Monitoring Chloride in the Spring Creek Watershed

Spring Creek Watershed Association
Water Resources Monitoring Project

2014 State of the Water Resources Monitoring Project

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FROM THE CHAIR

In this issue of the State of the Water Resources Report, we examine the topic of chloride in the environment. We've provided a significant amount of background information on chloride as a necessary preface to describing the observed occurrence of chlorides in the Spring Creek Basin. Unfortunately, chloride is completely soluble and very mobile in water, and there is no natural process by which chlorides are broken down, metabolized, taken up, or removed from the environment. Hopefully, this annual report will assist the local community in understanding issues related to chlorides in the Spring Creek Watershed.

2014 saw a change in the WRMP coordinators. Lori Davis accepted a position with the US Fish and Wildlife Service, but is staying local so you may still see her around the area. Lori advanced the mission and quality of data collected by the WRMP and collected all of the 2014 data. Lori was replaced by Adrienne Gemberling who is the primary author of this excellent annual report. We're really excited to have Adrienne on board for the WRMP. The WRMP has had several coordinators who have made the program possible over the years. I would like to take the opportunity to thank all of the people who have served in the coordinator role since 1998. The coordinators included: Lori Davis, Rebecca Dunlap, Adrienne Gemberling, Brianna Hutchinson, Katie Ombalski, Nick Schipanski, Roxanne Shiels, Geoffery Smith and Beth Thoma. There have also been a multitude of volunteers and student interns who have assisted the coordinators over the years that have helped keep costs down and the committee would like to thank them for their time and effort.

The WRMP committee members in 2014 can be found listed on page 28 of this report; however, there have been numerous committee members who have also shared their time and expertise to make this program successful and I would also like to take time to recognize them for their service over the years. Committee members over the years have included (asterisk indicates served as committee chair):

Boyer, Beth
Brown, Jason
Buda, Susan
Carline, Bob*
Carrick, Hunter
Cole, Andy
Dewolfe, Jim
Donovan, Ann
Dunlap, Becky
Finton, Chris
Foard, Steve
Genito, Dennis
Giddings, Todd
Hamlett, Jim
Harrison, Scott
Johnson, Peggy
Lavan, Bert
Odriscoll, Mike
Proch, Gene
Ralston, Mark*
Saacke-Blunk, Kristen
Sengle, John
Smith, Dave*
Stout, Hannah
Taylor, Malcolm
Tritsch, Shana
Wardrop, Rick*
Weikel, Doug
Wert, Jason
Yoxtheimer, Dave

Residents of the Spring Creek Watershed enjoy better water quality than the region has experienced in the last 100 years. The Water Resources Monitoring Project, which has been in place for 17 years, provides vital long-term data that can be used by local planning officials and engineers to make sound land use and water quality decisions. The Water Resources Committee, the advisory committee to the WRMP, is very appreciative of the donations the program receives on an annual basis from our sponsors. Your continued support will help maintain the program's ability to provide data needed to monitor changes within the watershed as our community continues to grow and thrive.

Larry Fennessey,
Chair

BACKGROUND INFORMATION ON CHLORIDES

An Introduction to Chloride

Chloride is a nutrient needed by all organisms to sustain life. It is found naturally in the Earth's crust and is a main component of salt dissolved in seawater. Freshwater, however, naturally contains low concentrations of chloride. Pollution occurs when high concentrations of chloride-containing salt products enter freshwater systems. Examples of salt pollutants include road deicers, water softening salt, and chloride based fertilizers. The main culprit in many inland areas is runoff containing deicing salts. This can be an issue because freshwater organisms are not adapted to "saltwater" conditions and thus can be harmed by high chloride concentrations.

What is Salt?

In the language of chemists, "salts" are a class of compounds that readily dissolve in water. In common usage, "salt" refers to a specific compound that consists of two elements: sodium (Na) and chlorine (Cl). In order to combine these two elements, they must be "charged" equally in opposite directions. The sodium in this case carries a positive charge (loses an electron) and the chloride carries a negative charge (gains an electron). The positive and negative charges attract and a neutral, stable product is formed. **Figure 1** illustrates the above process.

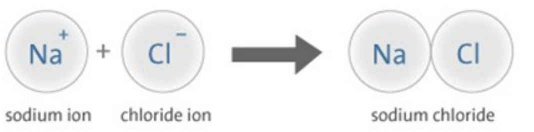

Figure 1. Formation of sodium chloride. From: www.gcsescience.com

In this case, the end result is a sodium chloride compound. Even though sodium chloride is stable, when it combines with water (another charged substance) the chloride (negatively charged) is attracted to the positive charge on the water and the sodium is attracted to the negative charge on the water. Water is more strongly charged than the salt compound, and thus the water ends up pulling the chloride and sodium ions apart, and keeps them dissolved in the water as ions (elements with a positive or negative charge). Negative ions are called anions and positive ions are called cations. **Figure 2** below shows Na+ and Cl^- ions dissolved in water.

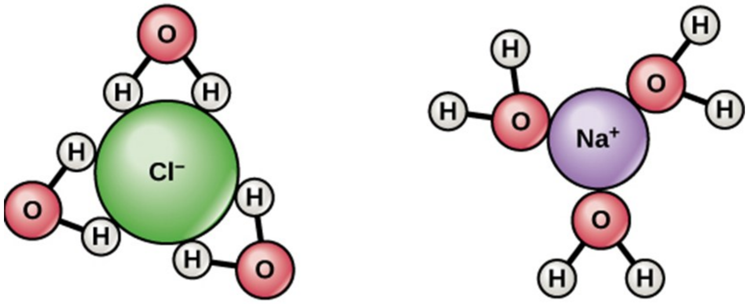

Figure 2. Sodium chloride dissolved in water. From: www.boundless.com

Natural Chloride

Chloride can be found in several forms on Earth. Seawater is naturally salty because it contains dissolved sodium chloride (salt). Seawater has an average salinity of about 35,000 mg/L. The taste of freshwater isn't the same as seawater because the concentration of dissolved salts is almost 200 times lower. Seawater has accumulated this high concentration of salt over time because rivers continually carry water containing dissolved salts to the ocean. Ocean water is constantly evaporating and carrying freshwater back to the land. However, while the water itself is leaving the ocean, the sodium and chloride ions remain and accumulate in the sea. This brings up the question: how does salt get into freshwater rivers and streams in the first place?

As precipitation falls over land, its acidity erodes rock over long periods of time. Rainwater is acidic because it contains carbon dioxide mixed with water (ingredients of acid rain). This erosion slowly releases trapped nutrients, ions, and salts. Chloride specifically can exist within rock as trapped seawater and solid salt. The trapped seawater solution and solid salt form concentrates through the same process that produces seawater. This process occurs when evaporation over time leaves sodium and chloride behind, eventually forming a solid precipitate.

Many of the nutrients, ions, and salts released from the rock during rain events can be taken up by plants and animals in the water and do not make it to an ocean. Chloride, however, doesn't participate in biological, chemical, or nutrient cycling. Since this ion is difficult to remove, it arrives and accumulates within freshwater systems. This accumulation has been accelerated by human chloride usage.

Salt extraction mine. From www.hamzasalt.com

How are Chlorides Used?

Humans use chloride compounds in a variety of ways. Salt (sodium chloride) is mined from the Earth and then further processed into usable products. Salt can be mined as a solid from ancient seabeds deep underground or as a solution. Solution mining is when water is added to a solid salt bed to create brine (saltwater) that can then be pumped from the ground and later undergo evaporation to produce a solid. Two main salt forms are derived from these processes: road deicing salt and table salt. Road deicing salt is mined, crushed, and ready to be used. Table salt needs to go through purification processes to ensure it is safe to consume.

BACKGROUND INFORMATION ON CHLORIDES

Sodium chloride is the most common form of salt used as a deicer on major roadways today because of its low cost and high performance at a wide range of temperatures. The five year average use of road salt in Pennsylvania is 976,000 tons, an amount that ranked number one nationwide for solid rock salt application in 2012[1]. A study in Canada found approximately one-half of the road salt applied in winter entered streams or rivers at the site of application, while the other half was removed via plow trucks or percolated through soil to enter the groundwater[2].

Water softener usage also contributes to chloride contamination. Drinking water from a carbonate aquifer means residents may have hard water as it contains more dissolved calcium and magnesium. Most homeowners treat hard water because of its adverse taste and effect on pipes and appliances. Water softener systems are used to prevent the formation of hard water scale and reduce any associated mineral tastes. To be able to remove these minerals from the water, common salt (NaCl) is added. An ion exchange (like that of sodium chloride dissolving in water) takes place that leaves a residual chloride brine, which is discharged to septic systems or to public sanitary sewer systems and wastewater treatment plants (POTWs).

Therefore, waste water from human septic systems can also carry high chloride loads. Other sources of this chloride include human waste, detergents, and household cleaners. Human waste can contain substantial concentrations of chloride because table salt is a common part of the everyday diet. Although high concentrations of chlorides can be found in wastewater, the University Area Joint Authority in State College says most water coming into their wastewater treatment plant does not contain high chloride levels. Therefore, chlorides are not specifically targeted for removal. However, they can be removed unintentionally during removal of other harmful pollutants.

Potassium chloride (KCl), another naturally occurring salt is widely used in agriculture as a crop fertilizer. It is currently the most popular potassium fertilizer applied and also contributes to chloride pollution. Rainwater and/or irrigation can mobilize the Cl^- into agricultural runoff which eventually leads to contamination of surface and ground water.

Brines associated with oil and gas development, including both conventional reservoirs and unconventional shale formations are another potential source of chloride contamination to waterways, but not in the Spring Creek Watershed because it is not a prospective area for oil and gas development. Currently, the Pennsylvania Department of Environmental Protect does not allow unconventional shale oil and gas brine to be discharged to a waterway without chloride removal to a level less than 250 mg/L. However conventional oil and gas brines may be

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[1] Washington Department of Transportation. 2013. 2012-2013 Department of transportation salt cost and five-year average use.

[2] Environment Canada. 2001. Priority substances list assessment report: road salt. Canadian Environmental Protection Act, 1999. Environment Canada, Health Canada, Minister of Public Works and Government Services: Ottawa, Ontario.

discharged without chloride treatment if a discharge permit exists.

Previous studies suggest road salt is the main contributor to chloride pollution in freshwater. Research in a rural watershed (9% developed, 91% forested) in Dutchess County, New York found that over 90% of the sodium chloride within their watershed was derived from road salt application, with the remainder coming from water softeners[3].

History of Road Salt Usage

In 1938, New Hampshire began using sodium chloride (NaCl) as a road deicer on an experimental basis. The usage of sodium chloride on roadways has significantly reduced crash rates and has become essential to treatment of roads in inclement weather across the U.S[4]. Unsurprisingly, its' usage has dramatically increased since the late 1930's. Today, 26 states use a combined total of between 10 and 20 million tons of road salt annually as their primary means of deicing roadways.

Chloride Road Salts

While sodium chloride is the main type of road salt applied, there are other chloride based deicers used in the U.S. The advantage of these alternative chloride salts is their ability to melt ice at lower temperatures compared to NaCl. The drawback, however, is that they are more costly (**Table 1**).

Salt Compound (Chemical Formula)	Form Used	Freezing Point (°F) and Concentration (%)		Median Cost (USD) per Ton
Sodium Chloride ($NaCl$)	Solid and brine	-5.8	23.3	$42
Calcium Chloride ($CaCl_2$)	Solid and brine	-60.0	29.8	$140
Magnesium Chloride ($MgCl_2$)	Solid and brine	-28.0	21.6	$111

Table 1. Characteristics of three chloride based salt compounds[5]

Above 25°F the three chloride based deicers (sodium chloride, magnesium chloride, and calcium chloride) require the same application rate and thus the cheapest (sodium chloride) is most commonly used.

While it is more expensive to purchase magnesium chloride and calcium chloride for road salt application, they are also more environmentally friendly. These deicers add magnesium and calcium to the landscape, which can actually improve soil structure unlike sodium which is often detrimental to terrestrial and aquatic ecosystems[6].

[3] Kelly, V.R. et al. 2008. Legacy effects of road salt on stream water concentration. Environmental Science and Technology; 42: 410-415.

[4] Kuemel, D.A, and Hanbali, R.M. 1992. Accident Analysis of Ice Control Operations. Marquette University and The Salt Institute of Virginia.

[5] Kelting, D.L., and Laxson, C.L. 2010. Review of effects and costs of road de-icing with recommendations for winter road management in the Adirondack park. Adirondack Watershed Institute.

[6] Frades, M. 2008. Hydrologic analysis of the headwater Lamprey River Watershed using water isotpes. MS Thesis, University of New Hampshire, Durham, New Hampshire.

Accumulation of Chlorides

Chloride can move through the landscape in a variety of ways. Focusing on chloride based road salts, we can track the different ways that pollution can enter surface water (creeks, lakes, or streams) and groundwater (water below Earth's surface). Once the salt is applied to the pavement, it can either dry or be carried by ice meltwater. The dry salt powder is then aerosolized as dust (later settling onto land) or resuspended in rainwater. Rainwater has the same impact as road surface melt: it can runoff to surface water or it can seep into soil and groundwater. The flow diagram in **Figure 3** highlights potential impacts of chloride on terrestrial and aquatic systems.

Because chlorides are usually not part of biological or chemical cycling, Cl^- ions remain in groundwater for decades[8], or in surface water until they can reach an ocean or be deposited ashore. Substrate type plays a large role in how chloride moves through the landscape. This is because soils differ in how porous they are and therefore how quickly ions can move through them. A discussion of how soil type affects chloride in the Spring Creek Watershed is found on page 13.

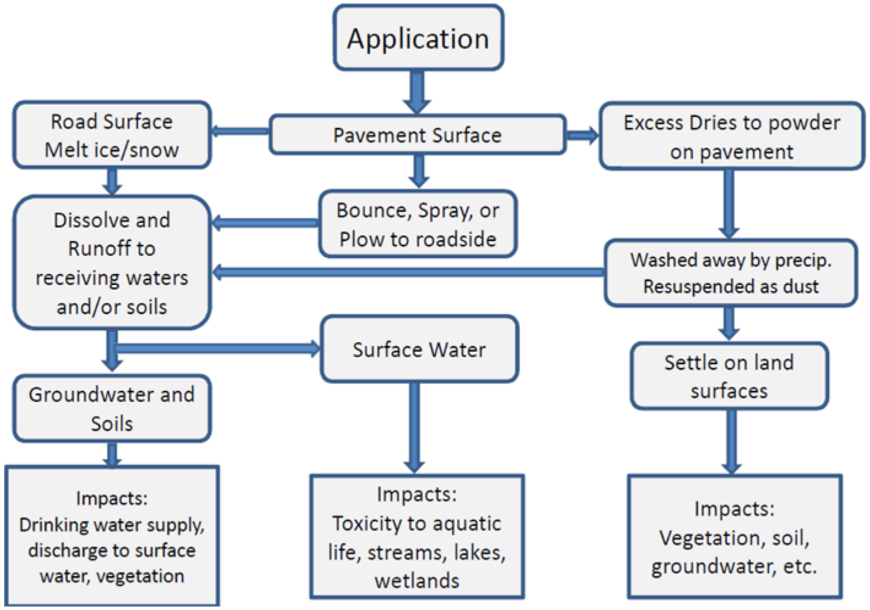

Figure 3. Environmental impact of road salt[7]

Urbanization has also been linked to increases in chloride concentrations in streams, rivers, and lakes across the United States. Urban areas are covered with impermeable surfaces such as roadways, parking lots, sidewalks, and buildings that prevent seepage of water into soil. During snow melt or rain events, chloride ions can be transported to nearby waterways in runoff more quickly on paved surfaces than a natural landscape. More impermeable surfaces also result in increasing rock salt usage because they are slippery during snow and ice events.

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[7] Corsi, S.R. et al. 2006. Road salt: widespread aquatic toxicity and water-quality impacts on environmental waters. U.S. Geological Survey Presentation.

[8] Kelly, V.R. et al. 2010. Road salt moving toward the solution. Special Report for the Cary Institute of Ecosystem Studies.

Season also affects chloride concentrations in freshwater. Road salt is applied during the winter. Therefore chloride concentrations are highest during late winter and early spring when runoff carries chloride into streams. While peak levels have been recorded during this time, increasing chloride concentrations have also been recorded across all four seasons indicating retention of chloride within aquatic ecosystems[9,10].

Salt accumulation on a river bank. From www.dwa.gov/za

Toxicity of Chlorides

Impacts of chloride accumulation in freshwater include drinking water contamination and mortality of aquatic species. Chloride itself is not directly harmful to human health, but its association with sodium does pose concerns for those who have sodium restrictive diets.

Human health is not directly affected by chloride in freshwater, but organisms living in streams and rivers can be sensitive to chloride pollution. Chloride presence in water can hinder an organism's ability to osmoregulate, i.e. it cannot keep its internal fluids from becoming too dilute or too concentrated. Since all aquatic organisms perform this process differently, they have varying tolerance levels to water pollution. Animals that reside in saltwater are equipped to maintain normal body conditions by getting rid of extra salt. Since freshwater animals don't have a way to excrete excess salt, they cannot handle high chloride concentrations. High chloride levels can harm a variety of aquatic species such as caddisflies[11] and amphibians[12].

Amphibians in particular are sensitive to chloride because they primarily osmoregulate and breathe through their

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[9] Silver, P.A., et al. 1996. Journal of Environmental Quality; 25: 334-345.

[10] Paul, M.J. and Meyer, J.L. 2001. Streams in an urban landscape. Annual Review of Ecological Systems; 32: 333-365.

[11] Hamilton, R.W., et al. 1975. Lethal levels of sodium chloride and potassium for an Oligochaeta, a chironomid midge, and a caddisfly of Lake Michigan. Environmental Entomology; 4: 1003–1006.

[12] Russell, R.W., and Collins, S.J. 2009. Amphibians as Indicators of Disturbance in Forests: Final Report. Nova Scotia Habitat Conservation Fund and Nova Scotia Department of Natural Resources.

skin[13]. These organisms also reproduce in roadside ponds during spring when chloride concentrations are highest[12]. Negative effects are most commonly seen at very high freshwater concentrations (>1,000 mg/L) which occur when chloride has accumulated over time in a single location due to loading or evaporation (e.g. in a roadside pool). Chloride pollution can result in deformities such as abnormal limbs, reproduction problems, and even death.

Chloride contamination of water is also a major cause of corrosion of steel reinforcement used within concrete structures. Structures that are heavily damaged by chloride containing water include bridge decks, parking garages, and structures located near salt water. These are the most highly impacted due to high road salt application or because of the high chloride concentration in salt water. In addition to sodium chloride, road salt may also carry small amounts of other elements such as phosphorus, nitrogen, copper, and cyanide.

Chloride salts also influence concentrations of heavy metals in soil and water. This is because positive metal ions can be readily exchanged for sodium, attaching chloride to those heavy metals and pulling them along with chloride. Since the metals are attached to the chloride, they also accumulate in the environment.

Restrictions on Chloride Concentrations

Typical streams and lakes in the United States with low chloride pollution have concentrations between 0 and 100 mg/L, with unpolluted streams ranging from 0-20 mg/L[14]. Chloride concentrations below 100 mg/L can therefore be considered “good”, with below 20 mg/L being the “best” water quality. Because many waterbodies today are seeing increases in chloride pollution, standards have put in place to regulate chloride concentrations.

Currently, there is no primary drinking water standard for chloride set by the Environmental Protection Agency (EPA). Primary standards are set to protect the public from consuming water that could have harmful heath effects. The secondary standard is based on aesthetic properties of the water that can be controlled at wastewater treatment facilities. The secondary EPA standard is set at 250 mg/L, the point where water begins to taste salty.

Because chloride concentrations can often reach toxic levels to freshwater organisms, water quality standards for chloride have been established[15]. In 1988 the EPA created standards that set the acute concentration limit (1-hour average criterion) at 860 mg/L. The chronic concentration limit (4-day average criterion) is 230 mg/L. The chronic criterion is equivalent to dissolving one teaspoon of salt in five gallons of freshwater.

[13] Shoemaker, V.H. and Nagy, K.A. 1977. Osmoregulation in amphibians and reptiles. Annual Review of Physiology; 39: 449-471.
[14] Goldman, C.R., and Horne. A.J. 1983. Limnology: New York, McGraw-Hill, 464 p.
[15] United States Environmental Protection Agency.1988. Ambient aquatic life water quality criteria for chloride.

Pennsylvania also has standards for publically owned treatment works and private wastewater treatment plants. These plants must maintain average chloride concentrations below 250 mg/L in their discharge water on a monthly basis. Although the 250 mg/L was established because of the shale gas industry it applies to all new or increased discharges of effluent with TDS greater than 2,500 mg/L. Some treatment plants may even have lower chloride effluent criteria.

How is Chloride treated?

Currently there are no biological methods to remove chloride from water and chemical and physical removal are costly for POTWs. The current methods to decrease concentrations within specific waterbodies include treatments such as reverse osmosis, dilution, and/or reducing chloride salt usage.

