Monitoring Stream Temperature in the Spring Creek Watershed

2016/2017 State of the Water Resources Report

Water Resources Monitoring Project

Water Resources Monitoring Project

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FROM THE CHAIR

In the 2017 State of the Water Resources Report we examine water temperature trends for the Spring Creek watershed. As population growth and development occurs in our watershed, increased thermal loads from stormwater runoff, industry, and wastewater can impact stream ecology and health. The Water Resources Monitoring Project has been monitoring stream temperature since the inception of the project and this year's report examines these trends to provide stakeholders a better understanding.

The Water Resources Monitoring Project has been very fortunate to have Lexie Orr as our Water Resources Coordinator for the last year. Lexie started as an Americorp member with The Clearwater Conservancy while she was finishing her master's degree at Penn State in Ecology. Lexie transitioned into the role of Water Resources Coordinator in August 2017 and has done a great job of maintaining our database and field stations.

The current WRMP committee members are listed in the back of this report. Together we would like to thank you all for your time and dedication to ensure this valuable project continues for many years into the future. The Water Resources Monitoring Project, which has been in place for 19 years, provides vital long-term data that can be used by local planning officials and scientists to make sound land use and water quality decisions. We could not conduct this valuable project without our volunteers, the landowners who provide us access to monitoring locations, and our project sponsors. On behalf of the committee I'd like to personally thank our participating landowners and project sponsors for the continued access and financial support the program receives on an annual basis. Your continued support will help maintain the program's ability to provide data needed to monitor water resources in the Spring Creek watershed, so as a community we can make well-informed decisions to ensure long-term stewardship for future generations. We hope you enjoy the report and always welcome the opportunity to discuss our efforts with you!

Warm regards,

David Yoxtheimer

Dave Yoxtheimer
Water Resources Monitoring Project Committee Chair

EXECUTIVE SUMMARY

Water temperature is a critical physical property of stream ecosystems that influences nearly all in-stream biochemical processes. Atmospheric, physical and hydrologic conditions all influence a stream's thermal regime, and anthropogenic effects on any of these factors, such as changes in land-use or natural flow patterns, can greatly impact stream temperature and ecosystem processes. The Spring Creek Watershed in Centre County, Pennsylvania is a small, headwaters watershed that exhibits wide variation in stream size, land-use, groundwater contribution to stream flow, and industrial inputs and withdrawals. The Water Resources Monitoring Project has been observing stream temperature at locations throughout the watershed regularly since 1999.

This report aims to outline the spatial and temporal variation of stream temperature within the Spring Creek Watershed and identify possible environmental and/or anthropogenic factors that may account for this variation. Temperature data from 2016 and 2017 were compared in the context of discharge rates, groundwater contribution to stream flow, locally contributing land cover, riparian cover, industrial inputs and withdrawals, air temperature and precipitation rates. Daily, monthly and yearly averages of temperature for all periods of record were also analyzed to identify possible long-term trends in stream temperature.

Results indicate that at specific locations, temperature regimes have remained fairly constant over time. However, stream temperature varied significantly between years and followed short-term trends in response to weather patterns. Groundwater contribution to stream flow and steady discharge rates may be the most critical factors in explaining the variation within and between monitoring locations and maintaining stable thermal regimes in varying atmospheric and physical conditions. Identifying areas (1) with low groundwater input and (2) that may be more susceptible to low flow conditions can help prioritize planning for riparian buffer restoration, stormwater management and other innovative strategies to maintaining and/or restoring natural stream temperature regimes.

AN INTRODUCTION TO STREAM TEMPERATURE

Introduction

Water temperature is a critical property of stream health that influences nearly all in-stream biochemical processes. Temperature is a major control on aquatic habitat ranges, chemical characteristics of stream water and sediments, and biological productivity. Atmospheric and physical conditions as well as hydrologic inputs all influence a stream's temperature regime (Caissie, 2006; Webb et al., 2008). Anthropogenic effects on any of these factors, such as changes in land use or natural flow patterns, can be an important influence on stream temperature and ecosystem processes. (Langford, 1990). The 2017 Annual Report examines temperature trends in the Spring Creek Watershed and the many factors that can both influence or buffer changes in typical stream temperatures.

Importance of Stable Temperature Regimes

Organismal Metabolic Rates

Because most aquatic organisms, large and small, are ectothermic and cannot regulate internal body temperature, stream temperature controls all levels of their biological processes from individual enzymatic reactions to whole organism metabolism. Even relatively small increases in water temperature can impact microbial and insect populations. Microbes are thermally adapted, so increases in even 1.8-2.6°F can alter populations and increase potential pathogen establishment. Additionally, increases in 2.6-5.4°F can significantly decrease macroinvertebrate populations because increased metabolic rates reduce available energy to develop and lay eggs (Firth and Fisher, 1992). For larger organisms like the brown trout, a main species of fish in the Spring Creek watershed*, trophic level interactions can magnify the impact of temperature. As the metabolic rate of trout increases, so too does the need for food and oxygen. While the most heat-acclimated brown trout can reportedly survive in temperatures of up to 80°F for short periods of time, the upper limiting temperature for brown trout survival is 68°F with negative impacts beginning to occur at 75.2°F (Raleigh et al., 1986).

Dissolved Oxygen

Dissolved oxygen is one of the most essential parameters

*While the brown trout is a prominent fish species in the Spring Creek Watershed, the brook trout is often used as a native indicator species of high water quality. Brown trout are referenced in this report due to the low population density and narrow distribution of brook trout in the watershed.

Figure 1: Gills on the underside of a stonefly nymph (Friends of the Boyne River)

for aquatic life. Most organisms that live in streams use gills to extract oxygen out of the water. Oxygen is incorporated into water by two main methods: atmospheric mixing and photosynthesis. As water flows over rocks in riffles, water and air mix and allow oxygen to dissolve into the water. Submerged aquatic plants are another major source of dissolved oxygen in streams, particularly in slower moving reaches. In ideal light conditions, submerged plants can produce six times more oxygen than they consume.

Oxygen demand depends on the species and life stage; some organisms are adapted to lower oxygen conditions, while others require higher concentrations. Oxygen requirements for brown trout can vary based on age, water velocity, water temperature, activity level and levels of other substances in the stream water. Brown trout will avoid water with less than 5 mg/l of dissolved oxygen and prefer levels as high as 12 mg/L at water temperatures greater than 50°F (Raleigh et al., 1986). All organisms use oxygen during respiration in order to produce energy to survive. The metabolic rate of that organism determines exactly how much oxygen it will need.

Unfortunately, just as temperature directly impacts respiration rates of aquatic organisms, it also impacts the solubility of oxygen in water. As temperature increases, the solubility of oxygen decreases, meaning that dissolved oxygen levels decrease with increasing temperature

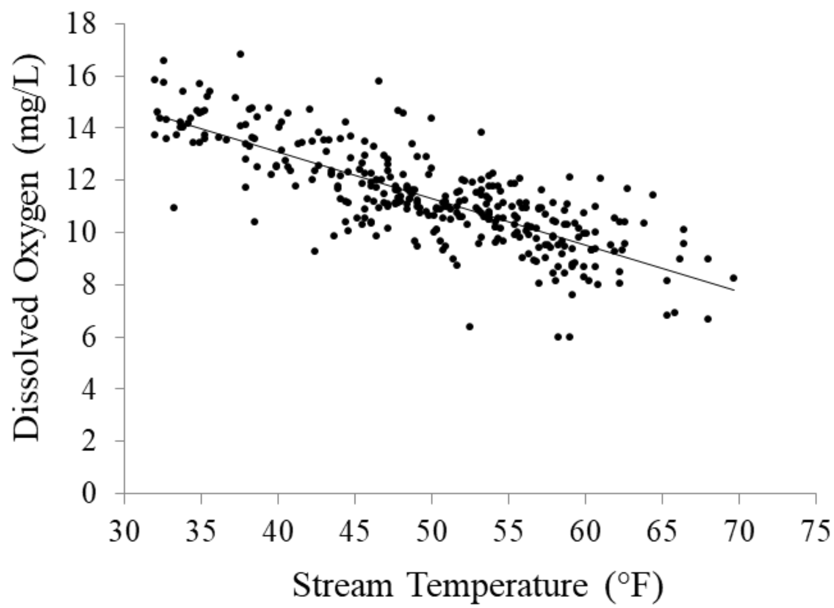

Figure 2: Stream temperature (°F) vs. dissolved oxygen concentration (mg/L) for WRMP tributary baseflow data (1999-2017)

(**Figure 2**). So while oxygen becomes less soluble, it also becomes more important for survival. Trout exhibit many behavioral patterns to account for high stream temperatures such as moving to deeper water, migrating to cooler mountain streams and simply slowing down their activity levels during high stress times.

Nutrient Cycling

Temperature and dissolved oxygen can jointly impact the solubility and availability of nutrients in streams. Increases in temperature directly increase decomposition rates of organic matter which can increase levels of nutrients. Additionally, in low oxygen conditions nutrients such as phosphate can be released from stream sediments. If nutrient levels become too high in a stream, particularly in slower moving reaches, algae can grow very quickly. This increased algal growth can become problematic once light becomes limited within the water channel. Not only will the algae use dissolved oxygen but will also limit both processes by which oxygen is dissolved in water by creating a barrier between the water and air and by blocking light for submerged photosynthesis. This process is called eutrophication and can have a myriad of negative effects on all aquatic life. For example, low oxygen levels can prevent nitrification, the biological process by which ammonia is converted to nitrite or nitrate through oxidation. Reduced nitrification rates can lead to increased concentrations of ammonia, which is toxic to fish. So not only will fish face low oxygen levels but also increases in toxin levels.

Figure 3: Eutrophication in a stream in NY. (SUNY Brockport)

Factors that Influence Stream Temperature

There are a number of factors that can contribute to or buffer against thermal pollution in a stream. Stream temperature like air temperature exhibits a seasonal pattern, so classically; stream temperature regimes have been modeled against air temperature. However, while some streams follow a very strong seasonal pattern, others may be well buffered against these shifts in temperature. More recent research has shown that while air temperature can model temperature regimes fairly accurately, other factors may be more important determinants of stream temperature ranges (Mayer, 2012; Johnson, 2004). These factors include geology and groundwater contribution to baseflow (streamflow unaffected by surface runoff), land use within the basin, riparian cover along the stream, flow rates within the stream channel, and industrial water inputs into the watershed.

Geology, Springs and Groundwater Contribution

Typically, stream temperature is closest to groundwater temperature (51.5°F) in headwater regions and tends to equilibrate with air temperature further downstream (Caissie, 2006). However, streams with high levels of groundwater contribution to baseflow do not follow this pattern. Baseflow is defined as the groundwater contribution to streamflow. Karst physiographic regions like the Spring Creek Watershed have many large springs from underground aquifers that directly discharge groundwater into streams as well as areas where groundwater diffuses through the streambed into the streamflow (Fulton et al., 2005). These inputs help moderate seasonal stream temperature changes by maintaining cooler stream temperatures in the summer and warmer temperatures during the winter (Tague et al., 2007). A water budget analysis of the Spring Creek Watershed discovered that approximately 85 percent of the total annual flow through the main stem of Spring Creek at Milesburg was contributed by groundwater (Giddings, 1974). With large groundwater inputs, streams may experience much less sensitivity to atmospheric and anthropogenic factors and maintain temperature ranges much closer to groundwater temperature.

Stream substrate is also a moderator of stream temperature. Stream water can be split up into two zones based on stream flow rates. Below the surface flow where water is moving fairly quickly, the hyporheic zone is an area where water flow decreases substantially and allows the water to interact with stream substrate (**Figure 4**). The influence of stream substrate is an area that still needs much research, but there is evidence that gravel bottom versus bedrock or sediment covered streambeds tend to have less fluctuation in daily maximum and minimum stream temperatures (Johnson, 2004).

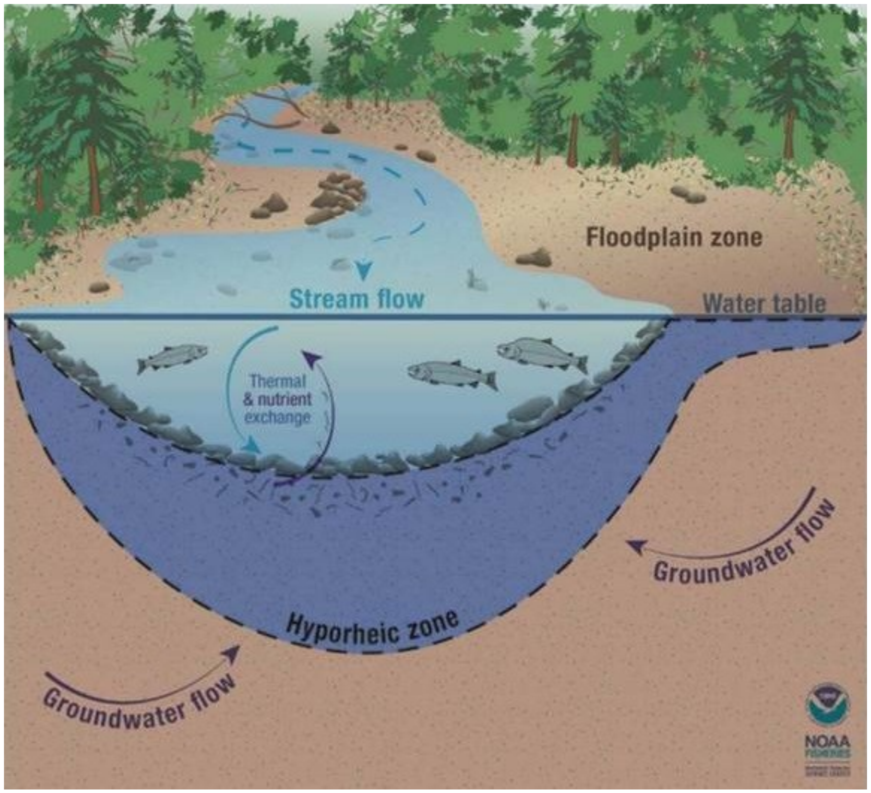

Figure 4: The hyporheic zone within a stream stream channel (NOAA)

<u>*Land Cover, Soil Type and Surface Runoff*</u>

Infiltration rates, the speed at which water penetrates the soil surface, of a specific area of land determine how much precipitation will ultimately be absorbed by the soil and potentially percolate into groundwater or run off of the land surface and most likely enter a stream. This overland flow will not only pick up sediment and other pollutants as it flows over the land but through conduction will also gain heat from warmed surfaces such as pavement. Soil type and topography determine baseline infiltration rates; however, land cover and management can ultimately alter soil characteristics as well as determine whether precipitation even reaches the soil surface. In this way, urban and suburban development and agricultural land management can substantially impact overland flow rates and, in turn, thermal pollution.

Soil types vary widely in their ability to hold and store water. The typical constituents of soil are sand, silt and clay. Coarser-grained sand will allow for the fastest infiltration rates while finer-grained clay content will greatly reduce water movement through the soil. Soil types vary both in lateral distribution of particle sizes as well as vertically in

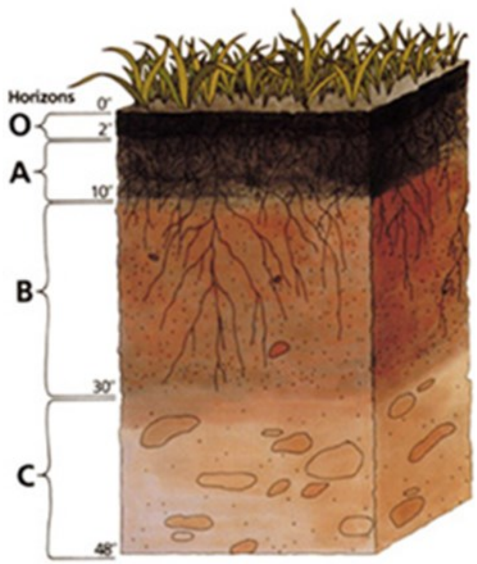

Figure 5: Soil horizons below the soil surface. O-horizon depth, organic matter content in A-horizons, rooting depth and clay content are all major factors influencing infiltration rates. (NRCS)

soil profile (**Figure 5**). Sites with deep well-drained soils will be less likely to encounter surface runoff directly flowing into the stream.

Land use management can greatly impact soil characteristics. Undisturbed, forest soils exhibit maximum water storage capacity and infiltration rates, due in large part to high levels of organic matter. This organic matter is contributed from yearly turnover of both tree leaves and roots. The organic-rich O-horizon in forest soils is substantially deeper than that of managed land. In a deciduous or mixed deciduous forest, a thick layer of leaves annually falls to the soil surface where it remains and decomposes into a mat of roots and organic material. Managed lawns and conventional agricultural systems typically remove annual organic matter contributions by raking leaves or harvesting crops. In order to make up for this loss, oftentimes fertilizers are applied to these lands, which increases root growth near soil surfaces rather than deeper in the soil profile. All of these factors can limit infiltration capacity of managed lawns and agricultural system. **Figure 6** shows differences in infiltration rates between various land types in the Spring Creek Watershed.

