Benthic Macroinvertebrate Monitoring in the Spring Creek Watershed

The Water Resources Monitoring Project's

2012 State of the Water Resources Report

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FROM THE CHAIR

In this issue of the State of the Water Resources, we examine benthic macroinvertebrate monitoring, which was sampled by the WRMP for the first time in 2012. The study of the macroinvertebrates provides a relatively inexpensive means of assessing the long-term cumulative effects of many ecosystem stresses. Biological monitoring involves sampling and cataloging macroinvertebrates that live in the sediments at the bottom of our streams. We also compare the 2012 data with historical studies that have been collected by others.

Additionally, 2012 also saw major changes in the Water Resources Monitoring Project's (WRMP) website, which can be found at: www.springcreekmonitoring.org

Not only does this new website provide information about the WRMP and its mission, but now the site also includes an interactive map with new site descriptions and information about the gages. We hope you find this new website useful.

It is also with regret that I inform you that Nick Schipanski, the current Water Resources Coordinator, will be leaving the WRMP before the end of 2013. Nick has advanced the mission and quality of data collected by the WRMP and is the primary author of this excellent annual report. Nick and his family are moving to Fort Collins, Colorado and we wish him and his family the best in all their pursuits.

We hope that you find this year's report on the State of the Water Resources both interesting and informative. Residents of the Spring Creek Watershed currently enjoy better water quality than the region has seen in nearly 100 years. The Water Resources Monitoring Project, which has been in place for over 15 years, provides vital long-term data that can be used by local planning officials to make sound land use decisions. The Water Resources Monitoring 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 the data needed to monitor changes within the watershed as our community continues to grow.

Larry Fennessey,
Chair

Monitoring Benthic Macroinvertebrates

Benthic macroinvertebrates are animals without backbones, such as larval insects, worms and molluscs, which live at the bottom of streams (and lakes) and are visible to the naked eye. A good way to assess the health of a watershed is to look at living things. A high quality stream typically supports a diverse assemblage of benthic macroinvertebrates. Streams impacted by human activities tend to have less diverse populations and those organisms present tend to be more resilient to adverse water quality and habitat conditions.

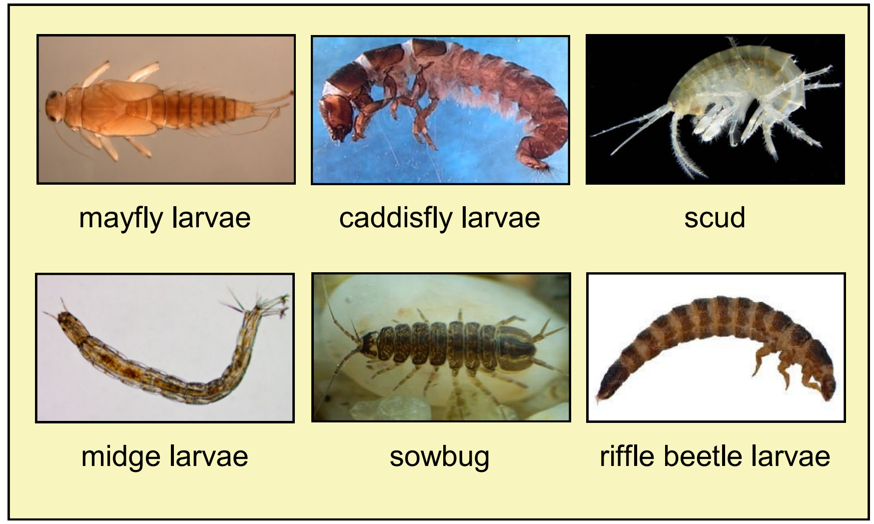


Figure 1. Examples of benthic macroinvertebrates commonly observed in the Spring Creek Watershed.

People tend to be more interested in fish than invertebrates. But many invertebrates are as sensitive or more sensitive to changes in their environment as trout. There are many good reasons to examine invertebrates:

- They are relatively easy to sample. Benthic macroinvertebrates are abundant and can be easily collected and identified.
- They are relatively immobile. Animals such as fishes can escape toxic spills or degraded habitats by swimming away. Most macroinvertebrates spend all or a large part of their life cycle in the same part of a stream. When such stable communities change over time, it often indicates problems in the stream.
- They are continuous monitors of environmental quality. The composition of benthic macroinvertebrate communities in a stream reflects the stream's physical and chemical conditions over time. In contrast, measuring for specific water quality parameters (such as the concentration of a chemical or the amount of dissolved oxygen) describes the condition of the water only at the time the samples were taken.
- They are a critical part of the aquatic food web. Benthic macroinvertebrates form a vital link in the web that connects plants and leaf litter to the fish that live in the stream. The condition of the benthic macroinvertebrate community reflects the stability of the streams food web.

Observing what types of invertebrates thrive, or don't thrive, in a stream can tell a lot about the biological health of the stream. If only a few types of invertebrates live there, or if the invertebrates are primarily ones that adapt well to water that is polluted in some way, there is likely a problem present.

Chemicals such as heavy metals, solvents and pesticides can be toxic to benthic macroinvertebrates [1,2]. Human land use in and around streams can impact aquatic life in a variety of ways[3]. Land development often removes shelter habitat and food sources, adversely impacting aquatic organisms. A lack of oxygen dissolved in the water is detrimental to both macroinvertebrates and fish. Too many nutrients from agricultural or lawn fertilizers, septic tanks and sewage treatment plant discharges can lead to excess plant growth than may result in a lack of dissolved oxygen during the night (when plants consume ,instead of release, oxygen) or when the plants decay after death, a process that consumes oxygen. The amount of oxygen dissolved in water decreases as water temperature increases, so removing shade trees from stream banks or directing stormwater runoff from impervious surfaces into streams can raise stream water temperatures and lower oxygen levels.

Biologists and other researchers have developed ways to sample invertebrates in a uniform manner, identify and count them, and then perform calculations to assess the stream health. A set of calculations can be developed that give a good indication of the biological health of a stream site by sampling at many sites, both pristine and polluted. The calculations measure such things as total biodiversity, the variety of mayflies, stoneflies, and caddisflies (invertebrates that are typically most intolerant of habitat and water quality impacts), the number of organisms that are known to adapt well or poorly to adverse water quality impacts, and other characteristics. These calculations, or metrics, and their methods are generally termed an Index of Biological Integrity, or IBI.

Since ecological conditions differ between regions, with an associated difference in the invertebrates that live in those streams, there exist different IBIs for use in specific areas. Typically, IBI's have been developed on a state-by-state basis, and often there is more than one IBI per state. The Pennsylvania Department of Environmental Protection (PDEP) has developed IBIs for use in this state.

Examining the macroinvertebrates in a stream can indicate if something is impacting the macroinvertebrate population, but it generally cannot specify the cause. Determining cause typically requires chemical water quality tests and/or

[1] Beltman, D., W. Clements, J. Lipton, and D. Cacela. 1999. Benthic invertebrate metal exposure, accumulation, and community-level effects downstream from a hard rock mine site. Environmental Toxicology and Chemistry, 18 (2), pg 299-307.

[2] Archaimbault, V., P. Usseglio-Polatera, J. Garric, J.G. Wasson, and M. Babut. 2009. Assessing pollution of toxic sediment in streams using bio-ecological traits of benthic macroinvertebrates. Freshwater Biology, 55 (7), pg 1430-1446.

[3] Barbour, M., J. Gerritsen, B. Snyder., J. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington D.C., pg. 3.4-3.5.

other surveys that are more time consuming and expensive than macroinvertebrate sampling. Therefore, study of the macroinvertebrates provides a relatively inexpensive means of flagging sites for follow-up investigations.

Pennsylvania's "true" limestone stream IBI

Currently, PDEP uses separate methodologies and metrics to monitor and assess macroinvertebrate communities depending on the size of the stream, underlying geology and type of stream habitat sampled[4]. Streams that are significantly influenced by inputs from springs in a limestone geology, or simply "limestone streams", are relatively rare. Of approximately 83,000 miles of streams in Pennsylvania, less than 800 miles are limestone streams[5].

Limestone streams share certain characteristics: they have relatively low gradient, high alkalinity, and have moderate water temperatures (in particular, a lack of freezing temperatures in the winter)[6]. These characteristics produce a unique macroinvertebrate community. The low diversity in habitat and temperature regime and the unique water chemistry produces a macroinvertebrate community of low diversity. However, these streams are very productive, producing a high density of macroinvertebrates. The end result is a community with a few types of very abundant organisms. If a limestone stream is assessed using the same methodology as for a freestone stream, a pristine site would look impaired. Therefore, correctly classifying a stream is critical for applying and interpreting Pennsylvania IBIs.

There are many reasons why limestone streams are so productive but high alkalinity and moderate temperatures are central. Associated with these criteria, limestone stream productivity is also influenced by high levels of dissolved minerals (especially calcium carbonate) and consistent baseflows.

The chemical composition of the water comes from compounds leached from surrounding rock. Spring-fed streams running through limestone topography have high alkalinity, a measure of the capacity of water to neutralize an acid. This alkalinity results from high levels of dissolved minerals, especially calcium carbonate. Carbonates counteract acidity. The amount of biomass in a stream is directly related to the pH. The more bicarbonate in solution, the more acid is neutralized, and the higher the pH. Streams originating in non-limestone geology, such as granite or shale, are typically low in alkalinity, with few dissolved minerals. Their productivity in terms of pounds of fish, invertebrates and plants is lower in comparison to a limestone stream. The excellent trout fishery in Spring Creek, with its resulting economic benefits, is a direct result

4 Chalfant, B. 2009. A Benthic Index of Biological Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania. Pennsylvania Department of Environmental Protection, Harrisburg PA.
5 Botts, W. 2009. An Index of Biological Integrity (IBI) for "True" Limestone Streams. Pennsylvania Department of Environmental Protection, Harrisburg PA, p. 3.
6 *Ibid.* p. 3.

Table 1. Pennsylvania Department of Environmental Protection criteria for classifying limestone streams and parameter observations at WRMP monitoring stations in the watershed.

Parameter	Criterion	Spring Creek at Houserville	Logan Branch below Pleasant Gap	Logan Branch in Bellefonte	Thompson Run below College Ave.	Slab Cabin Run below Millbrook Marsh	Slab Cabin at South Atherton	Buffalo Run above Fillmore	Buffalo Run in Bellefonte	Cedar Run in Oak Hall
Alkalinity (mg/l $CaCO_3$)[a]	**Minimum 140**	232	172	168	230	232	220	258	244	240
Water Temperature (° C)[b]	**4 to 18**	4.5 to 16.8	6.4 to 16.5	8.2 to 12.7	8.0 to 14.2	5.9 to 15.9	3.6 to 18.8	2.2 to 17.3	3.2 to 17.9	5.1 to 16.3

[a] Values measured by WRMP during baseflow conditions in July 2013
[b] Range of average monthly temperature at WRMP monitoring stations for period of record (average of 11.71 years/station)

of the high productivity resulting from the limestone geology of the Nittany Valley.

Since Spring Creek is spring-fed, temperature and flow conditions are relatively consistent throughout the year in comparison to non-limestone streams. Consistent baseflow means more consistent levels of food and nutrients. The large contribution to overall stream flow from groundwater sources moderate fluctuations in temperature (as compared to non-limestone streams) throughout the year. Lack of freezing temperatures in winter allow plants and animals to maintain a high metabolic activity for a larger portion of the year, while moderate water temperatures in the summer ensures high levels of dissolved oxygen.

The moderate temperatures in limestone streams also influences the diversity of benthic macroinvertebrates populations. Many macroinvertebrates depend on fluctuations in temperature, particularly down to near-freezing temperatures, to trigger internal processes that complete their life cycles[7]. The lack of these temperature triggers makes limestone streams unsuitable to many benthic macroinvertebrates.

The Pennsylvania Department of Environmental Protection (PDEP) considers two characteristics as particularly important in classification of a limestone stream: temperature and alkalinity[8]. (The stream must additionally be designated as a Cold Water Fishery) **Table 1** above is a summary of the PDEP limestone stream criteria and measured values of these parameters at select WRMP monitoring stations on the main stem of Spring Creek and its tributaries. Alkalinity is not routinely measured by the

[7] *Ibid.*, p.4.
[8] *Ibid.*, p.4.

WRMP but alkalinity data was collected for monitoring locations in Table 1 in July 2013 during baseflow conditions. Stream temperature data is continuously monitored with data loggers at these WRMP monitoring locations. Alkalinity values measured by WRMP meet the alkalinity criteria for a limestone stream at all locations. Temperature data from both Buffalo Run locations and from Slab Cabin Run at South Atherton Street fall outside of the PDEP temperature criteria for use of the limestone stream IBI methodology.

The PDEP and the Pennsylvania Fish and Boat Commission (PFBC) staff measure alkalinity, temperature, pH, dissolved oxygen (DO) and other water quality parameters when performing their IBI sampling. PDEP staff classify locations that they have routinely sampled on Spring Creek, Logan Branch, Cedar Run and Thompson Run as meeting the criteria for true limestone streams (Steve Means, personal communication).

Some streams, or some sections of streams, meet some but not all of the limestone stream criteria. These are termed “limestone-influenced” streams (Steve Means, personal communication). There is no specific Pennsylvania IBI for these types of streams and applying the existing metrics to samples taken from a limestone-influenced stream can misclassify a site in terms of impairment (Steve Means, personal communication).

Staff at PDEP consider Slab Cabin Run and Buffalo Run as “limestone-influenced” (Steve Means, personal communication). Although these streams have significant groundwater inputs and high alkalinity, average monthly water temperatures measured at WRMP locations fall below the minimum temperature criteria for a limestone stream at Slab Cabin Run at South Atherton Street and at both WRMP monitoring stations on Buffalo Run (see Table 1 on page 5). Since temperature variations outside of the criterion range can allow for a more diverse population of invertebrates than what is encountered in true limestone streams, applying limestone metrics to a sample taken from Slab Cabin Run above Millbrook Marsh or Buffalo Run can misclassify the site’s status. Temperature and alkalinity data from Slab Cabin Run below Millbrook Marsh indicates that this section of the stream can be considered limestone for purposes of the IBI. Note that WRMP’s Buffalo Run monitoring locations are each approximately two river miles from PDEP’s IBI sampling location, from which long-term water temperature data are not available.

The Pennsylvania limestone stream IBI takes a multi-metric approach to measuring impact. Several different ways of measuring the organisms in a sample are added together to arrive at a single score for each site. The method currently in use by the PDEP uses six metrics, or measurements: two richness measures (i.e. the number of different types of organisms in the sample); three pollution tolerance / intolerance measures (i.e. the ability of organisms present in the sample to survive polluted conditions) ; and one measure of sample diversity. **Table 2** on page 7 shows the score key for the IBI for limestone streams. An IBI value of greater than 73 is comparable to a site on a reference stream (reference streams support a high quality or

Table 2. Pennsylvania Department of Environmental Protection Limestone stream IBI scoring.

Classification	Reference	Non-impaired	Impaired	
			Moderately	Severely
Score	> 73	73—60	< 60 - 30	< 30

exceptional quality cold water fishery and reference sites were known to be free from direct water quality impacts from any abiotic source). Sites with a score between 60 and 73 support their designated uses (i.e. Cold Water Fishery) and are not impaired. An IBI value less than 60 indicates impairment. Values between 30 and 59 indicate moderate impairment; values below 29 are severely impaired.

Benthic Macroinvertebrate Monitoring in 2012

The last IBI conducted by the PDEP in the main stem of Spring Creek was in 2008. The Pennsylvania Fish and Boat Commission have sampled on a yearly basis since 2008 at four locations on Spring Creek and two locations on Logan Branch to monitor impacts from their hatcheries operations (one site immediately upstream and downstream of the Benner Spring, Bellefonte, and Pleasant Gap hatcheries). Identifying a data gap, the Water Resources Monitoring Project conducted an IBI survey in 2012. The main stem of Spring Creek was the major focus of the survey, although sites on Logan Branch, Cedar Run, Buffalo Run, Slab Cabin Run and Thompson Run were also included (see **Figure 2** on page 8).

The sites that WRMP selected to sample generally coincided with sites that PDEP and PFBC had historically surveyed in past years. To control costs, the WRMP did not sample immediately upstream or downstream of the Benner, Bellefonte or Pleasant Gap fish hatcheries, because PFBC was actively monitoring macroinvertebrates at those sites on a yearly basis. WRMP also did not sample sites that PDEP or PFBC sampled only intermittently or abandoned at some point in the sampling history. WRMP also did not sample headwater locations on Slab Cabin Run and Logan Branch due to the absence of identified sources of impacts in those these areas. To further analyze potential stormwater impacts, WRMP added two sampling locations on the main stem of Spring Creek: upstream from Boalsburg (at river mile 21.1) and immediately upstream from East College Avenue in Lemont (at river mile 16.2). All stream sites sampled have been designated as supporting a Cold Water Fishery.

The WRMP used sample collection, preservation, processing and identification methods developed by PDEP for limestone streams at all sites[9]. This includes the two sites that temperature data indicate are "limestone-influenced" and not "true" limestone stream segments: the site on Slab Cabin Run above South Atherton Street and the site on Buffalo Run. Samples were collected from riffle/run habitats, as these habitats are considered most productive, using the PA Modified Rapid Bioassessment Protocol (RBP) III method for limestone streams. All sites

[9] *Ibid,*. pp. 26-30.

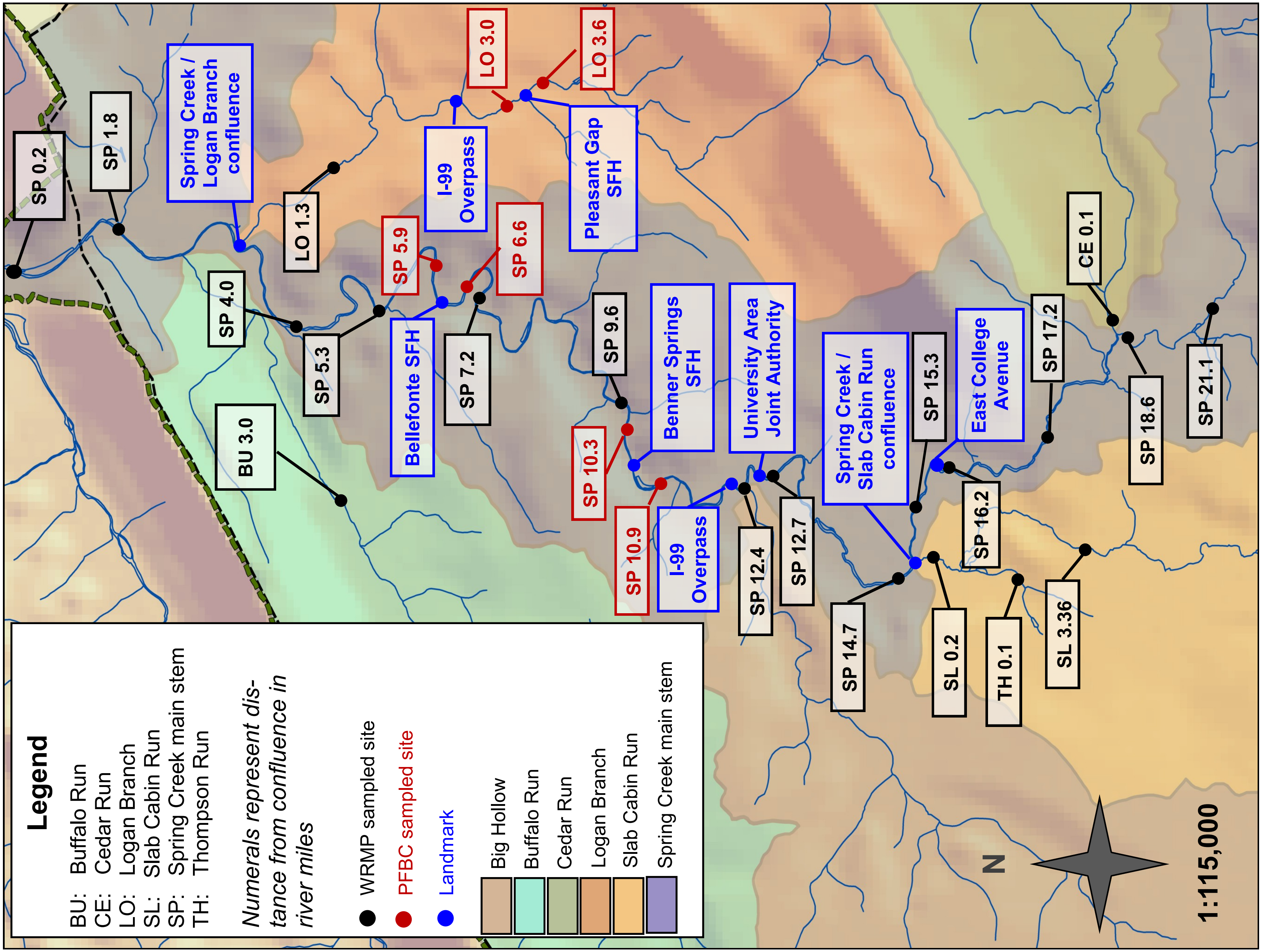


Figure 2. Sites sampled for IBI in 2012.

were sampled between March 7th and March 14th 2012. Samples were fixed in 95% ethanol, which allows for long-term storage of the sample. Each sample was then processed using an adapted EPA 1999 RBP method to randomly select a sub-sample of organisms for identification. The EPA RBP selection method yields quantitative data suitable for use in calculating IBI metrics. Most organisms were identified to the level of genus. Samples were processed and identified between April 2012 and February 2013.

In addition to the sample collection, each site was given a habitat score using the RBP Habitat Assessment Field Data Sheet for low gradient streams. Scores can range from 0 (low) to 200 (high). There can be much overlap in the habitat scores between reference sites and impaired sites: reference sites generally score above 150 but so can impaired streams, so habitat assessment scores are not a statistically useful parameter[10]. Sites that score below 120 are generally impaired.