Antiskid alternatives

Scientists are currently investigating commercial antiskid alternatives and other methods to decrease road salt application rates. While it would be ideal to replace chloride deicers completely, there are no known alternatives that perform as well as a deicer and are as cost effective as sodium chloride. Therefore, attempts are being made to reduce sodium chloride usage by mixing road salt with other products in order to optimize the amount of road salt applied. Alternatives being tested in different regions of the United States include beet juice, cheese brine, molasses, and sand.

Additional alternatives include organic deicers, which are commonly used to deice airplanes. The advantage to these is that they are non-corrosive and acetate based (no chloride component). Unfortunately this type of deicer creates low dissolved oxygen in streams, decreases soil quality and permeability, and increases microbial growth in water.

Technology has recently been used to optimize efficiency of road salt application. By having application mechanisms that regulate salt dispersal, the correct amount of salt can be calculated and applied as the driver covers the given route. Since over

Want to get your water tested?

A list of water quality labs within the Centre County region accredited by the Department of Environmental Protection to monitor chloride in drinking and non-drinking water can be found online at:

http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?%2fLabs%2fLab_Certification&rs:Command=Render

Once on the website use the following criteria:

Analyte: Chloride **Method**: Select All **County**: Centre salting provides no added deicing benefit, minimizing application rates can help reduce concentrations found in streams. Utilizing a salt brine instead of solid salt crystals has been effective in many municipalities because there are fewer opportunities for the salt to bounce off the road and into nearby areas and can be used before a storm to prevent ice formation. Additionally, temperature sensors installed underneath the salt truck can give real-time data on pavement temperatures. This information enables municipal workers to decide which type of road deicer will be the most effective.

How do beet juice and cheese brine work?

While many may think these solutions work well to deice roads themselves, they actually do not. They work well in combination with road salt because they are sticky! The solutions essentially work as glue that the salt can stick to, minimizing how much of the salt bounces off onto roadsides or into streams. Another added benefit of using cheese brine or beer waste is that they contain sugar, which lowers the freezing point of the salts, making sodium chloride more effective. There is a downside of using some of these products includes. Adding sugar to streams can stimulate growth of bacteria and enhance the residual odor from cheese brine.

A PennDot deicing truck uses a mixture of brine and beet juice in 2014. Photo from: news.nationalgeogrpahic,com

Chloride Trends in the U.S. and Chesapeake Bay

Human population growth and land development can explain much of the chloride changes seen in freshwater systems. As urbanization continues across the nation, impermeable surfaces and subsequent road salt usage increase. Since road salt does not degrade, it arrives and accumulates in the roadside landscape, eventually draining into freshwater ecosystems. A number of nationwide studies conducted over the past decade link road density and road salt application to rises in Cl^- levels in streams and rivers.

As a result of urbanization, chloride levels in many watersheds have reached all time high concentrations. Watersheds dominated by urban land use in Maryland, New York, and New Hampshire have documented chloride levels up to 25% of the concentration of seawater in winter and almost 100 times as concentrated as unimpaired freshwater streams in mid-summer[16]. Analysis of data from chloride concentration within surface and groundwater in

[16] Kaushal, S.S., et al. 2005. Increased salinization of fresh water in the northeastern United States: Proceedings of the National Academy of Sciences: 102, 13517–13520.

44 sub-basins in New Hampshire attributed over 75% of differences in chloride level to surrounding road density[15]. As road density increases within these areas, road salt usage is also projected to increase. In **Figure 4**, we show the correlation between percent impervious surfaces and mean annual chloride concentration in Baltimore streams[16].

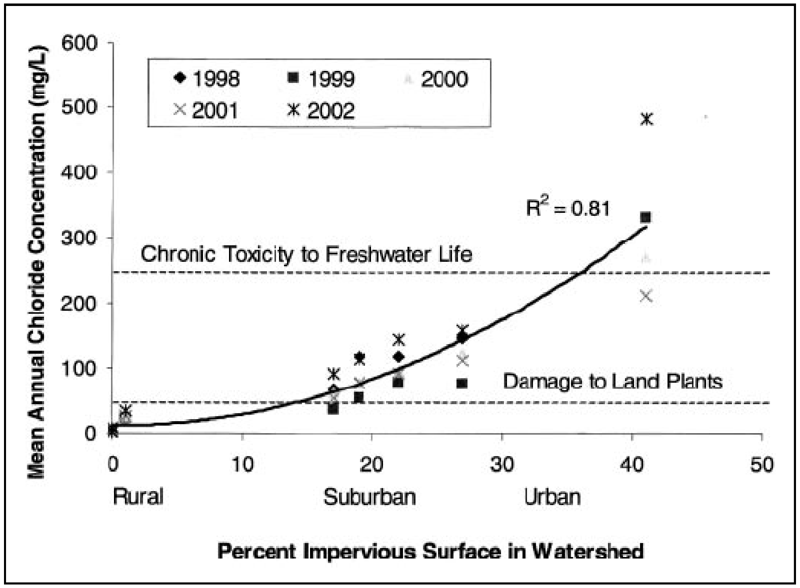

Figure 4. Relationship between impervious surfaces and mean annual chloride concentration.

Nationally, the United States used approximately 22 million tons of road salt in 2014, equating to about 137 pounds of salt per individual. Overall the trend in road salt application has increased since 1940. Unsurprisingly, waterbodies across the United States have mirrored upward chloride trends with time in regions where harsh weather conditions require road salt application. In 2015, the United States Geological Survey[17] reported that chloride levels sampled in streams across the northern U.S. often exceed the EPA's measure for chronic (4-day average) pollution. This occurred on more than 100 days annually between 2006 and 2011 which almost doubled the number of polluted streams from surveys in 1990 -1994.

The Chesapeake Bay watershed receives almost a third of the total salt load derived from deicers applied within the United States. The Chesapeake Stormwater Network estimated in 2005 approximately 2.5 millions tons of rock salt were used on 200,000 miles of road surfaces. Since salt usage in this area is high, chloride contamination sources in freshwater are of specific concern. Data from the previously mentioned long term study in Baltimore show land use, drainage area, and population density have a large influence on nearby stream chloride concentrations (**Table 2**).

Chloride concentration within rural streams were between 9 and 116 mg/L which is typical of waters with low chloride contamination[16]. Urban and suburban streams in the Baltimore study revealed a wide range of concentrations between 29 and 4629 mg/L. Chloride levels above 230 mg/L over four or more days and 860 mg/L over

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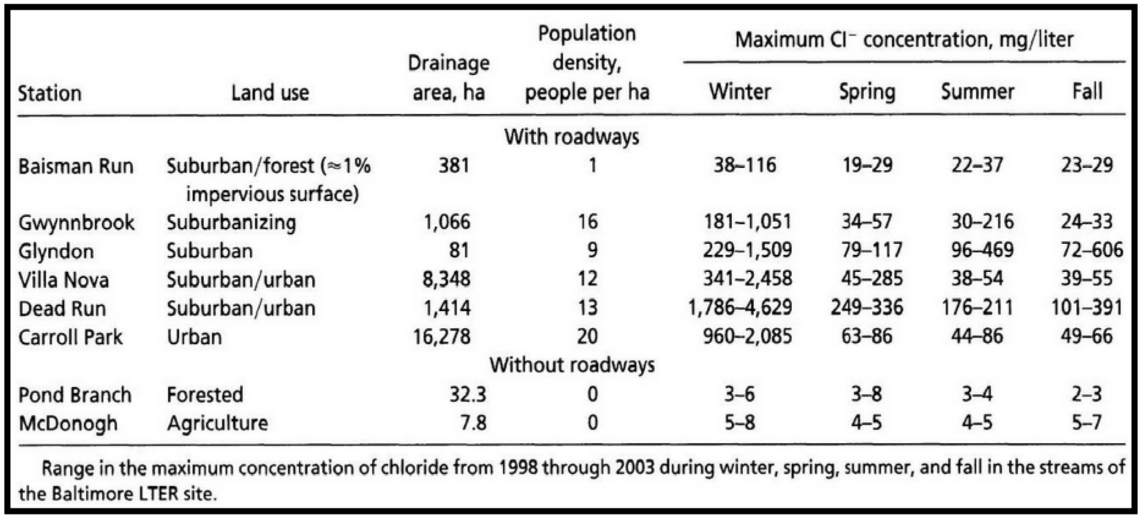
[17] Corsi, S.R. et al. 2015. River chloride trends in snow-affected urban watersheds: increasing concentrations outpace urban growth rate and are common among all seasons. Science of the Total Environment, 508:488-497.



Station	Land use	Drainage area, ha	Population density, people per ha	Maximum Cl⁻ concentration, mg/liter			
				Winter	Spring	Summer	Fall
			With roadways				
Baisman Run	Suburban/forest (≈1% impervious surface)	381	1	38–116	19–29	22–37	23–29
Gwynnbrook	Suburbanizing	1,066	16	181–1,051	34–57	30–216	24–33
Glyndon	Suburban	81	9	229–1,509	79–117	96–469	72–606
Villa Nova	Suburban/urban	8,348	12	341–2,458	45–285	38–54	39–55
Dead Run	Suburban/urban	1,414	13	1,786–4,629	249–336	176–211	101–391
Carroll Park	Urban	16,278	20	960–2,085	63–86	44–86	49–66
			Without roadways				
Pond Branch	Forested	32.3	0	3–6	3–8	3–4	2–3
McDonogh	Agriculture	7.8	0	5–8	4–5	4–5	5–7

Range in the maximum concentration of chloride from 1998 through 2003 during winter, spring, summer, and fall in the streams of the Baltimore LTER site.

Table 2. Land use and peak concentrations of chloride in Baltimore streams from 1998-2003.

multiple hours indicate levels when freshwater organisms are affected by chloride pollution. Results from the Baltimore study prompt concerns about chloride concentrations within Pennsylvania streams because of the substantial amount of road salt applied statewide each year.

Spring Creek Watershed

Many factors including bedrock and land use can affect the spatial distribution of chloride in surface and groundwater of the Spring Creek Watershed. The Spring Creek Watershed falls within what is known as the Ridge and Valley Province of the Appalachian Mountains in central Pennsylvania. Within this province both carbonate (limestone and dolomite) and sandstone and shale bedrock persist. Areas that are underlain with carbonate bedrock are especially susceptible to groundwater contamination because of the quick movement of contaminants through the substrate[18]. Water recharge occurs when precipitation drains through the valley floor and enters the soil or when precipitation moves through the landscape and enters surface flow, eventually becoming groundwater[18].

Because groundwater feeds many of the streams in the Spring Creek Watershed, there is a close relationship between groundwater and surface water contamination. Within this area of carbonate bedrock, the background source of chloride from limestone is low within springs[19]. Therefore, we assume bedrock contributes very little of the concentration found within springs and surface water in Spring Creek and its tributaries. Previous studies have linked most chloride contamination within the Spring Creek Watershed to road salt application[19].

Land use can explain much of the variation in chloride concentrations within different waterbodies. Land development is commonly associated with high chloride concentrations because of increased runoff from impermeable surfaces that have been treated with road salt. Sinkholes are a common feature of limestone geology and can transfer contaminants to groundwater more quickly than percolation through soil. Transfers through sinkholes provide a “direct injection” of contaminants to groundwater, which is often a source of baseflow to surface waters. Agriculture can also contribute to chloride contamination if high concentrations of fertilizer are applied near water sources. Forested areas are associated with low concentrations of chlorides in streams.

A previous study by Chang and Carlson in 2004[20] in the Spring Creek Watershed at the same sampling locations examined in the current study showed a positive relationship between chloride concentration and percent of urbanization. While this study examined stormwater concentrations, baseflow chloride should follow the same trends. During stormwater events, contaminants such as chloride peak during the first flush of stormwater and then

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[18] Konikow, L.F. 1969. Mountain runoff and its relation to precipitation, ground water, and recharge to the carbonate aquifers of Nittany Valley, Pennsylvania. M.S. Thesis, The Pennsylvania State University.

[19] Kastrinos, J.R., and White, W.B. 1986. Seasonal, hydrogeologic, and land-use controls on nitrate contamination of carbonate ground waters. Proceedings of the Environmental Problems in karst Terranes and Their Solutions Conference: 88-113.

[20] Chang, H., and Carlson, T.N. 2004. Water quality during winter storm events in Spring Creek, Pennsylvania. Hydrobiologia; 544:321-332.

drop off after the storm has passed. Because we sample streams at stable flows, we do not find the high chloride concentrations typically associated with storm flows.

In the 2004 study, the two highest average and maximum concentrations of Cl^- occurred at monitored sites in Thompson Run (97 and 551 mg/L, respectively) and Lower Slab Cabin Run (70 and 363 mg/L, respectively). Both of these locations are in highly urbanized settings where roads are in close proximity to the stream (**Figure 5** on page 15). The authors of this study suggest 3 possible sources of chloride: bedrock, leaking underground sewage pipes, and salts applied to impermeable surface such as roadways[20].

A later investigation in the Spring Creek Watershed during 2011 suggests that the downtown State College area stormwater runoff averaged ~20.5 mg/L[22]. This average only includes the stormwater running into the duck pond at The Pennsylvania State University and does not include any baseflow. Compared to other urban watersheds, this seems to be a very low concentration of chloride runoff entering surface water, suggesting that the pollution has infiltrated the water source, rather than entering the surface flow.

Statewide, Pennsylvania applied approximately 1.2 million tons of solid road salt, 10.6 million gallons of salt brine, and 854,000 tons of anti-skid during winter 2013-2014[21]. Data collected from two townships in the watershed indicate road salt application rates have been rising since the 1980's (Brent Brubaker-Patton Township and Gary Williams-College Township, personal communications). This trend is shown for Patton Township in **Figure 6**.

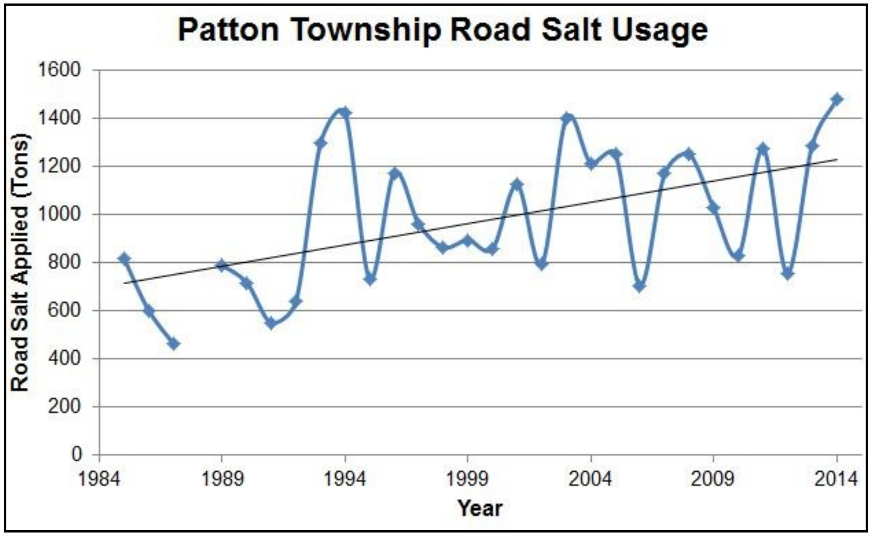

Figure 6. Road salt application in Patton Township from 1985 to 2014.

Road salt application (or purchase) by PennDot, Patton and College Townships, and The Pennsylvania State

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[21] Tosca, S., and Reck, N. 2014. Optimizing PennDOT's snow routes and planning process with GIS. Department of Transportation PowerPoint Presentation.

[22] Blansett, K. 2011. Flow, water quality, and SWMM model analysis for five urban karst watersheds. Ph.D. Thesis: The Pennsylvania State University.

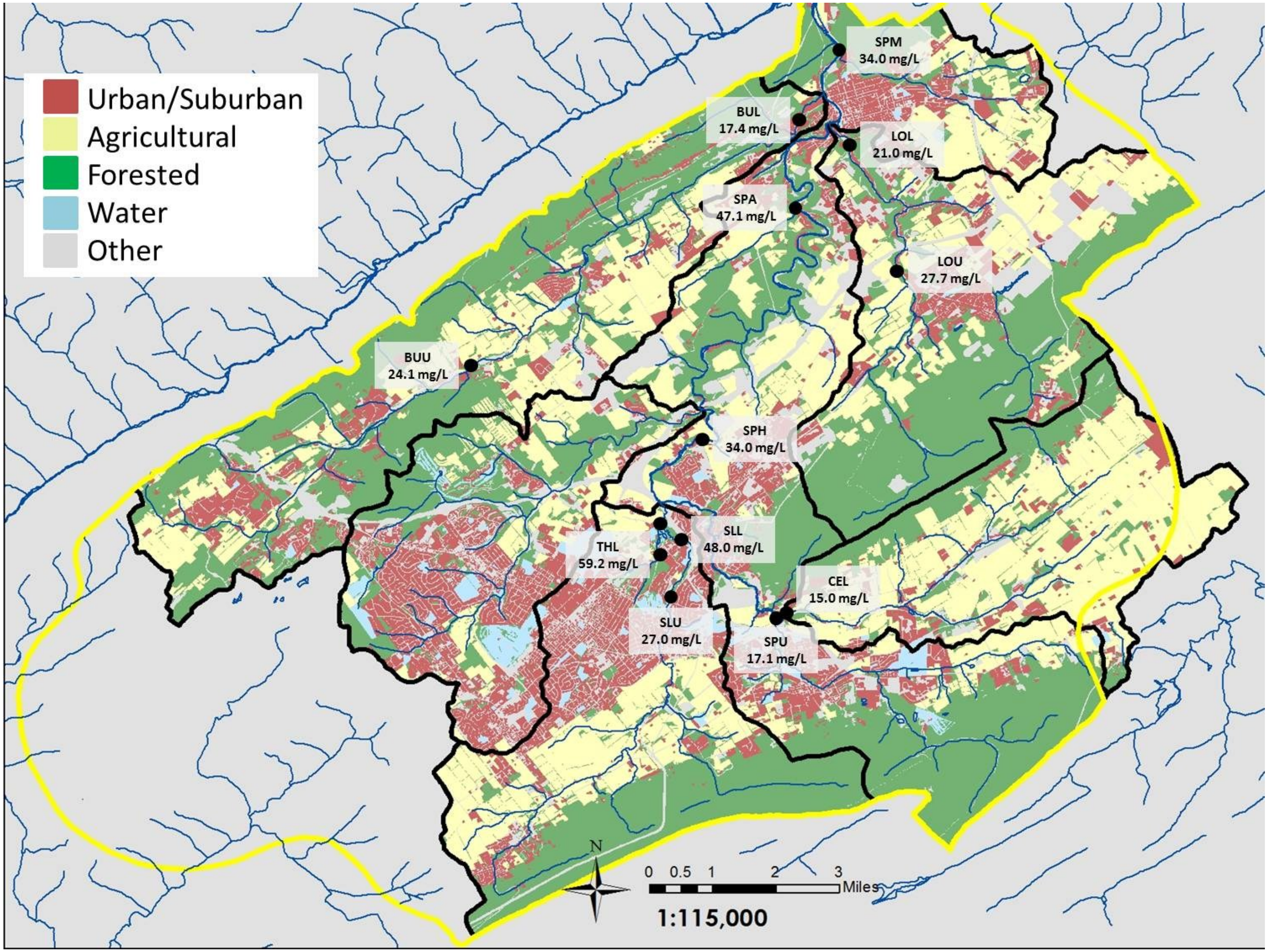


Figure 5. Map represents land use patterns in the Spring Creek Watershed, yellow line is groundwater boundary and black lines surface water boundaries. Boxes include WRMP site abbreviation and median chloride concentrations (mg/L) collected over the period of record. Land use data: Centre County Planning and Development Agency (2010).

University for 2014 is listed in **Table 3**. PennDOT is responsible for 7,709 lane miles in District 2, while municipalities are only responsible for 157 lane miles[20]. In general, municipalities apply much less deicer than PennDOT because they control a smaller portion of lane miles. Private salt usage is not reflected in these data because of difficulty obtaining the application rates.

Agency	**Tons Used (U) or Purchased (P)**
PennDot District 2	19,300 (U)
College Township	1575 (U)
Patton Township	1478 (U)
The Pennsylvania State University	1,000 (P)

Table 3. Road salt usage or purchase by agencies in Centre County.

The dataset collected by the Water Resource Monitoring Project provides an opportunity to track chloride levels in the Spring Creek Watershed over a long time period. We paired this dataset with land use within the area to attempt to explain variation in chloride concentrations and sources of chloride pollution. On the following pages we summarize chloride concentrations at several sites over a 16-year period.

Monitoring Chloride in the Spring Creek Watershed

The Water Resources Monitoring Project has been monitoring chloride concentrations in the Spring Creek Watershed since the project began in 1999. The long term dataset provided by the WRMP offers insight into chloride trends at 12 sites within the Spring Creek Watershed. Monthly sampling was conducted from 1999 to 2003, until 2004 when sampling frequency was changed to a quarterly time frame. All water quality monitoring takes place during base flow because of the influence storm water has on sample results. With the exception of 2005 and 2011 (only 3 sampling events), samples have been consistently collected at a quarterly interval. During 2014, chloride samples were collected at 14 water monitoring sites within the Spring Creek Watershed.

