Monitoring Nitrate in the Spring Creek Watershed

Spring Creek Watershed Association
Water Resources Monitoring Project

2013 State of the Water Resources Monitoring Project

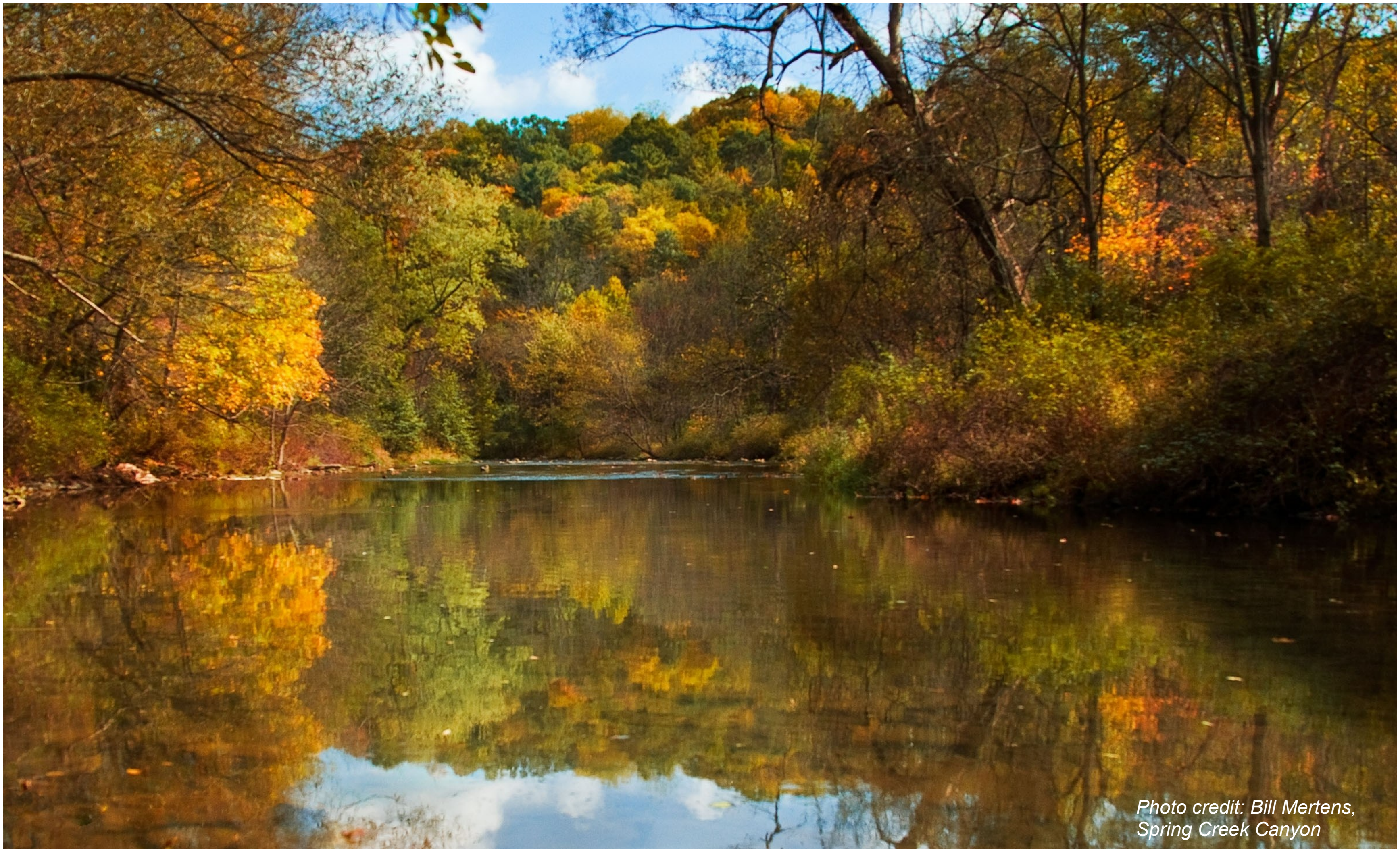


Photo credit: Bill Mertens, Spring Creek Canyon

FROM THE CHAIR

In this issue of the State of the Water Resources Report, we examine the complex topic of excess nitrogen in the environment. We discuss regulations related to nitrogen and WRMP's long term efforts to monitor nitrate in the Spring Creek Watershed. Nitrogen is a plant primary macronutrient and is an essential element to make plants grow. Nitrogen, more than any other element, promotes rapid plant growth and a deep green color. The conversion of atmospheric nitrogen to a form that plants can use is a natural process; however, in order to produce the necessary crops for society most growers use supplemental chemical fertilizers. Addressing the use of fertilizers and manure will be one of the challenges for the Spring Creek Watershed.

It's estimated that between 40 to 60 percent of the world food production is attributable to fertilizers, the primary ingredient of which is nitrogen. The first commercial nitrogen fertilizers were bat guano or bird droppings, and later mined saltpeter (sodium nitrate) from Chili. In the early 1900's, a German chemist named Fritz Haber developed a method to synthesize nitrate from atmospheric nitrogen, the Haber process, which is still used by fertilizer manufacturers today. While fertilizers have helped us feed a hungry world, nitrogen in fertilizers that isn't used by the plant can be easily leached into surface water and groundwater where it can cause environmental and health related problems.

The use of chemical fertilizers significantly increased following WWII, coincidently when the road salting and home owned wash machines that used phosphates also started to be commonly used. Today the Environmental Protection Agency estimates that approximately 40 million acres of lawn exist in the United States and that fertilizers used on lawns may be roughly equivalent to the application rates used on agronomic row crops. Corn, a common agronomic product in the watershed, requires more nitrogen per acre than any other crop. This hunger for food and beautiful lawns carries a high burden for society.

Residents of the Spring Creek Watershed enjoy better water quality that the region has experienced in the last 100 years. The Water Resources Monitoring Project, which has been in place for 16 years, provides vital long-term data that can be used by local planning officials and engineers to make sound land use and water quality decisions. The Water Resources Committee, the advisory committee to the WRMP, is very appreciative of the donations the program receives on an annual basis from our sponsors. Your continued support will help maintain the program's ability to provide data needed to monitor changes within the watershed as our community continues to grow and thrive.

Larry Fennessey,
Chair

MONITORING NITRATE

Nitrogen (N) is an essential and integral nutrient present in and used by all living things. Survival by any organism is impossible without an adequate supply of N in its diet. N is most commonly found in gaseous form known as dinitrogen, also referred to as atmospheric nitrogen (N_2). More than 78% of the Earth's atmosphere is comprised of nitrogen gas. However, in its gaseous form it is unusable by most plants, and consequently a large percentage of the Earth's bioavailable N remains unusable. This limited availability of N therefore governs the productivity of most of the world's ecosystems making it a limiting nutrient in terrestrial environments. To help offset the demand with the supply of bioavailable nitrogen, human sources of nitrogen (e.g., fertilizers and animal manures) are applied to soils. Other common sources of nitrogen in the environment include atmospheric deposition, decomposition of plant and animal material, and sewage.

Forms of Nitrogen

Nitrogen is found in many forms on Earth. It is the largest component of animal waste usually in the form of urea, uric acid, or ammonium (NH_4^+). In fish and aquatic invertebrates, ammonium is excreted directly into the water. However, in mammals and amphibians it is converted to urea, and in birds and reptiles it is converted to uric acid. Nitrate (NO_3^-) is also another common form of nitrogen that is typically applied as fertilizer. Excess or improper applications of animal manures or fertilizers can lead to the degradation of stream and groundwater water quality.

WRMP volunteer, Bryce Boyer, taking a water quality sample to be processed.

In an effort to monitor the level of nitrogen within the surface and groundwater of the Spring Creek Watershed, the Water Resources Monitoring Project (WRMP) samples nitrate (NO_3^-) at 15 surface monitoring locations and 8 spring monitoring locations throughout the watershed. Nitrate is the most common form of nitrogen present in water, and can cause adverse health and environmental impacts.

Measured values of nitrate (NO_3^-) can be reported as simply nitrate (NO_3^-) or as nitrate in the form of nitrogen (NO_3-N). The latter is the commonly preferred way of reporting nitrate because government agencies due to regulatory reasons are more concerned with the nitrogen aspect of NO_3^- as opposed to the oxygen aspect. Nitrate values collected by the WRMP are reported as nitrate-nitrogen (NO_3 - N).

MONITORING NITRATE

Importance of Monitoring Nitrate

Although nitrogen is essential to all living organisms, nitrate can have both negative environmental and health related effects. Health-related risks are associated with consumption of water with elevated nitrate. Because of these consumption risks, nitrate concentrations in water, especially water that serves as a drinking source, is regulated.

In 1974, Congress passed the Safe Drinking Water Act which requires the United States Environmental Protection Agency (US EPA) to determine the level of contaminants in drinking water that will result in no likely adverse health effects[1]. Containments are defined as any physical, chemical, biological or radiological substances or matter in water. For nitrate, the US EPA has determined the level to be 10 mg N/L NO_3-N or approximately 44 mg N/L NO_3, and has set an enforceable regulation for nitrate, called a maximum contaminant level (MCL) at 10 mg N/L. This drinking water regulation for nitrate became effective in 1992.

Consumption of water by humans with excess nitrate affects infants primarily. Infants below six months that drink water containing nitrate in excess of 10 mg N/L for a long period of time could become ill. Affected infants may experience symptoms of shortness of breath. Continued consumption of nitrate by infants may ultimately lead to what is known as blue-baby syndrome. This is a disorder which reduces the bloods' ability to carry oxygen, thus reducing the supply of oxygen to tissues. This results in the body's tissue turning blue, hence the name blue-baby syndrome. However, it is important to note that cases of blue baby syndrome are very rare, and for adults, consumption of nitrate over the MCL poses little threat. Regardless, the standard MCL set and regulated by the US EPA is still 10 mg N/L for all drinking water sources.

Nitrogen dioxide (NO_2) in the air from the pollution of air quality through the combustion of fossil fuels (e.g., gasoline, coal, etc.) has been linked to increased incidences of asthma[2].

Nitrate can also have negative environmental effects. Excess nitrate in our ecosystem can trigger imbalances that may result in negative consequences for ecosystems. However, the environmental effects of nitrate vary between freshwater, estuary, and saltwater ecosystems. In freshwater streams and lakes, effects of nitrate on water quality are less than that in saltwater ecosystems. However, as streams, such as in the Spring Creek Watershed, feed into the greater Chesapeake Bay via the Susquehanna River, nitrate leaving the watershed can affect the Bay. Because nitrogen is a limiting nutrient in saltwater ecosystems, nitrate that enters the Bay acts as a

[1] United States Environmental Protection Agency Rules and Regulations Implemented under the Clean Water Act: http://water.epa.gov/lawsregs/rulesregs/.

[2] United States Environmental Protection Agency Ground Level Ozone: http://www.epa.gov/groundlevelozone/.

fertilizer for algae and plants. When nitrate is present in high amounts, algae can multiply rapidly to form huge masses called algae blooms. These floating blooms fill the water, blocking sunlight needed by Bay grasses (rooted aquatic plants) that provide necessary food and habitat to many species. Dead, decomposing algae can then remove oxygen from the water, forcing some species to leave an area or die if unable to leave.

Satellite image of Chesapeake Bay after Tropical Storm Lee in 2011 (NASA Goddard Photo Video).

Regulatory Controls of Nitrogen

Due to the far reaching environmental and health-related negative impacts of elevated nitrate, regulations have been put in place to regulate the sources of nitrate. The US EPA and Pennsylvania Department of Environmental Protection (PA DEP) are two agencies that help regulate and set limits for nitrogen discharges.

These regulations cover point source discharges and some non-point source discharges. All point source discharges to waters of the Commonwealth are required by the US EPA under Section 402 of the Clean Water Act to obtain a National Pollutant Discharge Elimination System (NPDES) permit[3]. PA DEP administers the permits for Pennsylvania. These permits are issued to those point sources deemed “significant”. Pennsylvania’s Chesapeake Bay Program defines significant sources as any discharge at or above 0.4 million gallons per day (MGD) [4]. The majority of NPDES permits are issued for sewage, industrial waste, industrial waste stormwater, and municipal separate storm sewer systems (MS4; non-point discharges). For sewage and industrial waste discharges, the purpose of the permit is to establish allowable concentrations and loads of a wide range of regulated pollutants such as nitrogen.

---

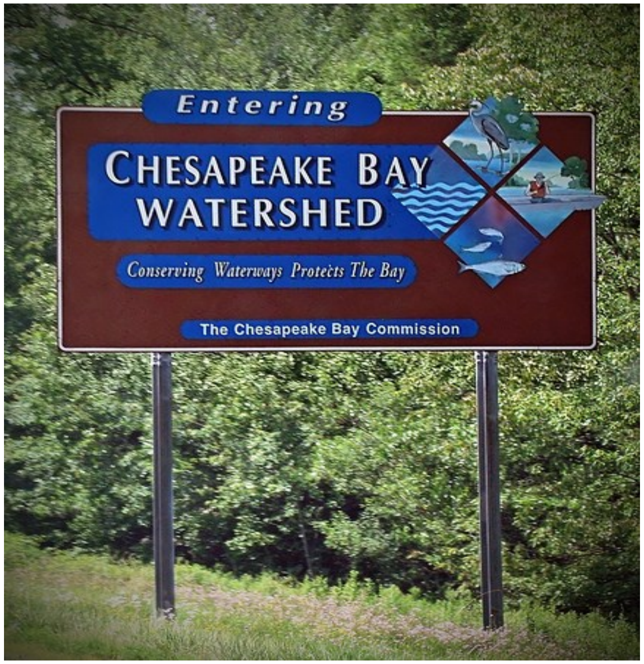
[3] United States Environmental Protection Agency Basic Information about Nitrate in Drinking Water: http://water.epa.gov/drink/contaminants/basicinformation/nitrate.cfm#one

[4] Pennsylvania Department of Environmental Protection. 2004. Pennsylvania's Chesapeake Bay Tributary Strategy.

MONITORING NITRATE

Sewage treatment facilities such as the University Area Joint Authority (UAJA) and the Bellefonte Wastewater Treatment facility both have an NPDES permit to discharge treated wastewater into Spring Creek. The Pennsylvania State University Wastewater Treatment facility does not discharge directly to surface water but rather uses a spray irrigation system known as the “Living Filter”. Therefore, the Penn State facility is not regulated by an NPDES permit. In Pennsylvania, PA DEP sets specific effluent criteria under NPDES permits that wastewater treatment facilities are required to meet. Because of Spring Creek’s high quality classification, discharge criteria for wastewater treatment facilities and other point sources into Spring Creek are more stringent. This results in increased treatment requirements by facilities. All public owned wastewater treatment facilities have also met additional requirements set forth in the Chesapeake Bay Tributary Strategy (CBTS), lowering even further the nitrogen concentration requirement in treated effluent discharged. The CBTS currently specifies a concentration limit of 6.0mg/L for N[5].

In addition to wastewater treatment facilities in the watershed, other groups within the watershed that maintain NPDES permits for point source discharges include the Pennsylvania Fish and Boat Commission, Graymont and the Coca Cola Company[6]. These permits have been issued for industrial waste discharges and therefore have to meet nitrogen discharge requirements.



NPDES permits are also required by larger farm operations known as Concentrated Animal Feeding Operations (CAFO). Feeding operations are determined to be CAFOs based on the number of animals. There are currently no CAFOs within the Spring Creek Watershed.

Another potential source of nitrogen pollution that is an area of concern for the US EPA and PA DEP is stormwater runoff. To help address potential nitrogen pollution from urban runoff, municipalities located in urbanized areas (based on U.S. 2000 census data), with Separate Storm Sewer Systems (MS4) are required under the NPDES

---

[5] Water Resources Monitoring Project. 2007. State of the Water Resources Report.

[6] Pennsylvania Department of Environmental Protection. Industrial Waste NPDES permit holders. http://www.portal.state.pa.us/portal/server.pt/community/wastewater_management/10582/npdes_and_wqm_electronic_permits_and_permit_application_forms/554182

Phase II Program to obtain MS4 permits. The Pennsylvania State University and the municipalities of College, Ferguson, Harris, and Patton Townships, and State College Borough are the six MS4s located in the Spring Creek Watershed. A portion of Benner Township has the population to require an MS4 permit, but has been granted a MS4 waiver not requiring it to have a permit. Although other municipalities within the watershed have separate storm sewer systems, these are the only seven, except for Benner Township, required to have MS4 permits for their stormwater discharge because of their population. Operators of MS4s are required by the US EPA and PA DEP to reduce discharges of pollutants in stormwater to the maximum extent practicable to protect water quality and to meet water quality requirements set forth in the Clean Water Act[7].

Industries, businesses and municipalities within the Spring Creek Watershed are under additional regulations because Spring Creek falls within the greater Chesapeake Bay Watershed. According to the Chesapeake Bay Program, the three main sources of pollutants to the Bay include sediment, phosphorous, and nitrogen. Because nitrogen is a limiting nutrient in saltwater and estuarine ecosystems like the Bay, it is a major area of focus for organizations like the Chesapeake Bay Foundation (CBF) and Chesapeake Bay Program (CBP) which seek to improve the Bay.

To help manage excess nutrients in both the Bay and in Pennsylvania streams and rivers, Total Maximum Daily Loads (TMDLs) have been established. TMDL is a calculation of the maximum amount of pollutant that a waterbody can receive and still safely meet water quality standards set by the US EPA under Section 303 of Clean Water Act of 1972. The US EPA under section 303(d) of the Clean Water Act requires states to develop a list of impaired waters. To meet this requirement, the Commonwealth of Pennsylvania has worked to assess the waters of the state. Once assessments for waterbodies are complete, the goal is to develop TMDL plans to restore water quality in the impaired waterways.

Impaired waters within the Spring Creek Watershed include sections of Spring Creek, Slab Cabin Run, Logan Branch, Thompson Run, Walnut Springs Run, and Buffalo Run. The major cause of impairment within most of these waters is siltation. This siltation is caused in part by urban runoff, and also in part by the grazing activities from agriculture. A TMDL for the impaired waters of the Spring Creek Watershed has not yet been developed, but PA DEP has set a date of 2017 for development and approval[8].

[7] 2012 National Pollutant Discharge Elimination System (NPDES) Stormwater Discharges From Small Municipal Separate Storm Sewer Systems (MS4s) General Permit (PAG-13). PA DEP. http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-95060/3800-PM-BPNPSM0100.pdf. Accessed 7/28/14.

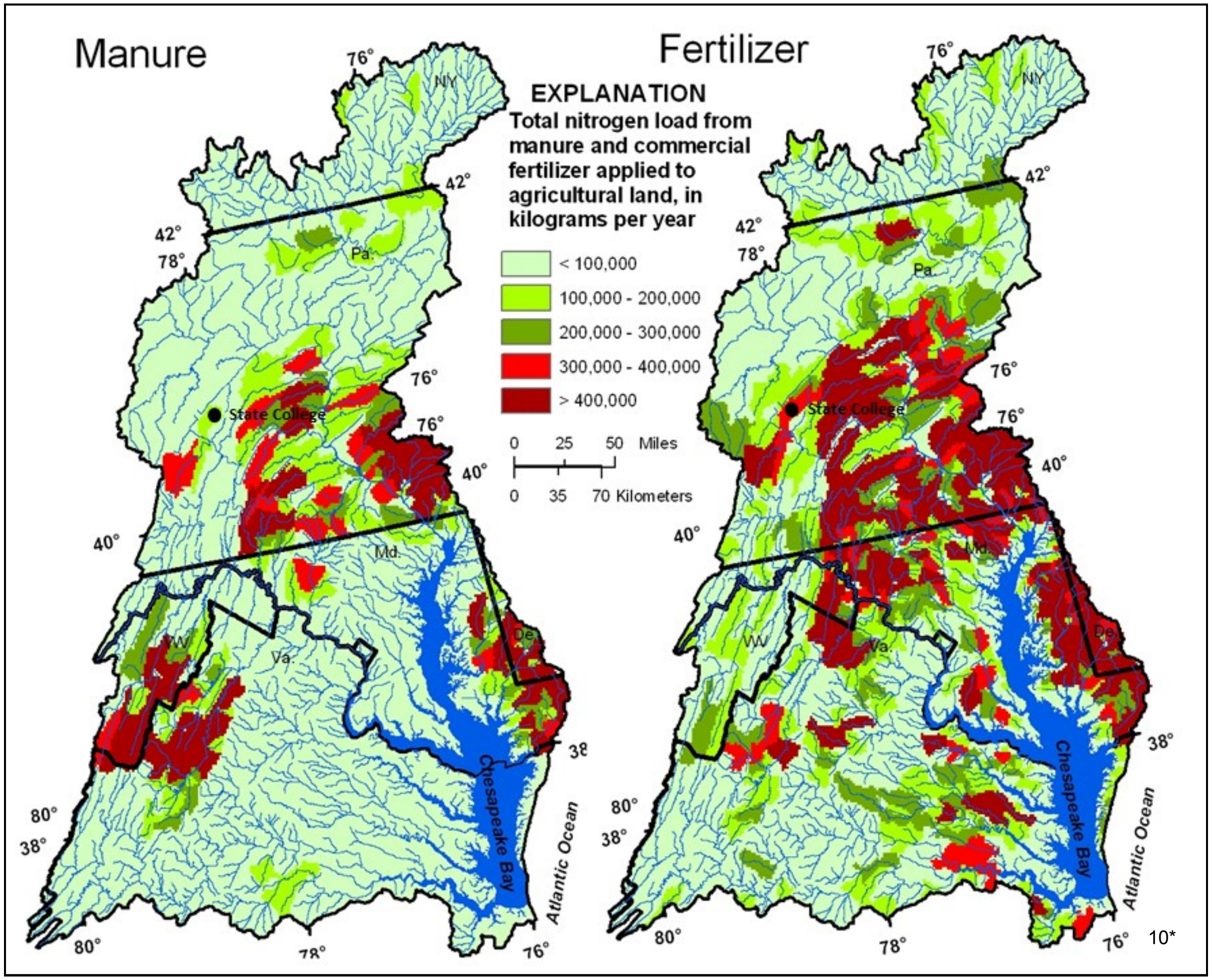
[8] Pennsylvania Department of Environmental Protection 2012 Pennsylvania Integrated Water Quality Monitoring and Assessment Report-Streams, Category 5 Waterbodies, Pollutants Requiring a TMDL.

MONITORING NITRATE

Once a TMDL is developed and approved, MS4s will additionally be required to develop a TMDL Plan for reducing pollutants in stormwater discharges according to the approved TMDLs. However, MS4s are being required already to develop a Chesapeake Bay Pollutant Reduction Plan (CBPRP). The objective of the CBPRP is to implement best management practices (BMPs) to produce tangible improvements to water quality of stormwater discharges to Bay watersheds. MS4s will be required to describe how each BMP is expected to reduce nitrogen, in addition to phosphorous and/or sediment to receiving waters[9].

Sources of Nitrogen

Because most of the Earth's bioavailable nitrogen is unusable in a gaseous form, it needs to be fixed. Fixed meaning transformed from unusable N_2 to a usable form of nitrogen such as NO_3. Nitrogen fixation occurs through natural and human sources. Lightning is one way that atmospheric nitrogen is fixed naturally, but this fixation is a small contribution to the overall nitrogen found in soils. Nitrogen-fixing bacteria and fungi are the primary natural pathways



10*

---

[9] Department of Environmental Protection. 2014. Municipal Separate Storm Sewer System (MS4) TMDL Plan/ Chesapeake Bay Pollution Reduction Plan Instructions.

[10] United States Geological Survey. 2002. Digital Data Used to Relate Nutrient Inputs to Water Quality in the Chesapeake Bay Watershed, Version 3.0. *Location of State College was approximated.

by which nitrogen enters soils. However, nitrogen fixation through bacteria and fungi doesn't occur at a rate fast enough to support the world's demand.

The demands on nitrogen are high especially as they pertain to food production. The conversion of nitrogen gas to a usable form of nitrogen fertilizer is done through an industrial process. Industrial generated nitrogen helps meet the world's food production demands. Increased cultivation of leguminous crops (e.g., beans and alfalfa) that fix nitrogen gas to make it bioavailable are also being used to supplement the demand placed on nitrogen. It has been estimated that industrial generated nitrogen fertilizer is responsible for sustaining one-third of the Earth's population.