Past IBI Data from the main stem of Spring Creek

Eighteen sites on the main stem of Spring Creek have been surveyed at least once since 2001. Surveys were conducted in 2001 and each year from 2004 through 2008 by PDEP. From 2009 through 2011, four sites (one site upstream and one site downstream of the Benner Spring

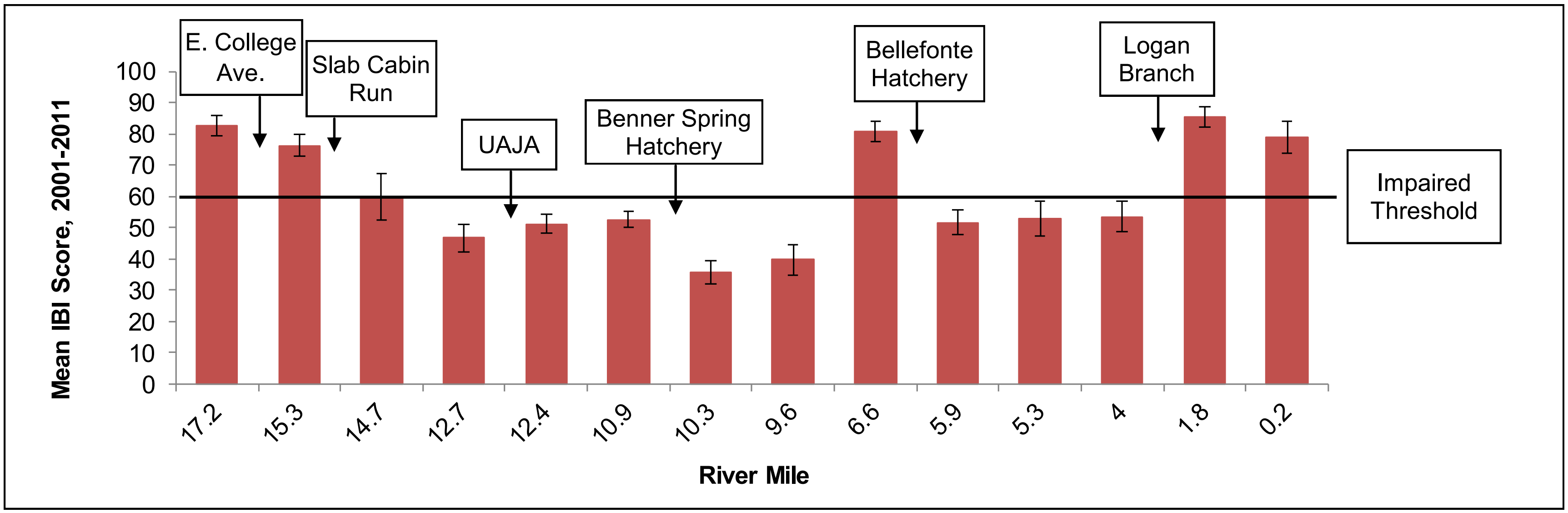


Figure 3. Mean IBI values on Spring Creek, 2001-2011. Data courtesy PDEP and PFBC. Error bars represent standard error.

[10] *Ibid*. pg. 2.

Table 3. Mean IBI values for all surveys conducted on Spring Creek between 2001 and 2011. Data for 2001 through 2008 courtesy of PDEP (Steven Means, personal communication). Hatchery data for 2009-2011 courtesy of PFBC (Steve Kepler, personal communication).

River mile	18.6	17.2	15.3	14.7	12.7	12.4	11.8	10.9	10.5
Site Description	Oak Hall	Between Oak Hall and Lemont	Downstream of E. College Ave.	Downstream of Spring Creek - Slab Cabin Run confluence	Upstream of UAJA	Downstream of UAJA	Downstream from I-99 overpass	Upstream from Benner Spring Hatchery	Downstream from Benner Spring and upstream from Benner Spring Hatchery discharge
Year									
2001	-	75	58	30	35	39	-	54	-
2004	-	79	79	82	57	61	-	63	-
2005	-	87	78	68	60	53	-	55	-
2006	-	99	83	53	41	48	-	48	-
2007	76	78	77	49	33	48	51	58	47
2008	-	78	83	77	55	58	57	59	48
2009	-	-	-	-	-	-	-	59	-
March 2010	-	-	-	-	-	-	-	41	-
April 2010	-	-	-	-	-	-	-	53	-
2011	-	-	-	-	-	-	-	35	-
site mean, 2001-2011	**76**	**82.7**	**76.4**	**59.9**	**46.8**	**51.3**	**54**	**52.5**	**47.5**
std error	**0.0**	**3.3**	**3.5**	**7.3**	**4.5**	**3.0**	**1.2**	**2.6**	**0.1**

Table 3 (*continued*). Mean IBI values for all surveys conducted on Spring Creek between 2001 and 2011. Data for 2001 through 2008 courtesy of PDEP (Steven Means, personal communication). Hatchery data for 2009-2011 courtesy of PFBC (Steve Kepler, personal communication).

River mile	10.3	9.6	8.6	6.6	5.9	5.3	4.0	1.8	0.2
Site Description	Downstream from Benner Spring Hatchery	Downstream from Shilo Road	Rockview Road	Upstream from Bellefonte Hatchery	Downstream from Bellefonte Hatchery	Spring Creek Road / USGS Axemann Gage	Upstream from Buffalo Run Road	Downstream from Spring Creek - Logan Branch confluence	Milesburg
Year									
2001	15	19	-	76	43	32	41	85	70
2004	41	49	-	82	74	67	66	80	81
2005	42	53	-	86	69	66	67	85	59
2006	41	49	-	89	55	59	62	89	84
2007	36	35	72	85	30	36	43	75	82
2008	58	33	84	95	50	58	43	100	99
2009	43	-	-	56	52	-	-	-	-
March 2010	19	-	-	82	44	-	-	-	-
April 2010	33	-	-	85	59	-	-	-	-
2011	29	-	-	74	40	-	-	-	-
Site mean,	**35.6**	**39.7**	**78.3**	**81.0**	**51.6**	**52.9**	**53.6**	**85.6**	**79.0**
std error	**3.7**	**4.8**	**4.1**	**3.1**	**4.0**	**5.7**	**4.7**	**3.1**	**5.0**

and Bellefonte hatcheries) were surveyed by PFBC. The IBI values for fourteen sites sampled in every survey conducted between 2001 and 2008, plus the 2009-2011 hatchery data, are shown in **Figure 3** on page 9. Data for all sites sampled between 2001 and 2011 are shown in **Table 3** on pages 10-11**.** For years prior to 2009, new IBI values were recalculated by PDEP staff using current limestone stream metrics (Steve Means, personal communication).

Historically, IBI scores were lower immediately downstream from urban areas and point sources (such as the fish hatcheries) as compared to sites upstream. The largest declines in IBI scores occur downstream from the confluence of Spring Creek with Slab Cabin Run below Millbrook Marsh and downstream from the Benner Spring and Bellefonte hatcheries. Thompson Run and Slab Cabin Run carry much of the stormwater discharge from the urban core of State College. Hatcheries have historically been a source of nutrients and organic wastes.

There has been no observed reduction in the IBI score downstream from the UAJA waste treatment plant in surveys conducted between the years 2001 and 2011. To the contrary, the downstream IBI score is typically higher than the upstream site score, likely due to the increase in stream flow at the downstream location where the added volume of water from UAJA is of relatively high quality.

The PFBC undertook an effort to improve the quality of the discharges from the three hatcheries in the watershed. Between 2007 and 2010 they installed microscreen filtration

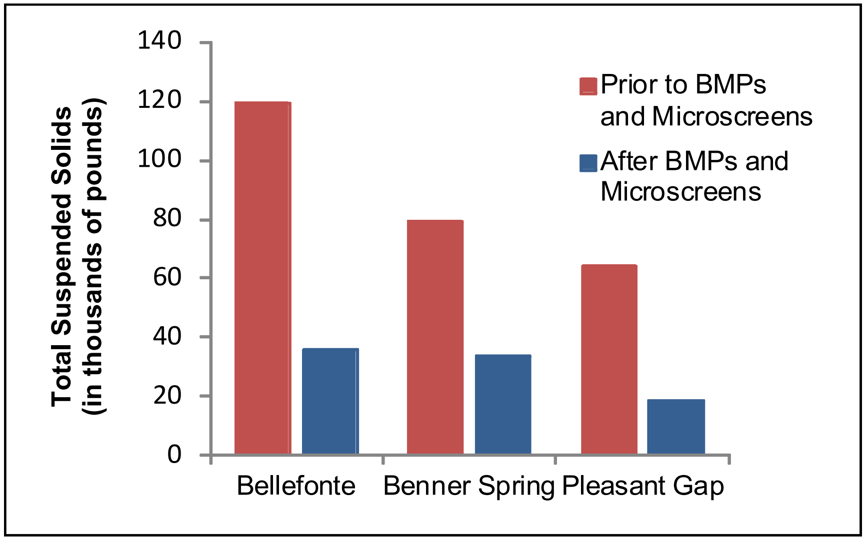


Figure 4. Pound of total suspended solids discharged from the PFBC hatcheries before and after installation of BMPs and microscreen filters. Data courtesy PFBC.

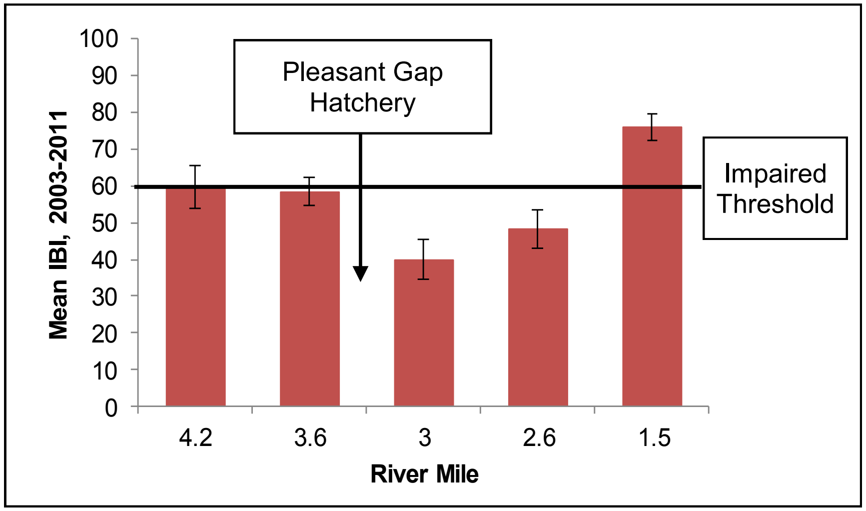


Figure 5. Mean IBI values on Logan Branch, 2003-2011. Data courtesy PDEP and PFBC. Error bars represent standard error.

Table 4. Mean IBI values for surveys conducted on Logan Branch between 2003 and 2011. Data courtesy of PFBC (Steve Kepler, personal communication).

River mile	4.2	3.6	3.0	2.6	1.5
Site Description	Downstream from Corning Asahi	Upstream from Pleasant Gap hatchery	Downstream from Pleasant Gap hatchery	At I-99 overpass	Upstream from Cerro
Year					
2003	-	40	28	-	-
2005	62	59	30	44	70
2006	-	75	32	44	-
2007	43	46	23	33	82
2008	-	48	16	-	-
2009	-	67	59	58	-
March 2010	67	59	58	42	-
May 2010	67	62	48	69	76
2011	-	68	52	-	-
Site mean, 2001-2011	**60**	**58**	**40**	**48**	**76**
std error	**5.7**	**3.6**	**5.3**	**5.3**	**3.5**

systems at a cost of $7.1 million (Robert Carline, personal communication). These new systems have greatly reduced the amount of total suspended solids leaving each hatchery (**Figure 4** on page 12). The microscreen filters are intended to remove particulate nutrients such as fecal matter and unconsumed fish feed, but dissolved nutrients remain in the hatchery discharge.

Past Logan Branch IBI Data

PDEP and PFBC have conducted IBI surveys in Logan Branch to monitor impacts from industrial sources (Corning Asahi, in particular) and impacts from the Pleasant Gap hatchery. With the termination of Corning Asahi's operations and the end to its discharge permit in 2007, surveys have focused on impacts from the Pleasant Gap hatchery. Data for the Logan Branch surveys between 2003 and 2011 are shown in **Table 4** above and **Figure 5** on page 12. Historically, a decrease in IBI score is seen immediately downstream of the hatchery, with a recovery to unimpaired conditions by river mile 1.5, located upstream from Bellefonte. Sites near the hatchery operations are also subject in impacts from mining operations in the area that discharge excess water from quarries. Since microscreen filters were installed at the hatchery in 2007, the IBI scores downstream of the discharge have improved.

IBI Data From Other Spring Creek Tributaries

Reports were obtained from PDEP for IBI surveys on Slab Cabin Run, Buffalo Run, and Cedar Run[11-15]. All pre-date 2004. Slab Cabin Run has been surveyed at various locations in 1987, 1990 and 2002 (these surveys included sampling at a single site on Thompson Run at the upstream edge of Millbrook Marsh). Cedar Run was sampled at a single site, just upstream from the confluence with Spring Creek in Oak Hall, in 2002. Buffalo Run was surveyed at a single location between Upper and Lower Gyp Roads at river mile 3.7 in 2003.

Comparing data from surveys pre-dating current IBI methods with current data can be problematic. There have been changes in the methods for collecting, processing the sample and interpreting the results. In many cases, raw data with which to re-evaluate results using current metrics were unavailable.

In all pre-2003 surveys of Slab Cabin Run, PDEP staff reported impaired conditions at the Thompson Run site and all sites on Slab Cabin Run below Pine Grove Mills while sites upstream from Pine Grove Mills were unimpaired . The site on Buffalo Run sampled in 2003 utilized an early draft version of the limestone stream IBI and resulted in reference level scores[11]. The site on Cedar Run sampled in 2002 was reported as impaired[12]. (Information about the methods used for this sampling was not available but the raw data indicate the result was due to the dominance of the sample by sow bugs, a pollution tolerant macroinvertebrate, combined with a lack of pollution sensitive organisms)

2012 IBI Results

Results from the 2012 WRMP survey on the main stem of Spring Creek are found in **Figure 6** on page 15 and **Table 5** on page 16. Data from the PFBC surveys upstream and downstream of their hatchery facilities are included. Results indicate non-impaired conditions at all WRMP sites

[11] Hughey, R.E. 1987. Aquatic Biological investigation, Slab Cabin Run, Stream File 23036, July-August 1987.

[12] Hughey, R.E. 1990. Aquatic Biological Investigation, Slab Cabin Run Watershed, Stream File 23036, July 1989.

[13] Hughey, R.E. 2002. Aquatic Biological Investigation, Slab Cabin Run- DEP File No. 22036

[14] Hughey, R.E. 2004. Aquatic Biological Investigation, Buffalo Run- DEP File No. 22972

[15] PADEP-RBP field sheet dated 04-24-2002 obtained from Steve Means, Pennsylvania Department of Environmental Protection, Harrisburg PA. .

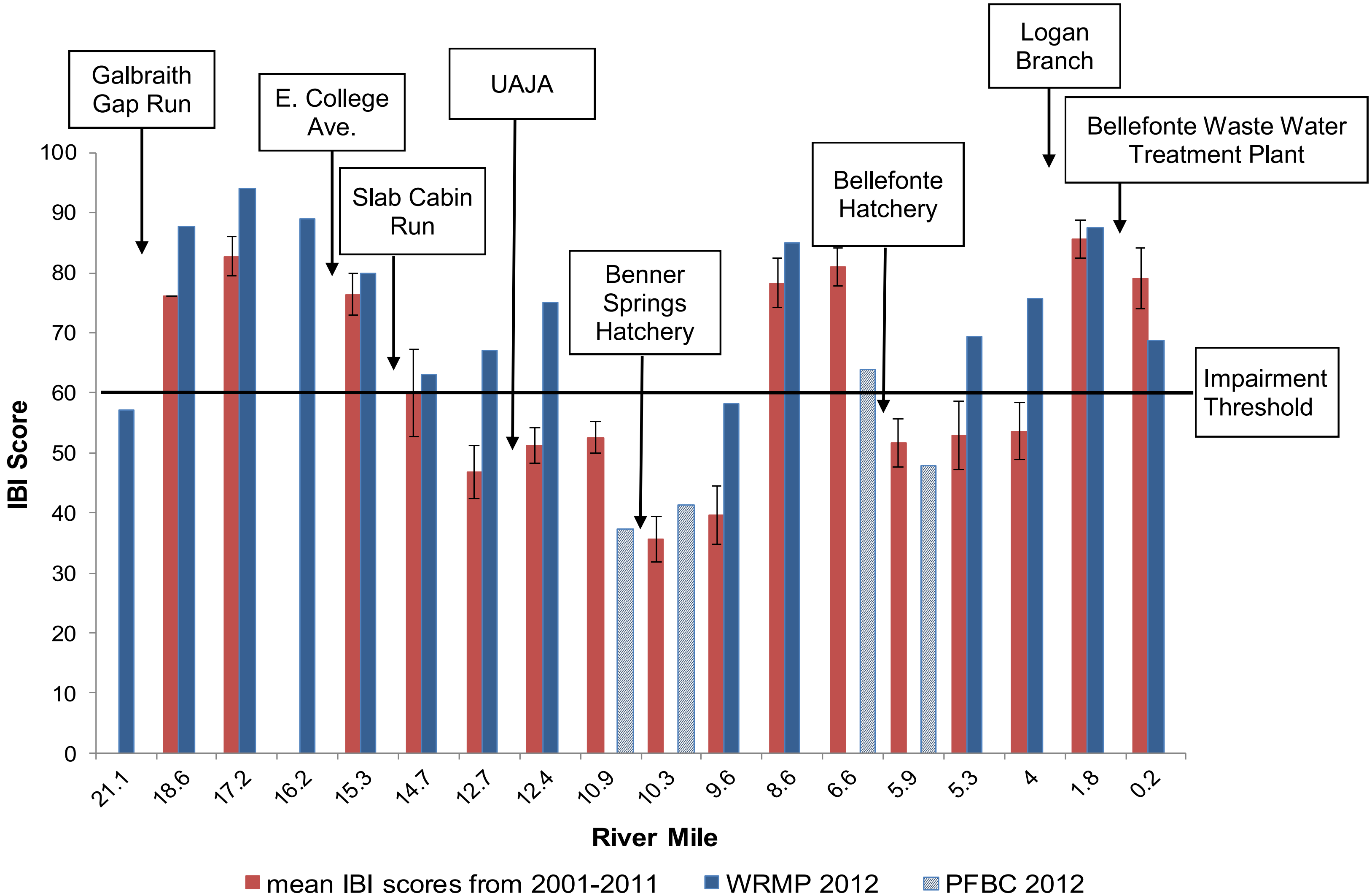


Figure 6. IBI results for 2012 from the main stem of Spring Creek. Error bars for mean data from 2001 to 2011 represent standard deviations.

Table 5. 2012 IBI results for the main stem of Spring Creek. **Bold** indicates impaired IBI score. NA= data not available

River Mile	Sample Site Description	Data Source	IBI Score	Habitat Score
0.2	Milesburg	WRMP	69	140
1.8	Downstream of Spring Creek / Logan Branch confluence	WRMP	87	156
4	Upstream of Buffalo Run Road	WRMP	76	155
5.3	Axemann USGS gage location on Spring Creek	WRMP	69	128
5.9	**Downstream of the Bellefonte hatchery**	PFBC	**48**	NA
6.6	Upstream of the Bellefonte hatchery	PFBC	64	NA
8.6	Downstream from Rockview Road	WRMP	85	169
9.6	**Downstream from Shiloh Rd**	WRMP	**58**	187
10.3	**Downstream from Benner Spring hatchery**	PFBC	**41**	NA
10.9	**Upstream of the Benner Spring hatchery**	PFBC	**37**	NA
12.4	Downstream from UAJA	WRMP	75	149
12.7	Upstream of UAJA	WRMP	67	161
14.7	Downstream of Spring Creek / Slab Cabin Run confluence	WRMP	63	167
15.3	Downstream of East College Avenue	WRMP	80	153
16.2	Upstream from East College Avenue	WRMP	89	172
17.2	Between Oak Hall and Lemont	WRMP	94	172
18.6	Oak Hall	WRMP	88	153
21.1	**Upstream from Galbraith Gap Run**	WRMP	**57**	156

sampled on Spring Creek, with the exception of the site at river mile 9.6 downstream from the Benner Spring Hatchery and the headwater location at river mile 21.1. Pennsylvania Fish and Boat Commission data indicated impaired conditions at the two hatchery locations. As seen in past years surveys, there was a drop in scores observed downstream of urbanized State College, in particular below the confluence with Slab Cabin Run.

The lowest WRMP score observed on Spring Creek was near the headwaters at river mile 21.1 at a site located just downstream of Fasick Memorial Park and upstream of the confluence with Galbraith Gap Run. There is land development on either bank at this location, but the low score may also be influenced by the site's headwater location, where unique food webs can influence macroinvertebrate communities[16].

In past surveys, there has usually been a drop in IBI score between river mile 14.7 and 12.7. This area receives discharges from the Shilo Road area and the Big Hollow. There was an increase in IBI score observed between these points in 2012.

In data collected by the PFBC, both sites bracketing the Benner Spring hatchery had similar

[16] Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences, 37, pp. 130-137.

scores indicating moderate impairment. Historically, PFBC data show a drop in IBI score from the site upstream of the Benner Spring hatchery to the downstream site (see Table 3 on pages 10 and 11, river mile 10.9 and 10.3), although this was not evident in 2012. The closest WRMP sampling location downstream from the Benner hatchery was located at river mile 9.6, approximately 0.7 river miles downstream from the hatchery. This location was impaired, with a score of 58.

The score for the site upstream of the Benner Spring hatchery at river mile 10.9 is lower than the mean score for this site in IBI surveys since 2001 (see Table 3 on page 10). The nearest WRMP site upstream from this site, at river mile 12.4, scored a 75, well above the impairment threshold. An overpass for I-99 lies between river mile 12.4 and river mile 10.9. The Department of Environmental Protection conducted IBI monitoring both upstream and downstream of the overpass in 2007 and 2008, finding non-impaired scores and little difference between sites (see Table 3, page 10- river mile 12.4 and 11.8). The Big Hollow, a recipient of urban stormwater, also discharges upstream from the Benner Spring hatchery but also upstream of WRMP's river mile 12.4 sampling location that had quite good water quality as measured by the IBI.

There was a sixteen-point drop in score observed downstream of the Bellefonte hatchery in comparison to the upstream site in the PFBC-provided 2012 data. The score indicated moderate impairment at this site. The PFBC data indicate impacts from hatchery discharges in spite of the recent installation of nutrient controls, although road runoff also enters Spring Creek close to where the Bellefonte hatchery discharge enters. The WRMP does not collect water quality samples from sites directly downstream from the hatcheries with which to document changes in hatchery discharges over time.

The IBI results at locations downstream from Bellefonte, at river mile 1.8 (upstream of the waste water treatment plant) and at river mile 0.2 (Milesburg) indicated good water quality. Scores at these sites were higher than the IBI score from the site upstream of Bellefonte at the intersection of Buffalo Run Road and Spring Creek Road. This increase in IBI score is likely due to two, large-volume sources of cold, high quality water: the Big Spring and Logan Branch.