While both lawns/sod and asphalt surfaces are mostly impervious, asphalt can hold a great deal of thermal energy. Direct solar radiation transfers heat to paved sidewalks, roads and parking lots. When rain contacts these surfaces, heat is transferred from the paved surface

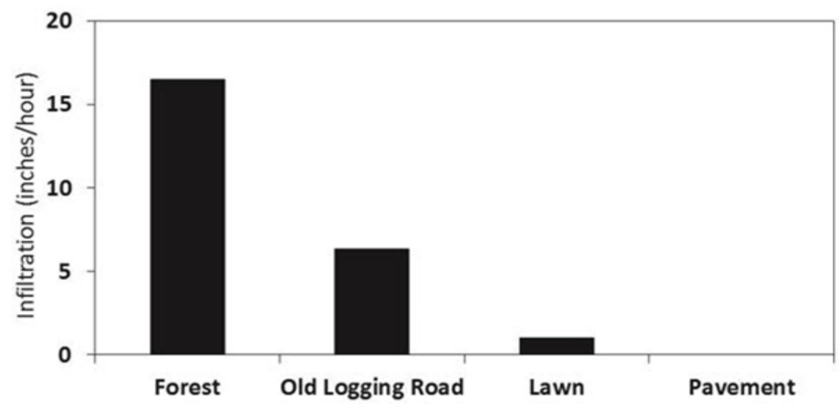

Figure 6: Infiltration rates determined with ring infiltrometers at various locations in State College, PA by students supervised by Brian Swystock in a Watershed Management Laboratory.

to the water. During summer months, experiments have shown rain can cool paved surfaces by up to 21.6°F while runoff from asphalt averages 9°F warmer than runoff from lawns or agricultural soils (Thompson et al., 2008). Because of this temperature difference, one of the largest non-point source contributors of thermal pollution in urban areas is runoff during summer storm events, particularly preceded by full or partial sun exposure (Herb et al., 2008).

Although overland flow originating from agricultural areas may be cooler than urban stormwater runoff, loss of riparian vegetation to increase crop production or grazing capacity can increase the direct solar radiation reaching the stream and, in turn, increase stream water temperature.

Shading from Riparian Cover

Riparian cover provides many functions for a healthy stream. In terms of stream temperature, riparian cover provides shade, a critical buffer to increases in stream temperature. Shade is extremely important in protecting streams from direct solar radiation. While air temperature has historically been considered a major influence on stream temperature, direct solar radiation has been proven to be the main factor in increasing stream temperature in smaller streams (Mayer, 2012). However; while shade can help prevent heating, there is little evidence that it can help cool stream water temperatures. Therefore, identifying areas that are most sensitive to direct solar radiation is the most effective strategy in utilizing riparian cover as a thermal buffering tool.

The potential for higher discharge rates and subsequent increased thermal capacity and stream velocity to reduce a stream's sensitivity to direct radiation and air temperature has been well documented (Webb at al., 2008; Hofmeister et al., 2015; Hannah & Garner, 2015). Regardless of groundwater contribution, larger streams in general are less sensitive to reduced riparian cover. However, groundwater contribution can both increase discharge rates and temperature buffering capacity through the addition of cooler water. Therefore, smaller tributary streams with more variable discharge rates and less groundwater contribution are more sensitive to both direct solar radiation as well air temperature fluctuations. Additionally, ponds and slower moving pools with little groundwater input are more likely to gain heat from solar radiation due to slower flow rates and extended exposure periods to the solar radiation.

Withdrawals and Inputs

In the Spring Creek watershed, there are several entities that use or manage water in their processes including fish hatcheries, waste water treatment plants, limestone mining operations, and public water suppliers.

Fish hatcheries are an important aspect of the Spring Creek watershed, even though no trout are stocked in the Spring Creek watershed. All fish hatcheries in the watershed are managed by the Pennsylvania Fish and Boat Commission. Fish hatcheries typically withdraw water from streams, groundwater wells or springs then release this water directly back into the stream. The withdrawals for fish hatcheries typically are not substantial enough to impact flow rates in a way that would alter sensitivity to temperature shifts. Pools and raceways used at fish hatcheries increase exposure time of water to direct solar radiation, so typical outflows from hatcheries are warmer than stream temperatures. However, discharge rates from the hatcheries are typically much smaller than that of the receiving stream (less than 5% of total flow), which reduces the potential for thermal pollution.

Wastewater treatment plants discharge lower volumes of water into Spring Creek than fish hatcheries, approximately 5% of the total flow of Spring Creek at Milesburg (Carline et al., 2011). The water received and discharged by wastewater treatment facilities is warmer than stream water because both businesses and homeowners heat some of the water they use. Both wastewater treatment plants and fish hatcheries are designed to treat chemical rather than thermal pollution, so water released from these facilities is typically warmer than stream temperature. If the receiving stream is large enough or maintains significant groundwater contribution, these discharges should not significantly impact thermal regimes. Direct discharges into streams also increase stream flow rates, which can decrease a stream’s sensitivity to atmospheric temperature changes. Therefore, the potential thermal impact or benefit of discharging water into stream reaches can be quite complex.

Limestone mining is another industry that can impact stream temperatures. Quarries excavate bedrock and must dewater and release any groundwater held in that bedrock back into the stream. This discharge water is similar in temperature to groundwater and can act as a buffering agent to atmospheric air temperature fluctuations.

Public water suppliers in the Spring Creek watershed withdraw the majority of the public water supply from groundwater or springs rather than streams. The primary potential impact of this withdrawal is the reduction of baseflow contribution from groundwater. Reducing groundwater contribution could impact stream temperatures by reducing cooler base flow rates and thermal capacity of streams.

Conclusion

Stream temperature is not only critical to many ecological and biochemical stream processes but is also affected by numerous physical, atmospheric and anthropogenic factors. Understanding the interplay of these factors can help prioritize stream and land management practices, particularly in the context of continued future growth and potential changes in local climate. The following sections of the report outline background information on the WRMP, a comparison of 2016 and 2017 stream temperature data and greater detail on all of the potential factors influencing spatial and temporal temperature differences observed within the Spring Creek watershed.

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 1** 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 fifteen 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 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, and the assistance of volunteers. A number of local partners continued to provide funding to carry out WRMP data collection. Donors in support of the 2016 and 2017 effort included:

- Bellefonte Borough
- Benner Township
- College Township
- Ferguson Township
- Graymont, Inc.
- Halfmoon Township
- Harris Township
- Patton Township
- Pennsylvania State University Office of Physical Plant
- Spring Township
- Spring Township Water Authority
- State College Borough

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Table 1. Active Water Resources Monitoring Committee Members in 2016 and 2017.

WRMP Committee Member	Affiliation
David Yoxtheimer, P.G. **Committee Chair** Extension Associate	Marcellus Center for Outreach and Research, The Pennsylvania State University
Elizabeth Boyer, Ph.D. Associate Professor of Water Resources	Department of Ecosystem Science and Management, The Pennsylvania State University
Robert Carline, Ph.D. Aquatic Ecologist	Pennsylvania Cooperative Fish and Wildlife Research Unit, USGS-retired
Ann Donovan / Justin Kozac Watershed Specialist	Centre County Conservation District
Larry Fennessey, Ph.D., P.E. Utility Systems Engineer - Stormwater	Office of Physical Plant, The Pennsylvania State University
Chris Finton, P.G. Senior Hydrogeologist	ARM Group Inc.
Lexie Orr Water Resources Specialist	ClearWater Conservancy
Todd Giddings, Ph.D., P.G. Hydrogeologist	Todd Giddings and Associates, Inc.
Peggy Johnson, Ph.D. Professor of Civil Engineering	Department of Civil and Environmental Engineering, The Pennsylvania State University
Mark Ralston, P.G. Hydrogeologist	Citizen Volunteer
Hannah Stout, Ph.D. Aquatic Entomologist	Citizen Volunteer
Robert Vierck Communications Specialist	Citizen Volunteer
Rick Wardrop, P.G. Hydrogeologist	Groundwater & Environmental Services, Inc.

- 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 2016 and 2017:

- PA Department of Conservation of Natural Resources (PADCNR)
- 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 six sites along the main stem of Spring Creek and 16 tributary sites located throughout the stream's five major sub-basins (**Figure 7**). Twelve of the twenty-two 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. Three additional sites were added in 2008 in the Walnut Springs sub-basin in State College Borough to monitor stormwater impacts. The last four site additions were added in 2015 to monitor temperature impacts. Two sites are located on Slab Cabin Run and two are located on the main stem of Spring Creek between State College and Houserville.

Groundwater Monitoring Stations

The WRMP monitored water levels at three wells in 2016 and 2017 (**Figure 8**). 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 8**). 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 8**). 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.

Table 2 outlines all stream, spring and groundwater monitoring stations. Spring and stream stations have a three letter abbreviation to indicate location within the watershed. The first two letters of the abbreviation are the first two letters of the stream or tributary, with the third letter referencing the location. For example, the Upper Spring Creek monitoring station is abbreviated to SPU. As locations and abbreviations will be used throughout the report, please reference the maps in **Figures 7 and 8** and **Table 2** as needed.

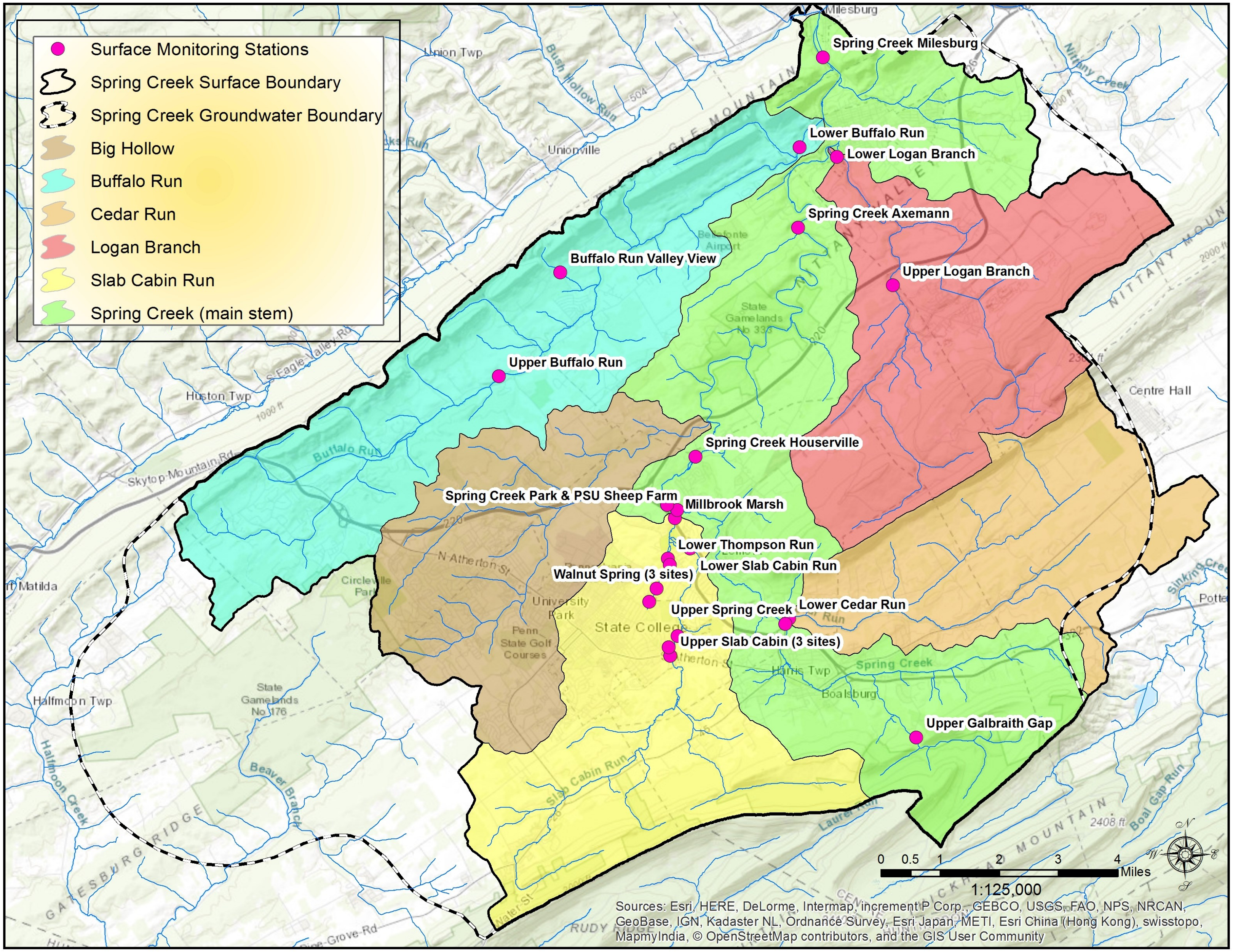

Figure 7. Stream sampling sites surveyed in 2016 and 2017 as part of the Water Resources Monitoring Project and USGS stream gages.

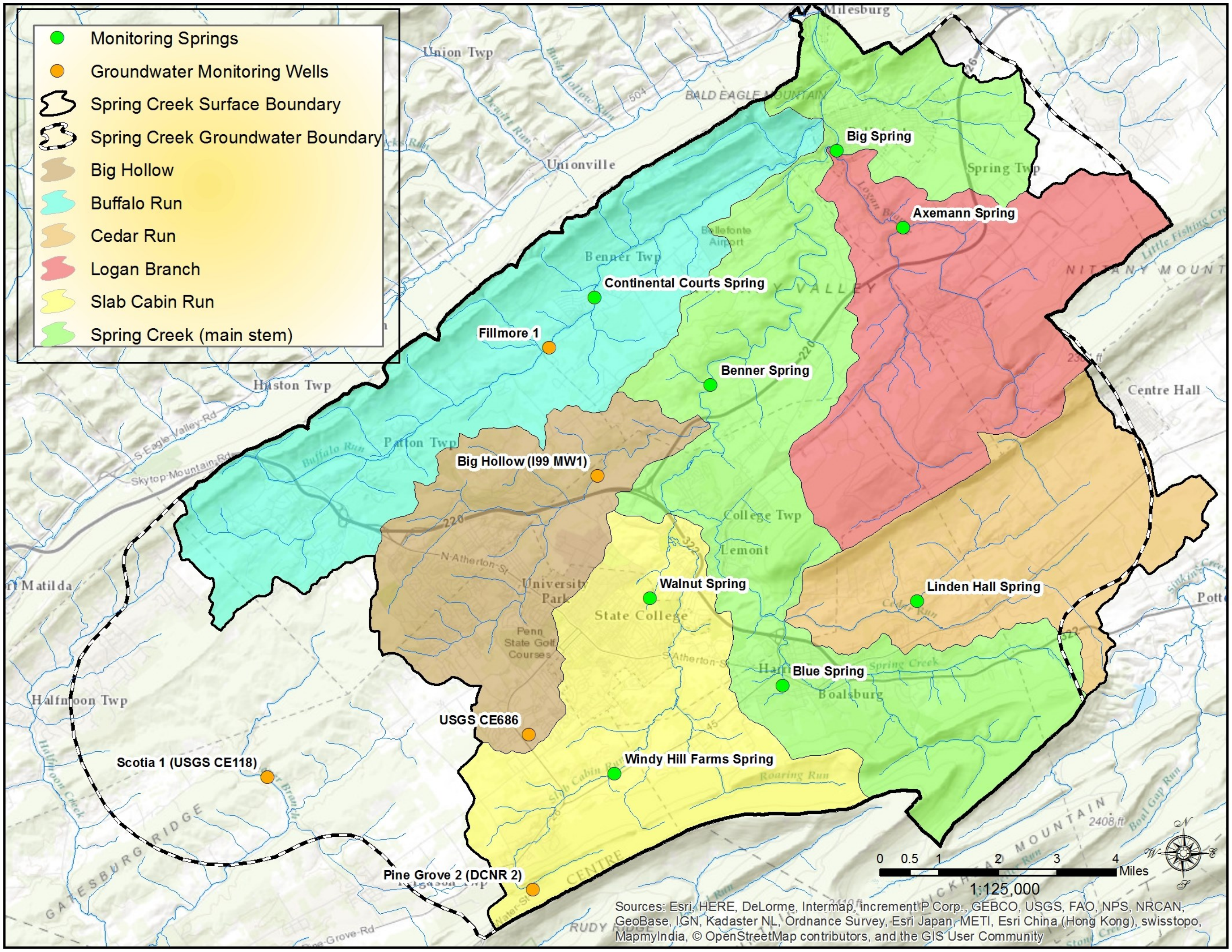

Figure 8. Groundwater and spring stations surveyed in 2016 and 2017 as part of the Water Resources Monitoring Project and USGS groundwater monitoring wells.

Table 2. WRMP monitoring stations with site abbreviation, type of monitoring and years monitored.

