GOOSE CREEK (PA) REASSESSMENT AND RECONSIDERATION

Prepared by the U.S. Environmental Protection Agency, Region III

May 4, 2017

Executive Summary

The purpose of this document is to report the U.S. Environmental Protection Agency's (EPA) findings in (1) reassessing the water quality of Goose Creek, located in southeastern Pennsylvania, and (2) reconsidering the validity of EPA's 2008 Total Maximum Daily Load (TMDL) for total phosphorus to address aquatic life use impairments in Goose Creek. West Goshen Sewer Authority (WGSA) filed a Complaint challenging EPA's establishment of the TMDL and, as part of an interim settlement agreement, EPA agreed to reassess whether Goose Creek is impaired by nutrients and/or sediments and reconsider the TMDL. As part of the reassessment, EPA used available data provided by Pennsylvania Department of Environmental Protection (PADEP) and WGSA to assess whether Goose Creek was impaired. Based on that assessment, EPA has determined that Goose Creek is impaired by sediment and nutrients (TP). The nutrient impairment determination is supported by multiple lines of evidence. Concentrations of total phosphorus are elevated, ranging, on average, from 70-80 µg/L (0.07-0.08 mg/L) at stations upstream of two STPs, and from 1120-1770 µg/L (1.12-1.77 mg/L) at stations downstream of the two STPs. These in-stream TP concentrations exceed many nutrient threshold values (described in Section 6.2). TP thresholds range from 2-200 µg/L (0.002-0.2 mg/L), and the stream exhibits excessive primary production, low dissolved oxygen, elevated daily dissolved oxygen swings, and an impaired macroinvertebrate community (based on PADEP's freestone macroinvertebrate IBI). The sediment impairment is supported by poor habitat scores and high percentages of fine sediments. Following the reassessment, EPA reconsidered the validity of the total phosphorus TMDL and found that the TMDL appropriately addresses the phosphorus impairment and will remain in place.

Table of Contents

Tables

Figures

1 Background

Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not supporting their designated uses. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and instream water quality conditions. By following the TMDL process, states can establish water quality-based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources.

The Goose Creek watershed covers 7.9 square miles and straddles the Chester and Delaware County boundary in Pennsylvania, with the majority of the watershed being in Chester County. Goose Creek confluences with East Branch Chester Creek and forms Chester Creek which then, after flowing southward for approximately 20 miles, drains to the Delaware River, as shown in Figure 1.1.

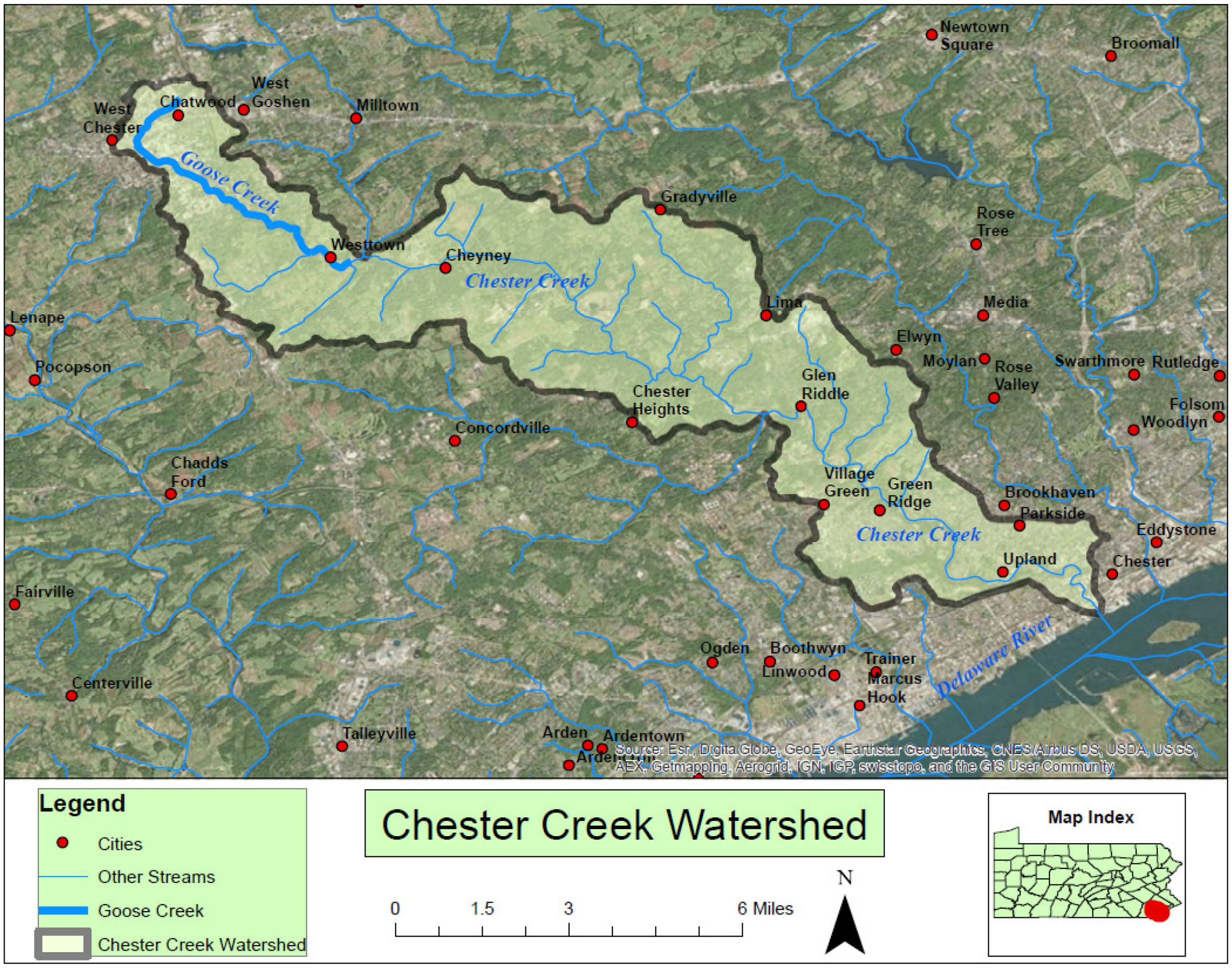

Figure 1.1 Chester Creek Watershed.

In 1996, Pennsylvania Department of Environmental Protection (PADEP) assessed Chester Creek, including Goose Creek, and determined that it was not meeting its aquatic life use. PADEP identified Goose Creek on Pennsylvania's 1996 303(d) list of impaired waters because of "municipal point sources." PADEP defines "municipal point source" as "[a]ny publicly owned treatment works (sewage and wastewater treatment plants) that process domestic, industrial, and commercial waste waters." (PADEP, 2013b). PADEP did not specify the pollutant causing the impairment. PADEP has continued to identify Goose Creek as impaired in biennial statewide water quality updates in 1998, 2002, 2004, 2006, 2008, 2010, 2012, and 2014.

At the request of PADEP and pursuant to requirements of the Pennsylvania TMDL Consent Decree, American Littoral Society v. EPA, Civil No. 96-489 (E.D.Pa.) (J. Katz, EPA, 2008), in 2008 EPA established a total phosphorus TMDL for the Goose Creek watershed to address the aquatic life use impairment. The total phosphorus impairment was based on nitrogen:phosphorus ratios which demonstrated that Goose Creek is a phosphorus limited system (EPA, 2008d; Paul and Zheng, 2007). The consent decree required EPA to establish TMDLs for water quality limited segments (WQLSs) identified on Pennsylvania's 1996 Clean Water Act

(CWA) Section 303(d) list of impaired waters if Pennsylvania failed to do so by a scheduled deadline.

In 2012, West Goshen Sewer Authority (WGSA) filed a Complaint (West Goshen Sewer Authority v. EPA, Civil Action No. 2:12-cv-05353-JS) challenging EPA's establishment of the Goose Creek TMDL. The parties agreed to an interim settlement agreement, wherein EPA would reassess whether Goose Creek was impaired by nutrients and subsequently reconsider whether to withdraw or retain the TMDL. More specifically, EPA agreed to analyze site-specific physical, chemical, and biological factors, based on available data, to determine if the impairment of Goose Creek is caused by nutrients or sediments or some combination thereof. EPA agreed to address to the extent allowed by the available data:

(1) Whether excessive plant growth is occurring and whether it or other causes are resulting in low dissolved oxygen (DO) conditions in Goose Creek; and
(2) Whether any observed impairment of macrobenthos communities could be attributable to impacts of excessive suspended sediments (e.g., excessive sediment input, flow alteration, and/or in-stream erosion).

EPA reserved the right to consider other relevant issues that may arise during the reassessment.

To collect available data for the reassessment, EPA published a data solicitation in a local newspaper, on EPA's website, and emailed the solicitation to stakeholders including WGSA, PADEP and the Delaware Riverkeeper. Both PADEP and WGSA developed sampling plans to collect adequate data for the reassessment. PADEP and WGSA collected instream water quality data, macroinvertebrate community data, habitat information, continuous instream monitoring and various algae data. Details of the various data sets are listed in Table 4.1.

This document describes EPA's approach and conclusions regarding its reassessment of whether nutrients and/or sediment cause or contribute to the impairment status of Goose Creek. It provides information on: potential stressors to Goose Creek's aquatic life (Section 2), PADEP's water quality standards (Section 3), data that was received from PADEP and WGSA to help in the reassessment (Section 4), methodologies used to assess biological, nutrient, and sediment impairments (Section 5-8), and results of assessments based on the data using those methodologies (Sections 5-8). Section 9 discusses other potential causes of impairment and Section 10 summarizes EPA's reassessment findings. Section 11 provides EPA's findings in reconsidering the validity of the total phosphorus TMDL.

2 Potential Stressors to Aquatic Life

In the interim settlement agreement, EPA agreed to reassess whether nutrients (phosphorus and nitrogen), sediment, or both, are contributing to Goose Creek aquatic life impairments; therefore, this stressor analysis focuses on those stressors. In addition, EPA reviewed data for chloride, another potential stressor related to urbanization in the watershed that could contribute to the impairment of aquatic life designated use. EPA did not include this analysis as part of the formal reassessment, but rather provides a summary of these analyses in Section 11.

2.1 Excess Nutrients

The plant nutrients phosphorus and nitrogen, often referred to as "nutrients," affect aquatic systems in diverse ways. Specifically, the term "nutrients" in this context refers to certain phosphorus- and nitrogen-containing chemical compounds that can be used by primary producers, e.g., microalgae, macroalgae, macrophytes, or plants in aquatic systems, for their nutrition and growth. For example, some nutrient compounds frequently measured in aquatic systems include, but are not limited to, the phosphorus containing compound phosphate (PO_4^{3-}), and the nitrogen containing compounds nitrate (NO_3^-), nitrite (NO_2^-), and ammonia (NH_3). However, total phosphorus and total nitrogen, which include all inorganic (i.e., phosphate, nitrate, nitrite, ammonia) and organic forms of phosphorus and nitrogen, are also frequently measured in aquatic ecosystems (refer to discussion in Section 6.2). Nutrients are found naturally in aquatic ecosystems, but high concentrations relative to reference conditions can be detrimental to the health and functioning of aquatic ecosystems. High concentrations of nutrients in streams can result from different types of sources, including but not limited to: wastewater treatment plant effluents; industrial discharges; wet weather runoff from impervious surfaces in urban or developed areas; wet weather runoff from landscaped areas (e.g., residential lawns, golf courses, athletic fields); wet weather runoff from agricultural or pasture areas, including animal feed lots and animal agricultural manure; discharges from combined stormwater and sanitary sewers; septic systems; or atmospheric deposition (e.g., from fossil fuel combustion) (EPA, 2010c).

Nutrient effects on most non-primary producer aquatic life uses are indirect[1]. Figure 2.1 provides a conceptual model that represents the many processes that may occur between nutrients and macroinvertebrates and that may contribute to impairment of the aquatic life use of the waterbody. Excess nutrients can lead to an increase in primary producers, which can result in excessive primary production. As aquatic vegetation photosynthesizes and respires, levels of DO and pH (acidity) will fluctuate. As primary production increases, the magnitude of DO and pH fluctuations will increase. Excessive primary production caused by nutrient enrichment can lead to excessive fluctuations in DO and pH. Not only can low levels of DO and extreme levels of pH be directly harmful to aquatic life (Welch, 1992 cited in EPA, 2000b), a range of fluctuations in DO and pH levels also can impact the health of aquatic life (EPA, 1986; EPA, 2010a; PADEP 2016a).

Excess nutrients in aquatic ecosystems can also lead to changes in the species assemblages of primary producers. Moreover, changes in primary producer assemblages can result in ecological changes such as changes in food quality (i.e., the nutritional value of a food source to a consumer) and quantity that, in turn, can cause shifts in the types of macroinvertebrates that will thrive (review also Section 7 and Figure 7.1). These intermediate processes can be measured to demonstrate a causal pathway between nutrients and macroinvertebrates. Figure 2.1 also identifies stressors that may co-vary with nutrients such as flow, sediment and toxic pollutant data. These stressors should also be evaluated for their potential to impact macroinvertebrate health (see Section 8 for sediment assessment).

[1] Ammonia can have direct toxic effects on aquatic life.

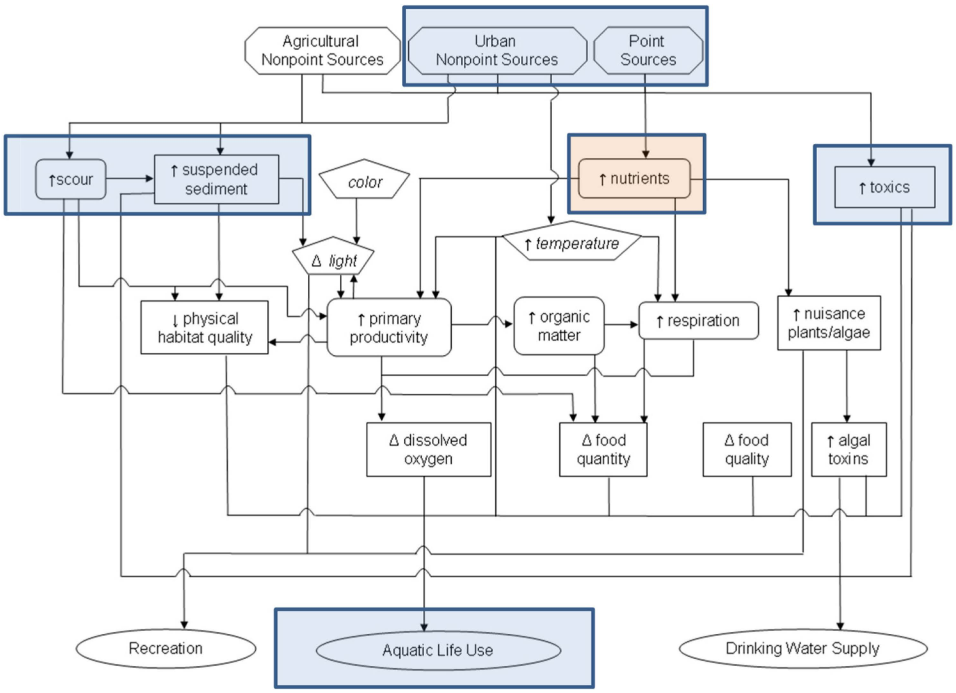

Figure 2.1 Conceptual Model of the Causal Relationship between Nutrients and Responses in Streams (EPA, 2010a)

2.2 Excess Sediments

Excess sediments can have deleterious impacts on aquatic life. Figure 2.2 illustrates many of the sediment related processes that can impact aquatic life. For example, excessive deposited and bedded sediment can alter benthic habitat quality and availability, thus shifting fish and macroinvertebrate communities (Kaller and Hartman, 2004). Changes in land use can affect sediment transport to a stream. Moreover, increased flow to a stream can lead to stream bank erosion, thus magnifying the burden of sediments.

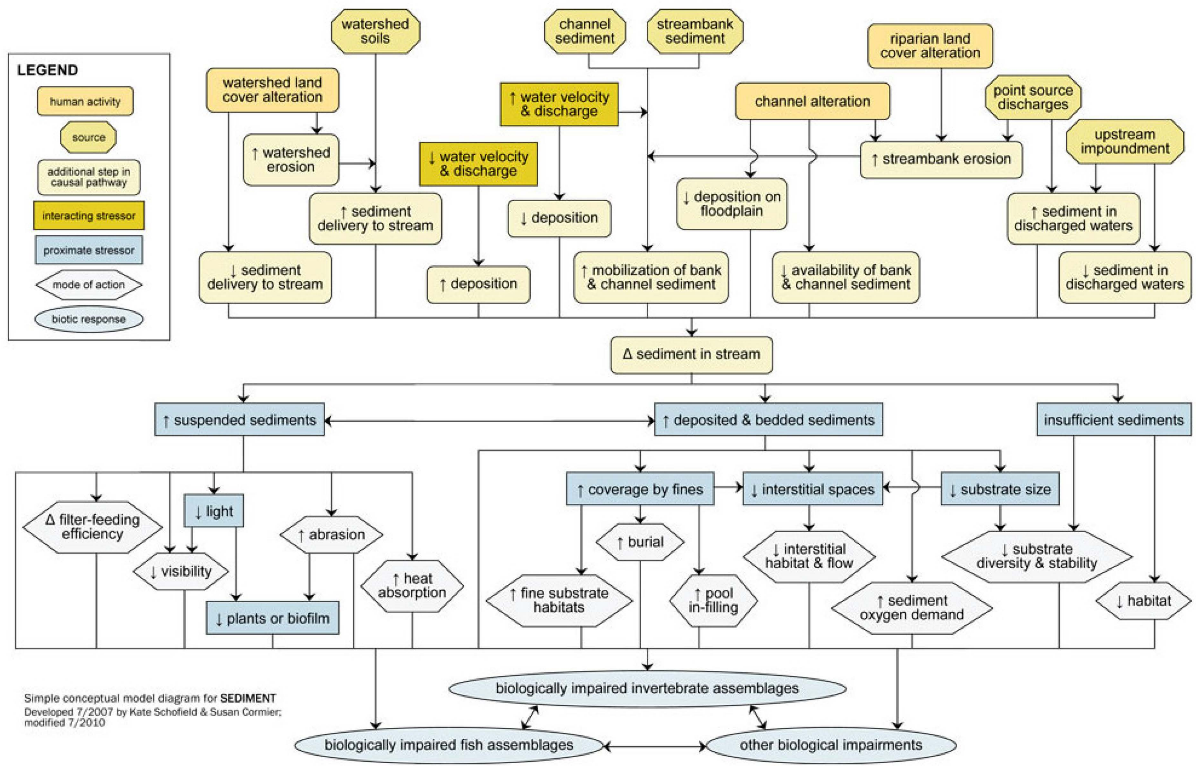

Figure 2.2 Conceptual Model of the Causal Relationship between Sediment and Responses in Streams (Cormier, 2007)

2.3 Other Stressors

As provided in the interim settlement agreement, EPA's reassessment focused on two discreet stressors, nutrients and sediments. While urbanization in a watershed can be associated with additional pollutant loading to its rivers and streams, it is well documented that urbanization increases nutrient loadings (Walsh et al., 2005). WGSA has suggested that urban stream syndrome (USS) may be impacting Goose Creek. USS describes the collective effect of stressors (e.g., increased storm water volume and velocity, increased sedimentation, increased concentrations of toxic substances, increased temperature, etc.) that impact streams, rather than focusing on a particular stressor of concern (Kominkova, 2012). Scientists have also included effluent from sewage treatment plants (STPs) as a stressor associated with USS (Kominkova, 2012). In a system like Goose Creek, it is possible that multiple stressors are impacting aquatic life. That being said, the fact that urbanization can result in multiple other stressors impacting a stream does not nullify the impacts of excessive nutrients or sediments, the agreed-upon focus of this reassessment.

Other potential stressors not studied in this reassessment include, for example, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), metals, bacteria, and chloride.

2.4 Focus of Stressor Analysis

As part of the settlement agreement, EPA agreed to analyze site-specific physical, chemical, and biological factors, based on available data, to determine if the aquatic life use impairment of Goose Creek is caused by nutrients or sediments or some combination thereof. Based on that agreement, this stressor analysis focuses on nutrients and sediment. To determine whether a nutrient or sediment stressor is impairing aquatic life in Goose Creek, EPA assessed the data against applicable numeric and narrative water quality criteria for the parameter that data were collected. For example, water column concentrations of dissolved oxygen were assessed against PADEP's numeric criteria for dissolved oxygen. In the event that a numeric criterion did not exist for a particular parameter, EPA identified suitable thresholds for biological, nutrient, and sediment impairments to assess whether or not the aquatic life use was attained. The biological, nutrient, and sediment assessment methodologies are discussed in Sections 5, 6 and 8, respectively.

EPA acknowledges that to fully restore the aquatic life use in Goose Creek all existing stressors (whether stormwater volume and velocity, sediment or nutrients) must be addressed. Addressing one stressor and not the others will improve water quality but will likely not fully restore the aquatic life use. Therefore, where the data collected suggests additional stressors, EPA has also identified those stressors as needing additional attention to identify and address impairment.

3 Pennsylvania's Water Quality Standards

Water quality standards consist of designated uses for a waterbody and the water quality criteria necessary to protect those designated uses, as well as an antidegradation policy. According to Pennsylvania Water Quality Standards (WQS), the term *water quality criteria* is defined as "numeric concentrations, levels or surface water conditions that need to be maintained or attained to protect existing and designated uses." Water quality standards also include narrative criteria.

3.1 Designated Uses

Pennsylvania Water Quality Standards (25 PA Code Chapter 93, specifically §§ 93.3, 93.4) designate water uses which shall be protected, and upon which the development of water quality criteria shall be based. Pennsylvania designates all state waters (unless specified otherwise) for aquatic life use, potable water supply, and recreation. Potable water supply refers to use by the public as defined by the Federal Safe Drinking Water Act (42 U.S.C.A. § 300f), or by other water users that require a permit from the Department under the Pennsylvania Safe Drinking Water Act (35 P. S. § 721.1—721.18), as well as water supply for wildlife, industry, livestock, and irrigation. Recreation includes water contact recreation (such as swimming and wading), fishing, boating, esthetics, and navigation. Aquatic life uses include the maintenance and propagation of aquatic life, coldwater or warmwater fisheries, and anadromous and catadromous fishes which ascend into flowing waters to complete their life cycle. Table 3.1 shows the specific aquatic life designated uses that apply to the Goose Creek 303(d) listed segments.

Table 3.1 Designated Water Uses of 2016 303(d) Listed Segments

303(d) Listed Segment (Assessment ID)	Stream Name	Designated Water Uses[1,2]	303(d) Impairment	Source	Original Listing Year
19406	Goose Creek (25621322)	WWF, MF, TSF	Cause Unknown	Municipal Point Source	2002
19408	UNT to Goose Creek (25621262)	WWF, MF, TSF	Cause Unknown	Municipal Point Source	2002
19408	UNT to Goose Creek (25621282)	WWF, MF, TSF	Cause Unknown	Municipal Point Source	2002
19408	UNT to Goose Creek (25621286)	WWF, MF, TSF	Cause Unknown	Municipal Point Source	2002
19408	UNT to Goose Creek (25621308)	WWF, MF, TSF	Cause Unknown	Municipal Point Source	2002

[1] According to § 93.9g of the Code of Pennsylvania the following uses apply to Goose Creek: WWF, MF, TSF

[2] WWF - Warm Water Fishes; MF – Migratory Fishes; TSF – Trout Stocking

3.2 Narrative Criteria

Pennsylvania does not have narrative criteria written expressly for nutrients and sediment. Instead, the General Criteria defined in Pennsylvania's WQSs (25 PA Code §93.6) provides narrative water quality criteria necessary to protect designated uses from any substances, including nutrients and sediment, that may interfere with their attainment. The general water quality criteria state:

a) Water may not contain substances attributable to point or non-point source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life.

b) In addition to other substances listed within or addressed by this chapter, specific substances to be controlled include, but are not limited to, floating materials, oil, grease, scum and substances which produce color, tastes, odors, turbidity or settle to form deposits.

3.3 Numeric Criteria

Pennsylvania does not have numeric criteria written expressly for nutrients and sediment. Pennsylvania does have numeric water quality criteria (25 PA Code §93.7) for certain water quality parameters related to nutrient (nitrogen and phosphorus) influences, as well as for the nitrogen-containing compounds ammonia and nitrate. The following numeric criteria apply to Goose Creek to protect aquatic life uses:

pH

From 6.0 to 9.0 inclusive

Dissolved Oxygen

For the period February 15 to July 31 of any year, 7-day average 6.0 mg/L; minimum 5.0 mg/L. For the remainder of the year, 7-day average 5.5 mg/L; minimum 5.0 mg/L.

Ammonia

The ammonia criteria are designed to protect aquatic life from direct toxic effects of elevated ammonia concentrations. The acute criterion and chronic criterion are represented below.

"The maximum total ammonia nitrogen concentration (in mg/L) at all times shall be the numerical value given by un-ionized ammonia nitrogen (NH_3-N) x ($\log^{-1}[pK_T - pH] + 1$), where:

un-ionized ammonia nitrogen = 0.12 x f(T)/f(pH), $f(pH) = 1 + 10^{1.03(7.32-pH)}$, f(T) = 1, $T \geq 10°C$, $f(T) = (1 + 10^{(9.73-pH)}) / (1 + 10^{(pK_T-pH)})$, T ‹ 10°C, , and pKT = 0.090 +[2730 / (T+273.2)], the dissociation constant for ammonia in water."

"The average total ammonia nitrogen concentration over any 30 consecutive days shall be less than or equal to the numerical value given by: un-ionized ammonia nitrogen (NH_3-N) * ($\log^{-1}[pK_T - pH] + 1$), where:

un-ionized ammonia nitrogen = 0.025 x f(T)/f(pH), f(pH) = 1, $pH \geq 7.7$, $f(pH) = 10^{0.74(7.7-pH)}$, pH ‹ 7.7, f(T) = 1, $T \geq 10°C$, $f(T) = (1 + 10^{(9.73-pH)})/(1 + 10^{(pKT-pH)})$, T ‹ 10°C"

The pH and temperature used to derive the appropriate ammonia criteria shall be determined by one of the following methods:

1) Instream measurements, representative of median pH and temperature—July through September.

2) Estimates of median pH and temperature—July through September—based upon available data or values determined by the Department.

Nitrate/Nitrite

The nitrate/nitrite numeric criterion protects the potable water supply use. Chapter §96.3(d) provides that the water quality standard for nitrite-nitrate nitrogen for the protection of potable water supply be applied at the closest existing or planned public water supply. While there is not a drinking water withdrawal on Goose Creek, there is one downstream on Chester Creek.

Maximum 10 mg/L as nitrogen

3.4 Pennsylvania's Impairment Cause Definitions

Pennsylvania's 2013 *Assessment and Listing Methodology for Integrated Water Quality Monitoring and Assessment Reporting* includes the Commonwealth's cause definitions for water quality impairments. Pennsylvania applies the cause definitions in its assessment methodology to assign causes to an impairment (PADEP, 2013b). Although the cause definitions are not WQS (because they are not applied to determine *if* a waterbody is impaired), they can be informative in interpreting Pennsylvania's narrative criteria. The cause definitions for nutrients and siltation (sediment) are:

> Nutrients – presence of excessive daily fluctuations in dissolved oxygen and pH caused by high primary production resulting from elevated levels of phosphorus and/or nitrogen. Biological impairment may occur based on general (narrative) criteria violations. Accompanying violations of 93.7 specific water quality criteria for dissolved oxygen or pH are not required.
>
> Siltation – aggradation of sediments or soils in excess of what the stream channel can transport. Results in smothering of streambed habitat for macroinvertebrates and fishes (PADEP, 2013b).

Because Pennsylvania does not have numeric criteria for nutrients and sediment, EPA interpreted Pennsylvania's narrative criteria by identifying suitable thresholds for biological, nutrient, and sediment impairments to assess whether or not the aquatic life use was attained. The biological, nutrient, and sediment assessment methodologies are discussed in Sections 5, 6, and 8, respectively.

3.5 Water Quality Standards Implementation

Pennsylvania's Code includes 25 §96.3:

> (c) To protect existing and designated surface water uses, the water quality criteria described in Chapter 93 (relating to water quality standards), including the criteria in §§ 93.7 and 93.8a(b) (relating to specific water quality criteria; and toxic substances) shall be achieved in all surface waters at least 99% of the time, unless otherwise specified in this title. The general water quality criteria in §93.6 (relating to general water quality criteria) shall be achieved in surface waters at all times at design conditions.
>
> (d) As an exception to subsection (c), the water quality criteria for total dissolved solids, nitrite-nitrate nitrogen, phenolics, chloride, sulfate and fluoride established for the

protection of potable water supply shall be met at least 99% of the time at the point of all existing or planned surface potable water supply withdrawals unless otherwise specified in this title.

4 Data Collection

In order to aid in its reassessment determination, EPA published a data solicitation in the daily local newspaper, on EPA's website, and by email to stakeholders. Interested parties were invited to submit relevant data from June 25, 2014 to September 1, 2015. EPA received data from WGSA and PADEP, and EPA considered that data in its reassessment decision. Table 4.1 shows the types of data that were received, and Figure 4.1 shows the study area along with the STPs and PADEP and WGSA sampling sites. PADEP sampled in three locations: PADEP-1 is located upstream of both West Chester Borough STP and WGSA STP, PADEP-2 is located downstream of both STPs, and PADEP-3 is far downstream near the confluence of Chester Creek. WGSA sampled in 6 locations: WGSA-1 and WGSA-2 are upstream of the STPs, WGSA-4 is downstream of West Chester Borough STP and upstream of WGSA, WGSA-5 is directly downstream of WGSA, WGSA-7 is downstream, and WGSA-10 is far downstream after a tributary has entered Goose Creek and before the confluence of Goose Creek and Chester Creek.

Table 4.1 Sampling Conducted in Goose Creek from 2013-2015

WGSA	**PADEP**
Continuous water quality data (DO, pH, temperature, conductivity)	Continuous water quality data (DO, pH, temperature, conductivity)
Physical habitat	Physical habitat
Macroinvertebrates	Macroinvertebrates
Visual algal survey	Benthic algal biomass
Discrete water quality data	Discrete water quality data
Pebble count (reference stream)	Pebble count
Benthic algal biomass	Algal toxicity
Algal taxa	Fish
	Sediment (pesticides, metals, etc.)

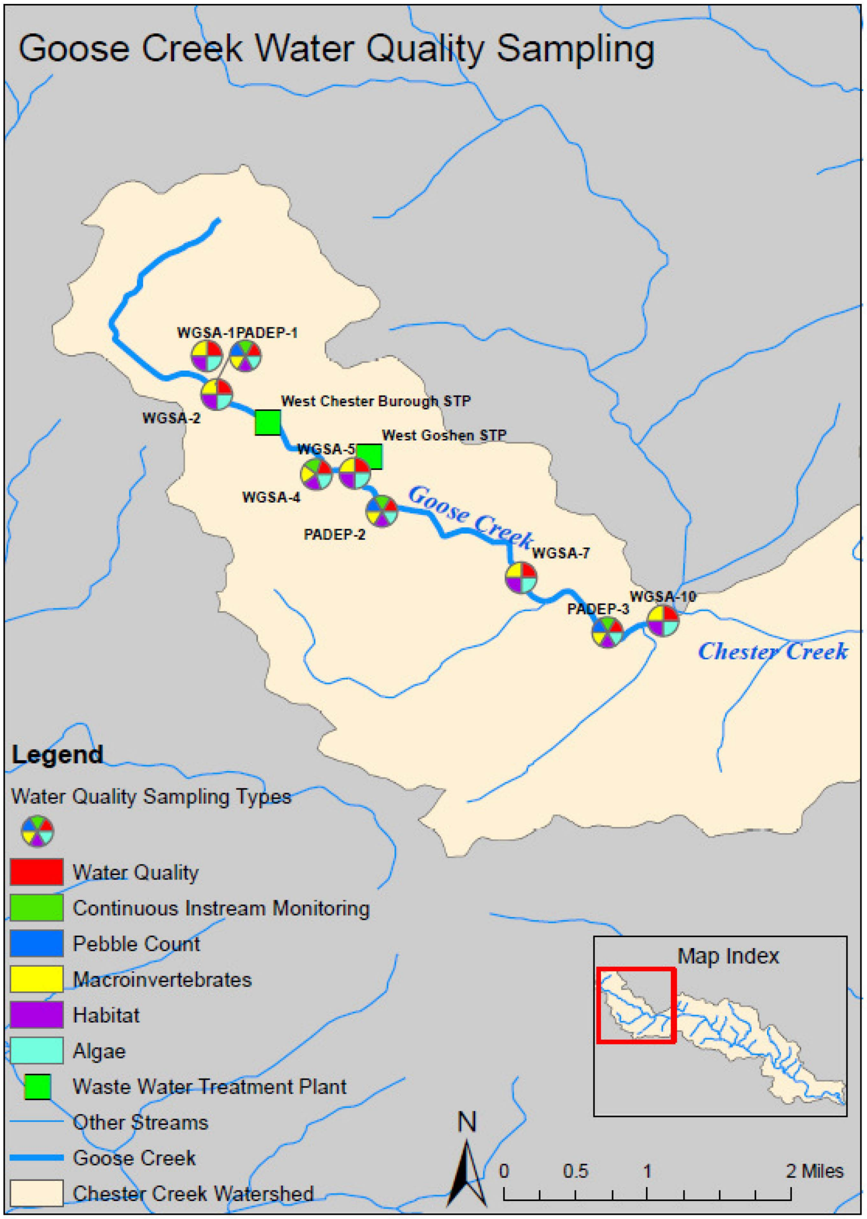

Figure 4.1 Sampling Locations in Goose Creek.

4.1 Quality Assurance

WGSA submitted a quality assurance project plan (QAPP) to EPA in the spring of 2014 prior to conducting Goose Creek sampling. EPA's Quality Assurance (QA) unit in Ft. Meade, MD reviewed WGSA's QAPP. PADEP has a Quality Management Plan (QMP) that outlines a quality system to ensure quality data are collected throughout its water monitoring and assessment programs. PADEP's QMP is updated and submitted to EPA for approval every five years. EPA approved PADEP's most recent QMP on April 22, 2016. PADEP's previous QMP was approved by EPA on January 7, 2011.