The 2012 IBI scores at sites in Spring Creek were generally higher than the average scores for these sites from 2001 through 2008. Robert Carline, an aquatic ecologist formerly at the Pennsylvania Cooperative Fish and Wildlife Research Unit, had noted that above average stream discharge typically results in higher IBI scores across all sites while below average discharges result in lower IBI scores across all sites (Robert Carline, personal communication). This relationship is seen in **Figure 7** on page 18 which plots the discharge data for Spring Creek at the USGS Axemann stream gage against the percent of sites impaired in IBI surveys conducted between 2001 and 2012. The discharge of Spring Creek at the Axemann gage over the twelve months prior to the 2012 sample

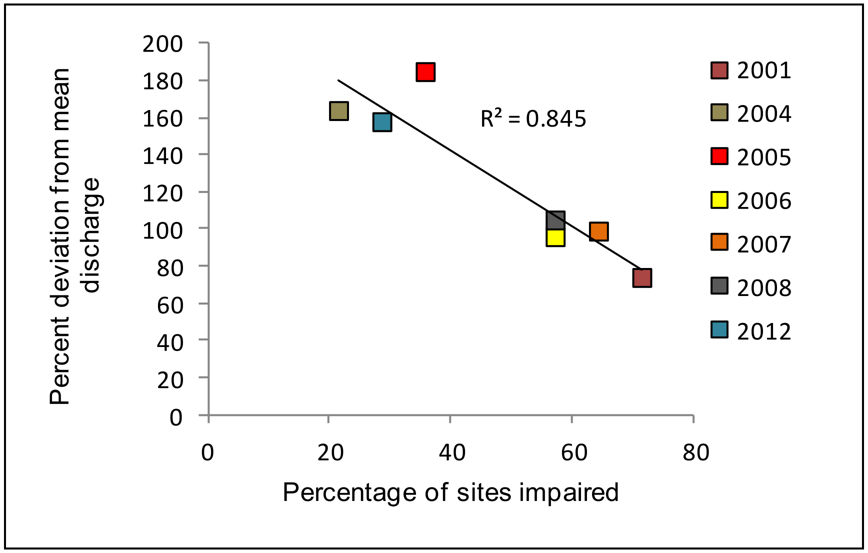


Figure 7. Deviation in Spring Creek discharge prior to IBI sampling versus percent of sites impaired in years 2001, 2004 through 2008, and 2012.

Discharge at Axemann USGS stream gage from http://waterdata.usgs.gov/usa/nwis/uv?site_no=01546500 , with assumed April 1 sample date. Percent of sites impaired includes only the fourteen sites surveyed in each of the Spring Creek surveys conducted in 2001, 2004 through 2008, and 2012.

collection was 158% of the mean discharge for the period of record at this gage (1940-2013). Whether this increase in IBI scores over median historic values is attributable to above average discharge in Spring Creek over the previous twelve months or to reductions in adverse water quality impacts from sources such as stormwater cannot be determined solely from our data. During the late winter of 2013, PDEP conducted IBI sampling at their historic sampling sites on Spring Creek and that data should be available in early fall of 2013. Discharge in Spring Creek during the twelve months previous to late-winter 2013 was similar to average flows (data not shown).

Data for the 2012 IBI survey for tributary streams are found in **Table 6** below. On Logan Branch a single site was sampled by the WRMP at river mile 1.5, approximately two river miles downstream of the Pleasant Gap hatchery. Results here indicated good water quality. From the PFBC data for 2012, there was a slight drop of 7 points in score from the site upstream of the hatchery to the downstream site. The downstream site score indicated moderate

Table 6. 2012 IBI results for tributary streams. **Bold** indicates impaired IBI score. NA= data not available.

Stream	River Mile	Sample Site	Data Source	IBI Score	Habitat Score
Logan Branch	1.5	Upstream from Cerro	WRMP	74	158
Logan Branch	3.0	**Downstream from Pleasant Gap hatchery**	PFBC	**54**	NA
Logan Branch	3.6	Upstream from Pleasant Gap hatchery	PFBC	61	NA
Slab Cabin Run	0.2	Downstream from Millbrook Marsh	WRMP	65	118
Slab Cabin Run	3.3	Upstream from South Atherton Street	WRMP	73	167
Thompson Run	0.1	**Thompson Run in Millbrook Marsh**	WRMP	**37**	144
Buffalo Run	3.7	Between Lower Gyp Road and Upper Gyp Road	WRMP	98	137
Cedar Run	0.1	Upstream from confluence with Spring Creek in Oak Hall	WRMP	96	147

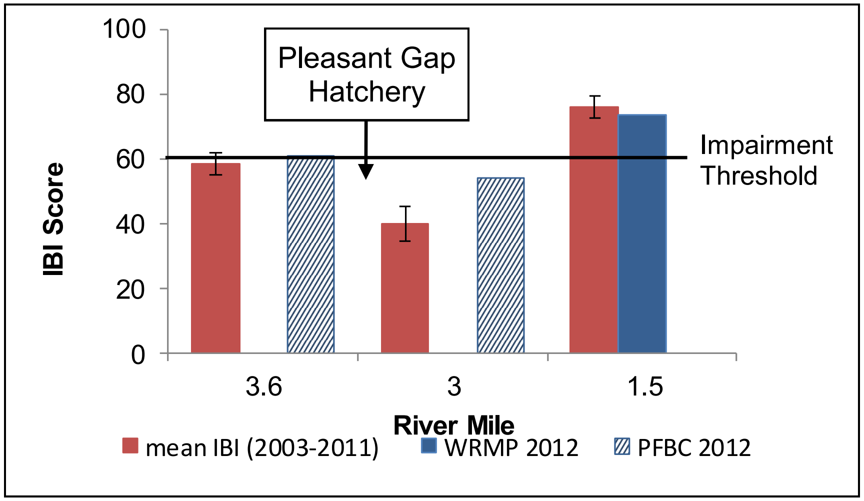


Figure 8. 2012 IBI results for Logan Branch. Median values from 2003 through 2011 courtesy of PDEP and PFBC. Error bars for mean data for 2003 to 2011 represent standard error.

impairment. Since installation of BMP's to remove particulate nutrients from hatchery discharge in 2007, the magnitude of the drop in score from the upstream site to the downstream site has improved (see **Table 7** on page 20).

Data collected by WRMP in 2012 for Buffalo Run, Cedar Run, Slab Cabin Run and Thompson Run are also shown in **Table 6** on page 18. The Thompson Run site, at the edge of Millbrook Marsh upstream from the confluence with Bathgate Springs, had the lowest IBI score in WRMP's survey. Thompson Run is a small tributary stream that receives large stormwater inputs from the urban State College area, subjecting this stream to extreme spikes in discharge and transient temperatures extremes.

Thompson Run is, however, designated a high quality cold water fishery by the State of Pennsylvania. Macroinvertebrate surveys by PDEP at this site in 1988, 1990 and 2002 have all indicated impaired conditions. The habitat assessment in 2012 noted that riparian conditions were excellent but the in-stream riffle habitat at the sampling location was poor.

The two Slab Cabin Run sites, one downstream from Millbrook Marsh at river mile 0.1 and the other upstream from South Atherton Street at river mile 3.3, received non-impaired scores. Both of these sites were impaired in PDEP surveys in 1988, 1990, and 2002. Long-term temperature data from the WRMP indicate that Slab Cabin Run above Millbrook Marsh does not meet the temperature criteria set by DEP for use of the Limestone IBI metrics. Low temperatures during the winter months allow for a more diverse macroinvertebrate community than is typical of a limestone stream and use of the limestone stream IBI methodology may have resulted in an inflated IBI score at river mile 3.3.

The most recent PDEP data for Buffalo Run, from a sampling in 2003 conducted in triplicate, utilized early draft version of the limestone stream protocol and results generated maximum scores for all replicates. The WRMP results at this site in 2012 conforms to the earlier PDEP finding. Temperature data from the two WRMP long-term monitoring sites on Buffalo Run indicate that Buffalo Run may not meet DEP criteria for a limestone stream. However, each of the WRMP stations is more than two river miles upstream and downstream of the IBI collection site at river mile 3.7 and insufficient data exists to characterize the stream at the IBI sampling location.

The result in 2012 at the single Cedar Run location in Oak Hall also indicated good water quality. The PDEP survey conducted at this site in 2002 found impaired conditions. Their sample was largely dominated by sow bugs and had few pollution sensitive organisms. The 2012 sample, in contrast, had few pollution tolerant, and many pollution sensitive, organisms.

Table 7. Downstream IBI scores for PFBC hatcheries after installation of microscreen filters and other BMP's. Data courtesy PDEP and PFBC. IBI score below 60 is impaired.

	Pleasant Gap: installed 2007	Bellefonte: installed 2009	Benner Spring: installed 2010
Mean IBI scores prior to BMPs (± std error)	28.3 ± 3.3	53.2 ± 4.8	36.4 ± 4.1
2008	16	-	-
2009	59	-	-
2010[a]	58 and 48	44.1 and 59.1	-
2011	52	40.4	28.8
2012	54	47.8	41.3

[a] Sites sampled twice in 2010.

Discussion

The WRMP and PFBC data collected in 2012 followed patterns observed in earlier IBI surveys and point to water quality impairments downstream from urbanized areas and downstream from the three fish hatcheries. These patterns suggest that the hatcheries represent the primary point sources adversely impacting IBI scores while in the upper watershed adverse impacts are primarily due to urban sources, most likely nonpoint source pollution from stormwater runoff, lawn care practices, road salt application, and similar activities.

As noted earlier, the PFBC has installed microfilters to control the amount of particulate nutrients in the discharges from all three hatcheries in the watershed. The IBI data from PFBC has indicated improved water quality downstream from the Pleasant Gap hatchery on Logan Branch but little evidence to date for improvement downstream of the Benner Spring or Bellefonte facilities on Spring Creek (**Table 7**). The microfilters remove particulates: dissolved nutrients and organic matter pass through. Dissolved organic matter feeds bacteria and fungi which in turn feed sowbugs (Gammaridae), a pollution tolerant organism whose presence in large numbers will reduce the IBI score (Robert Carline, personal communication).

In urban areas, nonpoint sources of pollution are the major concern for water quality impacts. Nonpoint source pollution is largely caused by precipitation running off the land surface. As this runoff moves, it picks up pollutants and deposits them into our streams and groundwater. Urban sources of nonpoint pollution include: excess fertilizers, herbicides and insecticides applied to lawns; road salt, metals, oils and other chemicals from road and commercial/industrial surface runoff; sediment from construction sites; and, pet waste and sewage from faulty sanitary sewer or septic systems.

The WRMP collects information on the quantity and quality of water throughout the Spring Creek Watershed, including urban locations (see **Figure 13** on page 31). The WRMP monitors stream flow at thirteen sites and stream temperature at 16 sites. In addition, the United States Geological Service (USGS) maintains three stream flow gages on the main stem of Spring Creek. The WRMP conducts baseflow (non-storm) water quality sampling approximately four times per year at both the WRMP and USGS locations. These water samples are analyzed by the Pennsylvania State Laboratory in Harrisburg for many metals, nutrients and physicochemical parameters. The complete list of parameters analyzed at each WRMP monitoring site is included in Appendix 1 and sampling results for 2012 are found in Appendix 5. This information about stream flow, water temperature, and chemical composition can help contextualize the urban stream environment and inform an analysis of biological data like the IBI survey detailed in this report.

Due to cost constraints, the WRMP does not analyze the water quality samples for many other substances harmful to aquatic life, such as solvents, pesticides, and herbicides. Many substances that adversely impact water quality are more prevalent in stormwater runoff and not as evident in baseflow. The baseflow water quality data collected by WRMP may underestimate inputs of stormwater-related parameters such as excess sediments (and phosphorous, which associates with sediment). Excess sediment in a stream adversely impacts aquatic macroinvertebrates by burying in-stream cobbles and woody debris, reducing suitable habitat, and by clogging their respiratory gills.

Excess inorganic nitrogen and phosphorous can lead to poor water quality in aquatic ecosystems through eutrophication, typically regarded as an excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms.

In freshwater systems, nitrogen is not a limiting nutrient for aquatic plant growth: more of this nutrient is available than plants can use. Pennsylvania does not have a nitrate nutrient water quality standard for streams. Nitrogen inputs to freshwater becomes a problem downstream as rivers empty into marine ecosystems where growth of saltwater plants typically is limited by available nitrogen in the ecosystem. Regulation of nitrogen inputs to streams in Pennsylvania center on alleviating downstream impacts to the Chesapeake Bay. There is evidence that chronic exposure to nitrate is toxic to aquatic organisms [17,18]. The State of Minnesota has proposed a chronic standard of 3.1 mg/L for economically important cold water fisheries [19].

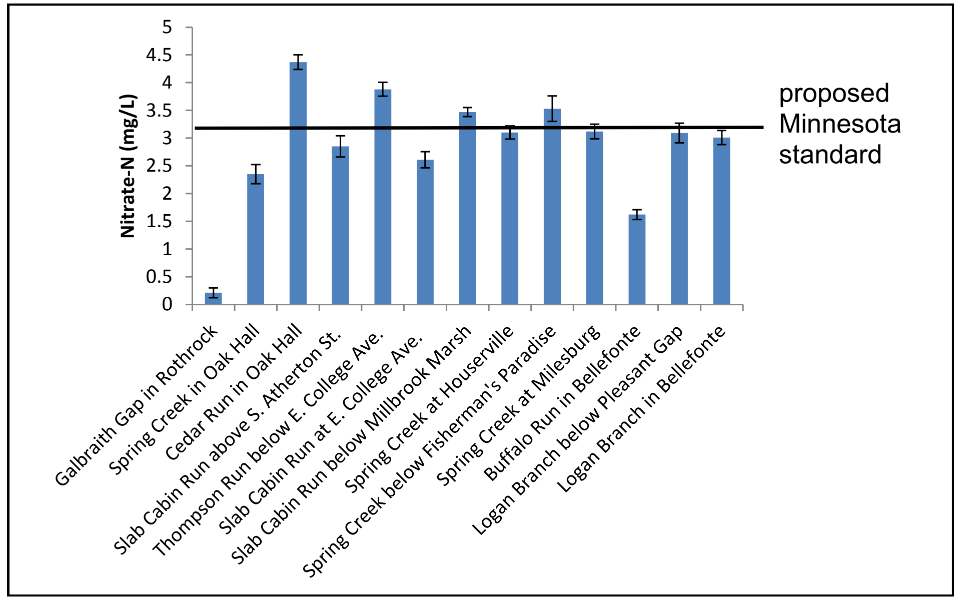


Figure 9. Mean nitrate-N concentrations for period of record at WRMP monitoring locations . Bars represent standard error. Detection limit, 0.04 mg/L. Where at least one sample had an undetectable concentration, a concentration of 1/2 detection limit was set as concentration for calculations.

Baseflow concentrations of nitrogen, measured as nitrate, is elevated at all valley floor monitoring locations in the watershed in comparison to our headwater stream monitoring location on Galbraith Gap Run located within Rothrock State Forest (**Figure 9**). Nitrogen is very soluble in water and elevated nitrogen levels have been attributed to urban lawn and agricultural fertilizers percolating into groundwater. High nitrate concentrations do not correlate to low IBI scores. The highest mean nitrate concentration over the WRMP period of record are seen in Cedar Run, likely attributable application of agricultural fertilizers upstream. The median nitrate-N concentration at this location on Cedar Run from water quality samplings in 2012 was 4.7 mg/L (see Appendix 5), while this site received a reference-level IBI score. Thompson Run also sees high levels of nitrate-N, likely due to urban landscape runoff of fertilizers, atmospheric deposition and, possibly, leaky sanitary sewage systems. High nitrate-N levels in Spring Creek below Fisherman's Paradise may be due to hatchery discharges, although septic systems from housing along Spring Creek Road are also a potential source.

[17] McGurk, M., Landry, F. Tang, A. and C. Hanks. 2006. Acute and chronic toxicity of nitrate to early life stages of lake trout *(Salvelinus n maycush)* and lake whitefish *(Coregonus clupeaformis)*. Environmental Toxicology and Chemistry, 25 (8), pp. 2187-2196

[18] Camargo, J. A. and A. Alonso. 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International, 32 (6), pp. 831-849

[19] Monson, P. 2010. Draft: Aquatic Life Water Quality Standards Technical Support Document for Nitrate: Triennial Water Quality Standard Amendments to Minn. R. chs. 7050 and 7052. Minnesota Pollution Control Agency, Saint Paul MN, pg 8.

Phosphorous is typically limited in freshwater ecosystems and excess inputs can result in excess algae growth and potential eutrophication. Baseflow levels of phosphorous at all sites in the watershed, measured as orthophosphate, is typically near or below the detection limit of the test (0.01 mg/L) throughout the watershed (**Figure 10**).

Chloride is present in urban waterways, primarily originating from winter road salt application but also present in waste water treatment plant and septic system discharges.

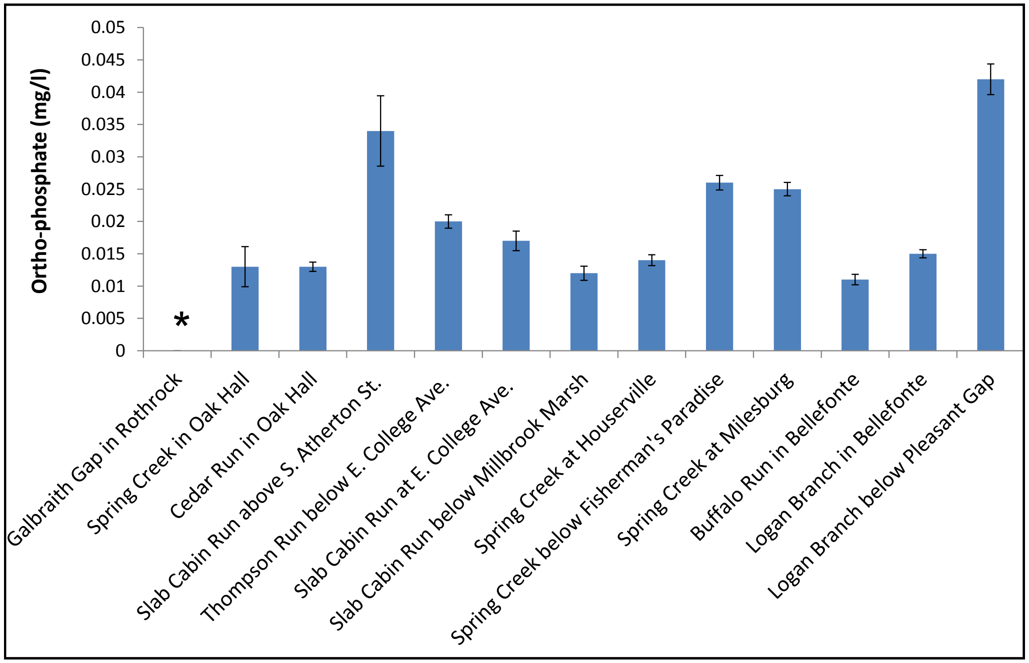


Figure 10. Mean ortho-phosphate concentrations for period of record at WRMP monitoring locations . Bars represent standard error. Detection limit: 0.01 mg/L.. Where at least one sample was below the detection limit, a concentration of 1/2 detection limit was set as the concentration for calculations. * = below detection limit in all sampling events.

Pennsylvania only has a drinking water standard for chloride. The Pennsylvania State chronic exposure standard for aquatic life is 250 mg/L[20]. Baseflow chloride concentrations are highest in those stream section immediately downstream from urban areas (**Figure 11** on page 24). Mean chloride concentrations at all sites are well below Pennsylvania's chronic exposure standard.

Thirteen metals are included in the U.S. EPA's list of the 126 priority water pollutants: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Of these, the WRMP measures levels of cadmium, chromium, copper, lead, nickel, and zinc. **Table 8** on page 25 shows the Pennsylvania State continuous exposure standard for fish and aquatic life for these six metals and mean values for these metals at WRMP stations for the period of record . The mean concentrations of metals are near or below detectable limits at most locations, and below the exposure standards for aquatic life at all locations.

Adequate dissolved oxygen (DO) in the water column is critical to aquatic life. Levels of DO typically are lower during the night as plants consume oxygen and increase during the day as plants release oxygen in photosynthesis.

[20] http://www.pacode.com/secure/data/025/chapter93/chap93toc.html

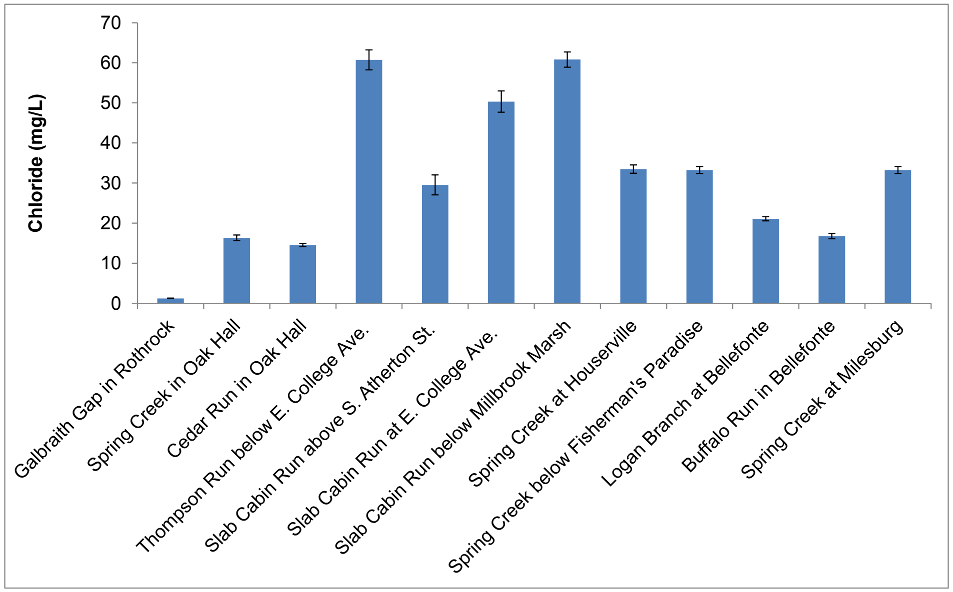


Figure 11. Mean total chloride concentrations for period of record at WRMP monitoring locations. Bars represent standard error. Detection limit, 1.0 mg/L. Where at least one sample had an undetectable concentration, a concentration of 1/2 detection limit was set as concentration for calculations.

Levels of dissolved oxygen are impacted by water temperatures, as the ability of water to contain dissolved oxygen decreases as temperature increases. Eutrophic waters also can adversely impact DO levels as decaying vegetation consumes oxygen or excess vegetation consumes oxygen at night. The State of Pennsylvania has standards for minimum DO and minimum average daily DO for cold water and high quality cold water fisheries (all WRMP stream monitoring locations are classified as supporting a cold water fishery or high quality cold water fishery[21]). The WRMP measures DO during water quality sampling, which are conducted during daylight hours, but does not monitor DO continuously to derive daily averages. The Pennsylvania State minimum standard for DO is 5.0 mg/L for a cold water fishery and 7.0 mg/L for a high quality cold water fishery[22]. For the WRMP stream stations over the period of record, the lowest recorded DO was 5.97 mg/L and there has never been a DO recording of less than 5.0 mg/L in over 600 measurements. There has been one recording of DO less than 7.0 mg/L in a location classified as a high quality cold water fishery since 1999 (6.64 mg/L at Spring Creek at Oak Hall) .