This long-term dataset on chloride concentration is not only one of a kind, but also provides an opportunity to evaluate the long-term trends in chloride concentrations over the past 16 years over a large portion of the watershed.

Chloride in 2014

Within the Spring Creek Watershed, recorded chloride concentrations at the 14 monitoring sites in 2014 ranged from 0.5 mg/L (Buffalo Run at Valley View) to 91.7 mg/L (Thompson Run at East College Avenue). Overall, median chloride values were between 1.15 and 79.7 mg/L. Chloride summary statistics for 2014 at all 14 monitoring sites are found in **Table 4** on page 17.

Chloride concentrations at the seven monitored springs ranged from 4.5 mg/L (Blue Spring) to 111.3 mg/L (Walnut Spring). Overall, median chloride values ranged from 4.7 mg/L (Blue Spring) to 101.9 mg/L (Walnut Spring) (**Figure**

Table 4. Chloride summary statistics for fourteen WRMP stream monitoring sites collected during 2014. N represents number of observations and SD represents standard deviation.

Site Name	Abbrev	N	Median	Mean	Max	Min	SD
Cedar Run - Oak Hall	CEL	4	16.4	17.6	22.9	14.9	3.2
Slab Cabin Run - S. Atherton	SLU	4	34.1	34.2	37.1	31.3	2.6
Slab Cabin Run - E. College	SLL	4	58.6	58.0	64.5	50.1	6.2
Slab Cabin Run - Millbrook Marsh	MIL	4	79.7	78.7	86.9	68.5	6.6
Thompson Run - E. College	THL	4	72.5	76.5	91.7	69.4	8.9
Buffalo Run - Fillmore	BUU	4	53.2	54.5	72.5	39.2	14.4
Buffalo Run - Valley View	BVV	4	27.1	26.2	50.2	0.5	17.9
Buffalo Run - Coleville	BUL	4	27.8	30.1	42.0	22.8	7.9
Logan Branch - Pleasant Gap	LOU	4	46.7	47.8	57.8	39.9	6.4
Logan Branch - Bellefonte	LOL	4	33.7	34.3	37.5	32.2	2.0
Spring Creek - Oak Hall	SPU	4	22.2	21.9	25.4	17.9	2.7
Spring Creek - Houserville	SPH	4	48.4	49.3	55.2	45.1	3.7
Spring Creek - Axemann	SPA	4	68.3	66.1	73.6	54.1	7.4
Spring Creek - Milesburg	SPM	4	50.1	50.9	56.2	47.4	3.2

Table 5. Chloride summary statistics for eight WRMP spring monitoring sites collected during 2014. N represents number of observations and SD represents standard deviation.

Site Name	Abbrev	N	Median	Mean	Max	Min	SD
Axemann Spring	AXS	4	50.0	49.4	51.1	46.6	1.7
Benner Spring	BES	4	62.8	64.8	72.0	61.7	4.2
Big Spring	BIS	4	22.6	22.9	24.2	22.3	0.8
Blue Spring	BLS	4	4.7	4.8	5.2	4.5	0.3
Continental Courts Spring	COS	4	21.8	22.1	23.4	21.4	0.8
Linden Hall Park Spring	LIS	4	8.0	8.5	10.3	7.8	1.0
Walnut Spring	WAS	4	101.9	103.0	111.3	96.7	5.6
Winding Hill Spring	WIS	4	27.7	28.5	34.9	23.8	4.2

7). Blue Spring is located at the base of Tussey Mountain and drains a predominately forested landscape. Walnut Spring, located on the border of a public park and residential development, has traditionally had elevated chloride levels. Land use could explain high concentrations at this sampling site.

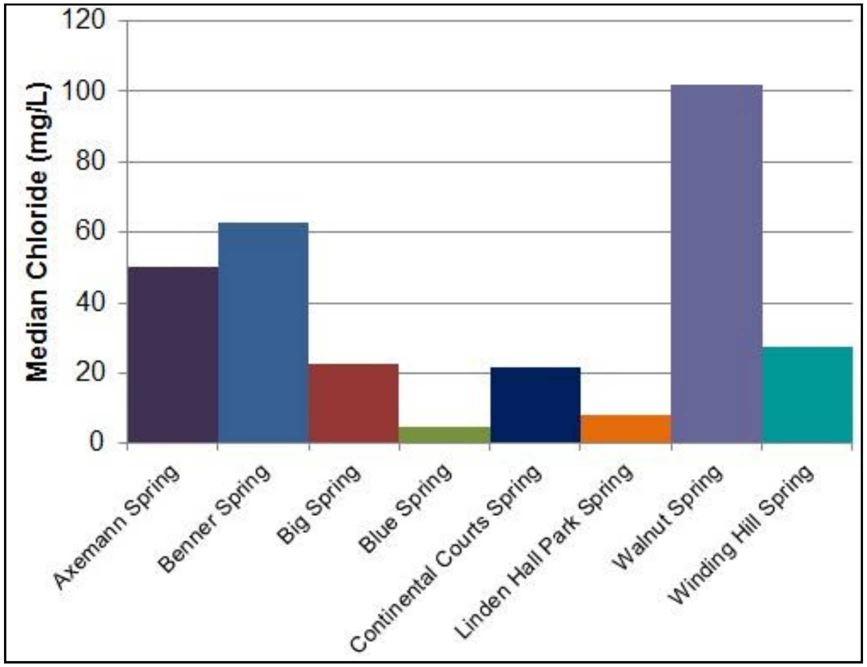


Figure 7. Median chloride concentration at eight spring sites during 2014.

Chloride summary statistics for the eight springs during 2014 are found in **Table 5** on page 17. The standard deviation for Benner Spring was high because of an increase in chloride during December 2014. Walnut Spring and Winding Hill Spring had high chloride concentrations during March 2014 but dropped off as the year progressed. Chloride summary statistics for the entire dataset (1999-2014) are presented for the 12 monitoring sites in **Table 6** on page 19.

The highest median chloride levels in 2014 within tributaries of Spring Creek were found in Slab Cabin Run at Millbrook Marsh (MIL) and Thompson Run on East College Avenue (THL). The median concentration at Millbrook Marsh was 79.7 mg/L and at Thompson Run was 72.5 mg/L.

The Thompson Run site has traditionally had the highest chloride concentration of all monitored sites, most likely because the site is the most urbanized of all sampling locations[20]. At this location, impervious surfaces cover ~50% of the landscape and drain into Thompson Spring, which feeds Thompson Run (Larry Fennessey, The Pennsyvlania State University, personal communication). The stream site and spring sit directly between two highly travelled roads and are located directly downgradient from State College Borough. High median values could be related to land use in this area and road salt application on impermeable surfaces.

The highest median chloride levels in Spring Creek were found at the Axemann site (SPA). The median concentration at this site was 68.3 mg/L.

Seasonal evaluation of chloride in 2014 showed peak concentrations occurring at different times among sites. There were two main trends in the data: peaks in early and late winter that declined during spring and summer

Table 6. Chloride summary statistics for twelve WRMP stream monitoring sites collected between 1999 and 2014. N represents number of observations and SD represents standard deviation.

Site Name	Abbrev	N	Median	Mean	Max	Min	SD
Cedar Run - Oak Hall	CEL	93	15.0	15.3	26.1	11.0	2.6
Slab Cabin Run - S. Atherton	SLU	74	27.0	29.8	139.4	16.0	21.6
Slab Cabin Run - E. College	SLL	93	48.0	53.4	114.0	24.0	23.3
Thompson Run - E. College	THL	93	59.2	63.6	230.0	40.6	21.3
Buffalo Run - Fillmore	BUU	81	24.1	28.0	72.5	13.0	10.9
Buffalo Run - Coleville	BUL	93	17.4	17.9	42.0	11.0	4.8
Logan Branch - Pleasant Gap	LOU	93	27.7	29.7	62.8	11.7	11.2
Logan Branch - Bellefonte	LOL	93	21.0	22.4	37.5	15.0	4.82
Spring Creek - Oak Hall	SPU	94	17.1	17.4	28.2	5.3	4.19
Spring Creek - Houserville	SPH	92	34.0	35.8	61.1	23.0	7.9
Spring Creek - Axemann	SPA	93	47.1	48.8	74.3	29.0	9.8
Spring Creek - Milesburg	SPM	93	34.0	35.7	56.2	23.0	6.4

(indicating no time of year when chloride loading is high), and steady trends across the seasons until early winter when an increase occurred (increase in Cl^- input). **Figure 8** shows chloride concentration across the four seasons in 2014 at Thompson Run. This site showed concentrations that stayed steady from early spring to late fall and then increased in early winter.

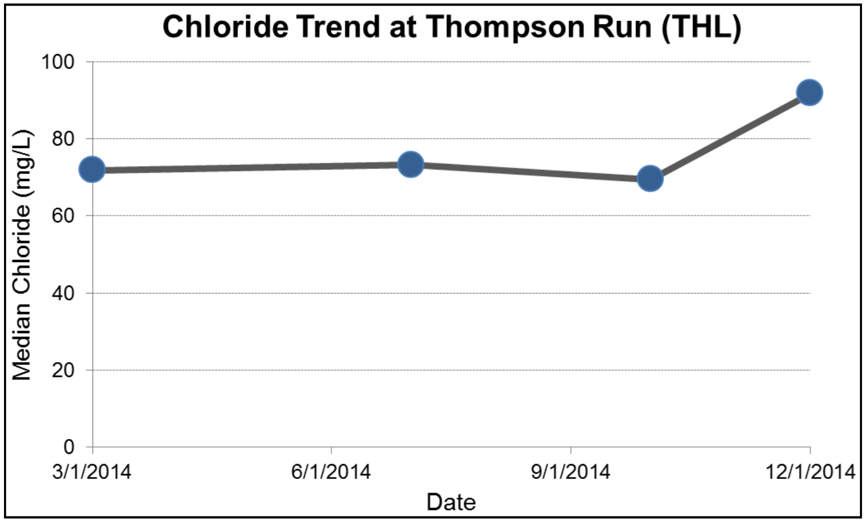


Figure 8. Chloride levels in Thompson Run during 2014.

Thompson Run receives almost 100% of its flow from Thompson Spring, meaning their chloride concentrations should be almost identical. Chloride was monitored at Thompson Spring from 2005-2006 (average 47.5 mg/L) by Penn State. The chloride concentrations were similar to Thompson Run. Because chloride concentrations were similar between the two sites, it is likely that chloride is infiltrating groundwater and being released into baseflow from the spring. The chloride concentrations at Thompson Spring are high likely due to urban runoff entering upslope sinkholes which are prevalent in the aquifer. Because the values are similar at these two sites, we can also suggest that almost all of the chloride within this urban area is entering the system via direct groundwater injection at sinkholes, with very little added through stormwater runoff into surface water.

Role of Land Use

Land use can explain much of the variation between chloride levels at sites within the Spring Creek Watershed. To evaluate the role of land use, percentages of agricultural, developed, and forested land were compared to chloride levels. A map of agricultural, developed, and forested land within the Spring Creek Watershed is found in **Figure 5** on page 15. The Spring Creek Watershed can be broken down into three main land uses: 30% agriculture, 22% commercial and residential development, and 41% forested. The remaining surfaces are either unclassified or waterbodies.

Percent land development appears to be the best land use predictor for chloride concentration (**Figure 9**) within four analyzed sites. These four sites were chosen because land use data were available and chloride levels existed for the sixteen year dataset. As developed land increased, median chloride concentration also increased. The current analysis only contained sites that were up to 30% developed. Even though developed land was not the dominant land use type, it explained 90% of the variation within the data collected

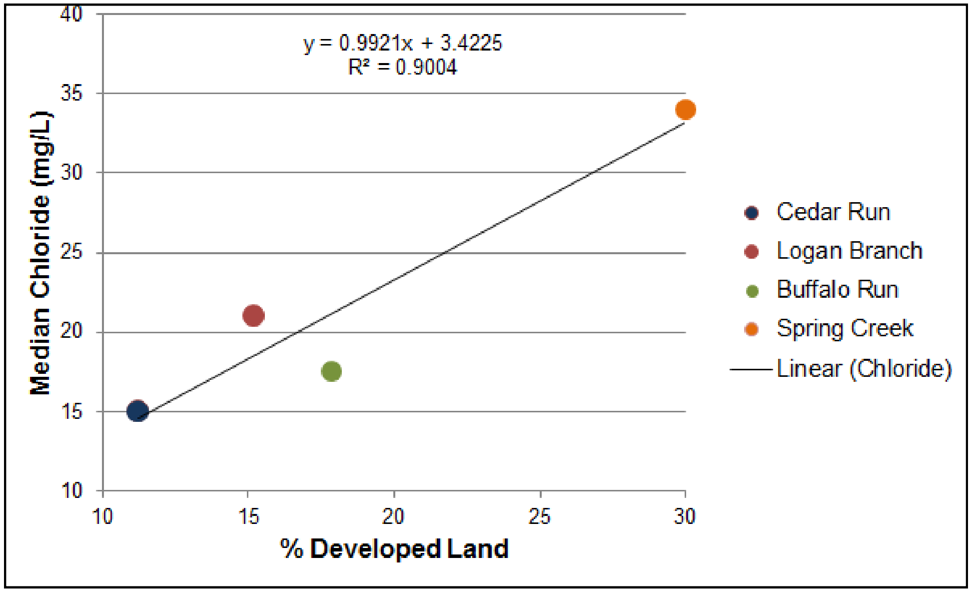


Figure 9. Median chloride concentration as a function of percent developed land within four sites in the Spring Creek Watershed.

from the four sites. This suggests land development has a strong influence on chloride. Possible explanations for this could include increases in impermeable surfaces, or increased use of chloride deicers on roads, sidewalks, or parking lots.

Agriculture and forested land did not display a strong relationship between land use and chloride concentration. Agriculture could explain approximately 20% of the variation between sites, while forested land explained less than 1%. There could be many explanations why these land uses did not correlate well with chloride. It may be that runoff from agriculture is percolating into the ground instead of entering the surface water, or it may be that runoff from agriculture does not strongly influence chloride concentrations at sampled sites within the Spring Creek Watershed.

These relationships highlight the influence that land use can have on chloride concentrations within a watershed. It is evident that development has an influence on the input of chloride into the surface water of the Spring Creek Watershed, matching trends seen across the U.S. We see high concentrations of chloride in urban areas in both groundwater and surface water because of the many sinkholes in the area which directly inject the contaminants into the aquifer.

Chloride Trends from 1999 to 2014

To evaluate long-term choride trends, a Theil-Sen Trend Analysis was performed using the Environmental Protection Agency's (EPA) ProUCL software. This is a software that has been developed by the EPA to allow for analyses of water quality data.

Although the present Water Resources Monitoring Project collects quarterly water quality samples at 23 stations including both stream and spring sites, trend analysis was only performed on 12 stations because of the 16 year dataset they provided. The remainder of the sites only included a subset of the sampling dates due to the addition of stations in later years of the project. Because of the reduced years of the collection, we did not feel that it was appropriate to include them in this analysis. Observations ranged from 74 to 94 measurements across the sites, and each observation was expressed in months (1-196). For example, January 1999 was “Month 1”, June 1999 was “Month 6”, and so on up to December 2014 which was defined as “Month 196”. Providing a date value by month for each sampling over the 16 yeas was required by the software to complete the trend analysis.

The results of the chloride (mg/L) trend analysis for each site are presented in **Table 7**. Plots of subset of the analyses (Buffalo Run Above Fillmore (BUU) and Spring Creek at Fishermans Paradise (SPU)) are presented in **Figures 10 & 11** on pages 24 and 25, respectively. These sites showed the greatest net change in the 16 year data set for a tributary (Buffalo Run above Fillmore) and for Spring Creek (Spring Creek below Fisherman’s Paradise).

All sites indicated either a statistically significant increase in chloride concentrations between 1999 and 2014, or no significant change in chloride concentrations. No decreasing trend in chloride was observed at any site through the analysis, indicating that chloride concentrations are predominately increasing throughout the watershed with exception of the Slab Cabin Run sub-watershed and at the Upper Logan Branch site.

Buffalo Run above Fillmore was the site that indicated the greatest rate of change in chloride over the 16 years (**Figure 10**). Concentrations at this site have risen from ~14 mg/L in 1999 to almost 73 mg/L in 2014. This represents almost a five-fold increase in a sixteen year time span. The

Table 7. Trend analysis results for average change in chloride concentration (mg/L) collected at 12 stream stations between 1999 and 2014 by year. Increasing indicates a statistically significant increase in chloride concentrations and no change indicates no statistically significant change in chloride concentrations over the years.

Site	Trend	Avg Change (mg/L/year)
Buffalo Run at Coleville	Increasing	0.60
Buffalo Run above Fillmore	Increasing	1.44
Cedar Run in Oak Hall	Increasing	0.12
Logan Branch in Bellefonte	Increasing	0.84
Logan Branch below Pleasant Gap	No Change	NA
Slab Cabin Run at E. College Ave.	No Change	NA
Slab Cabin Run at S. Atherton St.	No Change	NA
Thompson Run at E. College Ave.	Increasing	1.2
Spring Creek in Oak Hall	Increasing	0.48
Spring Creek in Houserville	Increasing	1.08
Spring Creek below Fisherman’s Paradise	Increasing	1.20
Spring Creek in Milesburg	Increasing	0.96

Buffalo Run above Fillmore. Photo: Lori Davis

Buffalo Run above Fillmore site is a mixture of agricultural, forested, and developed land (**Figure 5** on page 15, coded BUU). This site is located downstream from the I/99 highway overpass, which is a heavily traveled highway and therefore likely receives heavy road salt application.

All sites on the main-stem of Spring Creek also displayed increasing trends for chloride with Spring Creek below Fisherman's Paradise displaying the greatest rate of change (**Figure 11**). At this site, chloride levels have gone from 36 mg/L to 75 mg/L. This represents over a 100% increase in a 16 year time span. The Spring Creek Axemann site is directly downstream from the I/99 corridor. The elevated levels could potentially be due to road salt application or the acid mine drainage from pyrite used in construction of the highway. Acid mine drainage would have the same effects as acid rain on limestone, potentially releasing chloride ions.

Conclusions

Overall, chloride concentrations within the Spring Creek Watershed are increasing. While the median chloride concentrations recorded at the monitored sites did not exceed the secondary drinking water standard or either limit set for aquatic organisms, the data suggest chloride is increasingly impacting our surface water resources. Because the chloride concentrations in the current investigation are nearing (and in one instance exceed) the 100 mg/L threshold for "good" water quality, we should begin to take action to reduce chloride usage.

The highest concentration recorded within the Spring Creek Watershed in 2014 during baseflow conditions was at Walnut Spring (111.4 mg/L) and was still well below the 250 mg/L threshold for human consumption. This site, however, does exceed the 100 mg/L concentration that sets the "good" water quality benchmark. If concentrations continue to rise at the rate shown in our study, within 50 years our watershed could exceed drinking water standards and chronic toxicity limits for many freshwater species. This is a specific problem because spring water is commonly used as drinking water by residents of the Spring Creek Watershed and this water provides much of the baseflow for surface waters. Spring Creek and its tributaries are also home to a wide array of aquatic species, some of which are only found in this area.

The data from the Blansett thesis suggests that stormwater runoff to surface water is less in State College than in other urban watersheds. Since high concentrations of chlorides have been found in springs within the urbanized areas of the watershed, we suggest stormwater flows carrying high concentrations of chloride are entering groundwater via the numerous sinkholes located in downtown areas. This contamination leads to higher concentrations within the groundwater and subsequently in the surface water. Since chloride has increased dramatically over the sixteen year period, we propose it is worthwhile to examine groundwater contamination and measures that could be taken to decrease chloride inputs.

