel Station near the mouth of Chiques Creek (Figure 1) for the purpose of estimating sediment and nutrient loads in the watershed and informing updates to ARP load reduction targets when necessary. Data collection at the Sentinel Station follows standardized and rigorous sampling protocols established by the USEPA Chesapeake Bay Program's non-tidal water quality monitoring program (a.k.a., non-tidal network or NTN).[23] The NTN protocol involves collecting routine water samples at the same time every month, irrespective of flow conditions. Samples are analyzed for suspended sediment, nitrogen, and phosphorus concentrations. Additional samples are collected during major storm events to measure the influence of streamflow on water chemistry. Typically, 5 – 10 years of data are required before upward or downward trends in pollutant loads can be detected. SRBC is committed to long-term monitoring at the Chiques Creek Sentinel Station to provide a sound basis for assessment of watershed level pollutant loads as the ARP continues to unfold.

Preliminary data collected at the Sentinel Station clearly demonstrate the influence of flow on certain water quality parameters. Suspended sediment was much higher in storm samples than in routine samples, with concentrations close to 300 mg/L following the intense storm event that occurred in early August 2018 (Figure 7). Suspended sediment concentrations were below laboratory detection limits in most routine monthly samples except those collected during higher than average flows in June 2018, September 2018, March 2019, and May 2019. Patterns in phosphorus concentrations were similar to suspended sediment, with higher values observed in storm samples and in months with higher flows (Figure 8).

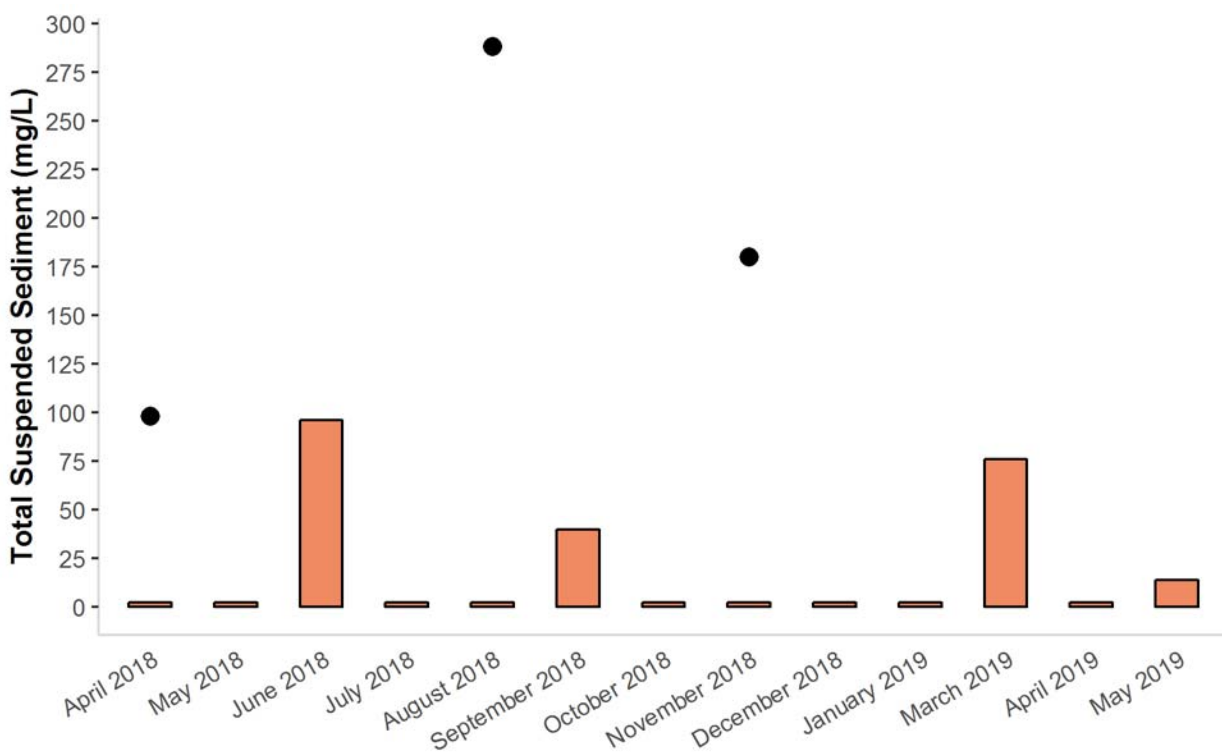

Figure 7. Total Suspended Sediment Concentrations (mg/L) In Samples Collected From The Chiques Creek Sentinel Station Between April 2018 To May 2019 (Bars represent routine samples; Black dots represent storm samples)