Urban streams are subject to increased sedimentation from erosion and instream instability due to increased frequency and intensity of stormflow, due to runoff from impervious surfaces and increased hydrologic connectivity of the landscape by stormwater pipes, and this excess sediment is detrimental to many sensitive benthic macroinvertebrates[23]. WRMP's baseflow water quality

21 http://www.pacode.com/secure/data/025/chapter93/s93.9l.html

22 http://www.pacode.com/secure/data/025/chapter93/s93.7.html

23 Walsh, C.J., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman, and R.P. Morgan II. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society. 24(3), pp. 706-723

Table 8. Mean dissolved metal concentrations at selected WRMP locations for the period of record (1999-2012), ± standard error. The Fish and Aquatic Life Criteria Continuous Concentrations are expressed in terms of dissolved metals and downloaded from http://www.pacode.com/secure/data/025/chapter93/s93.8c.html

			Sites					
Metal	**Criteria Continuous Concentrations (µg/L)**	**Detection limit (µg/L)**	Cedar Run in Oak Hall	Thompson Run below College Ave.	Slab Cabin Run above S. Atherton St.	Slab Cabin Run at E. College Ave.	Slab Cabin Run below Millbrook Marsh	Spring Creek in Oak Hall
Cadmium	0.25 +	0.20	ND	ND	ND	ND	ND	ND
Chromium	10	4.0	ND	ND	ND	ND	ND	ND
Copper	9.0 +	4.0	ND	2.11 ± 0.57 ^	2.05 ± 0.05 ^	2.05 ± 0.03 ^	ND	ND
Lead	2.5 +	1.0	0.52 ± 0.02 ^	ND	0.51 ± 0.01 ^	0.56 ± 0.06 ^	ND	ND
Nickel	52 +	4.0	ND	2.1 ± 0.13 ^	ND	ND	ND	2.1 ± 0.11 ^
Zinc	120 +	10	10.4 3.12 ^	10.2 2.66 ^	10.2 3.12 ^	16.5 4.56 ^	5.2 0.20 ^	8.6 1.67 ^

			Sites					
Metal	**Criteria Continuous Concentrations (ug/L)**	**Detection limit**	Spring Creek in Houserville	Spring Creek below Fisherman's Paradise	Spring Creek in Milesburg	Buffalo Run in Bellefonte	Logan Branch below Pleasant Gap	Logan Branch in Bellefonte
Cadmium	0.25 * +	0.20	ND	ND	0.122 ± 0.024 ^	ND	ND	ND
Chromium	10 *	4.0	ND	2.32 ± 0.32 ^	ND	2.34 ± 0.16 ^	ND	ND
Copper	9.0 * +	4.0	ND	ND	2.02 ± 0.07 ^	2.12 ± 0.09 ^	2.13 ± 0.13 ^	2.27 ± 0.14 ^
Lead	2.5 * +	1.0	ND	ND	0.64 ± 0.12 ^	ND	0.56 ± 0.04 ^	ND
Nickel	52 * +	4.0	2.1 ± 0.13 ^	2.1 ± 0.10 ^	ND	ND	ND	ND
Zinc	120 * +	10	11.5 3.31 ^	6.6 0.54 ^	15.9 5.73 ^	8.7 2.45 ^	8.3 2.86 ^	17.1 1.34 ^

\+ The freshwater criteria continuous concentration for this metal is inversely related to water hardness (mg/L). The value given here corresponds to a hardness of 100 mg/L. The minimum hardness measured at any location in Table 7 during the period of record was 139 mg/L.

^ At least one sample was below the detection limit. A concentration of 1/2 detection limit was set as concentration for non-detects for calculation of mean value.

ND All samples were below the detectable limit.

sampling therefor does not monitor sedimentation impacts from storms. The habitat assessment from the Thompson Run IBI location noted moderate deposition of sediment and marginal shelter habitat at the sampling site. Other sites assessments on Spring Creek downstream from urban locations found little sedimentation and good shelter habitat conditions. As noted earlier, habitat assessment scores and IBI scores do not correlate well.

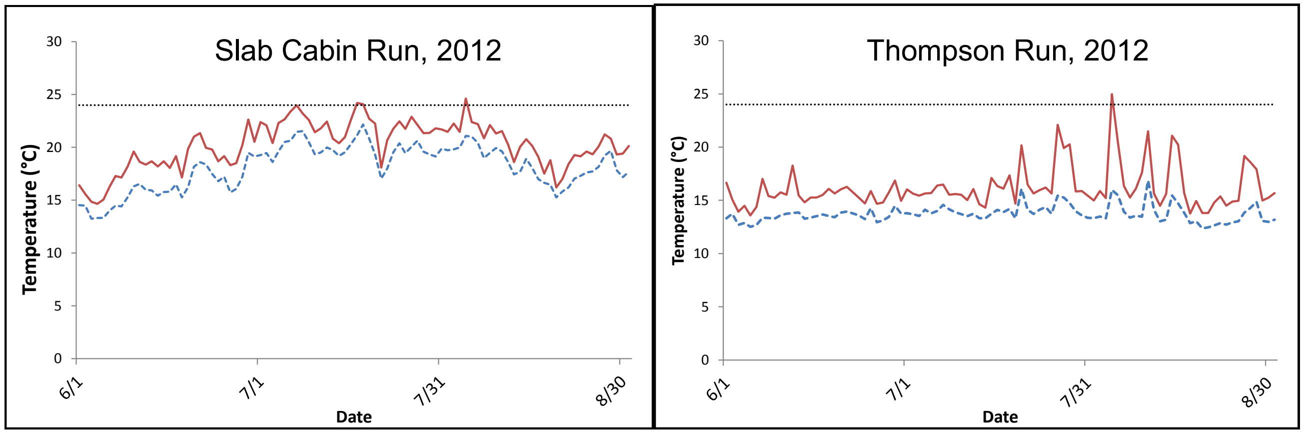


Figure 12. Summer 2012 average daily and maximum daily temperature for Slab Cabin Run at East College Avenue and Thompson Run at East College Avenue.

Average daily temperature — Maximum daily temperature

Lethal temperature threshold for trout

Urban stormwater runoff can significantly impact stream water temperatures and water temperatures have a significant impact on animals living in those streams[24]. As noted above, the solubility of oxygen in the water column goes down as water temperatures rise. Significant inputs of groundwater in the watershed generally maintain stream water temperatures below 24° C (76° F), the brown trout's lethal temperature threshold. Extended periods above 24° C can kill aquatic organisms. Long-term temperature monitoring by the WRMP has shown that extreme heat, drought or large storm events can cause transient, high temperature extremes in urban portions of streams lacking significant groundwater inputs or subject to large urban stormwater inputs. However, these transient temperature maximums very rarely lead to average daily temperatures exceeding 24° C. Summer 2012 temperature profiles are shown in **Figure 12** for two WRMP monitoring stations: Slab Cabin Run at East College Avenue (an example of an urban stream location lacking significant groundwater inputs) and Thompson Run below East College Avenue (an example of an urban stream receiving large stormwater inputs). Extreme spikes in temperature maxima correspond to rain events. Average daily summer water temperatures

[24] *Ibid.*

at Slab Cabin Run at East College Avenue are far more responsive to ambient air temperatures than average daily water temperatures in Thompson Run, which are kept cool due to significant inputs of cold groundwater from Thompson Spring. This spring discharges at least two million gallons per day of cold (51° F) water[25].

The Thompson Run sub-basin demonstrates factors that both threaten and protect streams subject to urban influences in the Spring Creek Watershed. The Thompson Run drainage basin encompasses an area of approximately 3.7 square miles and is highly urbanized, with 31% of its area being impervious surface[26]. Portions of the sub-basin are also highly connected hydrologically by engineered stormwater systems[27]. As seen in Figure 12, stormwater has significant transient thermal impacts. Although storm event water quality sampling is not currently being conducted systematically in the watershed, stormwater discharges also likely contain chemical pollutants. The single Thompson Run site included in WRMP's IBI sampling received the lowest IBI score. But Thompson Run also supports a wild brown trout population sufficient to be designated a High Quality Cold Water Fishery by the State of Pennsylvania. A prime reason for the healthy trout population in the stream is the groundwater contribution from Thompson Spring. This groundwater support buffers Thompson Run, as it does most other streams in the watershed, from some of the impacts to aquatic life that are typically observed in other urbanized watersheds.

Brown trout (*Salmo trutta*)

[25] Water Resource Publication, Thompson Spring, OPP-WRP-SW-TS:(2)-2010. Office of Physical Plant, The Pennsylvania State University. Accessed at http://www.opp.psu.edu/services/eng-resources/OPP-WRP-SW-TS-2-2010.pdf

[26] http://water.usgs.gov/osw/streamstats/pennsylvania.html

[27] Water Resource Publication, Duck Pond Drainage Basin, OPP-WRP-SW-DP:(3)-2010. Office of Physical Plant, The Pennsylvania State University. Accessed at http://www.opp.psu.edu/services/eng-resources/OPP-WRP-SW-DP-3-2010.pdf

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/early 1999. Groundwater, surface water, stormwater and spring monitoring stations were added as the project gained momentum. Over the past thirteen years, the WRMP has strived to:

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

The WRMP field stations and database are maintained primarily by the Water Resources Coordinator, a full-time staff position housed at ClearWater Conservancy, with the assistance of volunteers and ClearWater interns. A number of local partners continued to provide funding to carry out WRMP data collection activities to support this one-of-a-kind project in 2012. Donors in support of the 2012 effort included:

- Bellefonte Borough
- Benner Township
- College Township
- Ferguson Township
- Halfmoon Township
- Harris Township
- Patton Township
- Pennsylvania State University Office of Physical Plant

Table 9. Water Resources Monitoring Committee Members in 2012.

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

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

In addition to financial support, the WRMP received in-kind donations of professional services, water level and stream stage data, laboratory analyses and supplies, technical assistance, and transportation from the following in 2012:

- 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 13** on page 31). 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 baselines (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 to monitor stormwater impacts.

Groundwater Monitoring Stations

The WRMP monitored water levels at three wells in 2012 (**Figure 14** on page 32). 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 14** on page 32). 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 14** on page 32). 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.

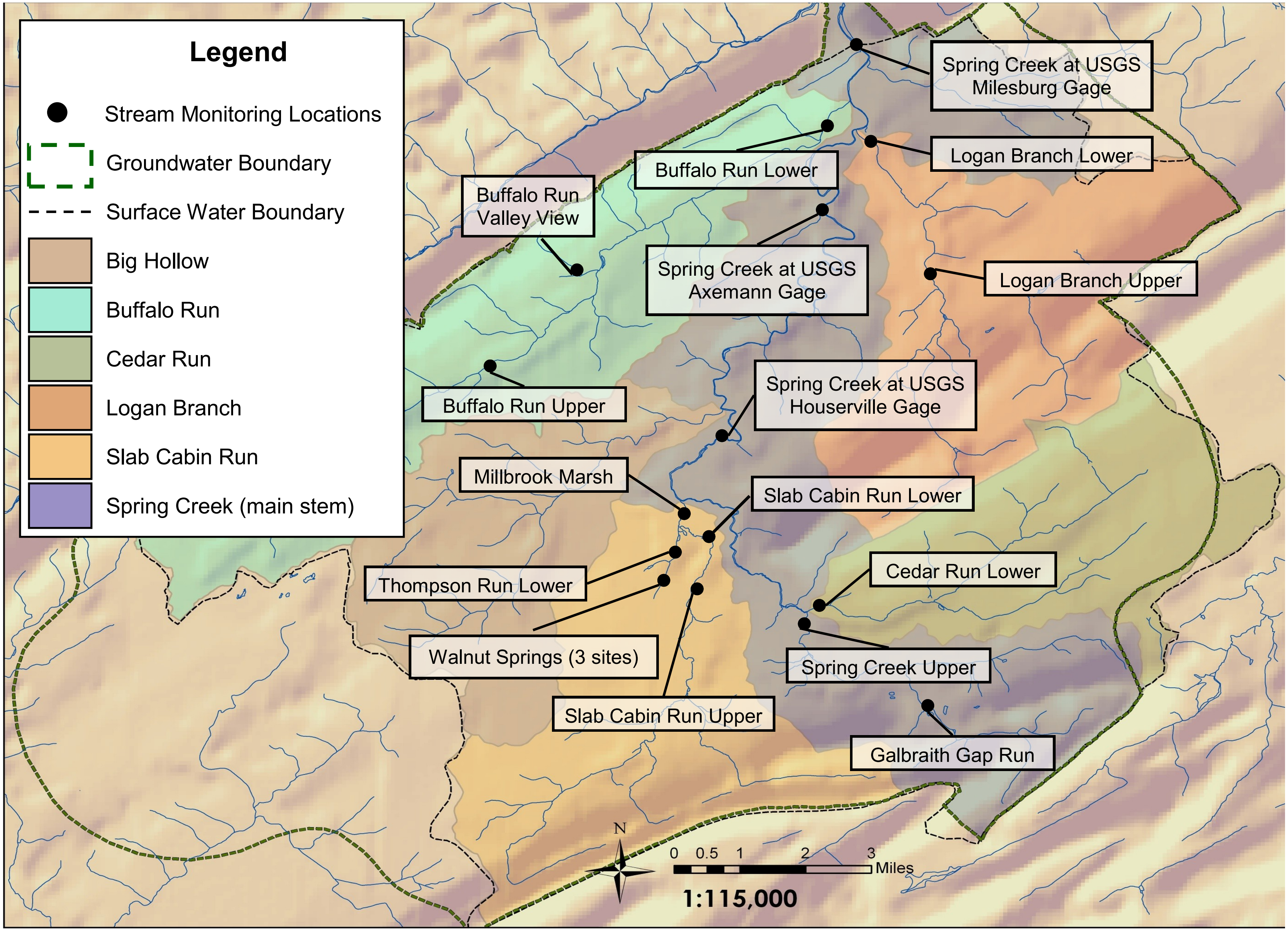


Figure 13. Stream sampling sites surveyed in 2011 as part of the Water Resources Monitoring Project. and USGS stream gages.

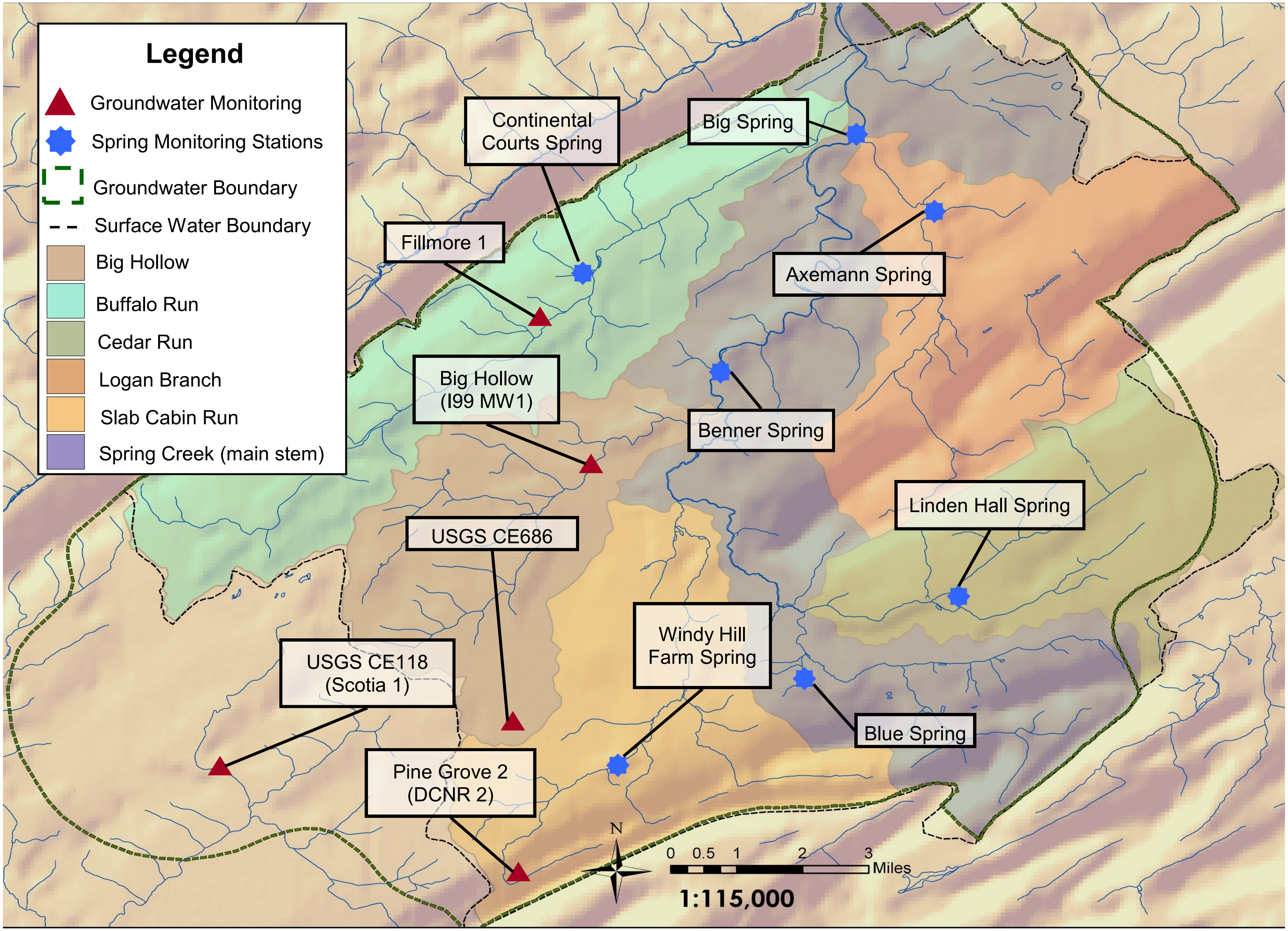


Figure 14. Groundwater and spring stations surveyed in 2011 as part of the Water Resources Monitoring Project and USGS groundwater monitoring wells.

Water Quality Monitoring

WRMP staff and volunteers collected water samples from fifteen stream sites and seven springs in 2012. Sampling took place in January, September, and November when streams were at baseflow conditions. The water samples were analyzed for chemical and nutrient content by the PADEP Analytical Laboratories. Coliform analysis of spring samples was conducted by the University Area Joint Authority laboratory. **Appendices 5** and **6** summarize the results of the 2012 water quality analysis.

Continuous Measurements

Thirteen stream stations were equipped with instruments to continuously monitor stream stage. Thirteen of these were maintained by the WRMP and outfitted with one of two types of pressure transducer: Solinst, Inc. Levelogger Gold pressure transducer, or; Solinst, Inc. Levelogger Edge pressure transducer. Both types of Solinst transducer are non-vented and were coupled with a Solinst Barologger Edge or Barologger Gold to compensate for atmospheric pressure. Stream stage was recorded every 30 minutes for all stations except Lower Thompson Run and the three stations on Walnut Springs, where stream stage was recorded every 5 minutes. Readings were taken more frequently at these stations because past data have shown that 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 2012 are presented in **Appendix 8**.

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 9** summarizes the groundwater elevation data for 2012.

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 15**). 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 processes such as 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.

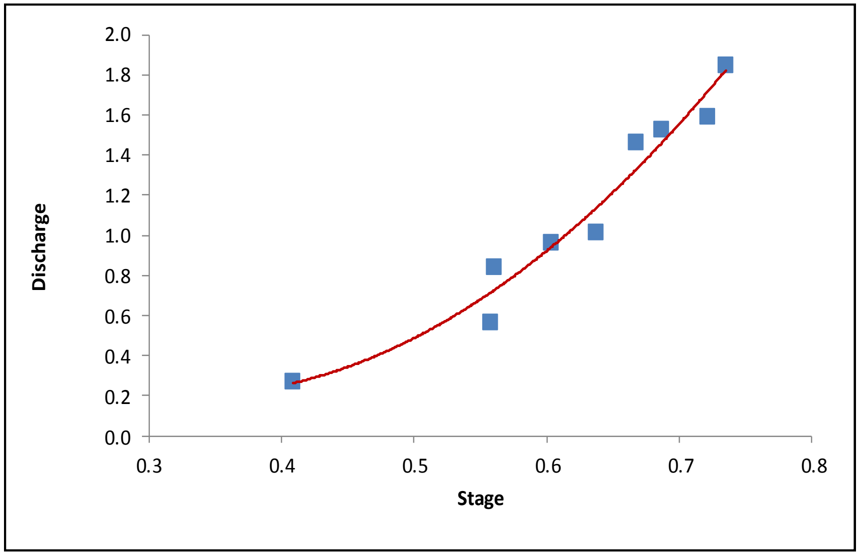


Figure 15. Stage-discharge relationship for the WRMP gage on Slab Cabin Run in Millbrook Marsh.

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

Appendix 7 summarizes the stream discharge data for 2012.

Dan Delotto, WRMP volunteer, braves a wintery day to help the project collect water quality data.

Data Quality

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

In addition to periodic review of rating curves, the Water Resources Coordinator and the WRMC also reviews operational procedures and equipment used in the monitoring program. In 2011, the WRMP discontinued the use of the type of pressure transducer used to record stream stage since the programs' inception in 1998 due to increasingly frequent unit failures. By the end of 2011, all stream monitoring stations were equipped with other pressure transducers considered more reliable. As a result of these changes, data logger reliability in 2012 has greatly improved while operational costs have decreased.

Water Quality Monitoring

Water Quality was assessed three times in 2012 in January, September and November at 15 stream and 7 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 5 and **6** show median 2012 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.

- The concentration of nitrate nitrogen were elevated at several stream and spring sites in comparison to headwater concentrations at Galbraith Gap Run and Buffalo Valley View but below the drinking water standard of 10 mg/l. Nitrate nitrogen is a common pollutant in wastewater discharge and agricultural runoff. Median concentrations ranged between 1.72 and 4.7 mg/l at stream sites. Among the springs, Axemann Spring and Linen Hall Spring had the highest median concentrations at 6.57 and 4.94 mg/l, respectively.
- Orthophosporous is a pollutant commonly associated with agriculture. It was detected at all stream sites at least once during the three sampling events but at low levels. Orthophosphorous was also detected at low levels at Benner Spring, Blue Spring, Continetal Courts Spring and Windy Hill Farm Spring.
- The highest median chloride concentrations were observed at Thompson Run below College Avenue (62.8 mg/l) and Slab Cabin Run in Milbrook Marsh (59.0 mg/l). Elevated Chloride concentrations are associated with urban impacts from stormwater runoff and wastewater treatment plant discharges.
- In 2011, the Buffalo Valley View site had elevated concentrations of aluminum , chromium, manganese and nickel in comparison to historic observations. This site is located on an unnamed tributary to Buffalo Run and is located 500 feet above the valley floor at the intersection of Fillmore Road and Valley View road. In 2012, these parameters were back to historic levels. At Logan Branch below Pleasant Gap, where total aluminum concentrations in 2011 were also elevated, the 2012 concentration of this parameter where also back to historic levels.
- Fecal coliforms are measured at spring sites only. Blue Spring and Windy Hill Farm Spring had quite elevated median fecal coliform levels for 2012 over historic norms due to very high counts from one

sampling, conducted in September. Spring discharge at this time were noted to be very low . These two locations have not shown such elevated coliform counts in the past, although Windy Hills Farm typically has higher counts than the other spring sites.