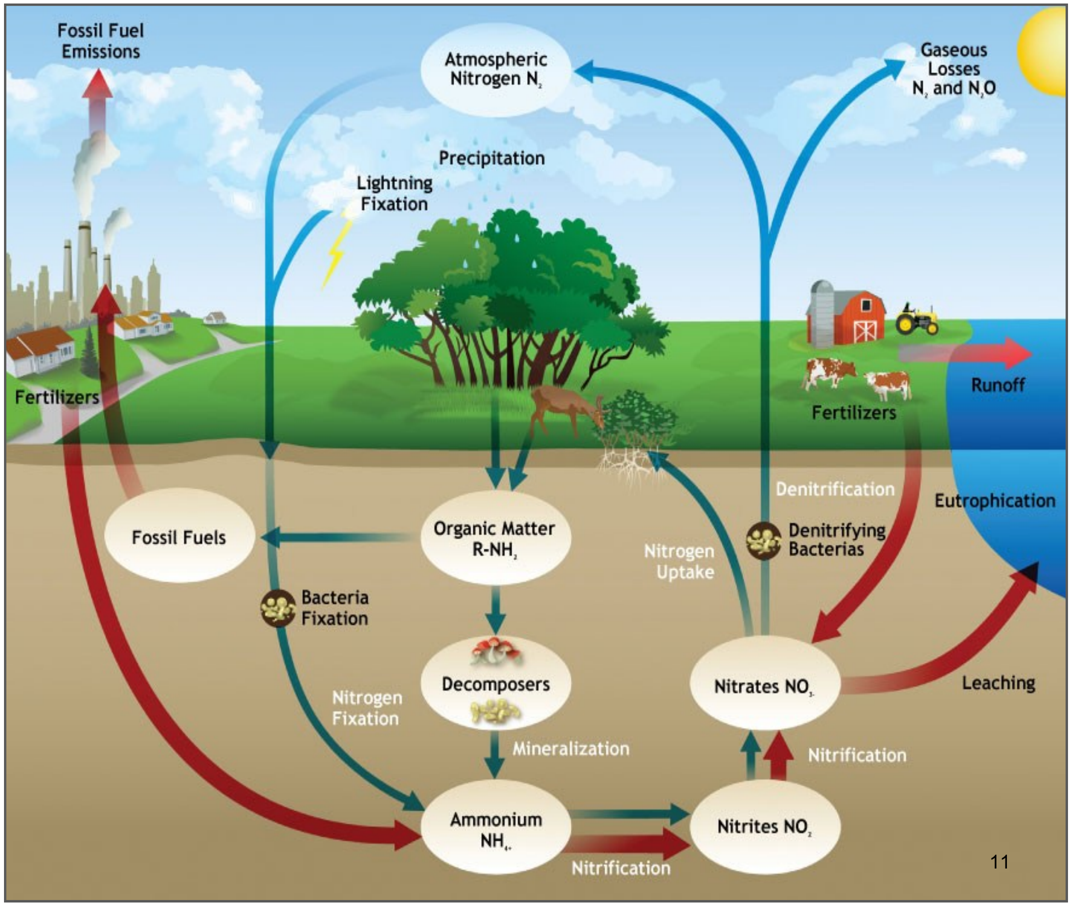
Other human sources of nitrogen include nitrous oxides which enter the atmosphere through the combustion of fossil fuels (e.g., coal, gasoline, and diesel). Nitrogen oxides in the atmosphere undergo numerous chemical changes that produce nitric acid (HNO_3) that can lower the pH of precipitation. This is referred to as wet deposition or nitrogen deposition. Dry deposition of nitrogen can also occur when gas and particles adhere to the ground, plants or other surfaces. Nitrogen deposition is one of the primary sources of nitrogen to forested streams. However, nitrogen losses generally exceed nitrogen gains in a forested landscape during the growing season. Other sources of nitrogen within a forest setting include the decomposition of soil organic matter on the forest floor, and nitrogen fixation. As nitrogen is taken up by plants for growth it is lost, resulting in a decline in concentration within the soils of the forest, and a decrease in the leaching of nitrogen from the soil into ground and surface waters.

In comparison, gains and losses of nitrogen differ in urban areas from forested areas. One of the primary sources of nitrogen in an urban area is from fertilizer used on lawns. These fertilizers are used to supplement the nitrogen that is being gained through precipitation and decomposition of leaves and grass. In agricultural areas, nitrogen in soils can be lost primarily through uptake by plants to be used for growth and through erosion and leaching which physically remove nitrogen from soils into groundwater and surface water. The latter is explained in more details in the following section of the report describing the nitrogen cycle. Besides fertilizers, animal manure is another common source of nitrogen from agriculture.

Other human sources of nitrogen may include wastewater treatment facilities, failing infrastructure of sewer lines and pipes, and failing septic systems. Industrial point sources such as fish hatcheries may also serve as a source of nitrogen pollution.

The Nitrogen Cycle

The nitrogen cycle traces the transformation and translocation of nitrogen in soil, water, and living and dead organic material. Because the large majority of nitrogen is unavailable to living organisms in the form of atmospheric nitrogen (N_2), it requires fixation to be converted into usable forms. Nitrogen fixation generally refers to the process in which N_2 is converted to ammonia (NH_3). This conversion is completed through the activities of microorganisms like bacteria. NH_3 is also produced when organic nitrogen from animal manure, soil organic matter, or human waste is converted by way of ammonification. When NH_3 comes in contact with water (H_2O) it ionizes and forms ammonium (NH_4^+).



Once in the soil as NH_4^+, a series of reactions can occur including: uptake by plants; fixation by clay minerals and organic matter; immobilization by microorganisms; transformation into ammonia gas and export to the atmosphere by volatilization; and nitrification. The latter is a two-step process. The first step is the oxidation of NH_3 or NH_4^+ to form nitrite (NO_2^-), and this is done by nitrifying bacteria. These bacteria can then convert NO_2^- to nitrate (NO_3^-) in the second step of this process.

NO_3^- is an inorganic form of nitrogen that is readily taken up through the roots of plants and assimilated into organic compounds. In the absence of oxygen, microbial bacteria can reduce NO_3^- through a series of reactions to N_2 and nitrous oxide (N_2O) in a process called denitrification. This allows for nitrogen to re-enter the atmosphere. However, NO_3^- that is not transformed to a gaseous form or taken into the roots of plants can enter surface and groundwater readily.

---

[11] Nitrogen Cycle, from landscapeforlife.org

MONITORING NITRATE

One of the primary sources of nitrogen transport into water is through leaching. Leaching refers to the export of nitrogen as NO_3^- from the soil which makes it unavailable for plant uptake. Unlike NH_4^+ ions which are positively charged and therefore attracted to negatively charged soil particles, the negative charge of NO_3^- ions causes them to be repelled by negative soil particles. Under wet conditions, NO_3^- moves downward with draining water and is readily removed from the soil. Nitrate can directly reach streams through surface flow, or may first enter groundwater and ultimately in to stream or lakes.

Nitrate in Water

Nitrogen poses the biggest risk to water quality when it is in the form of nitrate. This is a primary reason why the WRMP monitors nitrogen in the form of nitrate (NO_3-N). Once nitrogen is taken into the soil and converted to nitrate, water quality becomes a concern because nitrate is highly mobile and moves easily with water. Concerns are typically directed toward groundwater because groundwater generally serves as the source of drinking water in the Spring Creek Watershed. Nitrate can occur naturally in some groundwater, but in most cases higher levels are attributable to human activities. Within the Spring Creek Watershed, over 90% of residents use groundwater for their drinking water.

The Penn State Agricultural Analytical Laboratory and Penn State Extension gather data on private water well systems from residents who voluntarily submit water samples for testing. According to their data, the percentage of private drinking water wells that fail the MCM standard for nitrate-N is higher in Centre County (5.4%) than statewide (4.9%). Comparatively, Lancaster County which is over 65%

Interested in getting your water tested?

Water testing can be done by several different laboratories in the area. The Pennsylvania State University Agricultural Analytical Laboratory is one such lab that offers drinking water testing as well as other water testing for homeowners. More information on the different test packages offered and fees can be accessed at http://agsci.psu.edu/aasl/water-testing/drinking-water-testing.

---

[12] Changes in the Land Lancaster County, PA a report prepared by the Yale School of Forestry and Environmental Science for the USDA Forest Service under the Highlands Conservation Act of 2004.

[13] Private Water Well data collected by the Pennsylvania State University Agricultural Analytical Laboratory and Penn State Extension.

[14] Centre County Planning and Development Office. 2011. Centre County, PA. http://centrecountypa.gov/DocumentCenter/View/753. Accessed 7/14/14.

agriculture[12] has a failure rate of 26.1%[13]. Centre County in comparison is only 14.2% developed for agriculture[14]. The highest recorded concentration for Centre County was 17.1 mg/L compared to a highest recorded value of 18.8 mg/L in Lancaster County[13].

There is also a close link between groundwater and surface water within the Spring Creek Watershed because groundwater supplies over 80% of the flow to the surface waters of Spring Creek through springs and seeps. Therefore, groundwater plays a large role in the overall nitrate concentration in streams in the Spring Creek Watershed, and a much greater role in comparison watersheds such as those in Lancaster County.

Once in water, nitrate can cause both direct and indirect negative effects. An indirect effect of elevated nitrate can be acidification in freshwater systems. If stream acidity becomes elevated it can negatively affect aquatic communities including both fish and macroinvertebrates. Brown trout reportedly can tolerate a pH ranging from 5.0 to 9.5, but their optimal growth range is between 6.8 and 7.8[15]. Therefore, depending on nitrate inputs to Spring Creek brown trout populations can be indirectly affected. This makes it a vital water quality parameter to monitor.

A more direct effect of excess nitrate on aquatic communities includes increased plant and algae growth within streams. This in turn can cause an indirect negative effect because as plants and algae grow they photosynthesize in the presence of sunlight producing dissolved oxygen. Stressful conditions for fish may develop as levels of dissolved oxygen fluctuate between high levels during the day (as plants grow with sunlight) and low levels at night (algae take up oxygen). This creates stressful conditions for fish as levels of dissolved oxygen will fluctuate between high levels during the day (as plants grow with sunlight) and low levels at night (when sunlight dissipates). This can eventually kill aquatic plants because they require sunlight to survive. The dead aquatic plant material can then settle to the bottom of the stream, and bacteria will use the dissolved oxygen in the water to

Big Spring in Bellefonte. The spring was covered in 2006 by a synthetic cover in to help prevent contamination.

---

[15] Raleigh, R.F., L.D. Zuckerman, and P.C. Nelson. 1986. Habitat Suitability Index Models and Instream Flow Suitability Curves: Brown Trout. U.S. Fish and Wildlife Service Biological Report 82 (10.124).

consume this dead plant material. This will reduce the level of dissolved oxygen in the water and place fish and insects at risk. Secondly, it can change the habitat because as plants die and settle to the bottom of the stream channel changing the channel substrate. For fish like brown trout that rely on gravel and cobble substrate to spawn, this can reduce habitat resulting in negative spawning effects. Although nitrate levels in the Spring Creek Watershed are not likely to result in excessive algae blooms, it is important to continually monitor concentrations to assess the risk to the fishery.

Typical Values in the Chesapeake Bay Region

Several factors can affect the spatial distribution of nitrate concentrations in surface and ground water including physiography, bedrock type, and land use. Water quality in areas underlain with carbonate bedrock commonly have higher nitrate concentrations[16]. This is due in part to the degree of agricultural activity on the fertile soils of carbonate bedrock. In these areas, larger quantities of fertilizer are typically used to support the agricultural activities and a greater percentage of the land is being used leaving a small percentage idle.

Another factor contributing to the difference between carbonate and other bedrock types is due to runoff drainage. In carbonate systems characterized by excellent infiltration capacities of soil, nitrate can enter groundwater more easily. Highly weathered bedrock, including carbonate features such as sinkholes, losing streams, and conduit-dominated groundwater flow allow for short flow path times. This results in aerated conditions in groundwater because of increased dissolved oxygen concentrations. These aerated conditions can then inhibit denitrification.

The physiography of the carbonate systems may also play a role. Carbonate bedrock valleys are generally wider and flatter than sandstone and shale valleys and have more productive soils. This contributes to the increase of land use for agricultural activities. The lower infiltration capacity of sandstone and shale soils also generally results in less leaching of nitrate into groundwater.

The Spring Creek watershed falls within what is known as the Ridge and Valley Province. Within this province both carbonate, and sandstone and shale bedrocks persist. This area is typically characterized as having broad valleys with altitude ranges between 400 to 900 feet. In the broader spectrum of the Chesapeake Bay there also exists the Piedmont Province which is also underlain with carbonate bedrock, but differs in its general characterization in that it has low rolling hills with altitude ranges from 500 to 800 feet.

---

[16] Fishel, David K., P.L. Lietman. 1986. Occurrence of nitrate and herbicides in ground water in the upper Conestoga River basin, Pennsylvania. U.S. Geological Survey Water Resources Investigation Report 85-4202. 8pp.

[17] Nitrate in Ground Water and Stream Base Flow in the Lower Susquehanna River Basin, Pennsylvania and Maryland. 1997. U.S. Department of Interior. U.S. Geological Survey.

In a USGS study completed with similar sampling frequencies of the WRMP, median concentrations (mg/L) of nitrate were shown to vary widely across the Chesapeake Bay Region[17]. In general nitrate levels were higher in surface water and groundwater underlain with carbonate bedrock in comparison to sandstone and shale bedrock areas (**Table 1**). There was also variability among carbonate systems, with values in Piedmont systems and South-Eastern Pennsylvania Ridge and Valley systems being high in comparison to another Central Pennsylvania system within the Ridge and Valley Province. Furthermore, overall median concentration values for surface waters in the Spring Creek Watershed (3.1 mg/L) were almost two times less than the other Central Pennsylvania carbonate system (6.4 mg/L) and almost four times less than that of Ridge and Valley carbonate systems (11 mg/L).

Table 1. Median nitrate-N concentration for surface and groundwater systems throughout the Chesapeake Bay region.[17]

Geography and Bedrock Type	Surface Water (mg/L)	Groundwater (mg/L)
South-Eastern PA Ridge and Valley Carbonate System	11	8.6
Other Central PA Ridge and Valley Carbonate System	6.4	9.0
Non-Ridge and Valley Carbonate System (Piedmont)	10	11
Ridge and Valley Sandstone and Shale System (non-carbonate)	3.8	0.64
Spring Creek Watershed	3.1	3.6

Concentration versus Loads

Water quality can be measured in two ways, either by pollutant concentration or pollutant load. Concentration is defined as the mass of a pollutant in a defined volume of water (e.g., milligrams per liter). Load, however, is the amount (mass) of a pollutant that is discharged into a water body during a period of time (e.g., pounds per year). Although both concentration and load provide information about the water quality, each has its limitations.

To assess the biological significance of water quality to organisms and humans, concentration is a useful parameter to use. Concentration can help address questions of toxicity and nuisance concentrations, and compliance to water quality standards. Regulations governing water quality have long used concentration for monitoring point sources of pollution such as wastewater treatment facilities. Because point sources generally have defined release points and use industrial processes to reduce concentrations of pollutants, concentrations may not vary greatly. In addition, since point source discharges are typically required to measure discharge volume, pollutant load can easily be calculated with a known concentration.

Table 2. Mean concentration (mg/L), mean discharge (cms), and annual load (lbs/yr) of nitrate-N at Logan Branch in Bellefonte and Slab Cabin Run at E. College Avenue.

	Slab Cabin Run at E. College Ave	Logan Branch in Bellefonte
Concentration (mg/L)	2.56	2.86
Discharge (cms)	0.375	2.28
Load (lbs/yr)	66,809	452,545

When evaluating an entire watershed, pollutant load can be a useful calculation. Load of a given pollutant can be calculated according to various sources (e.g., agriculture, urban, etc.). Load can be used to address questions related to Best Management Practices' effectiveness or the amount of nutrients that are exported out of a watershed over a given time period.

Although concentrations may be similar between different sized streams, load may differ drastically. For instance Logan Branch contributes over 35% of the total discharge to the Spring Creek Watershed. In contrast, Slab Cabin Run contributes about 3% of the total discharge. The nitrate-N concentration is similar between these two streams at 2.86 mg/L and 2.56 mg/L, respectively (**Table 2**). However, by doing a simple load calculation using the concentration and discharge, the nitrate-N load between these two streams differs greatly. In fact, there is almost a six-fold difference in load between the two streams (**Table 2**).

Load opposed to concentration is the metric being used by the US EPA to quantify and establish the current pollution level of nitrogen in waterbodies. Based on the current loading, communities will have to work towards load reductions so that they can meet their TMDLs.

Influence of Stormwater on Nitrogen

Urbanization can substantially alter the flow of water in a watershed. In a forested, unaltered landscape rainfall and snowfall typically infiltrate the ground, allowing for the soils to help remove pollutants before they enter into groundwater. In an urbanized area where there are large quantities of impervious surfaces and lawns, water can flow rapidly across these surfaces, reducing the opportunity for infiltration to occur. Rain water that doesn't enter the ground is lost to surface waters either directly or inadvertently through the sewer system and other mechanisms. As water flows across impervious surfaces and lawns in an urban landscape, pollutants like nitrate are collected from roofs, roads, and parking lots.

The cycle of nitrogen in an urban system can be complex depending on a variety of factors within the environment. Removal of vegetation typically results in increased soil moisture and temperature that result in increased ammonification and soil acidity. This in turn results in increased ammonium availability which is readily converted to nitrate via nitrification. Clear-cutting woody vegetation in a rural or urban landscape can increase the concentration of nitrate in surface waters. In an urban landscape, riparian zones, which can help filter nitrate and reduce the concentration in surface waters, are often reduced. This leads to decreased infiltration due to channelization and impervious cover. Calcareous minerals used to construct paved surfaces can also influence the nitrogen cycle in an urban system by raising soil pH in the immediate environment. This in turn produces higher rates of nitrification in soil.

Primary sources of nitrate to stormwater include fertilizers applied to agricultural lands, lawns, and golf courses, in an urban setting sources may also include pet waste, household cleaners, improperly functioning septic systems, and failing sewer infrastructure. Stormwater is typically comprised of 29% dissolved inorganic nitrogen, also referred to as nitrate and 71% organic nitrogen.

Given the setting and land use patterns of the Spring Creek Watershed, residential and agricultural applied fertilizer is likely a primary contributor of nitrate to surface and ground waters. Urbanized areas have been shown to have higher but less frequent inputs of nitrate to surface waters. In comparison to forested lands, low-density suburban and agricultural areas export the greatest amounts of nitrate under low flow conditions[18].

Three storm drains located above the Duck Pond. The two furthest right pipes drain the Downtown and Main Campus area, respectively.

In order to better understand nitrate-N contributions from stormwater within the watershed, stormwater inputs from one of the larger impervious areas within the watershed, the Duck Pond drainage basin, have been studied[19]. The Duck Pond drainage basin receives stormwater inputs from the Downtown State College area (hereafter referred to as “Downtown”) and the Penn State Main Campus area (hereafter referred to as “Main Campus”). The contributing drainage area of the Duck Pond is approximately 867 acres, and about 50% is impervious. There are three main storm drains that discharge into a drainage swale above the

---

[18] Shields, C.A., L.E. Band, N. Law, P. M. Groffman, S.S. Kaushal, K. Savvas, G.T. Fisher, K.T. Belt. 2008. Streamflow distribution of non-point source nitrogen export from urban-rural catchments in the Chesapeake Bay watershed.

[19] Blansett, K.L. 2011. Flow, Water Quality, and SWMM Model, Analysis for Five Urban Karst Watersheds.

Duck Pond. The Downtown and Main Campus areas drain into two of these storm drains. The measured concentration of nitrate-N in stormwater at these two storm drains averages 0.17 mg/L and 0.66 mg/L, respectively.

Using known runoff measurements from the Duck Pond and precipitation data, the annual load of nitrate-N from stormwater can be calculated as approximately 1,076 pounds. Applying a similar procedure using the approximate average concentration of base flow nitrate-N in the Spring Creek Watershed (3.5 mg/L), and the known discharge of the Thompson Spring, the approximate annual load is calculated to be 78,000 pounds (**Table 3**). Therefore, stormwater from the Duck Pond drainage area contributes about 1% of the total nitrate-N load while base flow from Thompson Spring contributes approximately 99%.

The five municipalities and Penn State University which hold MS4 permits in the watershed will eventually be required by their permits to "develop, submit for approval, and implement an MS4 TMDL Plan that is consistent with applicable TMDLs and that achieves the required pollutant load reductions in the applicable wasteload allocations (WLAs) of the approved TMDL"[7]. Although an approved TMDL for impaired waters of the Spring Creek Watershed has not yet been established by PA DEP, one will likely be developed within the next few years.

Table 3. Estimated annual loadings of nitrate-N during base flow and storm flow conditions for the Duck Pond drainage basin. *Volume represents discharge (cfs) for baseflow and runoff for stormflow (cfs).

	Baseflow	Stormflow
Mean Conc (mg/L)	3.5	0.415
Volume (cfs)*	11.32	1.32
Load (lbs/yr)	78007.53	1076.47

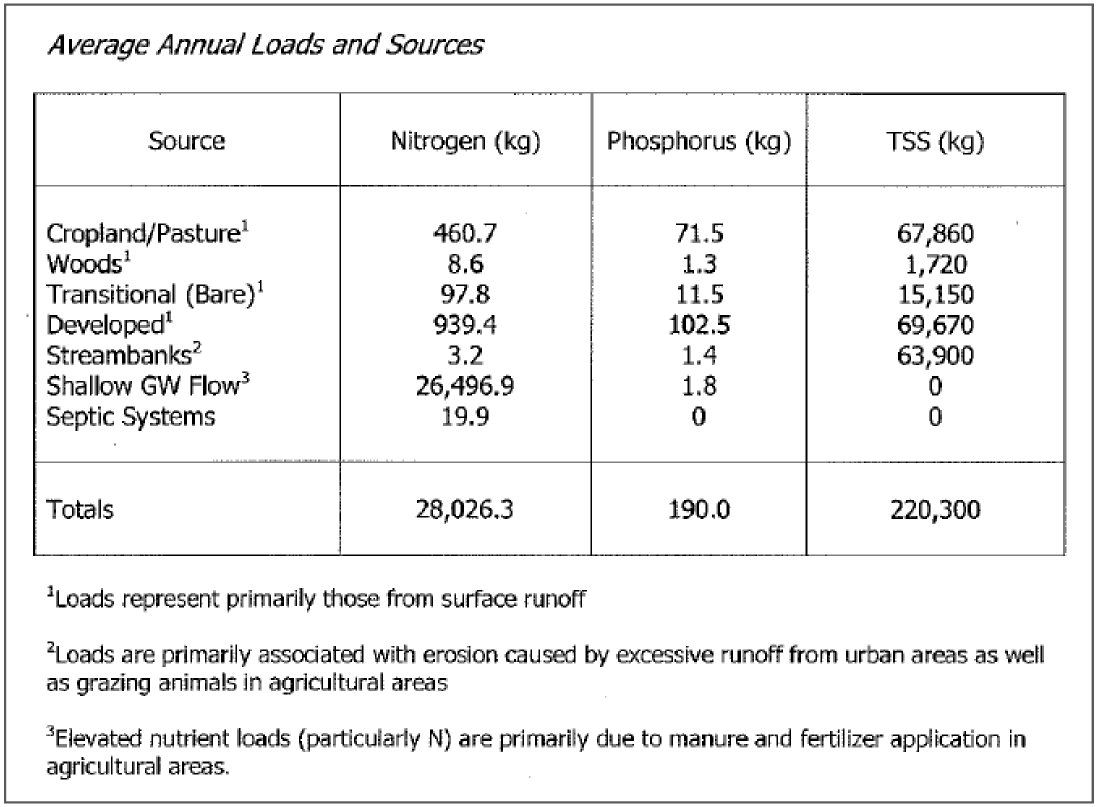
The current modeling framework used by the PA DEP to develop TMDLs is referred to as the ArcView Generalized Watershed Loading Function (AV-GWLF). In 2004, an AV-GWLF non-point source pollution model for the Spring Creek Watershed was developed for the Spring Creek Watershed Community Recovery Team through funding secured from the University Area Joint Authority and Penn State University. The Recovery Team decided to develop the model ahead of PA DEP to "quantify impairments both in and out of the urban area, and to identify Best Management Practices that both point source permit holders and other stakeholders in the community, including municipal government can begin implementing to reduce pollutant discharge"[20]. However, the PA DEP is the entity that will have to officially establish the TMDL for the watershed.

---

[20] AV-GWLF Non-Point Source Pollution Model for Spring Creek Watershed. 2004. Presented by the Spring Creek Watershed Community Recovery Team.

MONITORING NITRATE

Average annual loads of nitrogen, phosphorus and total suspended solids were calculated using AV-GWLF for several sub-watersheds within the Spring Creek Watershed. In all of the sub-watersheds, shallow groundwater flow was the primary contributor of nitrogen. The elevated nitrogen loads in shallow groundwater were attributed to intensive agriculture activities within each sub-watershed. In the Thompson Run Watershed in particular, shallow groundwater flow contributions were predicted to make up almost 95% of the nitrogen while developed areas contributed a little over 3% (**Figure 1**). Although developed areas seem to pose other issues in relation to total suspended solids, the model does not show it to be the major contributor of nitrogen. However, it is important to note that these model results were based on generalized assumptions, and not on data collected within the study area. Nonetheless, the AV-GWLF is the model being used to develop the majority of TMDLs, and regardless of the proposed inputs from developed areas, MS4 permit holders will still be required to develop and implement plans to reduce pollutants like nitrogen according to the established TMDL.



Average Annual Loads and Sources

Source	Nitrogen (kg)	Phosphorus (kg)	TSS (kg)
Cropland/Pasture[1]	460.7	71.5	67,860
Woods[1]	8.6	1.3	1,720
Transitional (Bare)[1]	97.8	11.5	15,150
Developed[1]	939.4	102.5	69,670
Streambanks[2]	3.2	1.4	63,900
Shallow GW Flow[3]	26,496.9	1.8	0
Septic Systems	19.9	0	0
Totals	28,026.3	190.0	220,300

[1] Loads represent primarily those from surface runoff

[2] Loads are primarily associated with erosion caused by excessive runoff from urban areas as well as grazing animals in agricultural areas

[3] Elevated nutrient loads (particularly N) are primarily due to manure and fertilizer application in agricultural areas.

Figure 1. Average annual loads and sources calculated for the Thompson Run watershed through the AV-GWLF non-point source pollution model.

Monitoring Nitrogen in the Spring Creek Watershed

The WRMP began monitoring nitrate-N at twelve stream sites in1999. Three additional stream sites and seven spring sites were added to the water quality monitoring network through 2004 and 2005. Monthly sampling was conducted from 1999 to 2003, until 2004 when sampling frequency was changed to a quarterly interval. All water quality sampling including nitrate-N is conducted during baseflow conditions to avoid stormflow influence on the samples. After 2004, at least four samples a year have been collected with the exception of in 2005 and 2011 when three and two samples were collected, respectively. Summary statistics for nitrate-N concentration (mg/L) at the surface and spring sites are presented in **Table 4 and 5**, respectively.