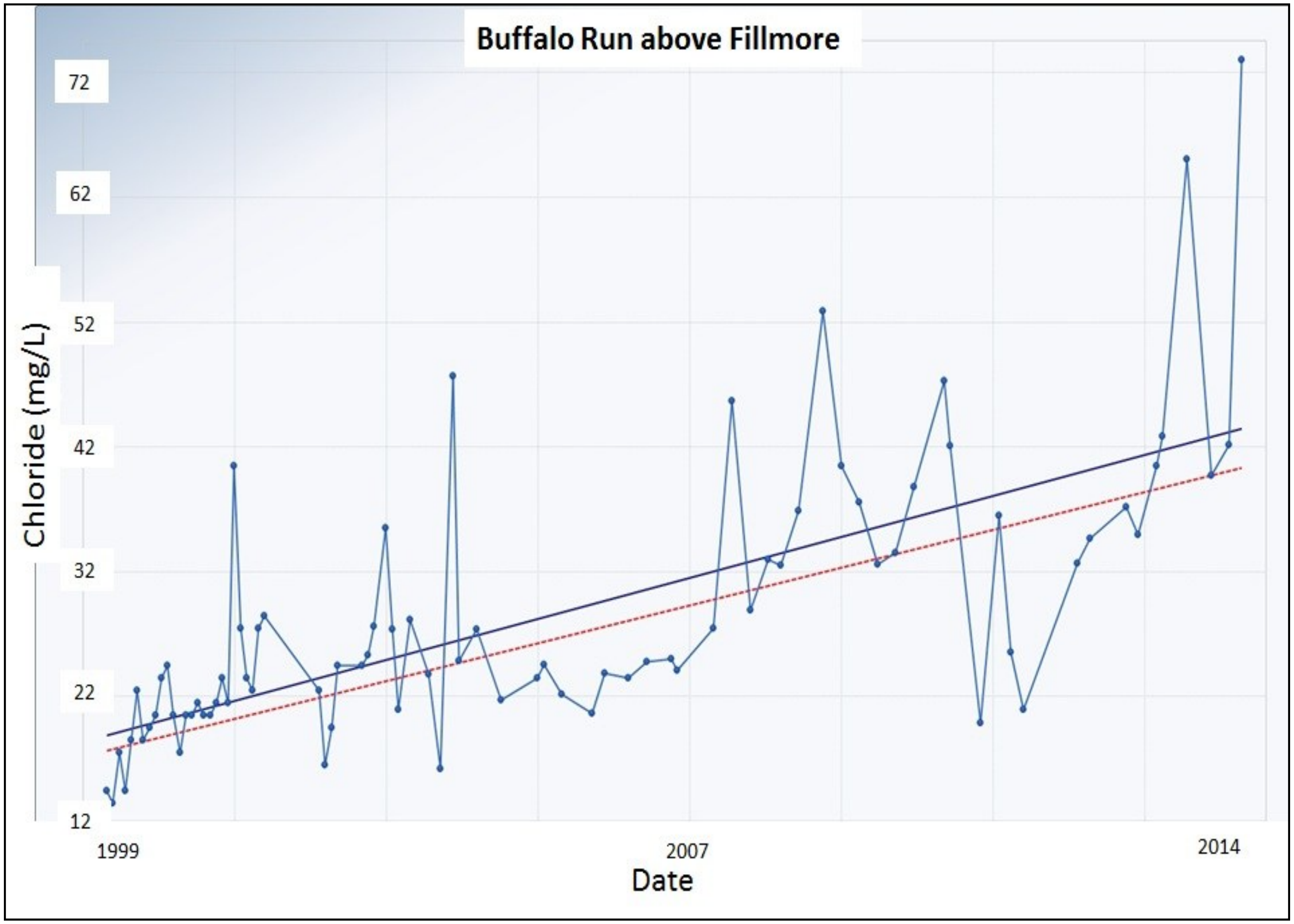


Figure 10. Trend analysis plot of chloride concentrations (mg/L) for Buffalo Run above Fillmore. Blue dots indicate individual observations, solid blue line and red dashed line indicate increasing trend.

It is important for officials and decision makers in the Spring Creek Watershed to realize that chloride contamination could become a local problem. As we proceed in the future, implementing additional chloride reducing initiatives will help municipalities and the general public meet chloride standards. We outline previous efforts to reduce chloride input to Spring Creek and ways that individuals can decrease their own chloride usage in the following section.

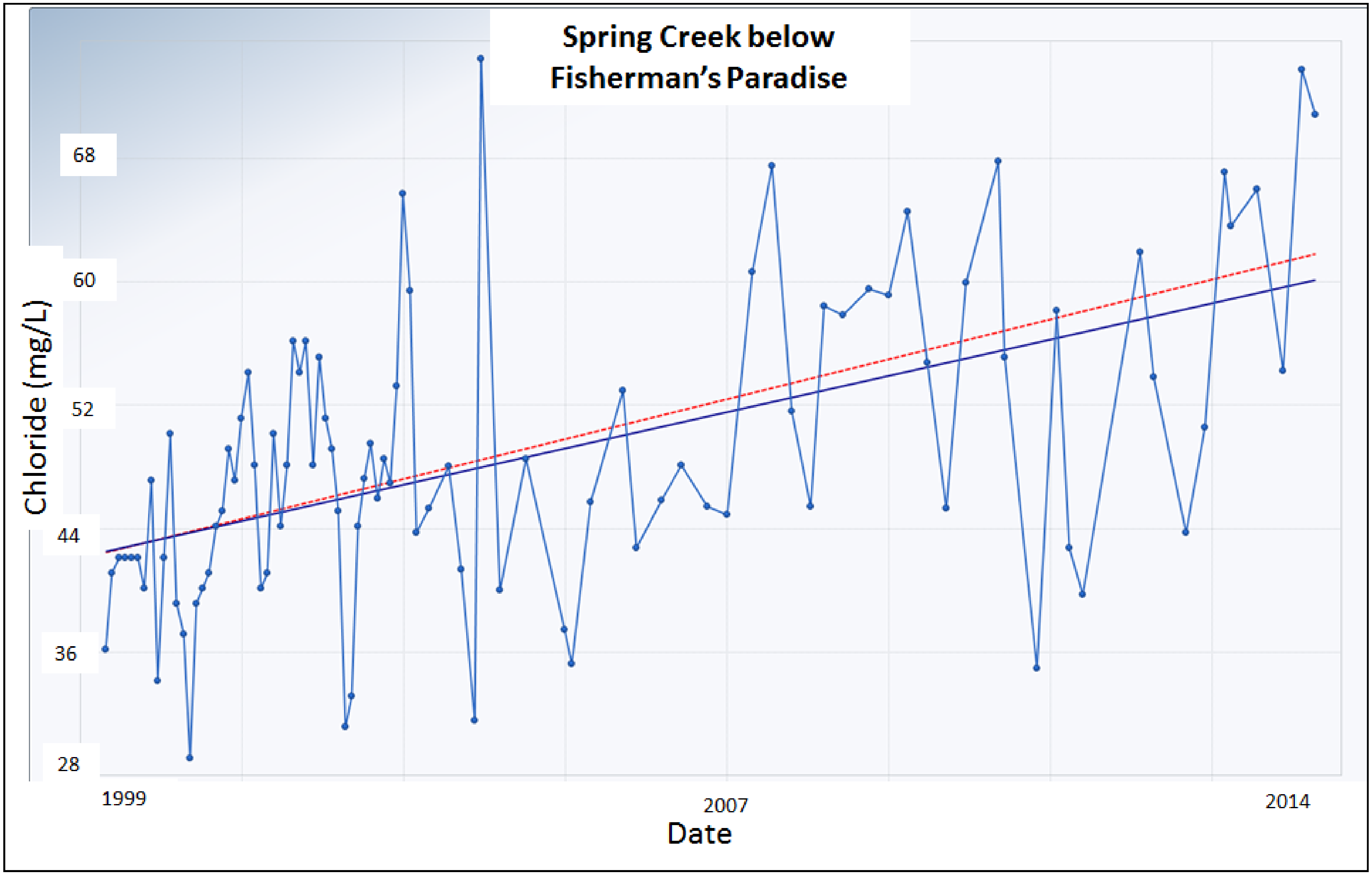


Figure 11. Trend analysis plot of chloride concentrations (mg/L) for Spring Creek below Fisherman's Paradise Blue dots indicate individual observations, solid blue line and red dashed line indicate increasing trend.

Local Road Salt Application

In a newspaper article from 2014, local authorities described how road salt is managed in Centre County, Pennsylvania. All of the road salt purchased for District 2, including Centre County, comes from American Rock Salt, located in Susquehanna County. To purchase road salt at a reasonable cost, boroughs piggyback on PennDOT's yearly salt contract to get a better price. State College, using PennDot's contract, paid $69.31 per ton for salt in 2014.

Highway Road Salt Application.
From: www.clf.org

Since the state and municipalities order salt for the next year before the winter season arrives, they must predict how much will be used. PennDOT's communication relations coordinator Marla Fannin states that agencies generally order 75-130% of the predicted demand for the next year. They make these estimates based on a five-year average usage of road salt.

Recently, more concerns have been voiced within the State College area about environmental issues resulting from road salt application. As a result, local municipalities and other agencies have been working to decrease application rates. Ferguson Township Public Works Director David Modricker says Ferguson has been using anti-skid material mixed in with the road salt to create a half and half mixture in an effort to decrease chloride usage. Modricker also says that municipalities concentrate salting efforts on tricky driving areas such as hills and curves where crash rates are higher. Areas that areas which are flat are plowed but not salted, in an effort to conserve salt.

How Can You Help?

Although the main contributor to chloride pollution of water is the application of road salt by state and government agencies, there are many ways that you can reduce chloride in your own home. These can include but aren't limited to:

- only soften water that needs to be softened (drinking water, etc.)
- calibrate water softener to the specific hardness of your water to conserve sodium chloride usage
- apply a brine to sidewalks before an icing event to minimize chloride application
- when applying salt to driveways or sidewalks consider prewetting and combining with a 1:1 sand to road salt mixture
- use mechanical (plow or by hand) snow removal as early as possible to prevent ice formation

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 9** 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, with the assistance of volunteers and ClearWater interns. A number of local partners continued to provide funding to carry out WRMP data collection. Donors in support of the 2014 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

(CONTINUTED ON PAGE 28)

Table 8. Active Water Resources Monitoring Committee Members in 2014.

WRMP Committee Member	Affiliation
Larry Fennessey, Ph.D., P.E. ***Committee Chair*** Utility Systems Engineer - Stormwater	Office of Physical Plant, The Pennsylvania State University
Adrienne Gemberling Water Resources Coordinator	ClearWater Conservancy
Beth Boyer, Ph.D. Associate Professor of Water Resources	Department of Ecosystem Science and Management, The Pennsylvania State University
Susan Buda Aquatic Ecologist	Citizen Volunteer
Robert Carline, Ph.D. Aquatic Ecologist	Pennsylvania Cooperative Fish and Wildlife Research Unit, USGS-retired
Ann Donovan Watershed Specialist	Centre County Conservation District
Chris Finton, P.G. Senior Hydrogeologist	ARM Group Inc.
Todd Giddings, Ph.D., P.G. Hydrogeologist	Todd Giddings and Associates, Inc.
James Hamlett, Ph.D. Associate Professor of Agricultural Engineering	Department of Agriculture and Biological Engineering, The Pennsylvania State University
Mark Ralston, P.G. Hydrogeologist	Citizen Volunteer
Kristen Saacke Blunk Consultant	Headwaters, LLC
Rick Wardrop, P.G. Hydrogeologist	Groundwater & Environmental Services, Inc.
David Yoxtheimer, P.G. Extension Associate	Marcellus Center for Outreach and Research, The Pennsylvania State University

- 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 2014:

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

Stream Monitoring Stations

The WRMP measures conditions at four sites along the main stem of Spring Creek and fourteen tributary sites located throughout the stream's five major sub-basins (**Figure 12** on page 30). Twelve of the eighteen sites currently included in the WRMP have been monitored since 1998. The WRMC chose the twelve original sites to be representative of land use practices across the watershed. Three of the original sites were chosen to coincide with existing USGS gaging stations. In 2004, the WRMP added two water quality monitoring sites on headwater tributaries to serve as reference (Buffalo Run Valley View and Galbraith Gap Run). A fifteenth WRMP stream monitoring station, located on Slab Cabin Run downstream of Millbrook Marsh, was added in 2005 to assess the marsh's ability to control stormwater impacts from downtown State College and University Park. The final three sites currently monitored are located in the Walnut Springs sub-basin in State College Borough, and were installed in 2008 to monitor stormwater impacts.

Groundwater Monitoring Stations

The WRMP monitored water levels at three wells in 2014 (**Figure 13** on page 31). 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 13** on page 31). 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 13** on page 31). Like the stream and groundwater sites, these springs were chosen to be representative of various land use, geologic, and hydrologic conditions encountered in the Spring Creek Watershed. With the addition of the Walnut Springs sub-basin monitoring in 2008, the Walnut Spring was added to the spring water quality monitoring in 2013, bringing the total to eight.

MONITORING STATIONS

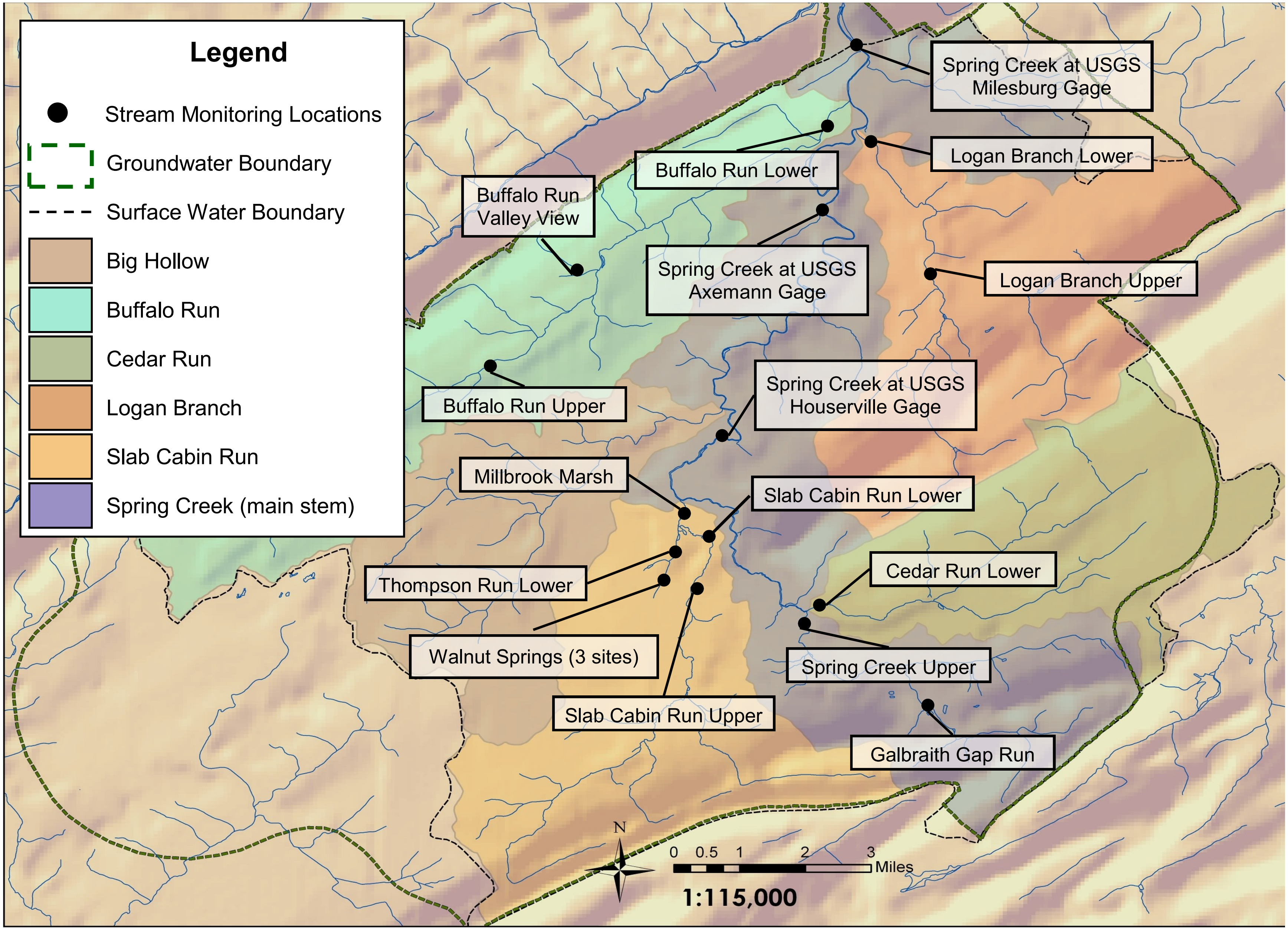


Figure 12. Stream sampling sites surveyed in 2014 as part of the Water Resources Monitoring Project and USGS stream gages.

MONITORING STATIONS

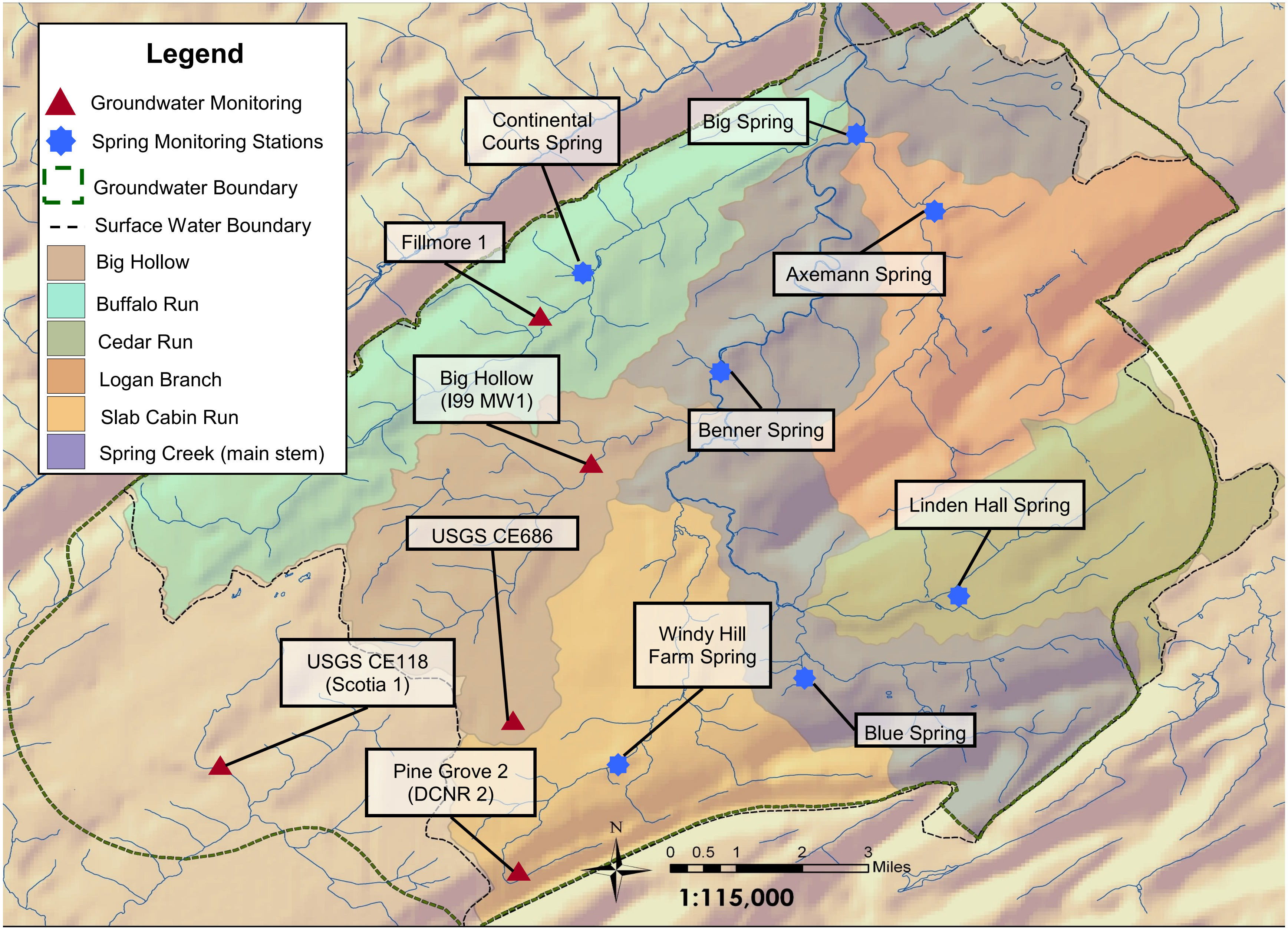


Figure 13. Groundwater and spring stations surveyed in 2014 as part of the Water Resources Monitoring Project and USGS groundwater monitoring wells.

Water Quality Monitoring

WRMP staff and volunteers collected water samples from fifteen stream sites and eight springs in 2014. Sampling took place in March, July, October, and December when streams were at baseflow conditions. The water samples were analyzed for chemical and nutrient content by the PADEP Analytical Laboratories. Coliform analysis of spring samples was conducted by the University Area Joint Authority laboratory. **Appendices 4** and **5** summarize the results of the 2014 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 transducer are non-vented and were coupled with a Solinst Barologger Edge or Barologger Gold to compensate for atmospheric pressure. Stream stage was recorded every 30 minutes for all stations except Lower Thompson Run and the three stations on Walnut Springs, where stream stage was recorded every 5 minutes. Readings were taken more frequently at these stations because past data have shown that the flow in Thompson Run and Walnut Springs can fluctuate rapidly in a short period of time during storm events. The other three stream monitoring stations are the stations maintained by the USGS.

Water temperature was measured hourly at fourteen stream stations using Onset Computer Corporation Optic Stowaway TidBitv2 data loggers. At the Thompson Run station and Middle Walnut Springs station, the temperature data logger was set to record temperature every 5 minutes instead of every hour. Again, readings were taken more frequently at these stations because, as with flow, past data have shown that temperatures in Thompson Run and Walnut Springs can fluctuate rapidly in a short period of time during storm events. Water temperature data summaries for 2014 are presented in **Appendix 7**.

Water surface elevation was recorded every 3 hours at the three wells comprising the groundwater monitoring network. These wells were equipped with InSitu miniTROLL pressure transducers. **Appendix 8** summarizes the groundwater elevation data for 2014.