PADEP's Continuous Instream Monitoring Protocol (PADEP, 2015a) outlines QA procedures for calibration of water quality monitoring sondes[2], field measurements to ensure accuracy and post deployment data evaluation. PADEP modeled their thorough protocols after U.S. Geological Survey (USGS) protocols for collecting and analyzing continuous monitoring data. USGS has a long standing history of collecting continuous monitoring data and is viewed as a leader in continuous water quality data collection. PADEP has robust QA procedures for continuous monitoring data to ensure any assessment decisions are made based on reliable information. EPA supports PADEP's application of its thorough Continuous Instream Monitoring Protocol.

WGSA placed a sonde at WGSA-4. WGSA cleansed their sonde data using a method described in Appendix B of their report, which differed from the method PADEP used to cleanse its sonde data.

EPA staff accompanied GHD Services, Inc. (GHD) staff on August 28, 2014 Goose Creek algal sampling. EPA noted that while GHD staff handled rocks collected for algal sampling and visual analysis, GHD staff rinsed rocks with site water to aid in visual algal analysis. Rinsing rocks prior to algal biomass and taxonomy sampling has potential to alter sampling results by dislodging some algae types and may skew results. In addition, GHD staff manipulated by hand the plant growth on rocks for visual identification prior to algal biomass and taxonomy sampling. This manipulation could have altered results by dislodging some alga types. After several verbal requests to GHD staff at multiple stations, sampling techniques on that date improved and algal biomass and taxonomy samples were collected prior to rocks being rinse or manipulated for visual analysis.

During analysis of WGSA supplied water chemistry data, GHD noted that July 10, 2014 TKN field blank when analyzed had a value of 1.47 mg/L. Due to the potential of sample contamination, EPA did not use the TKN and TN (TN is a summation of TKN (ammonia N + organic N), and nitrate/nitrite N) data from July 10, 2014 for nitrogen analysis. When WGSA reported data as <x, where x is a number, for any nitrogen species, or for total phosphorus only on 4/23/2015, this number was included in the data tables and figures in Sections 6.2.2 and 6.2.3. For example, where ammonia data was reported as <0.10 the number 0.10 was included in the data tables and figures (see Table 6.6).

5 Biological Impairment Assessment Methodology and Results

5.1 Biological Impairment Assessment Methodology

Aquatic life use attainment can be assessed using biological indicators present in that system. Such biological monitoring offers the ability to assess long-term, cumulative effects of many types of ecosystem stress, including stress related to chemical and physical habitat factors

[2] Sondes are probes that are deployed in a stream to collect data on a defined time interval.

(PADEP, 2012). Benthic macroinvertebrates are widely used biological indicators because of their limited mobility, abundance, known pollution tolerances, importance as a food source for fish, and ease of sampling, among other reasons (Barbour et al., 1999). One method to assess benthic macroinvertebrate data is through an index of biotic integrity (IBI), which combines multiple benthic macroinvertebrate metrics to calculate a single score which is compared to a reference condition to determine whether the aquatic life use is attained. PADEP has developed "A Benthic Macroinvertebrate Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania" (freestone IBI) to assess the composition of benthic macroinvertebrate communities in Pennsylvania's wadeable, riffle-run streams. This method was developed with input from EPA biologists, had a public comment period and is consistent with EPA guidance (PADEP, 2012; Barbour et al. 1999).

EPA used PADEP's freestone IBI to assess the aquatic life use attainment of Goose Creek. Specifically, EPA used the small stream IBI scores to determine whether or not there is a biological impairment in Goose Creek consistent with PADEP's impairment thresholds for IBI scores.

The freestone method is appropriate to assess Goose Creek because Goose Creek has the structural components of a wadeable, riffle-run stream. The small stream IBI was used because Goose Creek drains 8 square miles, which meets the requirements of a small watershed – defined as a watershed that drains less than 25 square miles. The freestone method collects macroinvertebrates in riffle-run habitats using a D-frame kick net with a 500-micron mesh. Macroinvertebrate samples are subsampled to 200 individuals ±40 and are identified to the genus level for most taxa. Six metrics are calculated for each site: total taxa richness, Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness, Beck's index, Hilsenhoff biotic index, Shannon diversity index, and percent sensitive individuals. These metrics are standardized to either small or large streams to account for changes in benthic biota with stream size. The standardized scores are combined to calculate the IBI score. When samples are collected from June – September, the impairment threshold is an IBI score less than 43, whereas when samples are collected in November – May, the threshold is less than 50 (PADEP, 2013f).

PADEP and WGSA collected macroinvertebrate samples that were used to calculate small stream IBI scores. PADEP collected samples in September 2013, therefore the IBI threshold for impairment of <43 was used. On the other hand, WGSA collected macroinvertebrate samples in December, for which the IBI threshold for impairment is<50 (PADEP, 2013f).

5.2 Biological Impairment Assessment Results

Results of the biological sampling are shown below in Table 5.1, with stations listed from upstream to downstream. All IBI scores for the PADEP and WGSA samples were below the attainment threshold, which indicated that the aquatic life, as assessed by the health of benthic macroinvertebrate communities, is impaired in Goose Creek. IBI scores from the December sampling date slightly improved farther downstream of the WGSA discharge, however the difference in scores is negligible and may be attributed to improved habitat (refer to Section 8.2 for more information on habitat scores). Even with improved habitat, IBI scores remain almost

20 points below the impairment thresholds, indicating that the improved habitat was not enough to negate the other stressors on macroinvertebrates. Additionally, IBI scores from macroinvertebrates collected in September were very similar throughout the watershed. This suggests that the macroinvertebrates do not improve downstream of the WGSA discharge. Overall, the analysis of the IBI scores shows macroinvertebrates are impaired in Goose Creek and as such, the aquatic life use is not attained.

Table 5.1 Goose Creek IBI Scores

Sample Date	Site	Small Stream IBI Score	Impairment Threshold	Impaired?
12/16/14	WGSA-1	20.3	<50	Y
9/20/13	PADEP- 1	25.7	<43	Y
12/16/14	WGSA-2	21.5	<50	Y
12/16/14	WGSA-4	25.5	<50	Y
12/16/14	WGSA-5	22.4	<50	Y
9/19/13	PADEP- 2	25.8	<43	Y
12/16/14	WGSA-7	27.2	<50	Y
9/19/13	PADEP- 3	26.8	<43	Y
12/16/14	WGSA-10	25.9	<50	Y

6 Nutrient Assessment Methodologies and Results

6.1 Nutrient Impairment Assessment Methodology

EPA evaluated multiple lines of evidence to assess whether the impairment of aquatic life use in Goose Creek is caused, at least in part, by nutrients. EPA first determined if nutrient concentrations (total phosphorus (TP), total nitrogen (TN), nitrate, and ammonia) were elevated (Section 6.2 below). Nutrient data was compared with values from EPA TP endpoint analyses in the same ecoregion as Goose Creek (refer to Paul and Zheng, 2007 and Paul et al., 2012; also review Section 6.2), EPA recommended reference criteria guidance, peer-reviewed scientific literature, and PADEP's numeric water quality standards for nitrate and ammonia. If there were nutrient levels elevated above thresholds (Section 6.2), EPA then determined whether those elevated levels caused:

1) High primary production by looking at periphyton biomass[3], relationships between nutrient levels and periphyton biomass, an algal taxonomy assessment, a visual algal survey, and an analysis of algal toxicity and biostimulation (Section 6.3 below)
2) exceedances of numeric criteria in PADEP's water quality standards for DO and pH, (Section 6.4 below)

[3]Periphyton are associated aquatic organisms attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the bottom of a water body (EPA 2000b).

3) the presence of excessive daily fluctuations or swings in DO and/or pH (Sections 6.4 and 7 below)

Each of these factors was considered individually to assess if numeric criteria (established by Pennsylvania for DO and pH) or thresholds (where Pennsylvania numeric criteria did not exist) were exceeded. Additional lines of evidence not discussed above that were evaluated include an analysis of tolerant macroinvertebrate taxa (Section 6.5). These factors were then considered together to assess if the narrative criteria were not being met. EPA considered the full breadth of this evidence – that is, exceedances of numeric criteria and thresholds and exceedances of the narrative criteria – to make a determination of impairment.

6.2 Nutrient Concentration Assessment Methodology and Results

The first step of the nutrient impairment assessment is to determine if nutrient concentrations (total phosphorus (TP), total nitrogen (TN), nitrate, and ammonia) were elevated. EPA selected TP and TN for the analysis of elevated nutrient levels because they provided a more complete picture of phosphorus and/or nitrogen available for primary production in the stream than dissolved inorganic P or N. The latter excludes organic and particulate P or N, thereby underestimating available P or N which may be available for primary production (EPA, 2000b; Paul and Zheng, 2007). PADEP has not adopted numeric nutrient criteria to protect aquatic life. Therefore, to make the determination that nutrients were elevated, EPA compared nutrient data to threshold values from EPA TP endpoint analyses in the same ecoregion as Goose Creek (refer to Paul and Zheng, 2007 and Paul et al., 2012; also Table 6.1 and Section 6.2 of this report), EPA recommended reference criteria guidance, peer-reviewed scientific literature, and Pennsylvania's numeric water quality standards for nitrate and ammonia. Additionally, EPA compared the nutrient data received from WGSA and PADEP (refer to Sections 6.2.1, 6.2.3) with values of nutrient levels that would control periphyton growth as demonstrated in several peer-reviewed studies and a mechanistic model in an EPA analysis (Sections 6.2.5 and 6.2.6 and Table 6.7). Table 6.1 presents a summary of nutrient thresholds considered in this assessment.

Table 6.1 Threshold values used for nutrient assessment.

		TP (mg/L)	TN (mg/L)	Nitrate/ Nitrite (mg/L)	Ammonia (mg/L)		Source
					Acute	Chronic	
Criteria							
	PA numeric criteria			10	7.327 PADEP-1 9.760 PADEP-2 6.539 PADEP-3	1.600 PADEP-1 1.932 PADEP-2 1.476 PADEP-3	25 PA Code Chapter 93
Reference Approach							
	Reference Site 75th Percentile	0.016-0.017	1.3-1.5				Paul and Zheng, 2007

	All Sites 25th Percentile	0.017	1.5	Paul and Zheng, 2007
	Modeled Reference Expectation	0.002-0.037	0.260	Paul and Zheng, 2007
Stressor-Response	Conditional Probability – EPT taxa	0.038		Paul and Zheng, 2007
	Conditional Probability – Percent Clingers	0.039		Paul and Zheng, 2007
	Conditional Probability – Percent Urban Intolerant	0.064		Paul and Zheng, 2007
	Conditional Probability – Diatoms TSI	0.036		Paul and Zheng, 2007
	Simple linear regression interpolation – EPT taxa	0.010-0.085		Paul et al., 2012
	Simple linear regression interpolation – Percent intolerant urban individuals	0.008-0.082		Paul et al., 2012
	Simple linear regression interpolation – Percent clinger individuals	0.008-0.052		Paul et al., 2012

Literature				
	EPA Recommended Regional Reference Criteria-Nutrient Level III Ecoregion IX	0.03656	0.692	EPA, 2000a
	EPA Recommended Regional Reference Criteria- Nutrient Level IV Ecoregion 64 Northern Piedmont	0.040	2.225	EPA, 2000a
	New Jersey Northern Piedmont Ecoregion	0.051	1.28	Ponader and Charles, 2003
	Reference Criteria Study for Nutrient Level III Ecoregion IX	0.060	0.681	Herlihy and Sifneos, 2008
	National Nutrient Criteria Study	0.013-0.020	0.375-0.500	Rohm et al., 2002 and Paul and Zheng, 2007
	USGS Regional Reference Study	0.020		Robertson et al., 2001 cited in Paul and Zheng, 2007
	Virginia stream diatom assemblage study	0.050	0.500	Ponader et al., 2005 cited in Paul and Zheng, 2007

NJ streams BCG for diatom assemblages	0.050		Hausmann et al., 2016
New Jersey TDI	0.025-0.050		Ponader et al., 2005 cited in Paul and Zheng, 2007
New England Nutrient Criteria Study	0.040	0.800	ENSR, 2003 cited in Paul and Zheng, 2007
Algal growth saturation	0.025-0.050		Horner et al., 1983 and Bothwell, 1989, both cited in Paul and Zheng, 2007
Delaware 303(d) Listing Criteria	0.1-0.2	2-3	DNREC, 2015

6.2.1 Total Phosphorus

To determine if total phosphorus levels were elevated, EPA directly compared TP data received from WGSA and PADEP to thresholds developed from EPA analyses that derived TP endpoints in the Northern Piedmont ecoregion of southeastern Pennsylvania to protect aquatic life uses. Goose Creek is part of the Northern Piedmont ecoregion. In addition, the TP data were also compared with thresholds in EPA-recommended ecoregional criteria guidance and peer-reviewed scientific literature (Table 6.1). Each threshold considered in this analysis (Table 6.1) was one line of evidence, and all lines of evidence were considered to determine a minimum and maximum threshold of TP. No single line of evidence was considered more important than another.

TP Thresholds Derived from EPA Analyses

The EPA analyses discussed in this section were developed by the EPA contractor Tetra Tech for the TMDL endpoint document “Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application” (Paul and Zheng, 2007) and the TMDL endpoint follow-up analysis document "Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application Follow-up Analysis" (Paul et al., 2012). Several of the EPA-recommended ecoregional criteria and peer-reviewed scientific literature are also discussed in these TMDL endpoint documents. Pennsylvania does not have numeric criteria for nutrients. The purpose of the 2007 endpoint document (Paul and Zheng, 2007) was to establish endpoints for TMDLs that were being established to protect aquatic life uses in several streams in the Northern Piedmont ecoregion of southeastern Pennsylvania impaired by nutrients. To develop endpoints Tetra Tech used a multiple (17) approaches (lines of evidence) that included frequency distribution based analysis, stressor-response analysis, and literature based values. Then, a weight-of-evidence selection process was applied to these 17 lines of evidence to develop an endpoint value of 0.040 mg/L (40 µg/L) TP, EPA's chosen target in the TMDLs.

In this reassessment report analysis EPA is not using this target value of 0.040 mg/L TP as a threshold value for nutrient assessment (see Table 6.1). Rather, EPA is using the individual endpoints developed as the 17 lines of evidence as threshold values for nutrient assessment, among other potential threshold values. The 2012 follow-up analysis document (Paul et al., 2012) updated and affirmed the 2007 document in response to new EPA guidance (EPA, 2010) and added 4 new analyses and one new literature value to the original 17 lines of evidence. The new analyses are also used as threshold values for nutrient assessment in this reassessment report. See Section 11.1 for a thorough discussion of these documents and their analyses.

TP endpoints derived from EPA analyses targeted to the Northern Piedmont ecoregion of southeastern Pennsylvania included: a frequency distribution-based approach (also called the reference approach); a modeled reference expectation approach; and, a stressor response analysis (refer to Paul and Zheng, 2007 and Paul et al., 2012 and sources therein for a discussion of these methods). These analyses were considered as lines of evidence, along with several other sources (Table 6.1), to determine minimum and maximum thresholds for TP. The analyses are valuable because they are based on the ecoregion that Goose Creek falls within, the Northern Piedmont ecoregion of southeastern Pennsylvania, and several of the analyses derived TP endpoints based on aquatic life use indicator response variables. The frequency distribution-based approach relies on percentiles calculated from TP concentrations in water quality samples. This method is recommended and thoroughly explained in EPA (2000b). There are two methods to apply the frequency distribution-based approach, based on whether or not data from reference sites are available. If sufficient reference site data is available, a 75th percentile of data (i.e., TP concentrations in water quality samples) from reference sites can be calculated to estimate an endpoint. If sufficient reference site data is not available a 25th percentile of data from all sites for which data is available (which could include reference sites and degraded or impaired sites) can be calculated. Paul and Zheng (2007) calculated a 75th percentile of TP concentration from samples collected from sites where reference criteria (refer to Paul and Zheng, 2007) could be applied. A 25th percentile of TP concentration was calculated from samples collected from all sites where nutrient data was available. The reference site 75th percentile produced TP endpoints from 16-17 µg/L (0.016-0.017 mg/L) and the all sites 25th percentile calculation produced a TP endpoint of 17 µg/L (0.017 mg/L).). The modeled reference expectation approach produced TP endpoints from 2-37 µg/L (0.002 to 0.037 mg/L). The stressor response approach used two analytical techniques to derive TP endpoints based on 4 aquatic life use indicator response variables (refer to Table 6.1, Paul and Zheng, 2007, Paul et al., 2012). The stressor response approach derived TP endpoints ranging from 8-85 µg/L (0.008 to 0.085 mg/L) (Table 6.1).

TP Thresholds from EPA-recommended Ecoregional Criteria Guidance

The TP thresholds in EPA-recommended ecoregional criteria guidance are 36.56 µg/L (0.03656 mg/L) TP for Nutrient Level III Ecoregion IX and 40 µg/L (0.040 mg/L) TP for the Northern Piedmont Nutrient Level Ecoregion 64, both based on 25th percentiles (EPA, 2000a; Table 6.1). The Northern Piedmont Nutrient Level IV Ecoregion is one specific ecoregion within the larger aggregate Nutrient Level III Ecoregion IX. Goose Creek falls within the Northern Piedmont Nutrient Level IV ecoregion.

TP Thresholds from Peer-reviewed Scientific Literature

In the Northern Piedmont ecoregion of New Jersey, Ponader and Charles (2003) (also cited in Paul and Zheng, 2007) estimated a TP threshold of 51 µg/L (0.051 mg/L) TP, similar to the EPA recommended value for the Northern Piedmont ecoregion. Herlihy and Sifneos (2008) (also cited in Paul et al., 2012) estimated reference stream nutrient concentration criteria upper quartiles, a method recommended in EPA (2000b) guidance, based on nutrient data collected as part of the EPA Wadeable Streams Assessment (WSA). They estimated a 75th percentile TP concentration of 60 µg/L (0.060 mg/L) in reference streams for Nutrient Level III Ecoregion IX. Rohm et al. (2002) (cited in Paul and Zheng, 2007), as part of a national study which presented a method for developing potential regional reference conditions and nutrient endpoints, used EMAP data from the Central and Eastern Forested Uplands area which includes much of central Pennsylvania and found that 13 µg/L (0.013 mg/L) TP could be used as a nutrient endpoint. Paul and Zheng (2007) state that a concentration of 20 µg/L (0.020 mg/L) TP can be given as a "rough estimate from the data presented for their Region IX that includes Eastern Pennsylvania."

A USGS study for "a broad area of the US," that included the New River and Big Sandy River in Virginia found that TP of 20 µg/L (0.020 mg/L) could be applied to an area the authors define as Environmental Nutrient Zone 2 based on the reference approach (Robertson et al., 2001 cited in Paul and Zheng, 2007). Ponader et al. (2005) (cited in Paul and Zheng, 2007) suggested a TP threshold not to exceed 50 µg/L (0.050 mg/L) would prevent nutrient impairment based on a study of diatom assemblages in streams in Virginia. Similarly, based on a biological condition gradient assessment of diatom assemblages in New Jersey streams, Hausmann et al. (2016) states that TP criteria should be no higher than a value of 50 µg/L (0.050 mg/L) to "better protect the ecological integrity of streams and rivers in NJ." Another study based on a trophic diatom index (TDI) in New Jersey found that TP below 25 µg/L (0.025 mg/L) would produce a low, protective TDI value while a range from 75 µg/L (0.075 mg/L) to 100 µg/L (0.100 mg/L) would produce a high TDI value (Ponader et al., 2005 cited in Paul and Zheng, 2007). The same authors also found that TP above 50 µg/L (0.050 mg/L) would be high enough to produce nuisance algal growth within this region. ENSR (2003) (cited in Paul and Zheng, 2007), in an endpoint study of rivers in New England, used more than one approach to suggest that based on the weight-of-evidence a TP of 40 µg/L (0.040 mg/L) would be an upper boundary where impaired aquatic community status is being approached. Delaware lists water segments on the Section 303(d) list in Category 5 (impaired) based on lower confidence limits of station-averaged TP concentrations (sampling event days ≥ 10) if TP levels exceed the maximum of the target value of 100-200 µg/L (0.1-0.2 mg/L) TP (DNREC, 2015). Delaware has revised these targets from previous listing requirements that relied on an exceedance of the minimum value of the target 50-100 µg/L (0.05-0.10 mg/L) TP.

In artificial streams algal growth was saturated (achieved maximum growth rate) at 25-50 µg/L (0.025-0.050 mg/L) phosphorus (Horner et al., 1983, Bothwell, 1989, both cited in Paul and Zheng, 2007). Dodds and Welch (2000) (also cited in Paul and Zheng 2007) found that a TP of 55 µg/L (0.055 mg/L) when using a nationwide dataset, or a TP of 21 µg/L for a detailed, smaller, local dataset, would control periphyton biomass (refer to discussion in Section 6.2.5). Similarly, Paul et al. (2012) applied a mechanistic model developed for Indian Creek (also in the Northern Piedmont ecoregion of southeastern PA) and found that average benthic chlorophyll a levels of about 100 mg/m^2 Chl-a are predicted when TP concentrations are between 20 and 33 µg/L (0.020-0.033 mg/L) in Indian Creek (Section 6.2.5). Dodds et al. (1998) analyzed published data for temperate streams to determine endpoints for trophic boundaries. They found that the boundary between mesotrophic and eutrophic streams, determined by the upper third of a cumulative distribution of the values from the streams, is represented by 75 µg/L TP (0.075 mg/L).

The thresholds discussed above range from a TP threshold of 2 to 200 µg/L (0.002 to 0.200 mg/L) TP[4]. EPA will assess the TP data against this range of threshold values for TP to determine if TP is elevated in the stream.

6.2.2 Results of Assessment of Phosphorus Levels

As discussed in Section 6.2.1, EPA compared TP data collected by WGSA and PADEP against a TP threshold range of 0.002-0.200 mg/L (2-200 µg/L). Figure 6.1 presents concentrations of TP and dissolved orthophosphorus (the major component of TP in these data) averaged for each station over multiple sampling dates compared to the threshold minimum and maximum. Tables 6.2 and 6.3 show concentration data for TP and orthophosphorus, respectively. Values highlighted in yellow indicate an exceedance of 0.002 mg/L and values highlighted in red indicated an exceedance of 0.200 mg/L. It is evident from Figure 6.1, Tables 6.2 and 6.3 that the upper bound of the TP threshold is exceeded most of the time throughout Goose Creek. In fact, the upper TP threshold is always exceeded downstream of the STPs. Average TP concentrations increase to over 6 times the upper threshold at WGSA-4, which is downstream of West Chester Borough STP. WGSA-5, which is directly downstream of WGSA STP, has average measured

[4] The purpose of this document is to assess whether or not Goose Creek is impaired for nutrients and/or sediments. One part of assessing nutrient impairment in this document is to determine if nutrient (total phosphorus, total nitrogen, nitrate, ammonia) levels are elevated. For the purposes of assessing elevated nutrient levels the range of TP endpoints discussed in the text of this document, as opposed to a weighting process to select one endpoint, is sufficient. A range allows analysis of a wider interval of endpoints that describe impairment, which will capture potential impairment without requiring the application of a stringent weighting analyses to assign more or less significance to different endpoints.

concentrations of TP as high as 9 times the upper threshold. At all stations the largest fraction of TP is dissolved orthophosphorus, which is readily available for algal uptake (Bostrom, Persson, and Broberg, 1988). All stations except WGSA-2 would be considered eutrophic based on exceedance of the Dodds et al. (1998) 75 µg/L (0.075 mg/L) TP threshold, though WGSA-2 closely approaches this threshold at 0.072 mg/L (Figure 6.1; Table 6.2). All of this evidence indicates that TP and orthophosphorus are unambiguously elevated in Goose Creek and that the STPs are significantly contributing phosphorus to the stream.

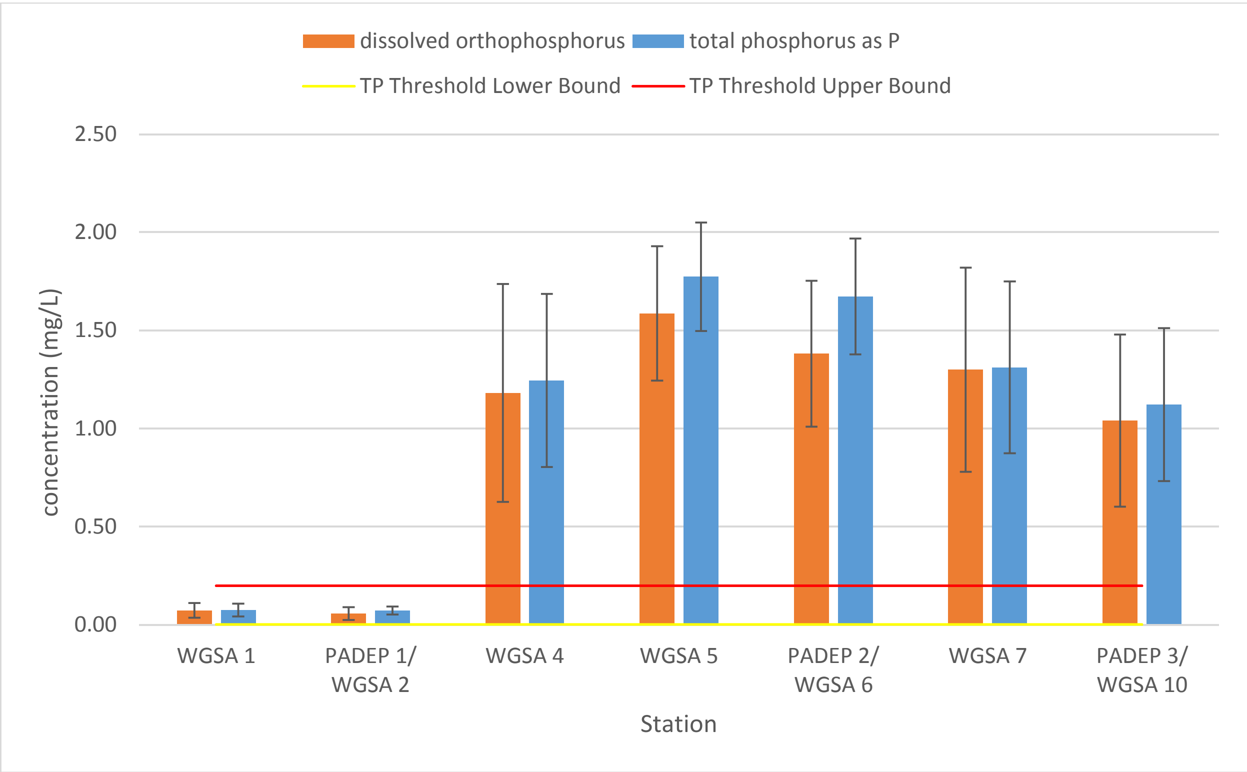

Figure 6.1 Average concentrations (mg/L) of inorganic and total phosphorus by station. Error bars are 1 standard deviation from mean.

Table 6.2 Total phosphorus (mg/L) concentrations collected by PADEP and WGSA.

		Station						
Date Collected	Collected By	WGSA 1	PADEP 1 / WGSA 2	WGSA 4	WGSA 5	PADEP 2 / WGSA 6	WGSA 7	PADEP 3 / WGSA 10
4/14/2014	PADEP		0.078			1.792		0.942
5/6/2014	PADEP		0.057			1.156		0.586
6/9/2014	PADEP		0.051			1.572		1.018
6/19/2014	PADEP		0.122			1.515		0.754
6/23/2014	PADEP		0.062			1.438		0.895
7/9/2014	PADEP		0.081			1.591		0.953
7/17/2014	PADEP		0.083			1.33		0.86
8/19/2014	PADEP		0.081			1.957		1.464
9/24/2014	PADEP		0.072			2.104		1.782
10/15/2014	PADEP		0.084			2.02		1.791
10/20/2014	PADEP		0.093			1.854		1.444
11/12/2014	PADEP		0.079			1.957		1.646
12/17/2014	PADEP		0.053			1.464		1.124
5/29/2014	WGSA	0.06	0.04	1.13			1.20	0.88
6/12/2014	WGSA	0.15	0.09	1.00			1.01	0.97
6/26/2014	WGSA	0.07	0.06	0.72			0.84	0.56
7/10/2014	WGSA			1.70			1.28	1.02
7/24/2014	WGSA	0.08	0.09	1.055**			0.59	0.54
8/6/2014	WGSA	0.09	0.05	1.05			1.46	1.17
8/21/2014	WGSA	0.07		1.52	1.82		1.60	1.36
9/4/2014	WGSA	0.08		1.76	1.86		1.66	1.42
9/18/2014	WGSA	0.07		1.67	2.08		1.89	1.69
10/2/2014	WGSA	0.05		1.65	2.04		1.85	1.56
10/16/2014	WGSA	0.10		0.39	1.40		0.60	0.51
10/30/2014	WGSA	0.04		1.65	2.00		1.83	1.44
4/23/2015	WGSA	0.02*		1.43**	1.58		1.18	0.84
5/21/2015	WGSA	0.12		0.71	1.41**		1.37	1.07
Station Average		0.08	0.07	1.25	1.77	1.67	1.31	1.12
st dev		0.03	0.02	0.44	0.28	0.29	0.44	0.39

*reported as <0.02

**differs from value presented in WGSA report because this analysis averaged duplicates submitted by WGSA

Table 6.3 Dissolved orthophosphorus concentrations (mg/L) collected by PADEP and WGSA.

		Station						
Date Collected	Collected By	WGSA 1	PADEP 1 / WGSA 2	WGSA 4	WGSA 5	PADEP 2 / WGSA 6	WGSA 7	PADEP 3 / WGSA 10
4/14/2014	PADEP		0.04			1.479		0.771
5/6/2014	PADEP		0.029			0.806		0.469
6/9/2014	PADEP		0.052			1.337		0.953
6/23/2014	PADEP		0.048			1.229		0.802
7/17/2014	PADEP		0.057			0.849		0.785
8/19/2014	PADEP		0.053			1.523		1.309
9/24/2014	PADEP		0.057			1.84		1.72
10/20/2014	PADEP		0.063			1.697		1.387
11/12/2014	PADEP		0.061			1.861		1.666
12/17/2014	PADEP		0.03			1.194		1.051
5/29/2014								
6/12/2014								
6/26/2014	WGSA	0.08	0.06	0.54			0.74	0.33
7/10/2014	WGSA	0.16	0.16	1.83			1.20	1.03
7/24/2014	WGSA	0.08	0.06	1.06			0.58	0.55
8/6/2014	WGSA	0.07	0.03	0.96			1.39	0.96
8/21/2014	WGSA	0.07		1.28	1.38		1.41	1.10
9/4/2014	WGSA	0.08		1.87	1.845*		1.83	1.45
9/18/2014	WGSA	0.04		1.41	1.82		1.76	1.49
10/2/2014	WGSA	0.12		1.80	2.06		1.99	1.69
10/16/2014	WGSA	0.05		0.27	1.24		0.44	0.26
10/30/2014	WGSA	0.07		1.58	1.84		1.91	1.50
4/23/2015	WGSA	0.04		1.16	1.37		1.16	0.78
5/21/2015	WGSA	0.02		0.42	1.14		1.18	0.84
Station Average		0.07	0.06	1.18	1.59	1.38	1.30	1.04
st dev		0.04	0.03	0.55	0.34	0.37	0.52	0.44

*differs from value presented in WGSA report because this analysis averaged duplicates submitted by WGSA

6.2.3 Total Nitrogen, Nitrate, and Ammonia

To determine if total nitrogen levels were elevated EPA directly compared TN data to thresholds developed from analyses designed to derive TN endpoints in the Northern Piedmont ecoregion of southeastern Pennsylvania to protect aquatic life uses. Goose Creek falls within the Northern

Piedmont ecoregion. In addition, the TN data were also compared to thresholds in EPA-recommended ecoregional criteria guidance and peer-reviewed scientific literature (Table 6.1)[5].

TN Thresholds from EPA Analyses

Analyses targeted to the Northern Piedmont ecoregion of southeastern Pennsylvania for TN included a frequency distribution-based approach (also called the reference approach) and a modeled reference expectation approach (another type of reference approach) (review Paul and Zheng, 2007 and Paul et al., 2012 for a discussion of these methods). The frequency distribution-based approach relies on percentiles calculated from TN concentrations in water quality samples. This method is recommended and explained in EPA (2000b). There are two methods to apply the frequency distribution-based approach, based on whether or not data from reference sites are available. If sufficient reference site data is available a 75th percentile of data (i.e. TN concentrations in water quality samples) from reference sites can be calculated to estimate an endpoint. If sufficient reference site data is not available a 25th percentile of data from all sites for which data is available (which could include reference sites and degraded or impaired sites) can be calculated. Paul and Zheng (2007) calculated a 75th percentile of TN concentration from samples collected from sites where reference criteria (refer to Paul and Zheng, 2007) could be applied. A 25th percentile of TN concentration was calculated from samples collected from all sites where nutrient data was available. The 75th percentile reference site calculation produced TN endpoints from 1300-1500 µg/L (1.3-1.5 mg/L), and the all sites 25th percentile calculation produced a TN endpoint of 1500 µg/L (1.5 mg/L). The modeled reference expectation approach produced TN endpoints from 260 µg/L (0.260 mg/L).

TN Thresholds from EPA-recommended Ecoregional Criteria Guidance

The EPA-recommended value for Nutrient Level III Ecoregion IX not to exceed is 692 µg/L (0.692 mg/L) TN, and for the Northern Piedmont ecoregion the recommended value not to exceed is 2,225 µg/L TN (2.225 mg/L) (both based on 25th percentiles of reported data; EPA, 2000a; Table 6.1).