Land Use

The land use of a watershed can play a large role in the water quality of both surface and groundwater within the watershed. As stated previously, agricultural activities are typically associated with increased nitrate-N levels because of fertilizer and manure applications. In contrast, forested catchments typically have low levels of nitrate-N. Although forested streams receive nitrate through nitrogen deposition, these streams typically do not display levels similar to those polluted by other human sources.

For the seven spring sites sampled by the WRMP from 2005 to 2013, Axemann Spring located in the village of Axemann along Route 144 had the highest median concentration of nitrate-N (6.35 mg/L; **Figure 2**), and Linden Hall Spring located in Linden Hall had the second highest median concentration (4.68 mg/L; **Figure 2**). Big Spring in Bellefonte and Blue Spring in Boalsburg had the lowest median nitrate-N concentration at 1.87 mg/L and 1.51 mg/L, respectively (**Figure 2**). The more than four-fold difference in nitrate-N concentrations between Axemann Spring and Blue Spring is most likely attributable to the land use in the areas draining these two springs. Blue Spring is located at the base of Tussey Mountain and therefore

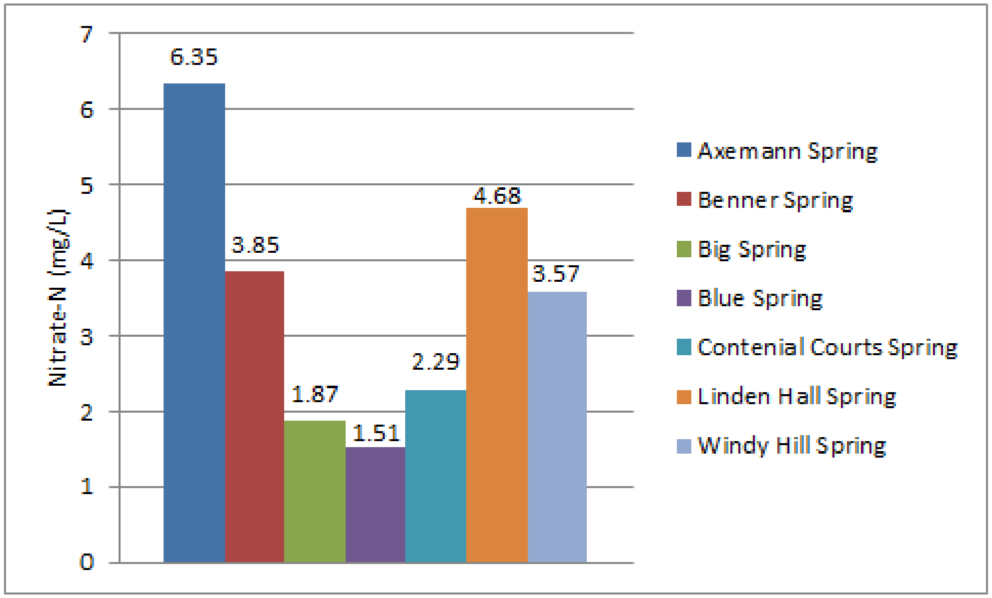


Figure 2. Median nitrate-N concentrations (mg/L) from seven spring sites sampled by the WRMP between 2005 and 2013. See page 33 for site locations.

Table 4. Nitrate-N summary statistics for fifteen WRMP stream monitoring sites collected between 1999 and 2013. N represents number of observations and SD represents standard deviation. ND indicates non-detect levels.

Site Name	Abbrev	N	Median	Mean	Max	Min	SD
Galbraith Gap Run	GGU	24	0.11	0.195	1.97	ND	0.38
Cedar Run - Oak Hall	CEL	89	4.67	4.45	5.41	3.34	0.39
Slab Cabin Run - S. Atherton	SLU	72	2.91	2.9	4.83	ND	1.00
Slab Cabin Run - E. College	SLL	88	2.43	2.42	4.56	0.34	0.91
Slab Cabin Run - Millbrook	MIL	33	3.58	3.48	4.11	2.29	0.43
Thompson Run - E. College	THL	89	4.04	4.06	7.48	3.27	0.45
Buffalo Run - Fillmore	BUU	81	1.34	1.31	1.85	ND	0.35
Buffalo Run Valley View	BVV	36	0.25	0.24	0.43	ND	0.09
Buffalo Run - Coleville	BUL	91	1.8	1.77	3.17	ND	0.39
Logan Branch - Pleasant Gap	LOU	89	2.86	2.98	5.82	ND	0.79
Logan Branch - Bellefonte	LOL	89	3.02	2.97	3.93	ND	0.52
Spring Creek - Oak Hall	SPU	90	2.38	2.35	4.86	ND	0.71
Spring Creek - Houserville	SPH	90	3.19	3.13	3.93	ND	0.52
Spring Creek - Axemann	SPA	89	4.29	4.21	7.35	ND	0.96
Spring Creek - Milesburg	SPM	89	3.34	3.37	6.8	ND	0.64

Table 5. Nitrate-N summary statistics for seven WRMP spring monitoring sites collected between 1999 and 2013. N represents number of observations and SD represents standard deviation. ND indicates non-detect levels.

Site Name	Abbrev	N	Median	Mean	Max	Min	SD
Axemann Spring	AXS	31	6.35	5.78	7.09	ND	1.67
Benner Spring	BES	30	3.85	3.55	4.36	ND	1.05
Big Spring	BIS	31	1.87	1.74	1.96	ND	0.47
Blue Spring	BLS	30	1.51	1.42	3.81	ND	0.76
Continental Courts Spring	COS	31	2.29	2.13	2.58	ND	0.58
Linden Hall Park Spring	LIS	30	4.68	4.53	5.11	ND	0.88
Windy Hill Farm Spring	WIS	26	3.57	3.2	4.78	ND	1.46

drains a predominately forested landscape. In contrast, Axemann Spring lies within and drains a predominately agricultural area. Similar reasoning can be used with the results seen at Linden Hall Spring and Big Spring. The area that feeds Big Spring is located over 15 miles away within State Game Lands 176. This area is also referred to as the Scotia Barrens area and is largely forested. In contrast, Linden Hall Spring drains a large agricultural area.

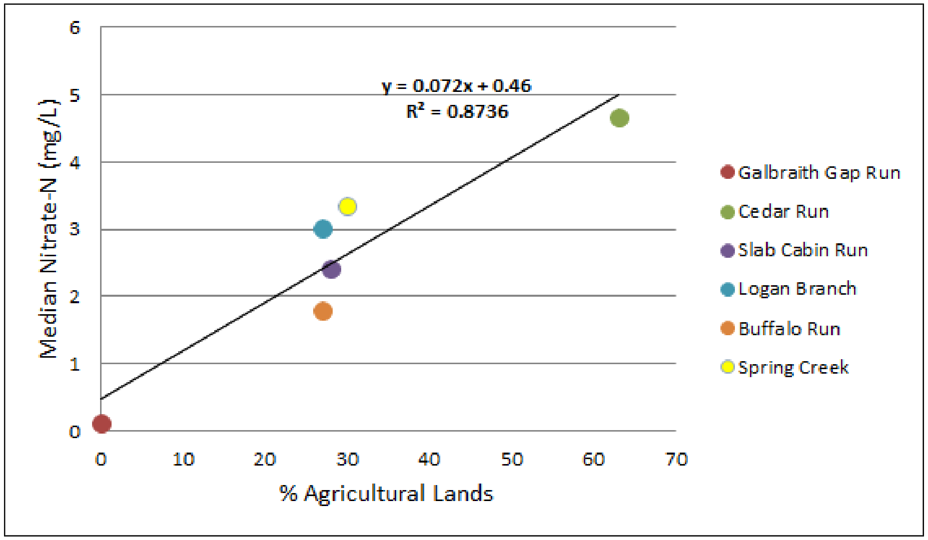


Figure 4. Relationship between the percentage of agricultural lands in each sub-basin of the Spring Creek Watershed and median nitrate-N concentration for six WRMP sites.

The Spring Creek Watershed is approximately 30% agriculture and 22% commercial and residential development. The remaining majority, 41% of the watershed, is forested. The predominately agricultural sub-basins of the watershed include Cedar Run, Upper Slab Cabin Run, and the mainstem of Spring Creek (**Figure 3**, page 21). WRMP median nitrate-N concentrations between 1999 and 2013 were highest at the Cedar Run site in Oak Hall, and at the USGS gage along Spring Creek below Fisherman's Paradise (**Figure 3**). Among the six sub-basin sites where the WRMP has collected data, there appears to be a positive relationship between the percentage of agricultural lands in the sub-basin, and median nitrate-N concentration (mg/L; **Figure 4**). Galbraith Gap, which is located in the headwaters of the watershed and flows off Tussey Mountain, has the lowest median nitrate-N concentration at 0.11 mg/L. The percentage of agricultural lands in the Galbraith Gap sub-basin is less than 1%, with the majority being forested (94%). An opposite relationship can therefore be seen between median nitrate-N concentrations and the percentage of forested lands in the sub-basin (**Figure 5**, page 22)*.

Although urban areas have the potential to input nitrate into surface and groundwater, the relationship is not as easily shown as that of agricultural and forested areas (**Figure 6**, page 22). This may potentially be due to the proposed complex cycle of nitrogen in urban areas. However, could also potentially be due to low fertilizer use in the urban areas of the watershed, resulting in a lack of relationship between nitrate-N (mg/L) and the percentage of urban area.

*Galbraith Gap Run differs from other sub-basins in that it drains a predominately sandstone and shale geology versus a carbonate geology.

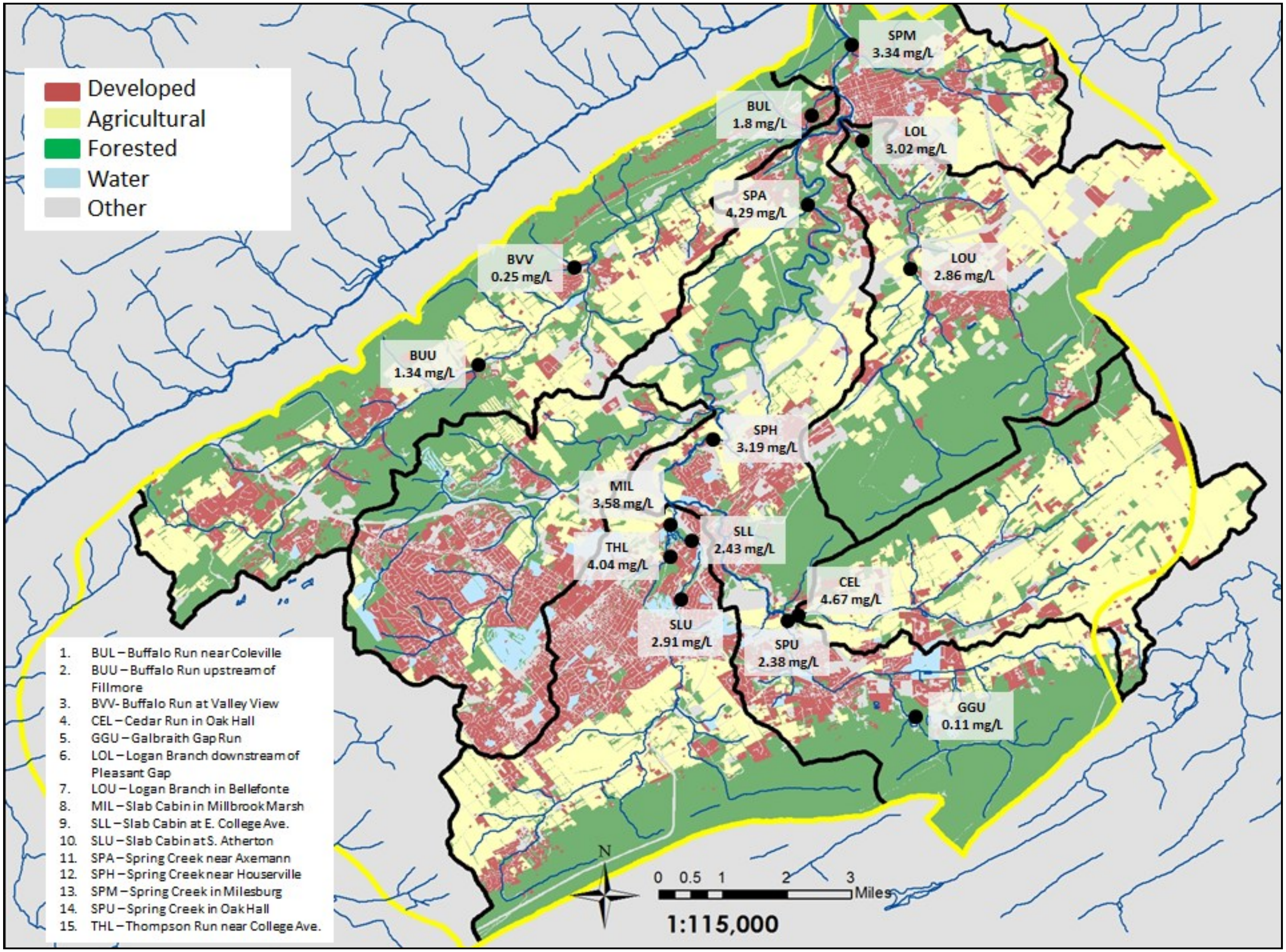


Figure 3. Map represents land use patterns in the Spring Creek Watershed, yellow line is groundwater boundary and black lines surface water boundaries. Boxes include WRMP site abbreviation and median nitrate-N concentrations (mg/L) collected over the period of record. Land use data: Centre County Planning and Development Agency (2010).

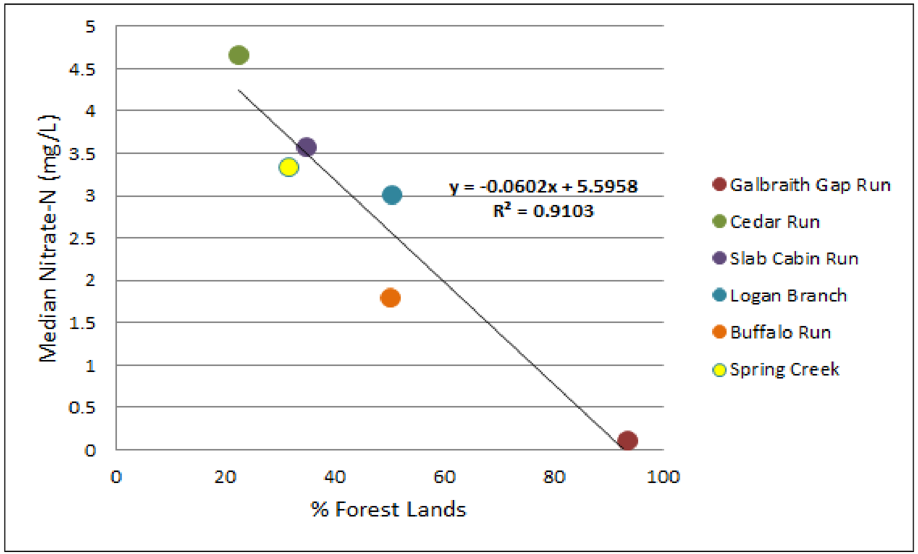


Figure 5. Relationship between percentage of forest lands in each sub-basin of the Spring Creek Watershed and median nitrate-N concentration for six WRMP sites.

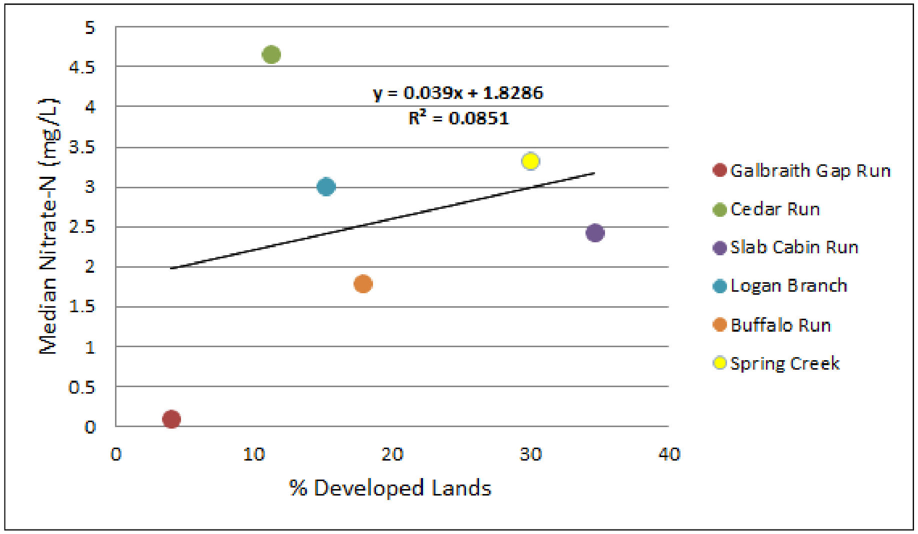


Figure 6. Relationship between percentage of developed lands in each sub-basin of the Spring Creek Watershed and median nitrate-N concentration for six WRMP sites.

Furthermore, this relationship may be more evident in urban areas with high fertilizer use.

These relationships highlight the influence that land use can have on nitrate-N concentrations within a watershed. It is evident that agricultural practices, that include the application of fertilizers and manure, have an influence on the input of nitrate into the surface and groundwater of the Spring Creek Watershed. This relationship is also typical for many other watersheds nationally.

Trends in Nitrate-N over Time

The 14 year WRMP dataset provides an opportunity to evaluate the trends in nitrate-N over the project's timeline. Since the project began in 1998, several changes (e.g., sewage treatment processes, riparian buffer installation, etc.) to improve the water quality of the watershed have occurred. To better understand the potential response or changes in water quality, an evaluation of the nitrate-N concentrations over time was completed. We used a graphical tool known as "loess" to evaluate the relationship (i.e., trend) in nitrate-N over time for samples collected in Spring Creek at the USGS gaging station near Milesburg.

Nitrate-N concentrations at this site appear to have decreased since 1999 at an approximate rate of 0.03 mg/L per year (**Figure 7**, page 23). However, there are several factors such as precipitation, discharge and seasonality that can affect the concentration of nitrate nitrogen in streams, and it's important to understand and consider their influence when evaluating time series trends.

For instance, typically as precipitation increases the concentration of nitrate in streams will also increase due to acid rain (e.g., nitrogen deposition) entering the system. However nationally, nitrogen deposition has decreased in the last 30 years[21] even though annual precipitation for Pennsylvania has increased over this same time period[22]. The primary reason for this national trend is due to the regulations that have been put in place to reduce nitrous oxide emission from coal and other industrial power plants that contribute to nitrogen deposition. Therefore, it's important to keep in mind that the general decrease in nitrate-N concentration over time may be in part due to the decrease in nitrogen deposition that is being observed nationwide.

Discharge is another key factor that can influence concentration of pollutants like nitrate-N. In general, as discharge increases, the concentration of pollutants will decrease due to dilution of pollutants. This general relationship can be seen in **Figure 8** in the years 2006 through 2013. As average annual discharge (cfs) increased, median annual nitrate-N concentrations (mg/L) decreased. No steady increase in average annual discharge over the study period was apparent. If average annual discharge did increase over time, this may help explain the observed decrease in concentration through time in **Figure 7**. However, a more thorough investigation of daily discharge during sampling events, as opposed to mean annual discharge, could elicit more details in discharge patterns over time. This could then potentially help further explain the relationship in nitrate-N

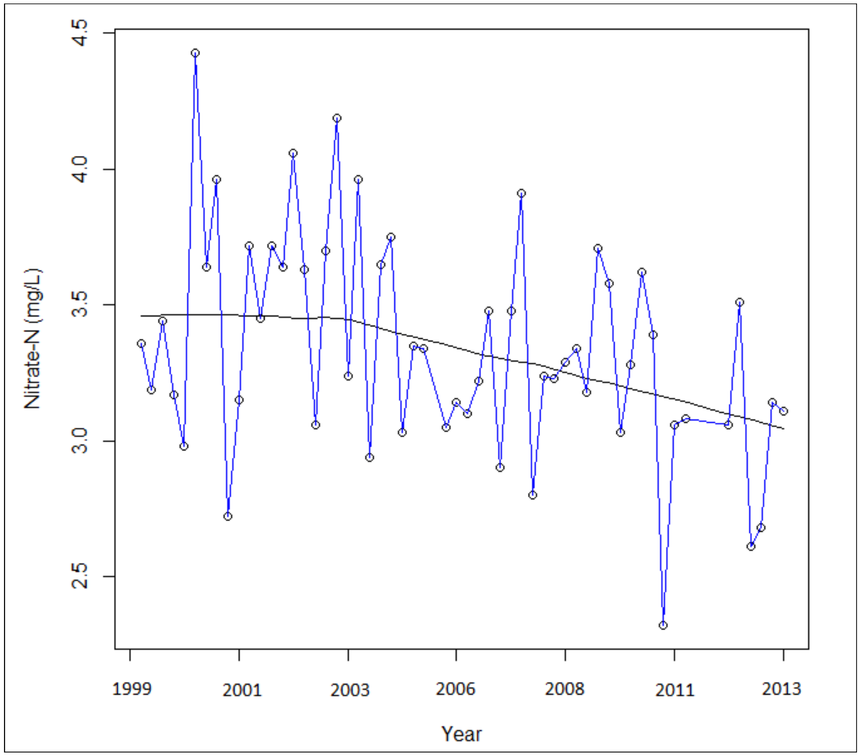


Figure 7. Nitrate-N concentration (mg/L) over time (1999-2013) for samples collected at the USGS gaging station on Spring Creek near Milesburg. Points represent raw data, black line represents the loess curve fitted to the data indicating the general trend of the data through time.

---

[21] Davidson et al. 2012. Issues in Ecology. Excess Nitrogen in the U.S. Environment: Trends, Risks, and Solutions. pg. 12.

[22] National Ocean and Atmospheric Administration. 2007. Time Bias Corrected Statewide-Regional-National Temperature-Precipitation Data.

concentration over time, although it is unlikely it would influence the observed trend since all WRMP samples are collected during baseflow conditions.

Nitrate-N concentrations may also vary seasonally, being lower during the growing season (April 1 – September 30) in comparison to the non-growing season (October 1 – March 31). This is due to the uptake of nitrate in the soils by plants as they grow, limiting the amount of nitrate that can be leached from the soil. The WRMP collects water quality samples on a quarterly basis in an effort to capture the seasonal variation that may occur with parameters. Some level of seasonal variation in nitrate-N concentrations can be seen at the USGS gage site on Spring Creek near Milesburg (**Figure 9**, page 25). Nitrate-N levels appear to be lower during the spring and summer (**Figure 9**: 1 & 2 respectively), than during fall and winter (**Figure 9**: 3 & 4 respectively). Although this may be a cause for variation among samples collected, it likely does not affect the overall annual trend.

Although several factors may influence nitrate-N concentration in streams, there appears to be an overall decrease in nitrate-N over time. The influence of discharge and seasonality on the observed trend appears to be minimal at most. National trends in precipitation and nitrogen deposition may be having an influence on the observed trend. However, other factors and changes that have led to improved water quality of point and non-point source discharges into the watershed may also be attributing to the observed decrease. Future years of data collection by the WRMP can ascertain more information and aid the understanding of this possible downward trend in nitrate-N concentrations.

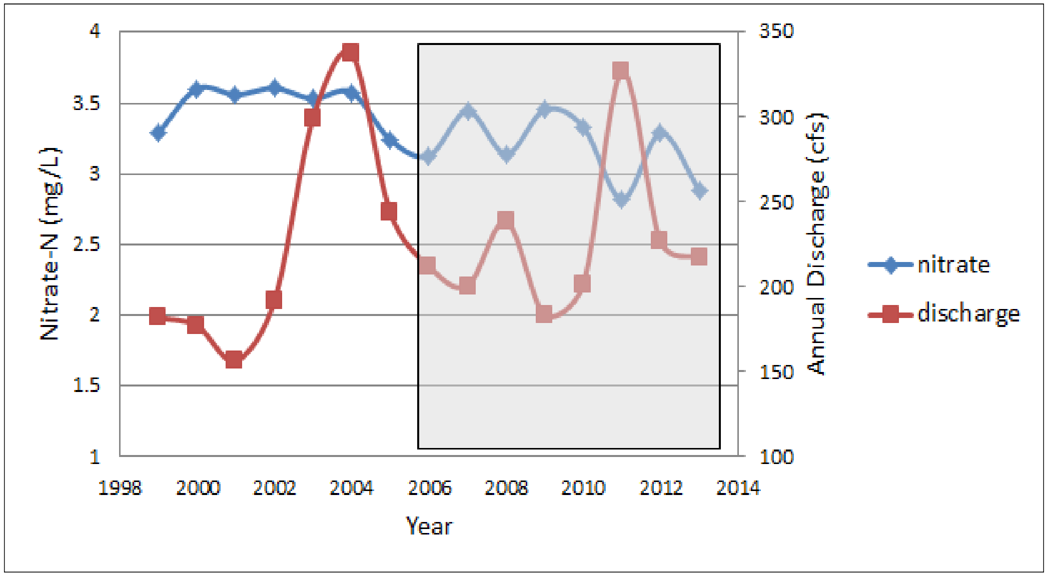


Figure 8. Mean annual nitrate-N concentration (mg/L) and average annual discharge (cfs) at the USGS gage located on Spring Creek near Milesburg. Shaded area highlights the years 2006 through 2013 where inverse relationships between discharge and concentration are most evident.