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 2012 discharge profiles for the main stem of Spring Creek at the USGS Axemann Gage and a representative tributary (Slab Cabin Run at South Atherton St.) are shown in **Figure 16** and **Figure 17**, respectively. In general, baseflow stream discharges during 2012 were above historic median discharges in January and February, fell below historic medians from

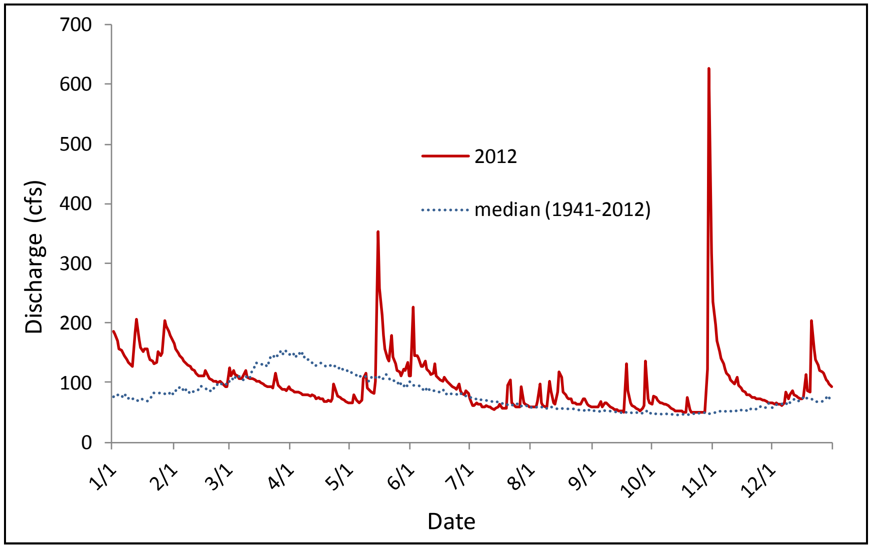


Figure 16. Average daily discharge at the USGS Axemann gage in 2012, from http://waterdata.usgs.gov/usa/nwis/uv?site_no=01546500

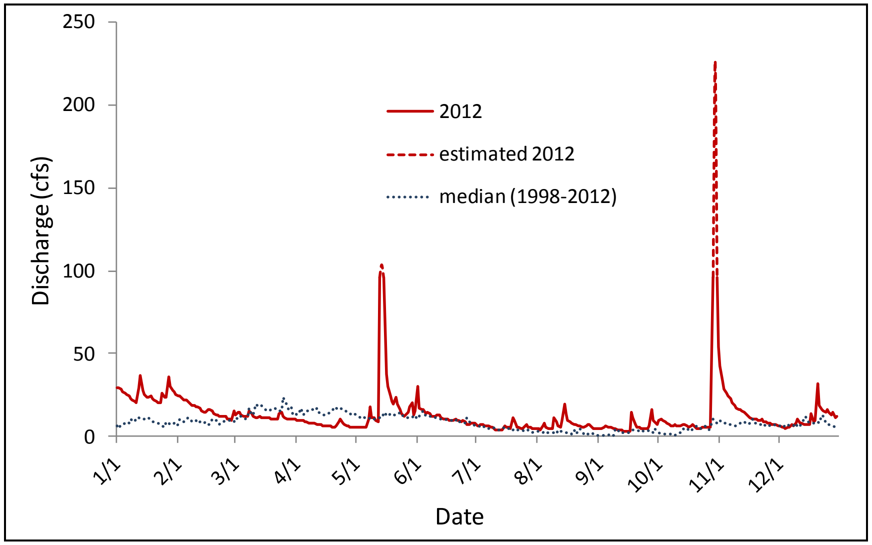


Figure 17. Average daily discharge for Slab Cabin Run at South Atherton Street in 2012.

mid-March to mid-May and returned to historic median discharges for the remainder of the year. These discharge profiles reflect a wet late-fall/early-winter of 2011 and a dry late-winter in 2012. A series of storms in May and June returned stream discharges to normal levels.

Slab Cabin Run at East College Avenue, just above Millbrook Marsh, often runs dry or becomes a series of pools with little or no flow during the late summer. Slab Cabin Run between South Atherton Street and East College Avenue is perched above the water table and water in the stream is lost through the stream bed to groundwater. Historically, the Centre Hills Country Club also withdrew its irrigation water from groundwater wells on their property, through which Slab Cabin Run traverses. Beginning in 2008, UAJA began supplying high purity reuse water to Centre Hills for irrigation as part of UAJA's beneficial reuse program. Since that time, Centre Hills Country Club has not been withdrawing any irrigation water from their groundwater wells (Jason Brown, personal communication).

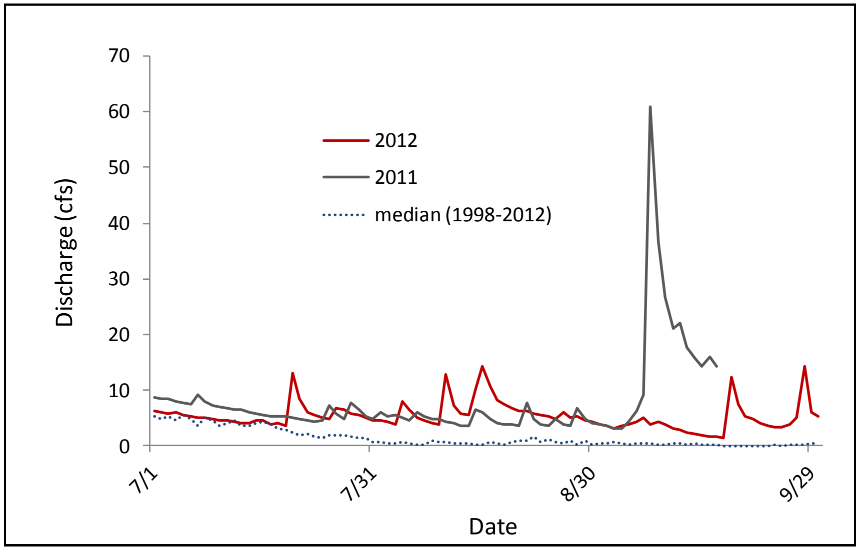


Figure 18. Average daily discharge at Slab Cabin Creek below East College Avenue from July1, 2012 to October 1, 2012.

In 2011, following a very wet spring, discharge in the summer months at this location remained above historic medians. In 2012, the stream also did not go dry (**Figure 18**). Elimination of groundwater withdrawals by Centre Hills Country Club may factor into this observation. UAJA is finalizing plans for a project located immediately upstream from Centre Hills County Club. This project consists of a constructed wetland and several stream augmentation sites where high purity reuse water can be reintroduced to the environment to enhance flow to Slab Cabin Run. This project is anticipated to go online in 2014.

The 2012 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, governing nearly every process that occurs in streams from regulating the solubility of oxygen and various chemicals to the metabolic functions of fish and other aquatic life. Although the Spring Creek Watershed has significant urban and agricultural impacts, a world-class trout fishery exists because significant inputs of groundwater generally maintain stream water temperatures below the brown trout's lethal temperature threshold of 76 ° F (24° C). Some portions of tributary streams lack significant groundwater inputs, such as lower Buffalo Run in and near Bellefonte and Slab Cabin Run in State College, or are subject to large urban stormwater inputs, such as Thompson Run and Walnut Springs. These waters can exceed 76 ° F during extreme heat, drought or large storm events. When the water temperatures rise above 76 ° F for extended periods of time, large-scale fish kills can result. The 2012 temperature profiles for all WRMP monitored locations in the watershed are included in **Appendix 7**.

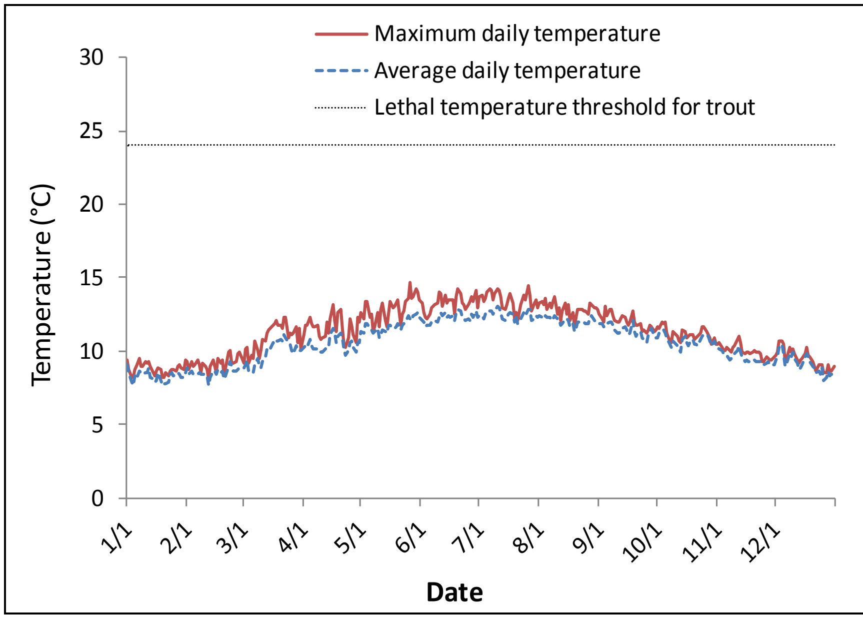


Figure 19. Maximum and average daily temperatures at Logan Branch in Bellefonte in 2012.

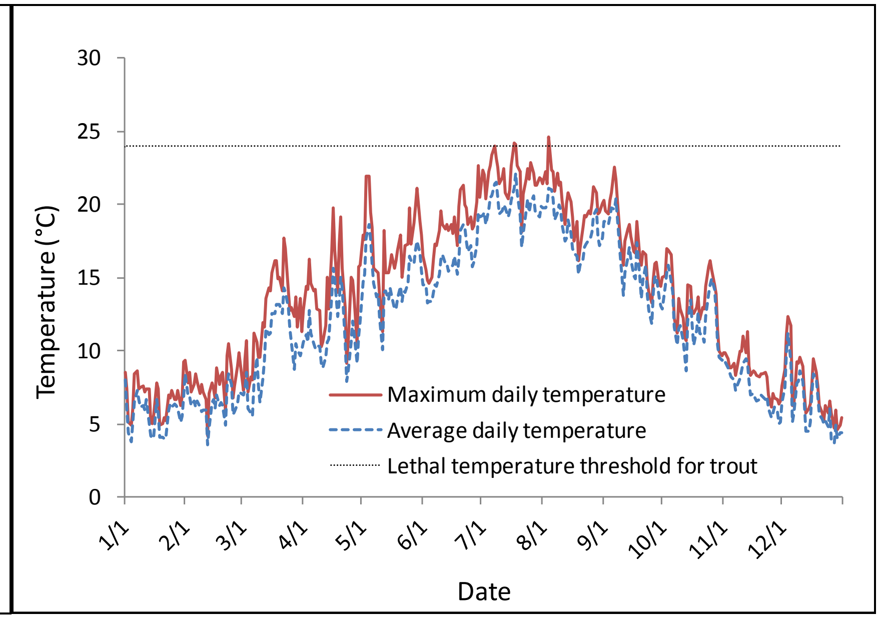


Figure 20. Maximum and average daily temperatures at Slab Cabin Run at College Avenue in 2012.

Logan Branch in Bellefonte (**Figure 19**) and Slab Cabin Run at College Avenue (**Figure 20**) demonstrate groundwater-influenced temperature moderation and stormwater-influenced instability, respectively. Logan Branch is supported by several large volume springs. Slab Cabin Run between South Atherton Street and College Avenue is somewhat anomalous in the watershed since it is perched above the water table and does not receive groundwater inputs. This location experienced three days in 2012 where maximum daily temperatures exceeded 76 ^{o} F .

In general, monitoring in 2012 observed few occurrences of extreme high temperatures. Several tributary stream locations that typically experience at least several days when maximum daily temperatures exceed 76 ^{o} F at most had one "hot" day in 2012.

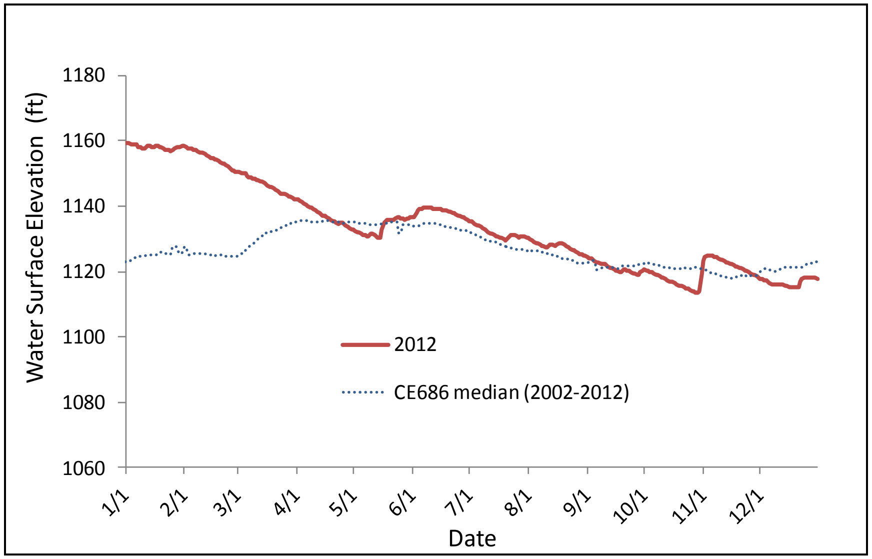


Figure 21. Average daily groundwater elevation at USGS Centre County observation well CE686 in 2012.

Groundwater

Groundwater supplies our streams with a constant supply of cold water that supports trout and other coldwater aquatic organisms. Most of the regions drinking water is also drawn from the many high volume springs and well fields. In 2012, the WRMP collected groundwater data from three monitoring wells and also assessed data from two additional wells maintained by the USGS. Groundwater elevation profiles for 2012 are found in **Appendix 8**.

The groundwater elevation profile for the USGS Centre County observation well CE686 is shown in **Figure 21**. Usually, groundwater aquifers are replenished in late winter and early spring by snow melt and rainfall that commonly occur at that time of year. In 2012, the groundwater replenishment occurred earlier in the year due to heavy precipitation in late 2011 through early 2012. In general, groundwater elevations at the WRMP and USGS wells from June through the remainder of 2012 were similar to, or slightly above, median elevations.

Appendix 1 Water Quality Parameters

Appendix 2 Summary of water management issues for each monitoring location

Appendix 3 Monitoring Summary by Location

Appendix 4 Aquatic life water quality standards for WRMP-measured parameters

Appendix 5 Stream Water Quality Results

Appendix 6 Spring Water Quality Results

Appendix 7 Daily Stream Flows

Appendix 8 Daily Stream Temperatures

Appendix 9 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	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	Toxic to humans and aquatic life	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 anthropogenic in origin. Include soil, bedrock, human and animal waste, fertilizers, pesticides, herbicides, and road	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	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	Urban runoff, industrial	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 include gasoline, batteries, solder, and paint	Toxic to humans and aquatic life. Solubility is effected by water hardness.	X	X

Appendix 1: Water Quality Parameters

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

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

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

Appendix 3: Monitoring summary by location

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

Appendix 3: Monitoring summary by location

Site Type	Site Name (Code)	Monitoring Type	Current Data Collection Interval	Period of Record
Stream	Spring Creek Axemann (SPA)	Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Spring Creek Houserville (SPH)	Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Spring Creek Milesburg (SPM)	Water temperature	1 hr	1999 - present
		Baseflow water quality	quarterly	2007 - present
	Walnut Springs Middle (WAM)	Water level	5 min	2008 - present
		Water temperature	5 min	January, 2012 - present
	Walnut Springs Lower (WAL)	Water level *	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
	Windy Hill Farm Spring (WIS)	Baseflow water quality	quarterly	2007 - present

* Stage discharge rating curves for the Walnut Spring s Lower (WAL) stream discharge monitoring stations is in development.

Appendix 4: Aquatic Life Water Quality Standards for WRMP-measured parameters

Parameters (metals)	Metals Criteria		Parameter (non-metals)	Specific Water Quality Criteria
	Acute	Chronic		
Aluminum (µg/L)[B E]	750	87	**Total Suspended Solids (mg/L) [A]**	Maximum 750
Cadmium (µg/L)[A C D]	2.0	0.25	**pH [A]**	6.0 to 9.0
Chromium (µg/L)[A C]	16	10	**Dissolved Oxygen (mg/L) [A]**	Minimum 5.0 , minimum daily average 6.0 ; for High Quality Cold Water Fishery, minimum of 7.0
Copper (µg/L)[A C D]	13	9	**Chloride (mg/L) [A]**	Maximum 250 mg/L
Iron (µg/L) [B C]	-	1000		
Lead (µg/L) [A C D]	65	2.5		
Nickel (µg/L)[A C D]	52	470		
Zinc (µg/L) [A C D]	120	120		

[A] From Chapter 93. Pennsylvania Quality Standards for freshwater aquatic life and Cold Water Fishery. Downloaded from http://www.pacode.com/secure/data/025/chapter93/chap93toc.html . Where PA State standard not available, U.S. EPA standard for freshwater aquatic life is given.

[B] U.S. EPA National Water Quality Criteria for freshwater aquatic life, downloaded from http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

[C] Freshwater criteria for these metals are expressed as dissolved metal in the water column

[D] The freshwater criterion for this metal is inversely related to hardness (mg/L) in the water column. The value given here corresponds to a hardness of 100 mg/L. The lowest hardness measured at a valley location in the Spring Creek watershed during the period of record (1999 to present) is 139 mg/L

[E] Value for aluminum is expressed as total recoverable metal in the water column.

Appendix 5: Median Stream Water Quality Results (Metals)

Site Name	Abbrev	Aluminum (µg/L)		Cadmium (µg/L)		Chromium (µg/L)		Copper (µg/L)		Iron (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Galbraith Gap Run	GGU	ND	20.1	ND	ND	ND	ND	ND	ND	ND	29*
Cedar Run - Lower	CEL	ND	24.8	ND	ND	ND	ND	ND	ND	ND	47.0
Slab Cabin Run - Upper	SLU	ND	47.6	ND	ND	ND	ND	ND	ND	ND	84.0
Slab Cabin Run - Lower	SLL	ND	13.8*	ND	ND	ND	ND	ND	ND	ND	24.0
Slab Cabin Run - Millbrook	MIL	ND	53.2	ND	ND	ND	ND	ND	ND	ND	103.0
Thompson Run - Lower	THL	ND	16.7*	ND	ND	ND	ND	ND	ND	ND	43.0
Buffalo Run - Upper	BUU	ND	18.3	ND	ND	ND	ND	ND	ND	ND	42*
Buffalo Run - Valley View	BVV	ND	28.38*	ND	ND	ND	ND	ND	ND	30.0	97.0
Buffalo Run - Lower	BUL	ND	21.9*	ND	ND	ND	ND	ND	ND	ND	50*
Logan Branch - Upper	LOU	ND	32.7	ND	ND	ND	ND	ND	ND	ND	65.0
Logan Branch - Lower	LOL	ND	25.2	ND	ND	ND	ND	ND	ND	ND	50.0
Spring Creek - Upper	SPU	ND	16.4	ND	ND	ND	ND	ND	ND	ND	21*
Spring Creek - Houserville	SPH	ND	31.3	ND	ND	ND	ND	ND	ND	ND	63.0
Spring Creek - Axemann	SPA	ND	24.9	ND	ND	ND	ND	ND	ND	ND	42.0
Spring Creek - Milesburg	SPM	ND	29.6	ND	ND	ND	ND	ND	ND	ND	48.0

Site Name	Abbrev	Lead (µg/L)		Manganese (µg/L)		Nickel (µg/L)		Sodium (mg/L)		Zinc (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Galbraith Gap Run	GGU	ND	ND	ND	4.2	ND	ND	0.6	0.6	ND	ND
Cedar Run - Lower	CEL	ND	ND	1*	2.9	ND	ND	5.7	5.7	ND	ND
Slab Cabin Run - Upper	SLU	ND	ND	4.7	7.4	ND	ND	10.3	10.3	ND	ND
Slab Cabin Run - Lower	SLL	ND	ND	2.21*	4.0*	ND	ND	19.0	19.3	ND	ND
Slab Cabin Run - Millbrook	MIL	ND	ND	6.1	10.2	ND	ND	26.0	27.1	ND	ND
Thompson Run - Lower	THL	ND	ND	2.5	4.1	ND	ND	24.8	25.9	ND	ND
Buffalo Run - Upper	BUU	ND	ND	2.5*	3.3*	ND	ND	14.6	15.2	ND	ND
Buffalo Run - Valley View	BVV	ND	ND	22.1	28.8	ND	ND	10.7	11.5	ND	ND
Buffalo Run - Lower	BUL	ND	ND	1*	4.2	ND	ND	8.8	8.9	ND	ND
Logan Branch - Upper	LOU	ND	ND	3.2	5.3	ND	ND	17.6	17.9	ND	ND
Logan Branch - Lower	LOL	ND	ND	ND	2.8*	ND	ND	12.8	13.3	ND	ND
Spring Creek - Upper	SPU	ND	ND	1*	1.0*	ND	ND	9.1	9.7	ND	ND
Spring Creek - Houserville	SPH	ND	ND	3.6	5.8	ND	ND	15.0	15.4	ND	ND
Spring Creek - Axemann	SPA	ND	ND	ND	2.4	ND	ND	24.6	27.5	ND	ND
Spring Creek - Milesburg	SPM	ND	ND	1*	3.3	ND	ND	20.1	20.9	ND	ND

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

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

Appendix 5: 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	2.7	1.4	13	1.1	ND	ND	ND
Cedar Run - Lower	CEL	76.5	22.7	288	13.4	18.3	ND	1.27*
Slab Cabin Run - Upper	SLU	54.1	21.1	222	21.6	17.7*	6*	2.09
Slab Cabin Run - Lower	SLL	59.7	23.6	246	36.4	18.7	ND	0.50*
Slab Cabin Run - Millbrook	MIL	67.4	27.9	283	59.0	19.6	ND	1.63*
Thompson Run - Lower	THL	67.6	29.1	289	62.8	17.4	ND	ND
Buffalo Run - Upper	BUU	71.4	27.1	290	32.2	28.2	6*	1.15*
Buffalo Run - Valley View	BVV	49.0	5.6	146	11.8	15.6*	ND	0.99*
Buffalo Run - Lower	BUL	58.5	25.0	243	19.2	18.2	6*	0.91*
Logan Branch - Upper	LOU	70.5	20.3	260	36.2	61.5	6*	0.05*
Logan Branch - Lower	LOL	51.7	19.1	208	28.8	21.2*	ND	ND
Spring Creek - Upper	SPU	57.2	18.5	219	20.4	18.4*	1*	0.05*
Spring Creek - Houserville	SPH	67.1	23.6	265	34.2	18.8	1*	1.22*
Spring Creek - Axemann	SPA	61.5	23.9	252	53.7	24.9	1*	ND
Spring Creek - Milesburg	SPM	55.0	21.6	226	42.5	23.0	6*	0.76*