Discharge Measurements

Data from the WRMP stream gages are collected as stream water level (or stage) data. In order to better understand the behavior of the streams, the data needs to be expressed as stream flow, or discharge. A rating table or curve is a relationship between stage and discharge at a cross-section of a stream. To develop a rating curve the Water Resources Coordinator and volunteers make a series of discharge measurements using a hand-held current meter (Marsh-McBirney FlowMate). These discharge points are plotted versus their accompanying stage, and a curve is drawn through the points (**Figure 14**). There can be significant scatter around this curve. Because of this, it is good to keep in mind that the discharge values provided by WRMP are estimates of the most likely discharge value. Also, wading into the stream to collect discharge measurements during high flows is not safe. Therefore, WRMP discharge values at high flows are calculated by extrapolating the rating curve to higher stages. As a result, there can be significant error in the rating curves at higher stages. Estimated discharges are indicated by the use of dashed lines in the graphs of WRMP discharge data.

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

The data for the USGS-operated stream gages 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 6** summarizes the stream discharge data for 2014.

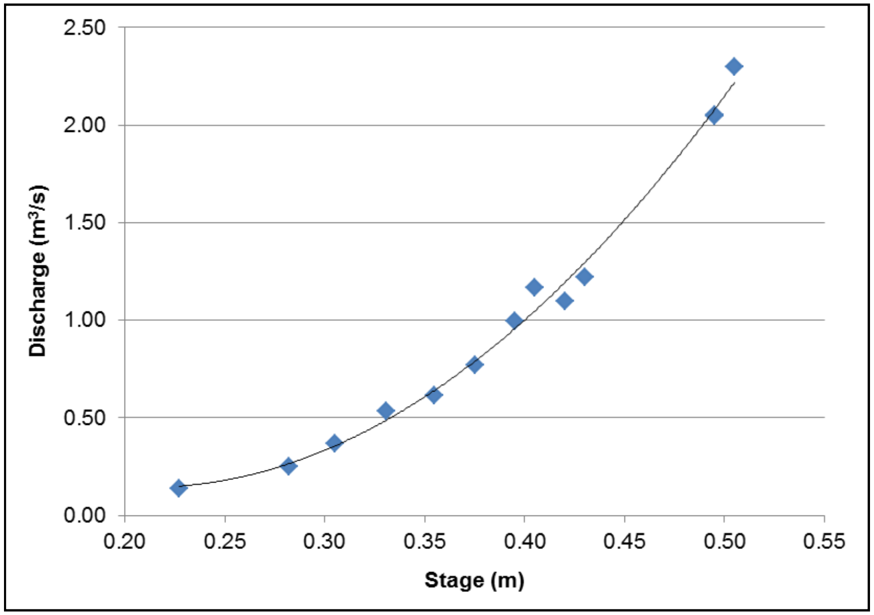


Figure 14. Stage-discharge relationship for WRMP sage at the Buffalo Run Lower (BUL) site.

A WRMP volunteer takes discharge measurements at the Buffalo Run Upper site to help maintain the stage-discharge relationship for this monitoring location.

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 Coordinator at ClearWater Conservancy at (814) 237-0400.

In addition to periodic review of rating curves, the Water Resources Coordinator 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.

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

Water Quality Monitoring

The WRMP water quality protocol is set up to collect samples on a quarterly basis throughout the year. Water Quality was assessed four times in 2014 in March, July, October, and December at 15 stream and 8 spring sites across the watershed during baseflow conditions. Water samples were evaluated for a number of common organic and inorganic pollutants (**Appendix 1**). A summary of water resource management issues for each monitoring site can be found in **Appendix 2**.

Appendices 4 and **5** show median 2014 concentrations of all parameters analyzed at each of the stream and spring sites, respectively. Results from the water quality monitoring were similar to results from past years.

- In 2014, the concentration of nitrate nitrogen at stream and spring sites were, as typically seen, higher in comparison to headwater concentrations at Galbraith Gap Run and Buffalo Run Valley View but below the drinking water standard of 10 mg/L. Median concentrations ranged between 0.10 and 4.51 mg/L at stream sites, with Galbraith Gap Run having the lowest and Cedar Run having the highest median concentration. Among the springs, Axemann Spring and Linden Hall Spring had the highest median concentrations at 6.11 and 4.77 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 in streams and rivers. Orthophosphates were detected at low levels (<0.03 mg/L) at all stream sites. Orthophosphorous was also detected at low levels at all springs except Linden Hall Spring and Walnut Spring.

- The highest median chloride concentrations were observed at Slab Cabin Run at Millbrook Marsh (79.2 mg/L) ,and Thompson Run at East College (72.5 mg/L). These values are similar to historical values. Walnut Spring had the highest observed median concentration in the springs at 101.9 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 (1918 µg/L) in 2013 but returned to 217.5 µg/L in 2014 . This spring has historically seen occasional elevated levels of iron. Iron can occur from natural sources when water comes in contact with particular types of rock. Typically the longer the water has been in contact with the rock, for example, during drier periods, the higher the iron concentration. The observed elevated level of iron occurred in November

2013 when baseflows were lower than the median.

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

The WRMP monitors five of these seven major ions. Based on the data collected, we can determine the percentage of the conductivity that can be attributed to each of these ions except bicarbonate and potassium, which the WRMP does not monitor. In 2014, conductivity was highest at Slab Cabin Run at College Avenue (729.5 mS) and Thompson Run at East College Avenue (708.5 mS), as it has been historically.

Stream Discharge

Stream discharge is defined as the volume of water in a stream passing a given point at a given moment of time. Large streams have higher discharge rates than smaller streams. A stream’s ability to move sediment and dilute chemicals is proportional to discharge. Generally, the higher the discharge, the more effective a stream will be at moving sediment downstream and diluting pollutants. A stream’s discharge determines the biological communities that will be found in it. Stream discharge also fluctuates with seasons and storm events, making it a measurement of interest when studying the effects of runoff and flooding.

The 2014 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 **Figures 15** and **Figure 16**, respectively. In general, discharge stayed above median values for most of the year. From January until early May, base flow was above median values and then dropped slightly until a large storm event increased discharge dramatically above median values. For the remainder of the year, discharge stayed fairly consistently above average. These discharge profiles reflect a fairly wet year, with major storms peaking discharge in mid-March, and late-April. The largest deviation occurred from a major storm

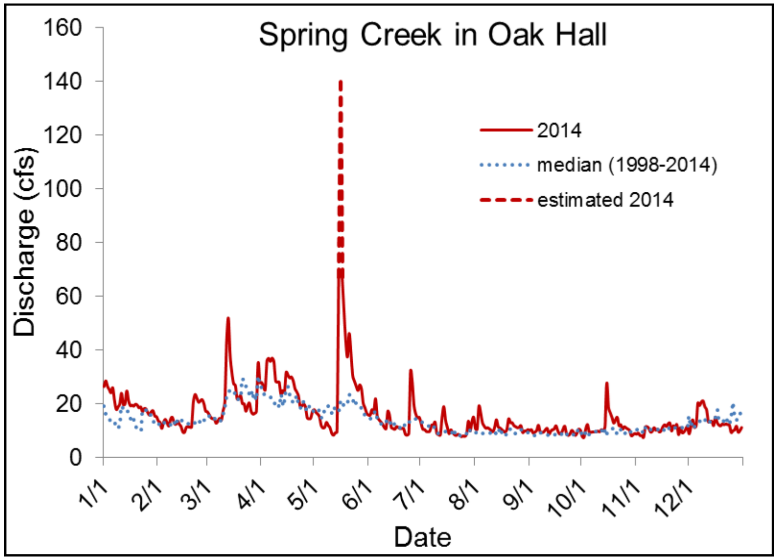


Figure 15. 2014 discharge and median discharge (cfs) for Spring Creek in Oak Hall.

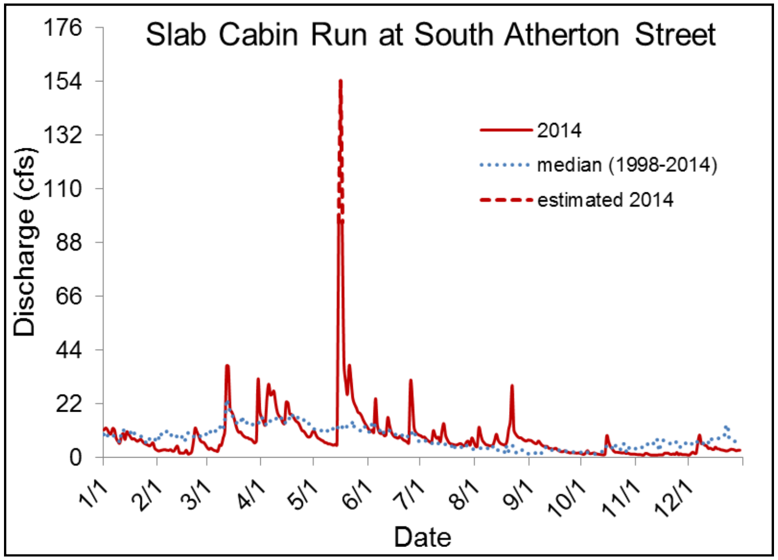


Figure 16. 2014 discharge and median discharge (cfs) for Slab Cabin Run at South Atherton Street.

event in mid-May.

The 2014 discharge profiles for all of the WRMP gages and the three USGS Spring Creek gages are included in **Appendix 6**.

Stream Temperature

Water temperature has a profound influence on aquatic life. It governs nearly every process that occurs in streams from regulating the solubility of oxygen and various chemicals to the metabolic functions of fish and other aquatic life. The significant inputs of groundwater throughout the Spring Creek Watershed protects the world-class trout fishery from the significant agricultural and urban impacts within the watershed. Brown trout's lethal temperature threshold is 76 °F (24 °C), and groundwater (10-11 °C) inputs help maintain temperatures well below this threshold. Some portions of tributary streams lack significant groundwater inputs, such as lower Buffalo Run near Bellefonte and Slab Cabin Run in State College. These streams are perched above the water table minimizing the inputs of groundwater, especially during dry periods which typically occur in the summer and fall when air temperatures are generally greatest. The 2014 data from Slab Cabin Run downstream from Millbrook Marsh align well with historical data that predicts the highest stream temperatures between June and August (**Figure 17**). Walnut Springs near East College Avenue was the only stream in which maximum daily temperatures

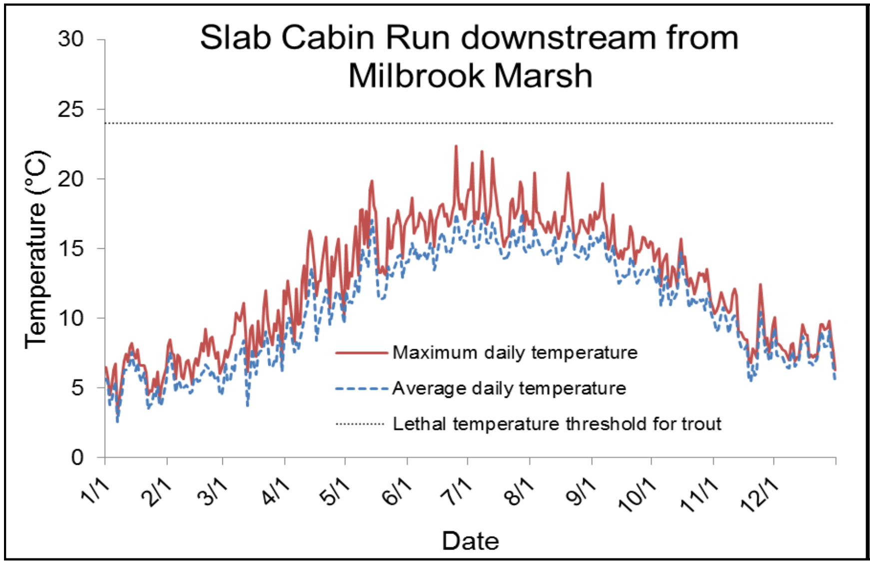


Figure 17. Temperature at the WRMP site at Slab Cabin downstream from Millbrook Marsh in 2014.

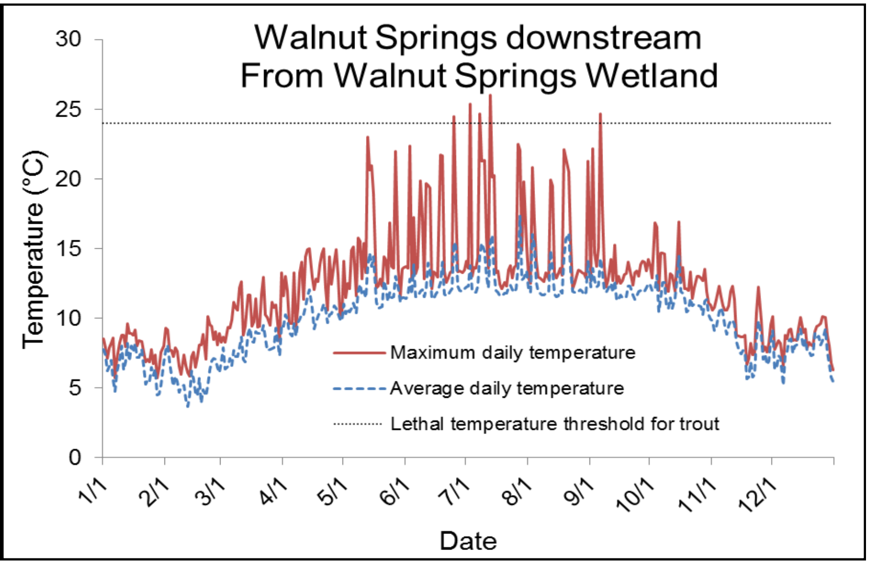


Figure 18. Temperature in 2014 at the WRMP site on Walnut Springs downstream from Walnut Springs wetland.

exceeded Brown Trout's temperature threshold (**Figure 18**). Temperatures exceeding this limit were observed on four days. In recent years (2013 and 2012) Thompson Run maximum temperatures also exceeded the threshold. Data for Thompson Run during summer 2014 were not collected because the temperature sensor was washed on shore during a large storm event.

These two streams are subject to large urban storm water inputs which can cause these temperature increases. These waters can also exceed 76 °F during extreme heat or drought. The mean July temperature for State College, PA was lower in 2014 (70.3 °F) than in 2013 (73.8 °F) and 2012 (75.7 °F) when mean July temperature was the second and fourth hottest on record. Large-scale fish kills can occur when water temperatures rise above 76 °F for extended periods of time. In general, temperatures do not exceed trout's threshold, and when they do, it is only for short (e.g., 1 day) periods of time. The 2014 temperature profiles for all WRMP monitored locations in the watershed are included in **Appendix 7**.

Groundwater

Groundwater supplies our streams with a constant supply of cold water that supports trout and other coldwater aquatic organisms. Most of the region's drinking water is also drawn from the many high volume springs and well fields. In 2014, the WRMP collected groundwater data from three monitoring wells and assessed data from two additional wells maintained by the USGS. Groundwater elevation profiles for 2014 are found in **Appendix 8**. Water surface elevation is used as the y-axis label and is equivalent to feet above mean sea level.

The groundwater hydrograph for the WRMP-maintained well near Pine Grove Mills is shown in **Figure 19**. As usually observed, snow melt and rainfall replenished most of the groundwater aquifers in the watershed in late winter and early spring. However, at the USGS CE118 well located in Scotia Barrens, a general decline in groundwater elevations was observed through 2014 (**Figure 20**). The CE 118 well is located in the Gatesburg Formation, a large aquifer that drains to the Big Spring and several other large magnitude springs in the Bellefonte area. Due to the relatively deep saturated zone in the Scotia Barrens area, the USGS CE118 well shows a lag in response to recharge events. 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 as observed in CE118. This particular well experienced a historic low in groundwater elevation in the fall of 2002 after an extreme dry period and a historic high in the spring of 2005.

In general, groundwater elevations at the WRMP and USGS wells were lower than median levels throughout the entire year during 2014.

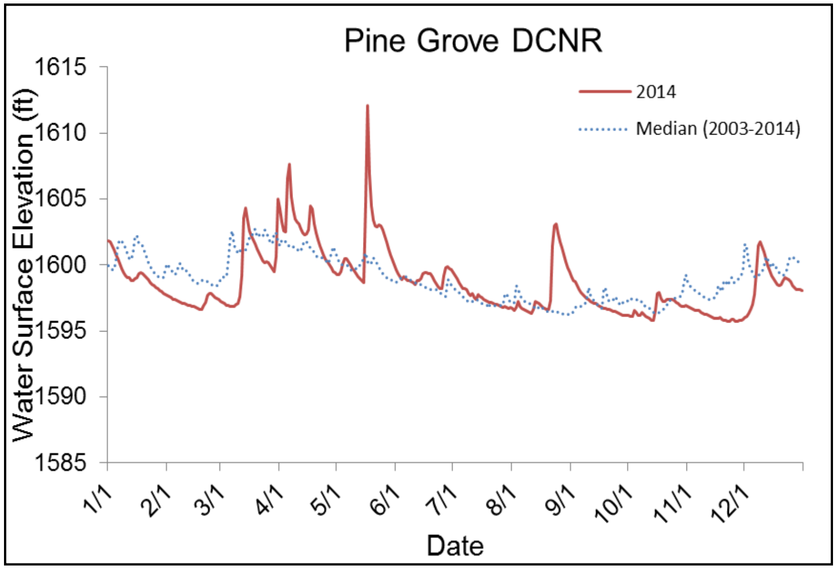


Figure 19. Water surface elevation (ft) in 2014 at the WRMP groundwater well located near Pine Grove Mills.

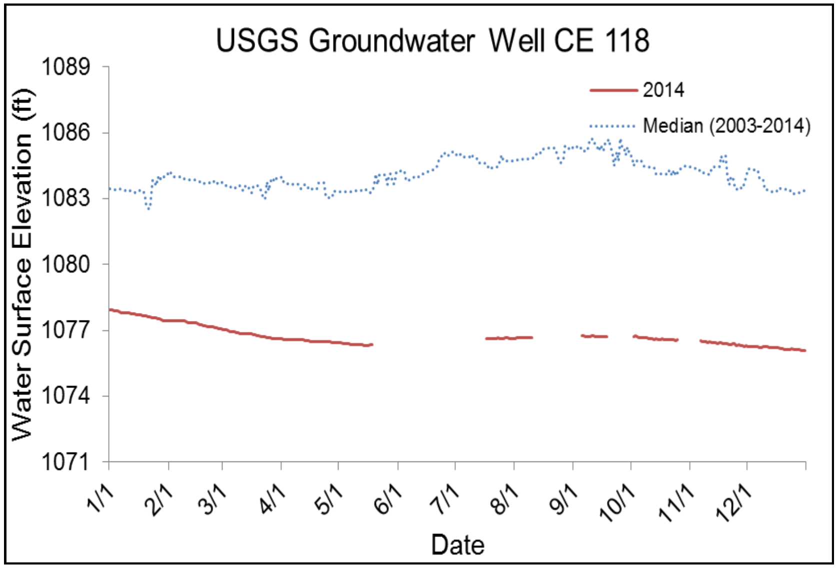


Figure 20. Water surface elevation (ft) in 2014 at the USGS CE118 well in Scotia Barrens.