TN Thresholds from Peer-Reviewed Scientific Literature

Herlihy and Sifneos (2008) (also cited in Paul et al., 2012) estimated reference stream nutrient concentration criteria upper quartiles, a method recommended in EPA (2000b) guidance, based on nutrient data collected as part of the EPA Wadeable Streams Assessment. They estimated a 75th percentile TN concentration of 681 µg/L (0.681 mg/L) in reference streams for Nutrient Level III Ecoregion IX. Ponader and Charles (2003) (also cited in Paul et al., 2007) estimated a TN threshold of 1280 µg/L (1.28 mg/L) in the Northern Piedmont ecoregion of New Jersey, comparable to the EPA recommended values. Rohm et al. (2002) (cited in Paul and Zheng, 2007), as part of a national study which presented a method for developing potential regional

[5] The analyses were developed for the TMDL endpoint document “Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application” (Paul and Zheng 2007) and the TMDL endpoint follow-up analysis document “Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application Follow-up Analysis” (Paul et al. 2012). Several of the EPA-recommended ecoregional criteria and peer-reviewed scientific literature are also discussed in these TMDL endpoint documents.

reference conditions and nutrient endpoints, used EMAP data from the Central and Eastern Forested Uplands area which includes much of central Pennsylvania and found that 375 µg/L (0.375 mg/L) TN could be used as a nutrient endpoint. Paul and Zheng (2007) state that a concentration of 500 µg/L (0.500 mg/L) TN can be given as a "rough estimate from the data presented for their Region IX that includes Eastern Pennsylvania." Ponader et al. (2005) (cited in Paul and Zheng, 2007) suggested a TN threshold not to exceed 500 µg/L (0.500 mg/L) would prevent nutrient impairment based on a study of diatom assemblages in streams in Virginia. ENSR (2003) (cited in Paul and Zheng, 2007), in an endpoint study of rivers in New England, used more than one approach to suggest that based on the weight-of-evidence a TN of 800 µg/L (0.800 mg/L) would be an upper boundary where impaired aquatic community status is being approached. Delaware lists water segments on the Section 303(d) list in Category 5 (impaired) based on lower confidence limits of station-averaged TN concentrations (sampling event days ≥ 10) if TN levels exceed the maximum of the target value of 2000-3000 µg/L (2-3 mg/L) TN (DNREC, 2015). Delaware has revised these targets from previous listing requirements that relied on an exceedance of the minimum value of the target 1000-3000 µg/L (1.0-3.0 mg/L) TN. In addition, Dodds et al. (1998) analyzed published data for temperate streams to determine endpoints for trophic boundaries. They found that the boundary between mesotrophic and eutrophic streams, determined by the upper third of a cumulative distribution of the values from the streams, is represented by 1500 µg/L TN (1.5 mg/L).

The thresholds discussed above range from a TN threshold of 260 to 3000 µg/L (0.260 to 3 mg/L) TN[6]. EPA will assess the TN data against this range of threshold values for TN to determine if TN is elevated in the stream.

Pennsylvania Numeric Criteria for Nitrate/Nitrite and Ammonia

EPA compared nitrate/nitrite and ammonia data to Pennsylvania numeric criteria for those compounds. The Pennsylvania drinking water numeric criterion for nitrate/nitrite is a maximum of 10 mg/L as nitrogen to protect public water supply (Table 6.1). Further, EPA (2000b) states that "in general, levels of nitrates (10ppm [10 mg/L] for drinking water) and ammonia high enough to be toxic (1.24 mg N/L at pH=8 and 25 °C) will also cause problems of enhanced algal growth (EPA, 1986)."

PADEP assesses attainment with the nitrate criterion at the point of water withdrawal. PA's nitrate criterion is applied to Goose Creek consistent with §96.3(d). Since there are not any drinking water intakes located on Goose Creek, attainment of PA's nitrate criterion is assessed at the first downstream drinking water intake on Chester Creek.

[6] The purpose of this document is to assess whether or not Goose Creek is impaired for nutrients and/or sediments. One part of assessing nutrient impairment in this document is to determine if nutrient (total phosphorus, total nitrogen, nitrate, ammonia) levels are sufficiently elevated to impair the aquatic life use. For the purposes of assessing elevated nutrient levels the range of TP endpoints discussed in the text of this document, as opposed to a weighting process to select one endpoint, is sufficient. A range allows analysis of a wider interval of endpoints that describe impairment, which will capture potential impairment without requiring the application of a stringent weighting analyses to assign more or less significance to different endpoints.

The ammonia criteria are designed to protect aquatic life from direct toxic effects of elevated ammonia concentrations. Pennsylvania has two types of numeric criteria for ammonia (in mg/L). The acute criterion requires the maximum total ammonia nitrogen concentration at all times to be the numerical value calculated from an equation dependent on median pH and temperature for the period from July through September (Section 3.3 above). The chronic criterion requires the average total ammonia nitrogen concentration over any 30 consecutive days to be the numerical value calculated from an equation dependent on median pH and temperature for the period from July through September (Section 3.3 above). These calculations produced acute criteria that were 7.327 mg/L calculated based on PADEP-1 continuous instream monitoring (CIM) data (median temperature=19.99 ℃; median pH=7.31, both for period from July through September), 9.760 mg/L calculated based on PADEP-2 CIM data (median temperature=21 ℃; median pH=6.86, both for period from July through September), and 6.539 mg/L calculated based on PADEP-3 CIM data (median temperature=20.705 ℃; median pH=7.37, both for period from July through September). Chronic criteria were 1.600 mg/L calculated based on PADEP-1 CIM data, 1.932 mg/L calculated based on PADEP-2 CIM data, and 1.467 mg/L calculated based on PADEP-3 CIM data (same medians apply to same sites as in acute criterion calculation).

WGSA collected one grab surface water sample once every two weeks from WGSA stations 1, 2, 4, 5, 7 and 10 (WGSA and GHD, 2015; CRA, 2013). These samples were sent to Suburban Testing Labs in Reading, PA for analysis (WGSA and GHD, 2015; CRA, 2013). PADEP collected samples according to PADEP (2013a) and PADEP (2013e) at stations PADEP 1, 2, 3. WGSA equated PADEP stations 1, 2, and 3 to WGSA stations 2, 6, and 10, respectively. WGSA samples were analyzed for the nutrient compounds total phosphorus as P (TP), dissolved orthophosphate as P, total kjeldahl nitrogen (TKN), nitrate-N (NO_3^--N), nitrite-N (NO_2^--N), ammonia-N (NH_3-N) (CRA 2013). PADEP samples were analyzed for nutrient compounds total phosphorus (TP), dissolved orthophosphorus (DIP), total nitrogen as N (TN), nitrate/nitrite-N (NO_3^-/NO_2^--N), and ammonia-N (NH_3).

6.2.4 Results of the Assessment of Total Nitrogen, Nitrate/Nitrite, and Ammonia Levels

Section 6.2.3 described the methodology that EPA used to analyze TN, nitrate/nitrite, and ammonia exceedances. EPA compared TN concentrations to a threshold range of 0.260 – 3 mg/L TN. Figure 6.2 presents TN, nitrate/nitrite, and ammonia data averaged for each station compared to the upper and lower thresholds for TN. Table 6.4 provides measured TN concentrations and highlights values in yellow and red when the lower or upper TN thresholds are exceeded, respectively. Both Figure 6.2 and Table 6.4 demonstrate that TN concentrations exceed the upper bound of the TN threshold downstream of the STPs and always exceed the lower bound of the TN thresholds, upstream and downstream of the STPs. TN concentrations rise at WGSA-4, just downstream of West Chester STP, and nearly triple between WGSA-4 and WGSA-5; WGSA-5 is just downstream of WGSA STP. All stations would be considered eutrophic based on exceedance of the 1.5 mg/L (1500 µg/L) TN threshold from Dodds et al. (1998) (Figure 6.2; Table 6.4). Overall, this evidence suggests that TN is highly elevated beyond the recommended thresholds.

However, the largest proportion of TN at all stations was nitrate + nitrite (Figure 6.2). EPA compared nitrate/nitrite concentrations to PADEP's drinking water numeric criterion for nitrate/nitrite of 10 mg/L as nitrogen. It is clear from Figure 6.2 that TN is comprised primarily of nitrate/nitrite due to the magnitude of nitrate/nitrite in each station average. Table 6.5 illustrates exceedances of the nitrate/nitrite criterion by highlighting in red those values greater than 10 mg/L. Nitrate/nitrite is highest directly downstream of WGSA-STP and remains high at subsequent sampling stations.

PA has a numeric water quality criterion (maximum of 10 mg/L as nitrogen) for nitrate for protection of the potable water supply use. PADEP assess attainment with the nitrate criterion at the point of water withdrawal. PA's nitrate criterion is applied to Goose Creek consistent with §96.3(d). Since there are not any drinking water intakes located on Goose Creek, attainment of PA's nitrate criterion is assessed at the first downstream drinking water intake on Chester Creek. Although nitrate data may be above some identified thresholds, EPA is not making an assessment decision or recommendation related to nitrate or total nitrogen. EPA suggests PADEP evaluate whether elevated TN and/or nitrate may be negatively impacting the aquatic life use in Goose Creek and/or potable water supply uses in Chester Creek.

Additionally, EPA compared ammonia concentrations to the acute and chronic criteria, which were calculated based on site specific data and are presented in Table 6.1. Table 6.6 shows ammonia concentration data collected at each station. No ammonia criteria exceedances occurred for the available data based on either the PADEP acute or chronic criteria for any sites on any dates.

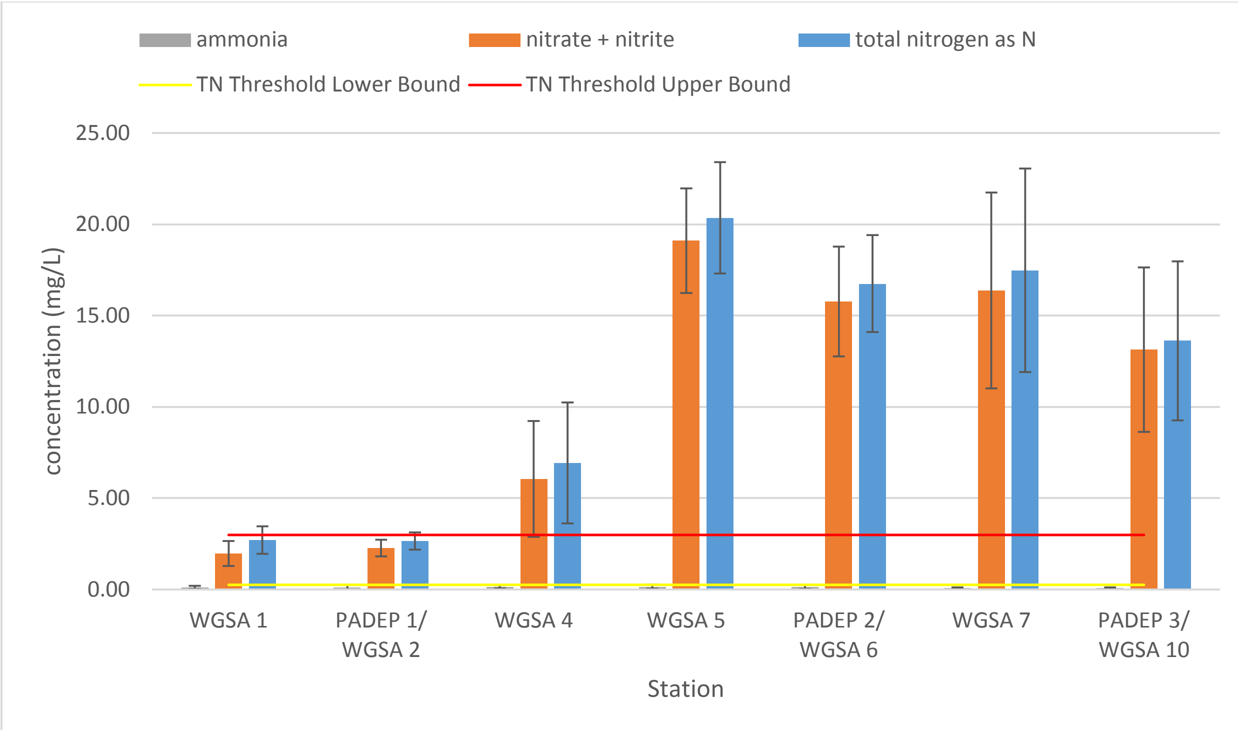

Figure 6.2 Average concentrations (mg/L) of inorganic nitrogen compounds and total nitrogen by station. Error bars are 1 standard deviation from mean.

Table 6.4 Total nitrogen concentrations (mg/L) collected by PADEP or calculated from data collected by WGSA.

Date Collected	Collected By	Station: WGSA 1	PADEP 1/ WGSA 2	WGSA 4	WGSA 5	PADEP 2/ WGSA 6	WGSA 7	PADEP 3/ WGSA 10
4/14/2014	PADEP		3.069			14.632		10.117
5/6/2014	PADEP		3.068			13.155		9.154
6/9/2014	PADEP		3.344			16.02		12.882
6/19/2014	PADEP		1.9			12.71		7.69
6/23/2014	PADEP		3.168			14.819		12.229
7/9/2014	PADEP		1.92			17.10		13.96
7/17/2014	PADEP		2.636			19.399		16.195
8/19/2014	PADEP		2.887			18.907		16.909
9/24/2014	PADEP		2.799			21.134		17.58
10/15/2014	PADEP		2.88			18.77		17.61
10/20/2014	PADEP		2.952			16.907		15.931
11/12/2014	PADEP		2.685			19.404		17.636
12/17/2014	PADEP		2.639			14.778		12.398
5/29/2014	WGSA	2.59	2.62	4.34			20.50	11.48
6/12/2014	WGSA	1.76	2.14	3.78			10.80	8.49
6/26/2014	WGSA	1.93*	2.06	3.31			9.83	5.51
7/24/2014	WGSA	1.80	1.97	5.05			15.60	10.17
8/6/2014	WGSA	3.08	3.18	4.12			21.53	16.29
8/21/2014	WGSA	3.78		9.93	18.99		19.36	15.88
9/4/2014	WGSA	2.54		10.55	20.00		20.20	16.10
9/18/2014	WGSA	3.45		9.46	24.19		21.71	18.27
10/2/2014	WGSA	3.51		11.13	23.86		22.89	20.15
10/16/2014	WGSA	1.60		2.90	15.20		6.04	3.85
10/30/2014	WGSA	2.70		11.05	20.46		21.19	18.38
4/23/2015**	WGSA							
5/21/2015	WGSA	3.03		7.58	19.75		20.05	15.55
Station Average[1]		2.71	2.66	6.93	20.35	16.75	17.48	13.62
Standard Deviation		0.75	0.47	3.32	3.05	2.65	5.57	4.35

*6/26 differs from value presented in WGSA report because this analysis averaged duplicates submitted by WGSA
**no nitrate/nitrite data due to lab error on 4/23/2015—total nitrogen calculation not possible; WGSA total nitrogen data was calculated as the sum of nitrate, nitrite, and total kjeldahl nitrogen
[1]station averages differ from WGSA report because 4/23/2015 data is not included here due to lab error on that date

Table 6.5 Nitrate + nitrite concentrations (mg/L) collected by PADEP or calculated from data collected by WGSA.

		Station						
Date Collected	Collected By	WGSA 1	PADEP 1 / WGSA 2	WGSA 4	WGSA 5	PADEP 2 / WGSA 6	WGSA 7	PADEP 3 / WGSA 10
4/14/2014	PADEP		2.426			13.013		9.253
5/6/2014	PADEP		2.778			11.938		8.583
6/9/2014	PADEP		2.699			14.791		12.157
6/23/2014	PADEP		2.842			14.005		11.645
7/17/2014	PADEP		2.191			18.324		15.249
8/19/2014	PADEP		2.649			16.534		16.91
9/24/2014	PADEP		2.65			20.372		17.974
10/20/2014	PADEP		2.049			17.011		16.112
11/12/2014	PADEP		2.343			19.351		19.037
12/17/2014	PADEP		2.282			12.316		11.128
5/29/2014	WGSA	1.81	2.12	3.34			14.40	10.40
6/12/2014	WGSA	1.26	1.64	3.21			10.30	7.99
6/26/2014	WGSA	1.24	1.44	2.46			8.93	4.59
7/10/2014	WGSA	1.94	2.20	6.31			18.80	14.40
7/24/2014	WGSA	1.25	1.47	4.19			14.50	9.57
8/6/2014	WGSA	2.58	2.68	3.33			20.47	15.30
8/21/2014	WGSA	2.92		8.87	17.80		18.50	15.30
9/4/2014	WGSA	2.04		9.85	19.50		19.70	15.60
9/18/2014	WGSA	2.95		8.92	22.10		20.90	17.50
10/2/2014	WGSA	2.92		10.10	22.50		22.10	18.80
10/16/2014	WGSA	1.10		1.90	14.10		4.92	2.71
10/30/2014	WGSA	1.86		10.20	19.80		20.40	17.50
4/23/2015	WGSA				lab error - no data			
5/21/2015	WGSA	1.81		6.12	17.91		18.90	14.50
Station Average		1.98	2.28	6.06	19.10	15.77	16.37	13.14
Standard Deviation		0.68	0.45	3.17	2.87	3.00	5.36	4.50

Table 6.6 Ammonia concentrations (mg/L) collected by PADEP and WGSA.

		Station						
Date Collected	Collected By	WGSA 1	PADEP 1 / WGSA 2	WGSA 4	WGSA 5	PADEP 2 / WGSA 6	WGSA 7	PADEP 3 / WGSA 10
4/14/2014	PADEP		0.038			0.046		0.024
5/6/2014	PADEP		0.116			0.15		0.146
6/9/2014	PADEP		0.135			0.15		0.05
6/23/2014	PADEP		0.056			0.124		0.033
7/17/2014	PADEP		0.109			0.065		0.023
8/19/2014	PADEP		0.06			0.317		0.033
9/24/2014	PADEP		0.046			0.059		0.025
10/20/2014	PADEP		0.623			0.366		0.072
11/12/2014	PADEP		0.066			0.073		0.019
12/17/2014	PADEP		0.089			0.188		0.049
5/29/2014	WGSA	0.10*	0.10*	0.36			0.15	0.23
6/12/2014	WGSA	0.10*	0.10*	0.23			0.10*	0.10*
6/26/2014	WGSA	0.10*	0.10*	0.20			0.10*	0.10*
7/10/2014	WGSA	0.10*	0.10*	0.16			0.10*	0.10*
7/24/2014	WGSA	0.10*	0.10*	0.10*			0.10*	0.10*
8/6/2014	WGSA	0.10*	0.10*	0.10*			0.10*	0.10*
8/21/2014	WGSA	0.10*		0.10*	0.10*		0.10*	0.10*
9/4/2014	WGSA	0.10*		0.10*	0.10*		0.10*	0.10*
9/18/2014	WGSA	0.10*		0.10*	0.10*		0.10*	0.10*
10/2/2014	WGSA	0.10*		0.10*	0.10*		0.10*	0.10*
10/16/2014	WGSA	0.10*		0.10*	0.10*		0.10*	0.10*
10/30/2014	WGSA	0.11		0.10*	0.14		0.10*	0.10*
4/23/2015	WGSA	0.11		0.24	0.22		0.10*	0.10*
5/21/2015	WGSA	0.41		0.26	0.42		0.10*	0.10*
Station Average**		0.12	0.12	0.16	0.16	0.15	0.10	0.09
Standard Deviation		0.08	0.14	0.08	0.11	0.11	0.01	0.05

*reported as <0.10

**values differ from those presented in WGSA report because this analysis includes 0.10 values in average

6.2.5 Relationship between Nutrient Levels and Periphyton Biomass

Several studies recommend TP or TN levels to control periphyton biomass (as measured by benthic chlorophyll-*a*). Review Section 6.3.1 below for a discussion of threshold levels of periphyton biomass. To restrict mean benthic chlorophyll to <50 mg chlorophyll-*a* /m^2 Dodds et al. (1997) suggested an endpoint for TN of 0.47 mg/L and for TP of 0.055 mg/L, while Lohman et al. (1992) suggest endpoints of 0.25 mg/L TN and 0.021 mg/L TP (both cited in Dodds and Welch, 2000). To restrict maximum benthic chlorophyll to <200 mg chlorophyll-*a* /m^2 Dodds and Welch (2000) calculated a TN endpoint of 3.0 mg/L and a TP endpoint of 0.415 mg/L from

Dodds et al. (1997) data. Similarly, Paul et al. (2012) applied a mechanistic model developed for Indian Creek (also in the Northern Piedmont ecoregion of southeastern PA) and found that average benthic chlorophyll-*a* levels of about 100 mg chlorophyll-*a* /m^2 are predicted when TP concentrations are between 20 and 33 µg/L (0.020-0.033 mg/L) in Indian Creek. A study in Paxton Creek, located in Harrisburg, Pennsylvania in the neighboring nutrient ecoregion XI, found that to maintain chlorophyll-*a* at 100 mg chlorophyll-*a* /m^2, a TP of 0.095 mg/L (95 µg/L) and TN of 0.731 mg/L (731 µg/L) would be required based on site-specific data (Carrick and Mays, 2006).

Dodds et al. (1998) analyzed published data for temperate streams to determine endpoints for trophic boundaries. They found that the boundary between mesotrophic and eutrophic streams, determined by the upper third of a cumulative distribution of the values from the streams, is represented by 75 µg/L TP (0.075 mg/L) and 1500 µg/L TN (1.5 mg/L). The mesotrophic-eutrophic boundary for chlorophyll-*a* is 70 mg chlorophyll-*a* /m^2.

EPA considered the data based on the range of values discussed (Table 6.7 below).

Table 6.7 Range of Nutrient levels associated with biomass (as measured by benthic chlorophyll-*a*)

		TP (mg/L)	TN (mg/L)	Chl-*a* (mg/m^2)	Nitrate/ Nitrite	Ammonia	Source
Mechanistic Model							
	Indian Creek	0.020-0.033		~100			Paul et al., 2012
Literature							
	Control mean benthic chlorophyll	0.055	0.47	<50			Dodds et al., 1997 cited in Dodds and Welch, 2000
	Control mean benthic chlorophyll	0.021	0.25	<50			Lohman et al., 1992 cited in Dodds and Welch, 2000
	Control maximum benthic chlorophyll	0.415	3.0	<200			Dodds and Welch, 2000 calculated from Dodds et al., 1997 data
	Paxton Creek study to maintain chlorophyll-*a*	0.095	0.731	Maintain 100			Carrick and Mays, 2006

6.2.6 Comparison of Nutrient Levels and Periphyton Biomass

The impact of phosphorus on periphyton biomass is shown by comparison of the total phosphorus data with the periphyton biomass data. All TP concentrations (all available data for the station averaged) exceed the TP endpoints of 0.055 mg/L and 0.021 mg/l cited in Dodds and Welch (2000) to keep mean benthic chlorophyll below 50 mg chlorophyll-*a* /m^2 (Figure 6.1; Table 6.2). WGSA 4, 5, 6, 7, and 10, all downstream of the two STPs, also exceed the TP target of 0.095 mg/L in Paxton Creek, Pennsylvania to maintain chlorophyll *a* at 100 mg/m^2 (Table 6.2). Periphyton biomass is discussed in more detail in Sections 6.3.1 and 6.3.2. Periphyton biomass at WGSA-2, and downstream of the two STPs at WGSA 4, 5, 6, 7, and 10 all exceed 100 mg/m^2 on average overall including or excluding 4/17/2015 data (Table 6.8). Periphyton biomass at WGSA 1 exceeds 200 mg/m^2 when 4/17/2015 data is included (Table 6.8). WGSA 4, 5, 6, 7, and 10 all exceed the 0.415 mg/L calculated TP endpoint to keep maximum benthic chlorophyll below 200 mg/m^2 (Figure 6.3; Table 6.8). The station average with or without 4/17/2015 data for WGSA 5 exceeds the 200mg/m^2 chlorophyll threshold (Table 6.8) and for WGSA 6 (which has no 4/17/2015 data) closely approaches it. When overall averages including 4/17/2015 data are considered, WGSA 1, 2, 4, and 7 also exceed the 200 mg/m^2 chlorophyll threshold (Table 6.8).

The impact of nitrogen on periphyton biomass is shown by comparison of the total nitrogen data with the periphyton biomass data. All station averaged TN concentrations exceed the TN endpoints of 0.47 mg/L and 0.25 mg/L cited in Dodds and Welch (2000) to keep mean benthic chlorophyll below 50 mg/L (Figure 6.3; Table 6.8). All periphyton biomass values exceed 50 mg/L (Table 6.8). All stations exceed the TN target of 0.731 mg/L in Paxton Creek, Pennsylvania to maintain chlorophyll *a* at 100 mg/m^2 (Figure 6.3; Table 6.8). Periphyton biomass at WGSA 2, 4, 5, 6, 7, and 10, all exceed 100 mg chlorophyll a/m^2 on average overall including or excluding 4/17/2015 data (Table 6.8). Periphyton biomass at WGSA 1 exceeds 200 mg chlorophyll $a\,/m^2$ when 4/17/2015 data is included (Table 6.8). WGSA 4, 5, 6, 7, and 10 all exceed the 3.0 mg/L calculated TN endpoint to keep maximum benthic chlorophyll below 200 mg/m^2 (Figure 6.3; Table 6.8). The station average excluding or including 4/17/2015 data for station 5 exceeds the 200mg/m^2 chlorophyll threshold (Table 6.8) and for station 6 (which has no 4/17/2015 data) closely approaches it. When station averages including 4/17/2015 data are considered, WGSA 1, 2, 4, and 7 exceed the 200 mg/m^2 chlorophyll threshold (Table 6.8).

Based on periphyton biomass station averages, all stations including or excluding 4/17/2015 data, except for station 1 station average excluding 4/17/2015 data, would be considered eutrophic by exceedance of the 70 mg chlorophyll-$a\,/m^2$ threshold for eutrophy from Dodds et al. (1998) (Figure 6.3; Table 6.8). All stations except WGSA 2 would be considered eutrophic based on exceedance of the 75 µg/L (0.075 mg/L) TP threshold from Dodds et al. (1998), although WGSA-2 closely approaches this threshold at 0.072 mg/L TP (Figure 6.1; Table 6.2). All stations would be considered eutrophic based on exceedance of the 1.5 mg/L (1500 µg/L) TN threshold from Dodds et al. (1998) (Figure 6.2; Table 6.4). WGSA 4, 5, 6, 7, and 10, which are downstream of the two STPs, are clearly eutrophic based on periphyton biomass, TP, and TN. Further, as levels of TP and TN rise, so do levels of periphyton biomass.

6.3 Periphyton Assessment Methodology and Results

EPA assessed four types of periphyton data submitted by WGSA and PADEP. EPA received data from WGSA that included a periphyton biomass assessment, an assessment of algal taxonomy, and a visual algal survey. EPA received data from PADEP including a periphyton assessment, and algal toxicity. The assessment of each of these types of data is described in the sections below.

Data was collected and submitted to EPA by WGSA and PADEP. GHD Services, Inc. (GHD), on behalf of WGSA, collected samples for the periphyton biomass assessment, algal taxonomy, and a visual algal survey on August 28, 2014 (summer) and April 17, 2015 (spring) at WGSA stations 1, 2, 4, 5, 7, and 10. PADEP collected data for algal toxicity on September 19, 2013 and July 30, 2014. PADEP collected samples for periphyton biomass assessment on July 9, 2014, August 29, 2014, and October 15, 2014 at 3 stations in Goose Creek identified in PADEP data as: "Goose Creek at Mosteller (GC1)," "Goose Creek at Oakbourne (GC2)," and "Goose Creek at Thornbury (GC3)." These stations will be referred to as PADEP-1, PADEP-2, PADEP-3, respectively, in this document (refer to Figure 4.1 for sampling locations). WGSA states in its data table that it assumed PADEP-1 was at the same location as WGSA-2, PADEP-2 was at the same location as WGSA-6, and PADEP-3 was at the same location as WGSA-10. EPA analyzed the data to be consistent with these assumptions.

WGSA noted in its report that a sanitary pipe break that was reported on April 6, 2015 contaminated Goose Creek upstream of WGSA 1 and 2 (WGSA and GHD, 2015). The leak was repaired on April 8, 2015 (WGSA and GHD, 2015). WGSA suggested that the leak may have possibly impacted nutrient concentrations in the stream, and data collected 9 days after the repair of the break may possibly have been affected. However, WGSA, in its own report, noted that "periodic water chemistry sampling by WG [West Goshen] on April 25 showed no residual effect on nutrient levels," nor did WGSA data collected on April 23, 2015, which was submitted to EPA as part of the reassessment (WGSA and GHD, 2015). In light of this possible concern, the analysis of WGSA data stated whether or not April 17, 2015 data was being considered.

However, April 17, 2015 is the only spring periphyton sample provided by either WGSA or PADEP. Spring samples should have occurred prior to the emergence of leaves, representing conditions of maximal light, and maximal light-based growth potential of periphyton. PADEP, in their 2013 Field Protocol: Periphyton Standing Crop and Species Assemblages (PADEP, 2013d) states "In small streams, riparian leaf canopies can intercept 95% of incident solar radiation (Borchardt, 1996)." This is significant since WGSA describes Goose Creek as "typically narrow, high-banked, and shaded by dense riparian vegetation during the summer" (WGSA and GHD, 2015). Therefore, spring (April 17, 2015) data, collected before the riparian leaf canopy emerged, will show effects of increased light availability, and represent conditions of maximal light-based growth potential of periphyton, compared to summer data where the stream would be "shaded by dense riparian vegetation," (WGSA and GHD, 2015). Spring data is much more likely to be representative of conditions of maximal light than to be showing a response to a sanitary pipe break as WGSA itself notes that "no residual effect on nutrient levels" (WGSA and GHD, 2015) was found. As such, all available data, including April 17th, 2015, the only spring sample, will be analyzed.

6.3.1 Periphyton Assessment Methodology

EPA received periphyton biomass data from PADEP and WGSA. PADEP collected periphyton and analyzed samples for chlorophyll-*a* content to obtain a measurement of periphyton biomass (in mg chlorophyll-*a* /m^2) consistent with PADEP guidelines in the PADEP Field Protocol for Periphyton Standing Crop and Species Assemblages (2013d). WGSA also collected periphyton, which were analyzed for chlorophyll-*a*, according to the WGSA report (WGSA and GHD, 2015).

The state of Pennsylvania does not have numeric or narrative criteria for periphyton biomass, however, the state does have narrative water quality criteria and an impairment cause definition for nutrients, as described above in Section 3. The impairment cause definition for nutrients uses the term "high primary production." Periphyton biomass was assessed to determine whether or not "high primary production" was present in Goose Creek.

Primary production is defined as the "Quantity of new organic matter created by photosynthesis or chemosynthesis, or stored energy which that material represents," (Wetzel, 1983 cited in EPA, 2000b). In other words, primary production is the amount (quantity) of organic matter produced through photosynthesis (a light-requiring chemical reaction in living cells that produces energy and synthesizes new organic cellular material) or chemosynthesis. Primary production is often measured as standing crop or biomass. Standing crop and biomass are often used interchangeably. Standing crop is "the quantity per volume or area that is present and can be measured;" when the unit of measurement is mass, the term biomass may be used (Welch, 1992 p 11). Both standing crop and biomass measurements are often based on chlorophyll-*a*; for example, periphyton biomass may be expressed as mg chlorophyll-*a* /m^2. Chlorophyll-*a* is a photosynthetic pigment regularly "used as a reliable index of algal biomass," (EPA, 2000b).

The state of Pennsylvania has a field protocol for sampling periphyton standing crop (PADEP, 2013d). This field protocol directs the collection of epilithic periphyton for standing crop, which is to be measured by chlorophyll-*a* analysis. The protocol states that "The purpose of this document is to provide a statewide standard field protocol for the collection of data that may be considered in conjunction with other chemistry and biological data *to assess nutrient impairment … and provide nutrient and biological response data* to support Pennsylvania's nutrient criteria development" (emphasis added by EPA). The protocol notes that while periphyton standing crop is influenced by several factors ("nutrient levels, light, hydrologic condition, temperature, substrate type, and herbivore grazing (Stevenson, 1996)"), its accrual is primarily dependent on nutrient levels and light (Biggs, 1996, cited in PADEP, 2013d). The protocol goes on to state that "nuisance" levels of standing crop can occur when "*high* nutrient levels and *adequate* sunlight are provided," (emphasis added by EPA). Similarly, EPA (2000b, p 30) states that the factors that influence periphyton standing crop (as discussed above), or allow periphyton biomass to accumulate, "will not result in high biomass without sufficient nutrient supply." Further, "the rate at which maximum biomass is attained is dependent mostly on nutrient availability, minus losses to grazing and scouring" (EPA, 2000b). In addition, the Pennsylvania protocol states that "nuisance levels of algae and periphyton community shifts associated with high nutrients may cause water quality impairment (e.g. low dissolved oxygen), negative impacts to macroinvertebrates and fish, and/or aesthetic impairments for water uses". Thus, the protocol suggests that: 1) periphyton standing crop or biomass measured as chlorophyll-*a* can be used to assess nutrient impairment, and chlorophyll-*a* is a reliable index of standing crop or biomass; 2) periphyton standing crop or biomass represents a biological response to nutrients; 3) nutrient levels and light will primarily determine biomass levels; 4) *high* nutrient levels are required to produce nuisance levels of biomass while only *adequate* sunlight is required, thus while light may modify a response, nutrient levels are the underlying cause of high primary production and high primary production will not occur without high nutrient levels; and 5) nuisance levels of periphyton biomass can cause water quality impairments, negative impacts to macroinvertebrates and fish, which could result in aquatic life use impairments, and/or aesthetic impairments.

The Pennsylvania nutrient cause definition describes symptoms of nutrient impairment. The stated purpose of the Pennsylvania field protocol for sampling periphyton standing crop (PADEP, 2013d) is to describe how standing crop (or biomass) data should be collected to be "considered in conjunction with other chemistry and biological data *to assess nutrient impairment"* (emphasis added by EPA). Pennsylvania assesses a nutrient impairment in regards to primary production based on periphyton standing crop (biomass) data using chlorophyll-*a* as an indicator to measure biomass. Thus, Pennsylvania measures biomass (as chlorophyll-*a*) as an indicator of primary production. This is a common and established practice. For example, EPA (2000b) states that chlorophyll-*a* "can be considered the most important biological response variable for nutrient-related problems."

The terms "primary production" and "primary productivity" are often used interchangeably, and may be confused. However, "primary production" as defined above is the "Quantity of new organic matter created by photosynthesis or chemosynthesis, or stored energy which that material represents," (Wetzel, 1983 cited in EPA, 2000b). Meanwhile, "primary productivity" is the photosynthetic rate (EPA, 2000b), or the rate of formation of new organic matter created by photosynthesis (or chemosynthesis), rather than the quantity or amount of newly formed organic matter. EPA (2000b) states "productivity is essentially growth, and therefore is a more direct measure of nutrient effects." However, periphyton biomass (quantity) is commonly used as a valid measure to indicate growth (a rate) or productivity (a rate). EPA (2000b) supports and defends the measurement of biomass (quantity), rather than productivity or growth (rates): "the greater analytical difficulty of productivity, has made algal biomass the preferred variable to indicate nutrient effects on periphyton," (EPA, 2000b).