Site Name	Abbrev	pH	Diss. Oxygen (mg/L)	Temperature (°C)	Conductivity (mS)	Nitrate-N (mg/L)	Orthophosphorus (mg/L) Total
Galbraith Gap Run	GGU	7.5	10.40	7.8	43	0.11	0.005*
Cedar Run - Lower	CEL	8.4	11.10	8.4	552	4.70	0.010
Slab Cabin Run - Upper	SLU	8.1	10.63	8.4	497	3.85	0.013*
Slab Cabin Run - Lower	SLL	8.1	11.51	8.7	566	2.95	0.010*
Slab Cabin Run - Millbrook	MIL	8.2	11.12	8.8	666	3.64	0.011*
Thompson Run - Lower	THL	8.0	10.97	9.4	712	3.90	0.120
Buffalo Run - Upper	BUU	7.9	14.60	10.5	628	1.13*	0.005*
Buffalo Run - Valley View	BVV	8.1	12.50	7.2	212	0.25	0.025
Buffalo Run - Lower	BUL	8.2	14.70	5.4	512	1.72	0.008*
Logan Branch - Upper	LOU	7.8	12.20	9.2	605	3.42*	0.035
Logan Branch - Lower	LOL	7.9	11.30	9.3	473	3.39	0.012
Spring Creek - Upper	SPU	7.8	10.39	9.0	468	2.54	ND
Spring Creek - Houserville	SPH	8.3	11.45	8.0	504	3.44	0.005*
Spring Creek - Axemann	SPA	8.0	14.00	7.0	630	4.20	0.013
Spring Creek - Milesburg	SPM	8.3	13.80	7.7	542	3.29	0.112

* 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: Median Spring Water Quality Results (Metals)

Site Name	Abbrev	Aluminum (µg/L)		Cadmium (µg/L)		Chromium (µg/L)		Copper (µg/L)		Iron (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Axemann Spring	AXS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benner Spring	BES	ND	36.6	ND	ND	ND	ND	ND	ND	ND	65.0
Big Spring	BIS	5.0*	ND	ND	ND	ND	ND	ND	ND	ND	ND
Blue Spring	BLS	ND	79.1	ND	ND	ND	ND	ND	ND	ND	117.0*
Continental Courts Spring	COS	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.0*
Linden Hall Park Spring	LIS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Windy Hill Farm Spring	WIS	ND	574.0	ND	ND	ND	ND	ND	ND	ND	1380.0

Site Name	Abbrev	Lead (µg/L)		Manganese (µg/L)		Nickel (µg/L)		Sodium (mg/L)		Zinc (µg/L)	
		Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total
Axemann Spring	AXS	ND	ND	ND	ND	ND	ND	15.8	15.8	ND	ND
Benner Spring	BES	ND	ND	ND	2.9*	ND	ND	21.6	22.7	ND	ND
Big Spring	BIS	ND	ND	ND	ND	ND	ND	9.8	9.8	ND	ND
Blue Spring	BLS	ND	ND	ND	2.8*	ND	ND	2.9	2.8	ND	ND
Continental Courts Spring	COS	ND	ND	ND	ND	ND	ND	9.0	9.3	ND	ND
Linden Hall Park Spring	LIS	ND	ND	ND	ND	ND	ND	2.9	2.9	ND	ND
Windy Hill Farm Spring	WIS	ND	1.2*	2.9*	57.8	ND	ND	10.8	11.5	ND	ND

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

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

Appendix 6: Median Spring Water Quality Results (Nutrients and Physicochemical)

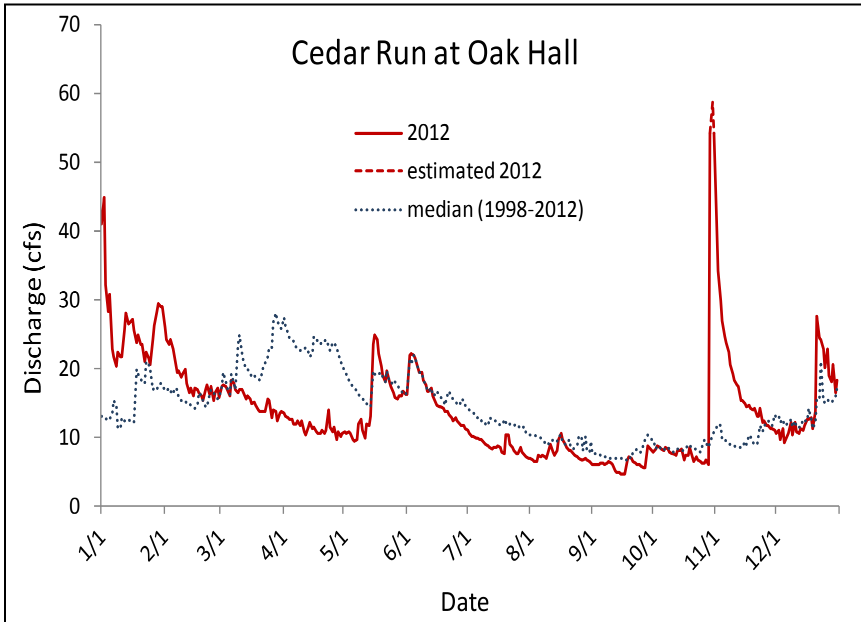
Site Name	Abbrev	Calcium (mg/L) Total	Magnesium (mg/L) Total	Hardness (mg/L) Total	Chloride (mg/L) Total	Sulfate (mg/L) Total	Suspended Solids (mg/L) Total	Turbidity (NTU)
Axemann Spring	AXS	75.5	32.9	325	40.2	27.0	ND	ND
Benner Spring	BES	59.5	21.6	243	51.0	10.0*	1.0*	1.54*
Big Spring	BIS	31.7	16.0	145	21.0	ND	1.0*	ND
Blue Spring	BLS	32.9	15.3	145	4.7	ND	1.0*	0.50*
Continental Courts Spring	COS	57.0	24.9	245	21.0	10.0*	1.0*	ND
Linden Hall Park Spring	LIS	77.8	31.4	325	7.8	20.4	ND	ND
Windy Hill Farm Spring	WIS	56.8	26.6	252	20.5	16.0*	130.0*	26.28*

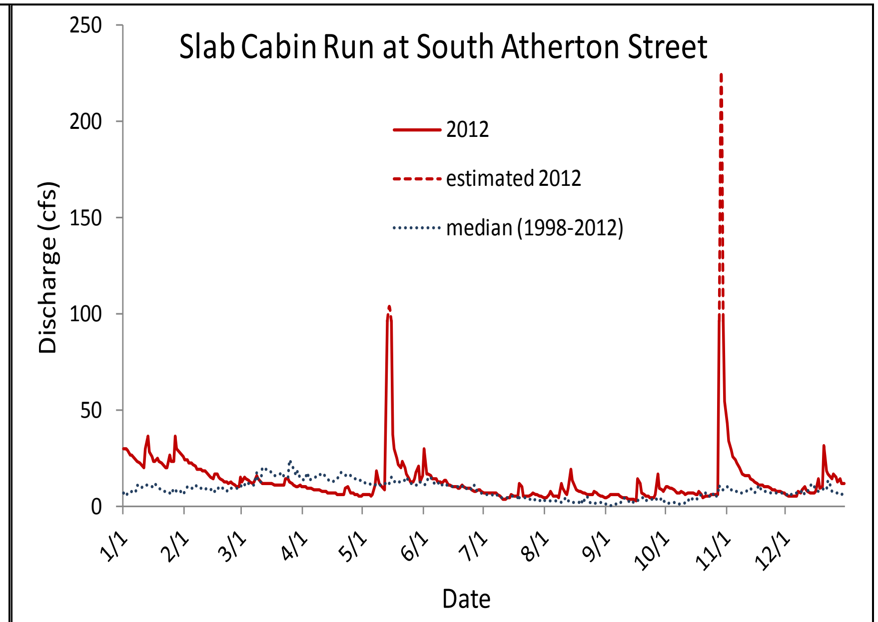
Site Name	Abbrev	pH	Diss. Oxygen (mg/L)	Temperature (°C)	Conductivity (mS)	Nitrate-N (mg/L)	Orthophosphorus (mg/L) Total	Fecal Coliforms (#col/ 100mL)
Axemann Spring	AXS	7.4	8.42	10.3	716.0	6.57	ND	ND
Benner Spring	BES	7.9	9.89	10.5	581.0	4.08	0.008*	33.8
Big Spring	BIS	7.9	10.23	10.3	348.0	1.94	ND	23.0
Blue Spring	BLS	7.8	7.52	9.9	293.0	1.57	0.012	246.0
Continental Courts Spring	COS	7.5	7.80	10.4	508.0	2.18	0.010*	1.0
Linden Hall Park Spring	LIS	7.4	6.93	9.9	605.0	4.94	ND	ND
Windy Hill Farm Spring	WIS	7.7	5.68	11.2	499.0	3.66	0.017	508.0

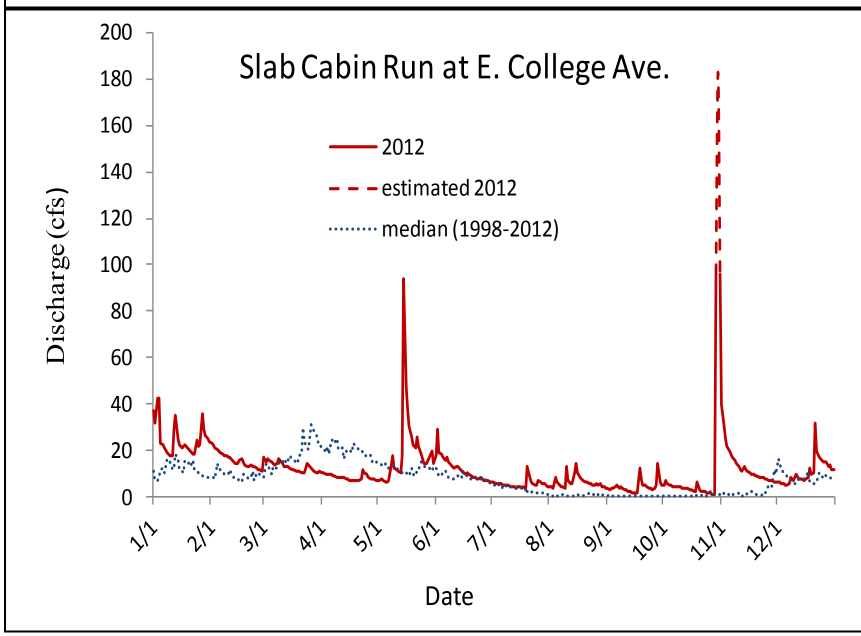
* At least one sample had an undetectable concentration so a concentration of 1/2 detection limit was set as concentration for calculations.

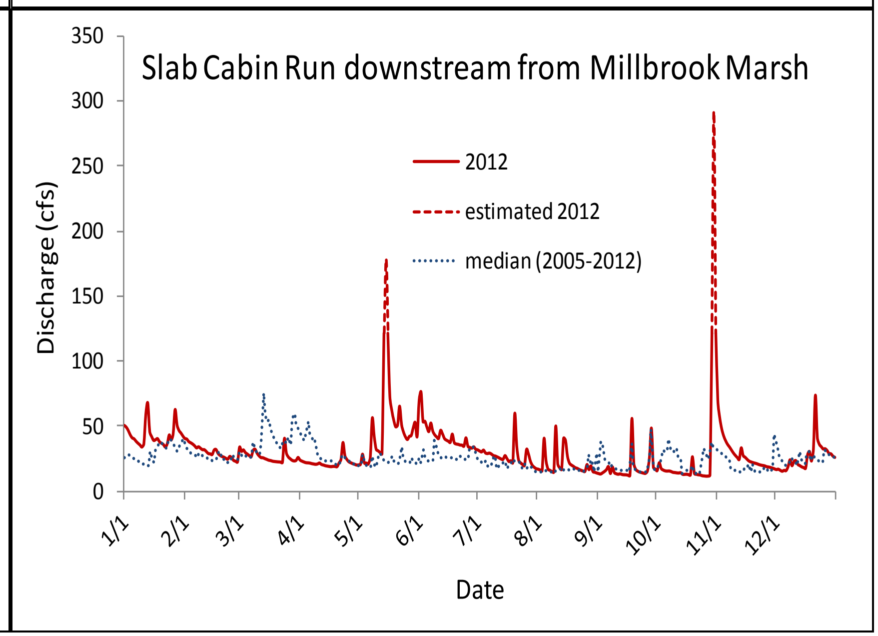
ND All concentrations for all sampling events were below detection limits so no value was assigned for concentrations

Appendix 7: Daily Stream Flow for 2012

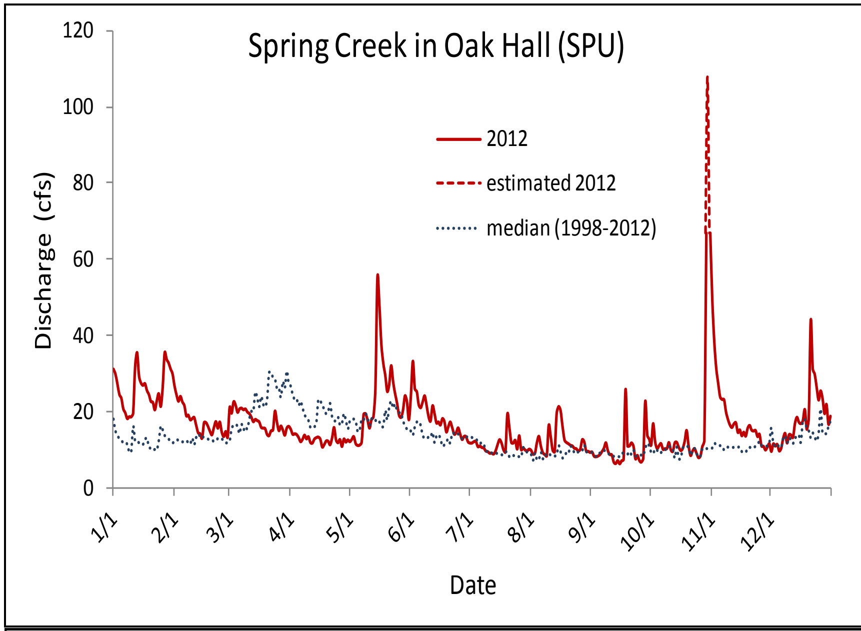


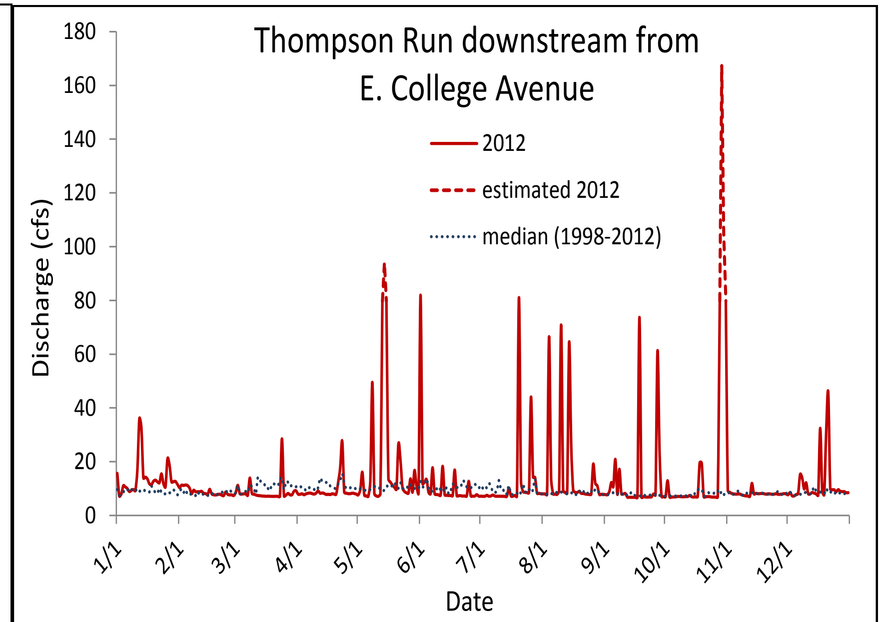


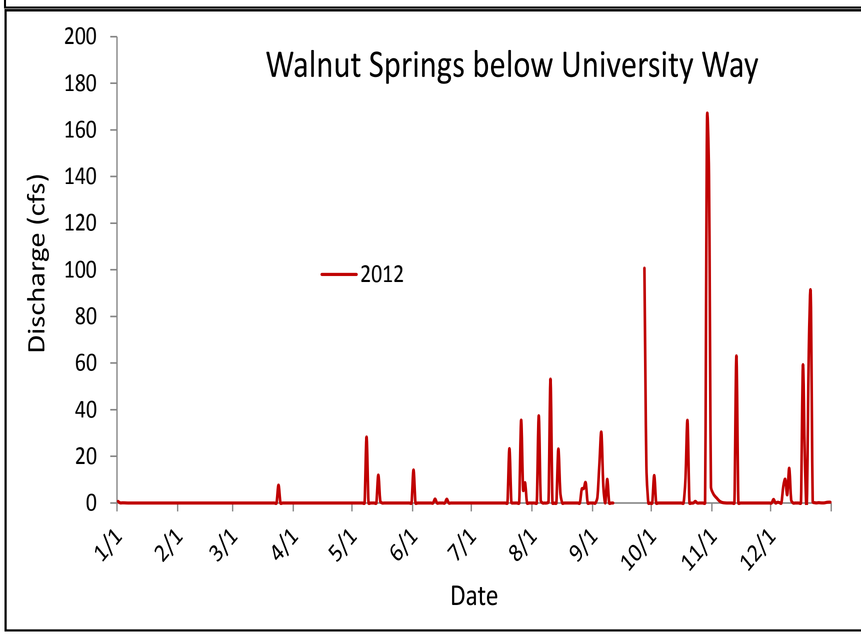


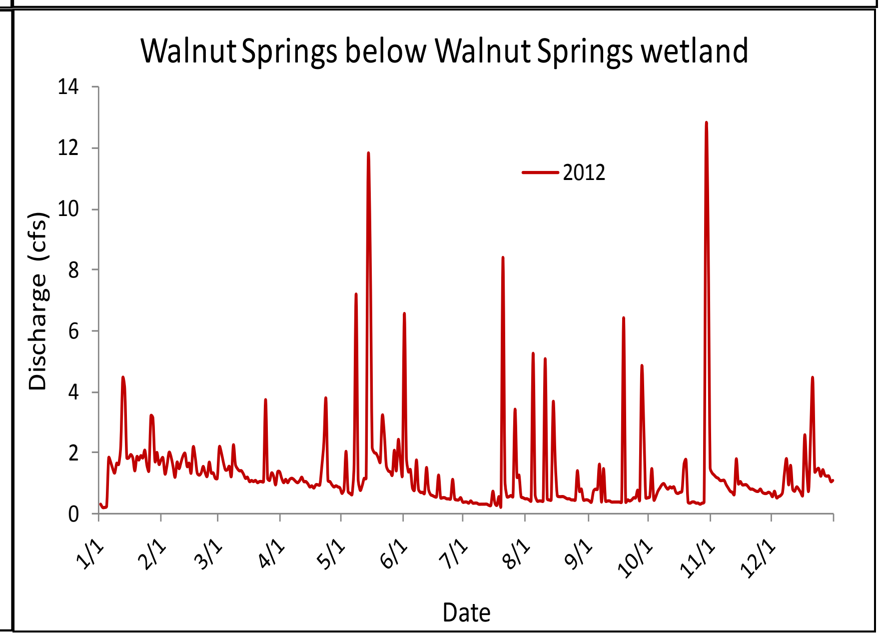


Appendix 7: Daily Stream Flow for 2012 (*continued*)