Both particulate and dissolved forms of phosphorus are monitored at the Sentinel Station. Particulate phosphorus (PP) readily binds with soils and other organic and inorganic molecules that form sediment, leading to the assumption that controlling soil erosion would effectively control phosphorus export from agricultural lands.[24] However, recent data have shown that some erosion control practices, such as conservation tillage and no-till farming cause dissolved phosphorus (DP) to build-up at the surface level of the soil, thus increasing DP concentrations in runoff.[25] This can have devastating implications for both streams and the Chesapeake Bay as the greater bioavailability (i.e., potential for uptake by living organisms like algae and plants) of DP makes it more likely than PP to contribute to water quality impacts. This scenario has already played out in Lake Erie, where a surge in DP in the mid-1990s led to a series of severe phosphorus-induced algal blooms.[26]

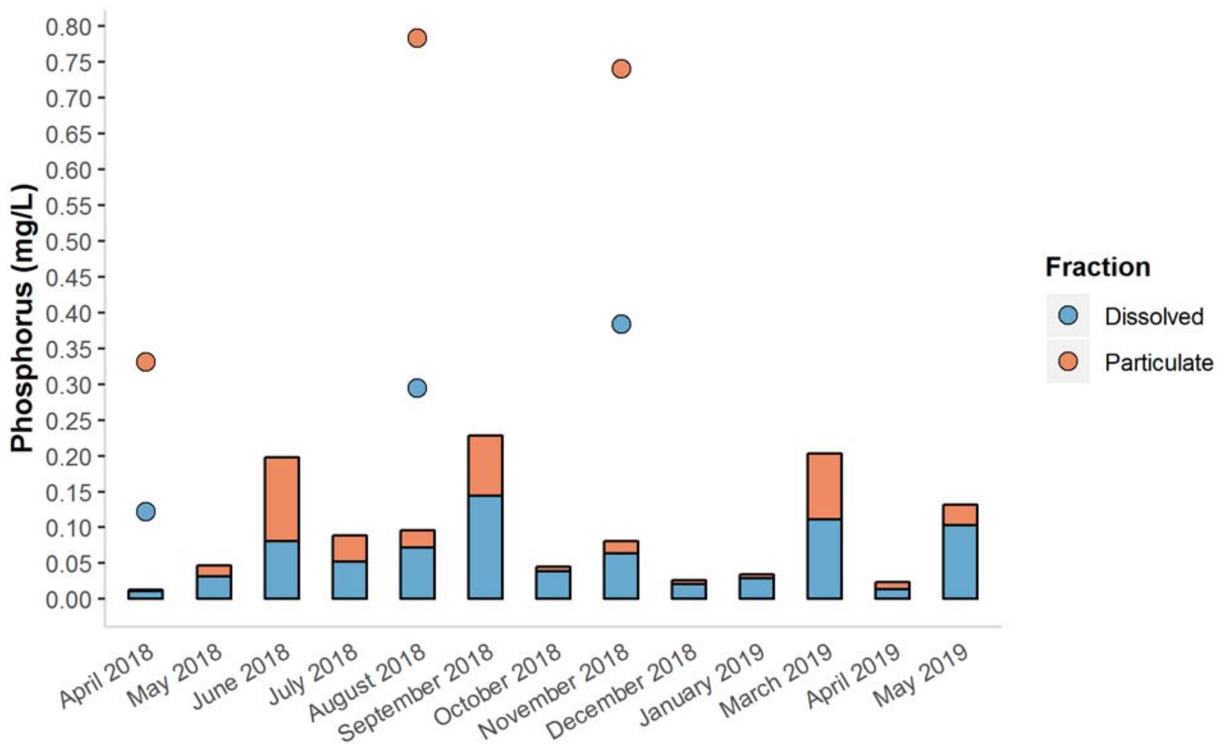

Figure 8. Dissolved (Blue) and Particulate (Orange) Phosphorus Concentrations (mg/L) in Samples Collected from the Chiques Creek Sentinel Station Between April 2018 To May 2019 (Bars represent routine samples; Black dots represent storm samples)

Recent data from SRBC's Sediment and Nutrient Monitoring Program (SNAP) suggest DP is on the rise in the Susquehanna River Basin.[27] Among the SNAP sites, trends in PP mirror suspended sediment while DP patterns are more consistent with total nitrogen concentrations, with the highest values of total nitrogen and DP occurring in watersheds with high proportions of agricultural row crops. When developing BMPs for the CCW, it is therefore important to consider their impact on DP export from agricultural lands and to include both PP and DP analyses in monitoring efforts.