Site Type	Site Name	Site Abbreviation	Monitoring Type	Current Data Collection Interval	Period of Record
Stream	Lower Buffalo Run	BUL	Discharge	30 min	1999 - present
			Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Upper Buffalo Run	BUU	Discharge	30 min	1999 - present
			Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Buffalo Run at Valley View	BUV	Baseflow water quality	quarterly	2007 - present
	Lower Cedar Run	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
	Lower Logan Branch	LOL	Discharge	30 min	1999 - present
			Water temperature	1 hr	2000 - present
			Baseflow water quality	quarterly	2007 - present
	Upper Logan Branch	LOU	Discharge	30 min	1999 - present
			Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Slab Cabin Run at Millbrook Marsh	SLM	Discharge	30 min	2005 - 2006 ; 2009 - present
			Water temperature	1 hr	2008 - present
			Baseflow water quality	quarterly	2007 - present
	Lower Slab Cabin Run	SLL	Discharge	30 min	1999 - present
			Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Upper Slab Cabin Run	SLU	Discharge	30 min	1998 - present
			Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Slab Cabin Run at Super 8	SL8	Water temperature	1 hr	2013 - present

Table 2. (continued)

Site Type	Site Name	Site Abbreviation	Monitoring Type	Current Data Collection Interval	Period of Record
Stream	Slab Cabin Run at Kissinger Meadow	SLC	Water temperature	1 hr	2013 - present
	Upper Spring Creek	SPU	Discharge	30 min	1998 - present
			Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Spring Creek at Axemann	SPA	Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Spring Creek at Houserville	SPH	Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Spring Creek at Milesburg	SPM	Water temperature	1 hr	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Spring Creek at Spring Creek Park	SPP	Water temperature	1 hr	2013 - present
	Spring Creek at PSU Sheep Farm	SPS	Water temperature	1 hr	2013 - present
	Lower Thompson Run	THL	Discharge	5 min	1999 - present
			Water temperature	5 min	1999 - present
			Baseflow water quality	quarterly	2007 - present
	Walnut Springs Middle	WAM	Discharge	5 min	2008 - present
			Water temperature	5 min	2012 - present
	Lower Walnut Springs	WAL	Discharge	5 min	2008 - present
	Upper Walnut Springs	WAU	Discharge	5 min	2008 - 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

Water Quality Monitoring

WRMP staff and volunteers collected water samples from fifteen stream sites and eight springs in 2016 and 2017. Sampling took place in April, August, October, and December in 2016 and February, May and November in 2017 when streams were at baseflow conditions. The water samples were analyzed for chemical and nutrient content by the PADEP Analytical Laboratories. Coliform analyses of spring samples were conducted by the University Area Joint Authority laboratory. **Appendices 2** and **3** summarize the results of the 2016 and 2017 combined water quality analysis.

Continuous Measurements

Thirteen stream stations were equipped with instruments to continuously monitor stream stage. Stream stage stations 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 transducers 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.

<u>Stream Temperature</u>

Water temperature was measured hourly at eighteen 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 2016 and 2017 are presented in **Appendix 5**. **Appendices 7, 8 and 9** summarize average daily, monthly and yearly stream temperatures for the entire period of record for all monitoring stations.

<u>Groundwater Elevation</u>

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 6** summarizes the groundwater elevation data for 2016 and 2017.

Discharge Rates

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 9**). 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 or when streams flow outside of the streambank. Estimated discharges are indicated by the use of dashed lines in the graphs of WRMP discharge data.

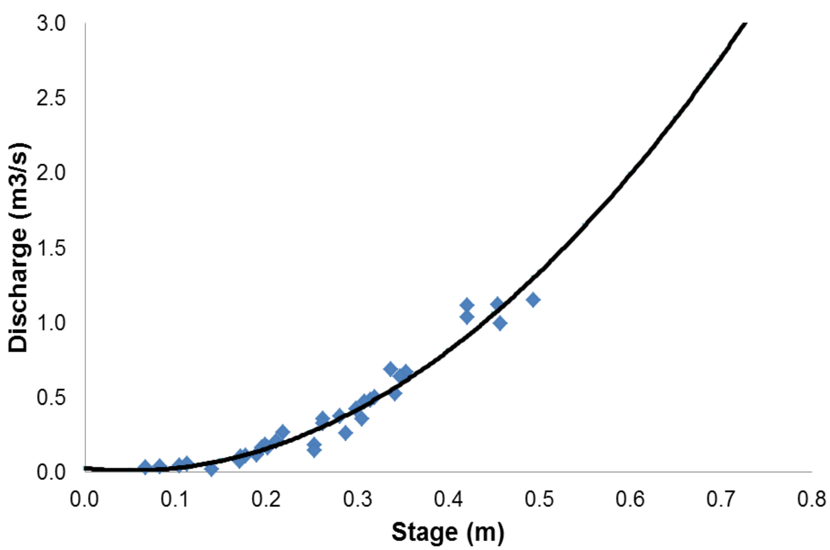

Figure 9. Stage-discharge relationship for WRMP site on Slab Cabin Run at East College Avenue.

Figure 10. The WRMP rating curve transect location at Lower Buffalo Run.

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 members of the Water Resources Monitoring Committee periodically review the rating curves and revise them as needed.

The data for the USGS-operated stream gages were 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 4** summarizes the stream discharge data for 2016 and 2017.

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 may be found in the Spring Creek Watershed Water Resources Monitoring Protocol. To review this document, please contact the Water Resources Specialist at ClearWater Conservancy at (814) 237-0400.

In addition to periodic review of rating curves, the Water Resources Specialist and the WRMC also review 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 and operational costs have decreased.

COMPARING DRY AND AVERAGE YEARS: 2016 AND 2017 IN THE SPRING CREEK WATERSHED

Air Temperature and Precipitation

2016 was generally drier and warmer than 2017. **Figure 11** outlines precipitation throughout both years. In total, the watershed received 36.89 inches of rain in 2016 and 42.13 inches in 2017. **Figure 12** outlines air temperature for both years. The average air temperature for 2016 and 2017 was 52.3 ± 0.6°F and 51.9 ± 0.6°F respectively.

During the warmest months of the year when evapotranspiration rates and solar radiation are at their highest, precipitation and subsequent stream discharge rates as well as peak temperatures are critical factors influencing stream temperature. During the summer months (June-August), 2016 had an average air temperature of 72.6 ± 0.5°F and total rainfall of 10.1 inches while 2017 had an average air temperature of 69.49 ± 0.5° F and total rainfall of 11.32 inches. During these critical months, 2016 received less precipitation and had higher air temperatures than 2017.

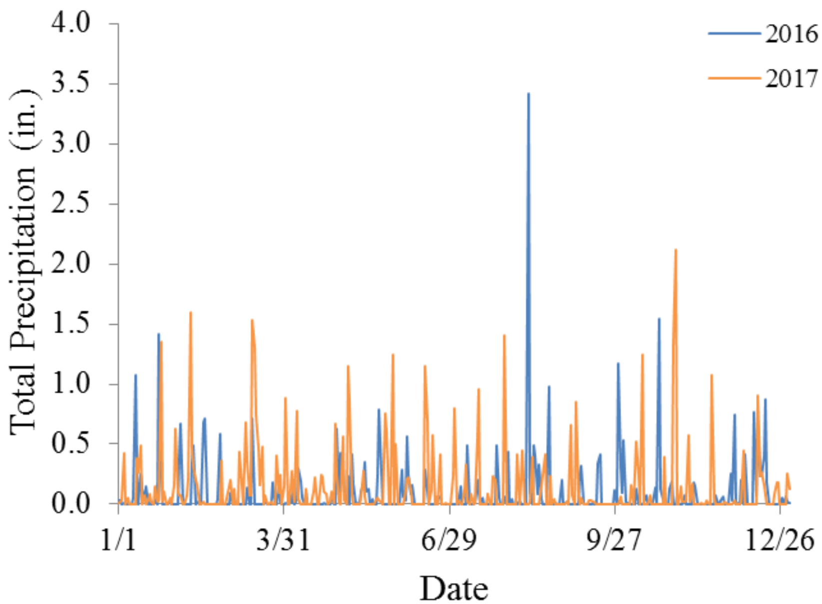

Figure 11: Total daily precipitation in 2016 and 2017. Snowfall was converted to rain equivalent using a 1/13 ratio. Source: Bill Syrett, PSU Walker Building

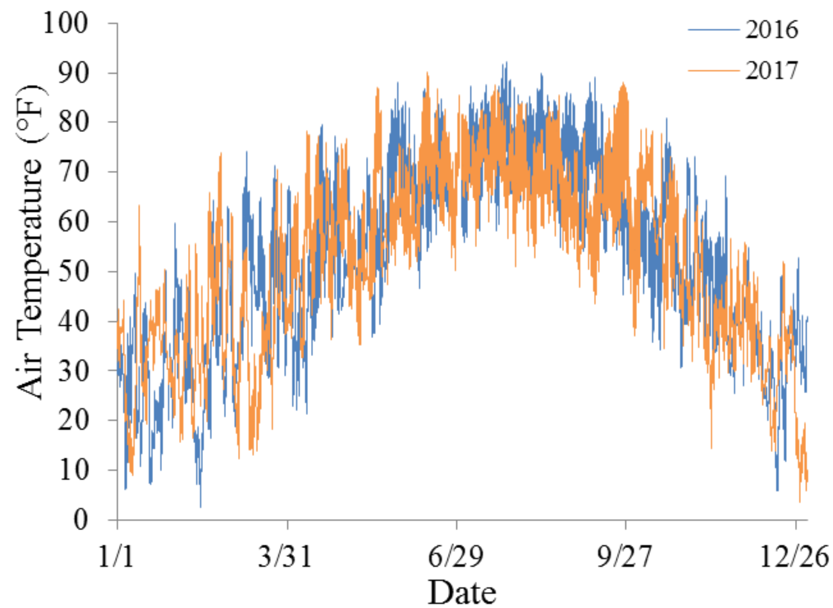

Figure 12: Air temperature in 2016 and 2017 taken at 5 minute intervals. Source: Bill Syrett, PSU Walker Building

Stream Temperature

In 2016, the WRMP's surface water monitoring stations recorded winter stream temperatures ranging from near freezing to 48°F and summer temperatures between 55°F and 76°F. In 2017, the winter temperature ranges were similar to 2016, but average daily stream temperatures in the summer rarely exceeded 68°F. **Figure 13** compares the annual average stream temperatures at surface monitoring stations for both 2016 and 2017. (Asterisks indicate stations with missing data.) Average stream temperatures tended to be lower in 2017 compared to 2016. Sites in smaller tributaries with more variable discharge rates tended to have larger differences between the two years. On the other hand, sites with larger discharge rates and greater groundwater contribution from springs (LOL, LOU and SPU) did not show any difference in average stream temperature between years.

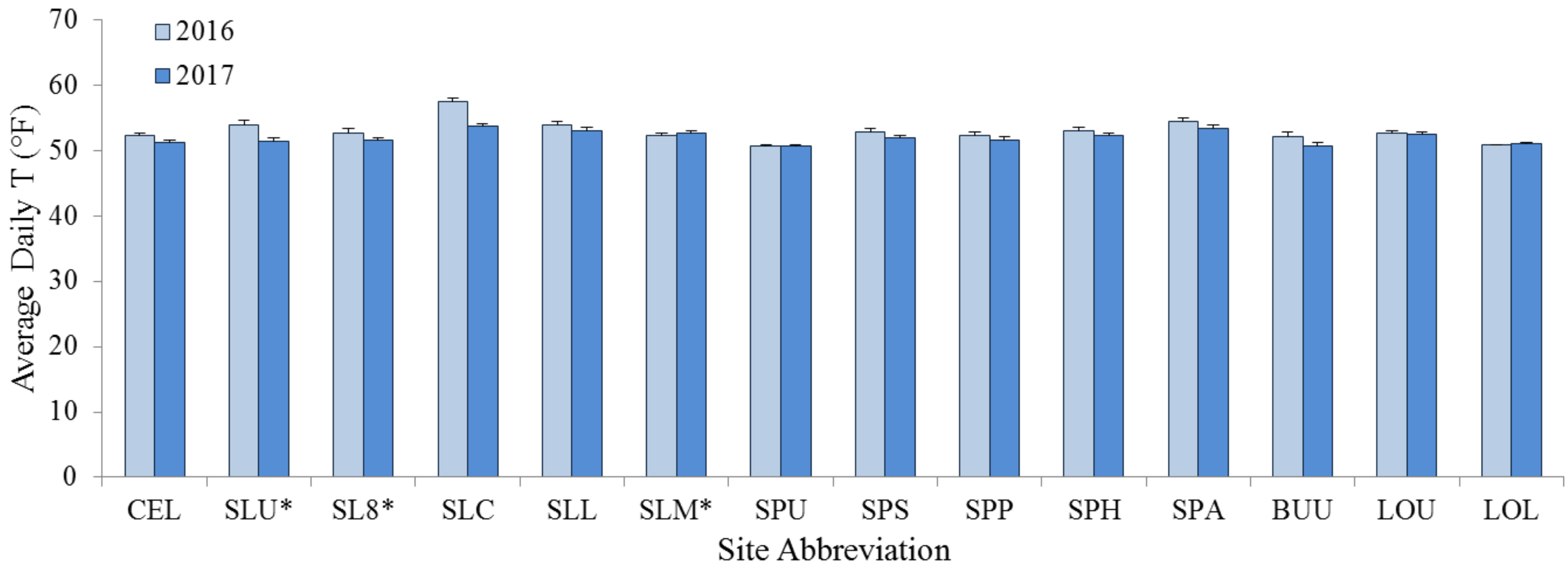

Figure 13: Yearly average daily stream temperature for 2016 and 2017. Error bars represent standard error with n equal to number of days. Full site names can be found in Table 2 on pages 15 and 16.
*SLU, SL8 and SLM were all missing data between late August and early October of 2016.

COMPARING DRY AND AVERAGE YEARS: 2016 AND 2017 IN THE SPRING CREEK WATERSHED

Table 3 compares the percentage of days above the lethal threshold (75.2°F) and stress threshold (68°F) for brown trout. 2016 had substantially more days above both the lethal and stress thresholds. Slab Cabin Run, before it meets other tributaries within the watershed, had the highest percentage of days above both thresholds. While Slab Cabin Run at Kissinger Meadow had the highest recorded percentage of days in 2016, it is important to note that data was unable to be collected between late August and October at both the Super 8 (SL8) and Upper Slab Cabin Run (SLU) locations, upstream of Kissinger Meadow, due to a lack of stream flow.

Table 3: Percent of days above the brown trout stress (68°F) and lethal (75.2°F) temperature thresholds. *Multiple days are missing from the SLM, SL8 and SLU datasets between August and October, so these numbers are likely lower than actual percentages. Loggers at SL8 and SLU were exposed to air temperatures due to low stream flow during this period.

	Days above Trout Stress Threshold (%)		Days above Trout Lethal Threshold (%)	
Site Abb.	**2016**	**2017**	**2016**	**2017**
CEL	12.9	1.4	0.0	0.0
SLU	27.0*	2.7	10.9*	0.0
SL8	29.7*	12.6	16.7*	1.1
SLC	38.1	12.1	16.7	0.3
SLL	28.5	19.5	1.1	0.0
SLM	0.0*	4.9	0.0*	0.0
SPU	0.0	0.0	0.0	0.0
SPP	9.6	0.0	0.0	0.0
SPS	0.0*	0.3	7.1	0.0
SPH	9.6	1.1	0.0	0.0
SPA	26.3	10.7	1.9	0.0
BUU	22.4	4.7*	3.0	0.0*
BUL	19.7	0.0	0.3	0.0
LOU	0.3	0.0	0.0	0.0
LOL	0.0	0.0	0.0	0.0

Stream Discharge Rates

Variability in discharge rates and groundwater contribution can greatly impact the sensitivity of a stream reach to high air temperatures and direct solar radiation. **Figure 14** displays the average discharge for each of the monitoring stations for 2016 and 2017. Unlike average stream temperatures, discharge rates vary quite dramatically between monitoring stations, which is a reflection in varying stream size. Again, similar differences were discovered across most sites with 2017 having higher average daily discharge rates than 2016 due to higher amounts of precipitation and higher groundwater levels throughout the year. However, the discharge rates of the Upper Spring Creek monitoring station in Oak Hall (SPU) and the Lower Logan Branch (LOL) monitoring station in Bellefonte showed very little if any variation between 2016 and 2017. Both of these sections of stream have very deep pools, significant groundwater contribution, and, therefore, large

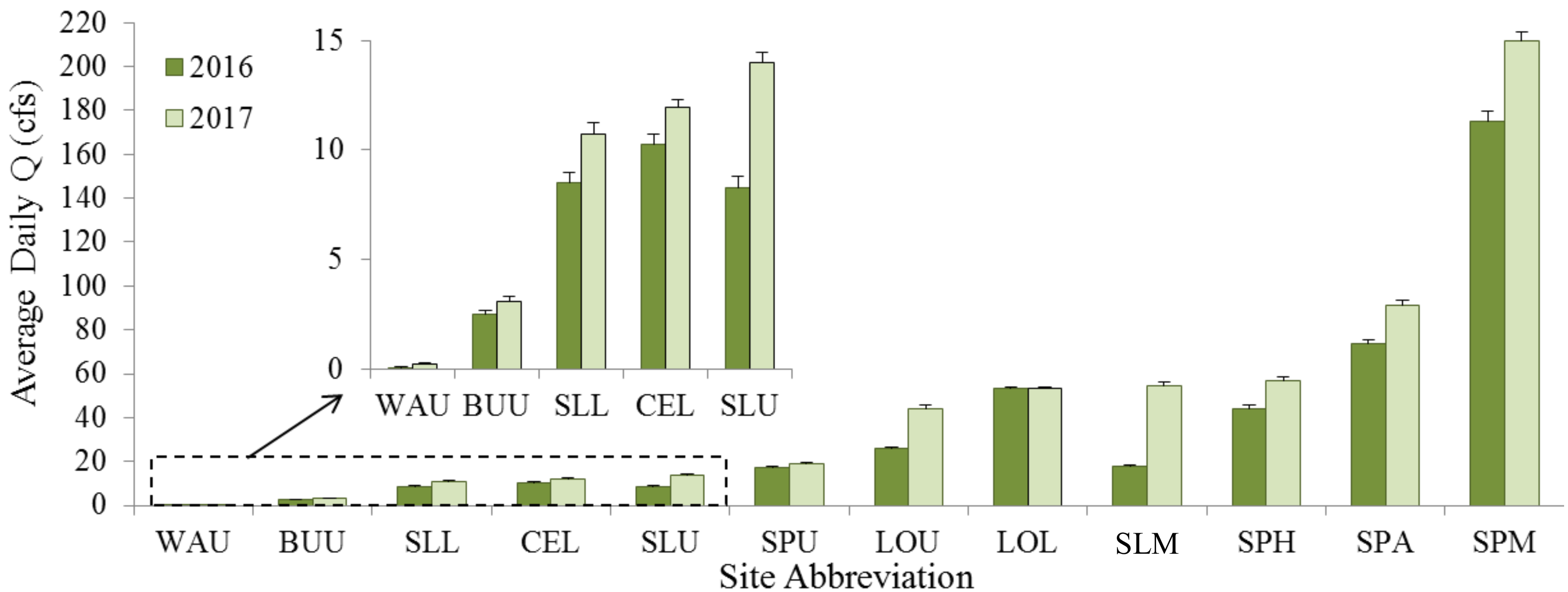

Figure 14: Yearly average daily discharge (Q) at surface water monitoring stations for 2016 and 2017. Full site names and locations can be found in Table 2 on pages 15 and 16.

thermal capacities which mitigated the impact of hot summer air.