Appendix 1	Water Quality Parameters
Appendix 2	Summary of water management issues for each monitoring location
Appendix 3	Monitoring Summary by Location
Appendix 4	Stream Water Quality Results
Appendix 5	Spring Water Quality Results
Appendix 6	Daily Stream Flows
Appendix 7	Daily Stream Temperatures
Appendix 8	Daily Groundwater Elevations

Appendix 1: Water Quality Parameters

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

Appendix 1: Water Quality Parameters

Parameter	Description	Sources	Environmental Effects	Stream	Spring
Manganese	Common element found in the Earth's crust	Urban runoff, industrial discharges, and natural sources	Toxic to humans and aquatic life	X	X
Nickel	A trace element essential for animals in small quantities	Industrial wastewaters	Toxic to humans and aquatic life if present in excess	X	X
Nitrate (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; particles may carry bound toxic compounds or metals	X	X
Turbidity	A measure of water clarity expressed as the amount of light penetrating the water	While in some cases high turbidity is natural, it is usually the result of earth-moving activities, urban runoff, and erosion	High turbidity blocks light from the water column, inhibiting productivity of aquatic plants and periphyton; increased sedimentation	X	X
Zinc	A heavy metal commonly found in rock-forming minerals	Urban runoff, industrial discharges, and natural sources	Somewhat toxic to humans and aquatic life; solubility is affected by water hardness	X	X

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

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

Appendix 3: Monitoring summary by location

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

Appendix 3: Monitoring summary by location

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

Appendix 4: Median Stream Water Quality Results (Metals)

		Aluminum (µg/L)		Cadmium (µg/L)		Chromium (µg/L)		Copper (µg/L)		Iron (µg/L)	
Site Name	**Abbrev**	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Galbraith Gap Run	GGU	ND	20.1	ND	ND	ND	ND	ND	ND	ND	36.0
Cedar Run - Lower	CEL	5*	48.8	ND	ND	ND	ND	ND	ND	ND	106.0
Slab Cabin Run - Upper	SLU	8.4*	110.5	ND	ND	ND	ND	ND	ND	ND	183.5
Slab Cabin Run - Lower	SLL	ND	11.7*	ND	ND	ND	ND	ND	ND	ND	31.5*
Slab Cabin Run - Millbrook	MIL	5.0*	28.1*	ND	ND	ND	ND	ND	ND	ND	117.0
Thompson Run - Lower	THL	ND	23.2*	ND	ND	ND	2.0*	ND	2.0*	ND	67.5
Buffalo Run - Upper	BUU	5.0*	51.5	ND	ND	ND	ND	ND	ND	10	95.0
Buffalo Run - Valley View	BVV	14.5*	55.5	ND	0.1*	ND	2.0*	ND	ND	59	119.5*
Buffalo Run - Lower	BUL	ND	53.9	ND	ND	ND	ND	ND	ND	ND	77.5
Logan Branch - Upper	LOU	5.0*	29.0	ND	ND	ND	ND	ND	ND	ND	93.5
Logan Branch - Lower	LOL	5.0*	16.4	ND	ND	ND	ND	ND	ND	ND	29.0*
Spring Creek - Upper	SPU	ND	23.7*	ND	ND	ND	ND	ND	ND	ND	46.5*
Spring Creek - Houserville	SPH	5*	34.5	ND	ND	ND	ND	ND	ND	10.0*	75.0
Spring Creek - Axemann	SPA	ND	48.4	ND	ND	ND	ND	ND	ND	ND	87.5
Spring Creek - Milesburg	SPM	10.4*	48.2	ND	ND	ND	ND	ND	ND	ND	80.0

		Lead (µg/L)		Manganese (µg/L)		Nickel (µg/L)		Sodium (mg/L)		Zinc (µg/L)	
Site Name	**Abbrev**	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Galbraith Gap Run	GGU	ND	ND	ND	1.5	ND	ND	0.7	0.7	7.5*	ND
Cedar Run - Lower	CEL	ND	ND	1.7*	23.5	ND	ND	6.7	6.9	ND	ND
Slab Cabin Run - Upper	SLU	ND	ND	4.3	24.3	ND	ND	16.2	16.4	ND	ND
Slab Cabin Run - Lower	SLL	ND	ND	ND	1.0*	ND	ND	28.2	29.3	5*	ND
Slab Cabin Run - Millbrook	MIL	ND	ND	4.4	6.2	ND	ND	34.7	37.0	5*	ND
Thompson Run - Lower	THL	ND	ND	4	30.1	ND	2.0*	30.8	32.3	ND	ND
Buffalo Run - Upper	BUU	ND	ND	1.0*	22.1	ND	ND	22.7	24.1	7.5*	5.0*
Buffalo Run - Valley View	BVV	0.5*	0.5*	24.5	32.1*	ND	2.0*	19.6	16.9	5.0*	ND
Buffalo Run - Lower	BUL	0.5*	ND	2.9	6.3	ND	ND	12.0	12.4	5.0*	ND
Logan Branch - Upper	LOU	ND	ND	3.0	5.3	ND	ND	20.0	20.6	ND	ND
Logan Branch - Lower	LOL	ND	ND	ND	1.7*	ND	ND	15.4	15.5	5.0*	ND
Spring Creek - Upper	SPU	ND	ND	ND	2.3	ND	ND	10.5	10.6	ND	ND
Spring Creek - Houserville	SPH	ND	ND	2.8*	4.1*	ND	ND	22.1	22.3	5.0*	ND
Spring Creek - Axemann	SPA	ND	ND	1.0*	4.2	ND	ND	32.3	33.0	ND	ND
Spring Creek - Milesburg	SPM	ND	ND	2.1	4.0	ND	ND	23.3	24.7	5.0*	5.0*

* At least one sample had an undetectable concentration, so a concentration of 1/2 detection limit was set as concentration for calculations.

ND All concentrations for all sampling events were below detection limits, so no value was assigned for concentrations.

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

Site Name	Abbrev	Calcium (mg/L) Total	Magnesium (mg/L) Total	Hardness (mg/L) Total	Chloride (mg/L) Total	Sulfate (mg/L) Total	Suspended Solids (mg/L) Total	Turbidity (NTU)
Galbraith Gap Run	GGU	3.1	1.5	14.0	1.2	10.0*	1.0*	2.8*
Cedar Run - Lower	CEL	77.7	23.5	288.0	16.4	18.5	4.5*	3.9
Slab Cabin Run - Upper	SLU	60.2	24.3	250.5	34.1	14.2*	8.5*	5.3
Slab Cabin Run - Lower	SLL	60.2	23.5	250.5	16.4	14.2*	4.5*	3.9*
Slab Cabin Run - Millbrook	MIL	70.6	29.9	300.0	79.7	22.9	4.5*	2.2
Thompson Run - Lower	THL	71.5	30.1	302.0	72.5	19.1	7.0*	1.6*
Buffalo Run - Upper	BUU	65.2	22.1	254.0	53.2	35.0	9.0	3.3
Buffalo Run - Valley View	BVV	46.4	5.7	115.5	27.1*	15.9*	1.0*	3.3*
Buffalo Run - Lower	BUL	62.9	24.0	256.0	27.8	31.3	3.5*	2.3
Logan Branch - Upper	LOU	77.7	21.3	282.0	46.7	62.3	3.5*	4.4
Logan Branch - Lower	LOL	52.3	20.8	216.0	33.7	27.9	1.0*	0.5*
Spring Creek - Upper	SPU	52.9	17.2	203.0	22.2	17.8	1.0*	1.4
Spring Creek - Houserville	SPH	68.7	24.2	271.5	48.4	22.2	8.0	3.5
Spring Creek - Axemann	SPA	63.9	23.2	254.0	68.3	24.8	1.0*	2.4
Spring Creek - Milesburg	SPM	56.9	21.8	235.0	50.1	26.7	3.5*	2.0

Site Name	Abbrev	pH	Dissolved Oxygen (mg/L)	Temperature (^{o}C)	Conductivity (mS)	Nitrate-N (mg/L)	Orthophosphorus (mg/L) Total
Galbraith Gap Run	GGU	7.0	10.8	8.5	38.6	0.11	0.008*
Cedar Run - Lower	CEL	8.3	11.1	9.4	559.0	4.51	0.009*
Slab Cabin Run - Upper	SLU	8.2	11.3	9.9	530.0	3.68	0.014
Slab Cabin Run - Lower	SLL	8.2	11.1	9.4	530.0	3.68	0.009*
Slab Cabin Run - Millbrook	MIL	8.1	10.7	11.2	729.5	3.41	0.005*
Thompson Run - Lower	THL	8.1	10.2	11.2	708.5	3.79	0.008*
Buffalo Run - Upper	BUU	8.3	11.7	4.9	619.5	1.30	0.016
Buffalo Run - Valley View	BVV	7.7	11.5	6.2	334.6	0.46	0.031
Buffalo Run - Lower	BUL	8.5	13.4	6.4	558.0	1.51	0.012
Logan Branch - Upper	LOU	8.0	11.0	9.8	652.0	2.97	0.022
Logan Branch - Lower	LOL	8.2	10.6	9.5	497.4	2.99	0.010*
Spring Creek - Upper	SPU	7.6	9.6	9.9	445.7	2.10	0.008*
Spring Creek - Houserville	SPH	8.4	10.4	10.5	600.5	3.04	0.008*
Spring Creek - Axemann	SPA	8.6	13.7	8.9	655.5	3.61	0.015
Spring Creek - Milesburg	SPM	8.5	12.4	9.0	564.0	2.96	0.016

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

Appendix 5: Median Spring Water Quality Results (Metals)

		Aluminum (µg/L)		**Cadmium (µg/L)**		**Chromium (µg/L)**		**Copper (µg/L)**		**Iron (µg/L)**	
Site Name	**Abbrev**	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Axemann Spring	AXS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benner Spring	BES	ND	56.1	ND	ND	ND	ND	ND	ND	ND	88.5
Big Spring	BIS	5.0*	5.0*	ND	ND	ND	ND	ND	ND	ND	10.0*
Blue Spring	BLS	ND	23.6	ND	ND	ND	ND	ND	ND	nd	37
Continental Courts	COS	ND	5.0*	ND	ND	ND	ND	ND	ND	ND	ND
Linden Hall Park Spring	LIS	ND	5.0*	ND	ND	ND	ND	ND	ND	ND	ND
Walnut Spring	WAS	ND	5.0*	ND	ND	ND	ND	ND	ND	ND	ND
Windy Hill Farm Spring	WIS	ND	132.3$	ND	ND	ND	ND	ND	ND	10.0*	217.5$

		Lead (µg/L)		**Manganese (µg/L)**		**Nickel (µg/L)**		**Sodium (mg/L)**		**Zinc (µg/L)**	
Site Name	**Abbrev**	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Axemann Spring	AXS	ND	ND	ND	ND	ND	ND	18.1	18.7	ND	ND
Benner Spring	BES	ND	ND	ND	3.5*	ND	ND	27.3	29.0	ND	ND
Big Spring	BIS	ND	ND	ND	ND	ND	ND	10.7	10.9	ND	ND
Blue Spring	BLS	0.5*	ND	ND	1.0*	ND	ND	2.4	2.3	ND	ND
Continental Courts	COS	ND	ND	ND	ND	ND	ND	10.0	10.1	ND	ND
Linden Hall Park Spring	LIS	ND	ND	ND	ND	ND	ND	2.9	3.0	ND	ND
Walnut Spring	WAS	ND	ND	ND	ND	ND	ND	40.9	42.2	ND	ND
Windy Hill Farm Spring	WIS	0.5*	ND	1.0*	17.9*	2.0*	ND	14.0	14.2	5.0*	ND

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

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

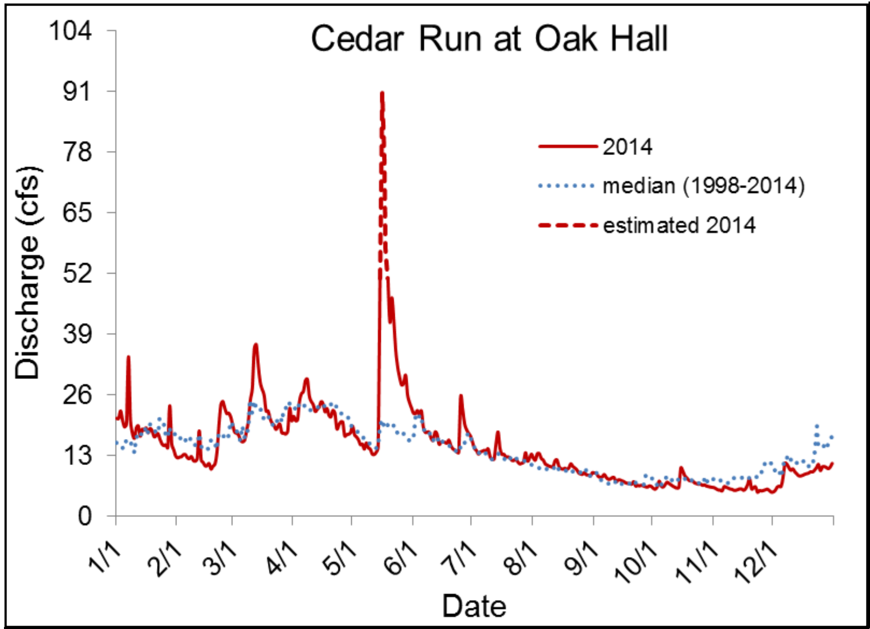
Site Name	Abbrev	Calcium (mg/L) Total	Magnesium (mg/L) Total	Hardness (mg/L) Total	Chloride (mg/L) Total	Sulfate (mg/L) Total	Suspended Solids (mg/L) Total	Turbidity (NTU)
Axemann Spring	AXS	78.1	33.8	334.5	50.0	30.4	ND	ND
Benner Spring	BES	64.2	23.3	257.5	62.8	14.1*	1.0*	2.6
Big Spring	BIS	32.7	16.5	149.5	22.6	ND	ND	ND
Blue Spring	BLS	26.7	13.3	121.5	4.7	10.0*	ND	1.0*
Continental Courts	COS	57.9	26.2	253.0	21.8	ND	8.0*	ND
Linden Hall Park Spring	LIS	80.4	32.6	335.0	8.0	16.9	ND	ND
Walnut Spring	WAS	81.6	41.9	376.5	101.9	19.6*	4.5*	ND
Windy Hill Farm Spring	WIS	57.4	25.5	248.5	27.7	15.6*	10.3*	5.4

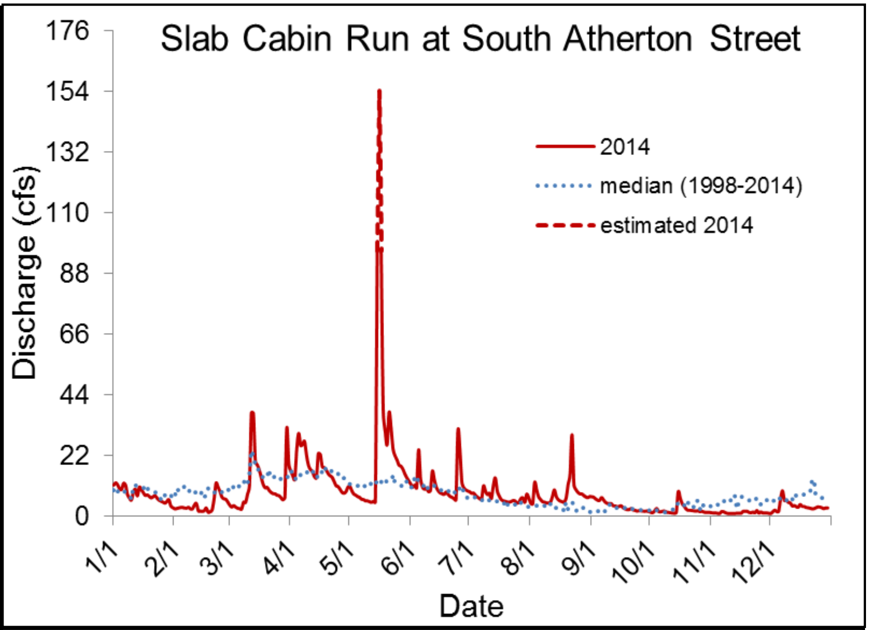
Site Name	Abbrev	pH	Dissolved Oxygen (mg/L)	Temperature (°C)	Conductivity (mS)	Nitrate-N (mg/L)	Orthophosphorus (mg/L) Total	Fecal Coliforms (#col/ 100mL)
Axemann Spring	AXS	7.2	7.6	10.3	744.0	6.1	0.005*	0.0
Benner Spring	BES	7.4	9.4	10.5	623.0	3.7	0.010*	17.4
Big Spring	BIS	7.9	9.8	10.2	349.9	1.9	0.005*	2.6
Blue Spring	BLS	7.0	9.2	9.6	248.1	1.3	0.005*	8.5
Continental Courts	COS	7.4	6.8	10.4	525.0	2.1	0.008*	0.0
Linden Hall Park Spring	LIS	7.1	6.9	10.0	620.5	4.8	ND	ND
Walnut Spring	WAS	7.2	6.7	10.5	892.5	3.6	ND	1.2
Windy Hill Farm Spring	WIS	7.2	7.0	10.8	532.0	3.6	0.015	10.7

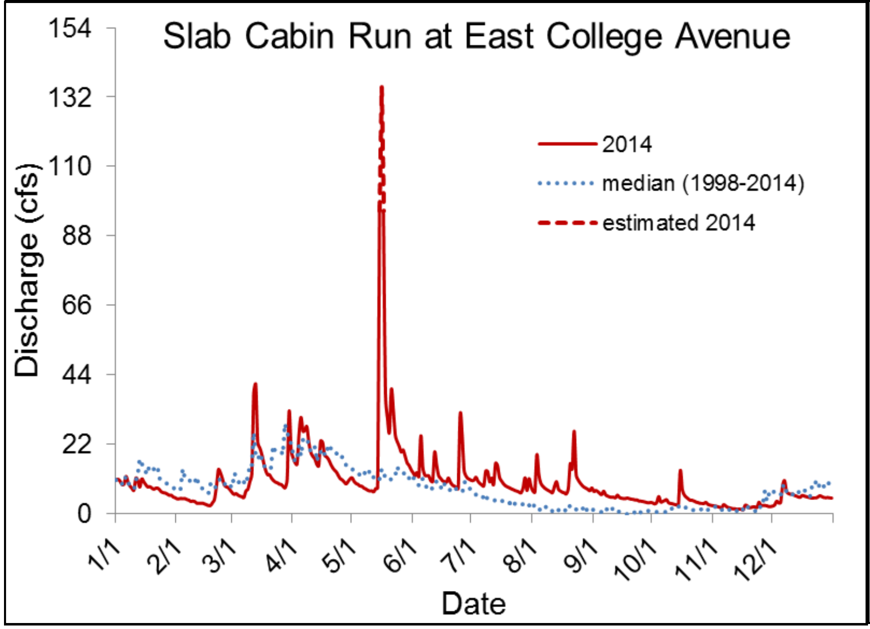
* At least one sample had an undetectable concentration, so a concentration of 1/2 detection limit was set as concentration for calculations.

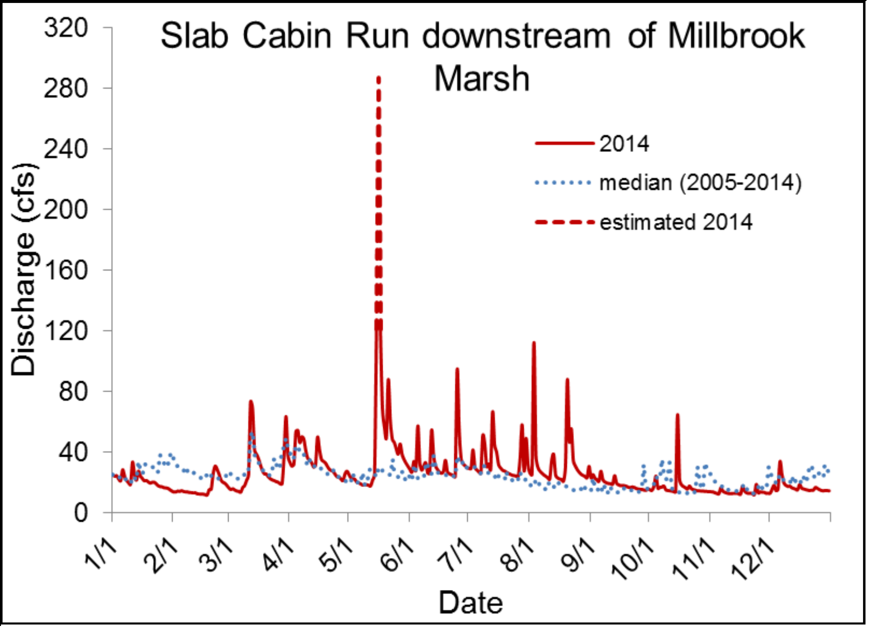
ND All concentrations for all sampling events were below detection limits, so no value was assigned for concentrations.