Total nitrogen levels were consistently high at the Chiques Creek Sentinel Station, ranging from 6.3 mg/L to 9.6 mg/L (Figure 9). Although local geology and atmospheric conditions can affect natural levels of nitrogen in streams, background concentrations are generally less than 1.0 mg/L in watersheds with minimal impacts from agriculture or urbanization.[28] Nitrate is the primary form of dissolved nitrogen in streams and groundwater, and is usually the largest contributor to total nitrogen. Figure 10 shows how total nitrate data from the CCW macroinvertebrate survey sites (Figure 1) compare to averages for the Lower Susquehanna River Valley and the entire Susquehanna River Basin. The Basin-wide average for total nitrate (0.5 mg/L) falls below background levels, while average concentrations in the Lower Susquehanna River Valley, which is both densely populated and heavily agricultural, are much higher (4.7 mg/L). Total nitrate concentrations in the CCW are high even for the Lower

Susquehanna River Valley, with an average of 6.9 mg/L and observations ranging from 1.42 mg/L at LC10 on Little Chiques Creek to 12.4 at D3 on Donegal Creek.

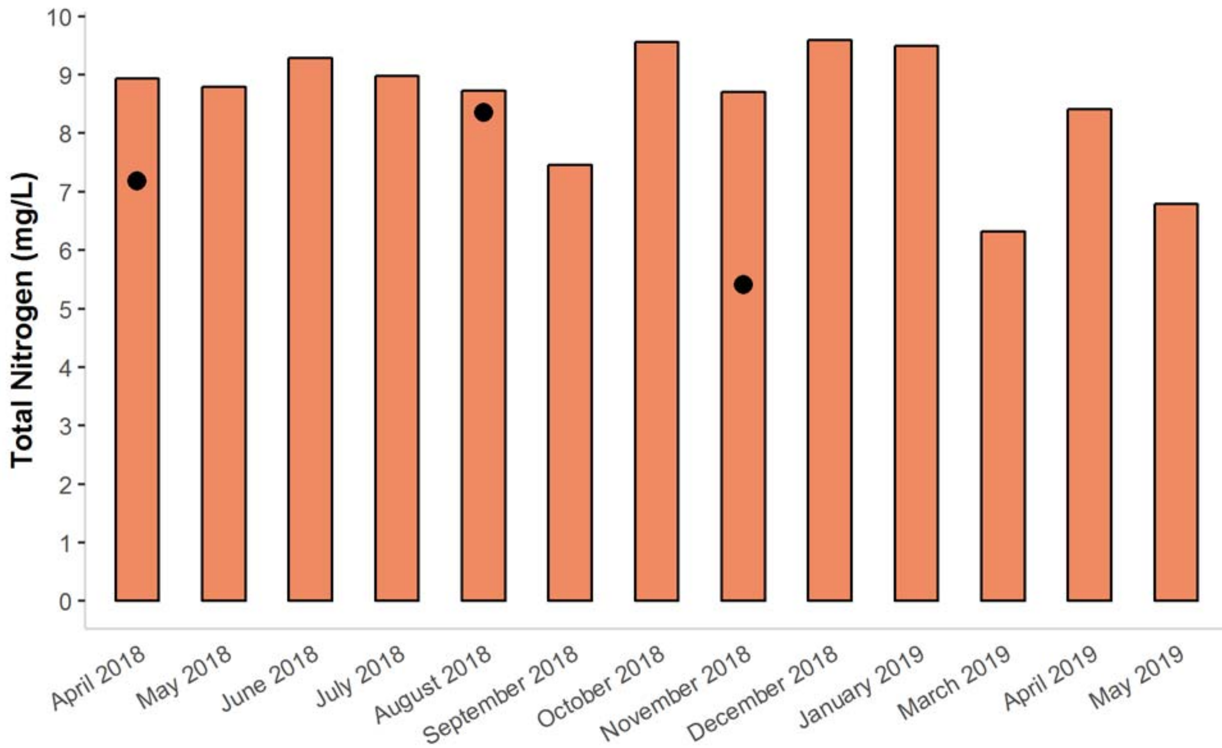

Figure 9. ***Total Nitrogen Concentrations (mg/L) in Samples Collected from the Chiques Creek Sentinel Station Between April 2018 To May 2019 (Bars represent routine samples; Black dots represent storm samples)***