Smaller tributaries with more variable discharge rates are more sensitive to high air temperatures. Therefore, the relationship between discharge rates of these streams and stream temperature will be most important during dry, hot periods. Multiple regression analysis of average daily discharge, average daily air temperature and average daily stream temperature using data from all sites revealed a strong positive correlation between air and stream temperature, but no significant relationship between discharge and stream temperature. However, when site location was added as an additional factor, discharge was significantly negatively correlated with average daily stream temperatures in 2016 with air temperature accounting for nearly 80% of the variation and discharge only accounting for 7% in 2017. There was no statistically significant relationship between average daily stream temperature and discharge for any of the sites. This highlights that as discharge rates become more variable, they also become more important to buffering against high air temperatures.

Figure 15 (on the following page) compares the relationship between average daily discharge and average daily temperature during the summer months (June-August) of 2016 and 2017 for Upper Slab Cabin Run (SLU), a site known for its variability in discharge rates, and Lower Logan Branch (LOL), a site with very consistent discharge rates. Summer stream temperatures at Upper Slab Cabin Run correlated very strongly with discharge rates (r^2=0.77) in 2016 but had no correlation in 2017. Other stations on smaller tributaries with variable discharge rates such as Lower Slab Cabin Run, Lower Cedar Run and Upper Buffalo Run showed similar trends. These results highlight how higher discharge rates can reduce the sensitivity of a stream section to hot summer air temperatures.

Lower Logan Branch exhibited no relationship between summer stream temperature and discharge in either year. The same results were true for the upper Logan Branch and all main stem Spring Creek monitoring stations, which highlights that the temperature of larger streams is less sensitive to atmospheric conditions than that of smaller tributary streams. In the Spring Creek watershed, a great deal of this increased discharge in the main stem and

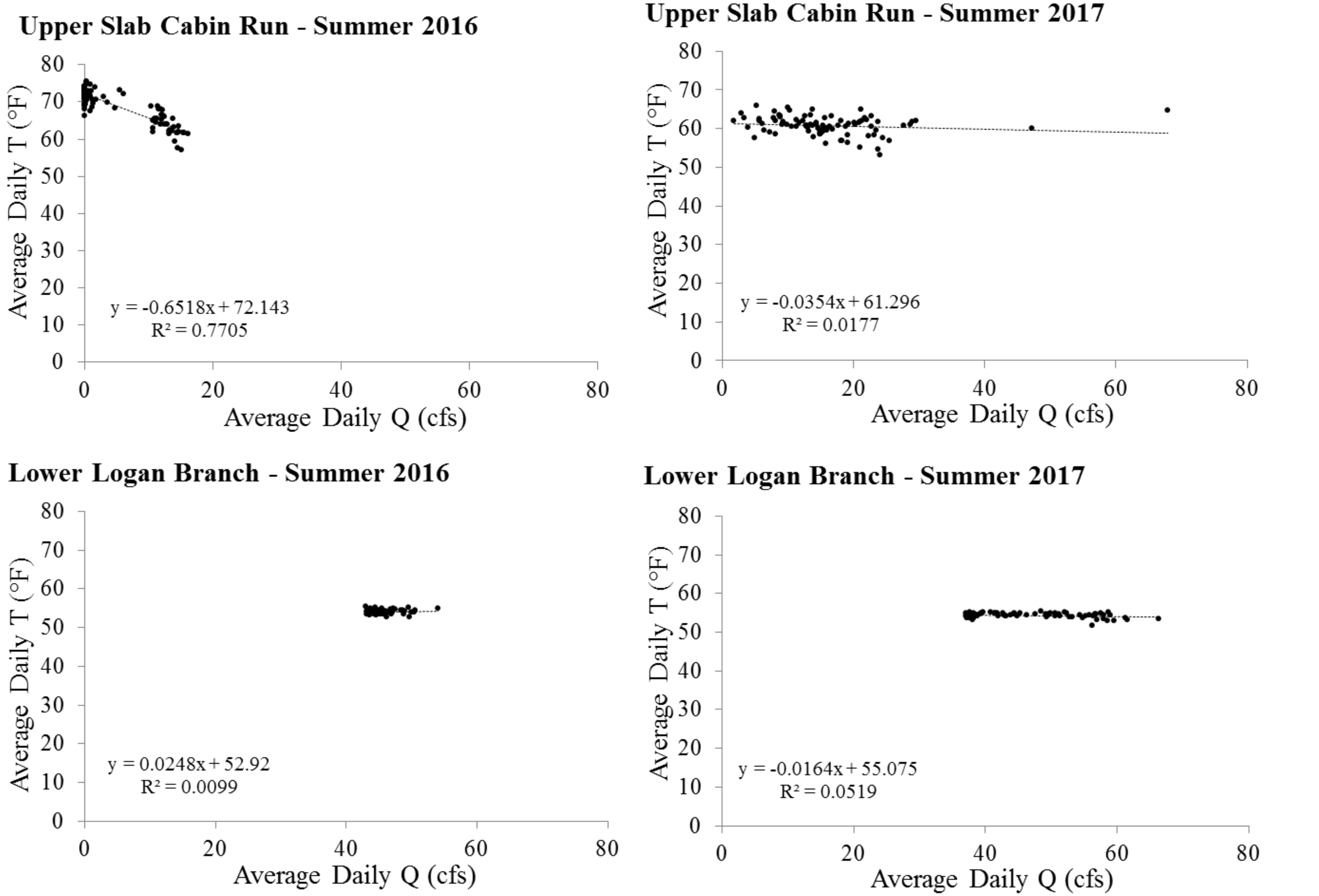

Figure 15: Average daily discharge (Q) vs. average daily temperature (T) at the Upper Slab Cabin Run (SLU) and Lower Logan Branch (LOL) monitoring stations for 2016 and 2017.

Logan Branch tributary can be attributed to higher contributions of groundwater to baseflow.

Springs and Groundwater Contribution

According to the Centre Region Planning Agency, in 2014 26 percent of the Spring Creek Watershed was developed land yet trout populations remain stable. In fact, trout populations generally decline when urban development reaches 6 percent and cannot persist at levels greater than 11 percent (Wang et al., 2003). Approximately 85 percent of Spring Creek's total annual discharge consists of groundwater baseflow (Giddings, 1974). This high percentage of groundwater is the most important factor in reducing the stream's sensitivity to anthropogenic and climatic factors that might raise its water temperature. However, hydrogeologic factors such as depth to groundwater and effective porosity create nonuniform spatial patterns of groundwater inflows into the streams. Some tributaries as well as reaches within the main stem receive much more groundwater than others.

The Spring Creek watershed is located in a karst physiographic region that has abundant seeps and springs. There are at least seven large springs in the watershed that contribute 1.41 cfs of outflow directly into streams (Carline et al., 2011). In addition to large springs, numerous sink holes in the watershed allow surface water to directly enter the aquifer where it can be cooled.

Big Spring, the second largest spring in Pennsylvania, discharges groundwater into Spring Creek at a rate of 29 cfs, which is equivalent to 19 million gallons of water each day. A unique characteristic of this spring is that it originates within the adjoining Spruce Creek Watershed. Due to a geologic fault, the groundwater watershed area of Spring Creek is approximately 23% larger than the surface-water watershed (Giddings, 1974). This means that groundwater beneath the surface-water watershed of Spruce Creek is actually contributing to Spring Creek, particularly through Big Spring.

Thompson Spring (11.27 cfs) and Benner Spring (16.26 cfs) are two other major sources of groundwater contribution to the Spring Creek watershed. **Figure 16** shows the location of 16 known springs in the watershed (including the eight monitored by the WRMP) and all

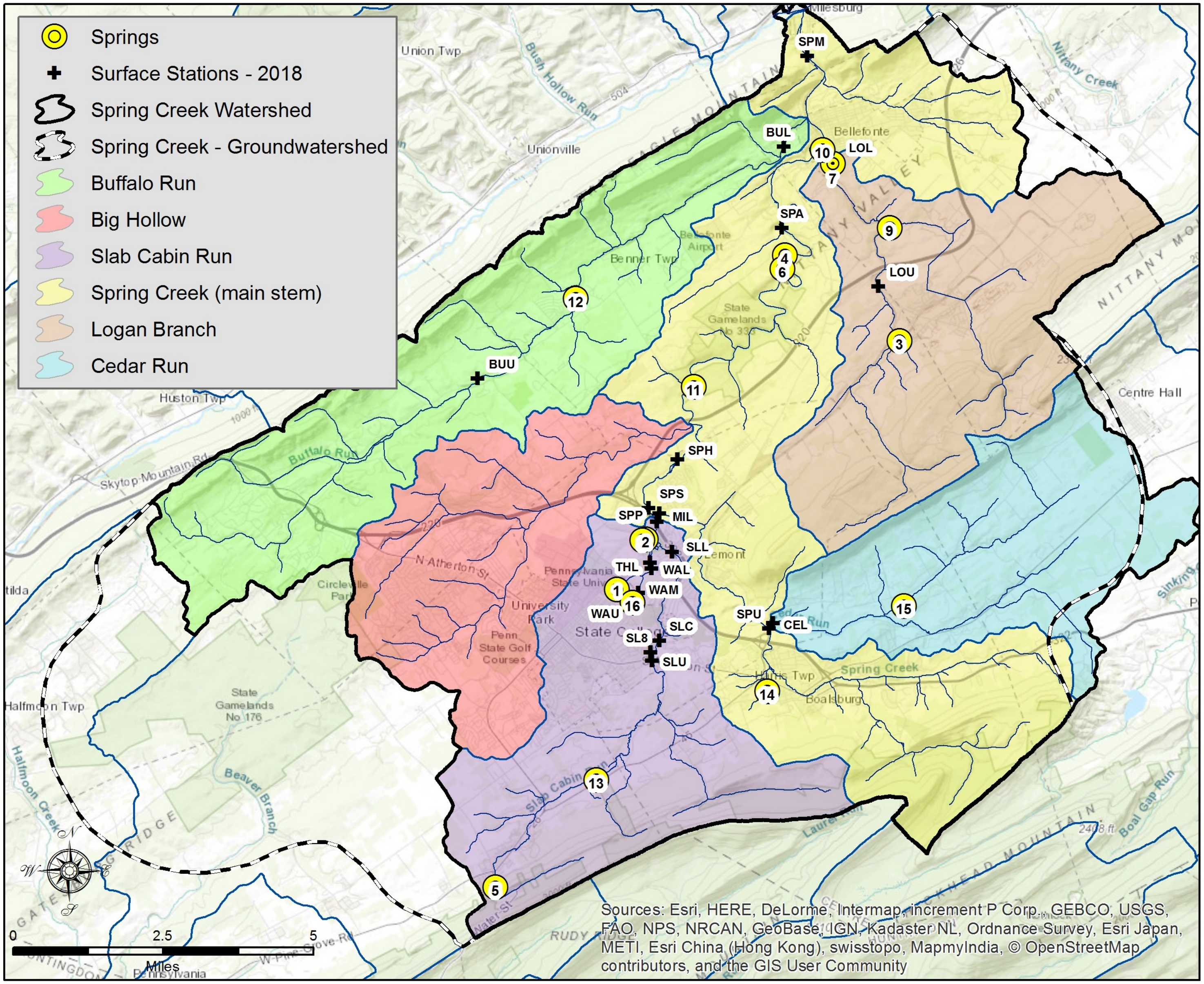

Figure 16. WRMP surface water temperature monitoring stations and large springs within in the Spring Creek watershed. Surface water stations are labeled using their site abbreviation (Table 2 on pages 15 and 16). Information on Springs

Table 4: Large springs within the Spring Creek watershed and average temperature (T), discharge (Q) and distance upstream of WRMP monitoring stations. Data Sources: Thompson Spring temperature (PSU); All other tempertuare data (WRMP Baseflow Data); Discharge (Saad & Hippe, 1990; Fulton et al. 2005)

ID Number	NAME	WRMP Site Abbreviation	Average T (°F)	Average Q (cfs)	Monitoring Stations within 5 km	Monitoring Stations within 10 km	Monitoring Stations within 15 km
1	Thompson Spring	-	51.06	11.27	THL, SLM, SPS, SPP, SPS		
2	O.H. Bathgate Spring	-	-	2.98	MIL, SPS, SPH		
3	Blue (Shutgart) Spring	-	-	21.56	LOU		LOL, SPM
4	NA	-	-	16.84	SPA	SPM	
5	NA	-	-	0.67			SLU, SL8, SLC, SLL
6	Forked Spring or Paradise Spring	-	-	8.76	SPA		SPM
7	Kelly Spring	-	-	15.6	LOL		SPM
8	John Bathgate Spring	-	-	-			
9	Axemann Spring	AXS	51.42 ± 0.04	4.52	LOL	SPM	
10	Big Spring	BIS	50.36 ± 0.21	29	SPM		
11	Benner Spring	BES	50.54 ± 0.34	16.26			SPA
12	Continental Courts Spring	COS	50.60 ± 0.24	-		BUL	SPM
13	Windy Hill Farms Spring	WIS	50.61 ± 0.46	-		SLU, SL8, SLC, SLL	SLM, SPH
14	Blue Spring	BLS	50.36 ± 0.21	-	SPU	SPP, SPS	SPH
15	Linden Hall Spring	LIS	49.90 ± 0.10	-	CEL	SPP	SPH, SPS
16	Walnut Spring	WAS	51.04 ± 0.41	-	SLM, THL, WAM, SPP, SPS	SPH	

WRMP surface water monitoring stations. **Table 4** outlines available temperature and discharge data for these springs in addition to their proximity to WRMP stream temperature monitoring stations. There are additional unmonitored springs within the watershed including several large springs before the confluence of Spring Creek and Cedar Run near the Upper Spring Creek (SPU) monitoring station. Stream temperature monitoring stations within close proximity (<5km downstream) to the largest springs include Lower Logan Branch (LOL), Upper Spring Creek (SPU) and Spring Creek at Milesburg (SPM).