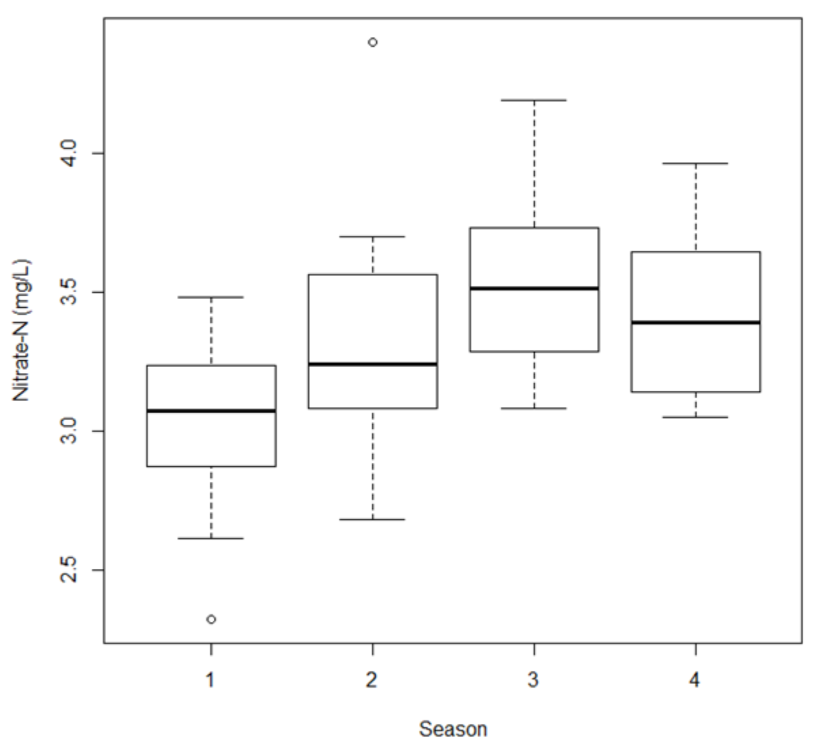


Figure 9. Box plot of nitrate-N concentration (mg/L) by season (1 = spring, 2 = summer, 3 = fall, and 4 = winter) for samples collected at the USGS gaging station on Spring Creek near Milesburg between 1999 and 2013. Solid black line represents median, dashed lines with bars represent the standard deviation, and point represents an outlier.

Existing Watershed Initiatives

The Spring Creek Watershed is unique in the types of innovative technologies, initiatives and community interests that are ongoing throughout the watershed. For instance, the WRMP itself serves as an example of a unique effort supported by the community to gain a better understanding of the watershed by monitoring potential impacts to the watershed. Few watersheds are understood to the level that the Spring Creek Watershed is understood, and the WRMP is a direct reflection of the community's interest in protecting the resource.

Sewage treatment plants are often a common and identifiable source of nitrogen pollution to waterways. All publically owned treatment works in the Spring Creek Watershed have met the Chesapeake Bay Tributary Strategy requirements for nitrogen discharges. In order to meet these limits and provide a greater benefit to the community, the University Area Joint Authority (UAJA) implemented what they call their beneficial reuse project. Although the main goal of the project is not to remove nitrogen but to help replace and offset the water that is removed from the ground, it does treat wastewater to extremely high standards. In fact, beneficial reuse water exceeds drinking water quality standards. The project doesn't remove all nitrogen, but UAJA is currently working towards improving the system, so that a portion of it will be removing nearly all the nitrogen (Cory Miller, personal communication, UAJA). Presumably any beneficial reuse water that is put back into the stream will help reduce nitrogen concentrations by diluting the nitrogen from the groundwater of Spring Creek.

In 1963, Penn State began using a spray irrigation system for disposal of their wastewater. This system is known as the living filter. The system was put in place for two primary reasons: first, to find a solution for the continued pollution of Spring Creek from sewage effluent, and second to replenish the then dwindling supply of groundwater due to drought conditions. In 1983, the Penn State University Wastewater Treatment Plant began applying all their treated effluent onto 606 acres of farm fields and forest areas near campus[4]. In the 1990s the project met with some challenges when groundwater in the area tested high for nitrate. However, changes in the crops that were planted, and the methods of spraying have helped resolve these issues. The project is likely the only one of its kind in Pennsylvania, and provides a unique method for removing nitrate from already treated wastewater that would otherwise be discharged into the waters of Spring Creek.

Aside from the innovative approaches to wastewater treatment in the area, there have been several projects implemented by organizations and agencies like ClearWater Conservancy, the Spring Creek Chapter of Trout Unlimited, and the Centre County Conservation District, to name a few, that aim to reduce nutrients in streams. These projects typically seek to improve stream banks within agricultural areas. Since 2004, ClearWater Conservancy has worked to install 72.5 acres of riparian buffer, and protect 47,746 linear feet of stream on private and public lands in the Spring Creek Watershed (Katie Ombalski, personal communication, ClearWater Conservancy). Although quantifying the impact of these projects on reducing nitrate is difficult, as buffers continue to establish themselves, the overall effect of these initiatives on reducing nitrate levels throughout the watershed may become more evident.

Riparian buffer planted at the Penn State Sheep Barn by the Spring Creek Chapter of Trout Unlimited and ClearWater Conservancy.

Contributed by Ann Donovan, Watershed Specialist, Centre County Conservation District

The Centre County Conservation District implements Best Management Practices on properties in watersheds throughout the county. Over the past ten years the District has, in collaboration with partners, worked on seven farms in the Spring Creek Watershed. The District has excluded animals from the streams by installing over 5,000 feet of streambank fencing. They have installed grazing systems, providing both the perimeter and interior fencing that is necessary for rotational grazing. They have developed alternative watering systems and installed stream crossings and stream access ramps. They stabilized an access road, built two large manure storages, and provided for the protection of a heavy use area.

The District has planted over 5000 linear feet of riparian buffers and installed over 20 instream structures, including a 56 foot mud sill in Talleyrand Park. They also assisted Bellefonte Borough and the Talleyrand Park committee in building a 77 foot stone retaining wall along Spring Creek. Stormwater Best Management Practices include the funding of three rain barrels and three roof top planters, the installation of a rain garden, and the removal of impervious pavement, replacing it with a meadow of native plants.

The above are just a select few of the initiatives undertaken throughout the watershed, and doesn’t describe indirect management and development decisions (e.g., protection of forested and wetland areas) that also provide benefits to nutrient reduction and water quality. For instance, Millbrook Marsh, a 50-acre wetland, located at the confluence of Slab Cabin Run and Thompson Run, serves as natural filter and buffer for water entering the wetland from the downtown and main campus[23]. This area is protected by a conservation easement between ClearWater Conservancy and Penn State University, and therefore protected from development. However, as areas upstream of the marsh continue to be developed, increased awareness and efforts will need to be taken to protect the water quality of the watershed.

Conclusion

The level of nitrate within streams and groundwater in the watershed is a direct testament to the community’s involvement and initiative in making decisions with the watershed in mind. Nitrate-N concentrations throughout the Spring Creek Watershed are lower than other watersheds throughout the Chesapeake Bay Region. However, it is important for leaders and decision makers in the watershed to further reduce nitrate in our waterways. As the US EPA continues to introduce stricter regulations on nitrogen discharges from both point and nonpoint sources, implementing additional nitrogen reducing initiatives will help municipalities and businesses meet the future requirements.

Furthermore, as development of the region continues, increased education to make residents aware their impact and ability to reduce nitrate (e.g., lawn fertilizers and care, septic systems, buffers etc.) will be important in helping municipalities reduce overall nitrogen inputs.

[23] Pennsylvania State University. 2009. Penn State Stormwater.

Reducing Nitrogen Pollution at Home

Although a large portion of nitrogen can come from agriculture and sewage treatment plants, nitrogen can also come from homes, and there are several initiatives homeowners can undertake to do their part in reducing nitrogen. The following outlines a few key sources of nitrogen, and ways homeowners can take to address them.

1.) *Fertilizers* - Fertilizers may vary in the amount of nitrogen they contain, and it's important for homeowners to take this into consideration before applying fertilizer to lawns or gardens. A simple soil test, that can be purchased at retail stores such as Home Depot, can aid homeowners in identifying how much nitrogen they need to apply. Another important aspect of applying fertilizer includes timing, for cool climates applying fertilizer in the spring and fall is best because soil uptake is generally greater at these times of the year. Additionally, leaving grass clippings on the lawn can reduce the need to apply fertilizer by up to 40%. How and where you apply fertilizer can also make a difference. For instance, applying fertilizer near streets or other paved surfaces may allow rain to wash them into storm sewers and eventually into streams. Lastly, the type of fertilizer you use can make a difference. Water-soluble forms of nitrogen that are made immediately available to plants are one of the common forms of nitrogen in bulk-blend garden and lawn fertilizers. Although these fertilizers provide an immediate green-up, the nitrate-N in them may drain quickly into groundwater supplies if applying to sandy or soils with high infiltration rates like that of the carbonate Spring Creek Watershed. Consider slow releasing fertilizers as an alternative, and applying it in small amounts more frequently to ensure uptake by plants.

2.) *Septic Systems* - Poorly functioning on-lot septic systems can also introduce nitrogen into groundwater supplies through leaks in the system. It's important to get your system checked if you suspect a leak. Additionally, pumping your septic tank regularly can prevent the build-up of solids that will inhibit the ability of the system to filter nitrogen. A general rule-of-thumb is to have your tank pumped every three years for a four person household and a 2500 gallon tank.

3.) *Household Cleaners* - Typical household cleaners like glass and oven cleaners contain ammonia, a form of nitrogen. Consider using natural cleaners such as borax, baking soda, and lemon juice as a low nitrogen alternative.

4.) *Airborne Nitrogen* - Nitrogen can also enter the Chesapeake Bay through the air through the emissions of nitrous oxide by cars and fossil fuel burning power plants. Conserving electricity, using public transportation or car-pooling can all help in reducing fossil fuel emissions.

5.) *Pet Waste* - In dense urban areas pet waste can contribute to nitrogen pollution. Pet owners should consider flushing waste down the toilet where nitrogen may be treated and removed, or burying the waste. When burying, homeowners should avoid gardens, wells and water to prevent harmful bacterial contamination.

WATER RESOURCES MONITORING PROJECT BACKGROUND

The Spring Creek Watershed Association (SCWA), a grassroots stakeholder group composed of concerned citizens and professionals, initiated the WRMP in 1997 as part of its strategic plan for the watershed. Their goal was to gather baseline information about the quantity and quality of the water resources in the Spring Creek Watershed that could be used for the long-term protection of these resources as demands on them increase over time. A group of local environmental professionals formed the Water Resources Monitoring Committee in 1998 to develop and oversee the WRMP (see the listing of the current committee in **Table 6** on the following page). The first surface water monitoring stations were established in late 1998 through early 1999. Groundwater, surface water, stormwater and spring monitoring stations were added as the project gained momentum. Over the past fourteen years, the WRMP has strived to:

- Provide a description of the quantity and quality of the surface waters of Spring Creek and its tributaries, including springs;
- Provide a description of the quality of storm-water runoff throughout the watershed;
- Monitor groundwater levels in critical areas;
- Provide the means to detect changes in quantity and quality of surface waters under both baseflow and stormwater runoff conditions, as well as groundwater reserves;
- Provide sufficient measurement sensitivity through long-term monitoring to permit the assessment of the previously mentioned parameters.

The WRMP field stations and database are maintained primarily by the Water Resources Coordinator, a full-time staff position housed at ClearWater Conservancy, with the assistance of volunteers and ClearWater interns. A number of local partners continued to provide funding to carry out WRMP data collection activities to support this one-of-a-kind project in 2013. Donors in support of the 2013 effort included:

- Bellefonte Borough
- Benner Township
- College Township
- Ferguson Township
- Graymont, Inc.
- Halfmoon Township
- Harris Township
- Patton Township

Table 6. Water Resources Monitoring Committee Members in 2013.

WRMP Committee Member	Affiliation
Larry Fennessey, Ph.D., P.E. ***Committee Chair*** Utility Systems Engineer - Stormwater	Office of Physical Plant, The Pennsylvania State University
Lori Davis Water Resources Coordinator	ClearWater Conservancy
Jason Brown Project Manager	University Area Joint Authority
Susan Buda Aquatic Ecologist	Citizen Volunteer
Robert Carline, Ph.D. Aquatic Ecologist	Pennsylvania Cooperative Fish and Wildlife Research Unit, USGS-retired
Ann Donovan Watershed Specialist	Centre County Conservation District
Todd Giddings, Ph.D., P.G. Hydrogeologist	Todd Giddings and Associates, Inc.
James Hamlett, Ph.D. Associate Professor of Agricultural Engineering	Department of Agriculture and Biological Engineering, The Pennsylvania State University
Bert Lavan West Nile Virus Program Coordinator	Centre County Office of Planning and Community Development
Mark Ralston, P.G. Hydrogeologist	Converse Consultants
Kristen Saacke Blunk Consultant	Headwaters, LLC
Rick Wardrop, P.G. Hydrogeologist	Groundwater & Environmental Services, Inc.
Doug Weikel, P.E., C.S.I. Service Group Manager	Herbert, Rowland, and Grubic, Inc.
David Yoxtheimer, P.G. Extension Associate	Marcellus Center for Outreach and Research, The Pennsylvania State University

- Pennsylvania State University Office of Physical Plant
- Spring Township
- Spring Township Water Authority
- State College Borough
- State College Borough Water Authority
- Spring Creek Chapter of Trout Unlimited
- University Area Joint Authority.

In addition to financial support, the WRMP received in-kind donations of professional services, water level and stream stage data, laboratory analyses and supplies, technical assistance, and transportation from the following in 2013:

- PA Department of Conservation of Natural Resources (PADCNR)
- Todd Giddings
- The Pennsylvania State University Office of Physical Plant (PSU OPP)
- United States Geological Survey (USGS)
- Pennsylvania Department of Environmental Protection (PADEP)
- University Area Joint Authority (UAJA)
- Volunteer field assistants

Stream Monitoring Stations

The WRMP measures conditions at four sites along the main stem of Spring Creek and fourteen tributary sites located throughout the stream's five major sub-basins (**Figure 10** on page 32). Twelve of the eighteen sites currently included in the WRMP have been monitored since 1998. The WRMC chose the twelve original sites to be representative of land use practices across the watershed. Three of the original sites were chosen to coincide with existing USGS gaging stations. In 2004, the WRMP added two water quality monitoring sites on headwater tributaries to serve as reference (Buffalo Run Valley View and Galbraith Gap Run). A fifteenth WRMP stream monitoring station, located on Slab Cabin Run downstream of Millbrook Marsh, was added in 2005 to assess the marsh's ability to control stormwater impacts from downtown State College and University Park. The final three sites currently monitored are located in the Walnut Springs sub-basin in State College Borough, and were installed in 2008 to monitor stormwater impacts.

Groundwater Monitoring Stations

The WRMP monitored water levels at three wells in 2013 (**Figure 11** on page 33). These wells were selected because they are not subject to frequent fluctuations caused by external factors such as high-yield pumping, stormwater, artificial groundwater recharge, or surface water discharges. In addition, the WRMP analyzes publically available data from two USGS monitoring wells (**Figure 11** on page 33). When considered together, the five wells provide a picture of representative groundwater conditions across the Spring Creek Watershed.

Spring Monitoring Stations

Spring monitoring became part of the WRMP in 2005 with the addition of water quality monitoring at seven spring stations (**Figure 11** on page 33). Like the stream and groundwater sites, these springs were chosen to be representative of various land use, geologic, and hydrologic conditions encountered in the Spring Creek Watershed. With the addition of the Walnut Springs sub-basin monitoring in 2008, the Walnut Spring was added to the spring water quality monitoring in 2013, bringing the total to eight.

MONITORING STATIONS

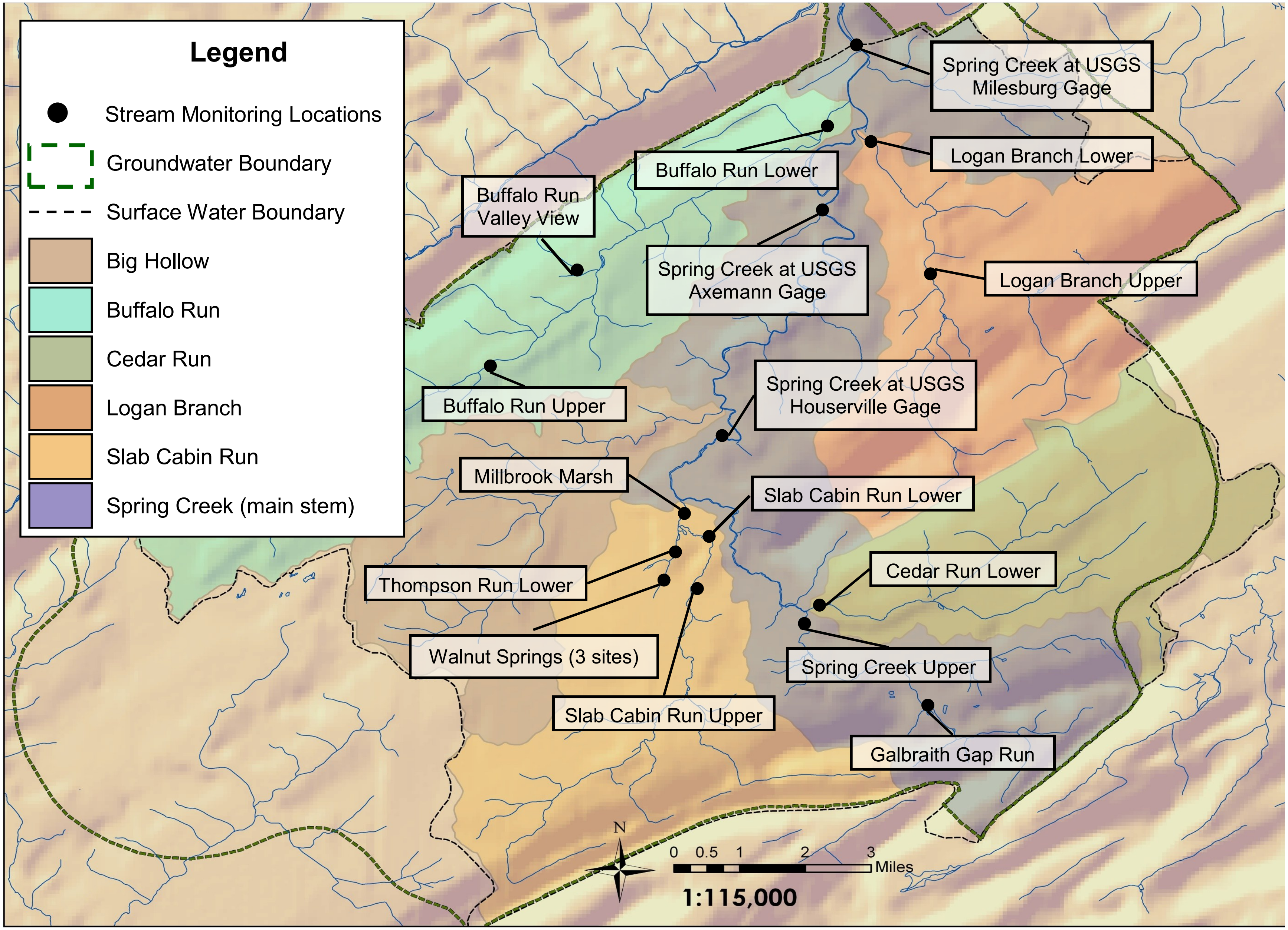


Figure 10. Stream sampling sites surveyed in 2013 as part of the Water Resources Monitoring Project and USGS stream gages.

MONITORING STATIONS

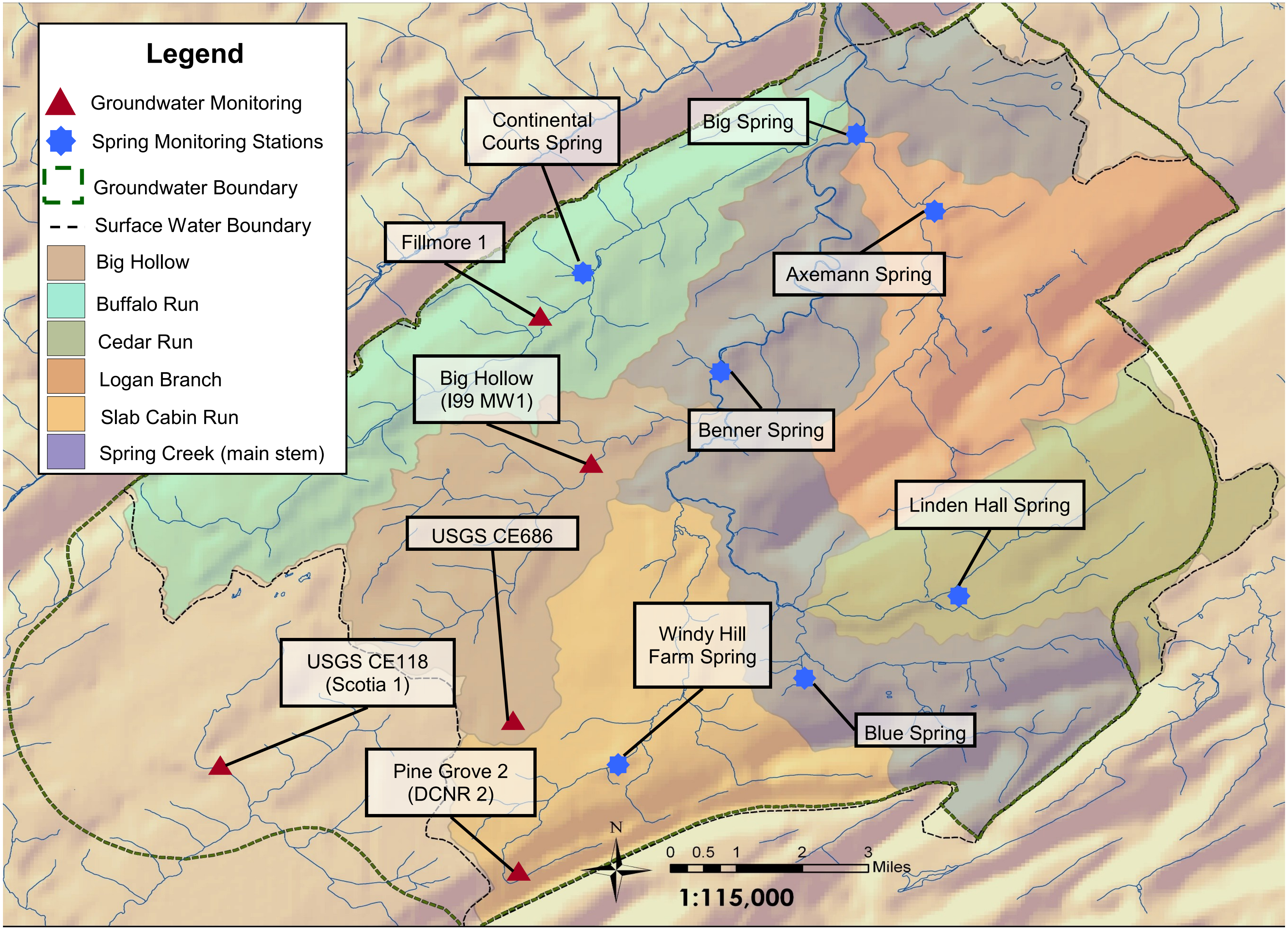


Figure 11. Groundwater and spring stations surveyed in 2013 as part of the Water Resources Monitoring Project and USGS groundwater monitoring wells.

MONITORING METHODS

Water Quality Monitoring

WRMP staff and volunteers collected water samples from fifteen stream sites and eight springs in 2013. Sampling took place in April, July, October, and November when streams were at baseflow conditions. The water samples were analyzed for chemical and nutrient content by the PADEP Analytical Laboratories. Coliform analysis of spring samples was conducted by the University Area Joint Authority laboratory. **Appendices 4** and **5** summarize the results of the 2013 water quality analysis.

Continuous Measurements

Thirteen stream stations were equipped with instruments to continuously monitor stream stage. Thirteen of these were maintained by the WRMP and outfitted with one of two types of pressure transducer: Solinst, Inc. Levelogger Gold pressure transducer or Solinst, Inc. Levelogger Edge pressure transducer. Both types of Solinst transducer are non-vented and were coupled with a Solinst Barologger Edge or Barologger Gold to compensate for atmospheric pressure. Stream stage was recorded every 30 minutes for all stations except Lower Thompson Run and the three stations on Walnut Springs, where stream stage was recorded every 5 minutes. Readings were taken more frequently at these stations because past data have shown that the flow in Thompson Run and Walnut Springs can fluctuate rapidly in a short period of time during storm events. The other three stream monitoring stations are the stations maintained by the USGS.

Water temperature was measured hourly at fourteen stream stations using Onset Computer Corporation Optic Stowaway TidBitv2 data loggers. At the Thompson Run station and Middle Walnut Springs station, the temperature data logger was set to record temperature every 5 minutes instead of every hour. Again, readings were taken more frequently at these stations because, as with flow, past data have shown that temperatures in Thompson Run and Walnut Springs can fluctuate rapidly in a short period of time during storm events. Water temperature data summaries for 2013 are presented in **Appendix 7**.

Water surface elevation was recorded every 3 hours at the three wells comprising the groundwater monitoring network. These wells were equipped with InSitu miniTROLL pressure transducers. **Appendix 8** summarizes the groundwater elevation data for 2013.

Discharge Measurements

Data from the WRMP stream gages are collected as stream water level (or stage) data. In order to better understand the behavior of the streams, the data needs to be expressed as stream flow, or discharge. A rating table or curve is a relationship between stage and discharge at a cross-section of a stream. To develop a rating curve the Water Resources Coordinator and volunteers make a series of discharge measurements using a hand-held current meter (Marsh-McBirney FlowMate). These discharge points are plotted versus their accompanying stage, and a curve is drawn through the points (**Figure 12**). There can be significant scatter around this curve. Because of this, it is good to keep in mind that the discharge values provided by WRMP are estimates of the most likely discharge value. Also, wading into the stream to collect discharge measurements during high flows is not safe. Therefore, WRMP discharge values at high flows are calculated by extrapolating the rating curve to higher stages. As a result, there can be significant error in the rating curves at higher stages. Estimated discharges are indicated by the use of dashed lines in the graphs of WRMP discharge data.