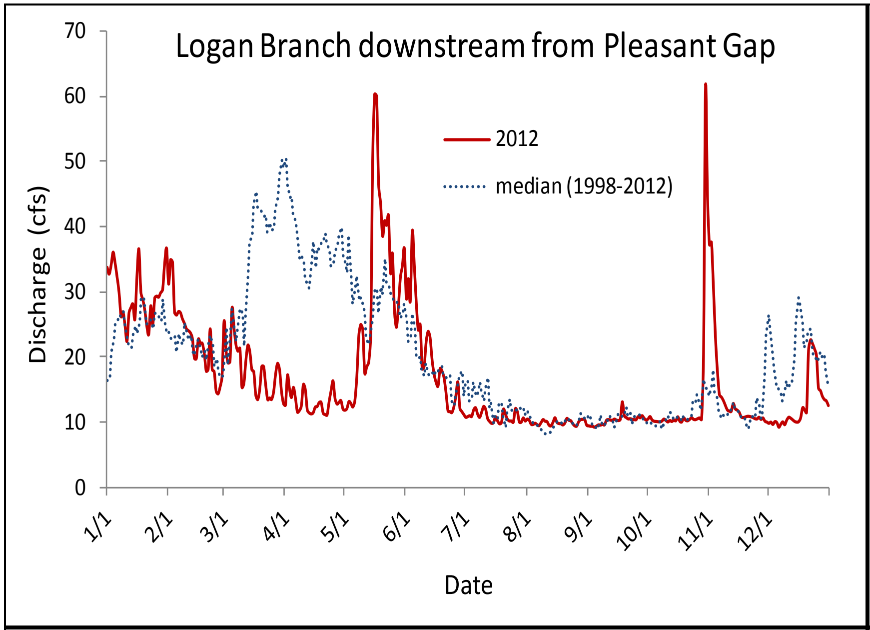


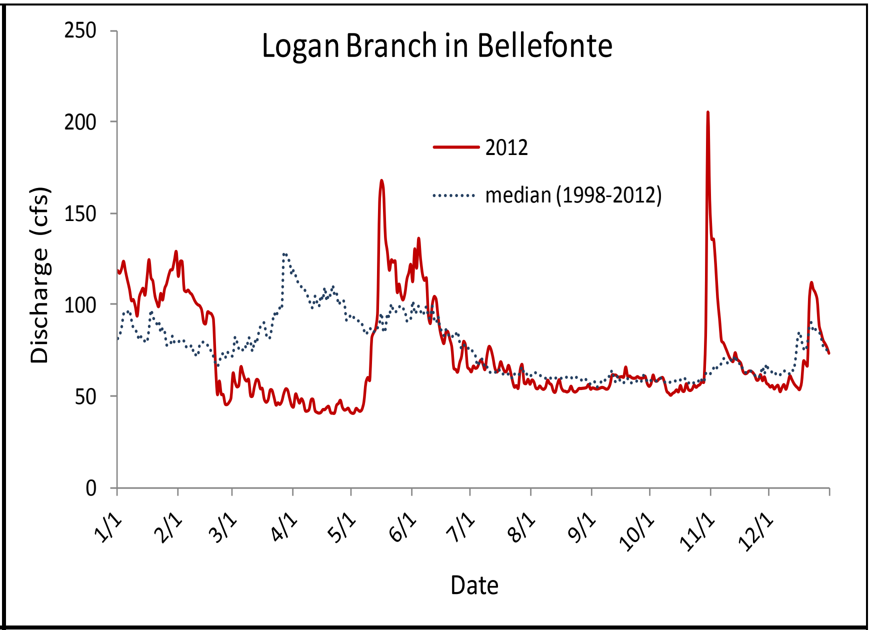


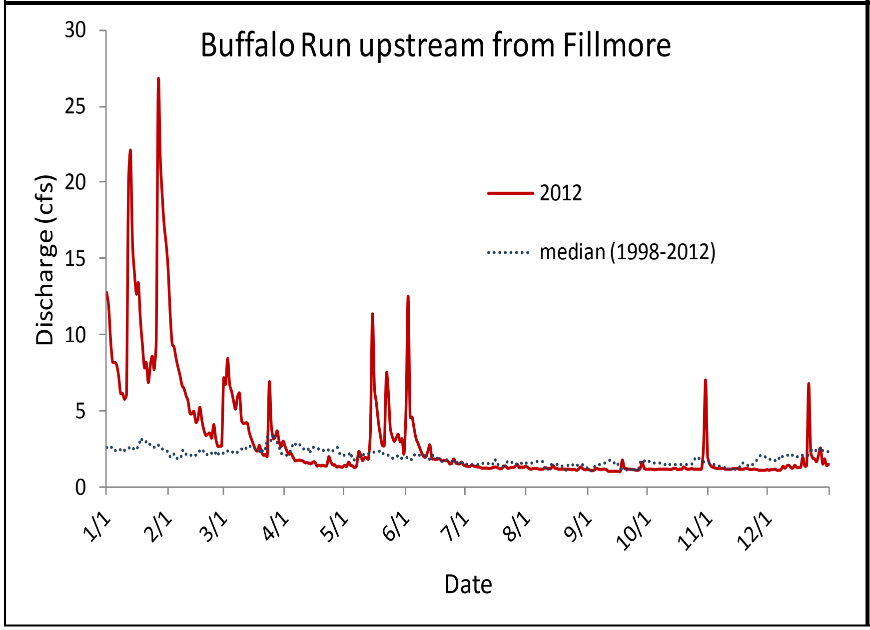


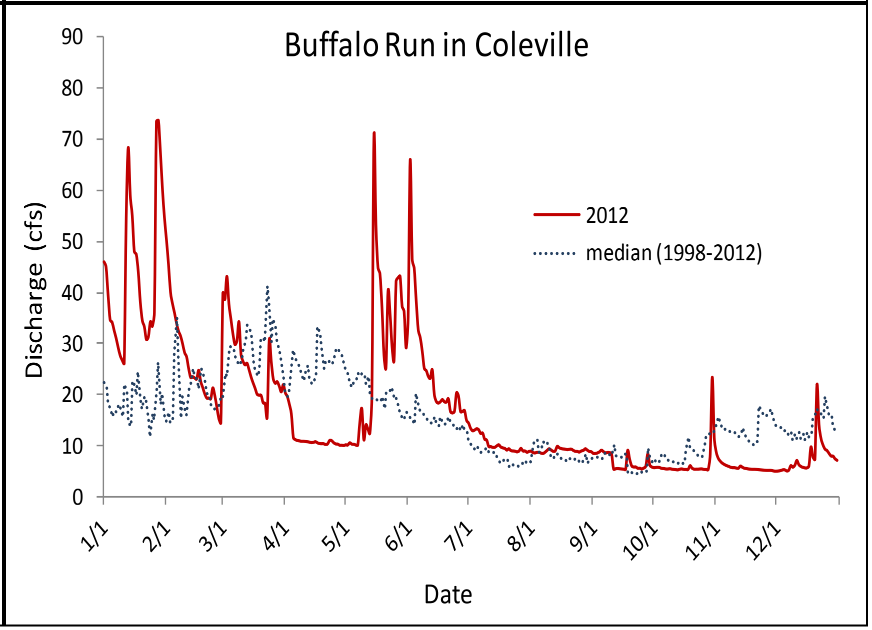


Appendix 7: Daily Stream Flow for 2012 (*continued*)



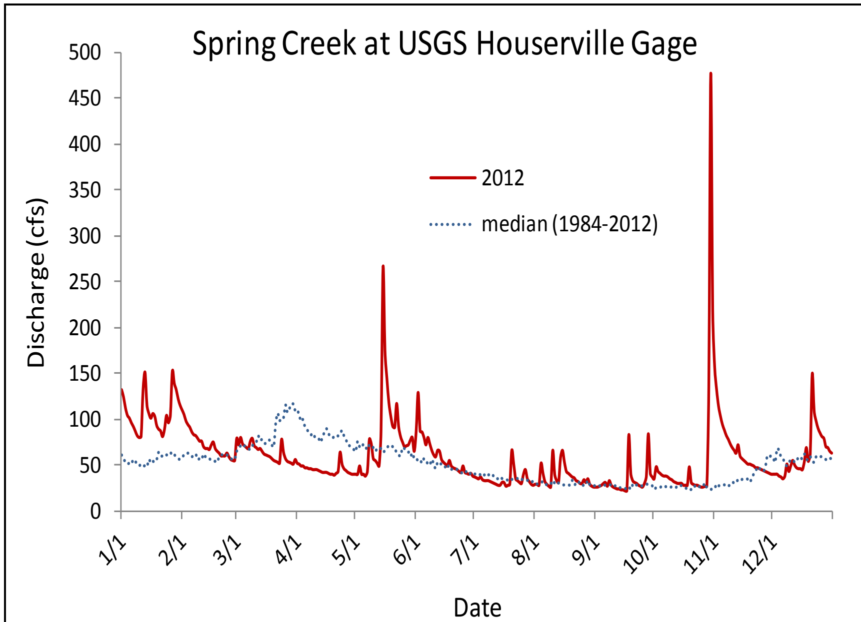


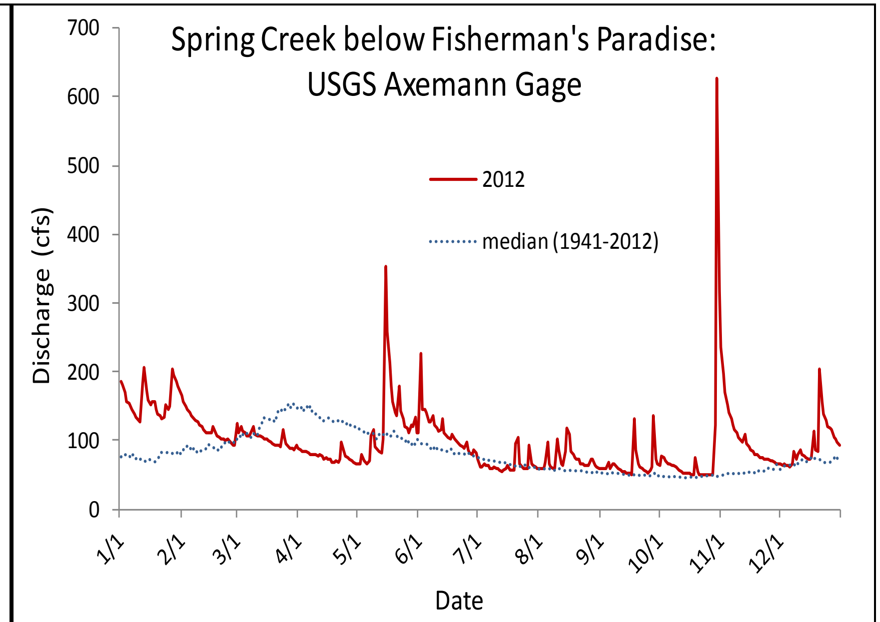


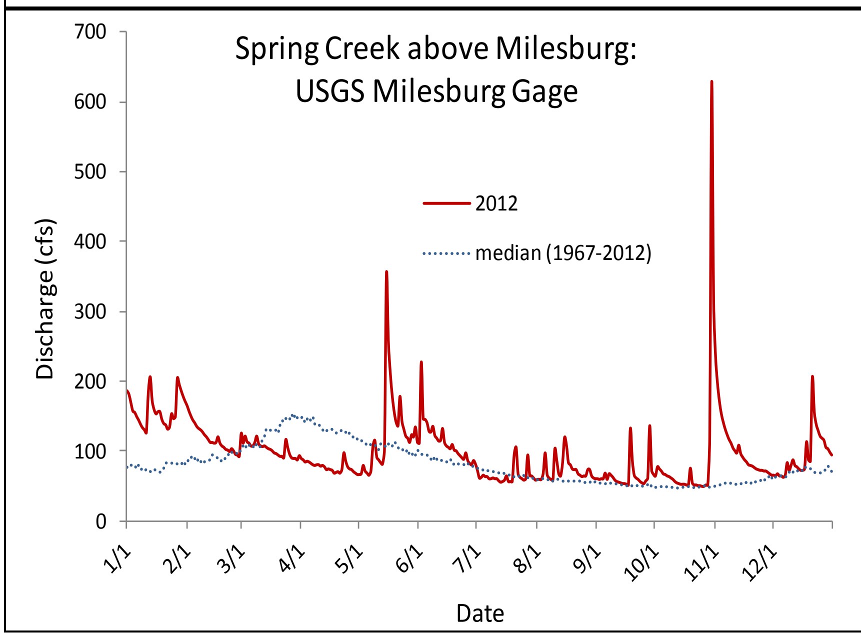


Appendix 7: Daily stream flow data for 2012 (*continued*)

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

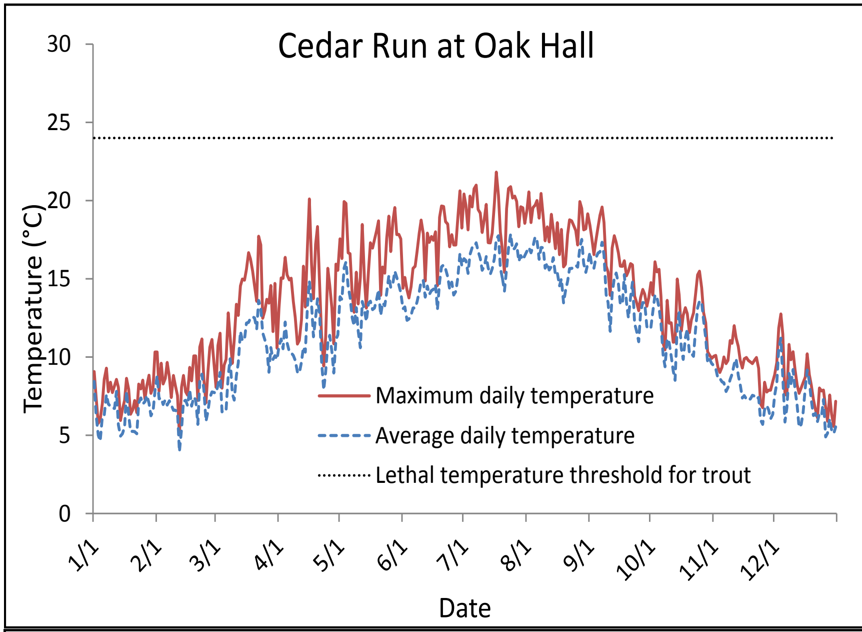


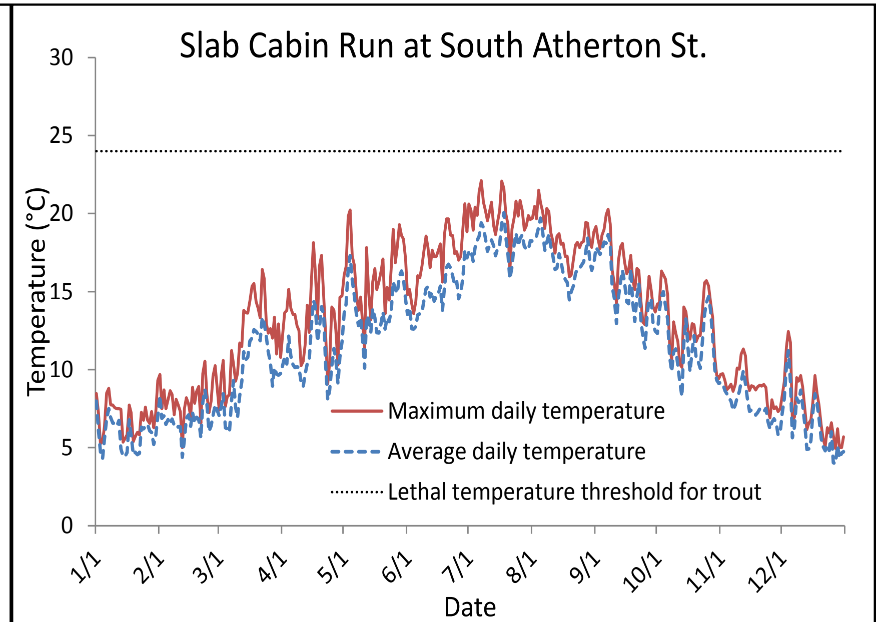


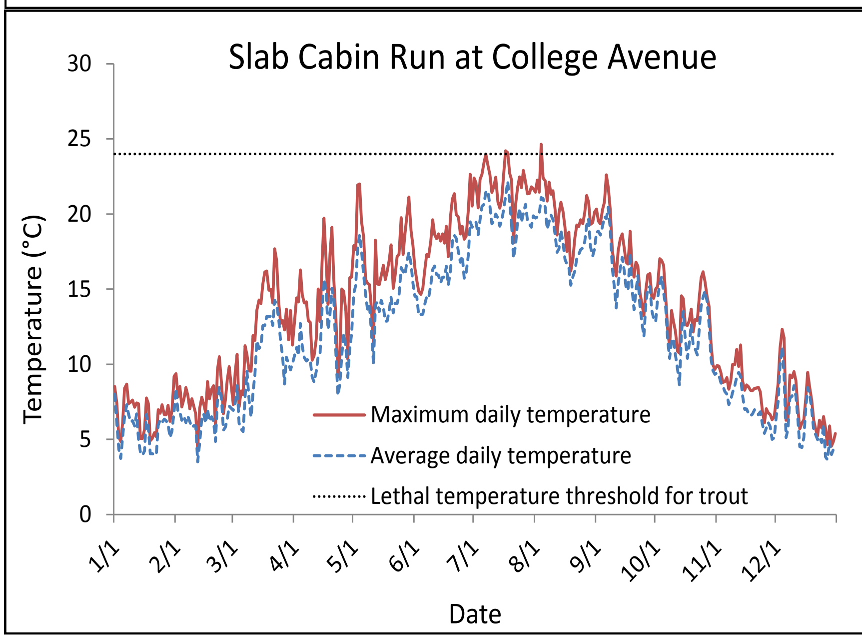


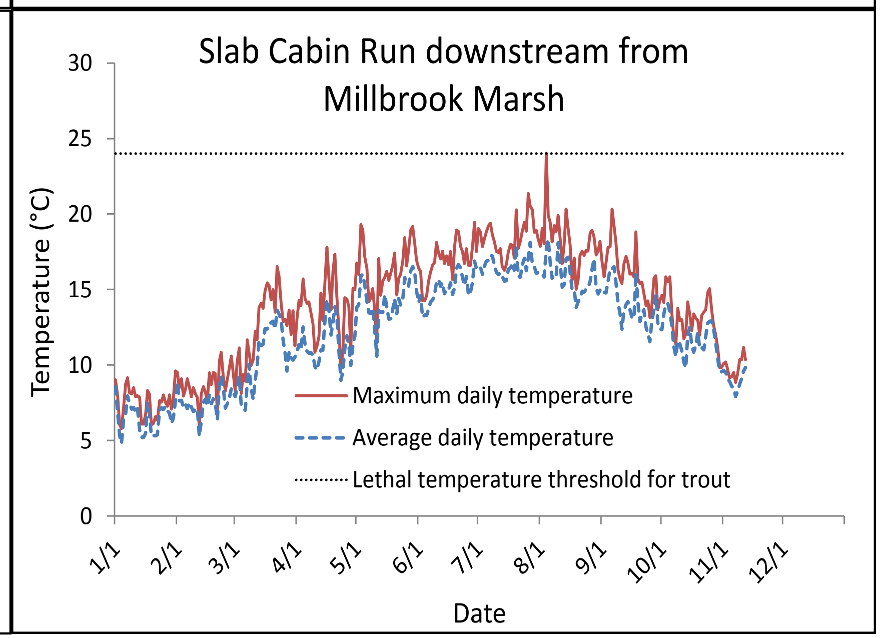
Appendix 8: Daily Stream Temperatures for 2012

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

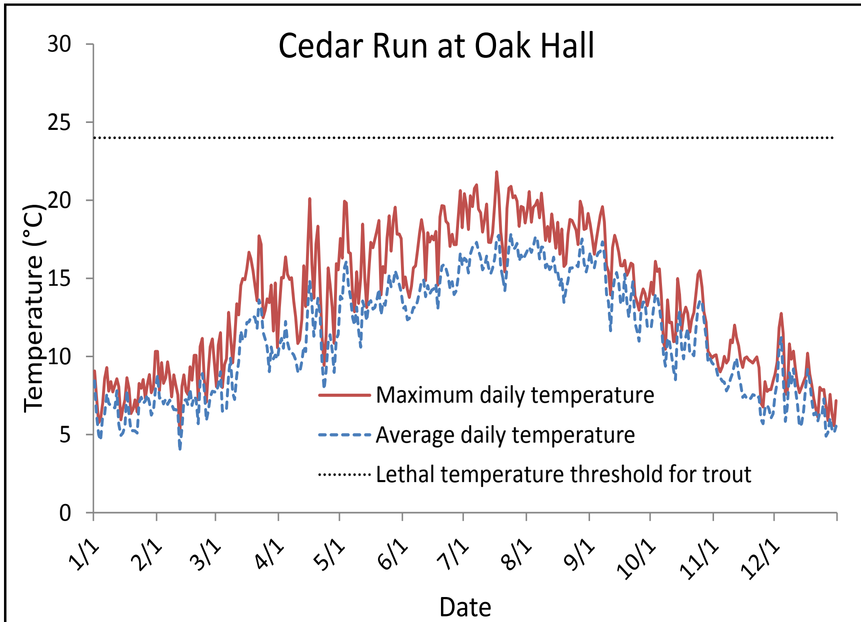


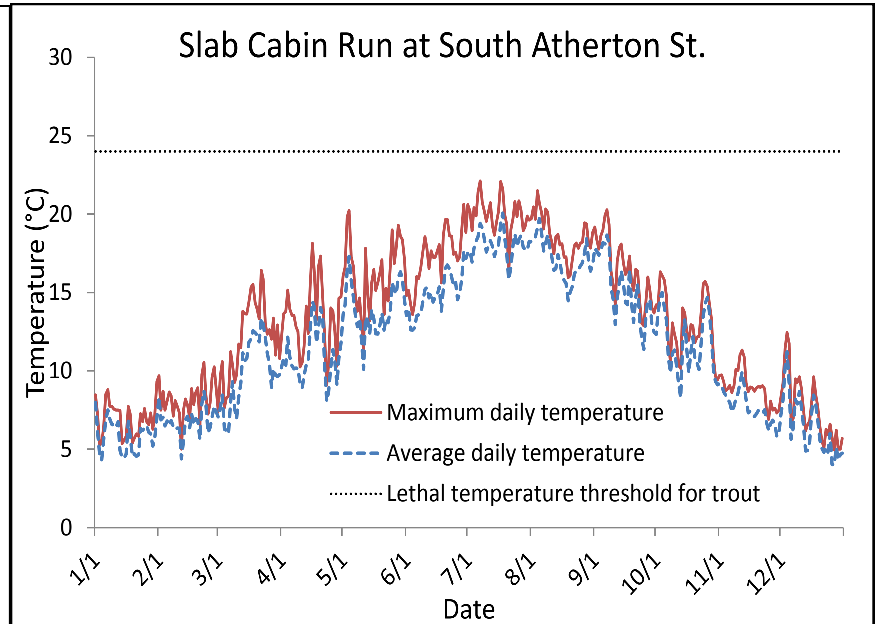


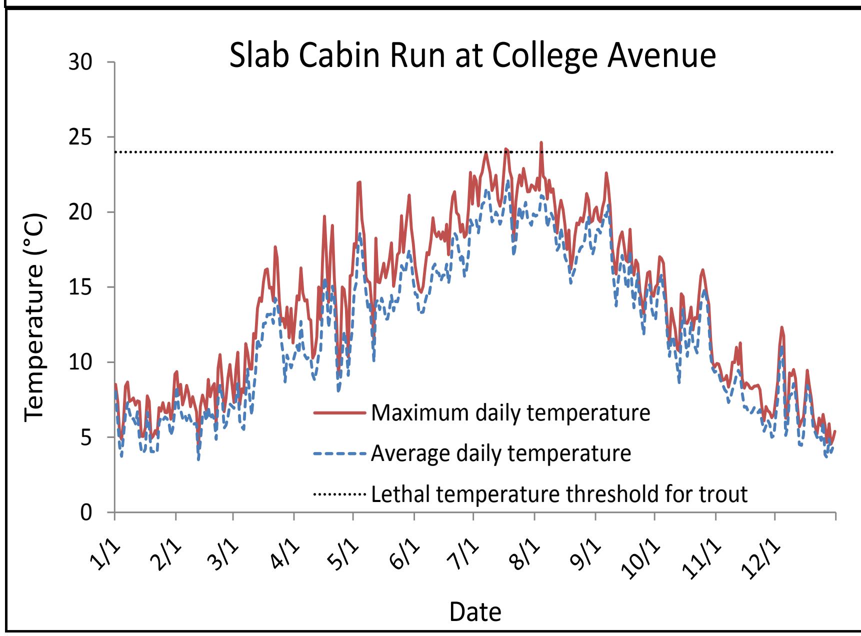


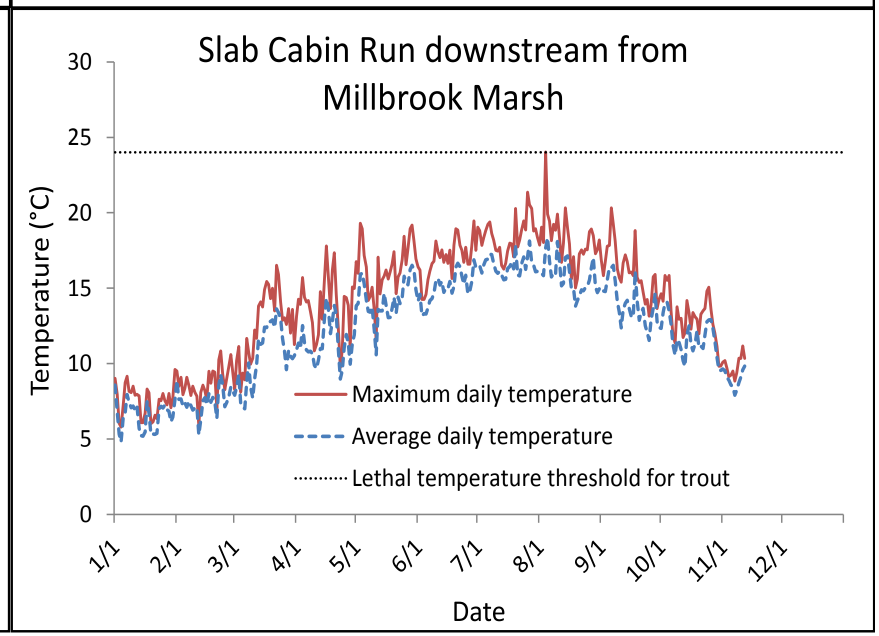


Appendix 8: Daily Stream Temperatures for 2012 (*continued*)