Figure 17 compares the daily average temperature during 2016 and 2017 of Lower Logan Branch with that of Lower Slab Cabin Run, a smaller tributary with little groundwater contribution to its baseflow. Daily temperatures for Lower Logan Branch remain close to groundwater temperature while the daily temperatures of Lower Slab Cabin Run

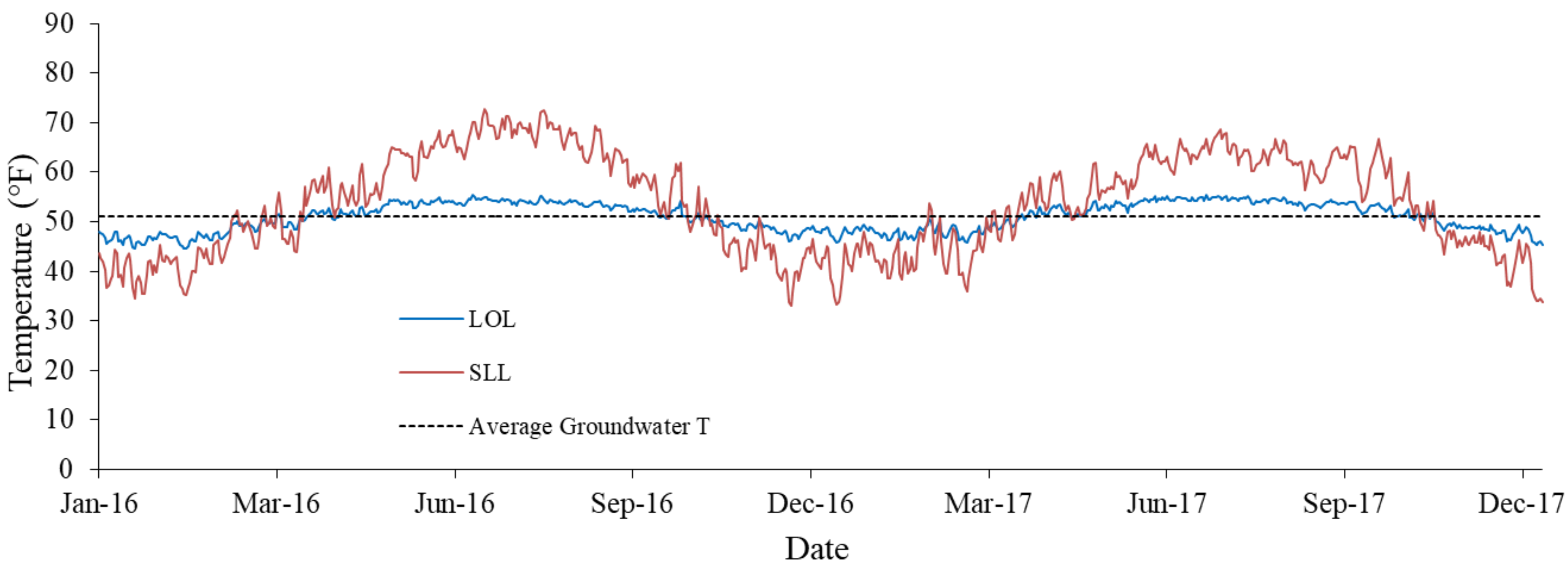

Figure 17. Comparison of daily average temperature (T) of 2016 and 2017 for Lower Logan Branch (LOL), a monitoring station that receives a large amount of groundwater contribution to its baseflow, and Lower Slab Cabin Run (SLL), a monitoring station that received little groundwater contribution. The daily average temperature of LOL deviates little from average groundwater temperature (51.5°F).

exhibit a much wider range. Additionally, the temperature range within the Lower Logan Branch remained steady between 2016 and 2017, while the range of temperature in Lower Slab Cabin Run was larger in 2016 than 2017. These results again indicate that groundwater contribution can greatly reduce the sensitivity of stream temperatures to environmental factors.

Land Cover

Figure 19 (on the following page) is a map of land cover in the Spring Creek Watershed with median temperature from 2016 at each continuous temperature monitoring station. The 2016 Chesapeake Conservancy's 1mx1m LiDAR land cover dataset was used to calculate land cover composition of both the entire drainage basin as well as local contributing area of each temperature monitoring station (**Table 5**). Local contributing area was defined as the area of land that drains water directly within 100 meters of the monitoring station.

Monitoring stations with the highest levels of impervious surfaces within the entire drainage basin were Lower Thompson Run (THL) and Walnut Springs (WAM) with 32.5% and 31.9% impervious cover, respectively. However, stations with the highest levels of impervious surfaces within the local contributing area were Lower Logan Branch (LOL) with 35% percent impervious cover and Upper Slab Cabin Run with 33.8% impervious cover.

Figure 18 shows the high levels of impervious cover near the Upper Slab Cabin Run monitoring station. Impervious cover will most likely impact stream temperatures temporarily through runoff after summer storm events.

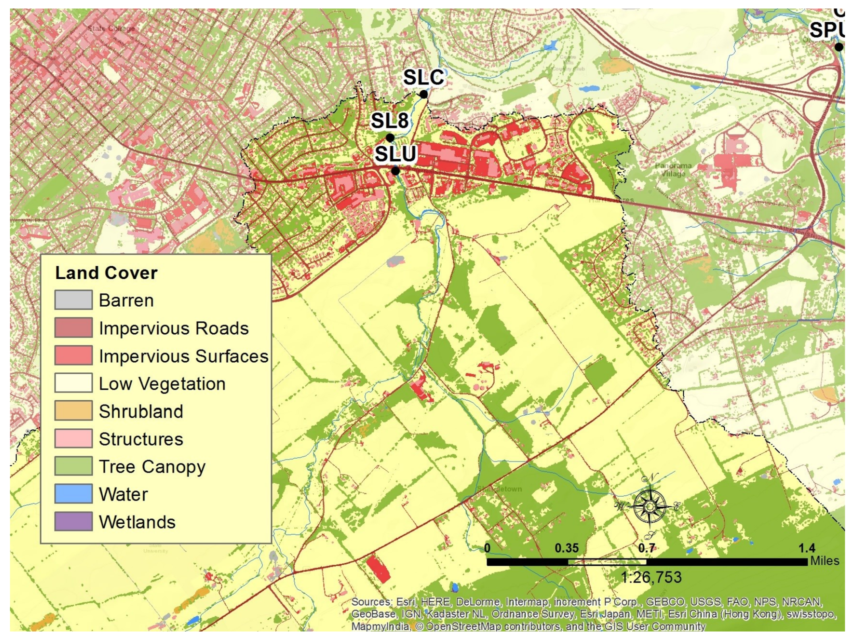

Figure 18: Land cover within the lower section of the Slab Cabin Run at Kissinger Meadow sub-basin.

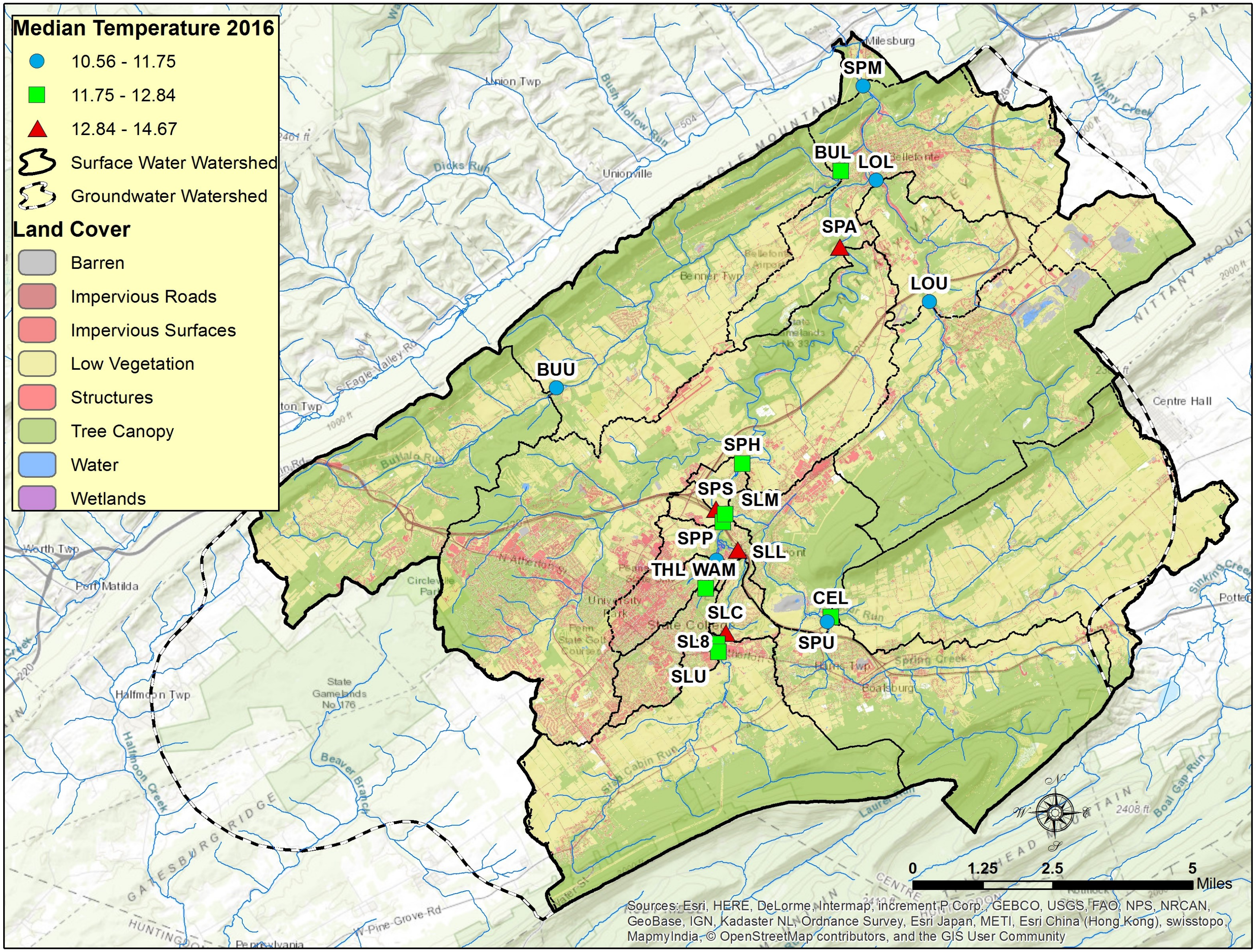

Figure 19: Land cover in the Spring Creek Watershed with all continuous surface temperature monitoring locations with median 2016 temperature ranges. (Land Cover Source: Chesapeake Bay Conservancy)

Table 5: Land cover composition of the drainage basin and locally contributing area (area that drains directly within 100m of the monitoring station) for WRMP surface water monitoring stations. Data source: Chesapeake Conservancy

	Water (%)		Wetlands (%)		Tree Canopy (%)		Low Vegetation and Shrubs (%)		Impervious (%)	
Site Abbrebiation	Locally Contributing	Entire Basin	Locally Contributing	Entire Basin	Locally Contributing	Entire Basin	Locally Contributing	Entire Basin	Locally Contributing	Entire Basin
CEL	0.0	0.6	0.0	0.0	54.1	32.4	44.3	62.3	1.5	4.4
SLU	0.1	0.1	0.0	0.0	32.7	52.4	33.4	43.4	33.8	3.9
SL8	0.7	0.1	0.0	0.0	42.6	51.8	35.6	43.1	21.0	4.8
SLC	1.2	0.1	0.0	0.0	26.3	43.6	48.9	51.2	23.6	4.7
SLL		0.1		0.0		40.2		47.1		12.3
SLM*	0.0	0.1	2.6	0.1	30.5	38.9	48.7	48.2	18.2	12.3
SPU	3.6	0.0	0.0	0.4	45.7	86.1	46.1	12.3	4.6	1.1
SPP	0.2	0.4	0.0	0.2	40.3	54.8	47.4	40.1	12.1	4.1
SPS	0.7	0.3	0.0	0.1	8.1	48.7	87.5	43.3	3.7	7.2
SPH	0.7	0.3	5.4	0.2	44.1	48.5	38.5	43.4	11.4	7.3
SPA	0.1	0.3	0.0	0.1	40.0	46.5	58.3	44.7	1.6	8.0
SPM	5.4	0.6	0.0	0.1	78.4	85.5	12.3	1.5	3.9	11.1
WAM	0.0	0.0	0.0	0.0	80.9	25.3	10.6	42.4	8.6	31.9
THL	0.0	0.1	0.0	0.0	30.7	27.2	48.8	39.9	20.5	32.5
BUU	0.1	0.2	0.0	0.0	46.5	59.9	43.3	34.9	10.1	4.6
BUL	0.0	0.5	0.0	0.1	50.8	66.4	26.7	28.8	22.6	3.9
LOU	0.4	0.1	0.0	0.0	21.4	70.1	60.4	26.8	17.8	2.7
LOL	6.0	0.5	0.0	0.0	37.9	56.0	21.0	35.6	35.0	5.6

*Locally contributing area could not be accurately determined at SLL due to a large number of structures that impacted the elevation around the monitoring station

Additionally, smaller stream sections with variable discharge rates will be most sensitive to storm water run off. In the Spring Creek Watershed, streams that may be most sensitive to these events include Thompson Run, Slab Cabin Run, Walnut Springs and lower Buffalo Run. When comparing total daily rain and maximum daily stream temperature of Lower Thompson Run during the summer months of 2016 and 2017 on days when rainfall exceeded 0.75 inches, maximum daily temperature positively correlated with the magnitude of the rain events (r^2=0.61). Similar trends were exhibited at monitoring stations on the other smaller tributaries with locally contributing impervious cover.

Tree canopy cover within the entire basin, excluding canopy over impervious surfaces, most likely indicates areas that are more forested and therefore well-drained. Monitoring stations with higher levels of ground cover with low infiltration rates (impervious surfaces, agricultural areas and lawns/sod) and less tree canopy cover within their basins and locally contributing areas, tended to have higher temperatures in 2016. This trend is likely a combination of both reduced runoff as well as increased shading due to the tree cover.

Shading from Riparian Cover

Tree canopy cover can provide an important barrier between streams and direct solar radiation. To determine riparian cover for each station, the Chesapeake Conservancy's land cover data was clipped to a 15m buffer on either side of the stream (**Figure 20**). The total amount of tree canopy cover, low vegetation and impervious surfaces were determined for a section of stream 100

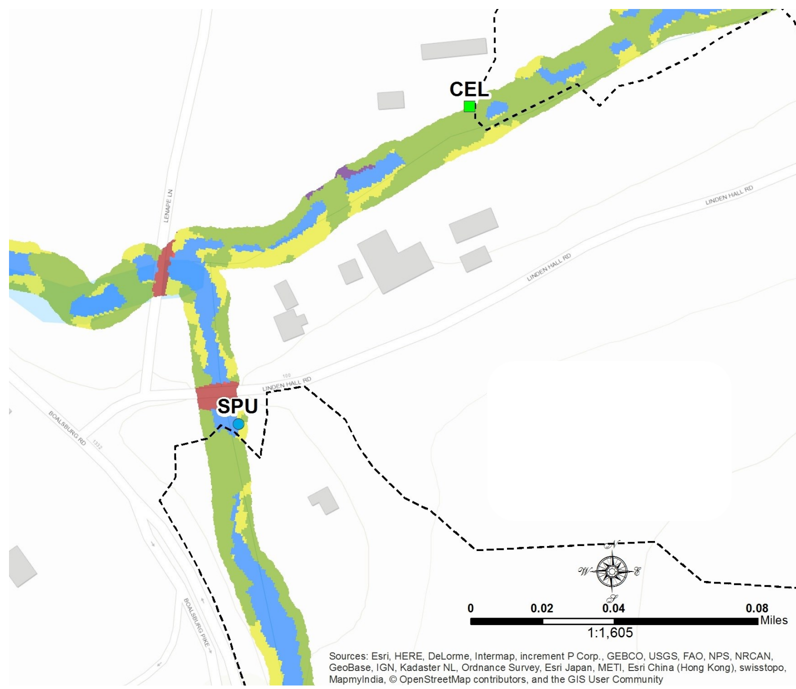

Figure 20: Example of 15m riparian buffer at the Lower Cedar Run (CEL) and Upper Spring Creek (SPU) monitoring stations.

meters upstream and 50 meters downstream of the monitoring station (**Table 6**).

Stations with the highest percent of tree canopy cover in their buffer zones were Upper and Lower Buffalo Run (BUU and BUL) and many sites along the main stem of Spring Creek. Both Lower Thompson Run (THL) and Middle Walnut Springs (WAM) had the most impervious surface within their buffer zones. Regression analysis did not show any relationships between riparian cover and stream temperatures. Because riparian buffers are most effective at preventing warming rather than cooling stream water, the tree canopy cover in close proximity to a monitoring station may not be critical to the temperature at that specific location.

Table 6: Land cover composition of a 15m wide buffer on either side of the stream and extending 100m upstream and 50m downstream of each surface water monitoring station. Data source: Chesapeake Conservancy

Site Abbreviation	Water (%)	Wetlands (%)	Tree Canopy (%)	Low Vegetation and Shrubs (%)	Impervious (%)
CEL	6.0	0.2	27.4	64.6	1.8
SLU	3.2	0.1	45.8	47.5	3.4
SL8	3.3	0.1	45.2	46.9	4.4
SLC	3.6	0.1	44.7	47.2	4.4
SLL	6.1	0.1	44.4	45.2	4.2
SLM	6.1	1.5	39.5	39.9	13.0
SPU	16.5	0.0	51.4	27.8	4.3
SPP	12.6	0.1	40.2	42.2	4.8
SPS	10.2	0.6	40.0	41.4	7.8
SPH	10.5	0.6	40.3	40.9	7.7
SPA	12.8	0.4	39.5	39.3	8.1
SPM	13.5	0.3	43.1	35.1	8.0
WAM	1.5	0.0	24.2	28.4	46.0
THL	4.6	0.0	24.7	23.1	47.6
BUU	8.0	0.5	49.5	34.6	7.3
BUL	6.2	0.3	55.1	33.6	4.7
LOU	24.6	0.0	43.8	21.4	10.2
LOL	22.0	0.0	42.2	24.9	11.0

Withdrawals and Inputs

The major withdrawals and inputs within the Spring Creek watershed that could impact stream temperature include wastewater treatment facilities, fish hatcheries, limestone mines and public water suppliers. **Figure 21** indicates the approximate locations of ground and/or surface water withdrawal areas for public water suppliers. Areas of water withdrawal must remain approximations in order to protect the security of the public water supplies.