Discharge measurements are made at each gaging station throughout the year to ensure the validity of the rating curves. Sometimes, stream channel dimensions at the gage site may change due to sediment erosion or deposition. The Water Resources Coordinator and the technical subcommittee of the Water Resources Monitoring Committee periodically review the rating curves and revise them as needed.

The data for the USGS-operated stream gages is also collected as stage data. Rating curves for these stations are maintained by the USGS. The USGS is equipped to measure discharge at higher flows to produce more reliable rating curves at high stages. **Appendix 6** summarizes the stream discharge data for 2013.

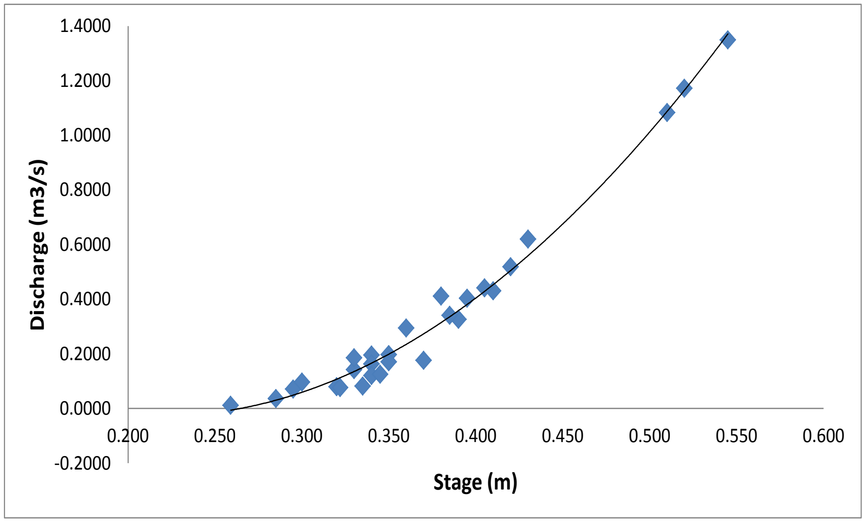


Figure 12. Stage-discharge relationship for WRMP gage on Slab Cabin at S. Atherton Street.

WRMP staff takes discharge measurements on Slab Cabin Run at the S. Atherton Street site to help maintain the stage-discharge relationship for this site.

Data Quality

To assure the consistency and quality of data collected as part of the WRMP, the Water Resources Monitoring Committee developed a set of standardized procedures for data collection, sample processing and database maintenance. A detailed description of these methods can be found in the Spring Creek Watershed Water Resources Monitoring Protocol. To review this document, please contact the Water Resources Coordinator at ClearWater Conservancy at (814) 237-0400.

In addition to periodic review of rating curves, the Water Resources Coordinator and the WRMC also reviews operational procedures and equipment used in the monitoring program. Due to increasing unit failures, the WRMP in 2011 discontinued the use of the type of pressure transducer used to record stream stage since the program's inception in 1998. By the end of 2011, all stream monitoring stations were equipped with Solinst, Inc. pressure transducers. These units have been considerably more reliable, and as a result the data logger reliability has greatly improved while operational costs have decreased.

Appendix 3 provides detailed summaries of the monitoring and data collected at each WRMP location.

Water Quality Monitoring

The WRMP water quality protocol is set up to collect samples on a quarterly basis throughout the year. Water Quality was assessed four times in 2013 in April, July, October, and November at 15 stream and 8 spring sites across the watershed during baseflow conditions. Water samples were evaluated for a number of common organic and inorganic pollutants (**Appendix 1**). A summary of water resource management issues for each monitoring site can be found in **Appendix 2**.

Appendices 4 and **5** show median 2013 concentrations of all parameters analyzed at each of the stream and spring sites, respectively. Results from the water quality monitoring were similar to results from past years.

- In 2013, the concentration of nitrate nitrogen at stream and spring sites were, as typically seen, higher in comparison to headwater concentrations at Galbraith Gap Run and Buffalo Run Valley View but below the drinking water standard of 10 mg/l. Median concentrations ranged between 0.1 and 4.5 mg/l at stream sites, with Galbraith Gap Run having the lowest and Cedar Run having the highest median concentration. Among the springs, Axemann Spring and Linden Hall Spring had the highest median concentrations at 6.2 and 4.8 mg/l, respectively. Cedar Run, Axemann Spring and Linden Hall Spring drain predominately agricultural areas.
- Orthophosporous is a pollutant commonly associated with agriculture. It is a limiting nutrient in fresh water, meaning elevated levels can cause adverse environmental effects in streams and rivers such as algal blooms. Orthophosphates were detected at low levels at all stream sites except for the two sites along Buffalo Run. Orthophosphorous was also detected at low levels at all but the Big Spring where it was undetected.
- The highest median chloride concentrations were observed at Thompson Run below College Avenue (64.6 mg/l) and Slab Cabin Run in Millbrook Marsh (69.3 mg/l). These values are similar to historical values. Elevated chloride concentrations are associated with urban impacts from stormwater runoff and wastewater treatment plant discharges.
- Median iron concentration was elevated at Windy Hill Spring (1918 ug/L and 921 ug/L, respectively) in 2013. This spring has historically seen occasional elevated levels of iron. Iron can occur from natural sources when water comes in contact with particular types of rock. Typically the longer the water has been in contact with the rock, for example, during drier periods, the higher the iron concentration. The observed elevated level of iron occurred in

November 2013 when baseflows were lower than the median.

- Conductivity is a fundamental water quality characteristic and is defined as the ability of the water to conduct an electrical current. Values of conductivity describe the total major ions dissolved in water. There are seven major ions found in water and they include:
    - Calcium (Ca^{2+})
    - Magnesium (Mg^{2+})
    - Sodium (Na^{+})
    - Potassium (K^{+})
    - Bicarbonate (HCO_3^{-})
    - Sulfate (SO_4^{2-})
    - Chloride (Cl^{-})

The WRMP monitors five of these seven major ions. Based on the data collected, we can determine the percentage of the conductivity that can be attributed to each of these ions except for bicarbonate and potassium, which the WRMP does not monitor. In 2013, conductivity was highest at Thompson Run near College Avenue and Slab Cabin Run at College Avenue, as it has been historically. Calcium and Magnesium explained about 25% and 16% of the conductivity in Thompson Run and Slab Cabin Run at East College Avenue (**Table 7**). This is not unusual as magnesium and calcium are primary components in limestone. Chloride was found to make up the second largest proportion of the overall conductivity at 17% and 20% for Slab Cabin Run and Thompson Run, respectively. This is not unusual given large urban drainage area of these two sites because sources of chloride can include deicing agents placed on roads.

	Chloride	**Sulfate**	**Magnesium**	**Calcium**	**Sodium**
Slab Cabin at E. College Ave	17.8%	9.8%	15.0%	24.8%	8.8%
Thompson Run at E. College Ave	20.4%	3.3%	16.2%	25.1%	8.5%

Table 7. Percentage of the conductivity attributed to five of the seven major ions found in water at the WRMP sites at Slab Cabin Run and Thompson Run near East College Avenue in 2013.

Stream Discharge

Stream discharge is defined as the volume of water in a stream passing a given point at a given moment of time. Large streams have higher discharge rates than smaller streams. A stream's ability to move sediment and dilute chemicals is proportional to discharge.

Generally, the higher the discharge, the more effective a stream will be at moving sediment downstream and diluting pollutants. A stream's discharge determines the biological communities that will be found in it. Stream discharge also fluctuates with seasons and storm events, making it a measurement of interest when studying the effects of runoff and flooding.

The 2013 discharge profiles for the main stem of Spring Creek at the USGS Axemann Gage and a representative tributary (Slab Cabin Run at East College Avenue) are shown in **Figure 13** and **Figure 14**, respectively. In general, baseflow stream discharges during 2013 were higher than historic median discharges in January and February, then fell below historic medians from mid-March to mid-April, rose above historic medians in early July to October and then returned to historic median discharges for the remainder of the year. These discharge profiles reflect a wet summer and early fall for 2013 caused by a series of storms in late June that resulted in discharges about normal levels. There were major storm events that resulted in two periods of high discharge. One occurred in late January and the other in late June 2013.

The 2013 discharge profiles for all of the WRMP gages and the three USGS Spring Creek gages are included in **Appendix 6**.

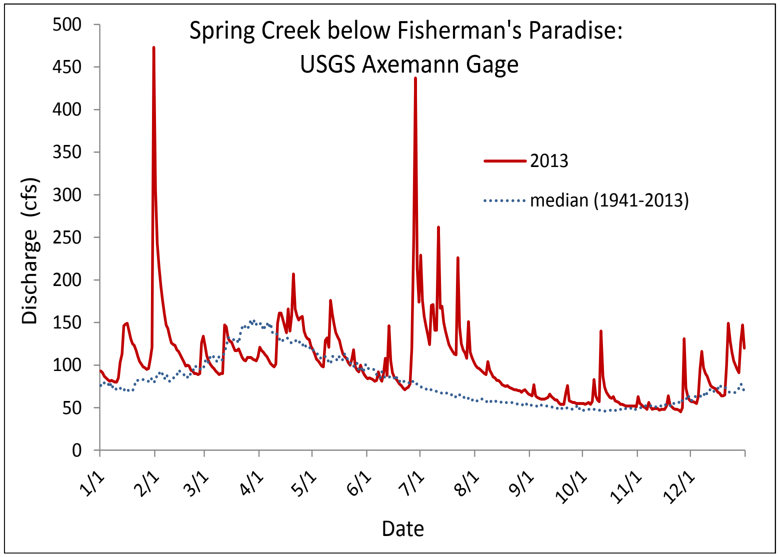


Figure 13. 2013 discharge and median discharge (cfs) for Spring Creek below Fisherman's Paradise.

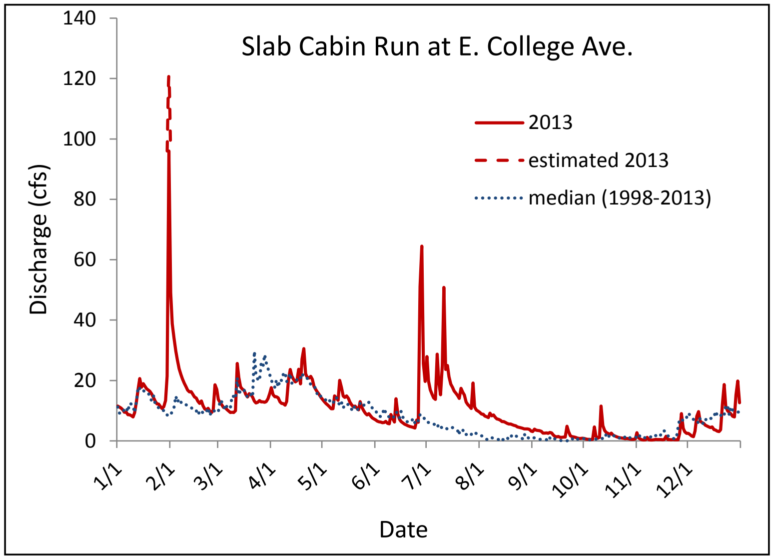


Figure 14. 2013 discharge and median discharge (cfs) for Slab Cabin Run at East College Avenue.

Stream Temperature

Water temperature has a profound influence on aquatic life, governing nearly every process that occurs in streams from regulating the solubility of oxygen and various chemicals to the metabolic functions of fish and other aquatic life. The significant inputs of groundwater throughout the Spring Creek Watershed allow the world-class trout fishery to exist despite the significant agricultural and urban impacts within the watershed. Brown trout's lethal temperature threshold is 76 ˚F (24 ˚C), and groundwater inputs help maintain temperatures well below this threshold. Some portions of tributary streams lack significant groundwater inputs, such as lower Buffalo Run near Bellefonte and Slab Cabin Run in State College. These streams are perched above the water table minimizing the inputs of groundwater, especially during dry periods which typically occur in the summer and fall when air temperatures are generally greatest. However, the opposite trend was seen in 2013 with average and maximum temperatures dropping between July and mid-August (**Figure 15**). The higher than historical median levels of discharge that occurred during this timeframe (**Figure 15**) may have helped offset the increase in temperature typically seen.

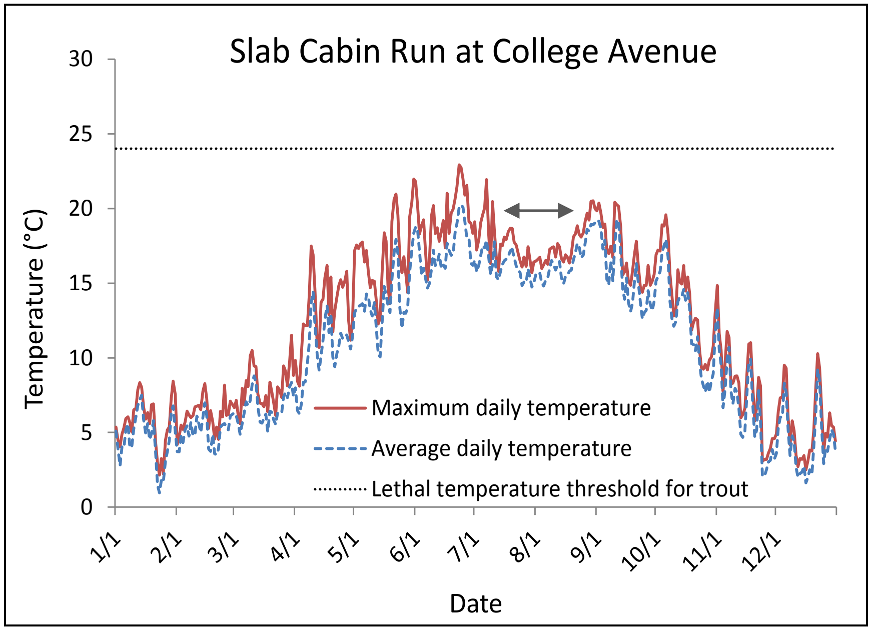


Figure 15. Temperature at the WRMP sites at Slab Cabin Run at East College Avenue in 2013.

Walnut Springs near East College Avenue was the only stream in which maximum daily temperatures exceeded Brown Trout's temperature threshold (**Figure 16**). This incident was observed for one day. In recent years (2012 and 2011) Thompson Run maximum temperatures also exceeded the threshold. These streams are subject to large urban stormwater inputs which can cause these temperature increases. These waters can also exceed 76 ˚F during extreme heat or drought. The mean July temperature for State College, PA was lower in 2013 (73.8 °F) than in 2011 (76.2 °F) and 2012 (75.7 °F) when mean July temperature was the second and fourth hottest on record. Large-scale

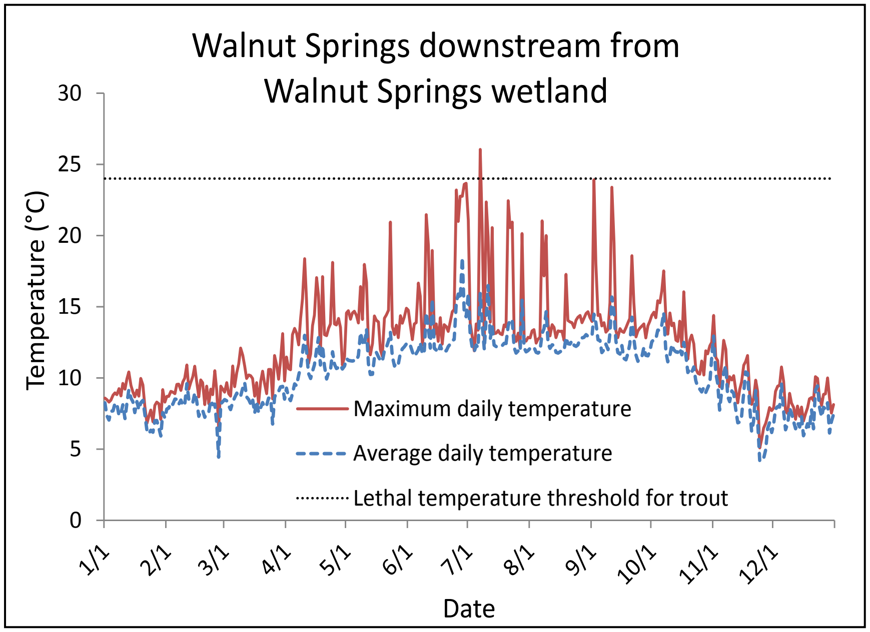


Figure 16. Temperature in 2013 at the WRMP sites on Walnut Springs downstream from Walnut Springs wetland.

fish kills can occur when temperatures rise above 76 °F for extended periods of time. In general, temperatures do not exceed trout's threshold, and when they do, it is only for short (e.g., 1 day) periods of time. The 2013 temperature profiles for all WRMP monitored locations in the watershed are included in **Appendix 7**.

Groundwater

Groundwater supplies our streams with a constant supply of cold water that supports trout and other coldwater aquatic organisms. Most of the region's drinking water is also drawn from the many high volume springs and well fields. In 2013, the WRMP collected groundwater data from three monitoring wells and assessed data from two additional wells maintained by the USGS. Groundwater elevation profiles for 2013 are found in **Appendix 8**.

The groundwater elevation profile for the WRMP-maintained well near Pine Grove Mills is shown in

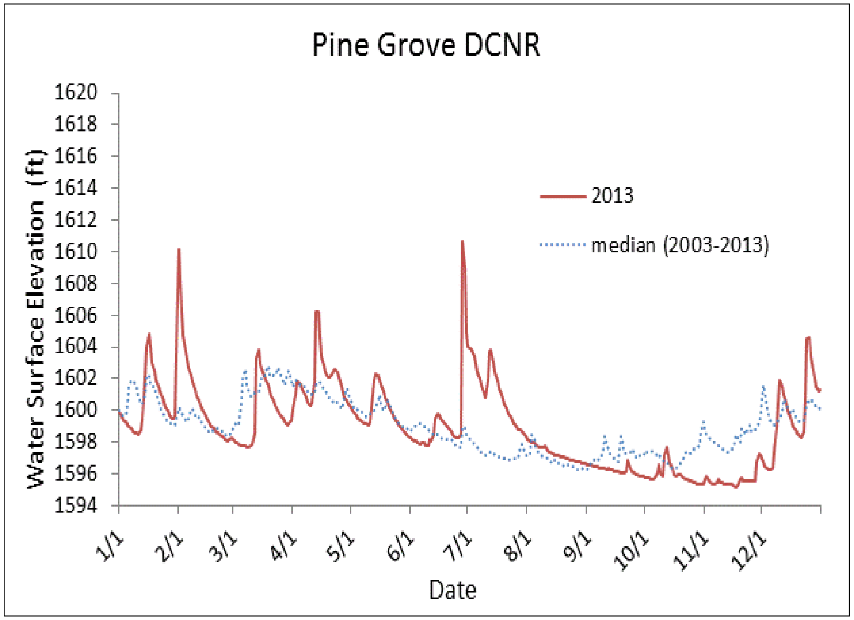


Figure 17. Water surface elevation (ft) in 2013 at the WRMP groundwater well located near Pine Grove Mills.

Figure 17. As usually seen, snow melt and rainfall replenished most of the groundwater aquifers in the watershed in late winter and early spring. However, at the USGS CE118 well located in Scotia Barrens a general decrease in groundwater was observed through 2013 (**Figure 18**). The CE118 well is located in the Gatesburg Formation, a large aquifer that drains to the Big Spring in Bellefonte. Because of its overall size and porosity, it typically takes a large amount of persistent precipitation to result in a change in the water surface elevation. This particular well experienced an all-time low in fall of 2002 after an extreme dry period and an all-time high in the spring of 2005.

In general, groundwater elevations at the WRMP and USGS wells were lower than median levels between mid-March and early-July 2013, higher than median levels from July to September, and then lower than median levels for the remainder of the year.

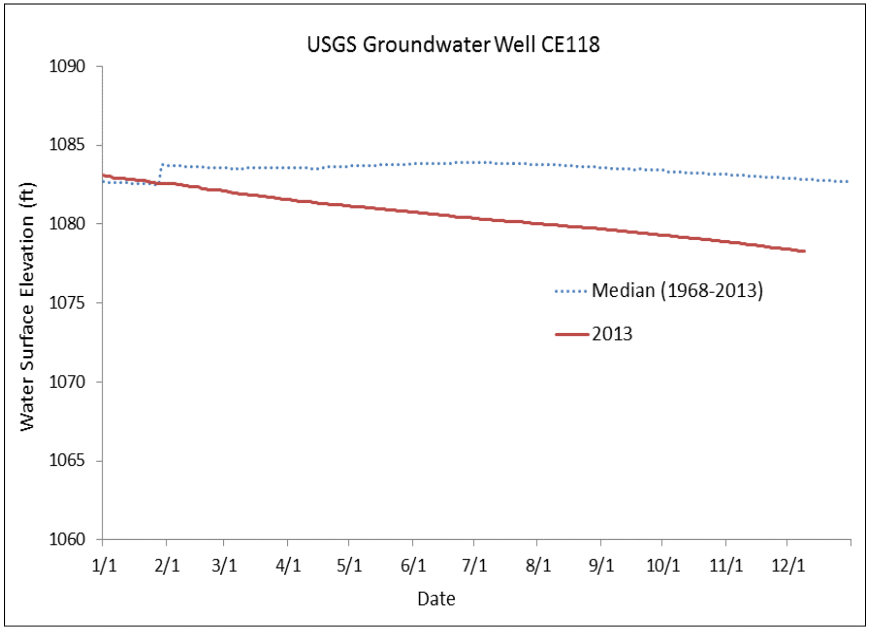


Figure 18. Water surface elevation (ft) in 2013 at the USGS CE118 well in Scotia.