Further, the presence of a nutrient impairment for aquatic life is more linked to primary production (i.e. biomass) than to productivity. The aquatic life impairment is caused by both the amount of biomass, and the changes in dissolved oxygen and pH due to photosynthesis and respiration. The amount of biomass is important because biomass may: decay and consume oxygen in the stream (more decaying biomass will lead to more oxygen consumption), negatively or positively impact habitat for aquatic life (dependent on the species), serve as a food source itself, or competitively reduce or eliminate a different food source, for aquatic life (dependent on the species), and impact the nutritional quality of the food. The changes in dissolved oxygen and pH due to photosynthesis and respiration will be greater or lesser (in a given primary producer species) as biomass increases or decreases since there will be more or less cells photosynthesizing. Given that one major purpose of this analysis is to determine whether or not Goose Creek is impaired for aquatic life uses due to nutrients, the consideration of primary production (rather than primary productivity) is further validated.

Pennsylvania uses periphyton biomass to determine whether there is "excessive algal growth." In addition to the PADEP impairment cause definition for nutrients, which uses the term "high primary production," PADEP also has an impairment cause definition for "excessive algal growth", that relies on standing crop as a measure of growth. Specifically, "excessive algal growth" is defined as "Large algal standing crops generally due to high concentrations of nutrients," (PADEP, 2013b). PADEP's definition of algal growth measured as standing crop offers further evidence of the validity of the measurement of periphyton biomass (quantity) to indicate growth (a rate) or productivity (a rate). PADEP does not collect data for direct measurements of productivity; instead it collects data for measurements of primary production as periphyton standing crop (biomass).

EPA analyzed periphyton biomass to determine whether or not there was "high primary production," a term noted in PA's cause definition for nutrients. Presence of high primary production was evaluated based on periphyton and benthic algal biomass thresholds defined as "nuisance," indicative of adverse effects, or indicative of eutrophic conditions, by considering existing EPA-recommended criteria guidance, thresholds used by other states, and peer-reviewed scientific studies.

EPA-recommended Criteria Guidance

EPA recommends regionally specific reference criteria for periphyton chlorophyll-*a* in rivers and streams "to protect against the adverse effects of nutrient overenrichment from cultural eutrophication" (EPA, 2000a). These criteria are EPA 304(a) recommended criteria. The Northern Piedmont Nutrient Level IV Ecoregion 64 is part of the larger aggregate Nutrient Level III Ecoregion IX (EPA, 2000a). Goose Creek falls within the Northern Piedmont ecoregion. EPA recommended criteria in Nutrient Level III Ecoregion IX for periphyton is 20.35 mg chlorophyll-*a* /m^2 based on 25^{th} percentiles of all seasons data, and is the same for the Northern Piedmont nutrient ecoregion.

Peer-reviewed Scientific Studies

EPA (2000b; p. 101, 102) cites several studies from northern to mid-temperate streams (similar to Goose Creek) to support that the level of periphyton (measured as benthic chlorophyll-*a*) in a stream that represents nuisance conditions ranges from 100-200 mg chlorophyll *a* /m^2 (e.g. Biggs, 2000, Dodds et al., 1997, Welch et al., 1988, 1989 all cited within EPA, 2000b). In addition, EPA (2000b), citing Welch (1992), notes that 150 mg chlorophyll *a* /m^2 is a threshold level below which adverse effects on water quality, benthic habitat, and aesthetic quality due to dense mats of filamentous algae can likely be avoided. This is similar to levels that represent eutrophy (as discussed below), and what a user survey conducted in Montana determined to be the point of excessive benthic algal biomass (Suplee et al., 2009).

In an effort to establish endpoints to categorize streams into trophic states based on nutrients (TN, TP) and algal biomass, Dodds et al. (1998) analyzed a published dataset of temperate streams. Natural waters are often categorized by trophic state, and the major state classifications are eutrophic, mesotrophic, and oligotrophic. In general, the term eutrophic is often used to describe systems with high nutrients and high production, while oligotrophic systems have low nutrients and low production, and mesotrophic systems fall in between (Dodds et al., 1998 and references therein; Dodds and Welch, 2000). Dodds et al. (1998) established that the boundary between mesotrophic and eutrophic stream systems is indicated by mean benthic chlorophyll of 70 mg chlorophyll a/m^2, or a maximum benthic chlorophyll of 200 mg chlorophyll a/m^2.

Similarly, Dodds and Welch (2000) state that benthic chlorophyll concentrations in (nutrient) enriched waters are often greater than the 150 mg chlorophyll a/m^2 breakpoint. Horner et al. (1983) also found that enrichment (and an increase in filamentous forms) occurred with biomass levels above 150 mg/m^2 based on a literature review of 19 cases (cited in EPA, 2000b).

Thresholds Used by Other States

Montana conducted a recreational use user survey that showed chlorophyll *a* levels at or below 150 mg/m^2 were "desirable" by a majority of survey respondents, while chlorophyll *a* levels at or above 200 mg/m^2 were "undesirable" by a majority of respondents (Suplee et al., 2009). Suplee et al. (2009) states that the 150 mg/m^2 "desirable" level corresponds with the primary literature and the public perception of the "onset of excessive algal growth." These numbers are directly related to recreational criteria and are informative as another perspective of what constitutes impairment of recreational use. Further, they add support to the finding of a 150 mg chlorophyll *a*/m^2 threshold above which adverse effects may occur.

Similarly, criteria recommended for streams in British Columbia is less than 50 mg/m^2 chlorophyll *a* for the protection of recreation and aesthetics, and a maximum biomass of 100 mg/m^2 chlorophyll *a* for the protection of aquatic life (Nordin, 2001). These values are informative as another perspective of what constitutes a recreational use impairment and a potential aquatic life use impairment.

Thresholds Selected by EPA for High Primary Production

EPA selected 150-200 mg chlorophyll-*a* /m^2 as the threshold above which periphyton biomass is considered to be indicative of high primary production. This threshold is consistent with the body of peer-reviewed scientific literature and sources discussed above and based on EPA literature and sources therein. EPA assessed the submitted periphyton data by directly comparing the data using the station averaged periphyton biomass value to the 150 to 200 mg chlorophyll *a*/m^2 threshold discussed above. While stations within the 100-200 mg chlorophyll *a*/m^2 range may be considered indicative of high primary production, only stations exceeding the 150-200 mg chlorophyll *a*/m^2 threshold will be considered to be showing evidence of high primary production.

The impairment cause definition for nutrients refers to "high primary production resulting from elevated levels of phosphorus and/or nitrogen". As discussed, the threshold above which periphyton biomass is considered to be indicative of high primary production is 150-200 mg chlorophyll-*a* /m^2. Although the impairment cause definition is not a WQS it can be informative in interpreting Pennsylvania's narrative criteria. Which states:

> "Water may not contain substances attributable to point or non-point source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life."

Where high levels of nutrients such as phosphorus or nitrogen lead to high primary production that impacts aquatic life, then the waterbody does not meet the narrative criteria. (See Sections 2.1 and 7). This threshold of high primary production is also considered to be indicative of the "excessive plant growth" EPA agreed to assess as part of the settlement agreement (see Section 1).

6.3.2 Results of Periphyton Assessment

Periphyton biomass, measured as mg chlorophyll-*a* /m^2, collected by WGSA and PADEP for this reassessment is presented in Table 6.8 and Figure 6.3 below. As discussed in Section 6.3.1, station-averaged periphyton biomass data that exceeded the 150 to 200 mg chlorophyll *a*/m^2 threshold was determined to fall in the category of "high primary production" as specified in the Pennsylvania cause definitions for nutrients.

WGSA had concerns about a sanitary pipe break in Goose Creek upstream of WGSA 1 and 2 which may have affected nutrient concentrations in the stream, and biomass data collected on April 17, 2015. However, WGSA, in its own report, notes that "periodic water chemistry sampling by WG [West Goshen] on April 25 showed no residual effect on nutrient levels," nor did WGSA data collected on April 23, 2015, which was submitted to EPA as part of the reassessment (WGSA and GHD, 2015). In light of this possible concern, EPA analyzed the WGSA data with and without April 17, 2015 data (refer to Section 6.3 for a discussion of this issue).

In the dataset provided by WGSA and PADEP, WGSA 5 exceeds the lower bound and the upper bound of the 150 to 200 mg chlorophyll-*a* /m^2 threshold for high primary production with and without April 17, 2015 data included (Figure 6.3; Table 6.8). WGSA 6 exceeds the lower bound and closely approaches the upper bound of the threshold for high primary production at all times. WGSA 4 and 7 closely approach the lower bound of the threshold for high primary production when April 17, 2015 data are excluded. When April 17, 2015 data are included WGSA 1, 2, 4, 5, 6, and 7, all stations except WGSA 10, exceed the lower bound of the threshold and WGSA 1, 2, 5, and 7 all exceed the upper bound of the threshold (Figure 6.3; Table 6.8). WGSA 5 and 6 are downstream of the WGSA STP. WGSA 5 and 6 show the highest levels of periphyton biomass compared to other stations for the same data set (date) (Table 6.8). Further, all stations when all data are included in the station average, and all stations when April 17, 2015 data are *excluded*, except station 1, fall within or exceed the range of nuisance biomass levels (100-200 mg chlorophyll *a*/m^2). These stations also exceed the Dodds et al. (1998) 70 mg/m^2 Chl-*a* threshold placing them within the eutrophic category (Figure 6.3). When April 17, 2015 data are considered on their own, several stations (WGSA 1, 2, 5, 7) exceed, while WGSA 4 and 10 approach, the Dodds et al. (1998) 200 mg chlorophyll-*a* /m^2 maximum threshold placing them in the eutrophic category. Further, WGSA 5 on 8/28/2014 (the only available data point that is not the April 17, 2015 data), and WGSA 6 on 7/9/2014 (WGSA 5 and 6 were never sampled on the same dates) exceed the 200 mg chlorophyll *a*/m^2 maximum threshold placing them in the eutrophic category.

Based on this assessment, Goose Creek is unambiguously impaired for high primary production (as evidenced by excessive periphyton biomass) at WGSA 5 and likely WGSA 6. Further, Goose Creek shows conditions of nuisance growth, indicative of high primary production, at all stations with the possible exception of station 1 only when data from April 17, 2015 are excluded. Goose Creek is experiencing conditions of high primary production that is contributing to the aquatic life use impairment in Goose Creek.

It is also worth noting that the April 17, 2015, spring, biomass data at WGSA 1 (431.93 mg/m^2 Chl-*a*) and WGSA 2 (583.63 mg/m^2 Chl-*a*) have values that are 7 times (WGSA 1) and 3 to 6 times (WGSA 2) as high as biomass levels at the same stations during summer and fall (Table 6.8). In fact, all stations show the highest level of biomass in the spring samples compared to the summer and fall samples (Table 6.8; Figure 6.3). This is due to high light conditions in spring compared to summer. As noted in Section 6.3, 95% of incident solar radiation in small streams can be intercepted by riparian leaf canopies (PADEP, 2013d). Further, PADEP (2013d) notes that standing crops "can be 4 to 5 times higher at open canopy sites than closed canopy sites (Hill, 1996)." The spring data in this report are representative of an open canopy, before leaves have emerged on riparian vegetation. These high levels of periphyton biomass in spring are likely due to higher growth rates resulting from the spring conditions of maximal light as discussed in Section 6.3. While all stations show the highest level of biomass in the spring sample compared to the summer and fall samples, WGSA 1 and 2, show the most pronounced response to spring conditions of increased light availability. This, again, is due to light. According to WGSA and GHD (p. 10, 2015), WGSA 1 and 2 are the most densely shaded stations after the emergence of leaves in summer, and so would be expected to show the most pronounced response to spring conditions of increased light availability.

Further, this data shows that thresholds are exceeded even in shaded conditions (summer and fall) (Table 6.8, Figure 6.3 blue bars), demonstrating that excess nutrients, and not light, are responsible for this high primary production. The increase of primary production at all sites, but most intensely WGSA 1 and 2, under spring conditions of high light suggests that, while nutrient and light levels in summer and fall are high enough to promote high primary production (determined by the exceedance of biomass thresholds), the increased light availability in spring enables an even greater autotrophic response to nutrient enrichment. It is important to reiterate here that, although light can impact periphyton growth, and the resulting biomass produced, as discussed above, nutrients are the controlling factor causing *excessive (*high) primary production. In the absence of elevated nutrient levels, above levels saturating for growth (0.025-0.050 mg/L TP, Table 6.1 above), production would not likely reach the excessive levels seen in this data in both shaded (summer and fall) and high light (spring) conditions. Biomass levels high enough to exceed the thresholds of high primary production (150-200 mg/m^2) and vastly exceed (from 3 to 18 times on average) the EPA recommended regionally-specific reference criteria (20.35 mg/m^2) are caused by elevated nutrient levels with light acting as a modifying factor. Please refer to further discussion in Section 6.3.1.

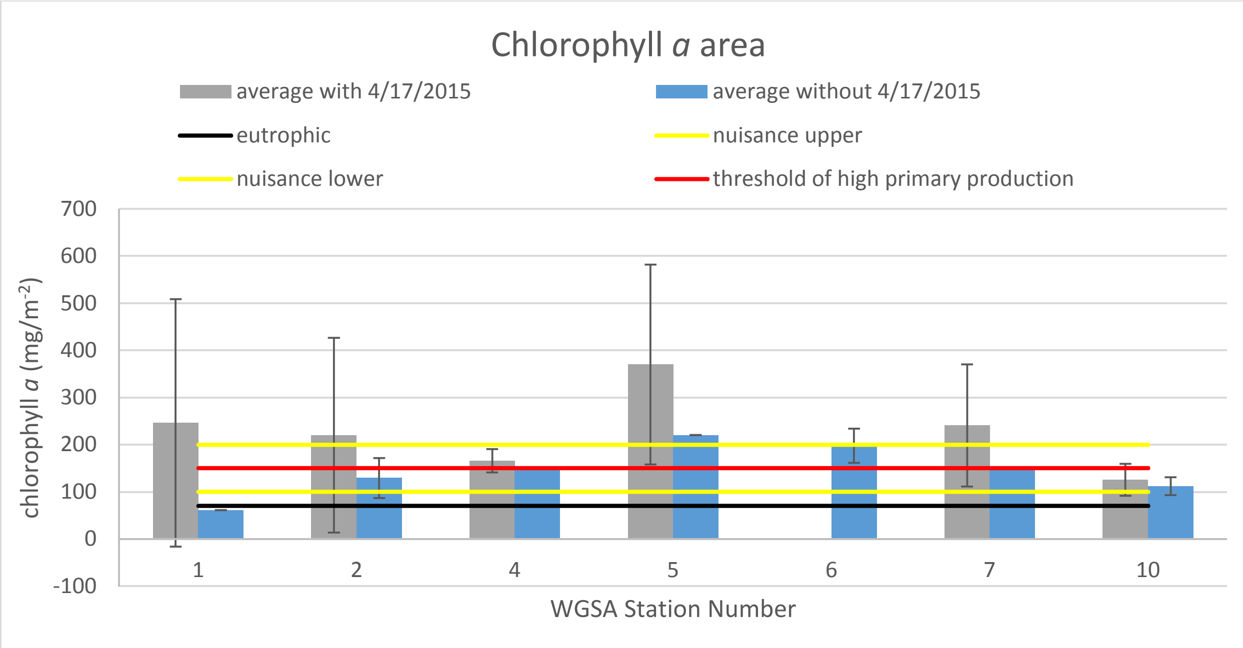

Figure 6.3 Chlorophyll *a* area (mg/ m²) averaged by station with and without 4/17/2015 data. Data was collected and submitted by WGSA and PADEP.

[1] There is no data point for station 6 on 4/17/2015.
[2] Black "eutrophic" line represents threshold of periphyton biomass (on average) considered eutrophic (70), yellow "nuisance" lines represent threshold range considered nuisance (100-200), and the upper bound of the nuisance threshold is also the upper bound of the the threshold of high primary production, red line represents the lower bound of the high primary production threshold (150-200).

Table 6.8 Chlorophyll *a* area (mg/m^2) collected and submitted by WGSA and PADEP.

Collector	Date	Upstream of STP		Downstream of STPs				
		WGSA 1	WGSA 2/ PADEP 1	WGSA 4	WGSA 5	WGSA 6/ PADEP 2	WGSA 7	WGSA 10/ PADEP 3
PADEP	7/9/2014		**92.47**			*238.74*		**92.63**
WGSA	8/28/2014	*60.95*	*183.42*	***148.69***	*220.25*		***149.15***	***132.86***
PADEP	8/29/2014		***141.86***			*186.39*		**99.64**
PADEP	10/15/2014		**99.44**			*168.67*		***123.41***
WGSA	4/17/2015	*431.93*	*583.63*	*183.56*	*519.88*		*332.26*	*178.59*
station average		*246.44*	*220.17*	*166.13*	*370.07*	*197.93*	*240.70*	***125.42***
station average without 4/17		*60.95*	***129.30***	***148.69***	*220.25*	*197.93*	***149.15***	***112.13***
average area		*227.67*		*198.19*				
average area without 4/17		***115.63***		*156.04*				

[1] Italicized values: chlorophyll *a* values greater than 50 mg/m^2
[2] Bold: values between 70 and 100 mg/m^2
[3] Bold italics: values between 100 and 150 mg/m^2
[4] Yellow highlighting: values between 150 and 200 mg/m^2
[5] Red highlighting: values over 200 mg/m^2

6.3.3 Algal Taxonomy Assessment Methodology

EPA assessed diatom taxa data from WGSA as a measure of periphyton taxonomy. Diatoms are a taxonomic group and a major component of the periphyton. The physiological tolerance of freshwater diatom species to environmental conditions is well understood and diatom species have been used as indicators of water quality (trophic conditions) (e.g. Porter, 2008 and references therein, Hausmann, 2016). The value of an assessment of the diatom assemblage is well-stated in EPA (2000b) "biological assemblages that develop over longer periods of time are adapted to the average conditions in those habitats and tolerant to the environmental maxima and minima. Thus … the physical, chemical, and potentially biological conditions for a habitat can be inferred if environmental effects differed among species." WGSA analyzed diatom taxa using the methods of Porter (2008) to place diatom taxa into a trophic index. The methods of Porter (2008) are based on the compilation of data from several studies of diatom species assemblages under varying environmental conditions (refer to Porter, 2008 for a discussion). EPA compared the diatom taxa data to the categories in the trophic index calculated by WGSA from the Porter (2008) methodology.

6.3.4 Results of Algal Taxonomy Assessment

Tables 6.9 and 6.10 display the percent of the diatom community with tolerance for each trophic category as analyzed and presented by WGSA. Diatoms were overwhelmingly the most abundant taxonomic group in all samples (Refer to Appendix B). Diatom species accounted for over 90% of the species found at sites WGSA 1, 2, and 4 in April, and WGSA 1, 2, 4, and 10 in August, and nearly or over 80% at sites WGSA 5, 7, and 10 in April and WGSA 5 and 7 in August. Therefore, EPA assessed the diatom taxa data as a measure of periphyton taxonomy. Results show that all stations in April and August are dominated by species tolerant of eutrophic conditions based on taxonomic composition of the diatom community (Tables 6.9; 6.10). This taxonomy data agrees with the data in Sections 6.2.2, 6.2.4, and 6.3.2.

Table 6.9 Diatom taxa trophic classification analysis for April 2015 sampling. Percent of diatom community with tolerance or optima for different trophic conditions.

Metric	April 2015	Station					
TROPHIC	Condition	1	2	4	5	7	10
	no index score	8	5	2	5	4	4
1	oligotrophic	0	0	0	0	0	0
2	oligotrophic-mesotrophic	0	0	0	0	0	0
3	mesotrophic	0	0	0	1	2	0
4	mesotrophic-eutrophic	3	2	1	2	0	2
5	Eutrophic	49	71	69	51	57	71
6	hypereutrophic	18	9	3	11	6	7
7	indifferent (wide range)	10	10	16	14	7	7

Table 6.10 Diatom taxa trophic classification analysis for August 2014 sampling. Percent of diatom community with tolerance or optima for different trophic conditions.

Metric	August 2014	Station					
TROPHIC	Condition	1	2	4	5	7	10
	no index score	7	7	9	7	20	12
1	oligotrophic	0	0	0	0	0	0
2	oligotrophic-mesotrophic	0	0	0	0	0	0
3	mesotrophic	0	1	3	16	3	2
4	mesotrophic-eutrophic	1	1	2	7	4	4
5	Eutrophic	50	60	46	34	48	58
6	hypereutrophic	1	0	0	3	2	1
7	indifferent (wide range)	24	24	29	10	8	12

6.3.5 Visual Algal Survey Assessment Methodology

The PADEP Field Protocol for Periphyton Standing Crop and Species Assemblages (PADEP, 2013d) recommends that a periphyton field description, visually estimating the percent coverage of periphyton assemblages on the same substrates sampled for standing crop (biomass) and species assemblage be conducted. This method is modified from Biggs (2000) Rapid Assessment

Method 2. WGSA conducted a Periphyton Field Description at each station, whereas PADEP did not conduct a visual algal survey. The method provides a visual estimate of periphyton present at the time of sampling. In this method a nine rock composite sample was collected from each station reach along three transects with three rocks collected per transect (review detailed method description in periphyton biomass section below and PADEP, 2013d). WGSA states "these were the same rocks from which periphyton had been scraped for chlorophyll-*a* analyses." The composite sample was scored by WGSA to estimate percent coverage by algal type and dominant color of the attached algae. Periphyton coverage is qualitatively assessed through this method. The PADEP protocol also states that "macrophyte coverage (ea. moss or river weed) should be noted," (PADEP, 2013d).

Description of algal percent cover can only be evaluated qualitatively due to the absence of any numeric criteria and the specificity of the PADEP (2013d) field protocol. As the field protocol notes: the procedure "provides a qualitative field description (% cover by type, color, growth form) of periphyton assemblages on substrates sampled for standing crop and species assemblage. This visual estimate of coverage will provide some description without significantly increasing sampling effort at each station. Visual descriptions may provide an inexpensive screening tool if they are found to correlate with periphyton standing crop," (PADEP 2013d). EPA (2000b) also notes that estimates of percent cover of periphyton is an indicator of algal biomass problems and intensity and increases as enrichment increases. Other states (e.g., West Virginia) have relied on this relationship and measure percent cover of filamentous algae to evaluate impacts to recreational uses (WVDEP 303(d) Listing Methodology for Algae Blooms). PA's visual algal surveys are not designed to allow comparison to those recreational use end points yet can still be indicative of changes in algal biomass intensity representative of enrichment.

6.3.6 Results of Visual Algal Survey Assessment

Qualitatively, algal survey August 28, 2014 samples show a decrease in bare substrate and an increase in moss and algal coverage in sampling locations downstream of STPs, as well as an overall increase in algal and moss coverage from the upstream stations to a maximum at WGSA 5, just downstream of the WGSA STP followed by a gradual decline (Figure 6.4, Table 6.11). This increase in coverage of photosynthetic biomass downstream of the two STPs qualitatively indicates an autotrophic response to nutrient enrichment. This pattern mirrors the periphyton biomass data when April 17, 2015 data are excluded (Figure 6.3) as well as the TP and TN data, suggesting that estimates of percent cover track enrichment.

April 17, 2015 visual survey results are similar to the periphyton biomass results when April 17, 2015 data are included in the average. WGSA 1 and 2 have high coverage compared to other stations (Figure 6.5). WGSA 1 and 2 are dominated by filamentous algae and mats while WGSA 4-10 include moss and algae (Figure 6.5, Table 6.11, 6.12). The presence of algal mats was also recorded at WGSA 4, 5, and 7 and filaments at WGSA 5, 7, and 10 (Table 6.11, 6.12). Similar to the August data, in April moss coverage is first recorded at WGSA 4 and reaches a peak at WGSA 5, downstream of the two STPs (Figure 6.5). The spring data demonstrate that algae is present at all stations, even where moss is present.

WGSA had concerns about a sanitary pipe break in Goose Creek upstream of WGSA 1 and 2 which it said may have affected nutrient concentrations in the stream, and algal data collected on April 17, 2015. However, WGSA, in its own report, notes that "periodic water chemistry sampling by WG [West Goshen] on April 25 showed no residual effect on nutrient levels," nor did WGSA data collected on April 23, 2015, which was submitted to EPA as part of the reassessment (WGSA and GHD, 2015). Therefore, a sanitary pipe break is not likely to be the explanation for any of the periphyton data. Further, April data represents spring samples where conditions of maximal light availability were present. WGSA 1 and 2, as discussed in Section 6.3.2, are the most shaded stations after leaves emerge in summer. Thus, these stations are expected to show the greatest response to full light (spring) versus shaded (summer) conditions. It is also interesting that the percent coverage of algal mats (WGSA 1 = 23 percent; WGSA 2 = 31 percent) and filaments (WGSA 1 = 51 percent; WGSA 2 = 22 percent) together was very large and dominated (mats and filaments at WGSA 1 = 74 percent; WGSA 2 = 53 percent) the primary producer community at these two stations while moss is only recorded downstream of the STPs where it dominates the primary producer community (Figure 6.5, Table 6.11, 6.12). Although the visual algal survey results are qualitative in nature, the results do point toward an increase in plant growth downstream of the STPs, as well as an increase in plant growth under higher light conditions. This increase in coverage of photosynthetic biomass downstream of the STPs qualitatively indicates an autotrophic response to nutrient enrichment. These results support that added nutrients supplied by the STPs is clearly causing excess primary production (described in more detail in section 6.3.2) and contributing to the aquatic life use impairment of Goose Creek.

In addition, as noted in Section 4.1, EPA noted handling of rocks during algal sampling which may have impacted the representativeness of the algal survey data. Please refer to Section 6.3.6.1 for a discussion of different types of primary producers in Goose Creek.

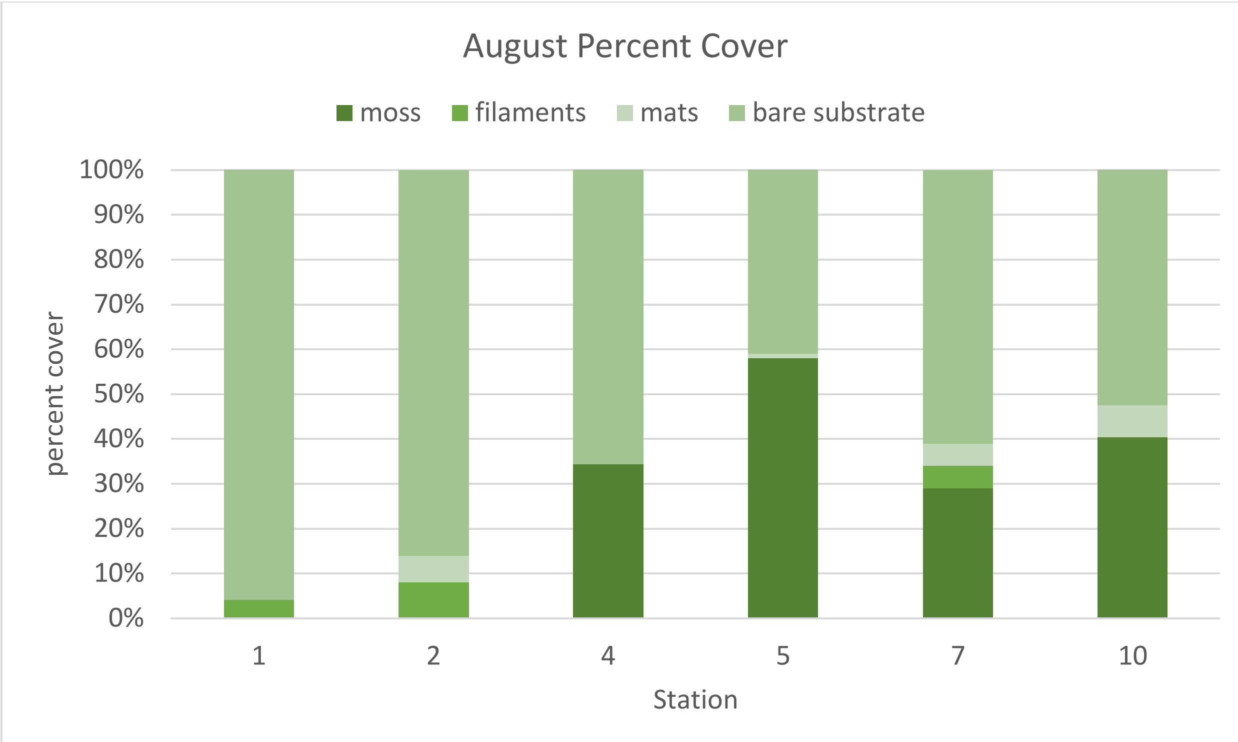

Figure 6.4 Percent cover of rock composite samples collected during visual algal survey on August 28, 2014 by WGSA.

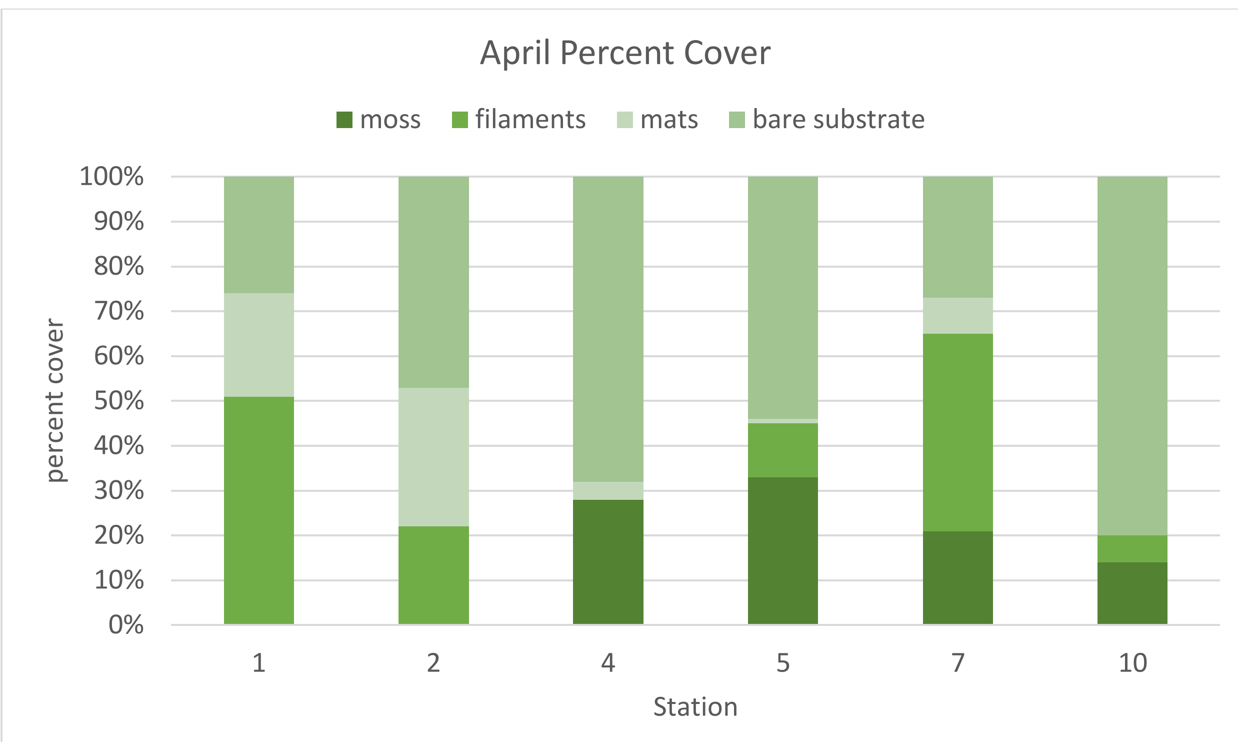

Figure 6.5 Percent cover of rock composite samples collected during visual algal survey on April 17, 2015 by WGSA.

Table 6.11 Percent cover of WGSA rock composite samples collected during visual algal survey on August 28, 2014 and April 17, 2015.

	Average Percent Cover (%)											
	Station 1		Station 2		Station 4		Station 5		Station 7		Station 10	
Sample Date	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015
Periphyton Class												
Thin Mat/Film												
Green	0	2	0	0	0	3	1	1	5	0	6	0
(under 0.5 mm) Light Brown	0	0	0	0	0	0	0	0	0	0	0	0
Black/Dark Brown	0	10	6	31	0	0	0	0	0	2	1	0
Medium Mat												
Green	0	11	0	0	0	1	0	0	0	0	0	0
(0.5-3mm) Light Brown	0	0	0	0	0	<1	0	0	0	0	0	0
Black/Dark Brown	0	0	0	0	0	0	0	0	0	0	0	0
Thick Mat												
Green	0	0	0	0	0	0	0	0	0	6	0	0
(>3mm) Light Brown	0	0	0	0	0	0	0	0	0	0	0	0
Black/Dark Brown	0	0	0	0	0	0	0	0	0	0	0	0
Filaments (Short)												
Green	4	9	8	1	0	0	0	0	<1	14	0	0
(<2cm) Brown/Reddish	0	0	0	0	0	0	0	0	0	0	0	0
Filaments (Long)												
Green	0	42	0	21	0	<1	0	12	5	30	<1	6
(>2cm) Brown/Reddish	0	0	0	0	0	0	0	0	0	0	0	0
Other:												
Moss	<1	0	<1	<1	34	28	58	33	29	21	40	14
Bare Rock/Mud/Silt film on Rock	95	26	86	47	65	68	24	54	61	27	50	80
Sand	-	-	-	-	-	-	17	-	-	-	2	-
Total Mats	0	23	6	31	0	4	1	1	5	8	7	0
Total Filaments	4	51	8	22	0	0	0	12	5	44	0	6
Total Bare Substrate	95	26	86	47	65	68	41	54	61	27	52	80

Table 6.12 Percent cover of WGSA rock composite samples collected during visual algal survey on August 28, 2014 and April 17, 2015.