Withdrawals

The majority of people living within the Spring Creek Watershed get their drinking water from groundwater sources including wells and springs. Therefore, public water suppliers are a major source of groundwater withdrawal, which intercepts water that would otherwise provide baseflow to Spring Creek and its tributaries. The largest public water suppliers in the Spring Creek Watershed are the State College Borough Water Authority, College Township Water Authority, Pennsylvania State University, Spring Township Water Authority and Bellefonte Borough. Two of the larger well fields in the watershed are located in close proximity to Slab Cabin Run. Because sections of Slab Cabin Run typically dry up both upstream and downstream of these fields during drought conditions, concerns of the potential impacts of water withdrawal on stream flow do exist. Tests have demonstrated some level of hydraulic connection from Slab Cabin Run to these wellfields, however sections of Slab Cabin Run are naturally perched thus surface water recharges the aquifer.

In total, combined withdrawals in the watershed average nearly 10 million gallons per day, which is ultimately returned to the Spring Creek watershed via municipal wastewater plant discharges.

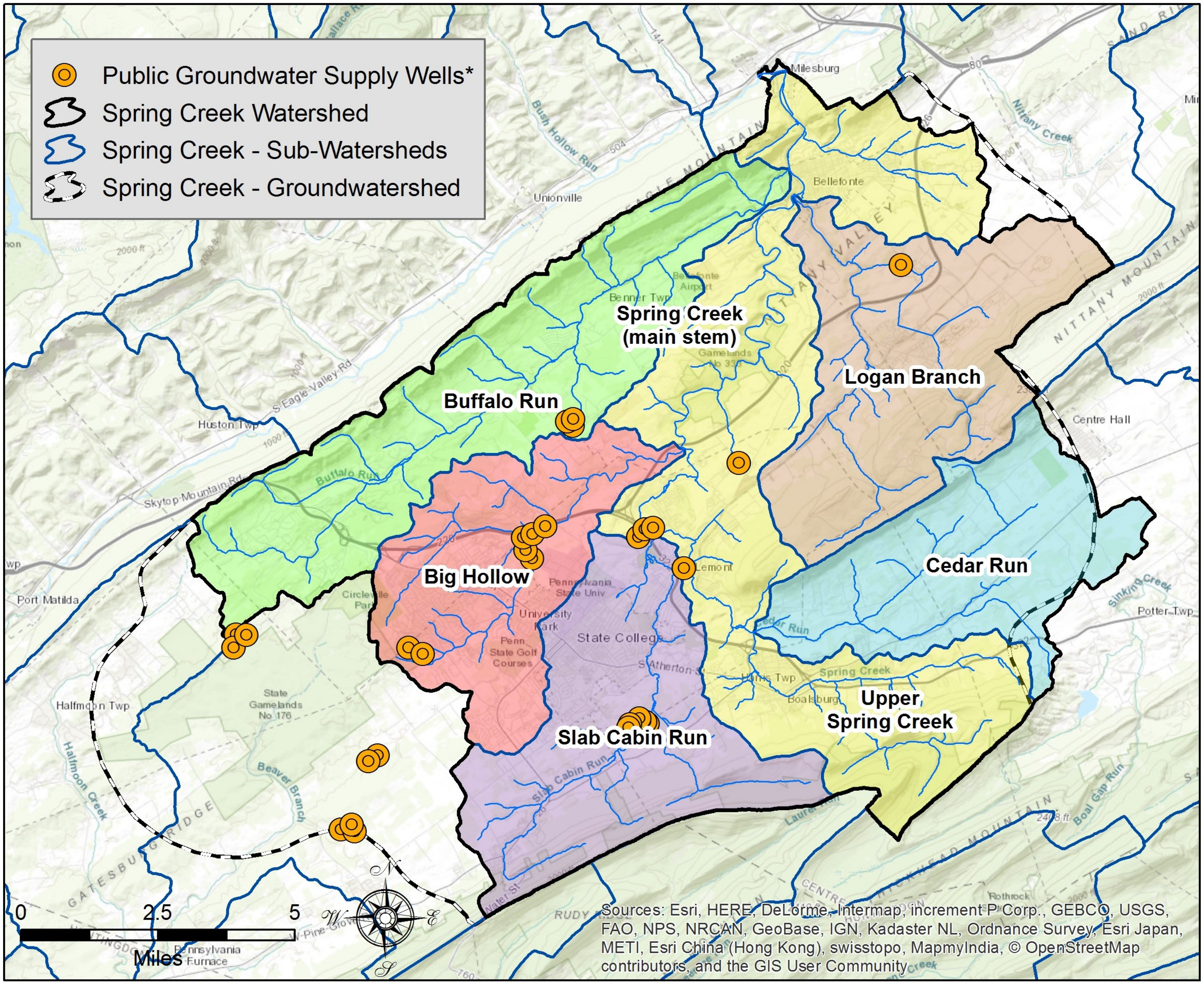

Figure 21: Public water supply wells within the Spring Creek watershed. *All locations for wells are approximations

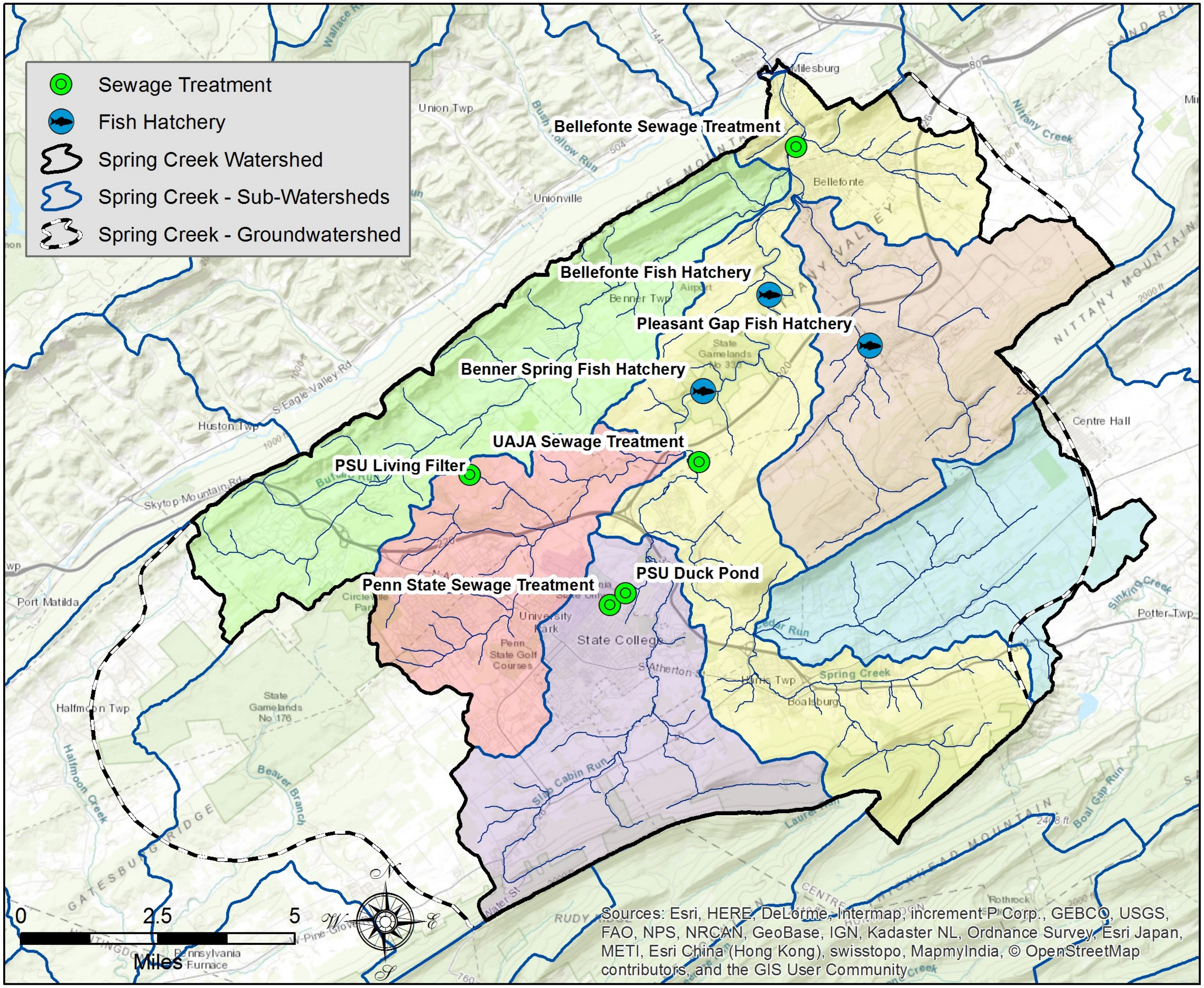

Figure 22: Wastewater treatment facilities and fish hatcheries in the Spring Creek watershed.

Inputs

The Spring Creek Watershed has several major discharges that contribute substantial volumes of water back into the watershed, including municipal wastewater, mine dewatering operations and fish hatcheries. **Figure 22** indicates locations of the major wastewater treatment facilities and fish hatcheries in the watershed.

Wastewater Treatment

Wastewater treatment plants contribute approximately five percent of the total flow of Spring Creek (Carline et al., 2011). Oftentimes treated wastewater is warmer than ideal temperatures for a cold-water fishery, so discharges of treated wastewater into streams has the potential to impact stream temperature regimes in areas with lower or more variable flow rates.

The University Area Joint Authority (UAJA) is the largest wastewater treatment facility in the watershed and serves much of State College and upper sections of the watershed. UAJA treats approximately five million gallons of wastewater each day. The majority of this treated water is discharged into the main stem of Spring Creek and contributes to a small portion of its total flow (<5%). Additionally, UAJA recycles approximately nine percent of wastewater into beneficial reuse water.

Beneficial reuse of wastewater can positively impact watersheds in many ways by reducing the need for groundwater withdrawals as well as helping maintain healthy stream flows. While the UAJA's beneficial reuse project is required to meet drinking water standards, it is still classified as non-potable water and therefore must be used for non-consumptive purposes. For example, the Centre Hills Country Club uses beneficial reuse water to irrigate their golf course. Slab Cabin Run at Kissinger Meadow is permitted to receive direct discharges of reuse water. This section of stream receives on average 450,000 gallons (0.70 cfs) of recycled water per day, which aids in augmenting stream flow.

Because this discharge is received by a smaller tributary in the watershed, the WRMP installed temperature loggers both upstream, at the Super 8 (SL8), and downstream of the beneficial reuse discharge into Kissinger Meadow at SLC (**Figure 23**) to monitor any potential temperature changes. No baseline data exists to compare stream

Figure 23: Aerial view of Kissinger Meadow where UAJA releases beneficial reuse water to increase flow rates in Slab Cabin Run with WRMP surface monitoring stations SL8 (Slab Cabin at Super 8) and SLC (Slab Cabin at Kissinger Meadow).

temperatures at the meadow prior to the installation of the beneficial reuse line to that of current stream temperature; however, no discernible increases in temperature have been noted downstream at other monitoring locations.

The Bellefonte Borough Authority Wastewater Treatment facility is another major treatment plant that discharges treated water into the main stem of Spring Creek. This facility on average treats 1.9 million gallons of wastewater each day from approximately 6,400 Bellefonte Borough residents, 10,000 additional customers in the adjoining Spring Benner Walker Joint Authority, three major prison facilities and deicing fluid from University Park airport. The Logan Branch and Big Spring, which contribute 35% and 5% respectively to the total flow of Spring Creek, intersect with the main stem prior to the treated effluent discharge (Carline et al., 2011). These cooler water inputs greatly offset any potential for thermal contribution from the treatment facility.

Another major wastewater treatment facility in the watershed is Penn State's wastewater treatment plant. Rather than discharge treated wastewater directly into streams, Penn State applies treated effluent to the land at the Living Filter. The campus also has plans to build a reuse system designed to recycle 300,0000 to 500,000 gallons of water per day. Historically, Penn State discharged treated water into Thompson Run at the Duck Pond. In 1983, this discharge was redirected to the Living Filter to be sprayed onto fields. Currently, an estimated 1.7

million gallons of water is returned to the aquifer each day through groundwater recharge at the Living Filter (sustainability.psu.edu/water).

Mining Operations

Another type of discharge within the Spring Creek Watershed is dewatering operations associated with limestone mining. A number of limestone quarries and mining operations exist within the Spring Creek Watershed. Groundwater consumed during the mining process can either be discharged directly into the stream system or returned to the aquifer. Locations within the watershed that receive this discharge include the Logan Branch and Whiterock Sinkhole, which recharges Blue and East Springs. Because this discharged water is at groundwater temperature, inputs into the Logan Branch may help to maintain its steady temperature regime.

Fish Hatcheries

There are three major fish hatcheries in the Spring Creek Watershed: Benner Spring State Fish Hatchery, Bellefonte State Fish Hatchery and Pleasant Gap State Fish Hatchery. The Benner Spring and Bellefonte hatcheries are located on the main stem of Spring Creek with the Benner Spring Hatchery located on the farthest upstream sections of the Spring Creek Canyon and the Bellefonte Hatchery located at the farthest downstream section of the canyon. The Pleasant Gap Hatchery is located on the Logan Branch.

Hatcheries both withdraw and release water into the watershed. The Bellefonte Hatchery sources it water from springs and groundwater. The Pleasant Gap hatchery sources its water from Graymont Inc.’s surface water reservoir, the Logan Branch, springs and groundwater wells. Water supplies for the Benner Spring Hatchery come from Benner Spring, Spring Creek and groundwater wells. All of these hatcheries redirect water from where it would naturally be stored belowground or contribute to surface water flow and release it at the site of the hatchery.

Hatcheries are strictly regulated on the quality of water that is released in the stream and have on-site treatment facilities to reduce physiochemical pollution. However, water that is released into Spring Creek is not monitored for temperature. Raceways and pools at fish hatcheries increase the exposure of water to direct solar radiation,

Temperature Variation between Monitoring Locations

The WRMP has been monitoring temperature in the Spring Creek Watershed since 1999. This breadth of data can provide insight into potential shifts in thermal regimes over time. The first sites established in 1999 include Upper Buffalo Run (BUU), Lower Buffalo Run (BUL), Lower Cedar Run (CEL), Upper Logan Branch (LOU), Lower Logan Branch (LOL), Upper Slab Cabin Run (SLU), Lower Slab Cabin Run (SLL), Spring Creek at Axemann (SPA), Spring Creek at Houserville (SPH) and Spring Creek at Milesburg (SPM). In 2008, a temperature logger was installed in Slab Cabin Run at Millbrook Marsh (SLM) and in 2013 temperature monitoring began at Middle Walnut Springs (WAM), Slab Cabin Run at Super 8 (SL8), Slab Cabin Run at Kissinger Meadow (SLC), Spring Creek at the Spring Creek Park (SPP) and Spring Creek at the Penn State Sheep Farm (SPS). **Figure 24** shows the average

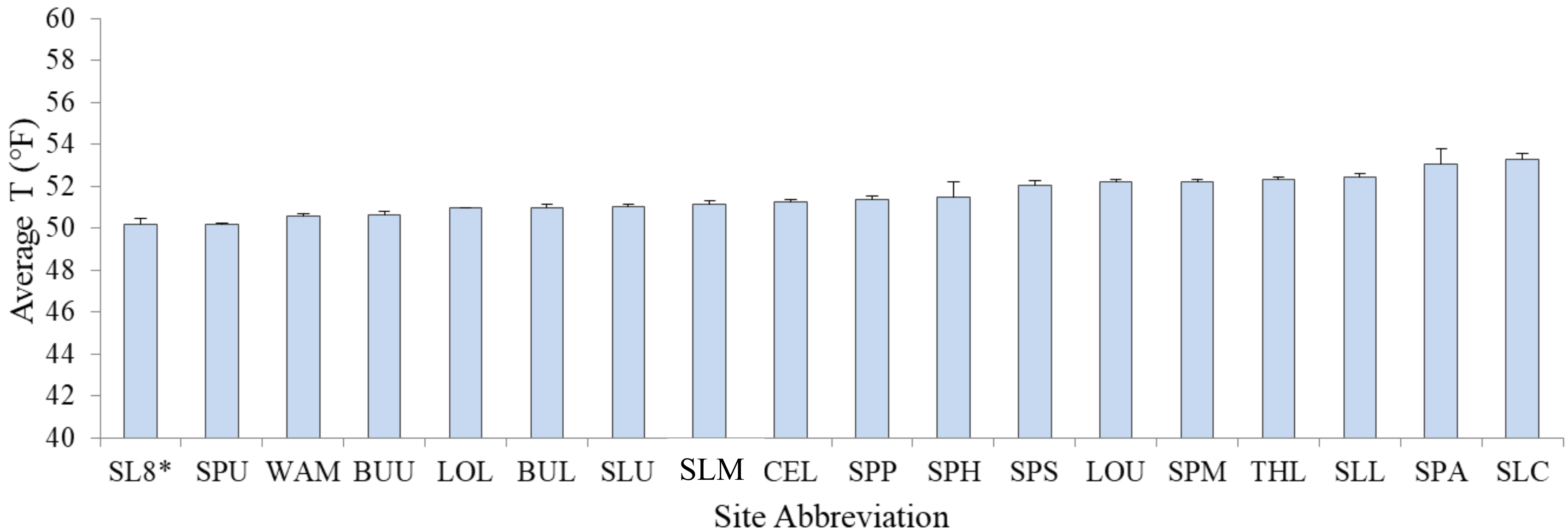

Figure 24. Average temperature of each monitoring station over time. Only years with complete datasets were used to calculate the average temperature for each station. Error bars represent standard error with n equal to the total number of days. *SL8 only includes three years of data. For information on which years were used please see Appendix 10.

temperature for each monitoring station from the year of its establishment. Large storm events and technical malfunctions left some gaps within the years of data. These years were not included in calculating the average temperature for that monitoring location.