APPENDICES

Appendix 1: Water Quality Parameters

Parameter	Description	Sources	Environmental Effects	Stream	Spring
Aluminum	The most abundant element on Earth	Urban runoff, industrial discharges, and natural sources	May adversely affect the nervous system in animals	X	X
Cadmium	Natural element found in the Earth's crust	Industrial sources and urban sources including fertilizer, non-ferrous metals production, and the iron and steel industry	Toxic to humans and aquatic life	X	X
Chloride	The concentration of chloride salt ions dissolved in the water	Washes off roads where used as a deicing agent	Very high chloride concentrations can be toxic to macroinvertebrates and limit osmoregulatory capacity of fish	X	X
Chromium	A trace element essential for animals in small quantities	Found in natural deposits of ores containing other elements	Toxic to humans and aquatic life if present in excess	X	X
Conductivity	Measure of the water's ability to conduct electricity; proportional to the amount of charged ions in the water	Sources of ions are both naturally occurring and human in origin, including soil, bedrock, human and animal waste, fertilizers, pesticides, herbicides, and road salt	Suspended solids clog fish gills and alter stream-bed habitat upon settling; dissolved materials limit the osmoregulatory ability of aquatic animals	X	X
Copper	A heavy metal less common than lead and zinc in nature	Used in wiring, plumbing, and electronics; also used to control algae, bacteria, and fungi	Toxic to humans and aquatic life; solubility is effected by water hardness	X	X
Dissolved Oxygen	The amount of oxygen gas dissolved in the water; saturation inversely related to temperature	Dissolved oxygen is depleted by respiration and microbial breakdown of wastes. It is restored by photosynthesis and physical aeration	Low levels of dissolved oxygen are harmful to aquatic animals; typically a result of organic pollution or elevated temps	X	X
Coliform Bacteria	Common intestinal bacteria	Animal wastes and sewage contamination	Pathogenic to humans		X
Iron	Common element found in the Earth's crust	Urban runoff, industrial discharges, and natural sources	Toxic to humans and aquatic life	X	X
Lead	A heavy metal that occurs naturally as lead sulfide but may exist in other forms	Urban and industrial uses including gasoline, batteries, solder, and paint	Toxic to humans and aquatic life; solubility is effected by water hardness	X	X

Appendix 1: Water Quality Parameters

Parameter	Description	Sources	Environmental Effects	Stream	Spring
Manganese	Common element found in the Earth's crust	Urban runoff, industrial discharges, and natural sources	Toxic to humans and aquatic life	X	X
Nickel	A trace element essential for animals in small quantities	Industrial wastewaters	Toxic to humans and aquatic life if present in excess	X	X
Nitrate (NO3)	One of three forms of nitrogen found in water bodies, this form is used by plants; organic nitrogen is converted to nitrate by bacteria	Any nitrogen-containing organic waste, including sewage from treatment plants and septic systems and runoff from fertilized lawns, farms, and livestock areas	High nitrate levels promote excessive plant growth and eutrophication. Excess nitrate in drinking water can cause illness or death in infants	X	X
Orthophosphate	The form of inorganic phosphorus required by plants; often the limiting factor in plant growth	Rocks and minerals provide low natural levels; human sources include commercial cleaning products, water treatment plants, and fertilized lawns and farmland	A small increase in orthophosphorus can cause eutrophication, the loss of dissolved oxygen through the stimulation and decay of excessive plant growth	X	X
pH	A measure of the acidity of water on a logarithmic scale of 1 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline	Alkaline conditions can be a result of carbonate bedrock geology; acidic conditions could be caused by acid deposition and pyritic reactions associated with acid mine drainage	Extreme acidity or alkalinity can inhibit growth and reproduction in aquatic organisms. Acidic waters also increase the solubility of metals from the sediment	X	X
Sodium	Soft metal commonly found in nature	Various salts of sodium occur in considerable concentrations in the Earth's crust	There is some evidence to suggest that these high levels of sodium are toxic to some plants	X	X
Total Suspended Solids	Any particles carried by the water including silt, plankton, organic stream matter, industrial waste, and sewage	Include urban runoff, wastewater treatment plants, soil erosion, and decaying plant and animal material	Suspended solids clog fish gills and alter stream-bed habitat when settled; particles may carry bound toxic compounds or metals	X	X
Turbidity	A measure of water clarity expressed as the amount of light penetrating the water	While in some cases high turbidity is natural, it is usually the result of earth-moving activities, urban runoff, and erosion	High turbidity blocks light from the water column, inhibiting productivity of aquatic plants and periphyton; increased sedimentation	X	X
Zinc	A heavy metal commonly found in rock-forming minerals	Urban runoff, industrial discharges, and natural sources	Somewhat toxic to humans and aquatic life; solubility is affected by water hardness	X	X

Appendix 2: Summary of monitoring sites and management issues in their vicinity by municipality

Municipality	Monitoring sites within the municipality	Other sites influenced by activities within the municipality	Water resources management issues
Benner Township	Unnamed tributary to Buffalo Run (BVV) Continental Courts Spring (COS) Fillmore Well Benner Spring (BES) Spring Creek at Axemann (SPA)	Buffalo Run near Coleville (BUL) Spring Creek at Milesburg (SPM) Logan Branch near Pleasant Gap (LOU)	Agricultural practices (ground and surface water) Urbanization/Suburbanization (stormwater and water supply)
Boggs Township	Spring Creek at Milesburg (SPM)		
College Township	Spring Creek at Houserville (SPH) Slab Cabin Run at Millbrook Marsh (MIL) Slab Cabin Run at East College Avenue (SLL) Thompson Run (THL) Spring Creek at Oak Hall (SPU) Cedar Run at Oak Hall (SPU) Big Hollow/ I-99 Well	Spring Creek at Axemann USGS gage (SPA)	Urbanization/Suburbanization (stormwater and water supply) Agricultural practices (upstream areas)
Ferguson Township	Windy Hill Farm Spring (WIS) DCNR/Pine Grove Mills Well USGS CE686 Monitoring Well USGS CE118 Monitoring Well	Thompson Run (THL)	Urbanization/Suburbanization (storm-water and water supply) Agricultural practices
Halfmoon Township		Buffalo Run near Fillmore (BUU) Big Spring (BIS)	Agricultural practices Suburban development
Harris Township	Blue Spring (BLS) Linden Hall Spring (LIS) Galbraith Gap Run (GGU)	Slab Cabin Run at South Atherton Street (SLU) Spring Creek at Oak Hall (SPU) Cedar Run at Oak Hall (CEL)	Agricultural practices (surface and groundwater) Suburban development
Patton Township	Buffalo Run near Fillmore (BUU)		Agricultural practices/suburbanization
Potter Township			Agricultrual practices
Spring Township	Logan Branch near Pleasant Gap (LOU) Axemann Spring (AXS) Buffalo Run near Coleville (BUL)	Logan Branch at Bellefonte (LOL) Spring Creek Milesburg (SPM)	Agricultural practices (surface and groundwater) Suburban development Industrial water usage
Walker Township			Agricultural practices/ suburbanization
Bellefonte Borough	Logan Branch in Bellefonte (LOL) Big Spring (BIS)	Spring Creek at Milesburg (SPM)	Urbanization/Suburbanization (storm-water)
Centre Hall Borough			Agricultural practices in surrounding areas
Milesburg Borough		Spring Creek at Milesburg (SPM)	Urbanization (storm-water)
State College Borough	Slab Cabin Run at South Atherton Street (SLU) Walnut Spring (WAU, WAM, WAL)	Thompson Run (THL) Slab Cabin Run at East College Avenue (SLL) Slab Cabin Run at Millbrook Marsh (MIL)	Urbanization/Suburbanization (storm-water)

Appendix 3: Monitoring summary by location

Site Type	Site Name (Code)	Monitoring Type	Current Data Collection Interval	Period of Record
Stream	Buffalo Run Lower (BUL)	Discharge	30 min	1999 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Buffalo Run Upper (BUU)	Discharge	30 min	1999 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Buffalo Run Valley View (BVV)	Baseflow water quality	quarterly	2007 - present
	Cedar Run Lower (CEL)	Discharge	30 min	1998 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Galbraith Gap Run (GGU)	Baseflow water quality	quarterly	2008 - present
	Logan Branch Lower (LOL)	Discharge	30 min	1999 - present
		Water temperature	1 hr	2000 - present
		Baseflow water quality	quarterly	2007 - present
	Logan Branch Upper (LOU)	Discharge	30 min	1999 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Slab Cabin Run at Millbrook (MIL)	Discharge	30 min	2005 - 2006 ; 2009 - present
		Water temperature	1 hr	2008 - present
		Baseflow water quality	quarterly	2007 - present
	Slab Cabin Run Lower (SLL)	Discharge	30 min	1999 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Slab Cabin Run Upper (SLU)	Discharge	30 min	1998 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Spring Creek Upper (SPU)	Discharge	30 min	1998 - present
		Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present

Appendix 3: Monitoring summary by location

Site Type	Site Name (Code)	Monitoring Type	Current Data Collection Interval	Period of Record
Stream	Spring Creek Axemann (SPA)	Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Spring Creek Houserville (SPH)	Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Spring Creek Milesburg (SPM)	Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Walnut Springs Middle (WAM)	Discharge	5 min	2008 - present
		Water temperature	5 min	January, 2012 - present
	Walnut Springs Lower (WAL)	Discharge	5 min	2008 - present
	Walnut Springs Upper (WAU)	Discharge	5 min	2008 - present
	Thompson Run Lower (THL)	Discharge	5 min	1999 - present
		Water temperature	5 min	1999 - present
		Baseflow water quality	quarterly	2007 - present
Groundwater well	Big Hollow:I-99	Water surface elevation	3 hr	2003 - present
	Fillmore 1	Water surface elevation	3 hr	2003 - present
	Pine Grove Mills/DCNR	Water surface elevation	3 hr	2003 - present
Spring	Axemann Spring (AXS)	Baseflow water quality	quarterly	2007 - present
	Benner Spring (BES)	Baseflow water quality	quarterly	2007 - present
	Blue Spring (BLS)	Baseflow water quality	quarterly	2007 - present
	Big Spring (BIS)	Baseflow water quality	quarterly	2007 - present
	Continental Courts Spring (COS)	Baseflow water quality	quarterly	2007 - present
	Linden Hall Spring (LIS)	Baseflow water quality	quarterly	2007 - present
	Walnut Spring (WAS)	Baseflow water quality	Quarterly	2013 - present
	Windy Hill Farm Spring (WIS)	Baseflow water quality	quarterly	2007 - present

Appendix 4: Median Stream Water Quality Results (Metals)

Site Name	Abbrev	Aluminum (µg/L)		Cadmium (µg/L)		Chromium (µg/L)		Copper (µg/L)		Iron (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Galbraith Gap Run	GGU	5.0*	31.3	ND	ND	ND	ND	ND	ND	ND	54.5
Cedar Run - Lower	CEL	5.0*	25.0*	ND	ND	ND	ND	ND	ND	10.0*	50.0*
Slab Cabin Run - Upper	SLU	ND	115.0	ND	ND	ND	ND	ND	ND	10.0*	199.5
Slab Cabin Run - Lower	SLL	ND	9.6*	ND	ND	ND	ND	ND	ND	ND	22.0*
Slab Cabin Run - Millbrook	MIL	ND	21.9*	ND	ND	ND	ND	ND	ND	ND	80.5
Thompson Run - Lower	THL	ND	24.1*	ND	ND	ND	2.0*	ND	2.0*	10.0*	128.5
Buffalo Run - Upper	BUU	5.0*	25.7	ND	ND	ND	ND	ND	ND	10.0*	56.0
Buffalo Run - Valley View	BVV	5.0*	61.7	ND	ND	ND	ND	ND	ND	57.0*	334.5
Buffalo Run - Lower	BUL	5.0*	13.0*	ND	ND	ND	ND	ND	2.0*	ND	3.0
Logan Branch - Upper	LOU	5.0*	94.5	ND	ND	ND	ND	ND	ND	ND	196.5
Logan Branch - Lower	LOL	ND	22.5*	ND	ND	ND	ND	ND	ND	ND	75.0
Spring Creek - Upper	SPU	ND	31.5*	ND	ND	ND	ND	ND	ND	ND	80.5*
Spring Creek - Houserville	SPH	ND	34.1	ND	ND	ND	ND	ND	ND	ND	89.5
Spring Creek - Axemann	SPA	ND	37.1	ND	ND	ND	ND	ND	ND	10.0*	86.0
Spring Creek - Milesburg	SPM	8.3*	43.9	ND	ND	ND	ND	ND	ND	16.0*	64.5

Site Name	Abbrev	Lead (µg/L)		Manganese (µg/L)		Nickel (µg/L)		Sodium (mg/L)		Zinc (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Galbraith Gap Run	GGU	ND	ND	ND	5.4*	ND	ND	0.7	0.7	ND	ND
Cedar Run - Lower	CEL	ND	ND	1.5*	2.6*	ND	ND	6.0	6.1	7.5*	ND
Slab Cabin Run - Upper	SLU	ND	ND	4.7*	11.3	ND	ND	18.2	18.5	ND	ND
Slab Cabin Run - Lower	SLL	ND	ND	1.0*	1.0*	ND	ND	28.2	29.3	ND	ND
Slab Cabin Run - Millbrook	MIL	ND	ND	4.8	6.8	ND	ND	28.5	29.7	ND	ND
Thompson Run - Lower	THL	ND	ND	7.7*	10.6*	ND	2.0*	27.0	27.4	5.0*	ND
Buffalo Run - Upper	BUU	ND	ND	3.0*	4.85*	ND	ND	18.3	19.0	ND	ND
Buffalo Run - Valley View	BVV	0.5*	ND	73.8	105.3	ND	ND	14.4	14.5	ND	ND
Buffalo Run - Lower	BUL	ND	ND	5.4*	2.4*	ND	2.0*	9.4	9.9	ND	ND
Logan Branch - Upper	LOU	ND	ND	4.5	7.9	ND	ND	27.6	28.2	ND	ND
Logan Branch - Lower	LOL	ND	ND	ND	2.2*	ND	ND	14.9	15.6	ND	ND
Spring Creek - Upper	SPU	ND	ND	1.0*	4.2*	ND	ND	10.2	10.4	ND	ND
Spring Creek - Houserville	SPH	ND	ND	2.7*	5.3	ND	ND	19.6	19.3	ND	ND
Spring Creek - Axemann	SPA	ND	ND	1.7*	4.0*	ND	ND	30.4	31.3	ND	ND
Spring Creek - Milesburg	SPM	ND	ND	1.6*	2.9*	ND	ND	22.6	22.7	5*	ND

*	At least one sample had an undetectable concentration, so a concentration of 1/2 detection limit was set as concentration for calculations.
ND	All concentrations for all sampling events were below detection limits, so no value was assigned for concentrations.

Appendix 4: Median Stream Water Quality Results (Nutrients and Physicochemical)

Site Name	Abbrev	Calcium (mg/L) Total	Magnesium (mg/L) Total	Hardness (mg/L) Total	Chloride (mg/L) Total	Sulfate (mg/L) Total	Suspended Solids (mg/L) Total	Turbidity (NTU)
Galbraith Gap Run	GGU	3.1	1.6	14.0	1.15*	ND	1.0*	2.2
Cedar Run - Lower	CEL	73.6	23.5	280.5	15.1	17.7	6.0*	4.1
Slab Cabin Run - Upper	SLU	61.9	23.5	251.5	38.9	13.2	5.5*	6.4*
Slab Cabin Run - Lower	SLL	66.9	27.1	278.5	58.2	23.9	ND	0.5*
Slab Cabin Run - Millbrook	MIL	67.9	28.8	289.0	69.3	19.4*	1.0*	1.5
Thompson Run - Lower	THL	65.0	28.8	280.5	64.6	15.7*	ND	1.8*
Buffalo Run - Upper	BUU	73.4	26.7	293.5	38.4	29.1	ND	1.5*
Buffalo Run - Valley View	BVV	46.1	5.5	138.0	21.8	10*	1.0*	3.4
Buffalo Run - Lower	BUL	57.3	25.5	252.0	21.2	21.4	1.0*	1.7*
Logan Branch - Upper	LOU	72.6	21.9	271.5	53.2	63.5	9.0*	5.6
Logan Branch - Lower	LOL	49.5	19.8	205.0	30.4	21.6	1.0*	1.2*
Spring Creek - Upper	SPU	60.9	21.1	239.0	21.9	17.3	1.0*	1.5*
Spring Creek - Houserville	SPH	66.7	24.8	268.5	43.0	20.3	1.0*	2.5
Spring Creek - Axemann	SPA	61.3	23.9	251.5	57.0	24.0	3.5*	3.2*
Spring Creek - Milesburg	SPM	53.6	21.6	225.5	43.9	22.1	1.0*	2.6*

Site Name	Abbrev	pH	Dissolved Oxygen (mg/L)	Temperature (^{o}C)	Conductivity (mS)	Nitrate-N (mg/L)	Orthophosphorus (mg/L) Total
Galbraith Gap Run	GGU	6.7	11.3	7.5	39.1	0.10	0.007*
Cedar Run - Lower	CEL	8.2	10.6	11.0	554.0	4.50	0.005*
Slab Cabin Run - Upper	SLU	7.7	10.5	9.0	569.0	3.46	0.012*
Slab Cabin Run - Lower	SLL	8.0	12.0	10.6	678.0	2.49	0.005*
Slab Cabin Run - Millbrook	MIL	8.2	12.2	12.1	633.0	3.57	0.010*
Thompson Run - Lower	THL	8.1	11.3	11.8	671.0	3.82	0.011
Buffalo Run - Upper	BUU	8.0	12.4	6.7	622.5	1.20	ND
Buffalo Run - Valley View	BVV	7.6	12.2	9.0	348.5	0.20	0.023
Buffalo Run - Lower	BUL	8.3	11.8	9.6	513.5	1.55	ND
Logan Branch - Upper	LOU	7.7	11.2	11.3	586.0	3.01	0.044
Logan Branch - Lower	LOL	7.8	11.5	10.8	460.0	2.83	0.010
Spring Creek - Upper	SPU	7.5	10.0	10.2	505.0	2.55	0.009*
Spring Creek - Houserville	SPH	8.3	13.6	10.6	608.5	3.07	0.005*
Spring Creek - Axemann	SPA	8.3	12.0	10.7	625.5	3.58*	0.016
Spring Creek - Milesburg	SPM	8.5	12.2	11.6	536.0	2.90	0.012*

*	At least one sample had an undetectable concentration, so a concentration of 1/2 detection limit was set as concentration for calculations.
ND	All concentrations for all sampling events were below detection limits, so no value was assigned for concentrations.

Appendix 5: Median Spring Water Quality Results (Metals)

Site Name	**Abbrev**	**Aluminum (µg/L)**		**Cadmium (µg/L)**		**Chromium (µg/L)**		**Copper (µg/L)**		**Iron (µg/L)**	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Axemann Spring	AXS	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.0*
Benner Spring	BES	ND	42.5*	ND	ND	ND	ND	ND	ND	ND	97.5
Big Spring	BIS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Blue Spring	BLS	5.0*	19.4	ND	ND	ND	ND	ND	ND	10.0*	52.5*
Continental Courts Spring	COS	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.0*
Linden Hall Park Spring	LIS	ND	13.1*	ND	ND	ND	ND	ND	ND	ND	ND
Walnut Spring	WAS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Windy Hill Farm Spring	WIS	ND	921$	ND	ND	ND	11.2*$	ND	4.1*$	ND	1918.5$

Site Name	**Abbrev**	**Lead (µg/L)**		**Manganese (µg/L)**		**Nickel (µg/L)**		**Sodium (mg/L)**		**Zinc (µg/L)**	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Axemann Spring	AXS	ND	ND	ND	ND	ND	ND	16.7	17.2	ND	ND
Benner Spring	BES	ND	ND	ND	2.5*	ND	ND	22.9	24.0	ND	ND
Big Spring	BIS	ND	ND	ND	ND	ND	ND	10.4	11.2	ND	ND
Blue Spring	BLS	ND	ND	1.9	4.1	ND	ND	2.7*	2.6*	ND	ND
Continental Courts Spring	COS	ND	ND	ND	ND	ND	ND	9.9	10.2	ND	ND
Linden Hall Park Spring	LIS	ND	ND	ND	ND	ND	ND	2.8	2.9	10*	ND
Walnut Spring	WAS	ND	ND	ND	ND	ND	ND	37.4	38.3	ND	ND
Windy Hill Farm Spring	WIS	ND	1.6*$	ND	62.9	ND	13.2*$	12.9	13.1	9.0*$	11.0*$

*	At least one sample had an undetectable concentration, so a concentration of 1/2 detection limit was set as concentration for calculations.
ND	All concentrations for all sampling events were below detection limits, so no value was assigned for concentrations.
$	Values possibly affected by low flow or stagnant conditions.

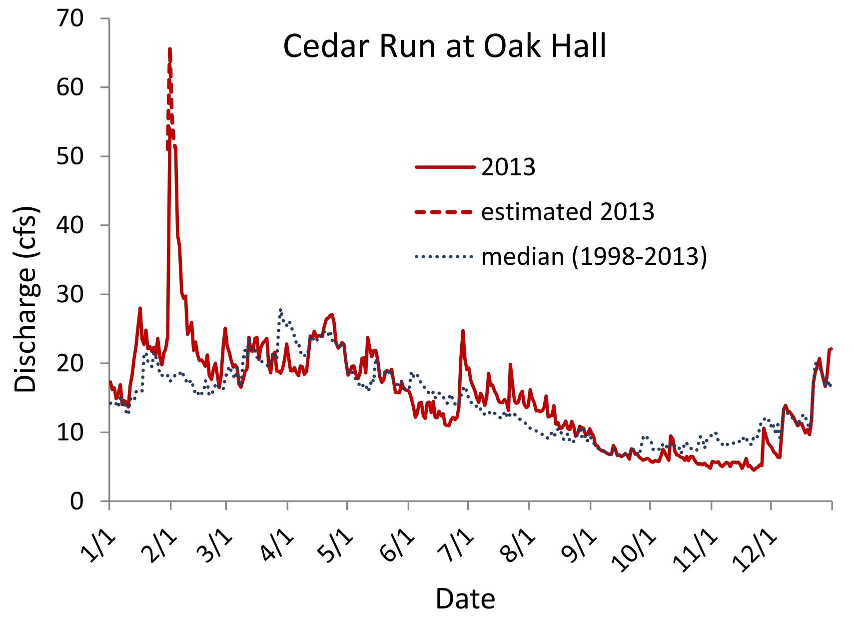
Appendix 5: Median Spring Water Quality Results (Nutrients and Physicochemical)

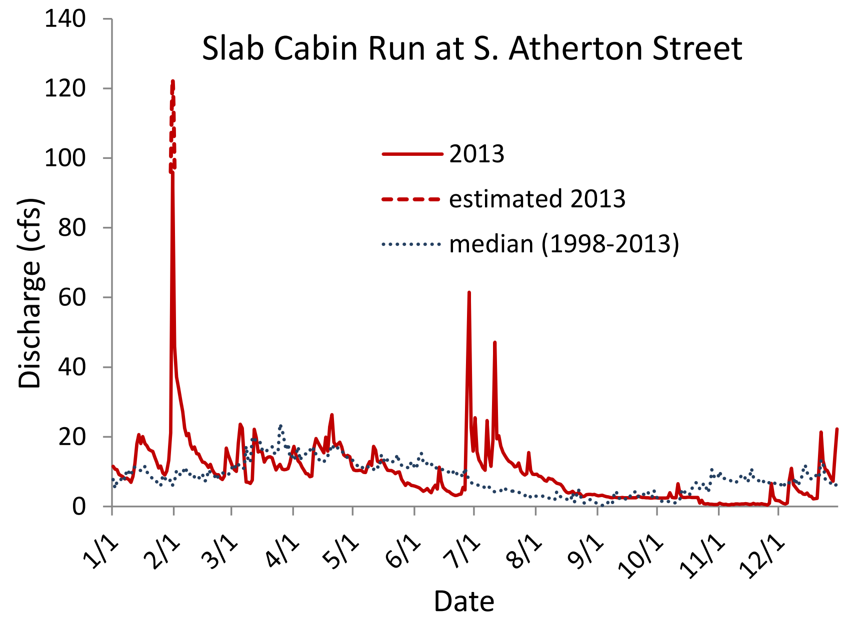
Site Name	Abbrev	Calcium (mg/L)	Magnesium (mg/L)	Hardness (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Suspended Solids (mg/L)	Turbidity (NTU)
		Total	Total	Total	Total	Total	Total	
Axemann Spring	AXS	77.3	33.9	332.5	43.5	26.3	ND	ND
Benner Spring	BES	61.1	23.2	248.5	57.0	10.0*	ND	2.8
Big Spring	BIS	31.7*	16.5	147.5	21.8*	ND	ND	ND
Blue Spring	BLS	31.6	15.0	151.0	5.1	ND	3.5*	1.2*
Continental Courts Spring	COS	56.9	25.9	249.5	21.2	ND	ND	ND
Linden Hall Park Spring	LIS	77.3	32.0	325.0	7.7	18.6	1.0*	ND
Walnut Spring	WAS	79.3	40.4	364.5	94.8	23.0	3.5*	0.5*
Windy Hill Farm Spring	WIS	58.2	26.2	253.5	25.9	13.1*	155.0	38.0

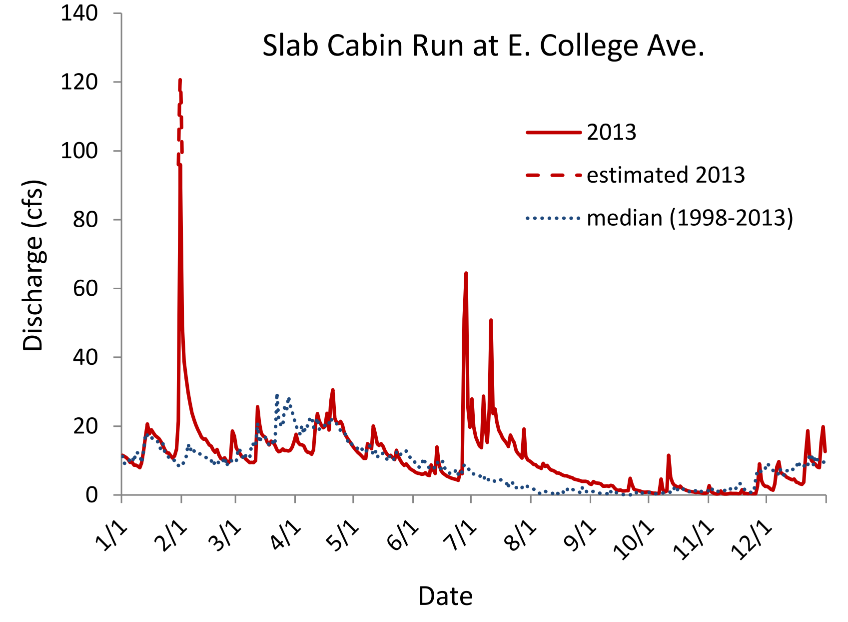
Site Name	Abbrev	pH	Dissolved Oxygen (mg/L)	Temperature (°C)	Conductivity (mS)	Nitrate-N (mg/L)	Orthophosphorus (mg/L)	Fecal Coli-forms (#col/ 100mL)
							Total	
Axemann Spring	AXS	7.2	7.68	10.3	714.5	6.24	0.005*	0.0
Benner Spring	BES	7.3	10.90	10.4	596.5	3.92	0.005*	0.0
Big Spring	BIS	7.7	10.48	10.2	343.4	1.90	ND	8.3
Blue Spring	BLS	7.1	8.03	9.6	298.1	1.41	0.013*	12.0
Continental Courts Spring	COS	7.1	7.40	10.6	510.0	2.10	0.010*	0.0
Linden Hall Park Spring	LIS	7.0	6.94	9.9	610.0	4.80	0.011*	0.0
Walnut Spring	WAS	7.1	7.02	10.4	870.0	3.68	0.008*	0.0
Windy Hill Farm Spring	WIS	7.1	8.19	9.3	508.0	3.46	0.015	3.9

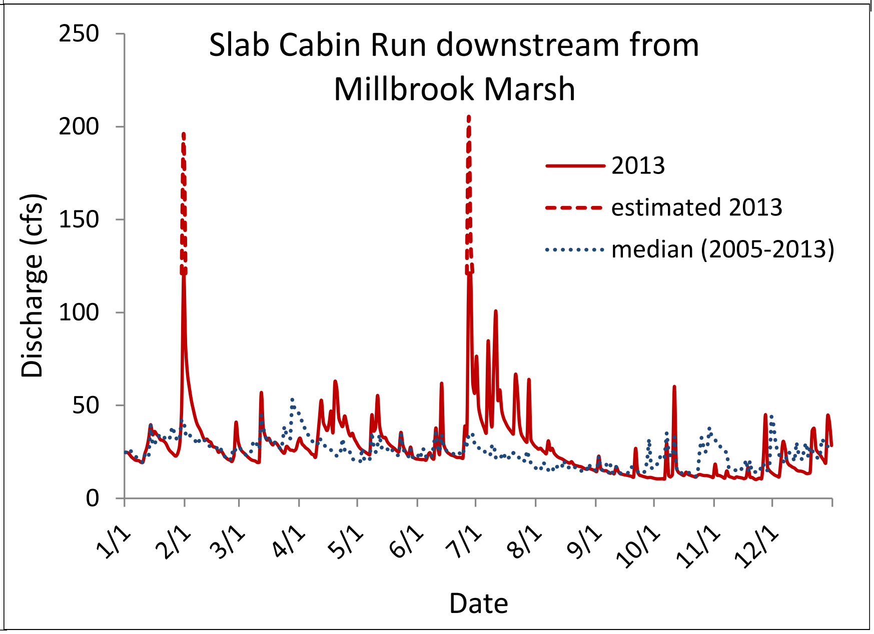
*	At least one sample had an undetectable concentration, so a concentration of 1/2 detection limit was set as concentration for calculations.
ND	All concentrations for all sampling events were below detection limits, so no value was assigned for concentrations.
$	Values possibly affected by low flow or stagnant conditions due to drought.