	Average Percent Cover (%)											
	Station 1		Station 2		Station 4		Station 5		Station 7		Station 1	
Sample Date	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015	August 2014	April 2015	August 2014	A 20
Periphyton Class												
Total Thin Mat/Film	0	12	6	31	0	3	1	1	5	2	7	
Total Medium Mat	0	11	0	0	0	1	0	0	0	0	0	
Total Thick Mat	0	0	0	0	0	0	0	0	0	6	0	
Total Mats	0	23	6	31	0	4	1	1	5	8	7	
Total Filaments Short	4	9	8	1	0	0	0	0	0	14	0	
Total Filaments Long	0	42	0	21	0	0	0	12	5	30	0	
Total Filaments	4	51	8	22	0	0	0	12	5	44	0	
Total Bare Substrate	95	26	86	47	65	68	41	54	61	27	52	8

6.3.6.1 Types of Primary Producers Present in Goose Creek

Percent cover of moss in Goose Creek downstream of the STPs is high (Section 6.3.6). On August 28, 2014 EPA staff observed dense moss mixed with *Cladophora* (an algae) at WGSA 5 in Goose Creek, just downstream of the two STPs. Similarly, WGSA recorded 58% coverage of moss in their visual algal survey and measured 220.25 mg chlorophyll a/m^2 in their periphyton biomass assessment at WGSA-5 on August 28, 2014, which exceeds the 150-200 mg chlorophyll a/m^2 threshold of high primary production (see Section 6.3.1, 6.3.2). On August 28, 2014 EPA staff also observed moss at WGSA 4, downstream of the West Chester Borough STP, and moss mixed with *Cladophora* at WGSA 5 and WGSA 7, both downstream of the West Chester Borough STP and the WGSA STP (see Figure 4.1). Similarly, WGSA recorded high moss coverage on August 28, 2014 at all stations downstream of one (WGSA 4) or both (WGSA 5, 7, and 10) STPs in their visual algal survey (WGSA 4=34%; WGSA 5=58%; WGSA 7=29%; WGSA 10=40%; see Section 6.3.6). High moss coverage potentially smothers stream habitat, which can negatively impact both fish and macroinvertebrate reproduction. The Stream Bryophyte[7] Group (1999) states "it is clear that bryophytes can profoundly influence both the abundance and community structure of stream invertebrates." They go on to state "the presence of the bryophytes alters the physical structure of the stream, providing increased surface area for periphyton and new habitat for some invertebrate species. The structure of the insect community may change as a result because the bryophytes may interfere with the activities of filter feeders and provide a new habitat for shredders and collector-gathers." Thus, while certain groups of invertebrates may increase in abundance, other groups may decrease in abundance. Excess moss blankets a stream bottom (similar to filamentous algae) limiting macroinvertebrates ability to access the underside of rocks. Many sensitive macroinvertebrates, such as stoneflies and mayflies (Lenat and Penrose 1996 cited in PADEP 2012, p 58), thrive on the underside of rocks. Therefore, the excess moss likely limits the habitat for sensitive species contributing to the impaired aquatic life use found in Goose Creek, while at the same time it can induce the proliferation of tolerant taxa (discussed in Section 6.5.1).

An expert from EPA's Freshwater Biology Team, Greg Pond, reviewed the series of photographs of primary producer coverage on the collected rock samples, which were provided by WGSA. According to Pond, the photographs at stations 4 through 10, downstream of the STPs, show that where mosses were dominant, substrates were mixed with abundant *Cladophora*, a macroalgae (Pond, 2017). The *Cladophora* was growing on the surface of the rocks and on the surface of the moss. Ylla (2007) also found moss and macroalgae in a forested stream to be covered in diatoms (algae) growing on the surface, which the author noted can greatly contribute to the photosynthesis and metabolism of the moss-algal complex. In a visual survey the contribution of algae growing on the surface of the moss could easily be underestimated. The WGSA photos and the results of the visual survey clearly suggests that algae (upstream of the STPs) or a mix of algae and moss (downstream of the STPs) are the dominant primary producers present in the creek. No quantification of the amount of moss was made; the only information available is from a qualitative visual survey, which notes the presence of both algae and moss downstream of

[7] Bryophytes are a group of plants that includes mosses (Stream Bryophyte Group, 1999).

the STPs, and algae upstream. Therefore, a consideration of periphyton and benthic algal thresholds are valid and relevant to this analysis.

The taxonomy (e.g., species or even type of plant) of the material visually identified as "moss" and presumed by WGSA to be "probably *Fontinalis* sp." was never quantified. In contrast, the types of algae present were determined via the taxonomy analysis, wherein diatoms were found to be overwhelmingly abundant at all sites (Section 6.3.4) with an unidentified cyanophyte also making up a large proportion of the algal community at WGSA 5 and 6 in August (Appendix B). However, this methodology only taxonomically identified algal species, not macrophytes such as mosses.

Macrophytes like moss respond to nutrient enrichment in the same way that algae do, by increasing photosynthetic rate and resulting primary production (EPA, 2000b). Macrophytes may grow to nuisance levels as a result of nutrient enrichment (EPA, 2000b). Mosses and algae respond to nutrient enrichment in a similar manner but with a different magnitude (Glime, 2014, Ylla, 2007). For example, nutrient uptake rates and metabolic rates (i.e., photosynthesis and respiration) in moss are lower than those in algae (Ylla, 2007, Glime, 2014). Lower rates of photosynthesis and respiration in moss compared to algae would lead to lower magnitude inputs of dissolved oxygen and removals of carbon dioxide during photosynthesis and, during respiration, lower magnitude removals of dissolved oxygen and inputs of carbon dioxide gas (CO_2). This would cause lower maxima and minima in DO and pH which would result in DO and pH swings of a smaller magnitude. This suggests that violations of numeric criteria for DO and pH may be less likely in a moss dominated versus an algal dominated system. However, the PADEP cause definition states that violations of numeric water quality criteria for DO and/or pH are not required for aquatic life use impairment to be present, thus aquatic life use impairment may still be occurring when violations occur and when they do not (refer to Sections 6.4.1 and 6.4.2 for a discussion).

6.3.7 Toxicity to Algae Assessment Methodology

EPA analyzed algal toxicity data from PADEP to evaluate if any toxicity was present. PADEP collected grab samples from three locations (PADEP-1, PADEP-2, and PADEP-3) on Goose Creek on September 19, 2013 and July 30, 2014 and sent samples to American Aquatic Testing, Inc. (AAT). To determine if any substances toxic to algae were present in Goose Creek that may inhibit algal growth, AAT employed EPA Method 1003.0 Green Alga, *Selenastrum capricornutum*, Growth Test, which consisted of exposing a green algae (*Selenastrum*) to Goose Creek site water to determine if algal growth is inhibited. Culture medium is formulated in the laboratory to contain 0.186 mg/L of phosphorus and 4.2 mg/L of nitrogen.

In addition, EPA evaluated algal toxicity data to determine if biostimulation occurred as outlined in section 14.13.3 in EPA Method 1003.0. Biostimulation is evaluated by determining if the growth response in effluent (or surface water) exceeds growth in the control flasks, the percent stimulation, S (%), is calculated. Values which are significantly greater than the control indicate a possible degrading enrichment effect on the receiving water (Walsh and Horning, 1980). Biostimulation or enrichments effects demonstrated by toxicity testing results are an indicator that water from test sites is nutrient enriched and has the capacity to promote excess algal growth.

6.3.8 Results of Toxicity to Algae Assessment

In the algal assay, while toxicity was not found, Goose Creek surface water exhibited a significant biostimulatory effect over the control (Section 6.3.7) which indicates a possible degrading enrichment effect (Table 6.13, Figure 6.6) due to elevated nutrient concentrations. To evaluate biostimulation and possible negative enrichment impacts, on September 19, 2013 and July 30, 2014, PADEP collected algal toxicity samples from three Goose Creek stations. In addition to the Goose Creek locations, algal toxicity samples were collected on July 30, 2014 from Wissahickon Creek and Rock Run for comparison against Goose Creek. Wissahickon Creek is an effluent dominated stream in southeastern Pennsylvania that has been identified as aquatic life use impaired by PADEP due to nutrients and siltation (PADEP, 2016b). The PADEP listing as "cause" "nutrients" does not specify whether the listing is based on phosphorus or nitrogen. However, in their 2016 Integrated Water Quality Monitoring and Assessment Report PADEP has listed Wissahickon Creek as impaired due to nutrients in IR category 4a-impaired with an approved TMDL for TP and siltation. Rock Run is a stream in Chester County attaining aquatic life use water quality standards and does not exhibit any known nutrient stress.

Samples collected at PADEP-1 and PADEP-2 on September 19, 2013 exhibited a stimulatory effect as compared to the control. Samples collected on July 30, 2014 exhibited a similar stimulatory effect for all the Goose Creek Stations as compared to Wissahickon Creek at Rt. 73 (nutrient impaired stream), when compared to the control. On the other hand, Rock Run, an aquatic life use attaining stream was not significantly different from the control. The stimulatory effect in Goose Creek (PADEP-2 and PADEP-3) and Wissahickon Creek was expected based on the high phosphorus and nitrogen concentrations (Figures 6.1 and 6.2) relative to the control media. PADEP-2 (downstream of wastewater plant discharges) had the highest level of algal stimulation. Both Goose Creek and Wissahickon Creek, a known nutrient impaired stream, have elevated nutrient concentrations that supported Selenastrum growth in the lab experiment. More simply stated, algal growth in the lab experiment demonstrated that elevated nutrient concentrations in Goose Creek will support increase algal growth when compared to the lab control and the unimpaired Rock Creek.

The algal toxicity test results indicate the water quality of Goose Creek contains elevated levels of nutrients sufficient to support Selenastrum growth similar to a known nutrient impaired stream (Wissahickon Creek).

Table 6.13 Percent Biostimulation of Stream Samples vs. Control

Date	PADEP 1	PADEP 2	PADEP 3	Rock Run	Wissahickon Creek at Rt. 73
9/19/2013	26	21	12	no sample	no sample
7/30/2014	23	29	17	-3	17

Highlighted % stimulation are significantly greater than control ($p<0.05$)

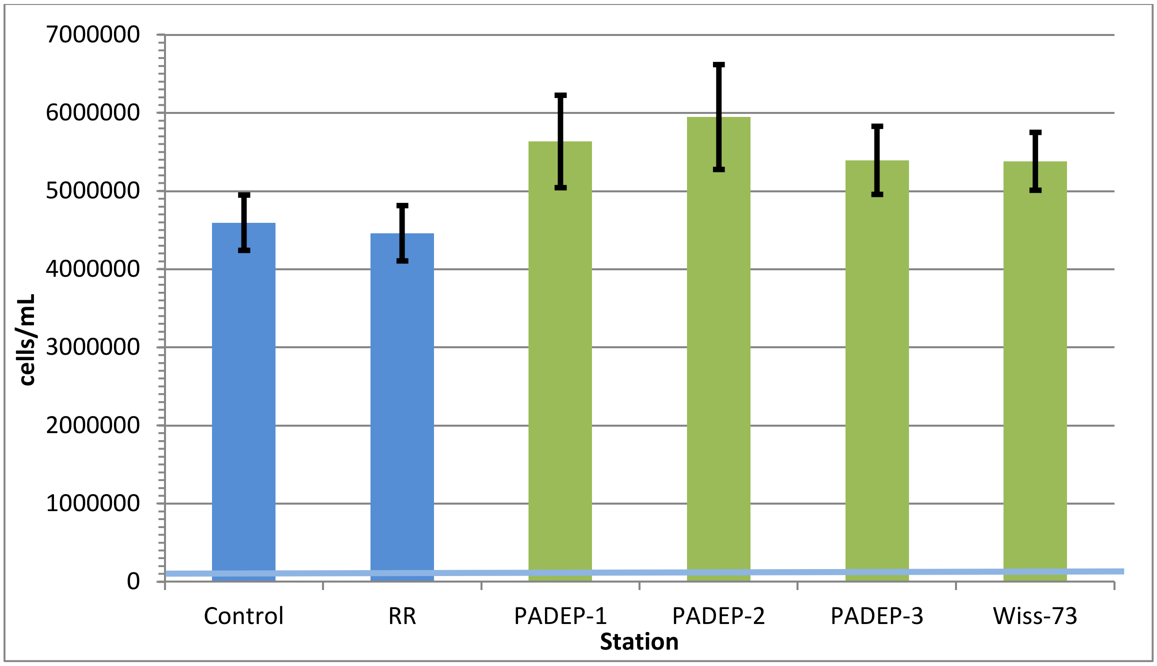

Figure 6.6 Graph comparing levels of green algae *Selenastrum* from July 30, 2014 algal toxicity samples of a control, Rock Run (RR), Goose Creek Stations (PADEP- 1, 2, and 3) and Wissahickon Creek (Wiss-73).

6.4 Dissolved Oxygen and pH Assessment Methodology and Results

EPA evaluated DO and pH continuous instream monitoring data collected by WGSA and PADEP against the Pennsylvania numeric water quality criteria (25 PA Code §93.7) for DO and pH to assess the data for exceedances of the criteria. Exceedances were identified when the criteria were not met 99% of the time, which is based on PADEP's implementing regulations. EPA also assessed DO and pH against Pennsylvania's cause definitions for water quality impairments as they relate to nutrients and the narrative criteria (25 PA Code §93.6). To assess DO and pH for the narrative criteria, EPA evaluated the data for the presence of excessive daily fluctuations and compared those results to an unimpaired reference watershed. The reference watershed used as comparison was Birch Run, which is located in the Northern Piedmont Ecoregion, has IBI scores above the impairment threshold, and is of similar watershed size to Goose Creek. For more information on the reference watershed comparison, see Appendix A. The data evaluated for Goose Creek included: data from sondes that PADEP deployed from April to October 2014 at PADEP-1, and from May to November 2014 at PADEP-2 and PADEP-3 and data from one sonde deployed by WGSA at site WGSA-4 from July to October 2014. Data from the reference site, Birch Run, sonde deployed by PADEP was collected from 3/3/2016 to 12/13/2016.

Pennsylvania numeric water quality criteria for the designated uses assigned in Goose Creek (discussed in Section 3.1) state that DO should not fall below 5.0 mg/L at any time, and 7-day averages from the period February 15 to July 31st of any year should not fall below 6.0 mg/L while 7-day averages for the remainder of the year (August 1 to February 14th) should not fall below 5.5 mg/L (discussed in Section 3.3 above). Pennsylvania numeric water quality criteria state that pH should be from 6.0 to 9.0 inclusive. PA's cause definitions for nutrients state that "excessive daily fluctuations in dissolved oxygen and pH caused by high primary production resulting from elevated levels of phosphorus and/or nitrogen" should not be present. Further, PA's cause definitions state that: "Biological impairment may occur based on general (narrative) criteria violations. Accompanying violations of 93.7 specific water quality criteria for dissolved oxygen or pH are not required," (refer to Section 3.4 above). PADEP's criteria implementing regulations (25 PA Code 96.3) require that most criteria not be exceeded 99% of the time.

6.4.1 Results of Dissolved Oxygen Numeric Criteria Assessment

Pennsylvania numeric criteria state that DO should not fall below 5.0 mg/L at any time, and 7-day averages from the period February 15 to July 31st of any year should not fall below 6.0 mg/L while 7-day averages for the remainder of the year (August 1 to February 14th) should not fall below 5.5 mg/L. The cause definitions for nutrients state that "excessive daily fluctuations in dissolved oxygen and pH caused by high primary production resulting from elevated levels of phosphorus and/or nitrogen" should not be present. The analysis in this section will discuss the DO and pH data, compare it to its respective numeric criteria, and will discuss the presence of daily fluctuations. The relationship between daily fluctuations and primary production will be discussed in the impairment assessment results section 7 below. Figure 6.7 displays DO continuous instream monitoring (CIM) data from PADEP 1, 2, and 3, while Figures 6.8, 6.9, 6.10, and 6.11 display DO CIM data from PADEP 1, 2, 3, and WGSA 4, respectively. The accuracy of the CIM data for PADEP 1, 2, and 3 are discussed in Appendix A. Table 6.14 shows the number and percent of days in the data for each site that exceeded the 5.0 mg/L DO numeric criterion, as well as the percent of data points that exceeded this criterion. Table 6.15 lists consecutive days of DO below 5.0 mg/L at each station. Tables 6.15 and 6.16 list data that exceeded the 7-day averaged standards.

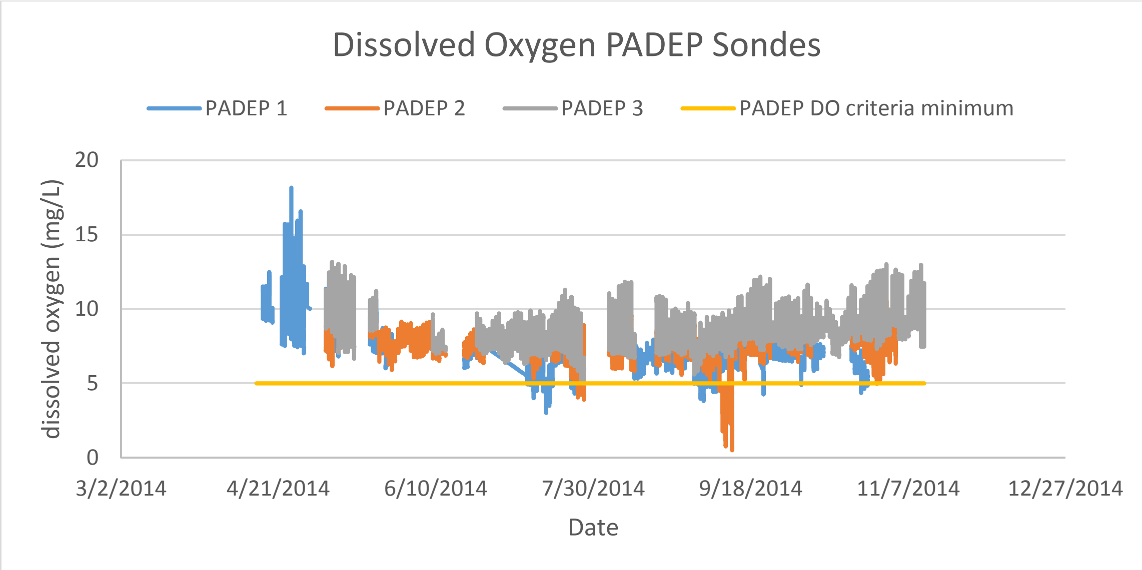

Figure 6.7 Dissolved oxygen (mg/L) over time from PADEP sondes at sites PADEP 1, PADEP 2, and PADEP 3.

Table 6.14 DO Exceedances of Numeric Criterion Minimum Threshold 5.0 mg/L

	Station			
	PADEP-1	WGSA-4	PADEP-2	PADEP-3
days DO below 5.0 mg/L	23	0	9	1
% days DO below 5.0 mg/L	18.4	N/A	7.2	N/A
% of data points below 5.0 mg/L	5.4	N/A	3.4	0.01

Table 6.15 Consecutive Days of DO below 5.0 mg/L

	Start Date	End Date	# consecutive days	Station
1	7/9/2014	7/12/2014	4	PADEP-1
2	7/14/2014	7/17/2014	4	PADEP-1
3	7/23/2014	7/24/2014	2	PADEP-1
4	9/1/2014	9/7/2014	7	PADEP-1
5	10/23/2014	10/25/2014	3	PADEP-1
6	7/25/2014	7/27/2014	3	PADEP-2
7	9/8/2014	9/12/2014	5	PADEP-2

Table 6.16 Dates from February 15, 2014 to July 31, 2014 where 7-day averaged DO Exceeded the 6.0 mg/L Criterion Minimum Threshold

	Start Date	End Date	7-day average (mg/L)	Station
1	7/9/2014	7/15/2014	5.258	PADEP-1
2	7/10/2014	7/16/2014	5.152	PADEP-1
3	7/11/2014	7/17/2014	5.204	PADEP-1
4	7/12/2014	7/18/2014	5.522	PADEP-1
5	7/13/2014	7/19/2014	5.782	PADEP-1
6	7/14/2014	7/20/2014	5.976	PADEP-1
7	7/27/2014	8/2/2014	5.661	PADEP-3

Table 6.17 Dates from August 1, 2014 to February 14, 2014 where 7-day averaged DO Exceeded the 5.5 mg/L Criterion Minimum Threshold

	Start Date	End Date	7-day average (mg/L)	Station
1	8/31/2014	9/6/2014	5.404	PADEP-1
2	9/1/2014	9/7/2014	5.226	PADEP-1
3	9/2/2014	9/8/2014	5.371	PADEP-1
4	10/25/2014	10/31/2014	5.419	PADEP-1
5	9/4/2014	9/10/2014	5.479	PADEP-2
6	9/5/2014	9/11/2014	5.273	PADEP-2
7	9/6/2014	9/12/2014	4.797	PADEP-2
8	9/7/2014	9/13/2014	4.895	PADEP-2
9	9/8/2014	9/14/2014	5.025	PADEP-2
10	9/9/2014	9/15/2014	5.302	PADEP-2

The DO sonde data collected by PADEP (Figures 6.7, 6.8) shows that at PADEP 1 DO levels were below the 5.0 mg/L minimum threshold at least one time each day on a total of 23 days (Table 6.14), including consecutive days in much of July, early September, and late October (Table 6.15). Consecutive days of low DO levels are especially stressful to aquatic life. These 23 days with DO below 5.0 mg/L represent 18.4% of the days with data available (Table 6.14). The number of individual data points (298) that fell below 5.0 mg/L represent 5.4% of the total data points (5535) (Table 6.14). These failures to meet the minimum DO criterion for 5.4% of the data represent compliance with the criterion *less than* 99% of the time. PADEP's criteria implementing regulations require that most criteria be met 99% of the time.

At PADEP-1 the 7-day average 6.0 mg/L minimum threshold from February 15 to July 31 was not met 6 times in 2014 (Table 6.16). This represents 12.24% of the data. At PADEP-1 the 7-day average 5.5 mg/L minimum threshold for the remainder of the year was not met 4 times in

2014 (Table 6.17). This represents 5.26% of the data. These 10 failures to meet the 7-day average minimum thresholds represent 10 week-long (7-day) periods of time where average DO fell below the DO minimum criterion. In addition, these 10 failures to meet the 7-day average minimum thresholds represent the numeric DO criteria being met *less than* 99% of time, where implementing regulations require criteria to be met *at least* 99% of the time. These exceedances indicate an impairment of the aquatic life use due to low DO.

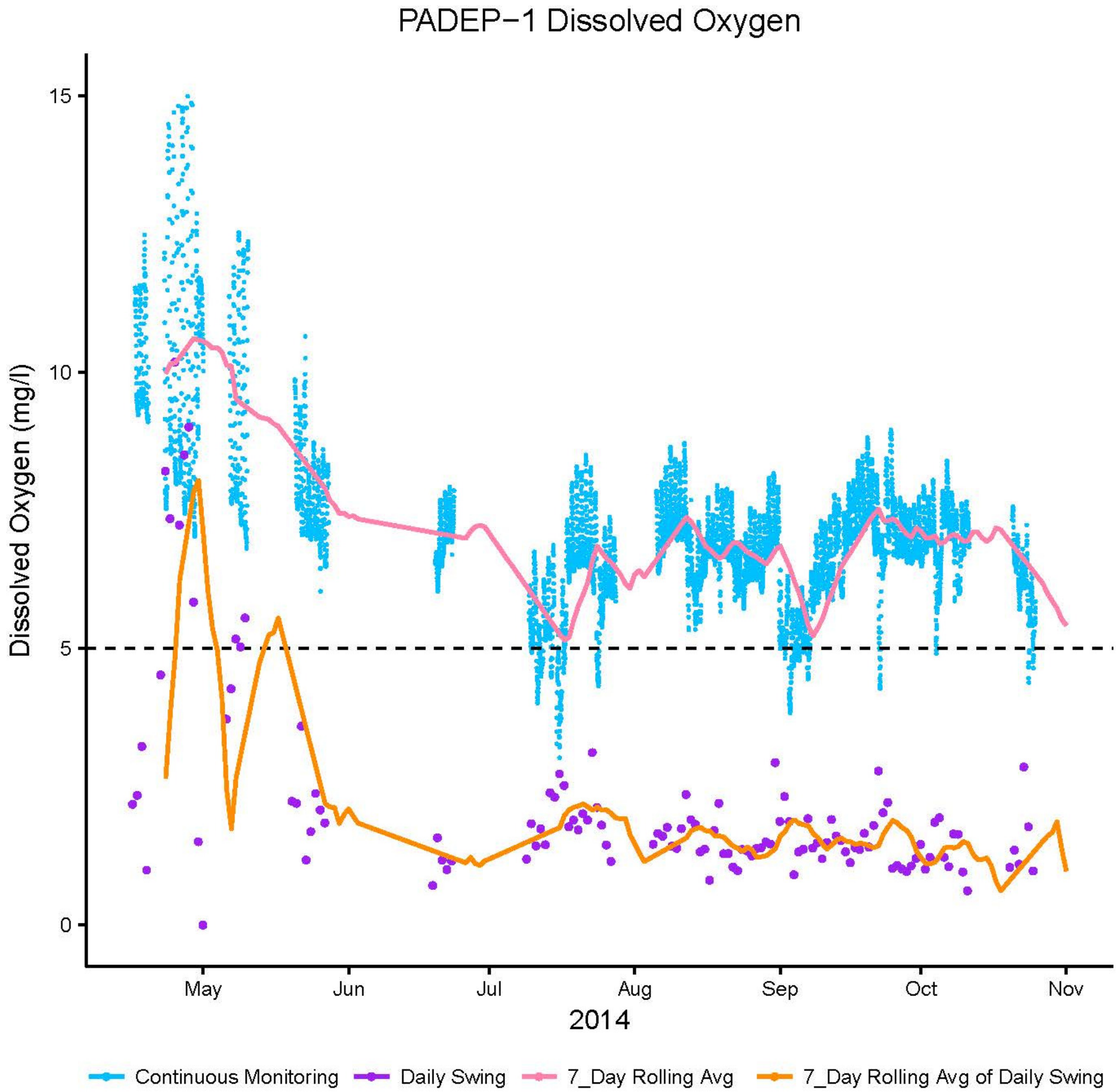

Figure 6.8 Dissolved oxygen (mg/L) from PADEP sonde at PADEP-1.

The DO sonde data collected by PADEP (Figures 6.7, 6.9) shows that at PADEP 2, DO levels were below the 5.0 mg/L minimum threshold at least one time each day on a total of 9 days (Table 6.14), including consecutive days in July and September (Table 6.15). Consecutive days of low DO levels are especially stressful to aquatic life. These 9 days with DO below 5.0 mg/L represent 7.2% of the days with data available (Table 6.14). The number of data points (193) that fell below 5.0 mg/L represent 3.4% of the total data points (5636) (Table 6.14). These failures to meet the minimum DO standards for 3.4% of the data represent compliance with the criterion *less than* 99% of the time. PADEP's criteria implementing regulations require that most criteria be met 99% of the time.

At PADEP-2 the 7-day average 6.0 mg/L minimum threshold was met from February 15 to July 31, 2014. The 7-day average 5.5 mg/L minimum threshold for the remainder of the year was not met 6 times in 2014 (Table 6.17). This represents 7.89% of the data. These 6 failures to meet the 7-day average minimum thresholds represent 6 week-long (7-day periods) where average DO fell below the DO minimum criterion. In addition, these 6 failures to meet the 7-day average minimum thresholds represent the numeric DO criteria being met *less than* 99% of time, where implementing regulations require criteria to be met *at least* 99% of the time. These exceedances indicate an impairment of the aquatic life use due to low DO.

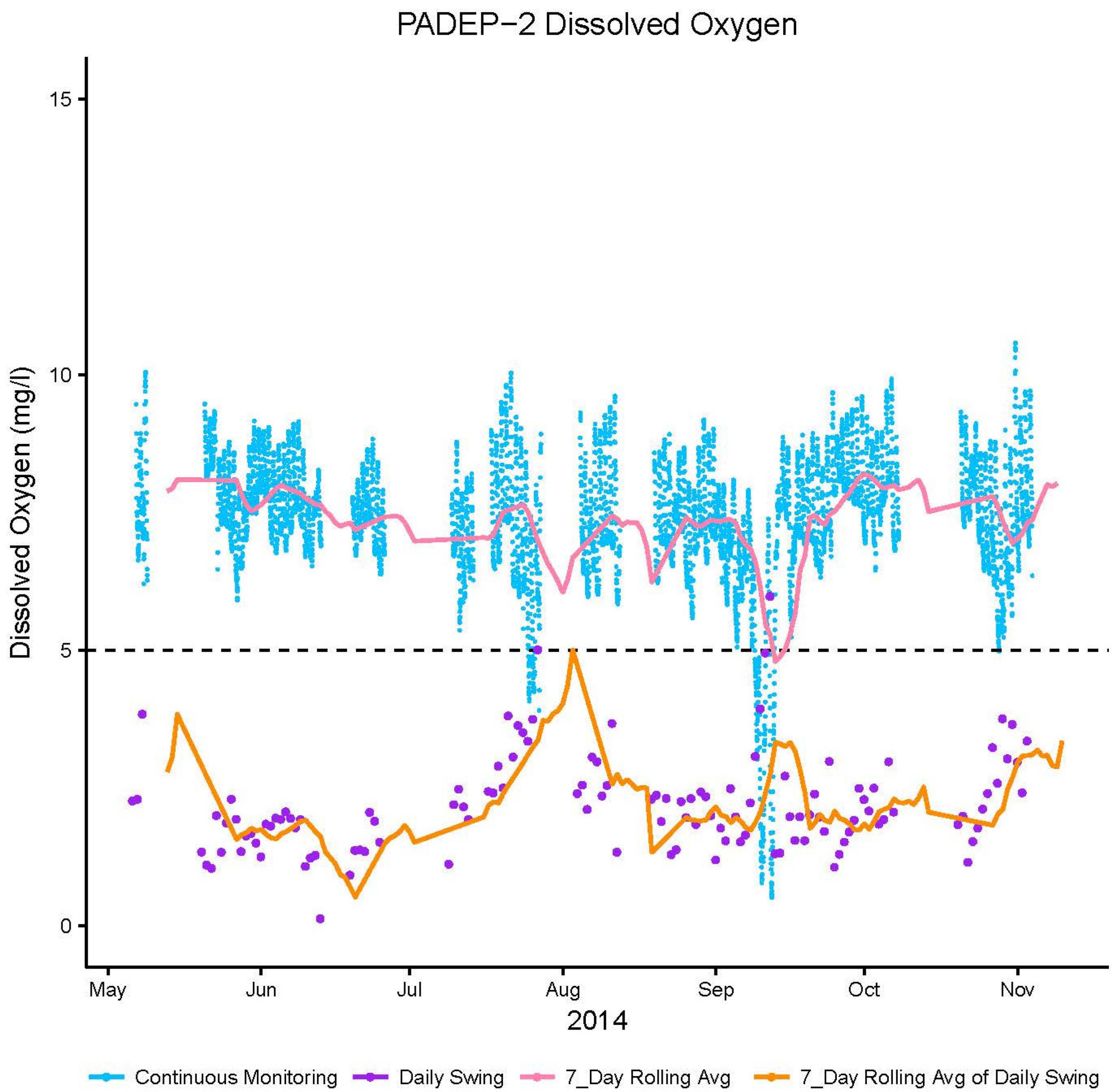

Figure 6.9 Dissolved oxygen (mg/L) from PADEP sonde at PADEP-2.

The DO sonde data collected by PADEP (Figures 6.7, 6.10) shows that at PADEP 3 DO did not meet the 5.0 mg/L minimum threshold for at least 1 data point on 1 day (7/27/2014) (Table 6.14). This 1 data point out of 6803 total data points represents 0.01% of the data (Table 6.14). At PADEP-3, the stream is meeting Pennsylvania's DO criteria.

At PADEP-3 the 7-day average 6.0 mg/L minimum threshold from February 15 to July 31 was met in 2014 (Table 6.16). The 7-day average 5.5 mg/L minimum threshold was met for the remainder of 2014.

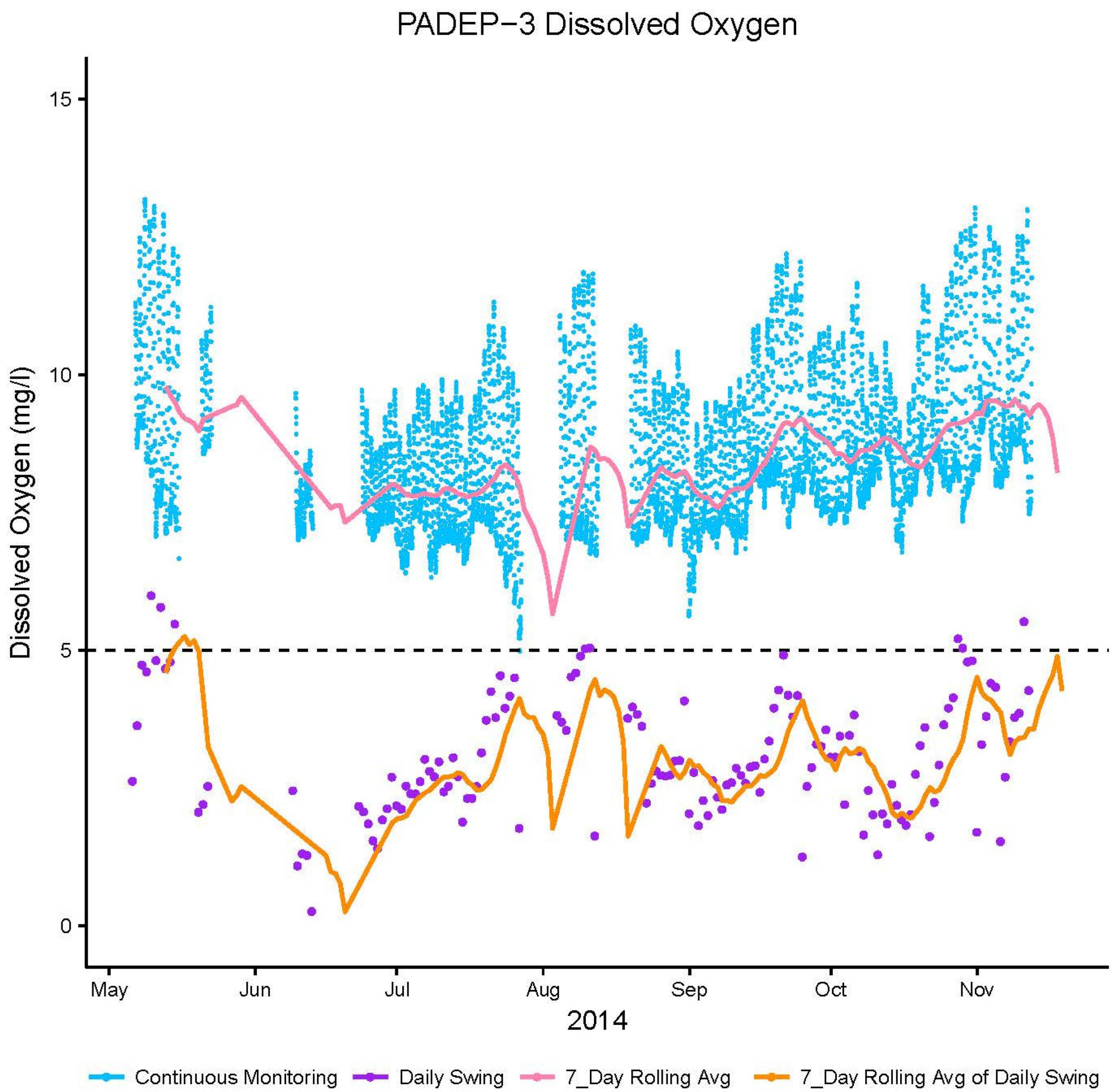

Figure 6.10 Dissolved oxygen (mg/L) from PADEP sonde at PADEP-3.