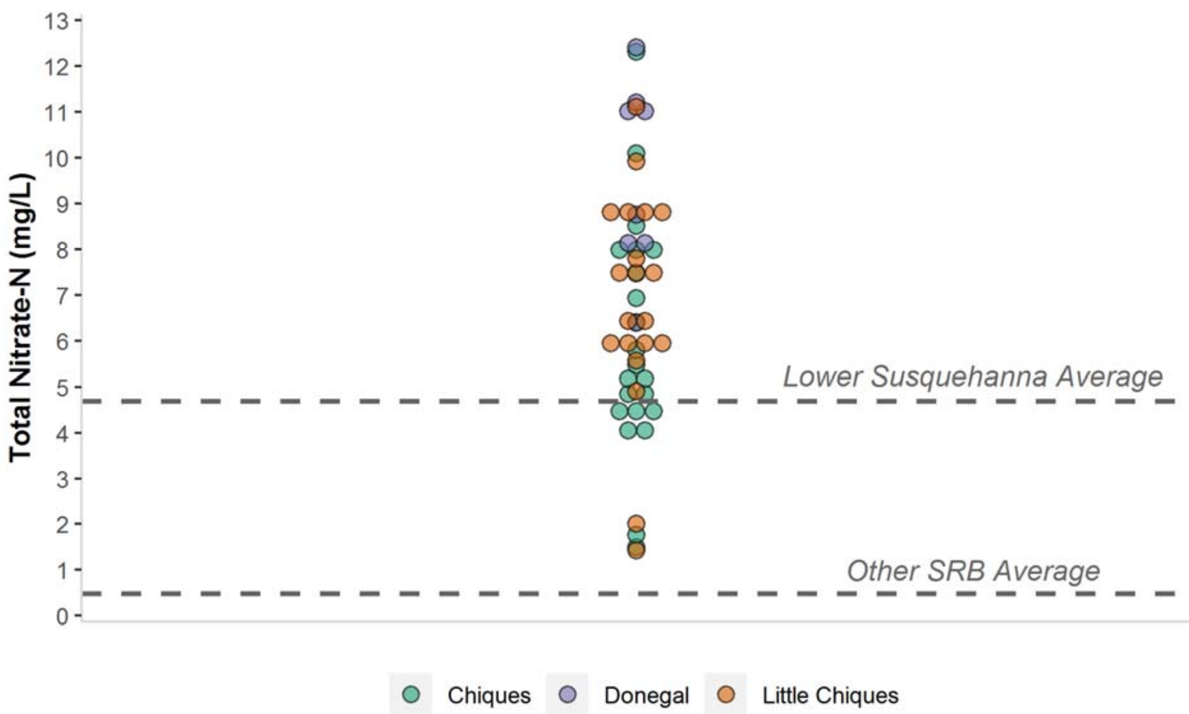

Figure 10. Total Nitrate-N Concentrations (mg/L) In the Chiques Creek Watershed Compared to Averages for the Lower Susquehanna River Valley and the Entire Susquehanna River Basin

FUTURE MONITORING PLANS

The data presented in this report indicate that the extent of degradation in the CCW is severe; however, the watershed is not unique in terms of deviation from unimpaired resource conditions. Although dramatic pollutant load reductions are required to reach the sediment and nutrient targets prescribed by the ARP, there are attainable pathways available to reduce loads sufficiently to support healthy aquatic communities. Specifically, these pathways involve implementation of BMPs focused on reducing impacts from the agricultural sector and urban/suburban areas. The timeline to achieve sediment and nutrient load reductions in the CCW is uncertain, and the restoration of healthy aquatic communities may very well take decades. Data collected since 2015 provide a sound baseline for measuring BMP success and ARP progress.

As an ARP technical steering committee member, SRBC is committed to continued monitoring in the CCW to track progress over the next several years towards the ultimate goal of restoring ecological integrity to local waterways. Planned monitoring activities include continued operation of the CIM stations on Chiques Creek and Little Chiques Creek, collection of routine and stormwater samples at the Sentinel Station, and periodic benthic macroinvertebrate surveys to track changes in water chemistry and biological response. SRBC will continuously analyze data obtained from the CIM stations and the Sentinel Station, and provide regular updates in report form and/or through the agency's website. Once sufficient data have been collected (5 – 10 years), trends analysis will be performed to identify patterns in CIM parameters (temperature, dissolved oxygen, pH, conductance, and turbidity) and watershed-level sediment/nutrient loads at the Sentinel Station.

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