Appendix 6: Daily Stream Flow for 2013

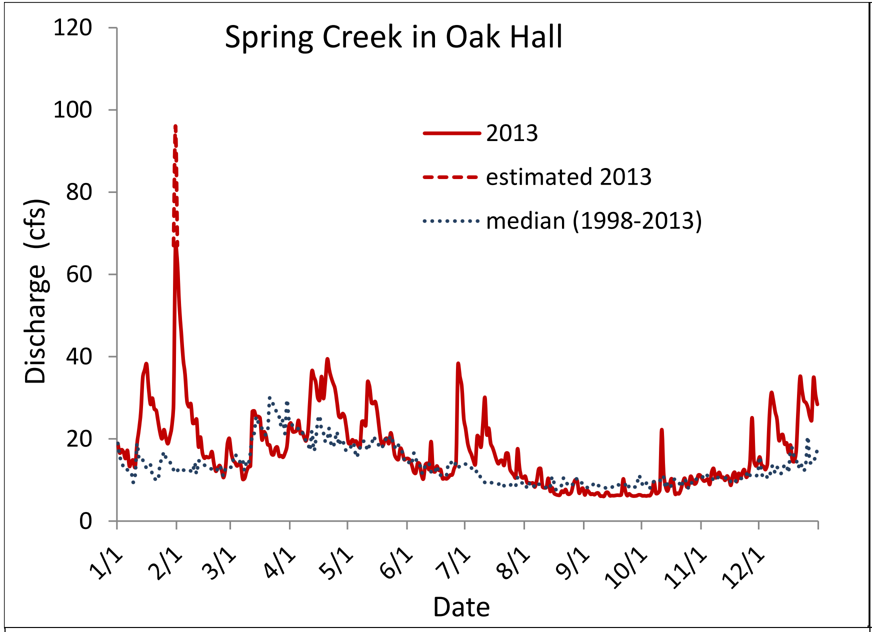


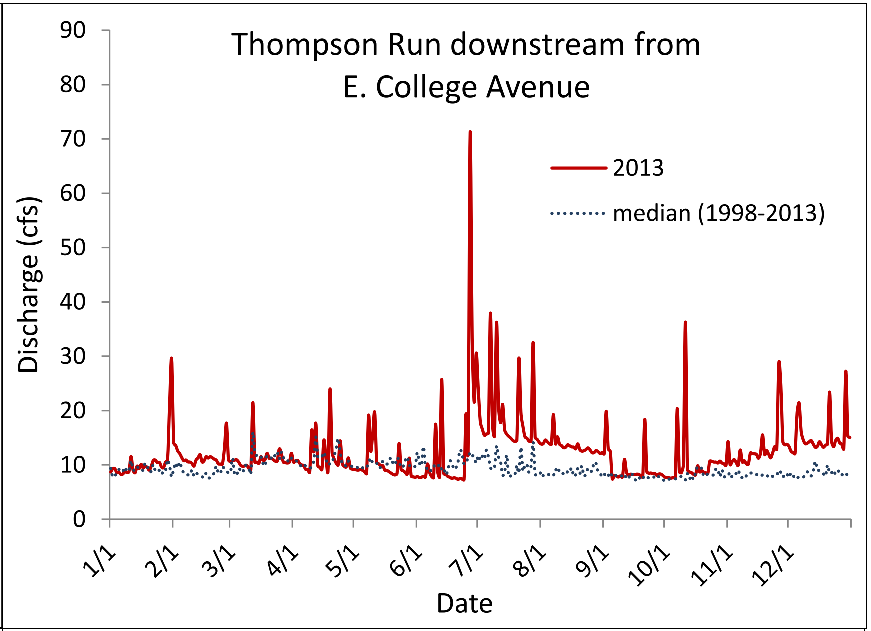


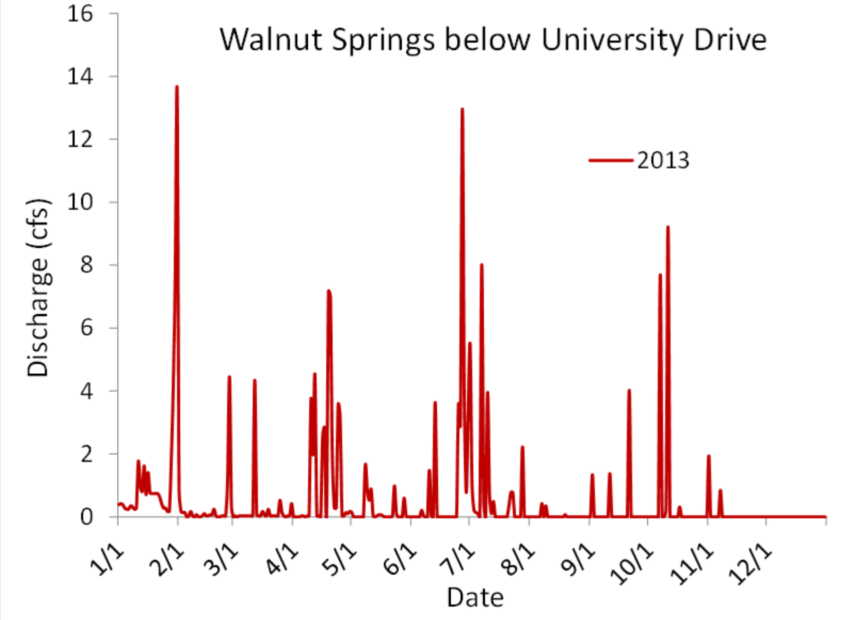


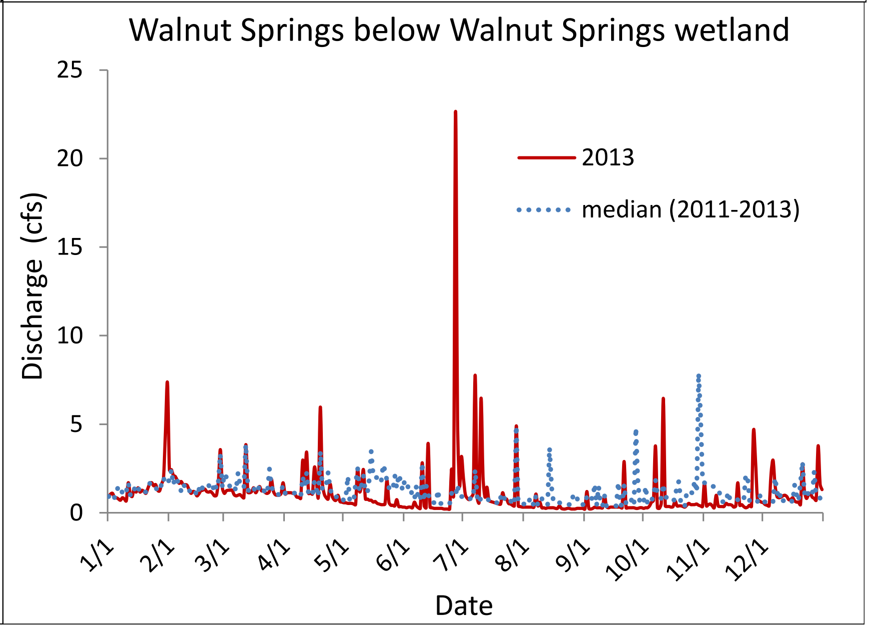


Appendix 6: Daily Stream Flow for 2013 (*continued*)

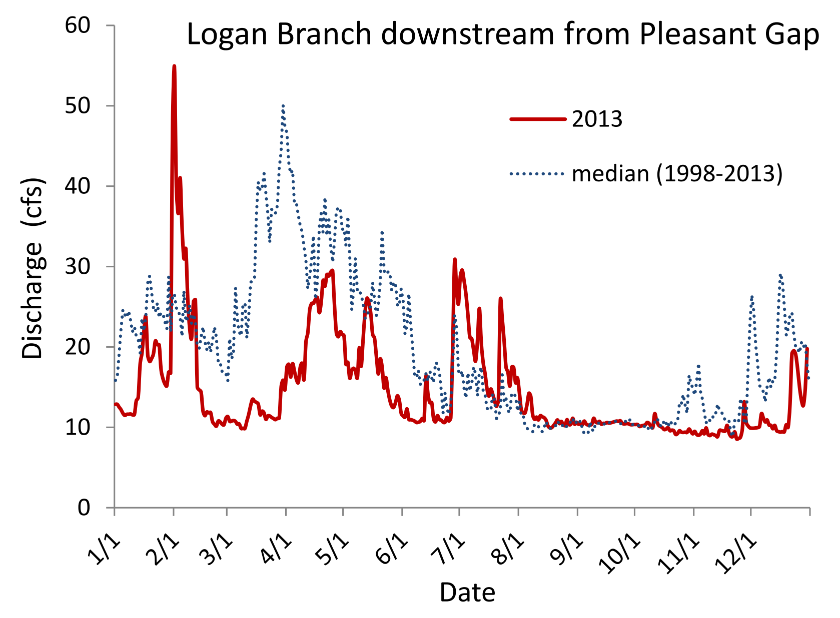


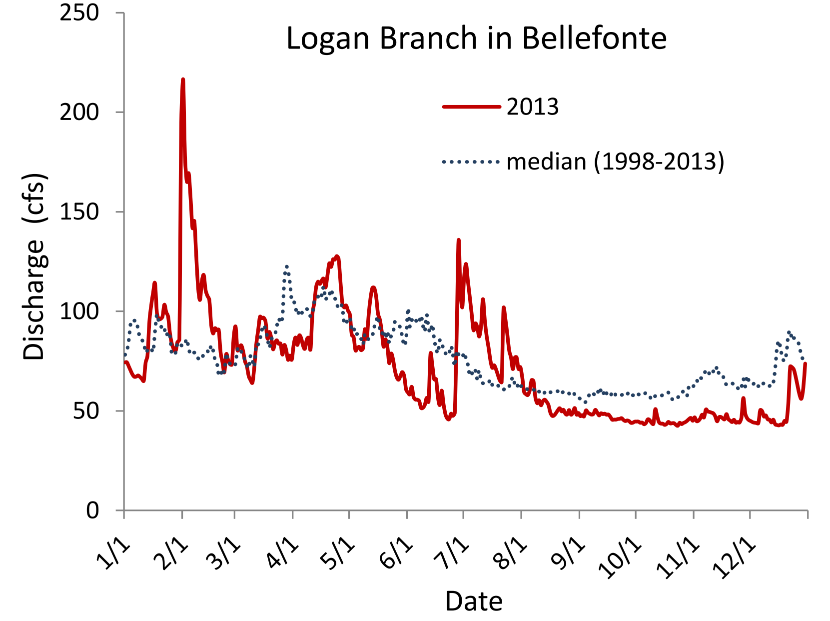


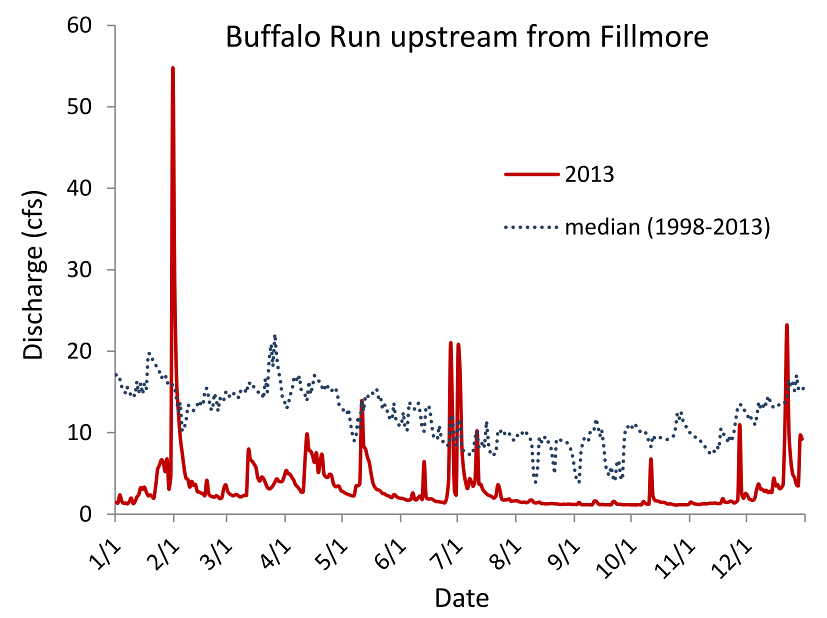


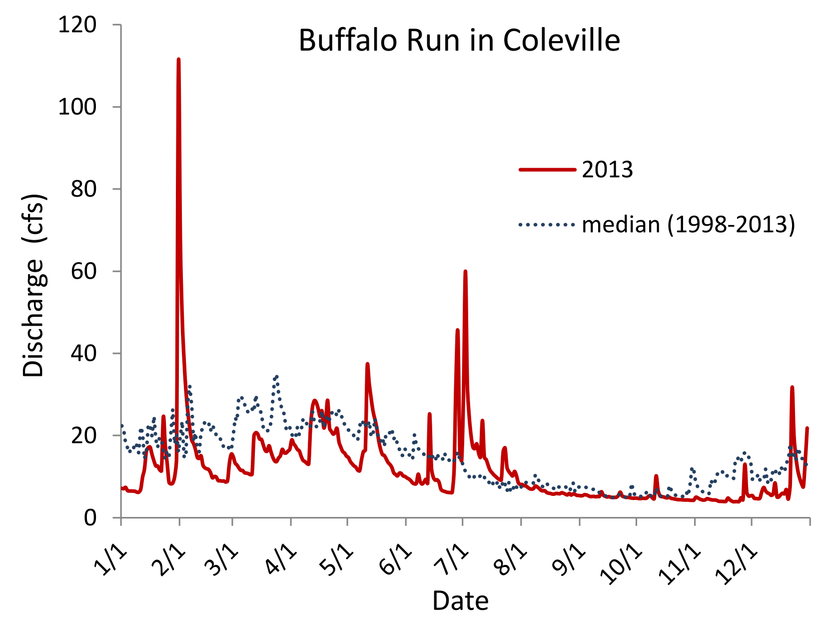


Appendix 6: Daily Stream Flow for 2013 (*continued*)


Logan Branch downstream from Pleasant Gap

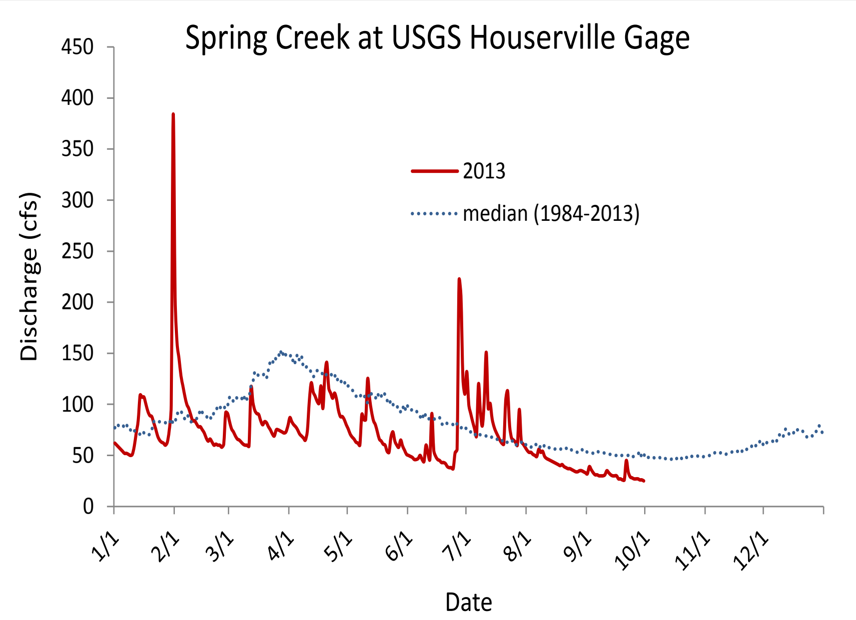

Logan Branch in Bellefonte

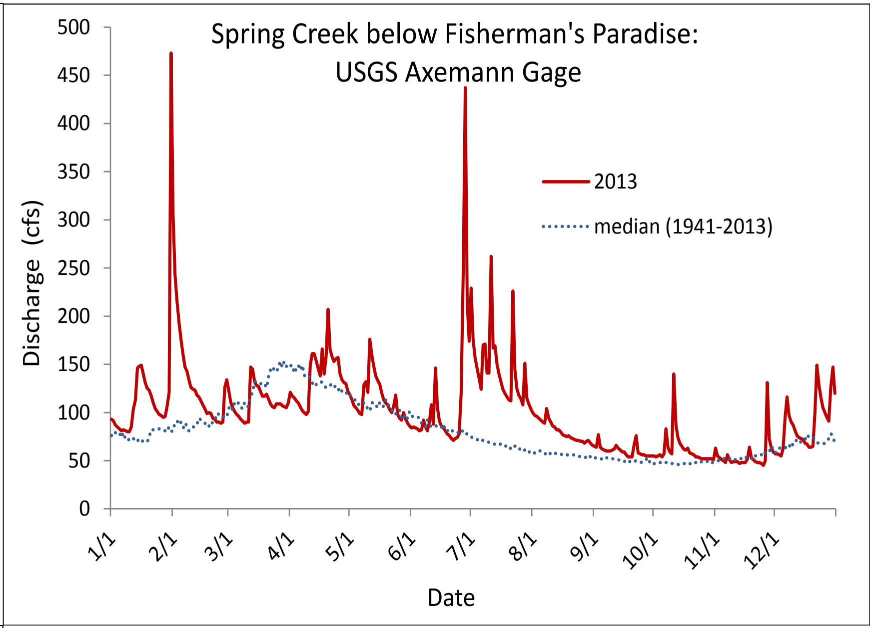

Buffalo Run upstream from Fillmore

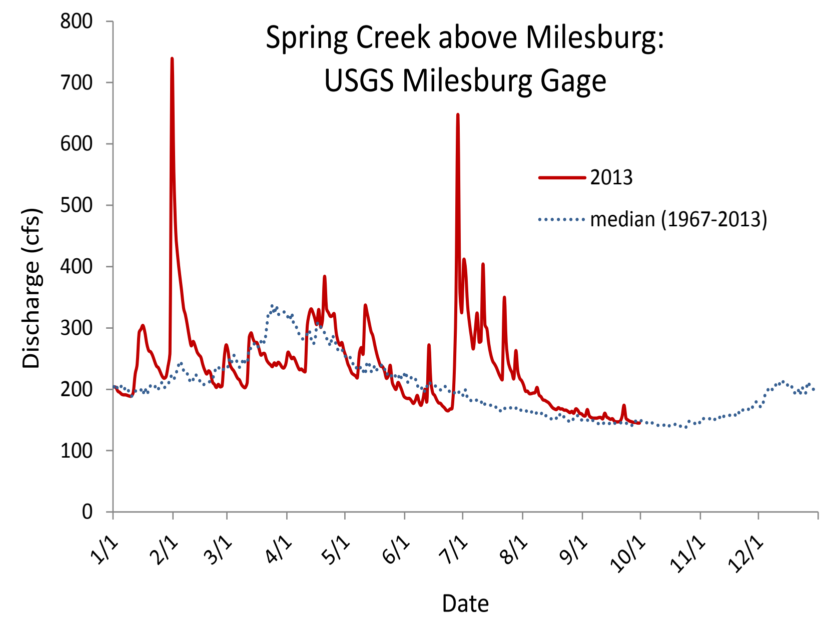

Buffalo Run in Coleville

Appendix 6: Daily stream flow data for 2013 (*continued*)

Flow data from the U.S. Geological Service gaging stations on Spring Creek. Downloaded from http://waterdata.usgs.gov/nwis/rt .

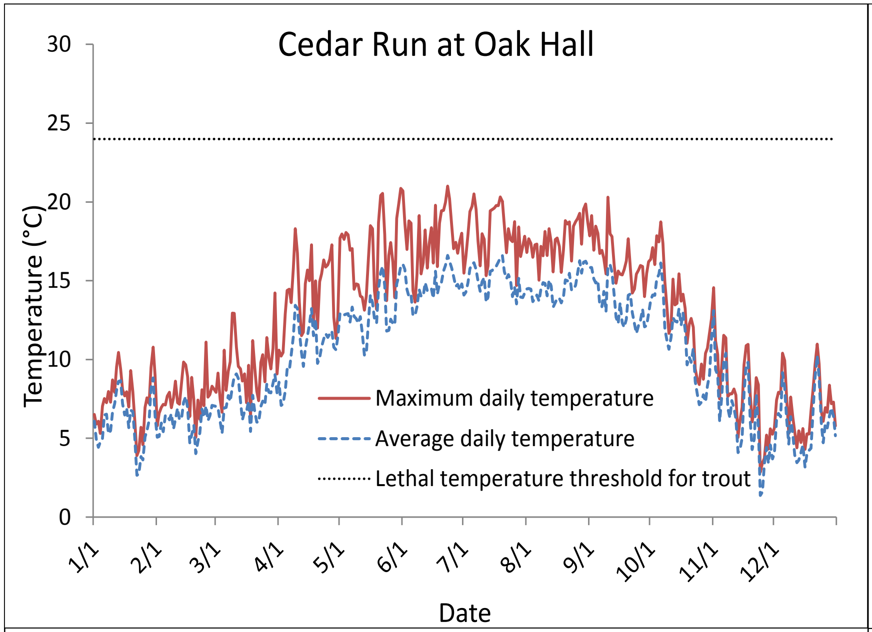


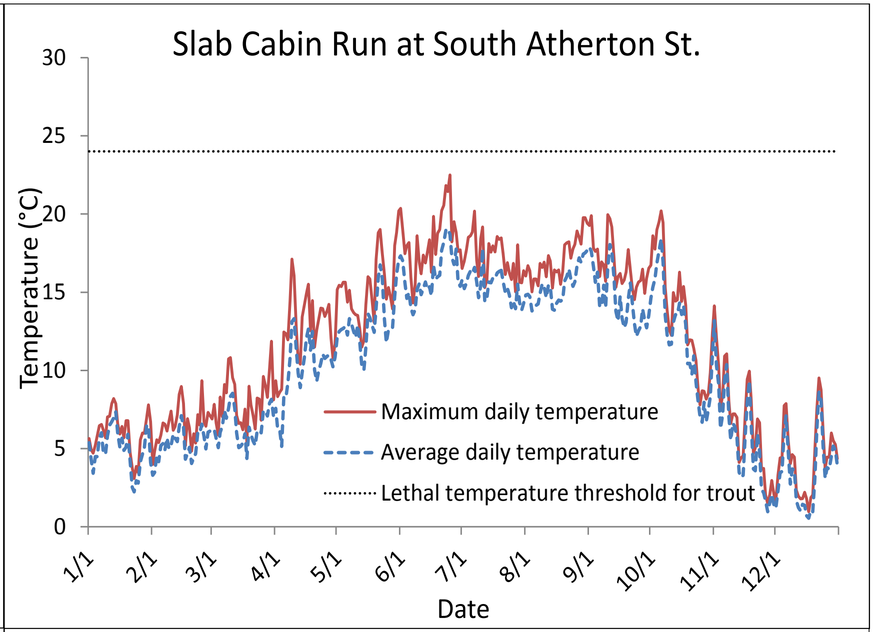


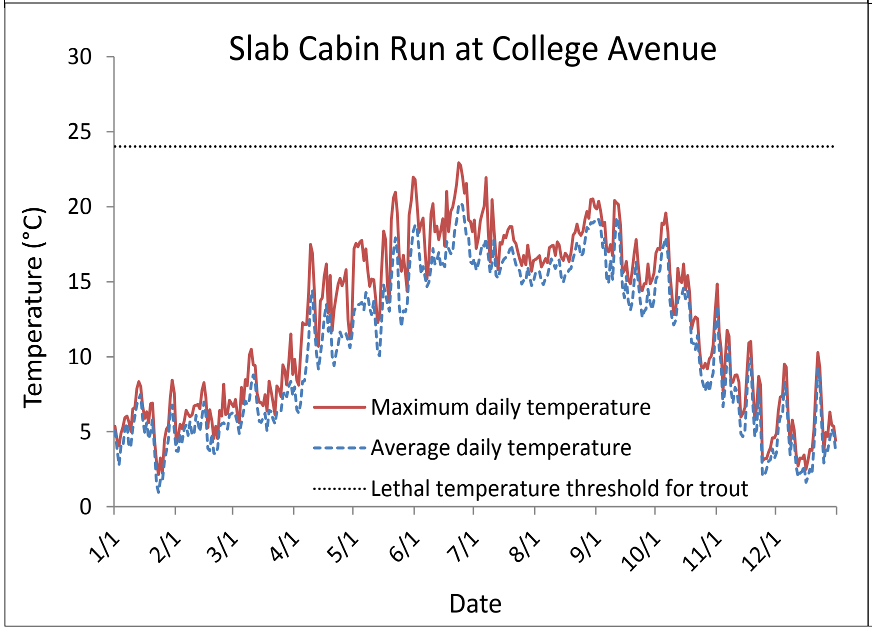


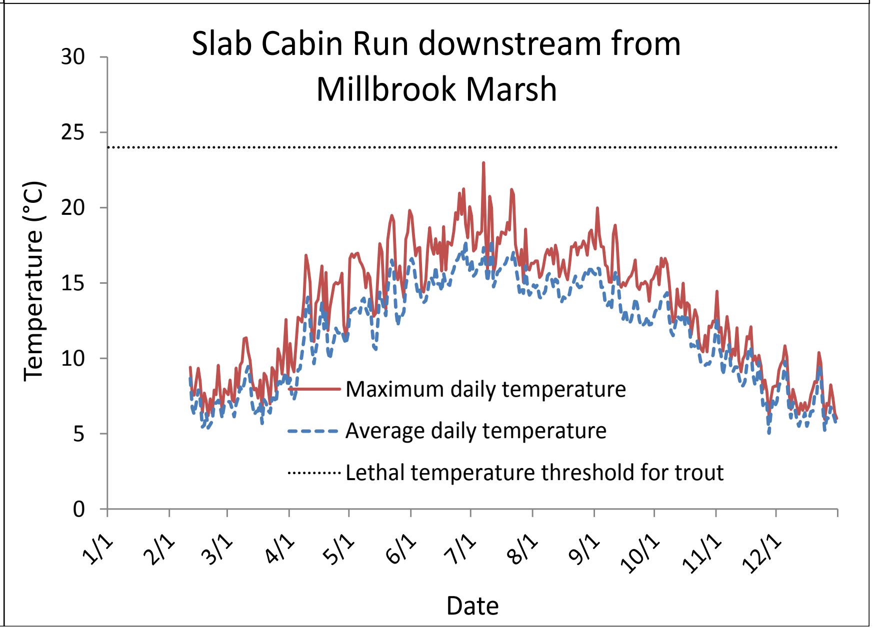
Appendix 7: Daily Stream Temperatures for 2013

Average daily stream temperature and maximum daily stream temperature for 12 locations in the Spring Creek Watershed.