Appendix 6: Daily Stream Flow for 2014

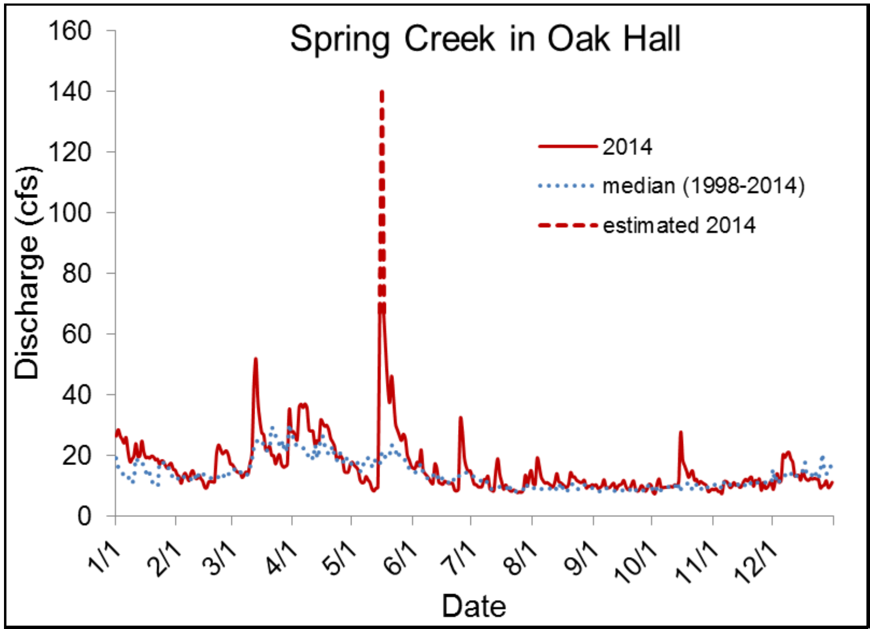


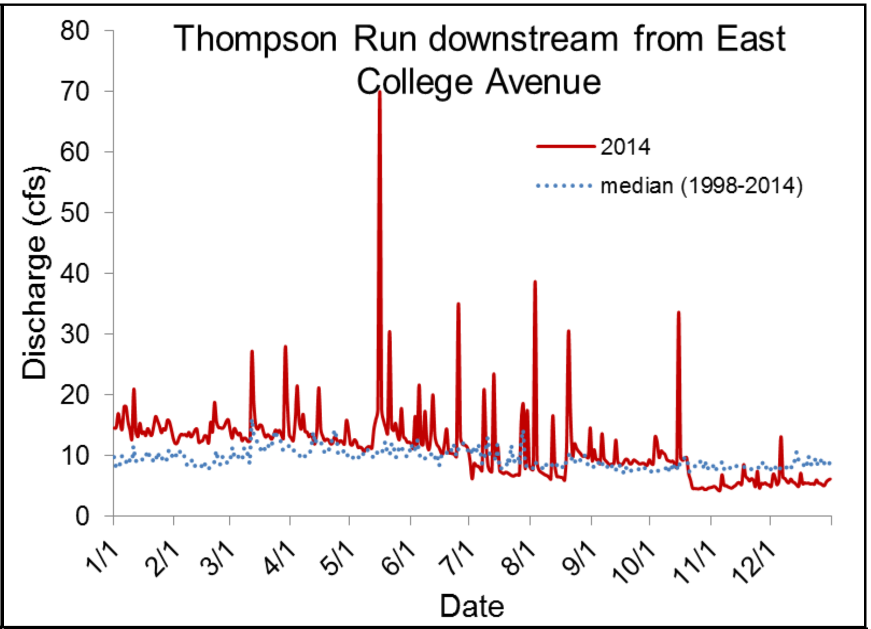


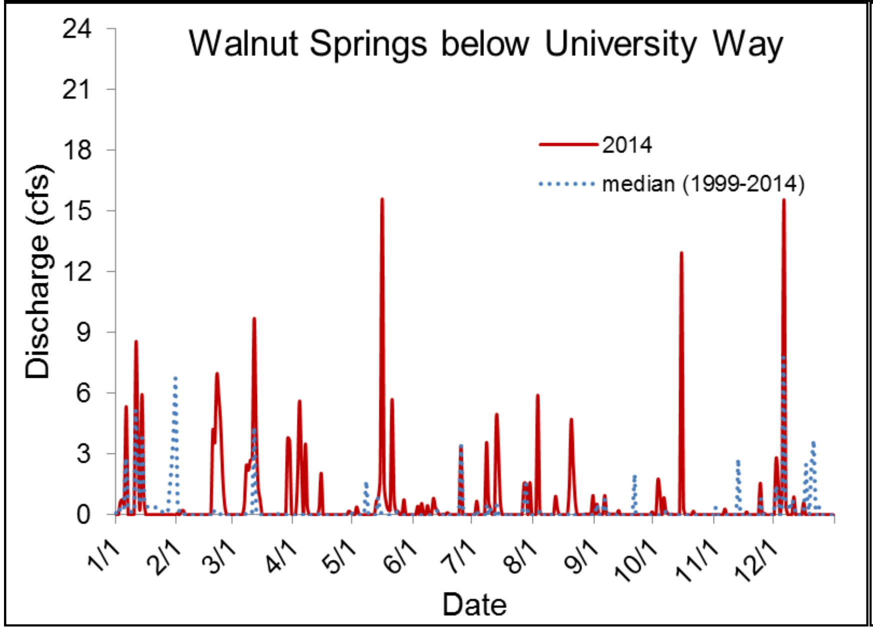


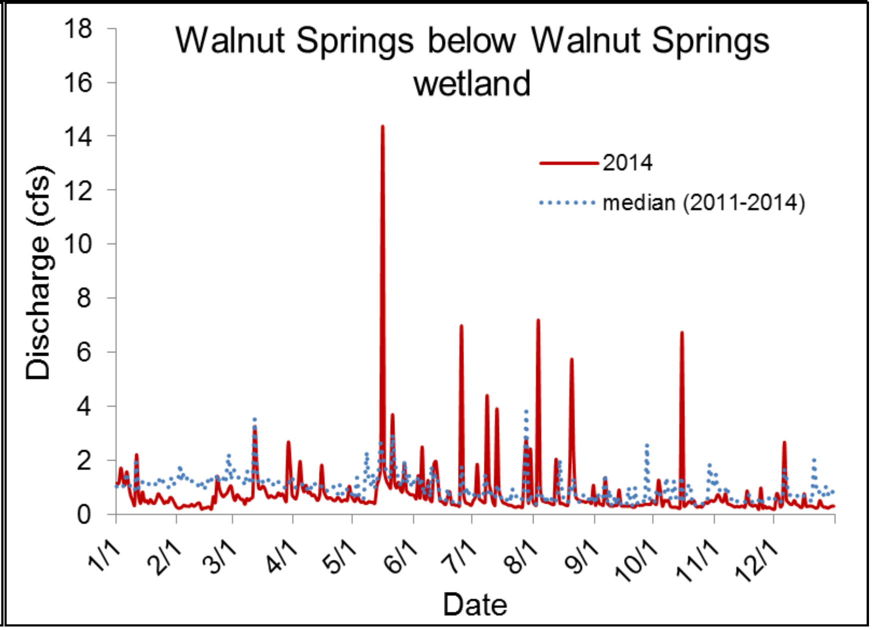


Appendix 6: Daily Stream Flow for 2014 (*continued*)

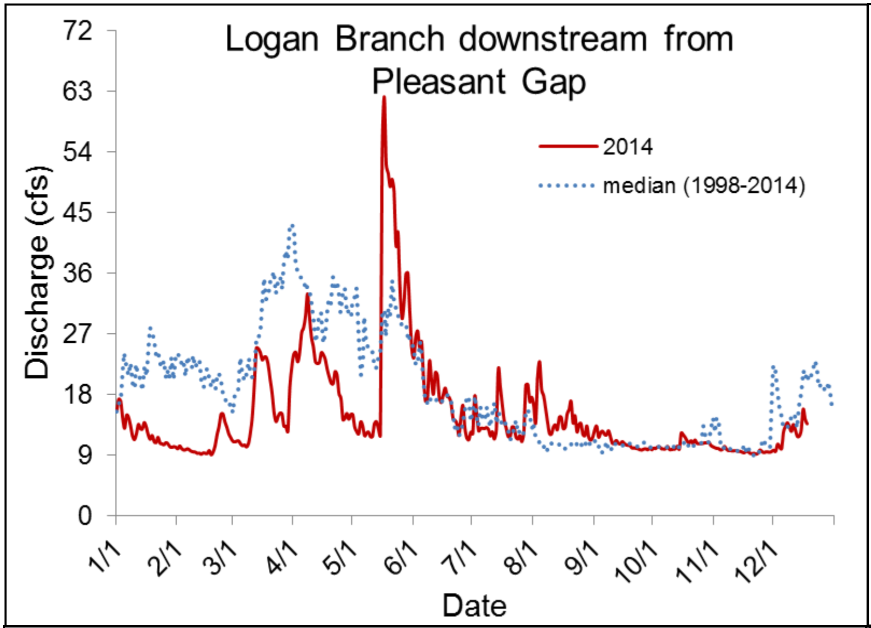


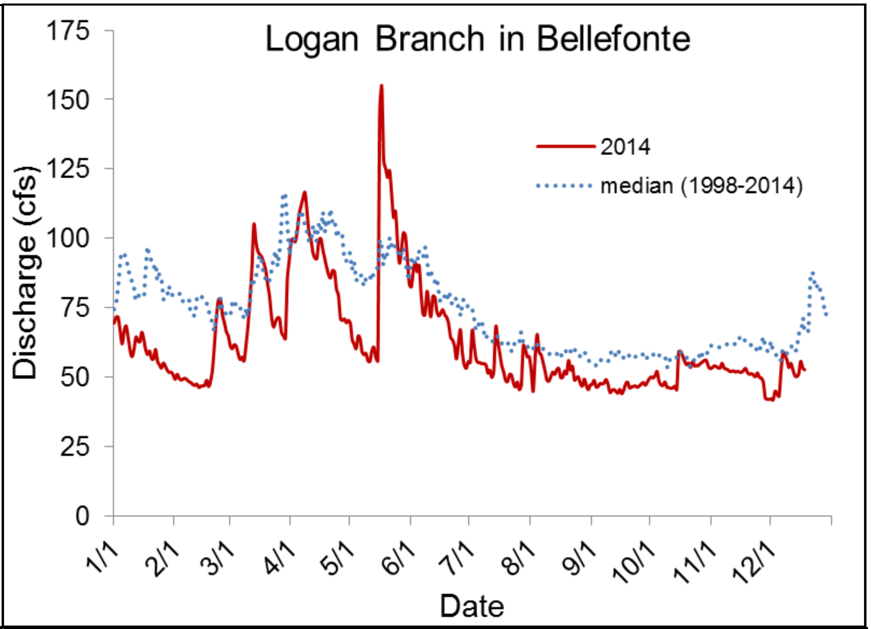


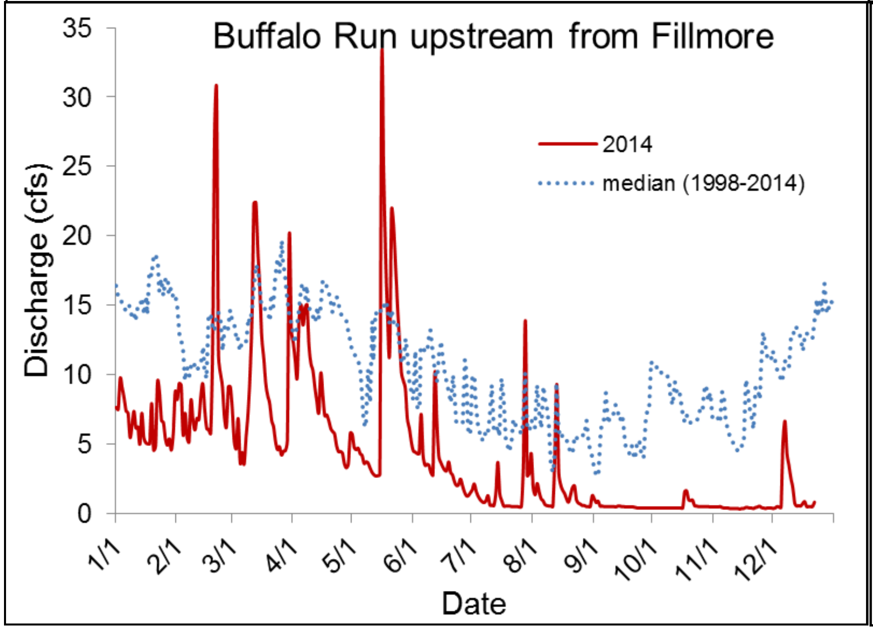


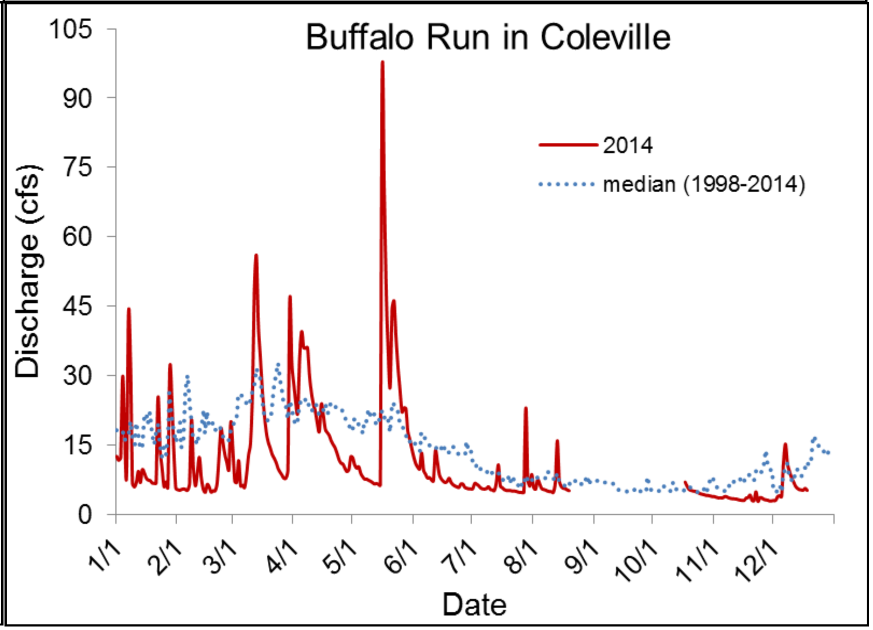


Appendix 6: Daily Stream Flow for 2014 (*continued*)



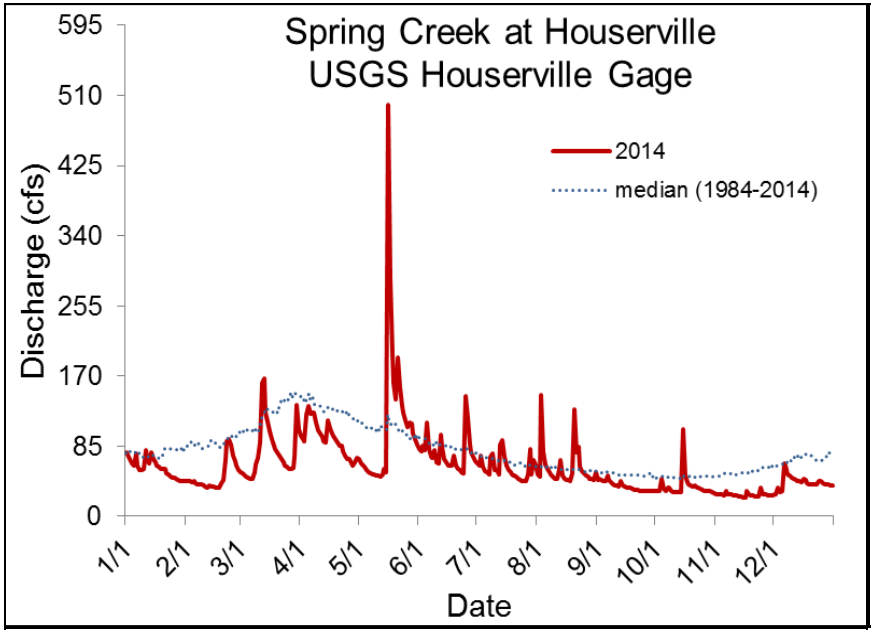


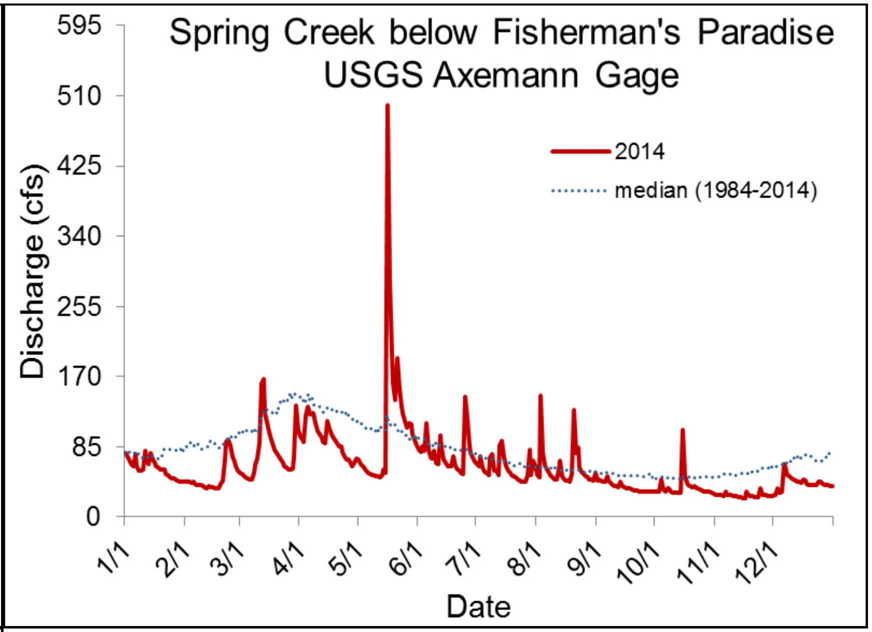


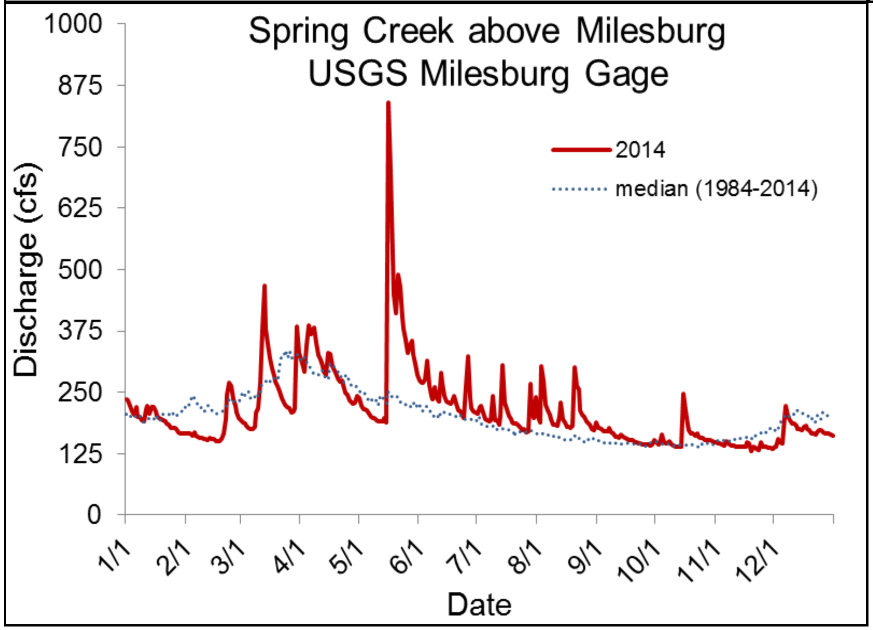


Appendix 6: Daily stream flow data for 2014 (*continued*)