The DO sonde data collected by WGSA (Figure 6.11) shows that at WGSA-4 DO did not fall below 5.0 mg/L for any measurements or days (Table 6.14). The 7-day average 6.0 mg/L minimum threshold for the period February 15 to July 31, and the 7-day average 5.5 mg/L minimum threshold for the remainder of the year, were met in 2014. At WGSA-4 DO in the stream appear to be meeting the Pennsylvania standards for DO. WGSA cleansed their sonde data using a method described in Appendix B of their report, which differed from the method PADEP used to cleanse its sonde data. The data presented by WGSA may not meet requirements for QA/QC. Refer to discussion in section 4.1 and Appendix A.

Based on these data, the Pennsylvania numeric DO criterion minimum of 5 mg/L is exceeded in 5.4% and 3.4% of the data for PADEP 1 and PADEP 2, respectively. Implementation requirements in Chapter 96 require that most criteria be met 99% of the time (as discussed above). In addition, the numeric DO criterion minimum of 5 mg/L is exceeded for several sets of consecutive days at PADEP-1 and PADEP-2 and the numeric criterion minimum for 7-day average is exceeded several times at all PADEP stations (as discussed above). The multiple DO failures support that Goose Creek is impaired for DO. The failures to meet the minimum DO criterion are significant because minimum DO represents lethal levels to sensitive aquatic life (EPA, 1986).

In addition, PADEP included a DO impairment for Goose Creek in their draft 2016 IR based on their own continuous monitoring data which EPA's analysis confirms.

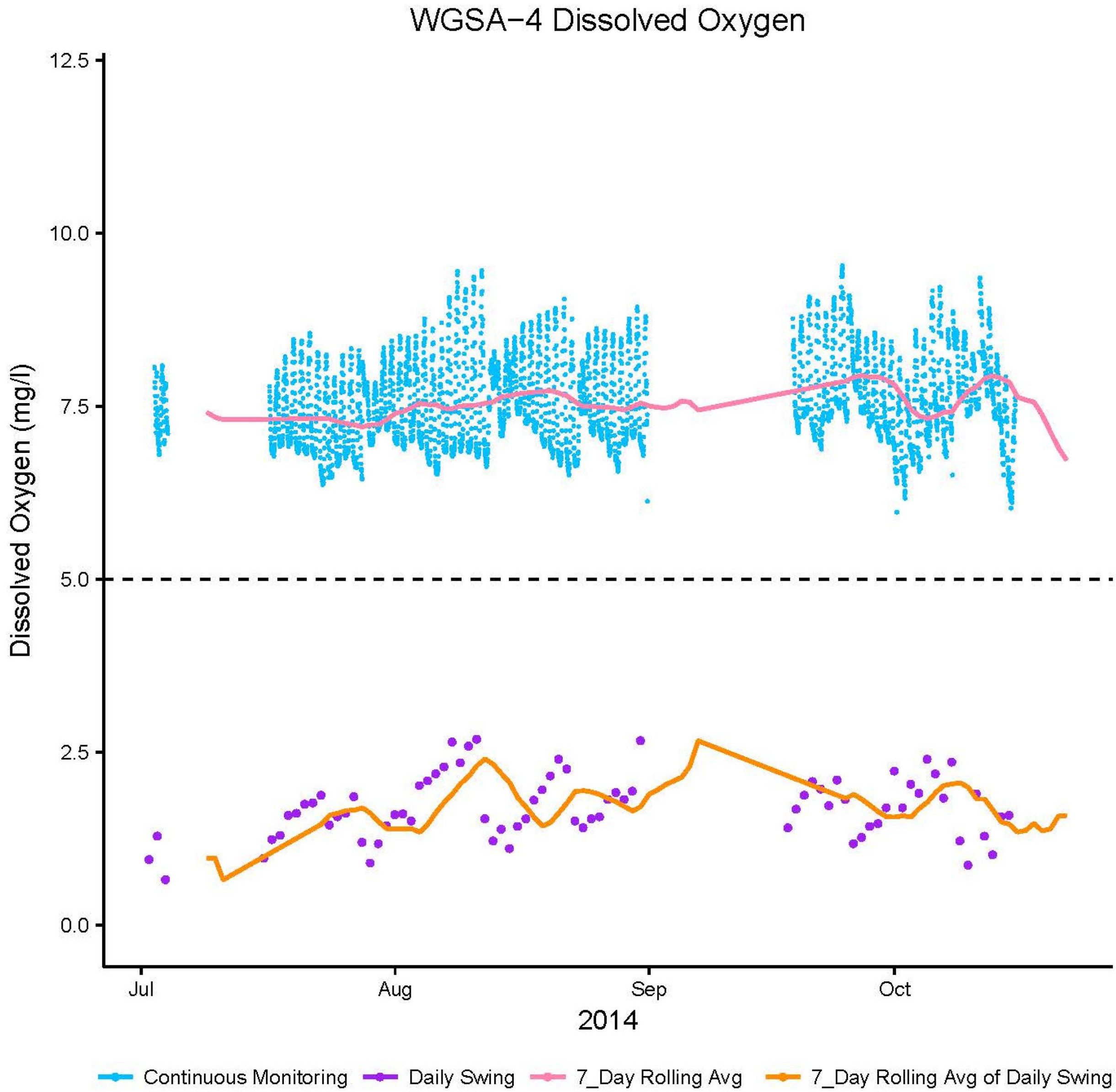

Figure 6.11 Dissolved oxygen (mg/L) from WGSA sonde at site WGSA-4.

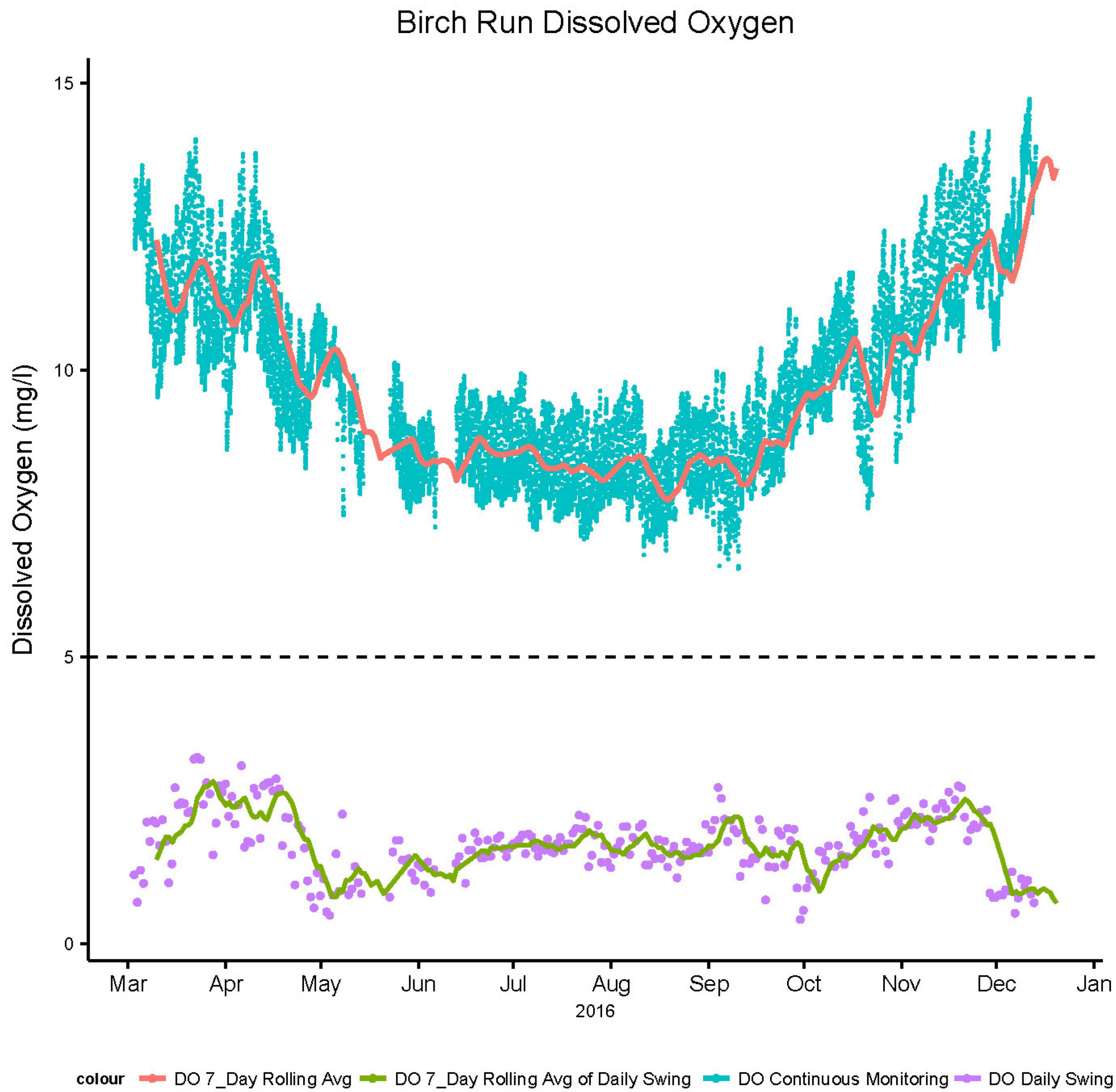

Figure 6.12 Dissolved oxygen (mg/L) from Birch Creek sonde.

EPA compared Goose Creek's DO data with Birch Creek, an unimpaired watershed in the same ecoregion, the Northern Piedmont. The data for the reference watershed includes the period of available data from 3/3/2016 to 12/13/2016 and did not present any excursions of the minimum DO numeric criteria of 5.0 mg/L or the 7-day averaged numeric criteria. The maximum DO daily swing at the reference site was 3.24 mg/L. Figure 6.12 displays DO data and demonstrates criteria attainment from Birch Creek, the reference watershed.

The Goose Creek continuous monitoring DO data demonstrated daily DO swings throughout the watershed (Figures 6.8, 6.9, 6.10, 6.11) with a maximum daily DO swing of 10.18 mg/L at PADEP-1, 5.98 mg/L at PADEP-2, and 5.99 mg/L at PADEP-3. WGSA-4 had a maximum daily swing of 2.69 mg/L. Birch Creek, the reference watershed, had a maximum daily swing of 3.24 mg/L (Figure 6.12). In comparison to the reference watershed, DO daily swings are elevated. PADEP-1 has a maximum daily DO swing that is 3 times greater than that of the reference watershed while PADEP-2 and PADEP-3 have maximum daily DO swings that are nearly 2 times greater than that of the reference watershed.

For comparison purposes, EPA considered DO data from Tohickon Creek, in the Northern Piedmont ecoregion in southeastern Pennsylvania. Tohickon Creek has been categorized by PADEP as showing evidence of "anthropogenic influences" in their CIM Report (PADEP, 2016a). PADEP (2016a) describes its data in the statement:

> "While continuous monitoring indicates that pH and DO in 2013 and 2014 at the Pipersville site meet WQS at least 99% of the time, elevated daily fluctuations indicate concerning levels of instream production likely due to nutrients (nitrogen and phosphorus) (Tables 2 & 3). Nutrients with adequate temperature and photoperiod will increase the standing biomass of photosynthetic organisms (Odum 1956, Strickland et al. 1970, Neori and Holm-Hansen 1982, Raven and Geider 1988, Rosemond et al. 1993, Mosisch et al. 2001, Valenti et al. 2011). An increase in biomass drives successive increases in production and respiration activity promoting increased daily fluctuations in both DO and pH (Odum 1956, White et al. 1991, Wurts 2003)."

The "elevated daily fluctuations" which "indicate concerning levels of instream production likely due to nutrients (nitrogen and phosphorus)" included a maximum daily fluctuation of 7.71 mg/L on October 3, 2013 with maximum daily fluctuations exceeding 6.0 mg/L on October 1,2013. In 2014 the maximum daily fluctuation was 5.02 mg/L on July 14, 2014.

This CIM reports indicate that PADEP considers DO daily swings of 7.71, 6.0 and 5.02 mg/L to be "elevated daily fluctuations" which "indicate concerning levels of instream production likely due to nutrients (nitrogen and phosphorus)." Maximum daily DO swings at the PADEP stations were 10.18 mg/L at PADEP-1, 5.98 mg/L at PADEP-2, and 5.99 mg/L at PADEP-3. These DO swings are representative of elevated daily fluctuations. These elevated daily DO swings likely represent the presence of high (excessive) primary production. These elevated daily DO swings also satisfy the cause definition statement of "excessive daily fluctuations in dissolved oxygen and pH caused by high primary production resulting from elevated levels of phosphorus and/or nitrogen." Section 7 provides further discussion of the daily DO swings.

WGSA has argued that the metabolism of moss, which the visual algal survey qualitatively suggested dominates downstream of the STPs, may be different from that of benthic algae and thus influence the daily swings of DO. DO is produced during photosynthesis, and consumed during respiration. The rates of DO production and consumption are dependent on the rates of photosynthesis and respiration, respectively. Therefore, during daylight hours when the process of photosynthesis dominates and oxygen is produced DO levels are expected to rise. During dark hours, when respiration dominates and oxygen in consumed, DO levels are expected to fall. The metabolism of moss, which has a lower photosynthetic rate than algae under similar conditions (Ylla, 2007), would lead to smaller magnitude swings in DO. Thus, the presence of large amounts of moss below the STPs would likely lead to lower potential DO swings compared to potential DO swings from benthic algae. In other words, if benthic algae were present with no moss below the STPs we would expect larger DO swings and *more* criteria exceedances with an even greater impairment. EPA (2000b) notes that above nuisance thresholds periphyton biomass often causes large diurnal (daily) fluctuations in DO and pH (EPA, 2000b). These data were found to exceed thresholds of high primary production and of nuisance conditions (Sections 6.3.1 and 6.3.2) and to exceed the dissolved oxygen minimum criterion. EPA (2000b) also observes that “excessive macrophyte biomass can produce similar swings in DO and pH (Wong and Clark, 1979; Wong et al., 1979).” While there were low DO swings at WGSA 4, throughout the rest of the watershed DO swings exceeded the daily fluctuations of an unimpaired stream and were comparable to the DO swings of an impaired watershed.

6.4.2 Results of pH Numeric Criteria Assessment

Pennsylvania’s numeric water quality criteria state that pH should be from 6.0 to 9.0 inclusive. The cause definition for nutrients state that “excessive daily fluctuations in dissolved oxygen and pH caused by high primary production resulting from elevated levels of phosphorus and/or nitrogen” should not be present. The analysis in this section will discuss whether the pH criterion is being met and the presence/absence of excessive daily fluctuations. Figure 6.13 displays pH continuous instream monitoring (CIM) data from PADEP 1, 2, and 3, while Figure 6.14 displays pH CIM data from WGSA 4. The accuracy of the CIM data for PADEP 1, 2, and 3 are discussed in Appendix A.

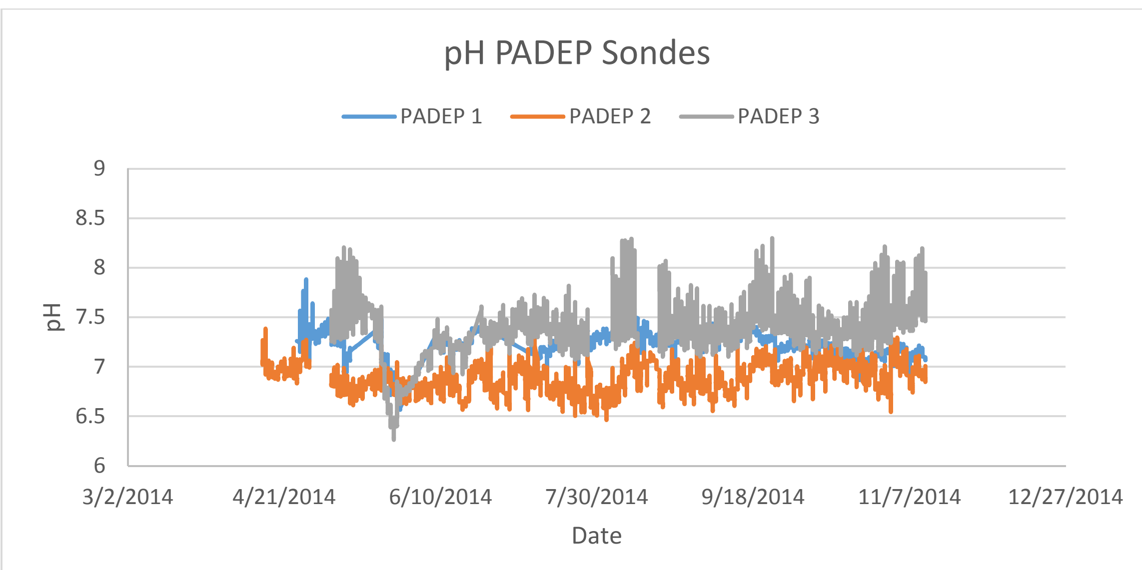

Figure 6.13 Sonde pH data from PADEP sondes at PADEP Stations 1, 2, 3.

PADEP 1, the furthest upstream station, fluctuates over this time period between pH of 6.567 and 7.882, with a maximum daily swing of 0.64 on 05/10/2014 (Figure 6.13). At PADEP 2, downstream from both STPs, pH data fluctuates between 6.464 and 7.414, with a maximum daily swing of 0.70 on 11/01/2014. At PADEP 3, the most downstream station, near the confluence with the East Branch of Chester Creek, pH data fluctuates from 6.265 to 8.3, with a maximum daily swing of about 1.01 on 08/08/2014.

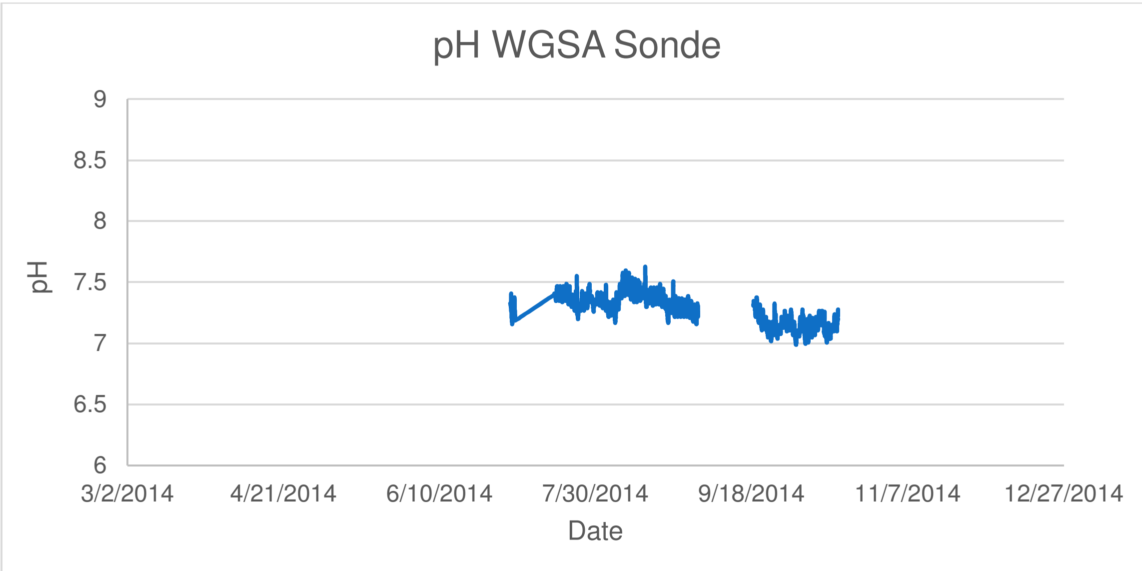

Figure 6.14 Sonde pH data from WGSA sonde at WGSA Station 4.

The pH sonde data collected by WGSA (Figure 6.14) shows that at WGSA-4 pH ranged between a minimum of 6.99 and a maximum of 7.63. The maximum daily swing for the data set was 0.28 on 07/23/2014.

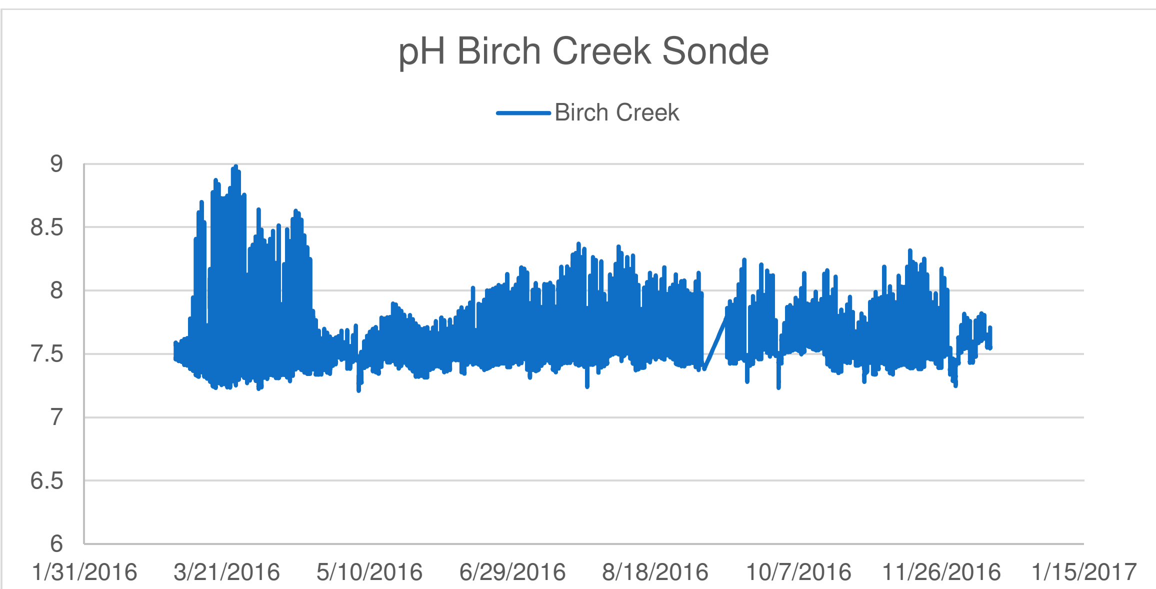

Figure 6.15 Sonde pH data from Birch Creek

The sonde data for the reference stream, Birch Creek, (Figure 6.15) demonstrates that for the period of available data pH ranged from 7.21 to 8.982 with a maximum daily swing of 1.729.

Data from both PADEP and WGSA sondes show that pH does not extend below 6.0 or above 9.0 at any time during the period of available data, and daily swings are not large (Figure 6.12, 6.13). Instream pH levels in Goose Creek are in attainment of PA water quality standards.

WGSA has argued that the metabolism of moss, which the visual algal survey qualitatively suggested dominates downstream of the STPs, may be different from that of benthic algae and thus effect the daily swings of pH. pH in aquatic systems is largely related to CO_2 and its transformations in water. During photosynthesis CO_2 is consumed, and during respiration CO_2 is produced. The rates of CO_2 consumption and production are dependent on the rates of photosynthesis and respiration, respectively. The metabolism of moss, which has a lower photosynthetic rate than algae under similar conditions (Ylla, 2007), would lead to smaller magnitude swings in pH. Thus, the presence of large amounts of moss below the STPs would likely lead to lower potential pH swings compared to potential pH swings from benthic algae. In other words, if benthic algae were present with no moss below the STPs we would expect larger pH swings and potential criterion exceedances and impairment.

6.5 Tolerant Taxa Assessment Methodology and Results

Individual macroinvertebrate metrics can also provide additional information about stressors to aquatic organisms. Research has shown that the proportional abundance of tolerant taxa can be a good indicator of elevated total phosphorus and habitat degradation (Yuan and Norton, 2003). Tolerant taxa are macroinvertebrates that are pollution tolerant. EPA used proportional abundance of tolerant taxa to determine whether there is a potential link between elevated phosphorus or habitat and macroinvertebrate assemblages. Proportional abundance of tolerant taxa was calculated by combining macroinvertebrates with pollution tolerant values of 7-10 and dividing by the total number collected. Then, EPA determined whether there was a co-occurrence of tolerant taxa with phosphorus levels or habitat scores.

6.5.1 Results of Pollution Tolerant Taxa Assessment Results

Figure 6.16 illustrates the proportion of tolerant taxa that were sampled at each station. The tolerant taxa make up a small proportion of the assemblages at each station, with the exception of WGSA-5. At WGSA-5, which is directly downstream of WGSA, the tolerant taxa make up 47% of the assemblage. This dramatic increase in tolerant taxa provides evidence that the discharge from WGSA is impacting the aquatic life in Goose Creek. Because the tolerant taxa are tolerant of elevated total phosphorus (Yuan and Norton, 2003), it suggests that the phosphorus discharge may be contributing to the aquatic life use impairment in Goose Creek. Proportion of tolerant taxa can also signal habitat degradation; however, referring to Table 8.1, the habitat score is actually the highest at WGSA-5, which is directly downstream of WGSA STP. This suggests that the high proportion of tolerant taxa is related to elevated phosphorus levels.

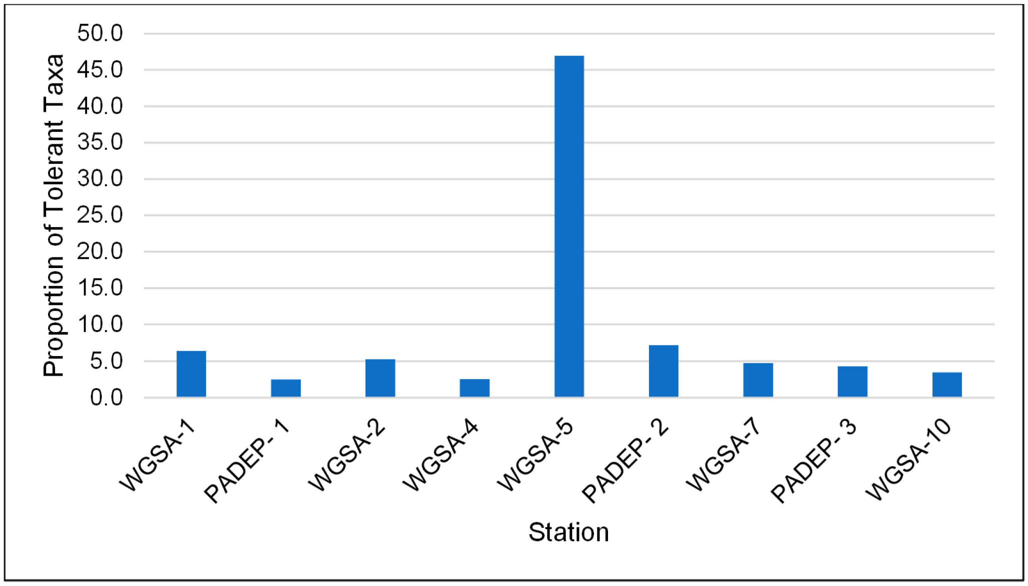

Figure 6.16 Proportion of Tolerant Taxa by Sampling Station

A closer examination of the taxonomic composition at the sites also signifies presence of a nutrient tolerant assemblage resulting in unbalanced dominance and reduced overall benthic diversity. While some sediment impacts are present in Goose Creek, the relatively high abundance of net-spinning hydropsychid caddisflies (*Cheumatopsyche* and *Hydropsyche*) would instead indicate that their microhabitat is relatively low in silt and sand and their dominance suggests more stable substrates, ample suspended food particles, as well as filamentous algae for attachment sites of their nets. Smith et al. (2007) and Yuan (2004) list these genera as highly nutrient tolerant, but in contrast, Yuan (2004) lists them as habitat-sensitive. The downstream increase in abundance of these nutrient tolerant caddisflies also implies sustained enrichment while the degree of embeddedness and sedimentation tended to decrease at downstream stations (Table 9.1). However, the marked decline of these caddisflies along with the concomitant increase in oligochaete worms, flatworms and leeches at Station 5 represent a classic signature of severe organic enrichment below the STP (e.g., Hynes and Pentelow, 1978).

7 Nutrient Stressor Impairment Assessment Summary

As discussed in Section 2.1, excess nutrients (nitrogen and phosphorus) can be detrimental to aquatic life. Because Pennsylvania does not have numeric criteria for nutrients, EPA interpreted PADEP's narrative criteria to assess if nutrients are the cause of impaired aquatic life. Elements of the narrative criteria that are relevant to excess nutrients include "…substances …in concentrations or amounts sufficient to be … harmful to the water uses to be protected or to … aquatic life." EPA has determined that nutrients, through a causal pathway, are related to impaired aquatic life uses.

The effects of the major plant nutrients nitrogen and phosphorus on aquatic life uses are usually indirect and mediated through responses in primary production including increased primary production (periphyton, phytoplankton, macrophytes) and altered species composition of aquatic primary producers or algae (e.g., diatom and/or periphyton assemblages in wadeable streams) (review discussion in Section 2.1 and Figure 7.1). Some algal species may also release toxins under varying nutrient conditions. Effects on aquatic life may be caused by changes in dissolved oxygen and pH caused by increased primary production resulting from the nutrient stressor. Nuisance or excessive levels of primary production (termed "high primary production" in Section 6.3), as well as changes in primary producer species assemblages (e.g. algal taxonomy), can alter food quality (the nutritional quality of food) for aquatic herbivores and impact fish and macroinvertebrate survival and reproduction by smothering stream beds or altering habitat structure. The data provided to the EPA can be assessed for an aquatic life use impairment by discussing it in terms of the impact of nutrient levels on primary production in the stream, alteration of diatom species assemblages, and dissolved oxygen.

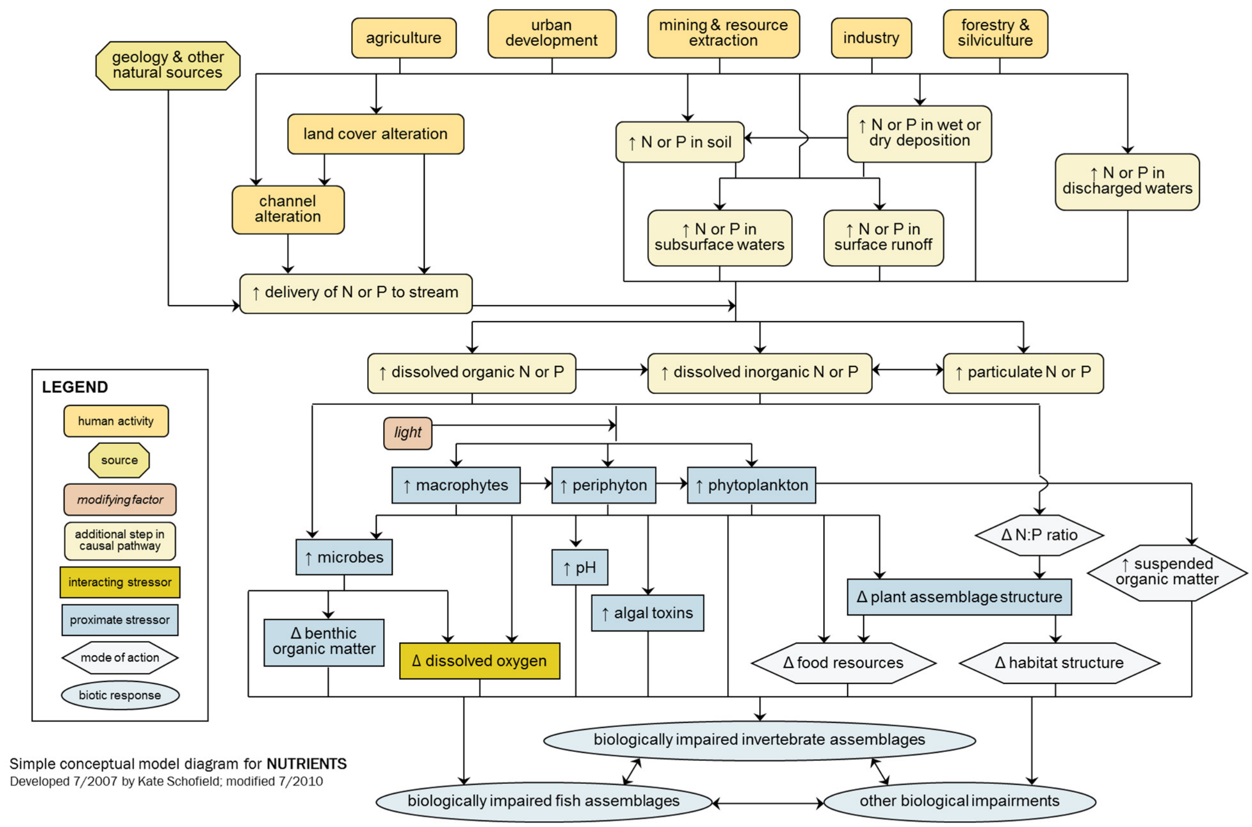

Figure 7.1 Conceptual diagram of causal pathways related to nutrients. Developed 7/2007 by Kate Schofield: modified 7/2010 (EPA, 2010c).

As discussed in Section 6.1, EPA evaluated multiple lines of evidence including nutrient (TP, TN) concentrations and whether they were elevated, high primary production, exceedances of dissolved oxygen and/or pH numeric criteria, and daily swings in DO and pH to assess for a nutrient impairment.

High primary production was evaluated in the periphyton assessment. The periphyton assessment discusses primary producer biomass, altered diatom (algal) species assemblages, percent cover of filamentous algae, algal mats, or moss (visual algal survey), and algal toxicity and biostimulation. Goose Creek experiences primary producer biomass that exceeds thresholds, particularly downstream of the STPs, for high primary production (see Section 6.3.2). High primary production is a term noted in Pennsylvania's impairment cause definition for nutrients (see Section 6.3.1 and 3.4), which was informative in interpreting Pennsylvania's narrative criteria as described above. The threshold of high primary production (150-200 mg chlorophyll *a*/m^2 is also indicative of the "excessive plant growth" EPA agreed to assess as part of the settlement agreement (see Section 1). In addition to exceedance of the threshold for high primary production, data show that primary producer biomass falls into the eutrophic category based on Dodds et al. (1998) for all stations, with the possible exception of WGSA-1 when spring data is excluded though WGSA-1 closely approaches the eutrophic threshold. These results agree with diatom (algal) taxonomy data which showed that all stations in Goose Creek are eutrophic (see Section 6.3.4). The visual algal survey also shows evidence of nutrient enrichment particularly downstream of the STPs, based on increased percent cover of primary producers (see Section 6.3.6). The algal toxicity and biostimulation assessment indicate the water quality of Goose Creek contains elevated levels of nutrients sufficient to support algal (*Selenastrum*) growth similar to a known nutrient impaired stream (Wissahickon Creek). The evidence of nutrient enrichment in the diatom (algal) taxonomy data, visual algal survey and algal toxicity and biostimulation assessments add support to the finding of high primary production in Goose Creek.