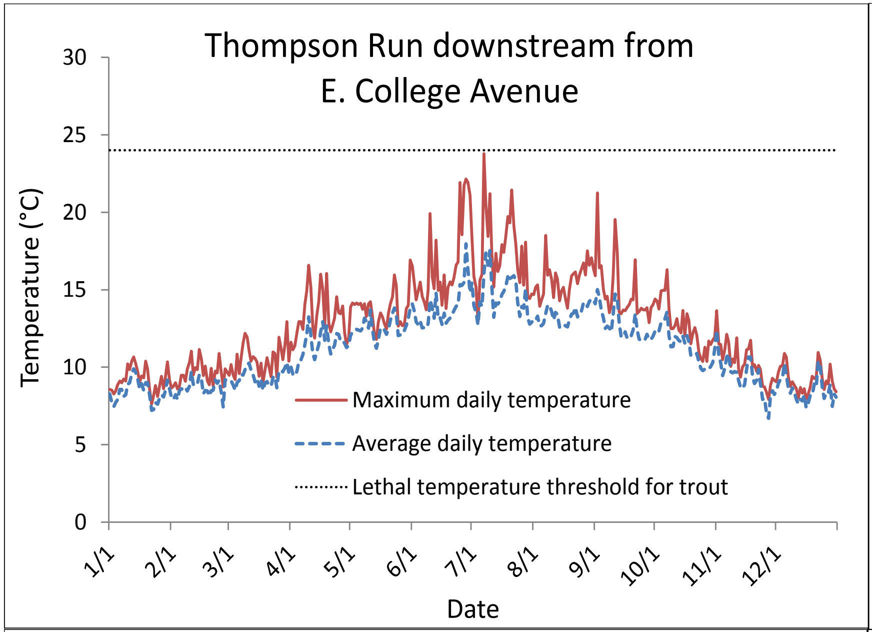

Cedar Run at Oak Hall

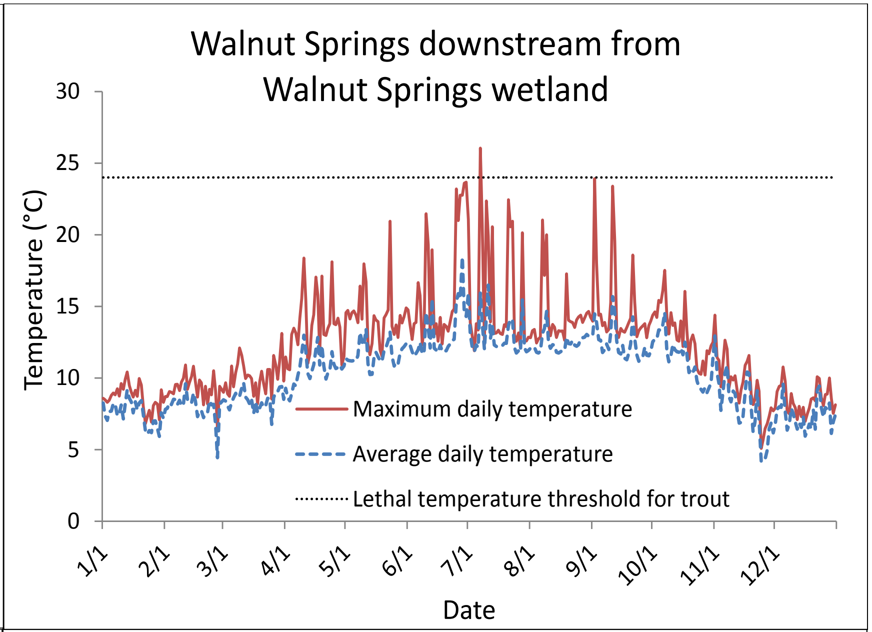

Slab Cabin Run at South Atherton St.

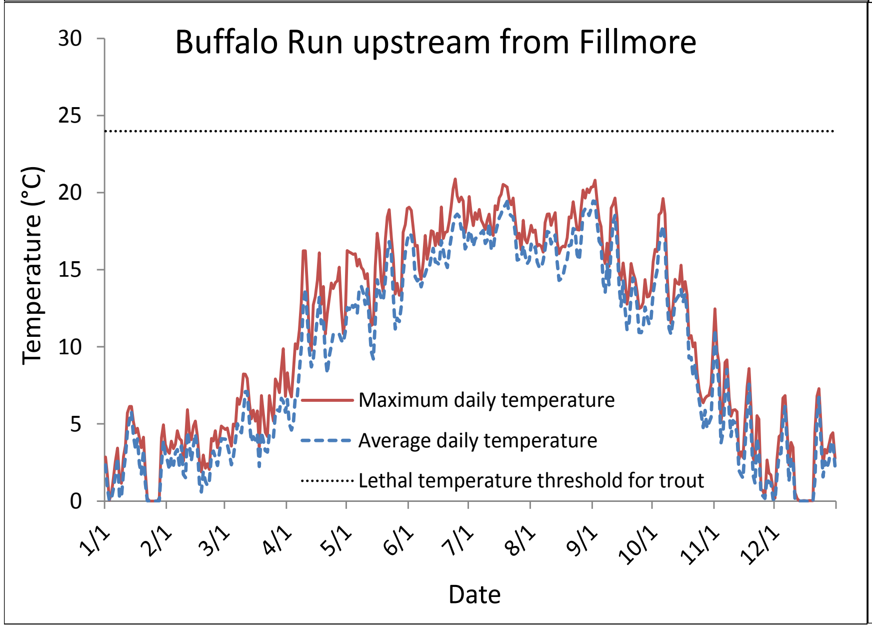

Slab Cabin Run at College Avenue

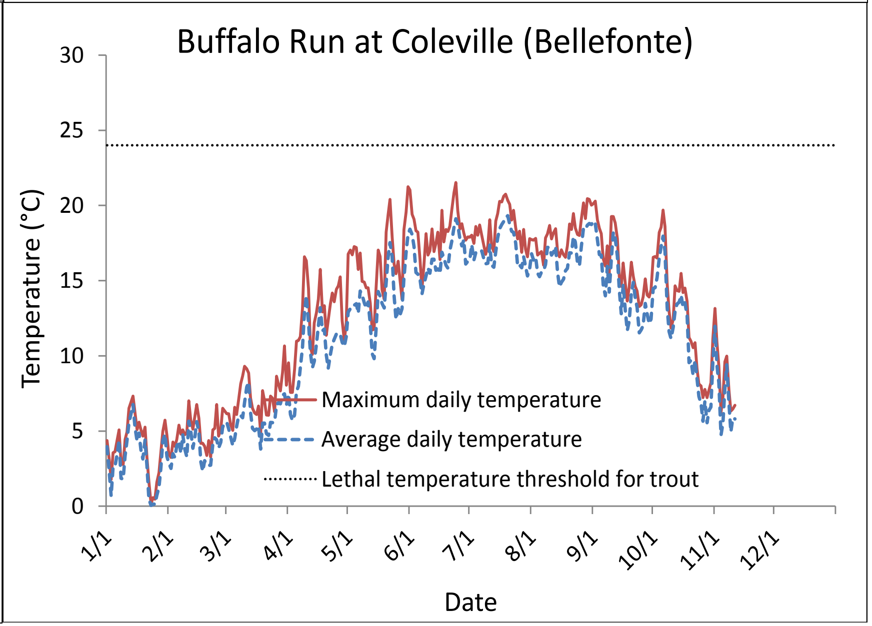

Slab Cabin Run downstream from Millbrook Marsh

Appendix 7: Daily Stream Temperatures for 2013 (*continued*)

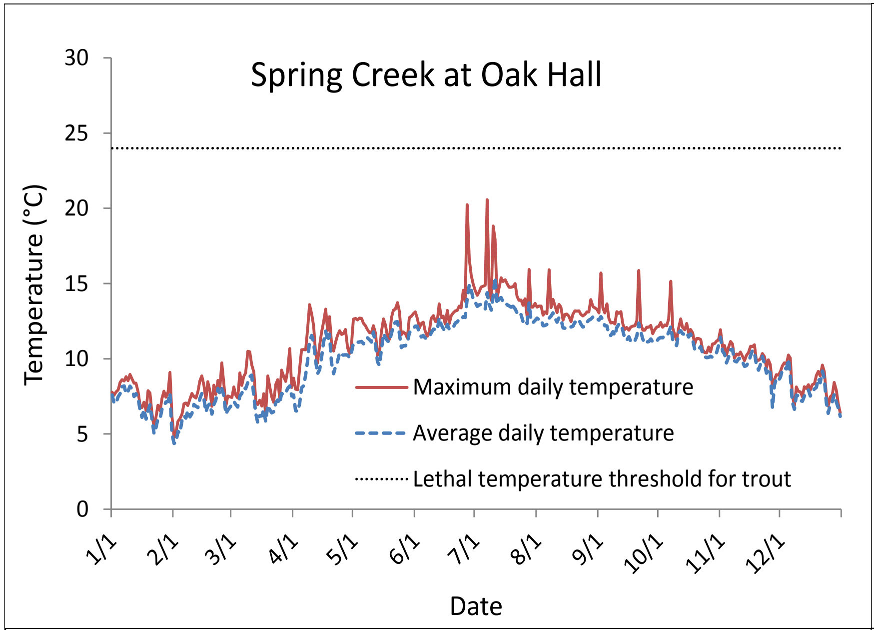

Thompson Run downstream from E. College Avenue

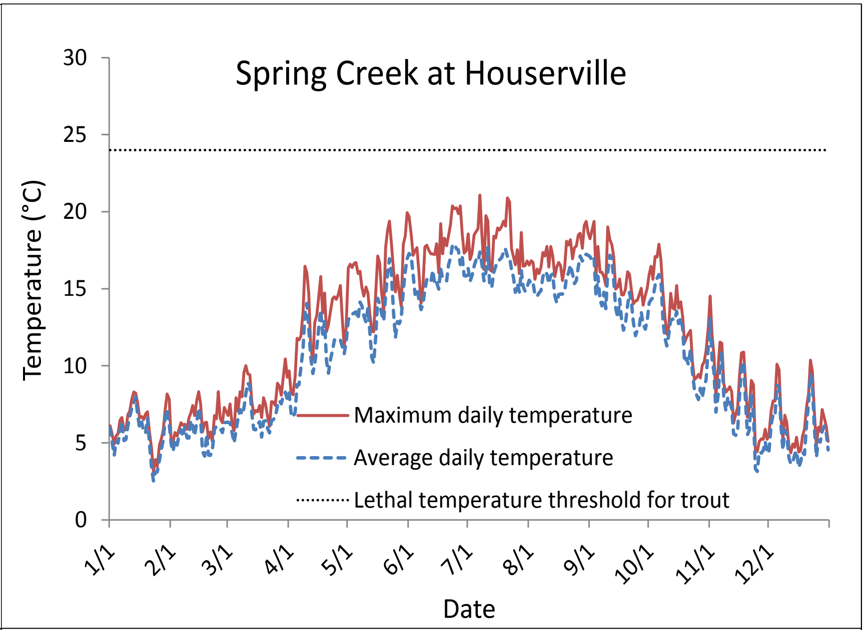

Walnut Springs downstream from Walnut Springs wetland

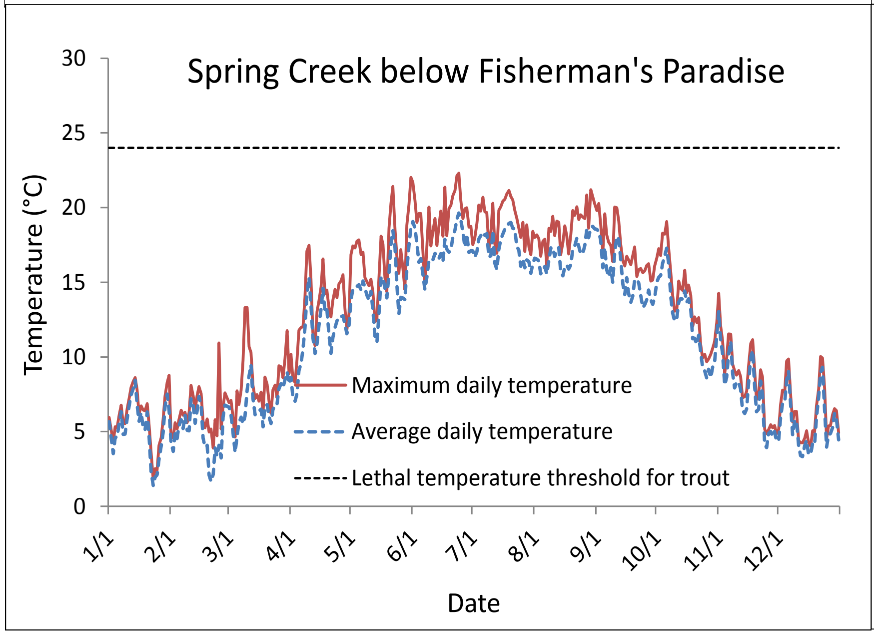

Buffalo Run upstream from Fillmore

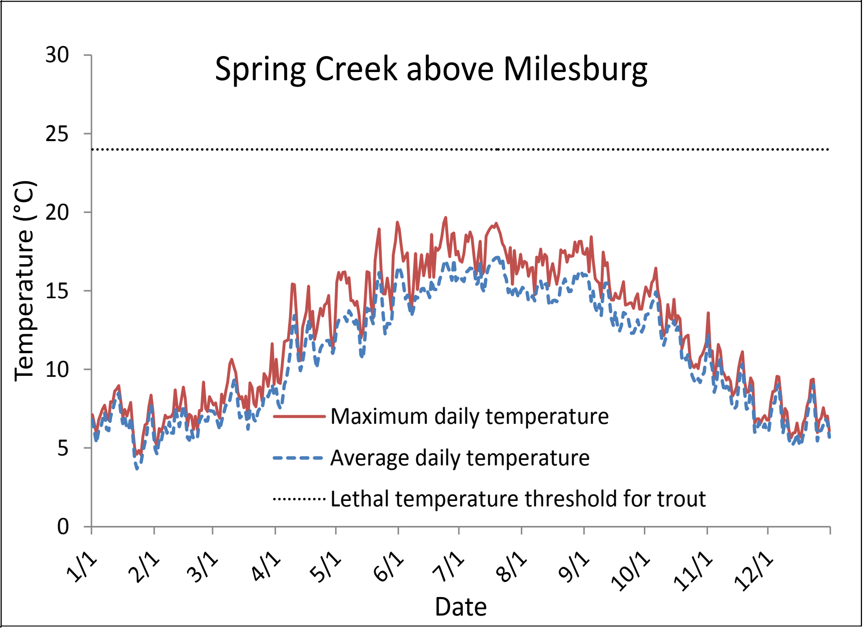

Buffalo Run at Coleville (Bellefonte)

Appendix 7: Daily Stream Temperatures for 2013 (*continued*)

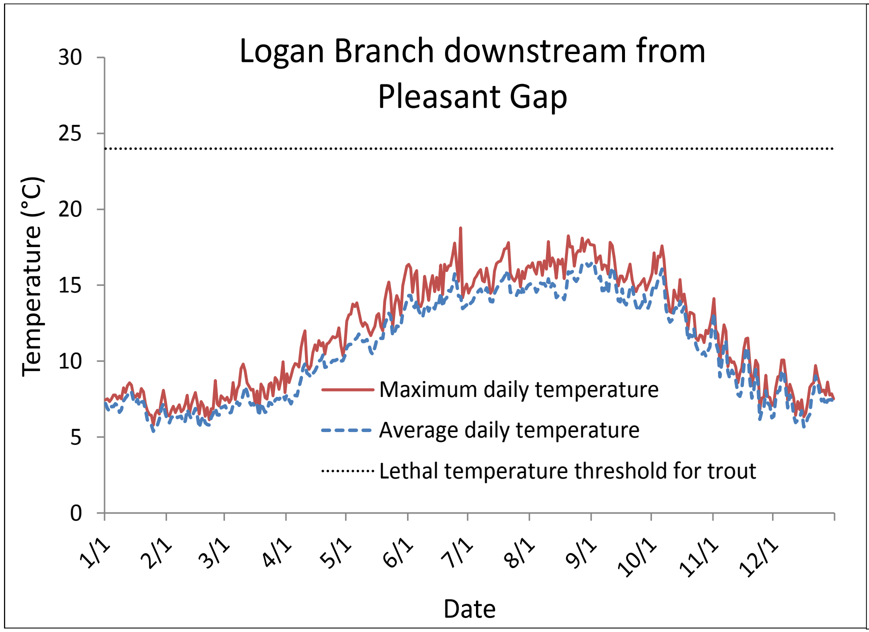


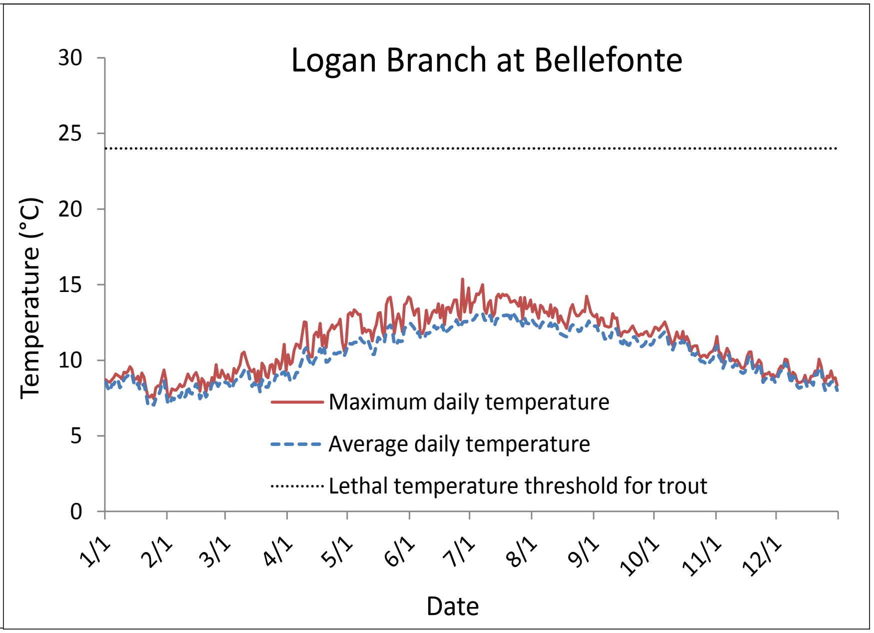






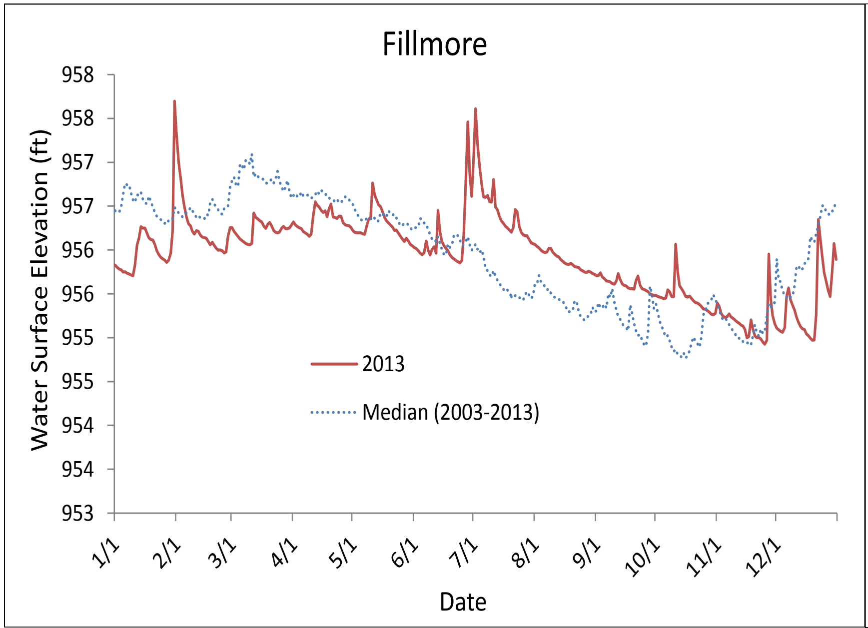
Appendix 7: Daily Stream Temperatures for 2013 (*continued*)

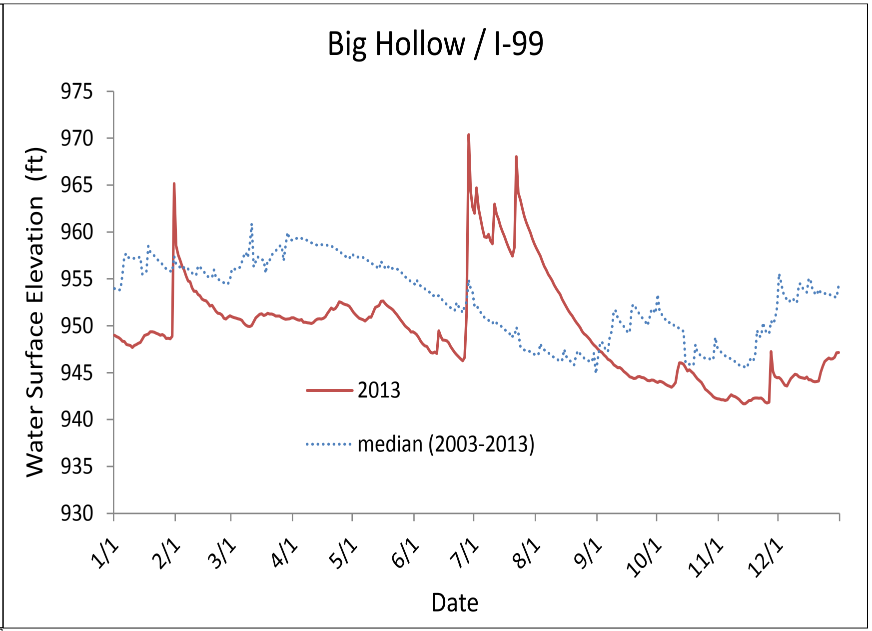


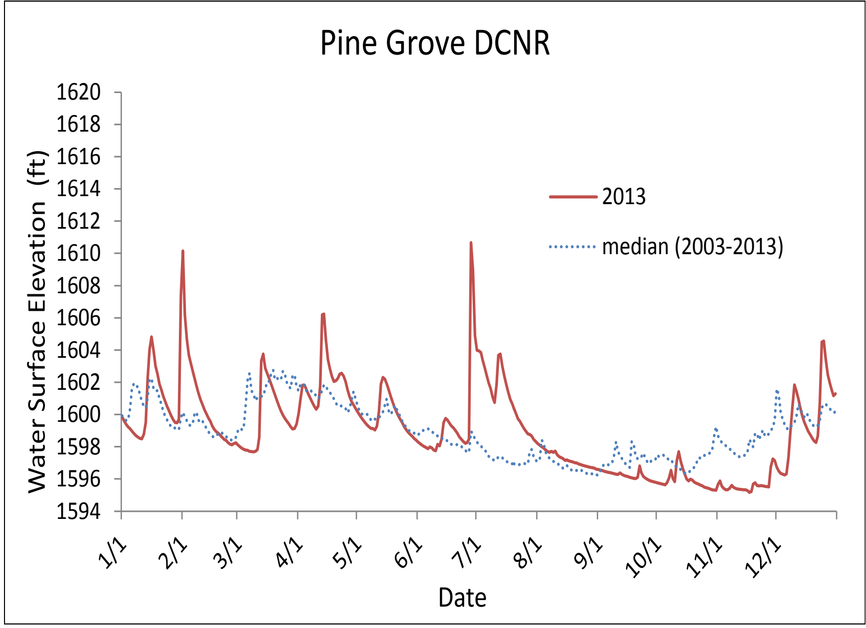


Appendix 8: Daily Groundwater Elevations for 2013

Groundwater elevations from groundwater monitoring wells within the Spring Creek Watershed.







Appendix 8: Daily Groundwater Elevations for 2013 (*continued*)

Water elevation data from the U.S. Geological Service. Downloaded from http://waterdata.usgs.gov/nwis/rt.