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

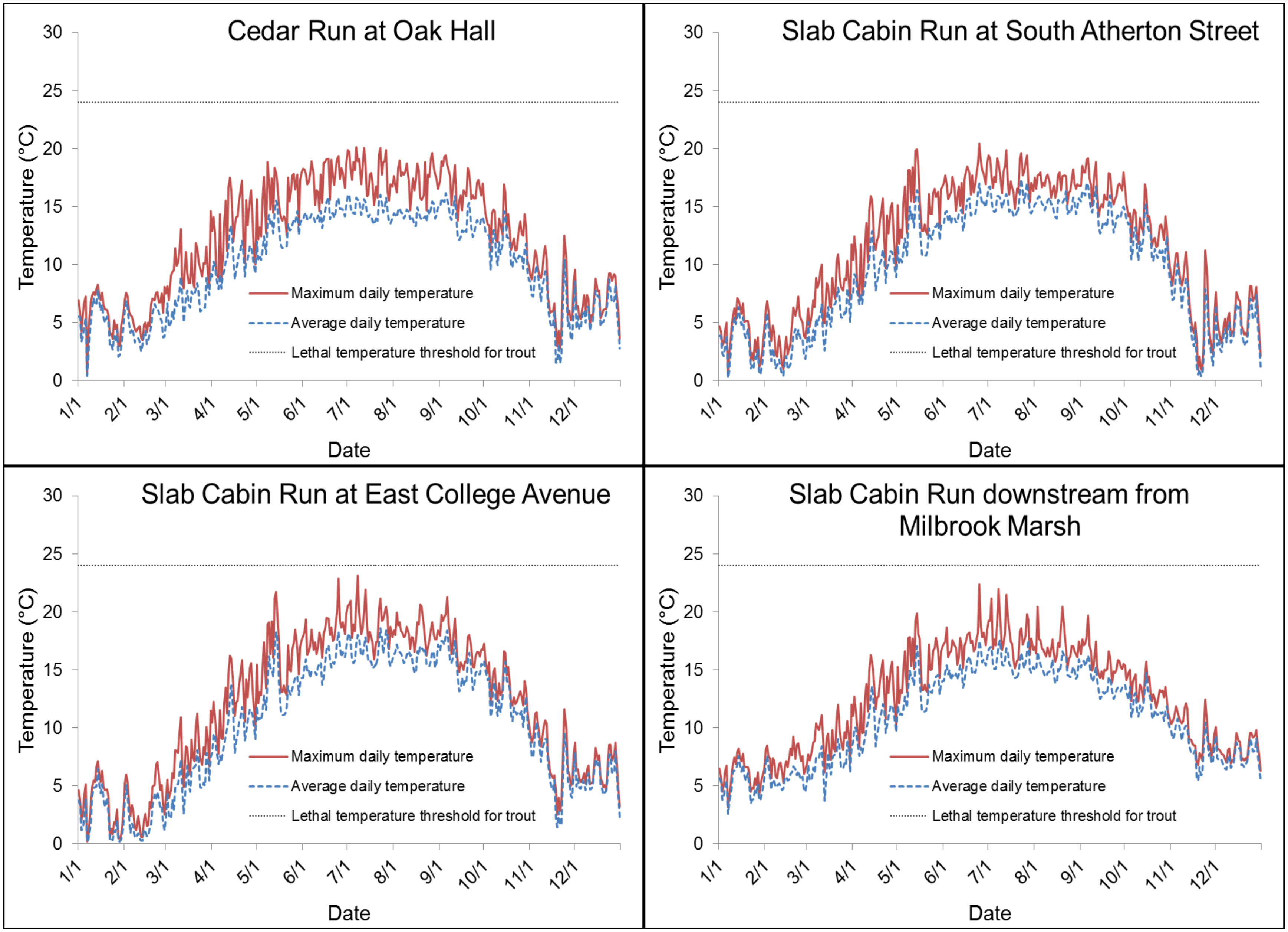




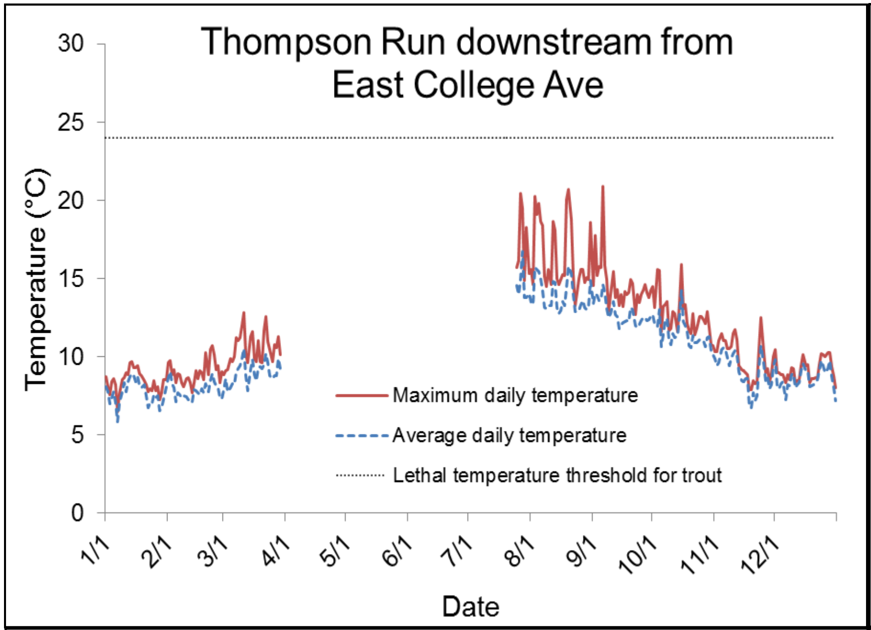


Appendix 7: Daily Stream Temperatures for 2014

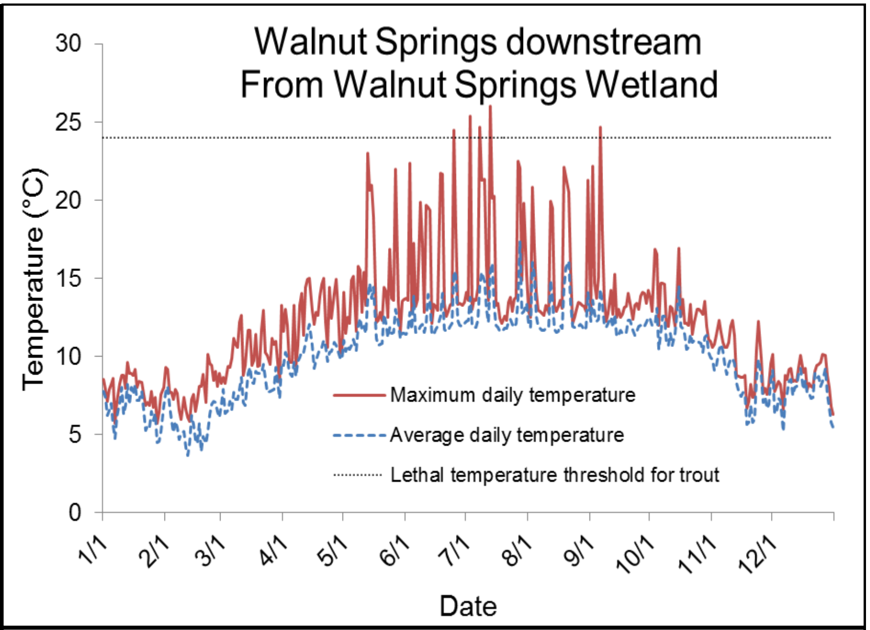
Average daily stream temperature and maximum daily stream temperature for 14 locations in the Spring Creek Watershed.



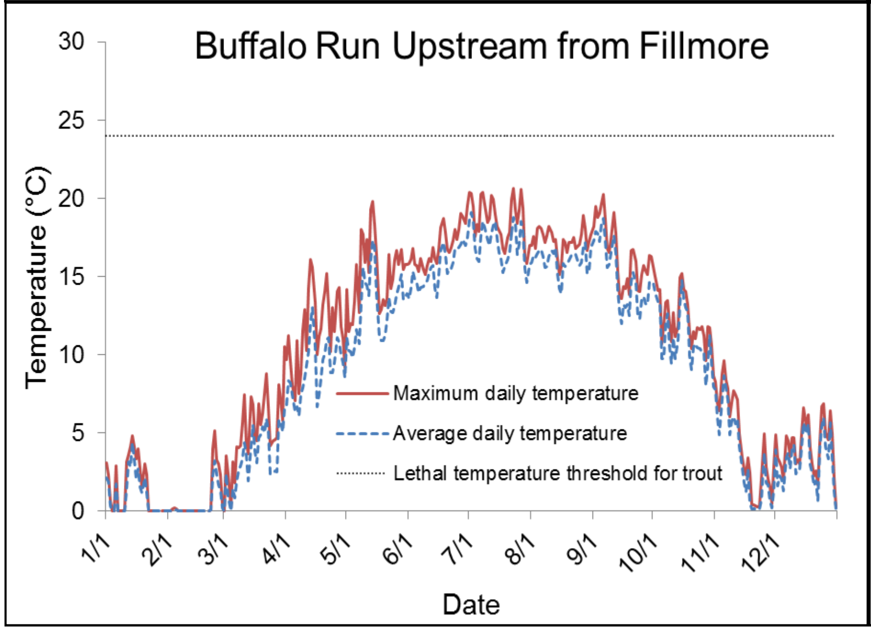
Appendix 7: Daily Stream Temperatures for 2014 (*continued*)



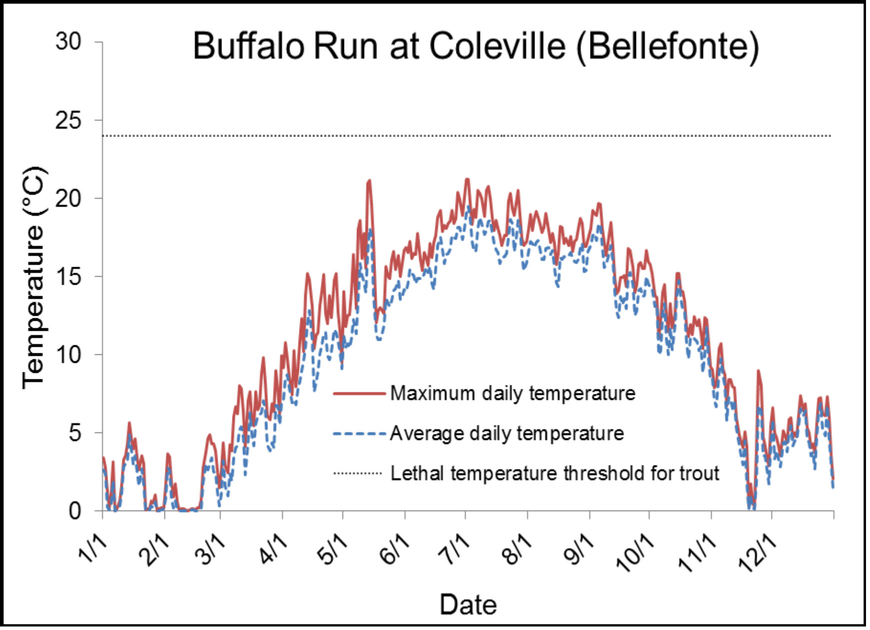
Thompson Run downstream from East College Ave



Walnut Springs downstream From Walnut Springs Wetland

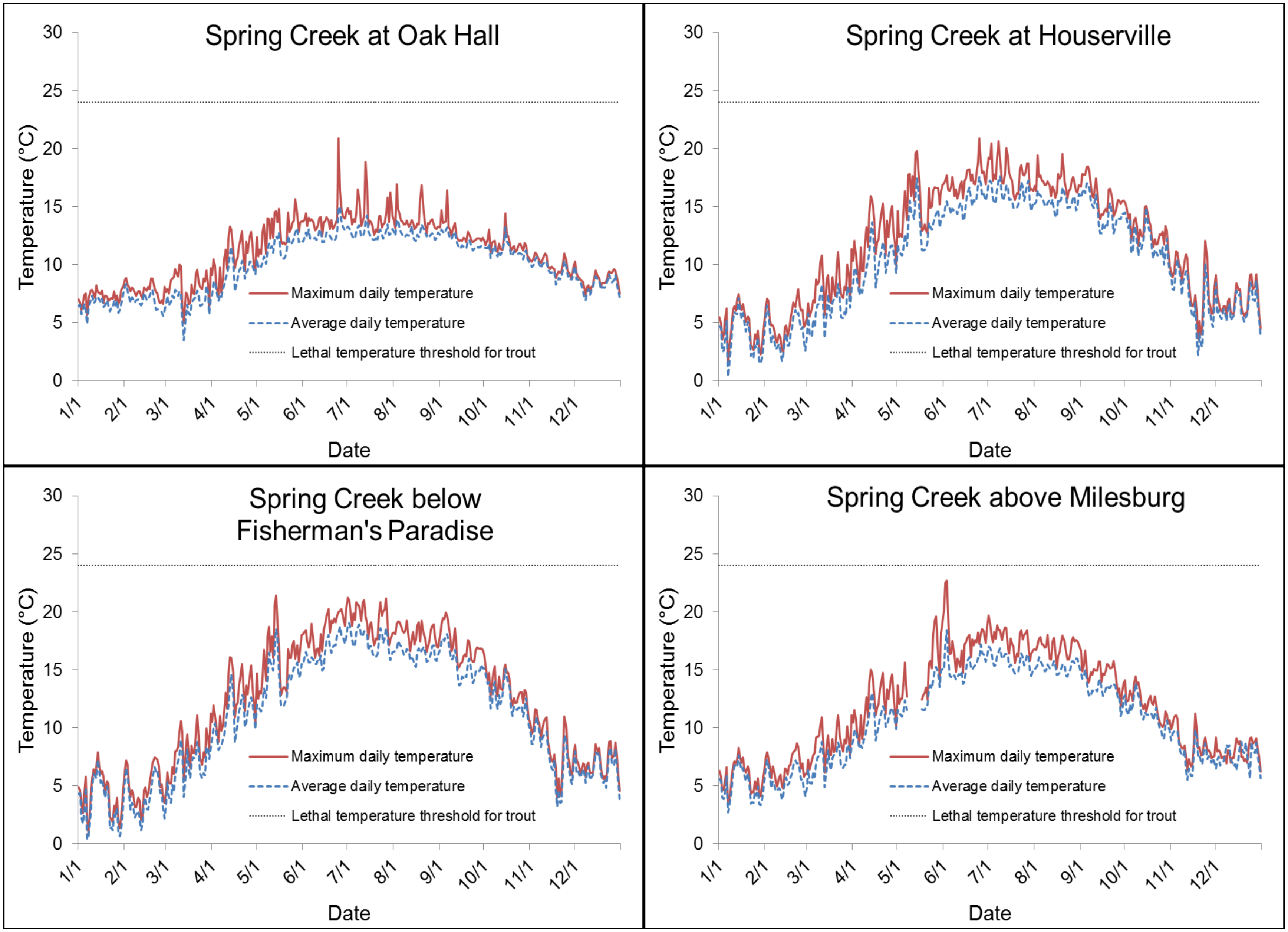


Buffalo Run Upstream from Fillmore

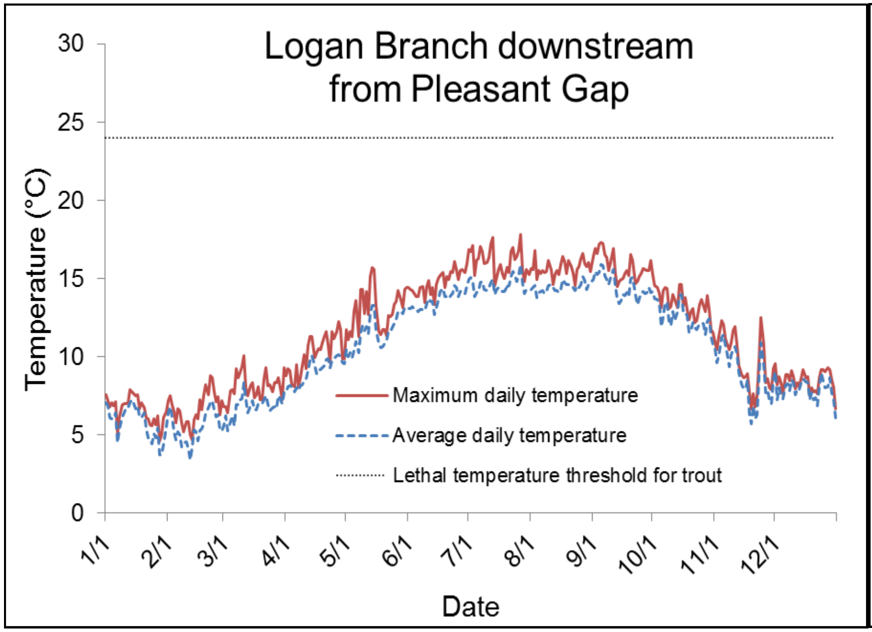


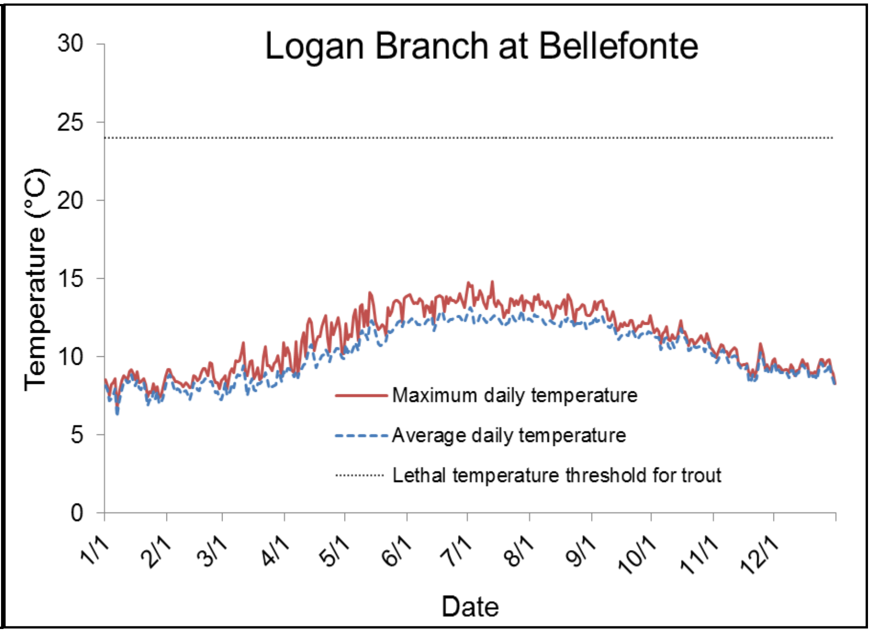
Buffalo Run at Coleville (Bellefonte)

Appendix 7: Daily Stream Temperatures for 2014 (*continued*)



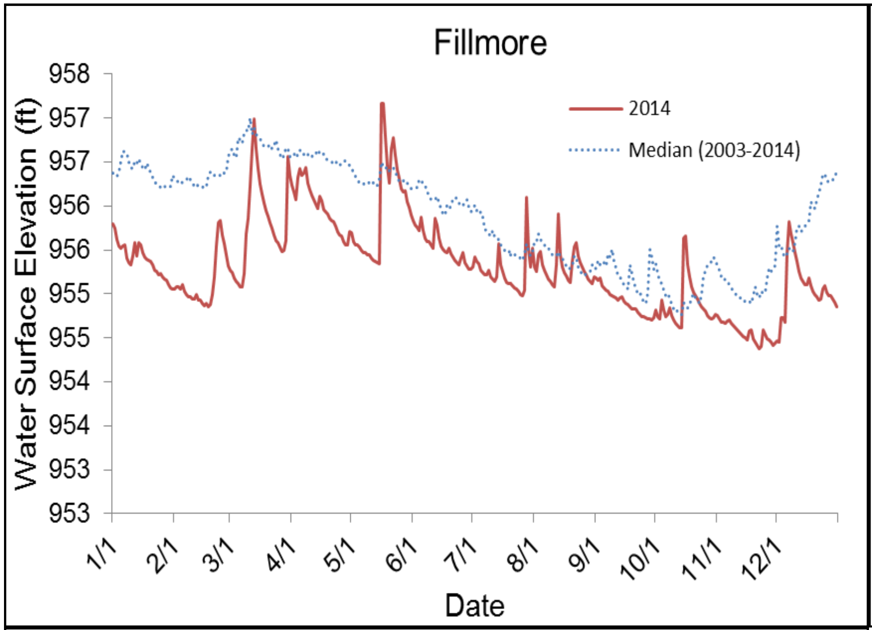
Appendix 7: Daily Stream Temperatures for 2014 (*continued*)

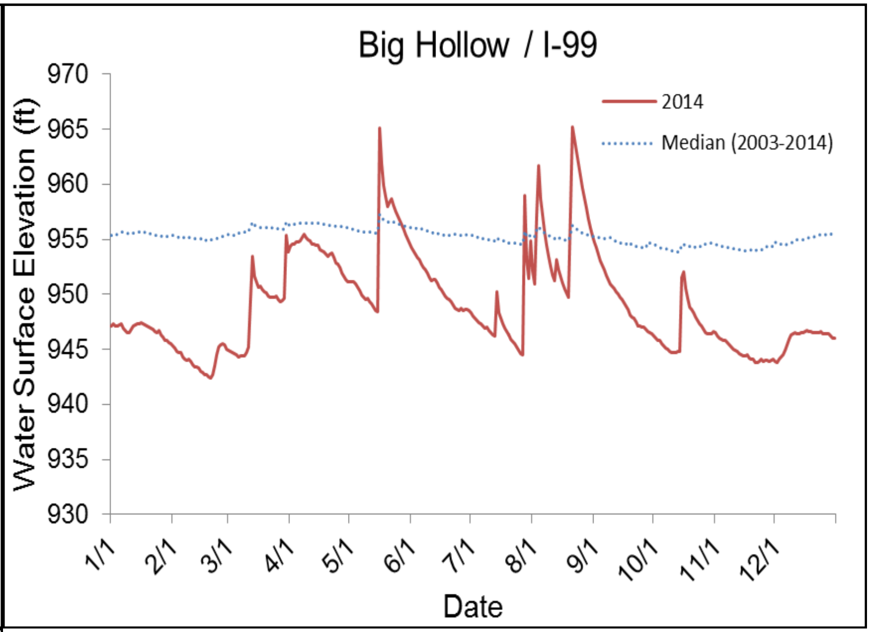


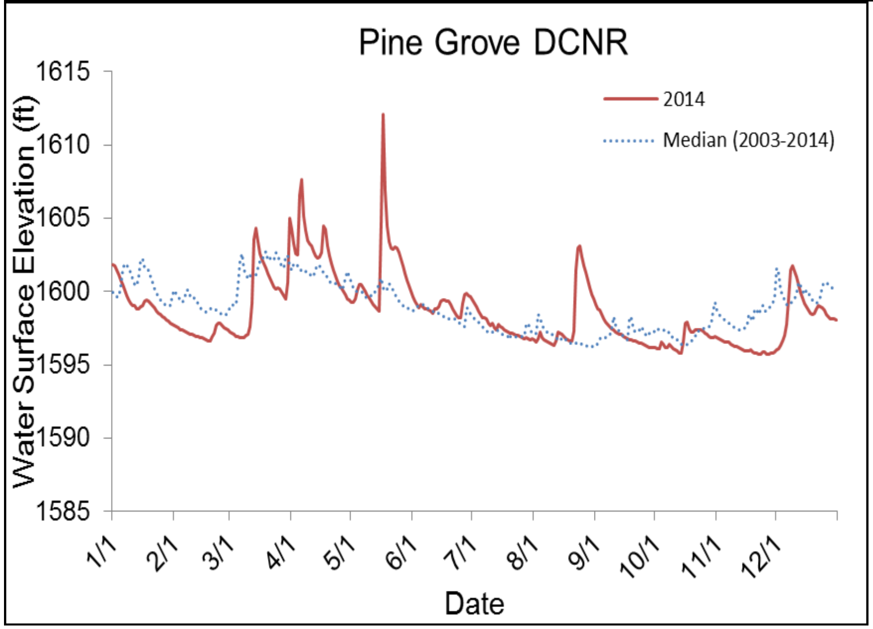


Appendix 8: Daily Groundwater Elevations for 2014

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







Appendix 8: Daily Groundwater Elevations for 2014 (*continued*)

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