Average temperature across all monitoring stations ranged from near 50°F to 53°F. The Upper Spring Creek Monitoring Station (SPU) had the lowest average temperature over time (50.19 ± 0.06 °F) and the highest average temperatures were at Spring Creek at Axemann (SPA) and Slab Cabin Run at Kissinger Meadow (SLC) with temperatures of 53.06 ± 0.74 °F and 53.29 ± 0.26 °F respectively. SPU is both relatively close to the headwaters of the watershed and is also fed by numerous unmonitored springs in close proximity to the monitoring station. Both of these factors help to reduce potential impacts on stream temperature as well as seasonal and diurnal temperature ranges.

On the other hand, Spring Creek at Axemann is much farther downstream from the headwaters. There are numerous environmental and anthropogenic factors that could influence stream temperatures at this location. For example, there are direct discharge inputs from two fish hatcheries and a large wastewater treatment facility, large sections of developed land, multiple top-flow dams and small tributaries (Slab Cabin Run, Cedar Run, Thompson Run, Walnut Springs) that are much more sensitive to atmospheric changes in temperature that enter the stream before Axemann. All of these factors can influence a stream's temperature.

Temperature Trends within Monitoring Locations

Due to the rapid rate of development in the Spring Creek Watershed, the potential impact of urban growth on stream water quality has been an important public concern. Daily, yearly and monthly temperature averages were established at each monitoring location to analyze trends in temperature over time. **Appendices 7, 8 and 9** include figures for all three averages.

LONG-TERM TEMPERATURE TRENDS IN THE SPRING CREEK WATERSHED

Average daily temperatures for all monitoring locations were graphed over time to analyze any correlation with daily stream temperature and time. **Figure 25** shows average daily temperatures of Spring Creek at Axemann from 1999 through 2017. No clear trends could be found within the daily data at any of the monitoring locations. However, such long-term, fine-scale data can have large amounts of variation both between and within years. In order to look at broader trends, average monthly temperatures were plotted for each season.

For monitoring stations with periods of record dating back to 1999, Lower Logan Branch (LOL) and Spring Creek at Milesburg (SPM) both had slight negative correlations with summer temperatures over time that accounted for approximately 20% of the variation in temperature (**Figures 26 & 27**). The Logan Branch contributes to over one-third of the flow of the Spring Creek at Milesburg, so similarities in

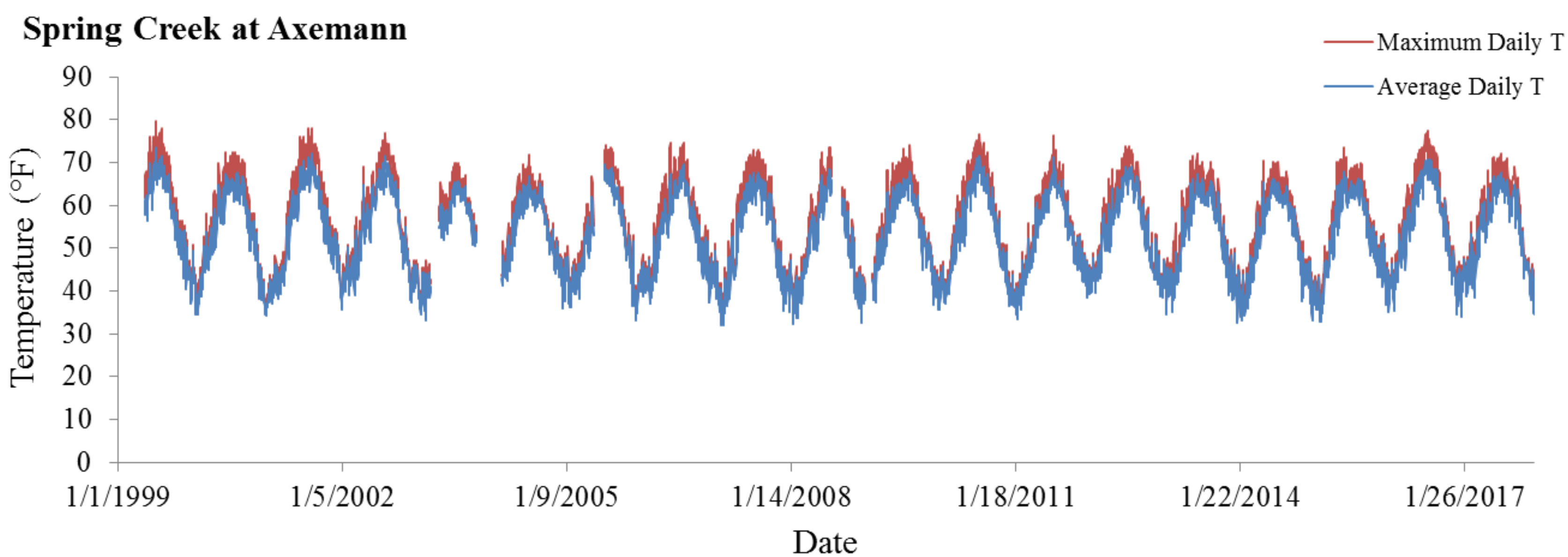

Figure 25 Average daily temperature (°F) for Spring Creek at Axemann (SPA)

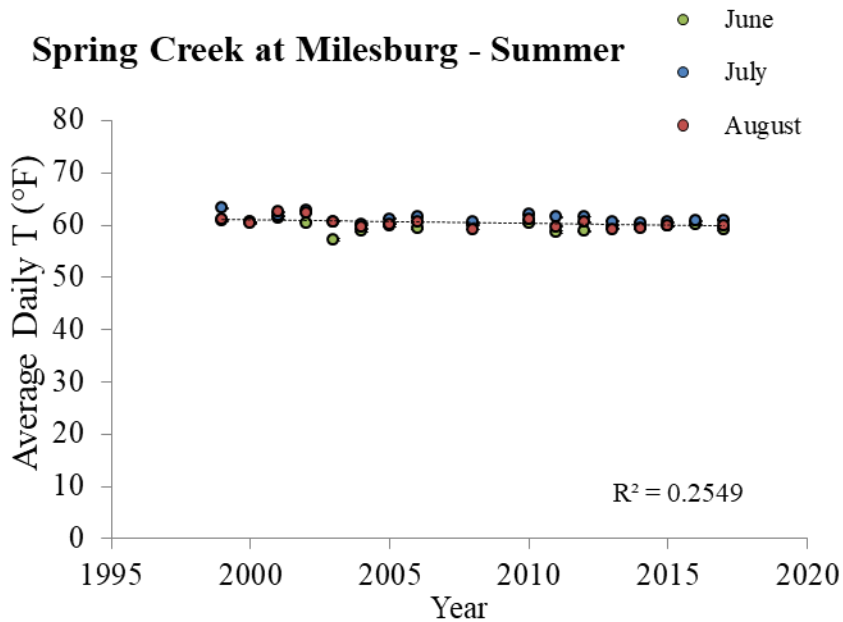

Figure 26 Average monthly temperature for the summer months (June-August) for the Spring Creek at Milesburg (SPM) surface water monitoring station.

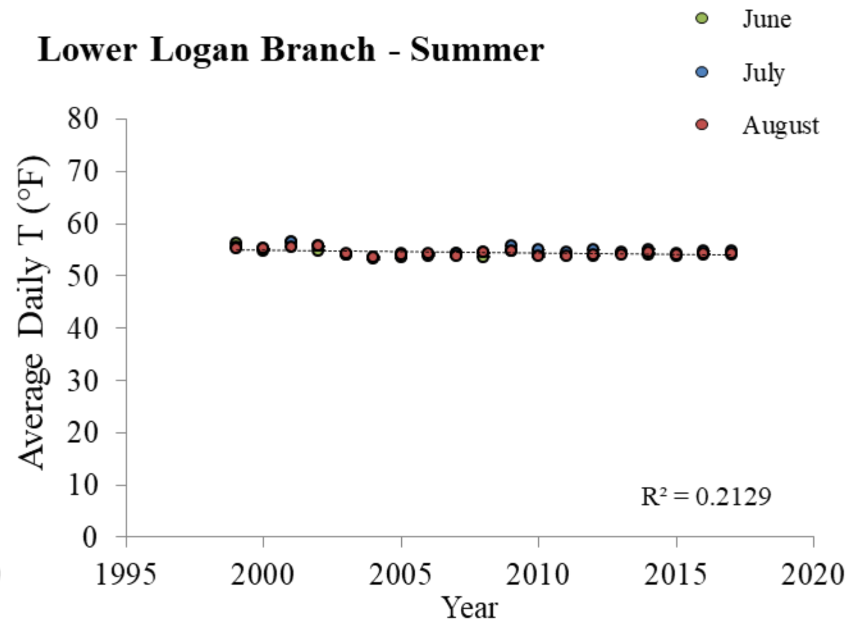

Figure 27. Average monthly temperature for the summer months (June-August) for the Lower Logan Branch surface water monitoring station.

trends at both of these locations could be expected. Additionally, large springs feed both the Logan Branch and Spring Creek at Milesburg.

Other monitoring stations did not exhibit similar long-term trends in average monthly temperature. However for locations with shorter periods of record, nearly all of the fall temperatures showed increasing trends over the last four to five years with 52 to 86 percent of the variation in temperature accounted for by year.

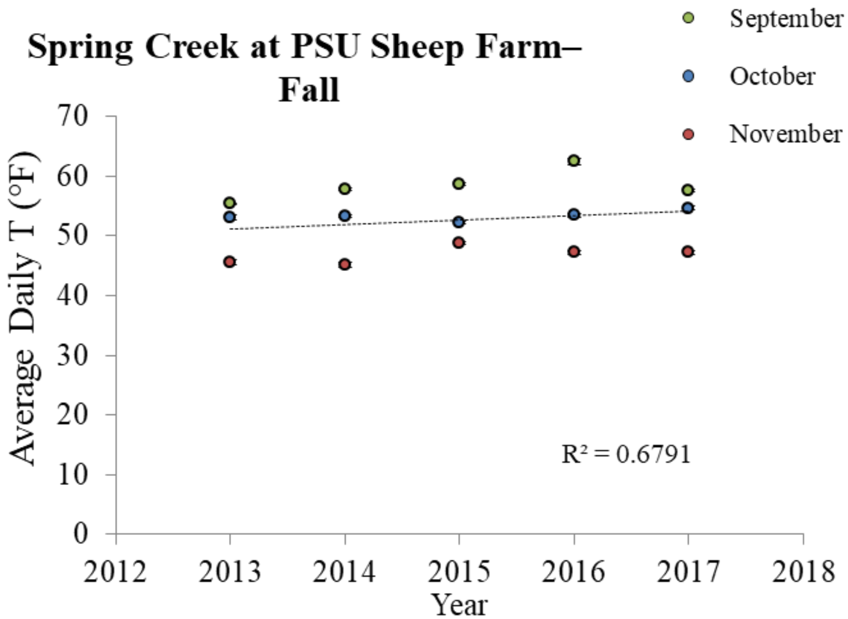

Figure 28 Average monthly temperature for Spring Creek at the PSU Sheep Farm during the fall months (September-October)

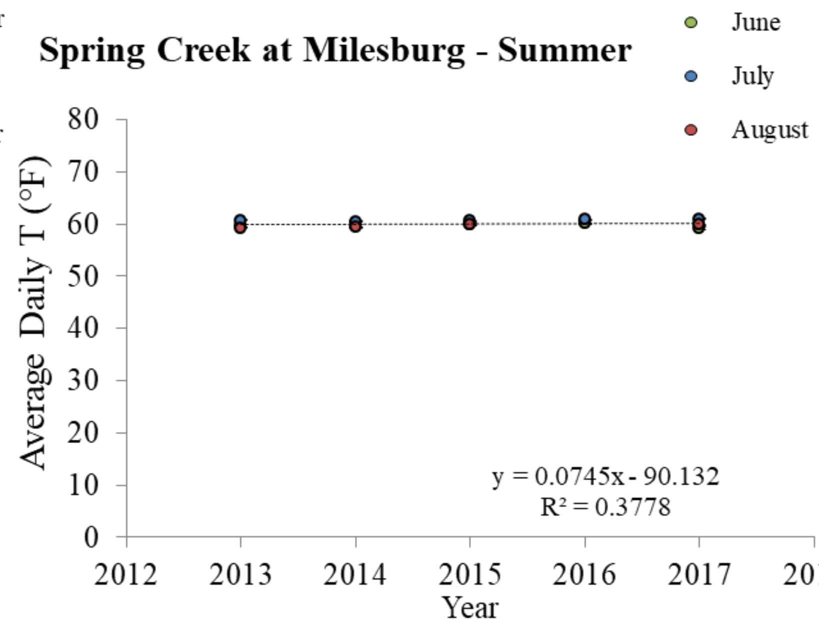

Figure 29. Average monthly temperature for Spring Creek at the Milesburg during the summer months (June-August) from 2013-2017.

Figure 28 shows the increasing trend in fall temperatures at the Spring Creek monitoring location at the Penn State Sheep Farm. However, trends in temperature in one direction for a number of years may not be indicative of long-term trends. The increasing fall temperatures over the past few years, does not indicate that long-term temperature trends are increasing. For example, while the average monthly summer temperatures may be reducing at the Spring Creek at Milesburg monitoring station, the summer temperatures for the last five years actually show a weak positive trend (**Figure 29**). Temperature trends can shift from one direction to another based on numerous environmental factors such as precipitation, air temperature, snow fall and humidity, which all also can show changing trends over periods of time.

LONG-TERM TEMPERATURE TRENDS IN THE SPRING CREEK WATERSHED

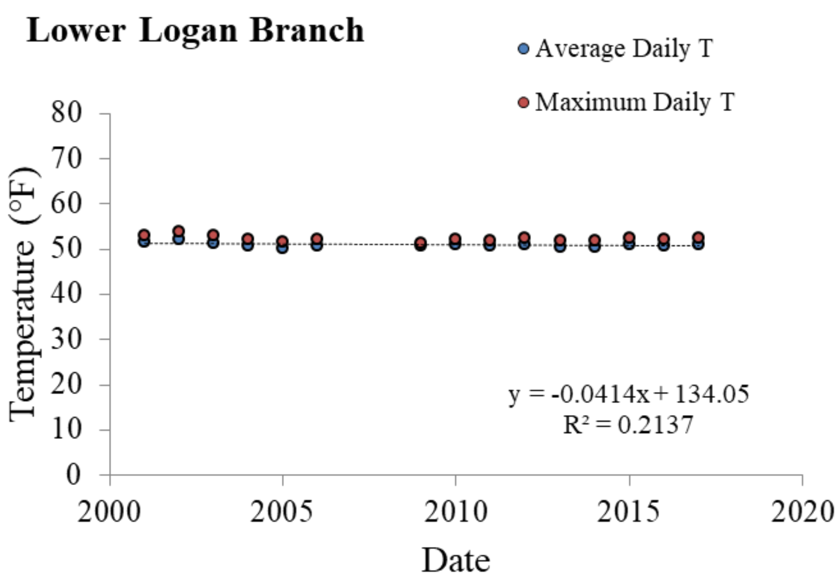

Figure 30. Average yearly temperature for the Lower Logan Branch surface water monitoring station.