The results of the periphyton assessment support the findings of elevated TP and TN in Goose Creek. On average, TP exceeds the lower threshold at all stations and the upper threshold downstream of the STPs (see Section 6.2.2). On average, TN exceeds the lower threshold at all stations and the upper threshold downstream of the STPs (see Section 6.2.4). Similar to the periphyton data, the Dodds et al. (1998) eutrophic threshold, based on station-averaged data, would be exceeded for TN (1.5 mg/L) at all stations, and for TP (0.075 mg/L) at all stations except WGSA-2, where the threshold is closely approached. Further, the average levels of TP and TN in Goose Creek frequently exceed the maximum TP and TN thresholds designed to control periphyton levels (see Section 6.2.6). However, the largest proportion of TN at all stations was nitrate + nitrite (Figure 6.2). PA has a numeric water quality criterion (maximum of 10 mg/L as nitrogen) for nitrate for protection of the potable water supply use. PADEP assess attainment with the nitrate criterion at the point of water withdrawal. PA's nitrate criterion is applied to Goose Creek consistent with §96.3(d). Since there are not any drinking water intakes located on Goose Creek, attainment of PA's nitrate criterion is assessed at the first downstream drinking water intake on Chester Creek. Although nitrate data may be above some identified thresholds, EPA is not making an assessment decision or recommendation related to nitrate or total nitrogen. EPA suggests PADEP evaluate whether elevated TN and/or nitrate may be negatively impacting the aquatic life use in Goose Creek and/or potable water supply uses in Chester Creek. The assessment of tolerant macroinvertebrate taxa also supports the finding of nutrient enrichment in Goose Creek. EPA looked at benthic macroinvertebrate data to evaluate whether there was a link between nutrient stressors and the composition of benthic macroinvertebrate communities and found evidence of enrichment downstream of the two sewage treatment plants particularly at WGSA 5 (Section 6.5).

One adverse effect of high primary production is altered dissolved oxygen dynamics. Section 6.4.1 of this report describes the assessment of dissolved oxygen levels in Goose Creek. The data demonstrate that Goose Creek is impaired due to dissolved oxygen based on exceedances of Pennsylvania's numeric criteria for minimum dissolved oxygen and 7 day averages of dissolved oxygen. Further, daily DO swings in Goose Creek were up to three times greater than those in the reference stream, and were also greater than or similar to daily DO swings PADEP categorized as "elevated daily fluctuations" which "indicate concerning levels of instream production likely due to nutrients (nitrogen and phosphorus)," (PADEP, 2016a; also see section 6.4.1). These elevated daily DO swings in Goose Creek likely indicate the presence of high (excessive) primary production. These elevated daily DO swings also satisfy the cause definition statement of "excessive daily fluctuations in dissolved oxygen and pH caused by high primary production resulting from elevated levels of phosphorus and/or nitrogen." Above nuisance (high primary production) thresholds periphyton biomass often causes large diurnal (daily) fluctuations in DO and pH (EPA, 2000b). "Excessive macrophyte biomass can produce similar swings in DO and pH (Wong and Clark, 1979; Wong et al., 1979)," (EPA, 2000b). DO and pH criteria are often not attained as a result of photosynthesis and respiration by "dense" periphyton mats (Anderson et al., 1994, Wong and Clark, 1976 both cited in EPA 2000b). EPA (2000b, p35) states that "aquatic animals are affected most by maximum pH and minimum DO, rather than by the daily means for these variables (Welch, 1992)."

In the case of Goose Creek, the magnitude of fluctuations in DO and pH may be a reflection of moss growth, which was qualitatively noted to be high through a visual assessment in Goose Creek (Section 6.3.5). While both benthic algae and moss are major primary producers in streams, the impact of benthic algal production and respiration on DO fluctuations in streams has been found to be significantly higher than that of moss (Ylla et al., 2007); therefore, moss would cause lower amplitude fluctuations in DO and pH, which may or may not result in violations of numeric criteria (discussed in Sections 6.4.1, 6.4.2 and 6.3.6.1). The Pennsylvania cause definition for nutrients states that biological impairment may be present where DO or pH criteria are attained, as well as where they are not. DO impairment based on numeric criteria was present in Goose Creek while pH impairment based on numeric criteria was not.

Based on EPA interpretation of Pennsylvania's numeric and narrative criteria, and the data and analysis discussed herein, EPA determined that the aquatic life use of Goose Creek is impaired by total phosphorus. EPA based this determination on multiple lines of evidence – specifically, elevated levels of total phosphorus; excessive (high) primary production; non-attainment of the DO numeric criteria, excessive daily DO swings – EPA has determined that Goose Creek is impaired for aquatic life by TP.

8 Sediment Impairment Assessment

8.1 Sediment Impairment Assessment Methodology

As discussed on Section 2.2, excess sediments can be detrimental to aquatic life. Because Pennsylvania does not have a numeric criterion for sediment, PADEP interprets its narrative criteria to assess if sediment is the cause of impaired aquatic life. Elements of the narrative criteria that are relevant to excess sediment include "…substances in amounts to be harmful to aquatic life use" and "substances which produce… turbidity or settle to form deposits."

There were two lines of evidence for EPA to assess for a sediment impairment: the habitat assessment information and pebble count data. Both lines of evidence are used by PADEP to assess their narrative criteria and to make siltation impairment determinations. Pennsylvania's Methodology for Habitat assessment has been modified from EPA's Rapid Bioassessment Protocol (Plafkin et al., 1989) and is used to assess the physical characteristics of a stream. PADEP's pebble count is used to assess stormwater impacts and is a modification of the Wolman (1954) pebble count procedure. EPA looked at data collected by WGSA and PADEP at each sample site, compared the results as described below, and summarized the sample site data for the entire watershed.

8.1.1 Habitat Assessment

The habitat assessment is used to evaluate potential impacts of existing physical stream conditions on aquatic life. The habitat assessment process involves rating twelve parameters as excellent, good, fair, or poor, by assigning a numeric value (ranging from 20-0), based on the criteria included in the Habitat Assessment Field Data Sheets (PADEP, 2013c).

Three metrics in the habitat assessment are related to impacts from excess sediment: embeddedness, sediment deposition, and conditions of the bank. Embeddedness estimates the percent (vertical depth) of the substrate interstitial spaces filled with fine sediments. Sediment deposition estimates the extent of sediment effects in the formation of islands, point bars, and pool deposition. Condition of the bank evaluates the extent of bank failure or signs of erosion.

After all parameters in the matrix are evaluated, the scores are summed to derive a total habitat score for that station. The habitat parameters of "instream cover", "epifaunal substrate", "embeddedness", "sediment deposition", and "condition of banks" are more critical because they evaluate the instream habitat components that have the most direct effect on the benthic macroinvertebrate community. Scores in the "marginal" (6-10) or "poor" (0-5) categories for these parameters are of greater concern than for those of the other parameters due to their ability to influence instream benthic macroinvertebrate and periphyton habitat. Total scores in the "optimal" category range from 240-192; "suboptimal" 180-132, "marginal" 120-72, and "poor" is 60 or less. The decision gaps between these categories are left to the discretion of the field investigator.

EPA used the sediment relevant habitat metrics as lines of evidence regarding whether Goose Creek is impaired for sediments. Scores in the "poor" range were considered strong evidence for sediment impairment, whereas scores in the "marginal" category were considered to be moderate evidence.

8.1.2 Pebble Count

PADEP's pebble count method is undertaken in riffle/run dominated, gravel, or cobble bed stream segments that may be impaired due to stormwater runoff. This method characterizes the particle size distribution in the stream bed in order to determine whether there is an excess of fine particles. Particles 8 mm or smaller are of primary concern since they should have the most biological significance and are most likely to smother macroinvertebrate and fish spawning habitat. Once the data are collected, the cumulative particle size distribution of reference and study reaches are plotted to generate a graph or spreadsheet for data interpretation. Reference reaches are those streams that have less than 15% of total particles finer than 8 mm, and stable study reaches are those streams with less than 30% of particles finer than 8 mm. Based on PADEP's method, if total fine particles are greater than 35% (estimated), the study reach is very likely unstable and may be impaired. These percentage fines are to be used as a general guideline and will vary from stream to stream with some streams being unstable at lower percentage fines while others will be stable at higher percentage fines (PADEP, 2013a, Rosgen, 1994).

Based on PADEP's methodology, EPA used the threshold of greater than 35% total fine particles as a metric for sediment impairment. Pebble count data was compared across sampling stations in Goose Creek as well as analyzed for the entire watershed.

8.2 Habitat Assessment Results

PADEP and WGSA both performed habitat assessments in Goose Creek. PADEP sampled on September 19, 2013 for stations PADEP -2 and -3 and September 20, 2013 for station PADEP-1. WGSA performed a habitat assessment at stations WGSA-1, -4, -5, -7, and -10 on September 9, 2015. PADEP uses the following scoring categories for habitat assessments: total scores in the "optimal" category range from 240-192; "suboptimal" 180-132, "marginal" 120-72, and "poor" is 60 or less, whereas individual metrics in the "optimal" range from 16-20, "suboptimal" is 11-15, "marginal" 6-10, and "poor" 0-5. Habitat scores and metrics related to sediment impacts are presented in Table 8.1 and stations are presented upstream to downstream. Values highlighted in yellow represent marginal scores whereas red values represent poor scores. Habitat is clearly the poorest in the upstream stations of Goose Creek where all metrics related to sediment impacts are either poor or marginal. Sediment metrics and overall habitat scores improve downstream, likely due to land use differences throughout the watershed, which become less developed and more pervious. Habitat scores decline again at the far downstream locations, stations PADEP-3 and WGSA-10. Overall, the habitat scores in Goose Creek suggest that aquatic life is impacted by excess sediment.

Table 8.1 Goose Creek Habitat Scores

Station	Sampling Date	Embeddedness	Sediment Deposition	Condition of Banks	Total Habitat Score
WGSA- 1	9/9/2015	7	6	6	109
PADEP- 1	9/20/2013	5	6	2	137
WGSA- 2	9/9/2015	7	4	4	104
WGSA- 4	9/9/2015	12	12	13	134
WGSA- 5	9/9/2015	13	15	14	180
PADEP- 2	9/19/2013	6	5	11	138
WGSA- 7	9/9/2015	12	15	14	174
PADEP 3	9/19/2013	5	5	9	128
WGSA- 10	9/9/2015	9	10	7	126

8.3 Pebble Count Results

PADEP performed a pebble count at their three stations in Goose Creek on October 18, 2013 for stations PADEP-1 and -2 and on October 17, 2013 for PADEP-3. Table 8.2 illustrates pebble count data in comparison to the impairment threshold. The percent fine sediment at each site exceeds the 35% impairment threshold, providing evidence that Goose is impaired for sediment for the entire watershed. The percent fine sediment is lowest downstream of the WGSA discharge. This could be attributed to increased bank vegetative protection near the WGSA plant which reduces streambank erosion.

Table 8.2 Goose Creek Pebble Count

Station	Fine Sediment (%)	Impairment Threshold (%)	Impaired?
PADEP-1	49.0	>35	Yes
PADEP-2	40.5	>35	Yes
PADEP-3	56.1	>35	Yes

8.4 Sediment Impairment Summary

Based on the habitat assessment and pebble count lines of evidence, EPA has determined that Goose Creek is impaired for aquatic life by excess sediment. The sediment-related habitat scores ranged from sub-optimal to poor. The pebble count scores indicated that percent fine sediment at each site exceeded the 35% impairment threshold. With the combination of the habitat scores and the pebble count both providing evidence that sediments are impacting the stream, PADEP has added siltation as another cause of impairment to aquatic life in Goose Creek in PA's draft 2016 Integrated Water Quality Monitoring and Assessment Report which includes PA's Section 303(d) list of impaired waters (PADEP, 2016b). These findings are consistent with EPA's assessment results that Goose Creek is impaired by excess sediment.

9 Other Potential Causes of Impairment

As mentioned in Section 2.3, nutrients and sediment are not the only stressors that may be contributing to an aquatic life use impairment in Goose Creek. Urbanization can negatively impact aquatic systems in several ways, such as leading to increased transport of many pollutants, including nutrients. WGSA and PADEP performed a suite of water chemistry analyses on their water grab samples. Most of those analytes remained below the applicable numeric water quality criteria; however, concentrations of chloride were particularly high in the winter months, especially at the most upstream station – PADEP-1 (Table 9.1). Pennsylvania does not have numeric criteria for chloride to protect aquatic life use; however, many of the sampled concentrations exceeded EPA's recommended chloride criteria maximum concentration (860 mg/L) (EPA, 1986) for protection of aquatic life, as well as PA's chloride criteria for potable water supply (250 mg/L) (25 PA Code §93.7). EPA recommends PADEP continue to work towards adopting a numeric criterion for chloride in order to better characterize how chloride affects aquatic life and consider additional monitoring to determine if chloride should be considered a cause of impairment for Goose Creek and listed in PA's 303(d) list.

Table 9.1 Goose Creek Chloride Data

Chloride Concentration (mg/L)			
Date	PADEP-1	PADEP-2	PADEP-3
12/10/2013	1198	485	294
12/17/2013	420	263	250
12/23/2013	206	236	222
1/5/2014	2951	777	288
1/27/2014	675	233	256
2/4/2014	1935	592	628
2/14/2014	2273	1159	734
3/5/2014	581	297	284
4/14/2014	223	164	153
5/6/2014	209	144	129
6/9/2014	206	140	121
6/23/2014	199	138	123
7/17/2014	184	138	124
8/19/2014	199	150	132
9/24/2014	154	130	120
10/20/2014	179	139	131
11/12/2014	185	148	132
12/17/2014	0.5	196.85	183.1

10 Reassessment Conclusions

EPA has determined that Goose Creek is impaired by sediment and TP. Table 10.1 outlines the multiple lines of evidence that support that TP and sediment are causing aquatic life use impairments in Goose Creek.

Additionally, EPA concludes that chloride may be a potential cause of aquatic life use impairment. EPA recommends PADEP continue to work towards adopting a numeric criterion for chloride in order to better characterize how chloride affects aquatic life use and consider additional monitoring to determine if chloride should be considered a cause of impairment for Goose Creek and listed in PA's 303(d) list. In addition, EPA notes that TN is highly elevated, predominantly due to nitrate/nitrite concentrations. The PADEP numeric water quality criterion for nitrate is for the designated use protection of potable water supply. PADEP assess attainment with the nitrate criterion at the point of water withdrawal. PA's nitrate criterion is applied to Goose Creek consistent with §96.3(d). Since there are not any drinking water intakes located on Goose Creek, attainment of PA's nitrate criterion is assessed at the first downstream drinking water intake on Chester Creek. EPA is not making an assessment decision or recommendation related to nitrate or total nitrogen. EPA suggests PADEP evaluate whether elevated TN and/or nitrate may be negatively impacting the aquatic life use in Goose Creek and/or potable water supply uses in Chester Creek.

The presence of one cause of impairment, such as sediment or nutrients, does not preclude there from being additional causes of impairment to aquatic life. In an urbanized watershed like Goose Creek, it is highly likely that multiple stressors are affecting aquatic life. Each stressor is a separate potential cause of aquatic life impairment and should be assessed independently against thresholds for applicable criteria. This reassessment focused on nutrient and sediment stressors.

Table 10.1 Summary of Causes of Aquatic Life Use Impairment

Aquatic Life Impairment Causes	Line of Evidence	Results	Cause of Impairment?
Nutrients	Total Phosphorus	Levels Exceed Thresholds	Yes
	High (excessive) primary production	Levels Exceed Thresholds	
	DO numeric criteria	Not attained	
	pH numeric criteria	Attained	
	DO daily swings	Excessive	
	pH daily swings	within numeric criteria	
Sediment	Habitat Assessment	Threshold Exceeded	Yes
	Pebble Count	Threshold Exceeded	

11 Goose Creek TMDL Reconsideration

Pursuant to the "Interim Settlement Agreement" entered into on January 3, 2014 between WGSA, DRN, and EPA, EPA agreed to reassess the water quality of Goose Creek and reconsider whether to withdraw or retain the Goose Creek TP TMDL. As stated above, EPA has concluded that Goose Creek is impaired for aquatic life by TP and sediment. This section presents EPA's conclusions regarding whether to withdraw or retain the Goose Creek TP TMDL.

In conducting its TMDL reconsideration, EPA evaluated whether the TMDL remained effective at protecting aquatic life from the effects of excess TP, by reviewing the validity of the TMDL's total phosphorus endpoint. Additionally, EPA reconsidered the total phosphorus TMDL after determining that Goose Creek is also impaired by sediment and has elevated concentrations of TN. As a result of the reconsideration, EPA has concluded that the TP TMDL is set at a level necessary to implement the applicable WQS, i.e., a level that will protect the Creek's aquatic life and will remain in place.

11.1 Review of the Total Phosphorus Endpoint

EPA set the Goose Creek TP TMDL endpoint at a level necessary to protect Goose Creek's designated aquatic life use. The TP endpoint was based on an analysis prepared by Tetra Tech on behalf of EPA for nutrient impaired streams in southeastern Pennsylvania (Paul and Zheng, 2007; Paul et al., 2012). The TP endpoint is not itself a water quality standard or criterion pursuant of Section 303(c) of the CWA. Rather, it reflects EPA's interpretation of Pennsylvania's existing narrative water quality criteria (which are discussed in Section 3) to develop the TP endpoint. The narrative criteria language most relevant to the selection of the nutrient impairment endpoint is "water may not contain substances…in concentrations…to be harmful to…aquatic life and…specific substances to be controlled include…floating materials, and substances which produce color, tastes, odors, turbidity or settle to form deposits." Nutrients in excess quantities can cause excess primary production that affects aquatic organisms and produce low dissolved oxygen conditions.

EPA developed the total phosphorus endpoint using a stressor-response methodology (4 lines) as part of a 17-line weight-of-evidence approach (Table 11.1). Taken together, the 17 lines of evidence present TP endpoint values that, using the weight of evidence approach, reasonably supported EPA's chosen target of 0.040 mg/L TP.

Table 11.1 Summary of candidate endpoints considered for each of the analytical approaches (Paul and Zheng 2007).

	Approach	TP Endpoint (mg/L)
Reference Approach		**0.002-0.037**
	Reference Site 75th Percentile	0.016-0.017
	All Sites 25th Percentile	0.017
	Modeled Reference Expectation	0.002-0.037
Stressor-Response		**0.036-0.064**
	Conditional Probability – EPT taxa	0.038
	Conditional Probability - % Clingers	0.039
	Conditional Probability - % Urban Intolerant	0.064
	Conditional Probability - Diatoms TSI	0.036
Other Literature		**0.013-0.10**
	EPA Recommended Regional Criteria	0.037
	EPA Regional Criteria Approach – Local Data	0.040-0.051
	Algal Growth Saturation	0.025-0.050
	Nationwide Meta-Study TP-Chlorophyll	0.021-0.060
	USGS Regional Reference Study	0.020
	USGS National Nutrient Criteria Study	0.013-0.020
	New England Nutrient Criteria Study	0.040
	Virginia Nutrient Criteria Study	0.050
	New Jersey TDI	0.025-0.050
	Delaware Criteria	0.050-0.10

Partly in response to a request on behalf of Pennsylvania jurisdictions, EPA's Office of Science and Technology (OST) requested that EPA's Scientific Advisory Board (SAB) conduct a peer review of EPA's draft technical guidance document entitled "Empirical Approaches for Nutrient Criteria Derivation." This was a draft guidance document EPA developed as a supplement to several EPA Nutrient Criteria Guidance documents.[8] That draft document was intended to supplement existing nutrient criteria guidance (EPA, 2000b, 2000c, 2001, and 2008b) by providing detailed approaches for estimating and interpreting stressor-response relationships for developing numeric criteria to address nitrogen and/or phosphorus pollution. Such a document when final would enable water resource scientists to use additional scientifically valid statistical tools in the derivation of state-specific numeric nutrient criteria. The SAB undertook the peer review of that draft in 2009-2010. This peer review was not focused on a review of any specific EPA TMDLs (including the Goose Creek TMDL). This peer review did, however, review one of the methodologies EPA Region 3 used to develop the Goose Creek TMDL nutrient endpoints, namely the stressor-response (conditional probability) approach. Several Pennsylvania municipalities provided comments on the draft SAB Report. The SAB issued its final report on

[8] *Nutrient Criteria Technical Guidance Manual: Rivers and Streams*. EPA-822-B-00-002. (EPA, 2000b);. *Nutrient Criteria Technical Guidance Manual. Lakes and Reservoirs*. EPA-822-B-00-001 (EPA, 2000c); *Nutrient Criteria Technical Guidance Manual. Estuarine and Coastal Marine Waters.* EPA-822-B-01-003. (EPA, 2001); *Nutrient Criteria Technical Guidance Manual. Wetlands.* EPA-822-B-08-001. (EPA, 2008b)

the draft guidance on April 27, 2010, which included several conclusions and recommendations to EPA for improving the draft guidance document. (EPA, 2010b).

SAB's fundamental conclusion is that "[t]he stressor-response approach is a *legitimate, scientifically based method* for developing numeric nutrient criteria if the approach is appropriately applied (i.e., not used in isolation but as part of a weight-of-evidence approach)."

In November 2010, EPA published the final guidance entitled *Using Stressor-response Relationships to Derive Numeric Nutrient Criteria* (EPA-820-S-10-001) (EPA, 2010a) which supplemented several guidance documents (footnote 7). EPA has developed this guidance to assist water resource scientists in the derivation of state-specific numeric nutrient criteria. The final guidance addendum incorporates the recommendations made by the SAB. The guidance provides the scientific foundation for using empirical approaches to describe stressor-response relationships and outlines a five-step process for using stressor-response relationships to derive criteria. Stated simply, the stressor-response analyses help identify the probability of having some adverse condition occur as a stressor concentration increases.

EPA developed the TMDL endpoint used in the Goose Creek nutrient TMDL using multiple lines of evidence including the stressor-response analyses. This is the same approach that the EPA's final 2010 guidance recommended for a weight of evidence approach. However, since the SAB and the final guidance provided additional recommendations that might improve upon the TMDL endpoint selection, EPA Region 3 re-analyzed the nutrient endpoint methodology used by EPA in the Goose Creek TMDL and discussed in its 2007 document, *Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application* (Paul and Zheng, 2007a).

First, in 2008, EPA Region 3 evaluated the TP endpoint in the Goose Creek nutrient TMDL by removing the four lines of evidence related to the stressor-response analyses from the 17 lines of evidence. Using the remaining 13 lines of evidence, including the literature values and the reference condition approach, EPA confirmed that its initial decision of 0.040 mg/L of total phosphorus was a reasonable TMDL endpoint. The results of this analysis are discussed in detail in the *Technical Memorandum on PA TMDL Endpoints* (EPA, 2008c).

Second, EPA addressed concerns raised by these comments that the four lines of evidence that relied on stressor-response analyses in the endpoint development were flawed. In 2012, EPA Region 3 refined its analysis of the appropriate TP endpoint following the recommendations noted by the SAB Review and recommended in EPA's guidance *Using Stressor-response Relationships to Derive Numeric Nutrient Criteria* (EPA, 2010a). The results of that analysis can be found in the EPA report entitled, *Development of Nutrient Endpoints for Northern Piedmont – Follow Up Analysis"* (Paul et al., 2012).

The follow-up analysis applied a 4-step process to evaluate the effects of confounding or co-varying stressors on total phosphorus, to attempt to refine the original endpoint analysis to account for those effects, and to research and develop additional lines of evidence. Those four steps were: (1) develop a conceptual model, (2) assemble and explain the data, (3) analyze the data to derive candidate criteria, and (4) review and document the analysis.

Table 11.2 is a result of this follow up analysis and updates the original report endpoint summary based on the additional analysis and information provided in the 2012 report.

Table 11.2 Summary of candidate endpoints for each of the analytical approaches discussed (Paul et al. 2012). Differences and new lines of evidence are highlighted in yellow.

	Approach	TP Endpoint (mg/L)
Reference Approach		**0.002-0.037**
	Reference Site 75th Percentile	0.016-0.017
	All Sites 25th Percentile	0.017
	Modeled Reference Expectation	0.002-0.037
Stressor-Response		**0.008-0.085**
	Conditional Probability – EPT taxa	0.038
	Conditional Probability - % Clingers	0.039
	Conditional Probability - % Urban Intolerant	0.064
	Conditional Probability - Diatoms TSI	0.036
	Simple linear regression interpolation – EPT taxa	0.010-0.085
	Simple linear regression interpolation – Percent intolerant urban individuals	0.008-0.082
	Simple linear regression interpolation – Percent Clinger individuals	0.008-0.052
Other Literature		**0.013-0.10**
	EPA Recommended Regional Criteria	0.037
	EPA Regional Criteria Approach – Local Data	0.040-0.051
	Algal Growth Saturation	0.025-0.050
	Nationwide Meta-Study TP-Chlorophyll	0.021-0.060
	USGS Regional Reference Study	0.020
	USGS National Nutrient Criteria Study	0.013-0.020
	New England Nutrient Criteria Study	0.040
	Virginia Nutrient Criteria Study	0.050
	New Jersey TDI	0.025-0.050
	Delaware Criteria	0.050-0.10
	National Reference Criteria Study	0.060
Mechanistic Model		**0.020-0.033**
	Indian Creek	0.020-0.033

In this follow-up analysis, EPA looked at one additional literature value, four additional stressor response analyses and a mechanistic model to estimate TP concentrations associated with adverse benthic algal concentrations in a Piedmont stream in Pennsylvania, specifically Indian Creek. Indian Creek is similar to Goose Creek in that it is a small watershed (approximately 7 square miles) in Nutrient Level III Ecoregion IX with various degrees of residential development and STPs and MS4 discharges to the stream (EPA, 2008a). Even though the mechanistic model indicated that TP levels between 0.020-0.033 mg/L in Indian Creek would prevent benthic chlorophyll *a* density above the conservative end of the range frequently cited as nuisance, EPA decided that the 0.040 mg/L TP endpoint for Goose Creek should remain unchanged. This is because the new stressor-response analyses provided a range of endpoints that included the 0.040 mg/L endpoint (i.e., between the lower quartile and average estimate ranges), the distribution based values remain unaltered, and one additional scientific study estimating regional reference concentration recommends a value of 0.060 mg/L TP (close to the original value and within the range of previous literature). Accordingly, EPA confirms that the recommended TP in the Goose Creek TMDL was appropriately set at 0.040 mg/L of TP.

11.2 Multiple Causes of Impairment

The Goose Creek impairment reassessment showed that in addition to the TP impairment, Goose Creek is impaired for sediment and has elevated concentrations of TN. As discussed below, the presence of an additional sediment impairment and elevated TN concentrations does not undermine the validity of the total phosphorus TMDL. TMDLs are developed independently for each pollutant that is causing an impairment and are designed to achieve water quality standards.

The elevated concentrations of TN do not invalidate the TP TMDL. As discussed previously in Section 2.1, both nitrogen and phosphorus are nutrients that stimulate plant growth. Ratios of nitrogen to phosphorus are informative in understanding whether a system is nitrogen or phosphorus limited. If a system is nitrogen limited (low N:P ratio), increases in nitrogen concentrations are more likely to influence primary production than increases in phosphorus (the converse is true when a system is phosphorus limited). Using data from the northern piedmont ecoregion, the average molar N:P ratio for all sites was 259:1 (184:1 or 208:1 for reference sites), in comparison to the EPA-recommended ecoregional criteria ratio of 43:1 (Paul and Zheng, 2007). This high ratio indicates that the northern piedmont ecoregion is phosphorus limited. Therefore, the TP TMDL is more critical for controlling excess primary producer growth and, thus, protecting the aquatic life use of Goose Creek. Due to the high concentrations of TN, EPA recommends that PADEP evaluate whether TN is a contributor to impairment for Goose Creek in its future 303(d) list.

The presence of a sediment impairment does not challenge the validity of the TP TMDL. First, sediment and phosphorus have different mechanisms of impact on aquatic life (specifically, macroinvertebrates). As shown in Figure 2.2, fine sediments can smother macroinvertebrate habitats, making it difficult for macroinvertebrates to find food and proper shelter. In contrast, excess TP impacts macroinvertebrates through a complex interplay of processes, which were described Section 2.1. Therefore, each pollutant is having its own, independent deleterious impact on aquatic life and should be considered discreetly. Second, while phosphorus actively binds to sediment particles, much of the phosphorus delivery to Goose Creek is not bound to sediment, but rather, transported from STP effluent. As presented in Figure 6.1, the large majority of phosphorus in Goose Creek is dissolved orthophosphorus. Phosphorus concentrations significantly increase downstream of the STPs, indicating that they are the major source of phosphorus rather than sediment bound phosphorus from runoff. That being said, implementation of a sediment TMDL could have positive impacts on meeting the TP TMDL because as sediment loads are decreased, TP loads bound to sediment would decrease. A sediment TMDL is not necessary to achieve the TP TMDL.

In summary, TMDLs should be developed for each pollutant that is causing impairment in a waterbody in order to achieve the applicable designated uses. The health of macroinvertebrate communities in Goose Creek may not completely recover until all causes are addressed. Additionally, the development and implementation of additional sediment TMDLs in Goose Creek will likely have a positive impact on meeting the TP TMDL reductions. Therefore, PADEP should consider developing sediment (siltation) TMDLs in the Goose Creek watershed.

11.3 Reconsideration Summary

Based on this reconsideration, EPA confirms that Goose Creek is impaired by total phosphorus. The total phosphorus endpoint was based on a strong technical analysis that included 17 lines of evidence, and as such, is an appropriate endpoint to meet the aquatic life designated use of Goose Creek. Therefore, the total phosphorus TMDL is scientifically and legally valid. The Goose Creek total phosphorus TMDL will remain in place.

12 References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling.1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Bostrom, B., Persson, G. and B. Broberg. 1988. Bioavailability of different phosphorus forms in freshwater systems. *Hydrobiologia* 170: 133-155.

Carrick, H.J., and S.J. Mays. 2006. Water quality assessment for Paxton Creek (Pennsylvania) based upon periphyton assemblages. Final Report, U.S. Environmental Protection Agency (through Louis Berger, Inc.), 28 p.

Cormier, S.M. 2007. Sediment: Simple Conceptual Diagram. https://www3.epa.gov/caddis/ssr_sed4s.html.

Delaware Department of Natural Resources and Environmental Control (DNREC). 2015. State of Delaware 2014 Combined Watershed Assessment Report (305(b)) and Determination for the Clean Water Act Section 303(d) List of Waters Needing TMDLs.

Dodds, W.K., V. H. Smith, and B. Zander. 1997. Developing nutrient targets to control benthic chlorophyll levels in streams: a case study of the Clark Fork River. *Water Research* 31: 1738–1750.

Dodds, W.K., J.R. Jones and E.B. Welch. 1998. Suggested classification of stream trophic state: distribution of temperate stream types by chlorophyll, total nitrogen and phosphorus. *Water Research* 32: 1455-1462.

Dodds, W.K. and E.B. Welch. 2000. Establishing nutrient criteria in streams. *Journal of the North American Benthological Society* 19: 186-196.

Glime, J. M. 2014. Photosynthesis in Aquatic Bryophytes. Pp. 201-231 in D.T. Hanson and S.K. Rice (eds.), Photosynthesis in Bryophytes and Early Land Plants.

Hausmann, S., D. F. Charles, J. Gerritsen, T. J. Belton. 2016. *Science of the Total Environment* 562: 914-927.

Herlihy, A.R. and J.C. Sifneos. 2008. Developing nutrient criteria and classification schemes for wadeable streams in conterminous United States. *Journal of the North American Benthological Society* 27(4): 932-948.

Horner, R. R., E. B. Welch, and R. B. Veenstra. 1983. Development of nuisance periphytic algae in laboratory streams in relation to enrichment and velocity. In: *Periphyton of Freshwater Ecosystems: Proceedings of the First International Workshop on Periphyton of Freshwater Ecosystems*. R. G. Wetzel (ed.). Developments in Hydrobiology Series, Vol. 17: 21-134.

Hynes, H.B.N. and Pentelow, F.T.K., 1978. *The biology of polluted waters*. Liverpool University.

Kaller, M.D., and K.J. Hartman. 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. *Hydrobiologia* 518: 95-104.
Komínková, D. 2012. The Urban Stream Syndrome – a Mini-Review. *The Open Environmental and Biological Monitoring Journal* 5(1): 24-29.

Komínková, D. 2012. The urban stream syndrome – a mini-review. *The Open Environment & Biological Monitoring Journal* 5: 24-29.

Lohman, K., J.R. Jones, and B.D. Perkins. 1992. Effects of nutrient enrichment and flood frequency on periphyton biomass in northern Ozark streams. *Canadian Journal of Fisheries and Aquatic Sciences* 49:1198–1205.

Nordin, R.N. 1985. Updated August 7, 2001. Water Quality Criteria for Nutrients and Algae. Water Quality Unit, Resource Quality Section, Water Management Branch, British Columbia Ministry for the Environment, Victoria, Canada. http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/nutrients-or.pdf

Paul, M.J. and L. Zheng. 2007. Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application. Prepared for US Environmental Protection Agency, Region 3, Philadelphia, PA.

Paul, M.J., J. Robbiani, L. Zheng, T. Rafi, S. Bai, and P. Von Loewe. 2012. Development of Nutrient Endpoints for the Northern Piedmont Ecoregion of Pennsylvania: TMDL Application Follow-up Analysis. Prepared for US Environmental Protection Agency, Region 3, Philadelphia, PA.

Pennsylvania Department of Environmental Protection (PADEP). 2012. A Benthic Macroinvertebrate Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania, Division of Water Quality Standards, March 2012.

Pennsylvania Department of Environmental Protection (PADEP). 2013a. Instream Comprehensive Evaluation Surveys, Bureau of Water Standards and Facility Regulation, July 2013.

Pennsylvania Department of Environmental Protection (PADEP).2013b. Assessment and Listing Methodology for Integrated Water Quality Monitoring and Assessment Reporting, Appendix A: Source and Cause Definitions. December 2013.