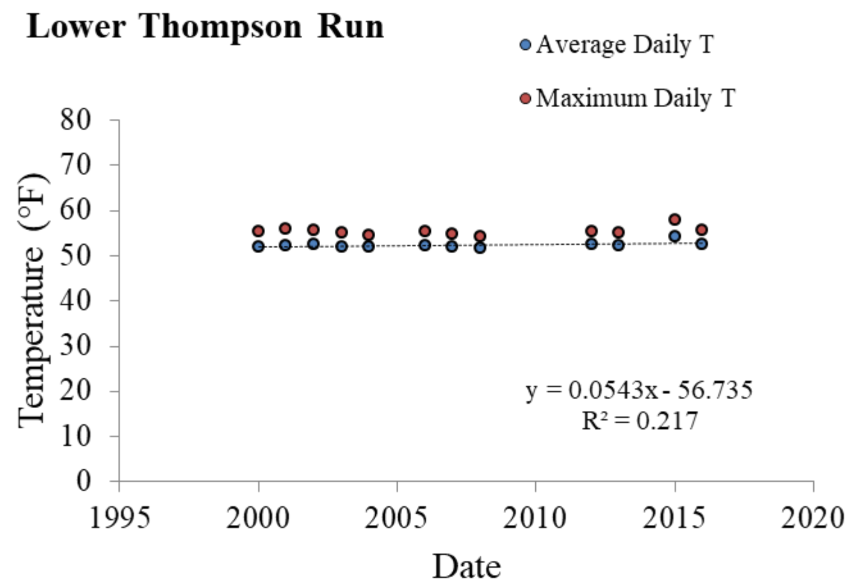

Figure 31. Average yearly temperature for the Lower Thompson Run monitoring station.

In addition to average daily and monthly temperatures, average yearly temperature for each monitoring station was plotted over time. When looking at this yearly data, the Lower Logan Branch again showed a slight negative trend in temperature since 1999 (**Figure 30**). This trend could potentially be explained by the large amount of groundwater it receives from both springs and dewatering from limestone mines. On the other hand, the lower Thompson Run monitoring station showed a slight positive trend in temperature over time (**Figure 31**). This monitoring station is fairly urban with over 30% of its basin in impervious cover. Runoff from these impervious surfaces during summer months creates much flashier daily maximum temperatures at this site. So this trend may be indicative of stronger, summer storm events in recent years.

Conclusions

The comparison of 2016 and 2017 temperature data highlight that groundwater contribution and steady flow rates may be the most important factor in buffering against the impact of atmospheric and anthropogenic warming effects. The temperature of streams with little groundwater input and more variable flow rates may be more sensitive to lack of riparian shading, urban runoff from summer storm events and higher summer air temperatures.

Beyond a two-year comparison, most monitoring stations showed minimal trends in temperature shifts over time despite significant increases in urban development. This again highlights how the large groundwater component of the total annual flow of Spring Creek mitigates potential thermal impacts in the watershed.

Short-term trends can sometimes indicate rising stream temperatures. Understanding the factors that control stream temperature as well as reaches of streams most sensitive to potential impacts can help prioritize management decisions to reduce even short-term temperature increases.

Due to the numerous factors that can contribute to thermal trends within the Spring Creek Watershed, management and mitigation of thermal impacts is a multi-faceted endeavor. Natural factors such as groundwater inputs and stream flow rates determine the sensitivity and buffering capacity of a given stream section. A more holistic understanding of where groundwater inputs and flow rates tend to be lowest can help to prioritize stream restoration projects.

Human impacts on land use can decrease riparian shading, increase impervious surfaces and sediment loads, and increase groundwater withdrawals and wastewater discharges. These are all factors that can be managed by sensible development, use of best management practices for stormwater, and adoption of innovative water management approaches such as Penn State’s Living Filter and UAJA’s Beneficial Reuse Project.

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 2016 in April, August, October, and December. In 2017, this occurred in March, May and November. Water Quality assessment is performed 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 (**Table 7**). **A summary of water resource management issues for each monitoring site**

Table 7. Water quality parameter descriptions, sources and potential environmental effects. (*continued on pg. 50*)

Parameter	Description	Sources	Environmental Effects	Stream	Spring
Aluminum	The most abundant element	Urban runoff, industrial	May adversely affect the	X	X
Cadmium	Natural element found in the Earth's crust	Industrial sources and urban sources including fertilizer, non - ferrous metals production,	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	X	X
Chromium	A trace element essential for	Found in natural deposits of	Toxic to humans and aquatic	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,	Suspended solids clog fish gills and alter stream-bed habitat upon settling; dissolved materials limit the osmoregulatory ability of	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	Low levels of dissolved oxygen are harmful to aquatic animals; typically a result of organic pollution or elevated temps	X	X
Coliform	Common intestinal bacteria	Animal wastes and sewage	Pathogenic to humans		X

Parameter	Description	Sources	Environmental Effects	Stream	Spring
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
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 (NO_3)	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; p articles 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

Appendices 2 and **3** show median 2016 and 2017 concentrations of all parameters analyzed at each of the stream and spring sites, respectively. The data from both years was combined because only 3 measurements were taken in 2017. Results from the water quality monitoring were similar to results from past years.

- For this two year period, the concentration of nitrate nitrogen at stream sites, as typically seen, was highest at sites downstream 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 0.11 and 4.36 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 5.80 and 4.80 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 such as algal blooms. Orthophosphates were detected at low levels (<0.04 mg/L) at all stream sites. Orthophosphorous was also detected at low levels at all springs.

- The highest median stream chloride concentrations were observed at Slab Cabin Run downstream of Millbrook Marsh (73.5 mg/L) and at Thompson Run at East College (72.6 mg/L) . These values are similar to historical values. Walnut Spring had the highest observed median concentration in the springs at 107.2 mg/L. Elevated chloride concentrations are generally associated with increases in urbanization such as impermeable surfaces and increases in road salt application.

- Median iron concentration was elevated at Windy Hill Spring (1532 µg/L) in 2015 but dropped to 536 µg/L in between 2016 and 2017. 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. The drying and wetting of rock surfaces has a tendency to increase iron concentration. This can occur when the water table fluctuates over a cycle of a dry period followed by a wet period. The observed elevated level of iron occurred in October (2534 µg/L) and December (3311 µg/L) of 2015.

- Conductivity is a fundamental water quality characteristic and is defined as the ability of the water to conduct an electrical current. Values of conductivity are directly related to the total major dissolved ion concentrations 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 bicarbonate and potassium, which the WRMP does not monitor. In 2016, conductivity was highest at Slab Cabin Run at Millbrook Marsh (669.0 mS) and at Upper Logan Branch (652.5 mS).

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

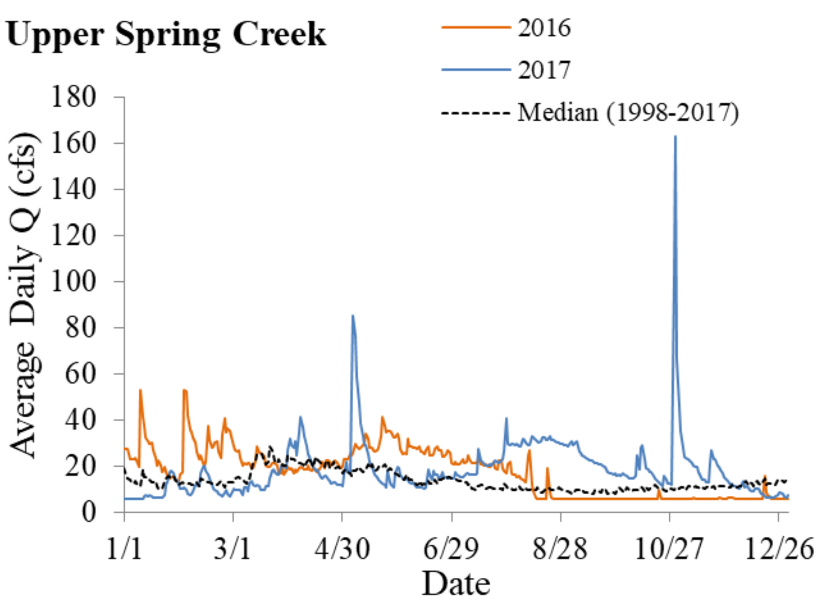

Figure 31: 2016 and 2017 Discharge and median discharge (cfs) for Upper Spring Creek at Oak Hall.

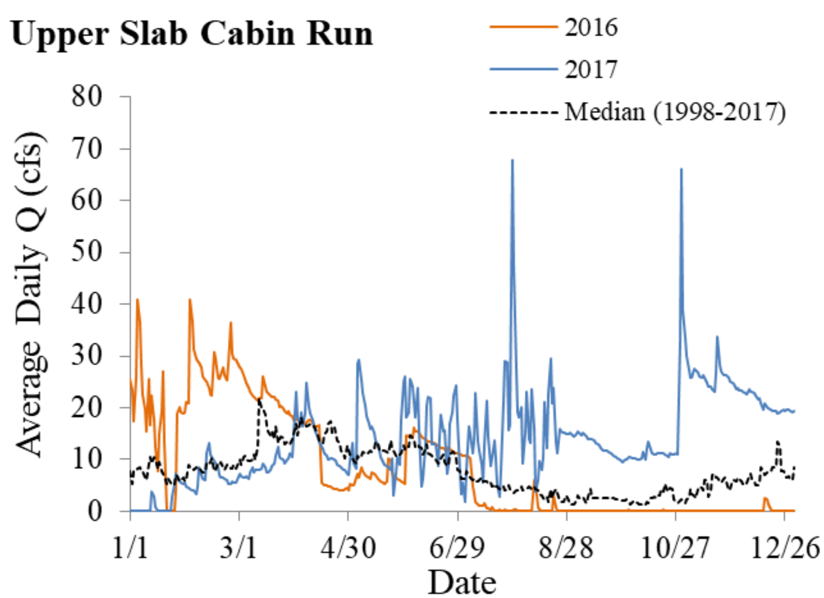

Figure 32: 2016, 2017 and Median discharge (Q) for Upper Slab

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 2016 discharge profiles for the main stem of Spring Creek at Oak Hall and a representative tributary (Slab Cabin Run at South Atherton Street) are shown in **Figure 31** and **Figure 32**, respectively.

In 2016, discharge rates were initially higher than median values but dropped below median rates in July and remained below the median the remainder of the year.

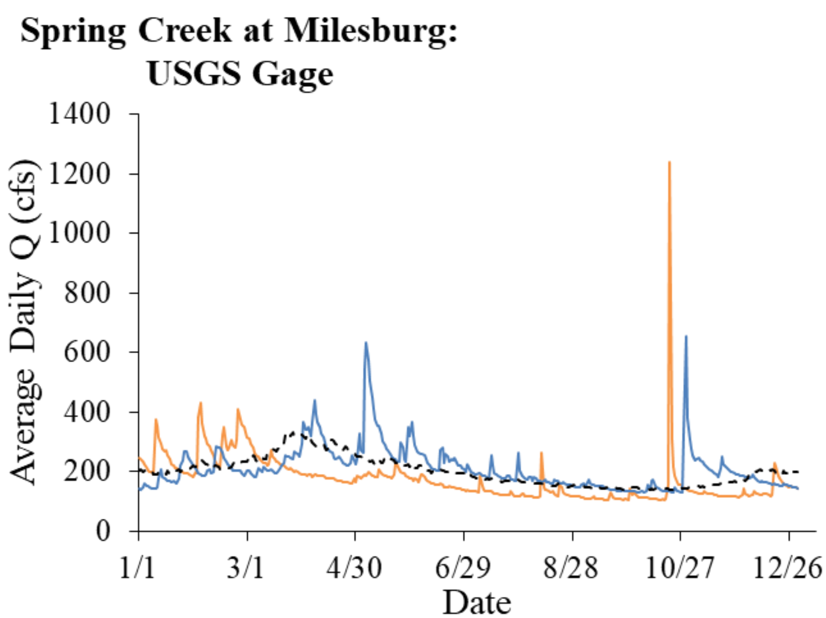

Figure 33: 2016, 2017 and Median discharge (Q) for Spring Creek at Milesburg (SPM)

The summer and fall of 2016 were exceptionally dry. 2016 received almost seven inches less precipitation than a typical year. However, in October an isolated thunder storm impacted the Buffalo Run tributary and Miliseburg area, which experienced serious flooding due to the event. This event destroyed our monitoring stations on Buffalo Run and caused substantial damage to the surrounding community infrastructure. **Figure 33** shows the discharge profile for Spring Creek at Milesburg. This storm event can be seen in the large spike in discharge rates.

2017 received much steadier and above-average rainfall throughout the year with a couple isolated storm events. This steady rain raised the discharge rates above the median level for the majority of the year.

The 2016 and 2017 discharge profiles for all of the WRMP gages and the three USGS Spring Creek gages are included in **Appendix 4**.

Stream Temperature

The 2016 and 2017 temperature profiles for all WRMP monitored locations in the watershed are included in **Appendix 5**.

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 2016 and 2017, the WRMP collected groundwater data from three monitoring wells and assessed data from two additional wells maintained by the USGS. Groundwater elevation profiles for 2016 and 2017 are found in **Appendix 6**. Water surface elevation is used as the y-axis label and is equivalent to feet above mean sea level.

The groundwater hydrograph for the USGS CE118 well located in the Scotia Barrens (**Figure 34**) indicates that 2016 groundwater elevations were well below the median for the entire year. The CE 118 well is located in a large aquifer that drains to the Big Spring and several other large magnitude springs in the Bellefonte area. Additionally, due to the aquifer's large size and permeability, it typically takes a large amount of persistent precipitation to result in a positive change in the groundwater elevation in CE118, which can be seen by the very slow increase after March of 2017.

In contrast, the WRMP Fillmore groundwater well (**Figure 35**) is a shallower well and experiences relatively quick

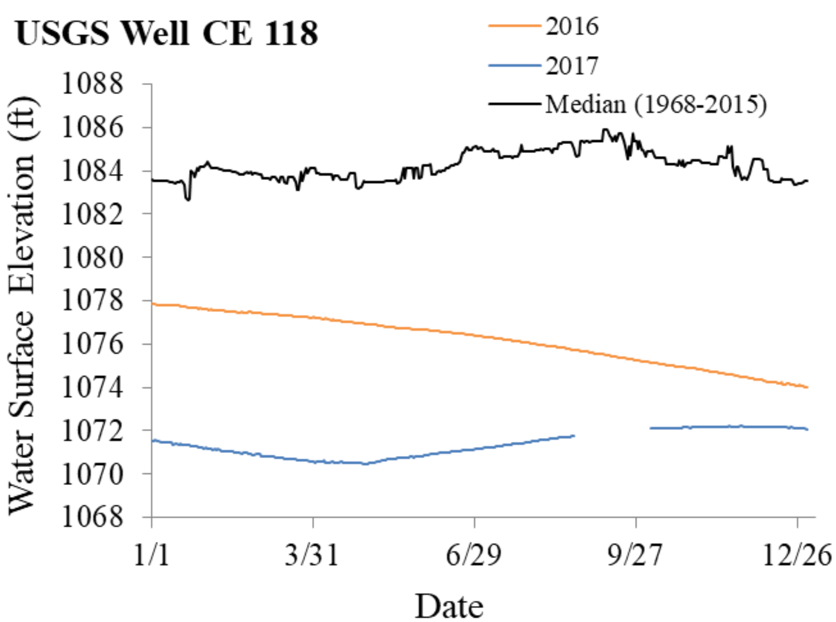

Figure 34. Water surface elevation (ft) in 2016 and 2017 at the USGS Well CE 118.

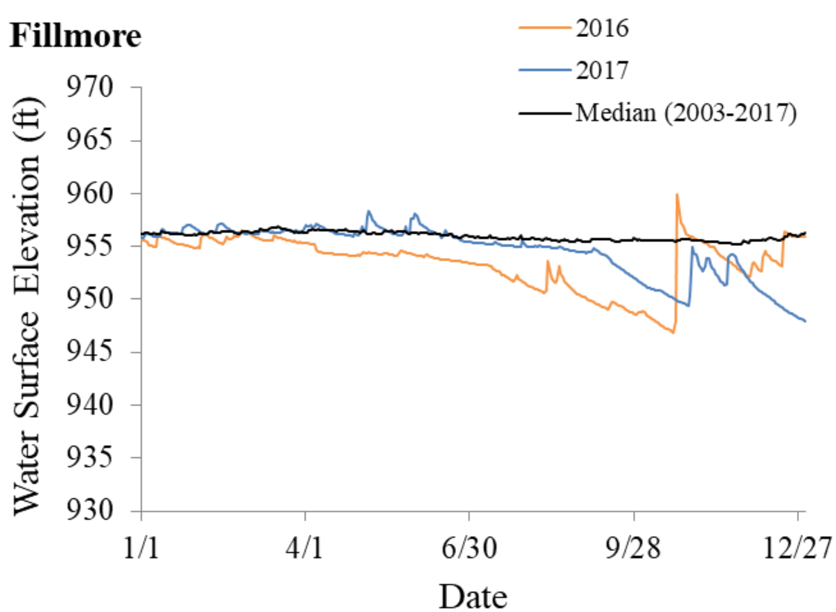

Figure 35. Water surface elevation (ft) in 2016 and 2017 at the Fillmore WRMP groundwater well.

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