Pennsylvania Department of Environmental Protection (PADEP). 2013c. Appendix C – Biological Field Methods, C1. Habitat Assessment. December 2013.

Pennsylvania Department of Environmental Protection (PADEP). 2013d. Pennsylvania DEP Field Protocol: Periphyton Standing Crop and Species Assemblages, December 2013.

Pennsylvania Department of Environmental Protection (PADEP). 2013e. Surface Water Collection Protocol, Bureau of Clean Water, December 2013.

Pennsylvania Department of Environmental Protection (PADEP). 2013f. Appendix C – Biological Field Methods, C2. Benthic Macroinvertebrates. December 2013.

Pennsylvania Department of Environmental Protection (PADEP). 2015a. Continuous Instream Monitoring Protocol, Bureau of Point and Non-Point Source Management.

Pennsylvania Department of Environmental Protection (PADEP). 2016a. Continuous Instream Monitoring Report, Tohickon Creek, Bureau of Point and Non-Point Source Management.

Pennsylvania Department of Environmental Protection (PADEP). 2016b. 2016 Draft Pennsylvania Integrated Water Quality Monitoring and Assessment Report. Clean Water Act Section 305(b) Report and 303(d) List.

Ponader, K. & D. F. Charles. 2003. Understanding the relationship between natural conditions and loadings on eutrophication: Algal indicators of eutrophication for New Jersey streams. Final Report Year 2. Report No. 03-04. Patrick Center for Environmental Research, Academy of Natural Sciences. Philadelphia, PA.

Ponader, K., C. Flinders, and D. Charles. 2005. The Development of Algae-based Water Quality Monitoring Tools for Virginia Streams. Report No. 05-09 for the West Central Regional Office, Virginia Department of Environmental Quality. Patrick Center for Environmental Research, Academy of Natural Sciences. Philadelphia, PA.

Pond, G. 2017. Personal communications.

Porter, S.D., 2008, Algal attributes: An autecological classification of algal taxa collected by the National Water-Quality Assessment Program: U.S. Geological Survey Data Series 329, http://pubs.usgs.gov/ds/ds329/

Robertson, D.M., D.A. Saad, A.M. Wieben, U.S. Environmental Protection Agency Region V, U.S. Environmental Protection Agency Region VII, and U.S. Geological Survey. 2001. An Alternative Regionalization Scheme for Defining Nutrient Criteria for Rivers and Streams. U.S. Geological Survey Water-Resources Investigations Report 01-4073. Middleton, WI.

Rohm, C.M., J.M. Omernik, A.J. Woods, and J.L. Stoddard. 2002. Regional characteristics of nutrient concentrations in streams and their application to nutrient criteria development. *Journal of the American Water Resources Association* 38: 213-239.

Rosgen, David L. 1994. A Classification of Natural Rivers. *Catena* 22: 169-199. Elsevier Science, Amsterdam.

Stream Bryophyte Group. 1999. Roles of Bryophytes in Stream Ecosystems. *Journal of the North American Benthological Society* 18:151-184.

Smith, A.J., Bode, R.W. and Kleppel, G.S., 2007. A nutrient biotic index (NBI) for use with benthic macroinvertebrate communities. *Ecological Indicators*, *7*(2): 371-386.

Suplee, M.W., V. Watson, M. Teply, H. McKee. 2009. How green is too green? Public opinion of what constitutes undesirable algae levels in streams. *Journal of the American Water Resources Association* 45:123-240.

United States Environmental Protection Agency (EPA). 1986. Quality Criteria for Water 1986. Office of Water, Washington, DC. EPA 440/5-86-001.

United States Environmental Protection Agency (EPA). 2000a. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Rivers and Streams in Nutrient Ecoregion IX. EPA 822-B-00-019. Washington, DC.

United States Environmental Protection Agency (EPA). 2000b. Nutrient Criteria Technical Guidance Manual. Rivers and Streams. United States Environmental Protection Agency, Office of Water, Washington, DC. EPA-822-B-00-002

United States Environmental Protection Agency (EPA). 2000c. Nutrient Criteria Technical Guidance Manual. Lakes and Reservoirs. US Environmental Protection Agency, Office of Water, Washington, DC. EPA-822-B-00-001.

United States Environmental Protection Agency (EPA). 2001. Nutrient Criteria Technical Guidance Manual. Estuarine and Coastal Marine Waters. US Environmental Protection Agency, Office of Water, Washington, DC. EPA-822-B-01-003.

United States Environmental Protection Agency (EPA). 2008a. Nutrient and Sediment TMDLs for the Indian Creek Watershed, Pennsylvania. Established by the U.S. Environmental Protection Agency, June 30, 2008.

United States Environmental Protection Agency (EPA). 2008b. Nutrient Criteria Technical Guidance Manual. Wetlands. US Environmental Protection Agency, Office of Water, Washington, DC. EPA-822-B-08-001.

United States Environmental Protection Agency (EPA). 2008c. Technical Memorandum PA TMDL endpoints without conditional probability analysis. Prepared for EPA by Tetra Tech, Inc., Michael Paul and Lei Zheng. November 10, 2008.

United States Environmental Protection Agency (EPA). 2008d. Total Phosphorus Total Maximum Daily Load for the Goose Creek Watershed, Pennsylvania. Established by the U.S. Environmental Protection Agency, June 30, 2008.

United States Environmental Protection Agency (EPA). 2010a. Using Stressor-response Relationships to Derive Numeric Nutrient Criteria. United States Environmental Protection Agency, Office of Water, Washington, DC. EPA-820-S-10-001.

United States Environmental Protection Agency (EPA). 2010b. Letter from Dr. Deborah L. Swackhamer and Dr. Judith L. Meyer to Lisa Jackson, U.S. Environmental Protection Agency, Regarding SAB Review of Empirical Approaches for Nutrient Criteria Derivation. April 27, 2010.

United States Environmental Protection Agency (EPA). 2010c. Causal Analysis/Diagnosis Decision Information System (CADDIS). Office of Research and Development, Washington, DC. Available online at https://www3.epa.gov/caddis/ssr_nut_int.html. Last updated September 23, 2010.

Walsh, G.E. and W.B. Horning, 1980. Toxicity of Textile Mill Effluents to Freshwater and Estuarine algae, Crustaceans and Fishes. *Environmental Pollution* 21: 169-179.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, R. P. Morgan II. 2005. The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society*. 24: 706-723.

Welch, E.B., J.M. Jacoby, R.R. Horner, and M.R. Seeley. 1988. Nuisance Biomass Levels of Periphytic Algae in Streams. *Hydrobiologia* 157: 161-168.

Welch, E.B., R.R. Horner and C.R. Patmont. 1989. Prediction of nuisance biomass: a management approach. *Water Research* 23: 401-405.

Welch, E. B. 1992. Ecological Effects of Wastewater. Chapman and Hall, London.

West Goshen Sewer Authority (WGSA) and GHD Services, Inc. (GHD). 2015. 2014/2015 Goose Creek Reassessment.

West Virginia Department of Environmental Protection (WVDEP). 303(d) Listing Methodology for Algae Blooms.

Wolman, M. G. 1954. A Method of Sampling Coarse River-bed Material. *Transactions American Geophysical Union* 35(6): 951-956.

Ylla, I., A. M. Romaní, S. Sabater. 2007.Differential effects of nutrients and light on the primary production of stream algae and mosses. *Fundamental and Applied Limnology Archiv für Hydrobiologie* 170:1-10.

Yuan, L.L. and S.B. Norton. 2003. Comparing responses of macroinvertebrate metrics to increasing stress. *Journal of the North American Benthological Society* 22(2): 308-322.

Yuan, L.L., 2004. Assigning macroinvertebrate tolerance classifications using generalized additive models. *Freshwater Biology* 49(5): 662-677.

13 Appendix A-Continuous Instream Monitoring (CIM) Data from PADEP

PADEP provided CIM dissolved oxygen and pH data from sondes for PADEP Stations 1, 2, and 3. Similar CIM data was also obtained from PADEP for the Birch Creek reference site (see 13.1). As discussed in this document in Section 4.1 the raw data were evaluated following PADEP's Continuous Instream Monitoring Protocol (PADEP, 2015a) to assess the performance of the sonde and the accuracy of the data. This protocol outlines QA procedures for calibration of water quality monitoring sondes, field measurements to ensure accuracy and post deployment data evaluation. PADEP modeled their thorough protocols after U.S. Geological Survey (USGS) protocols for collecting and analyzing continuous monitoring data. USGS has a long standing history of collecting continuous monitoring data and is viewed as a leader in continuous water quality data collection. PADEP has robust QA procedures for continuous monitoring data to ensure any assessment decisions are made based on reliable information. EPA supports PADEP in the application of this methodology. As evidence of the accuracy of the submitted DO and pH CIM data, presented below are charts comparing the relationship between the DO and pH CIM data and field-collected data for each PADEP station. (WGSA has done a similar comparison in their report WGSA and GHD, 2015). Figures 13.1, 13.2, and 13.3 display the DO data from PADEP 1, 2, and 3. These figures show good agreement between CIM data and grab (field) samples of DO where CIM data were included. Figures 13.4, 13.5, and 13.6 display the pH data from PADEP 1, 2, and 3. These figures show good agreement between CIM data and grab (field) samples of pH where CIM data were included. This comparison suggests that the PADEP CIM protocol accurately removes data that does not meet standards of quality for inclusion.

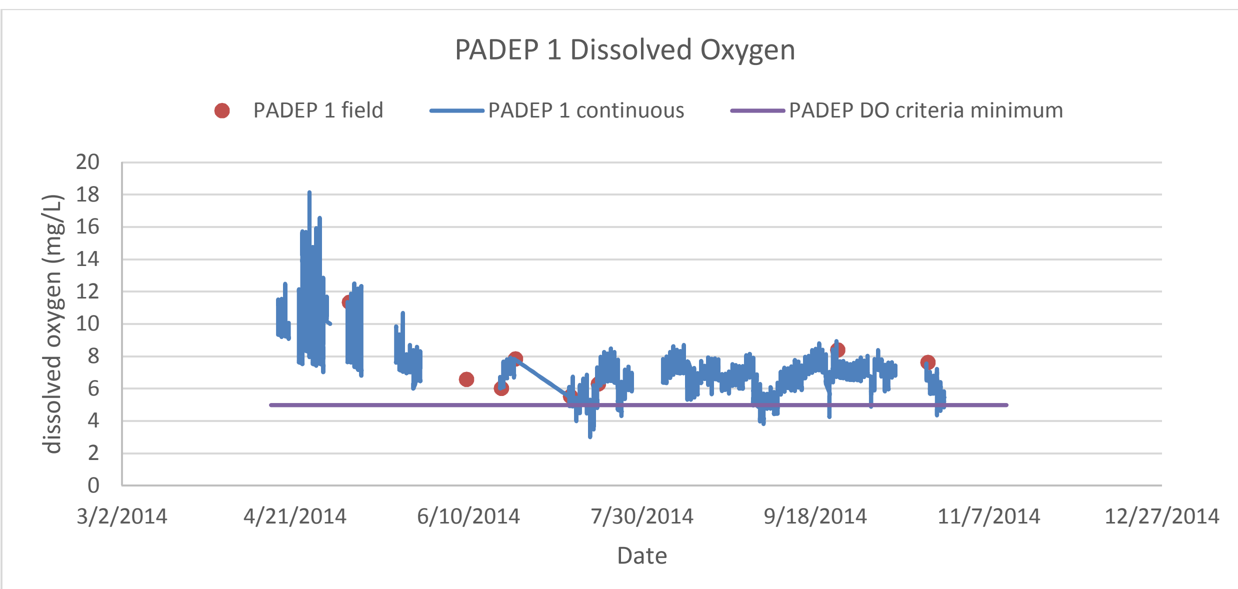

Figure 13.1 Dissolved oxygen data from grab samples and continuous instream monitoring sonde data at PADEP 1.

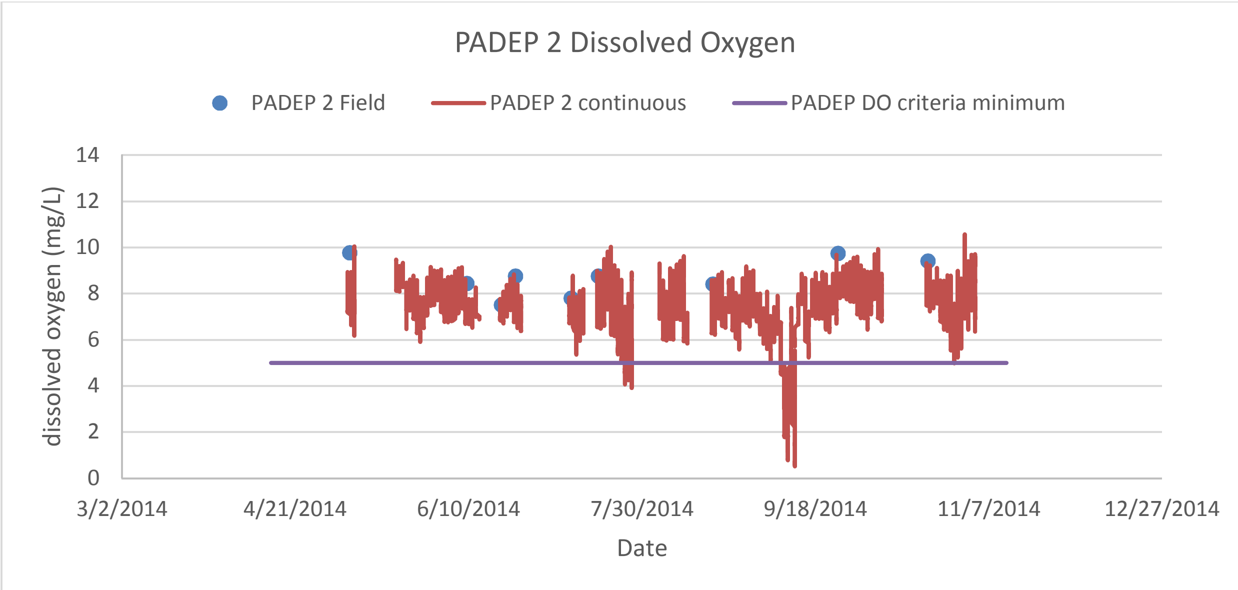

Figure 13.2 Dissolved oxygen data from grab samples and continuous instream monitoring sonde data at PADEP 2.

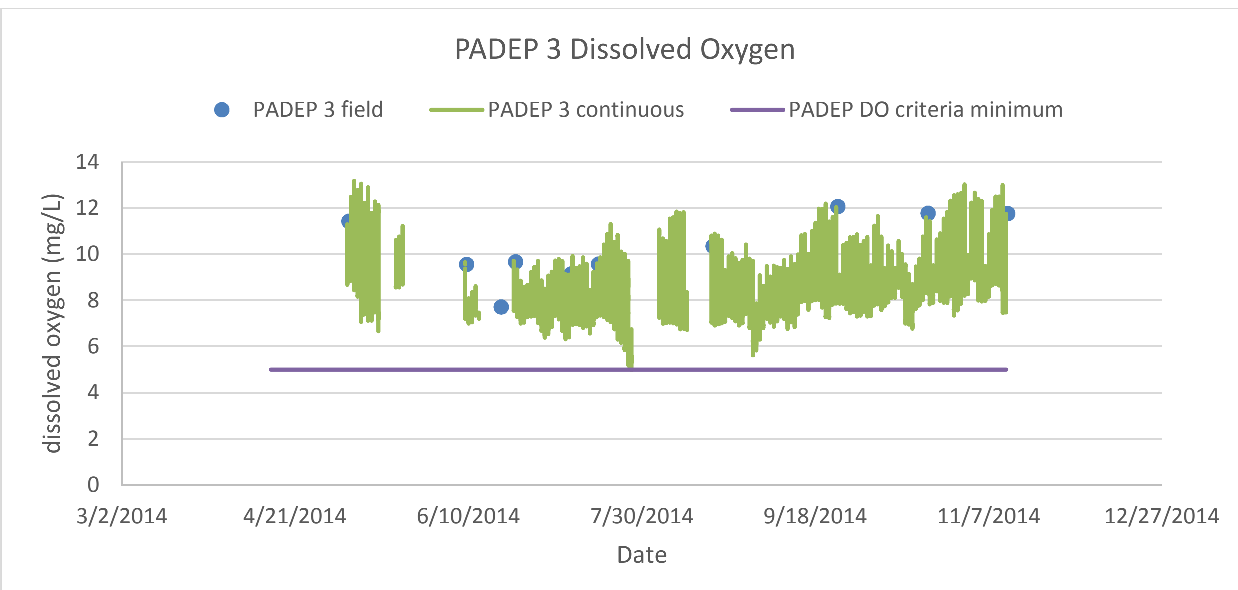

Figure 13.3 Dissolved oxygen data from grab sample and continuous instream monitoring sonde data at PADEP 3.

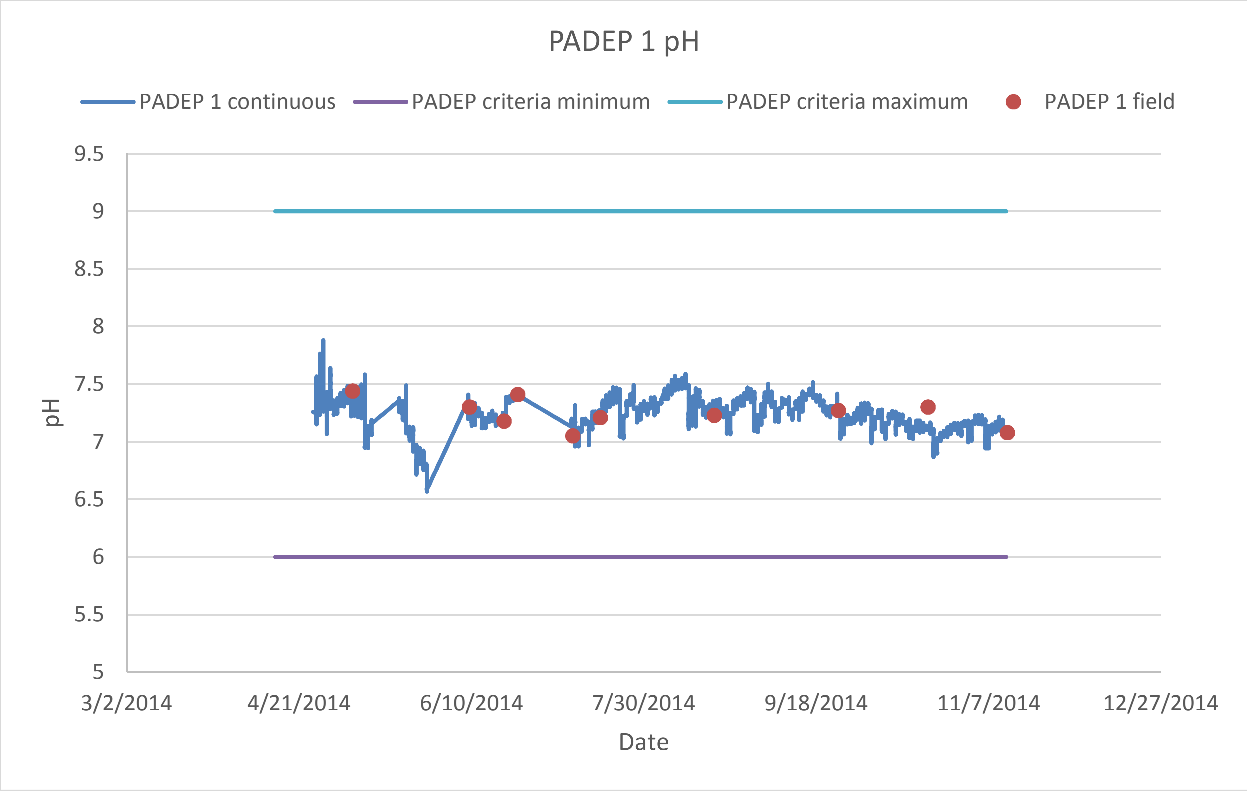

Figure 13.4 Grab sample and continuous instream monitoring sonde pH data at PADEP 1.

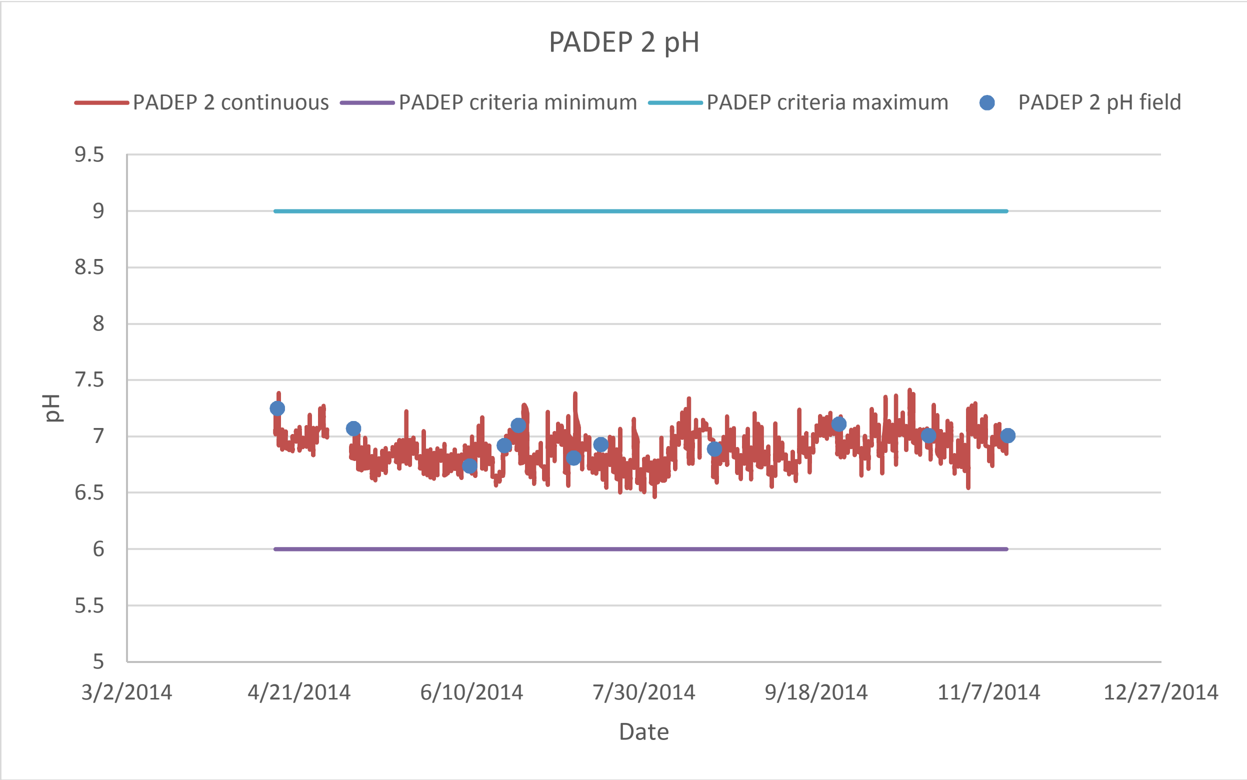

Figure 13.5 Grab sample and continuous instream monitoring sonde pH data at PADEP 2.

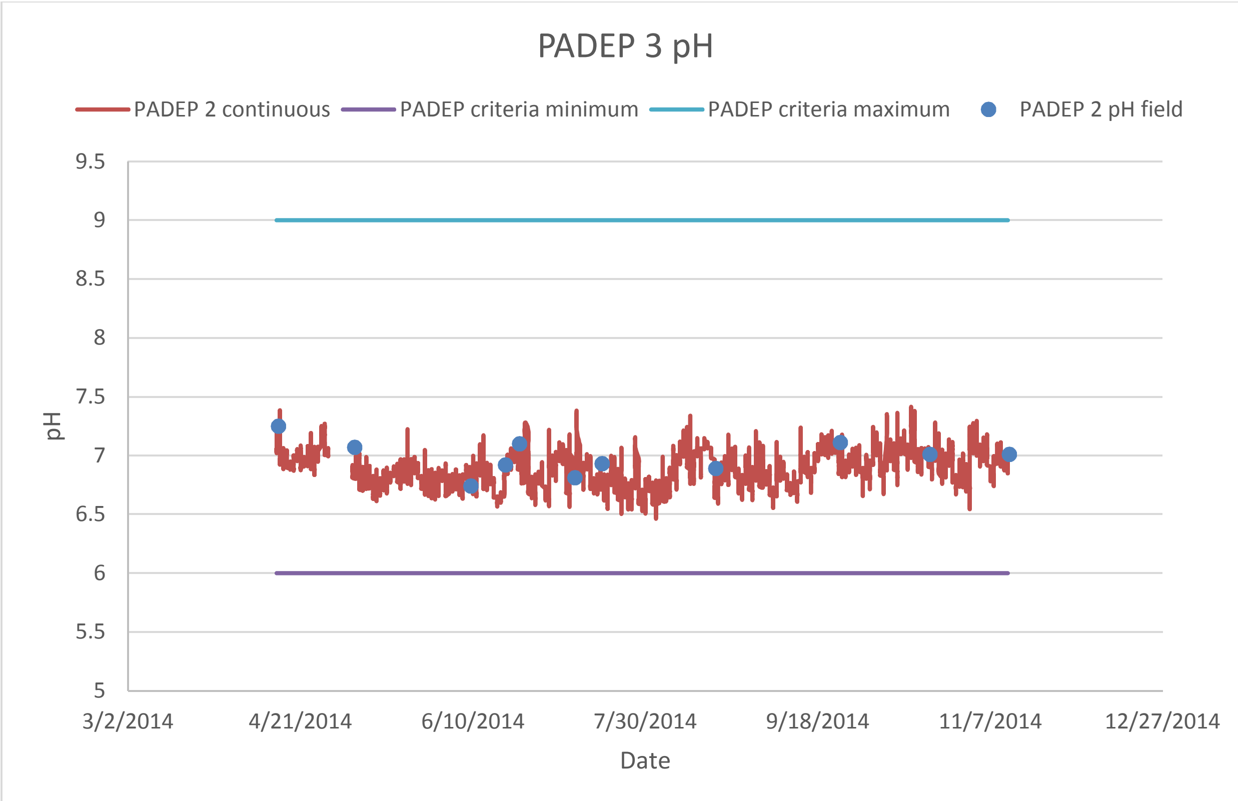

Figure 13.6 Grab sample and continuous instream monitoring sonde pH data at PADEP 3.

13.1 PADEP Reference Sites and CIM Data

EPA chose a reference (unimpaired) watershed in order to compare daily swings of DO and pH. Birch Run watershed was chosen based on watershed location, size, IBI score, and data availability. CIM data for this watershed was obtained from PADEP and is presented and discussed in Section 6.4. Figure 13.7 displays the location of each watershed and sonde deployed by PADEP. Table 13.1 shows watershed characteristics, such as size and land use.

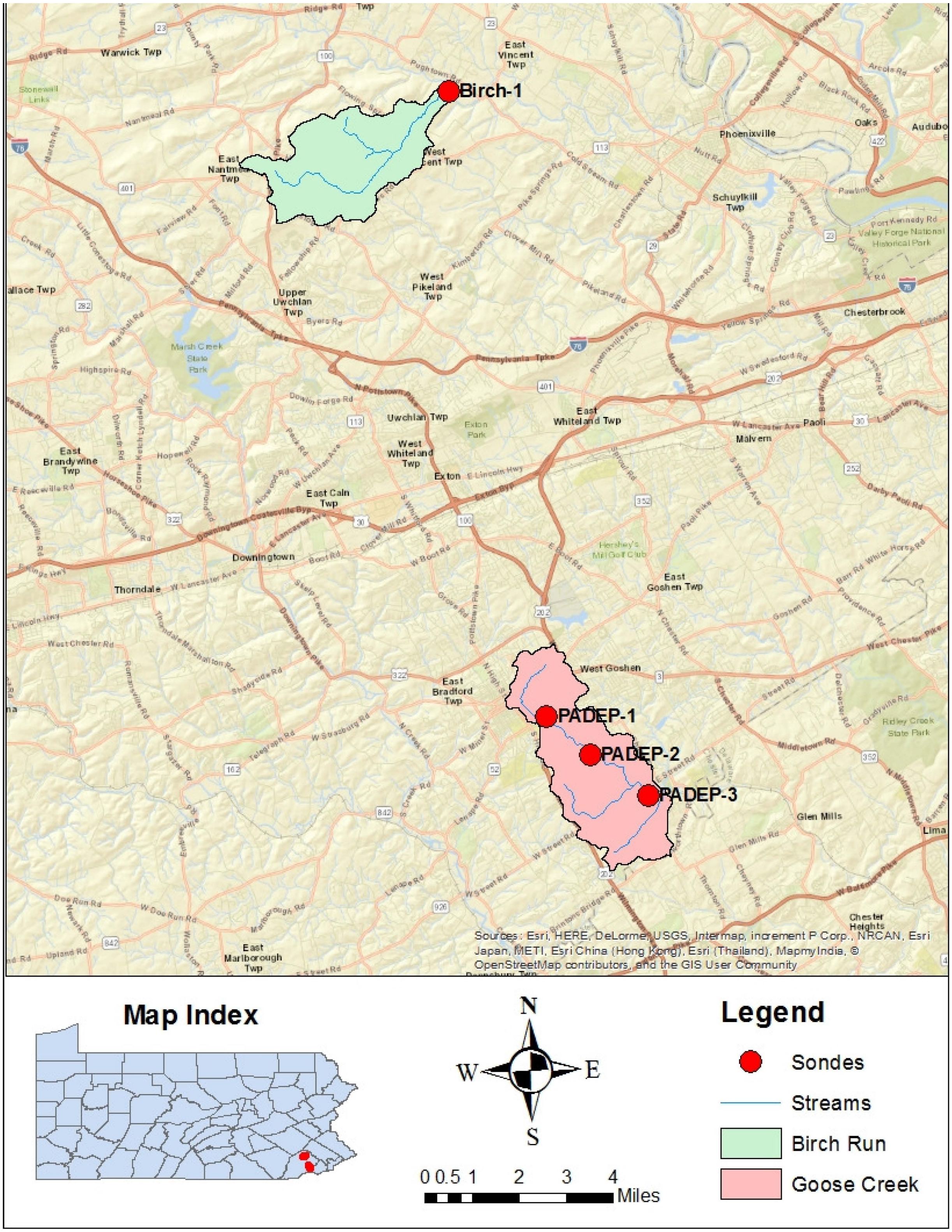

Figure 13.7 Watershed and Sonde Locations for Goose Creek and Reference Streams

Table 13.1 Watershed Characteristics of Southeastern Pennsylvania Streams

Watershed	Goose Creek	Birch Run
ICE IBI Score	25.7, 25.8, 26.8	74.6
ICE IBI Date	9/19/2013, 9/20/2013	4/26/2012
DA (sq. mi.)	7.9	6.5
Level 4 Ecoregion	Piedmont Uplands (64c)	Piedmont Uplands (64b)
Level 3 Ecoregion	Northern Piedmont	Northern Piedmont
Geology	Gneiss	Gneiss
Chapter 93 Protected Use	TSF	EV[1]
Landuse (%)*		
Developed, Open Space	41	10
Developed, Low Intensity	12	1
Developed, Medium Intensity	11	1
Developed, High Intensity	6	0
Barren Land	0	0
Deciduous Forest	18	40
Evergreen Forest	0	0
Mixed Forest	1	0
Scrub/Shrub	4	9
Grassland/Herbaceous	0	1
Pasture/Hay	3	19
Cultivated Crops	0	14
Woody Wetlands	3	3
Impervious Cover (%)*	18.5	1.6

[1]EV represents exceptional value

14 Appendix B-Additional Data

Table 13.1 Periphyton Species Composition Provided by WGSA as "Table 3.9 Periphyton Species Composition" in their Report (WGSA and GHD, 2015).

Sample Date: April 17, 2015	Number of Natural Counting Units (NCUs x 10 exp 6)					
Species	STA #1	STA #2	STA #4	STA #5	STA #7	STA #10
Bacillariophyceae (diatoms)	111.51	87.58	5.79	14.64	2.81	36.59
empty diatom valves	21.68	40.52	1.82	3.27	0.81	14.33
Chlamydomonas sp.	--	--	--	--	--	0.19
Chroococcus sp.	--	--	--	--	0.02	--
Cladophora glomerata	--	--	--	--	--	--
Euglena sp.	--	--	--	0.04	--	--
Gloeocapsa sp.	--	--	--	--	--	--
Homoeothrix sp.	--	--	--	0.13	--	--
Phormidium sp.	0.39	1.76	0.02	--	--	--
Stigeoclonium sp.	0.77	--	0.02	--	--	--
Ulothrix sp.	1.55	0.50	--	0.04	--	--
Undetermined Cyanophyte	3.10	1.51	0.46	3.27	0.77	4.65
Unknown alga coccoid	0.39	0.25	0.06	0.57	0.02	0.19
Unknown Rhodophyte Florideophycidae (chantransia)	--	0.25	--	--	--	--
Xenococcaceae	1.94	0.25	--	--	--	0.58

Sample Date: August 28, 2014	Number of Natural Counting Units (NCUs x 10 exp 6)					
Species	STA #1	STA #2	STA #4	STA #5	STA #7	STA #10
Bacillariophyceae (diatoms)	67.84	260.20	326.28	500.27	161.30	262.98
empty diatom valves	41.82	99.43	112.54	216.33	62.69	122.66
Chlamydomonas sp.	--	--	--	--	--	--
Chroococcus sp.	--	--	--	--	--	--
Cladophora glomerata	--	0.93	--	--	--	--
Euglena sp.	--	--	--	--	--	--
Gloeocapsa sp.	--	--	--	1.69	--	--
Homoeothrix sp.	--	--	--	--	0.57	--
Phormidium sp.	0.46	3.72	--	1.69	1.14	--
Stigeoclonium sp.	0.23	0.93	5.16	1.69	0.57	0.93
Ulothrix sp.	--	--	--	--	--	--
Undetermined Cyanophyte	1.16	4.65	4.13	59.15	11.40	8.36
Unknown alga coccoid	2.32	7.43	3.10	10.14	2.85	9.29
Unknown Rhodophyte Florideophycidae (chantransia)	0.23	1.86	--	1.69	--	--
Xenococcaceae	0.70	3.72	2.07	3.38	1.71	2.79

Notes:

These were qualitative samples. Results indicate the number of NCUs present in the sample times 1 million.

Numbers are comparable only if sampling area was approximately similar.