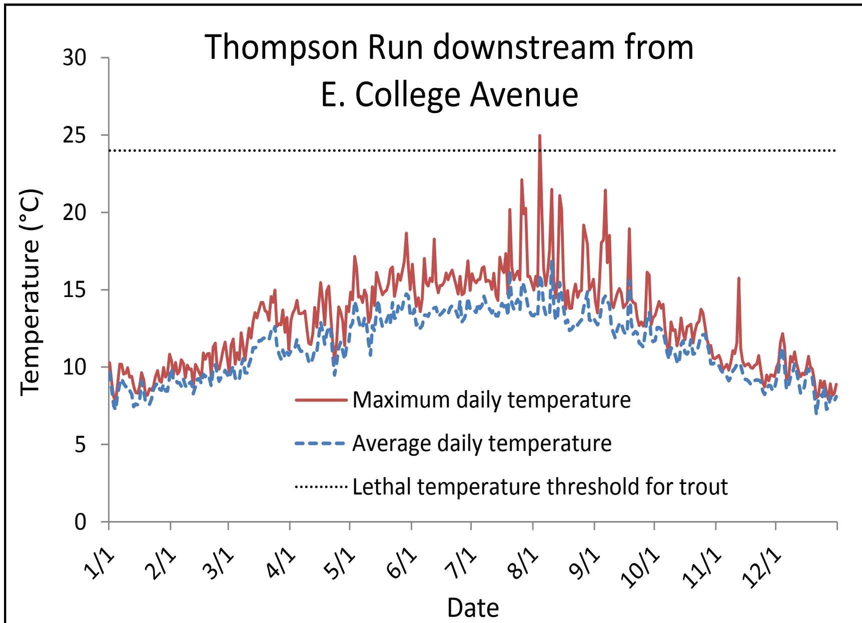


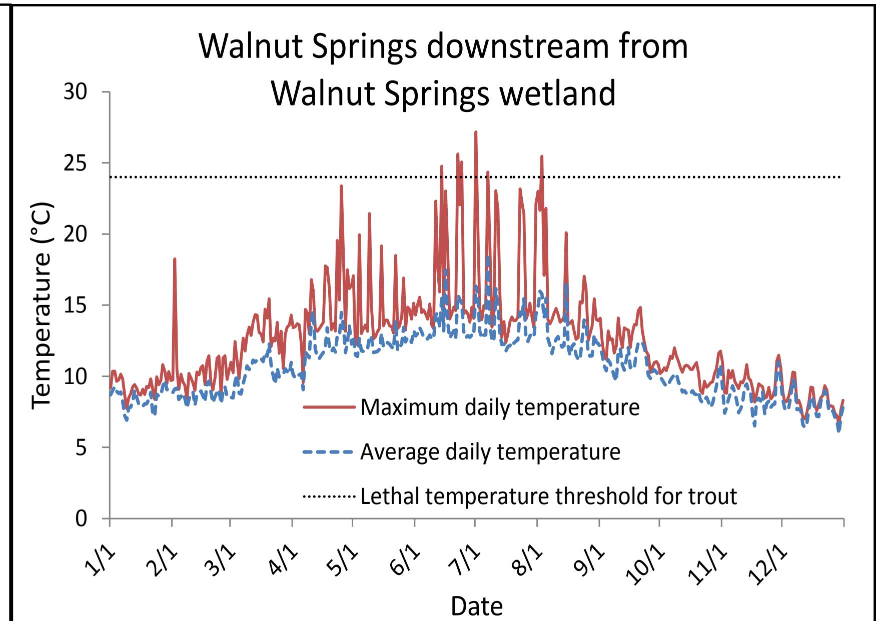


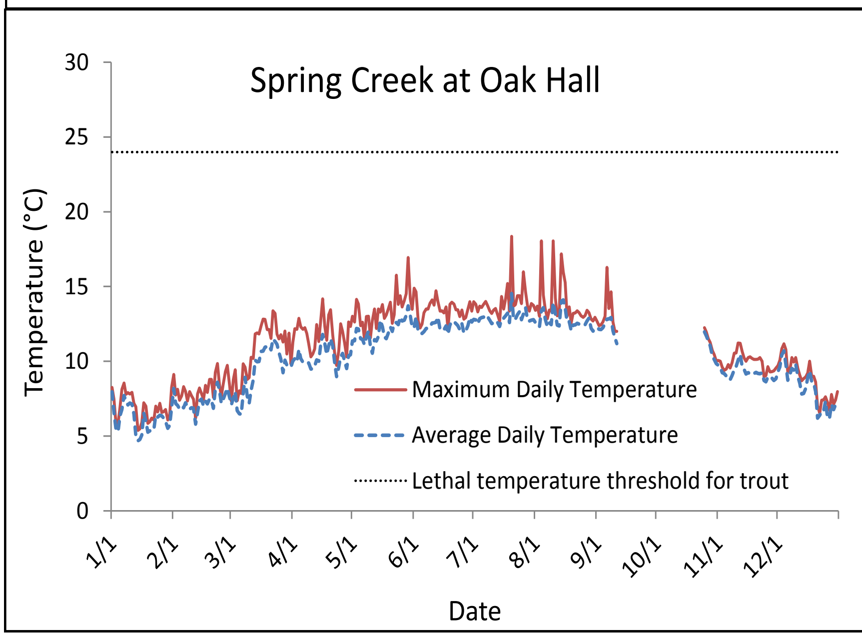


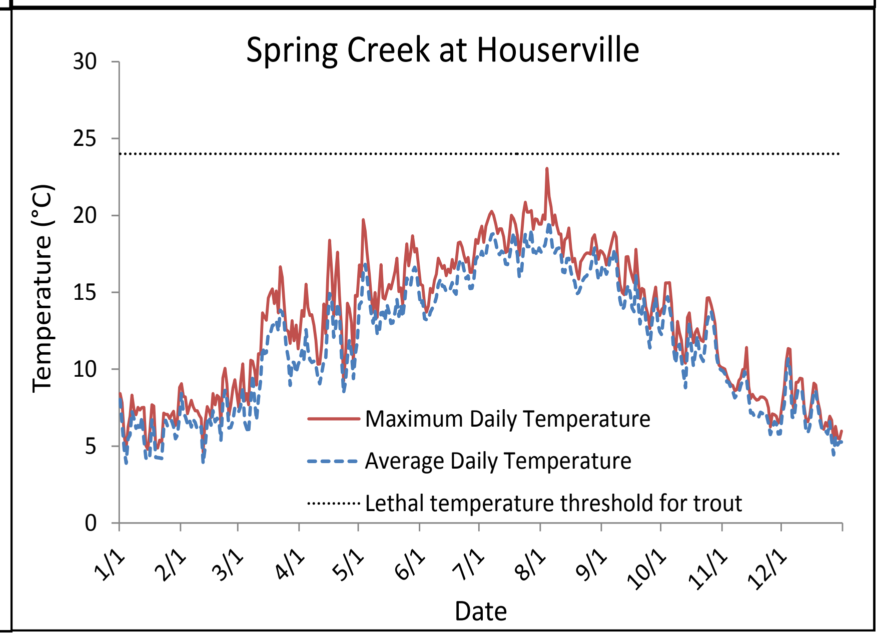


Appendix 8: Daily Stream Temperatures for 2012 (*continued*)

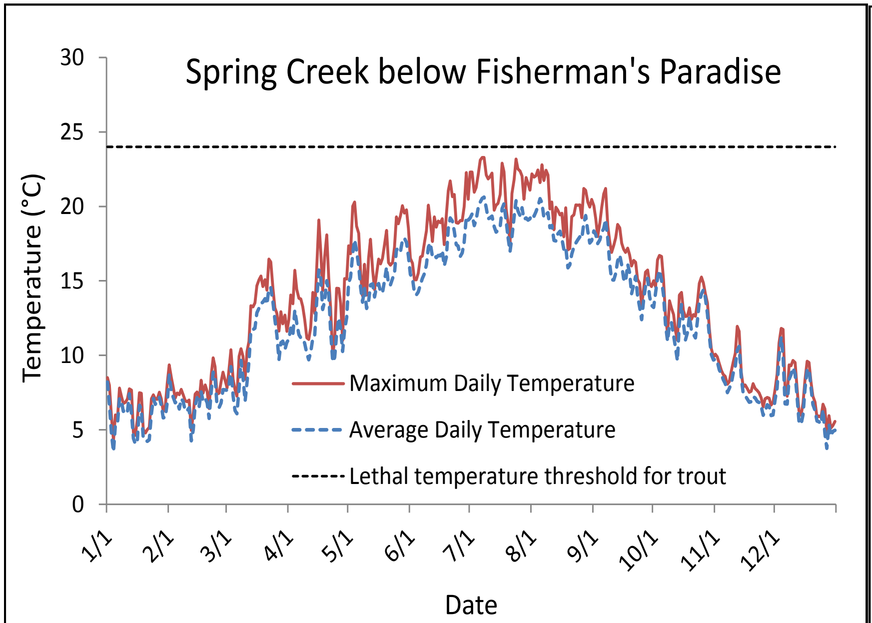


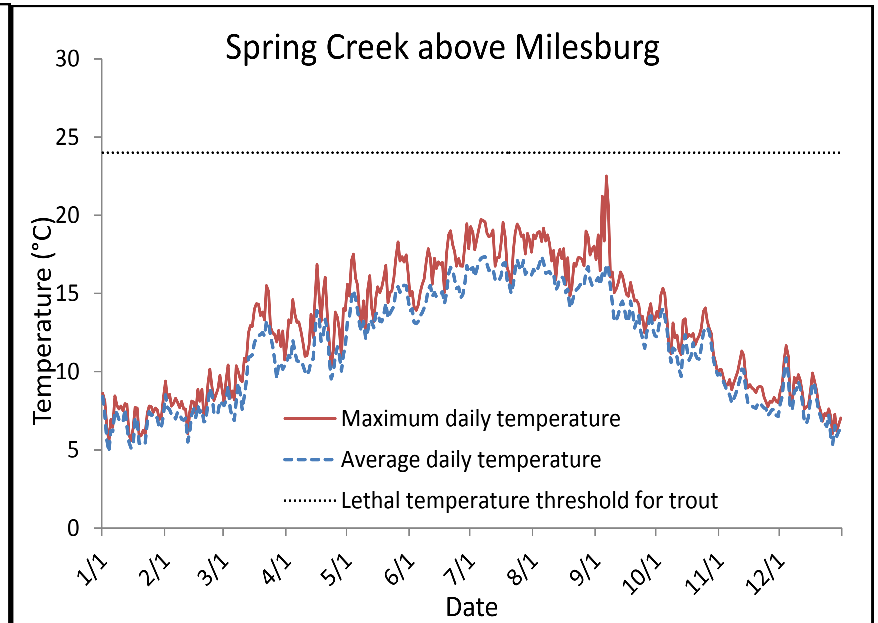


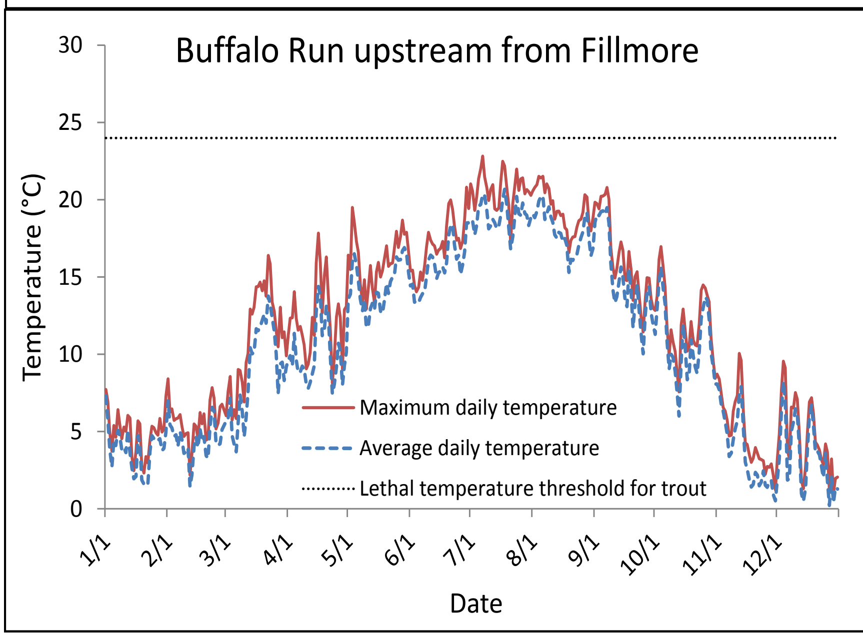


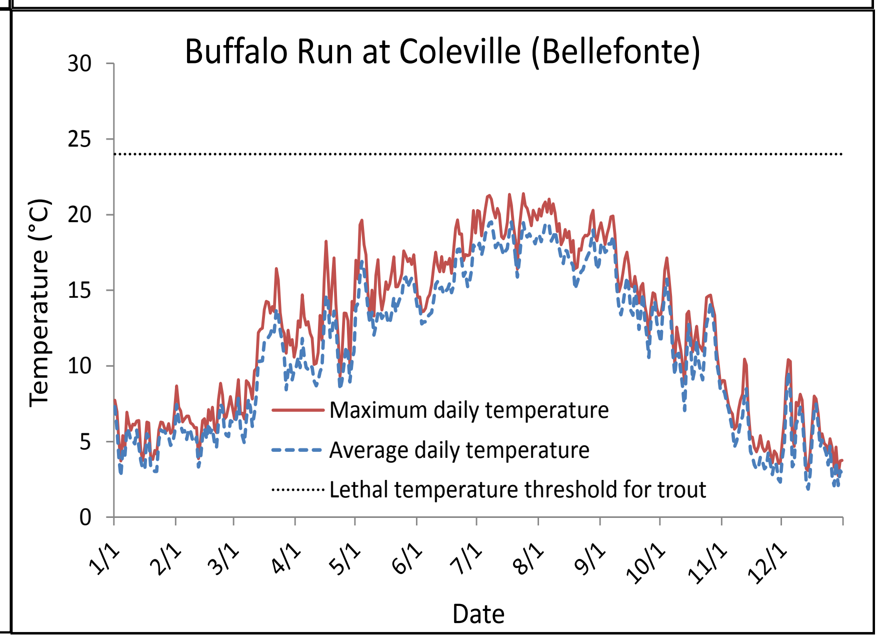


Appendix 8: Daily Stream Temperatures for 2012 (*continued*)

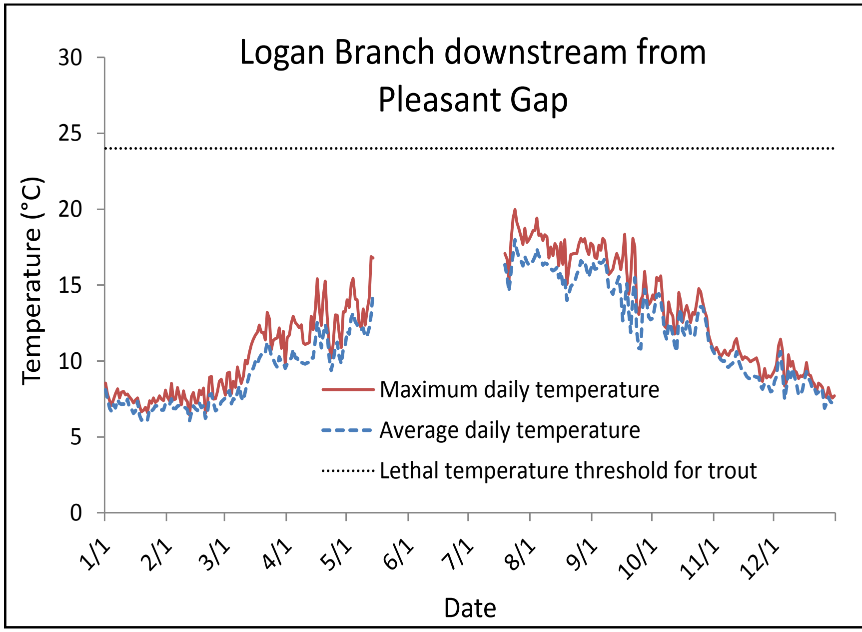


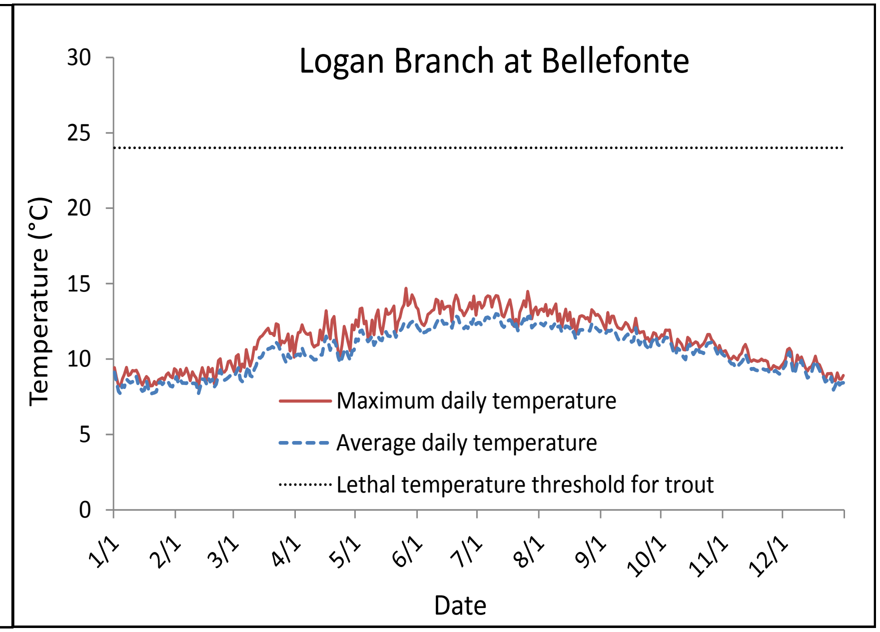






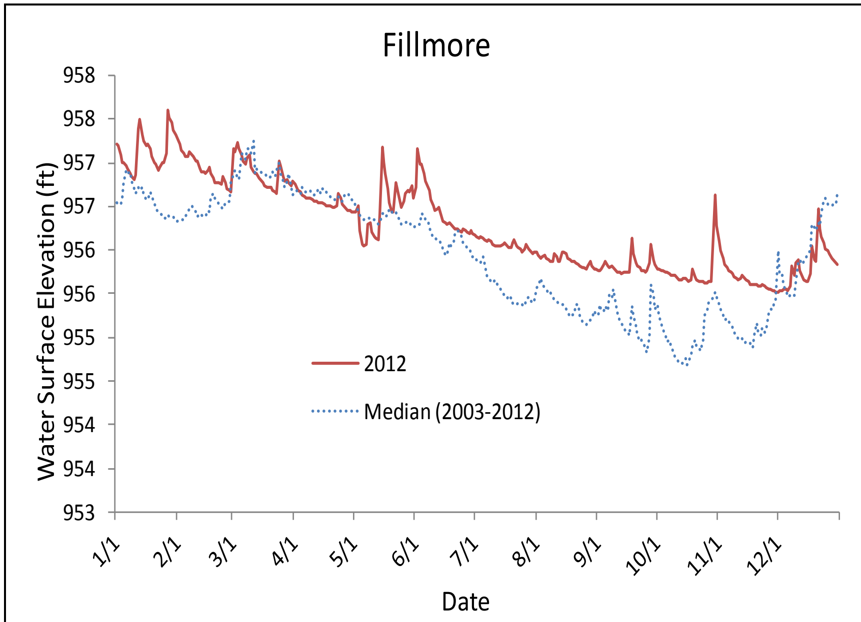
Appendix 8: Daily Stream Temperatures for 2012 (*continued*)

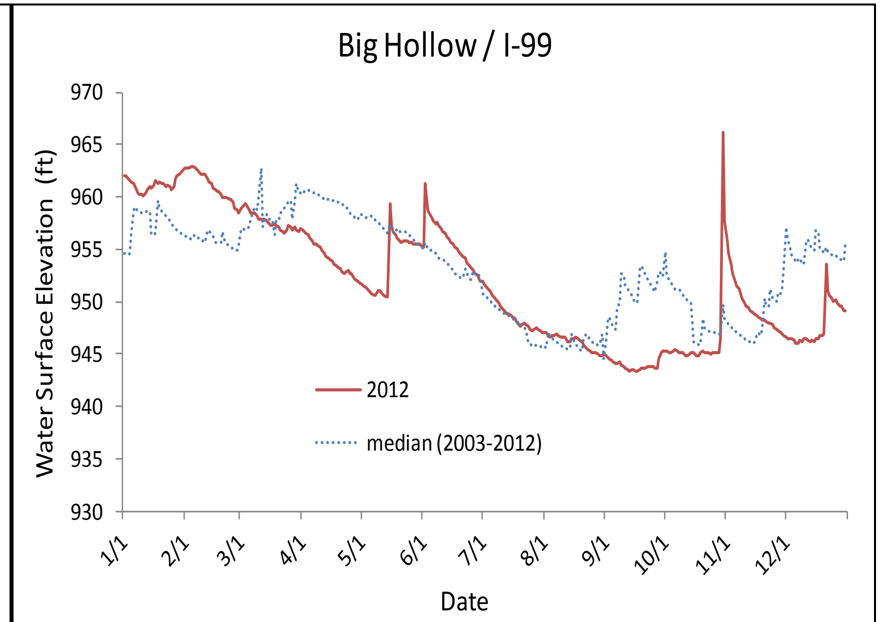


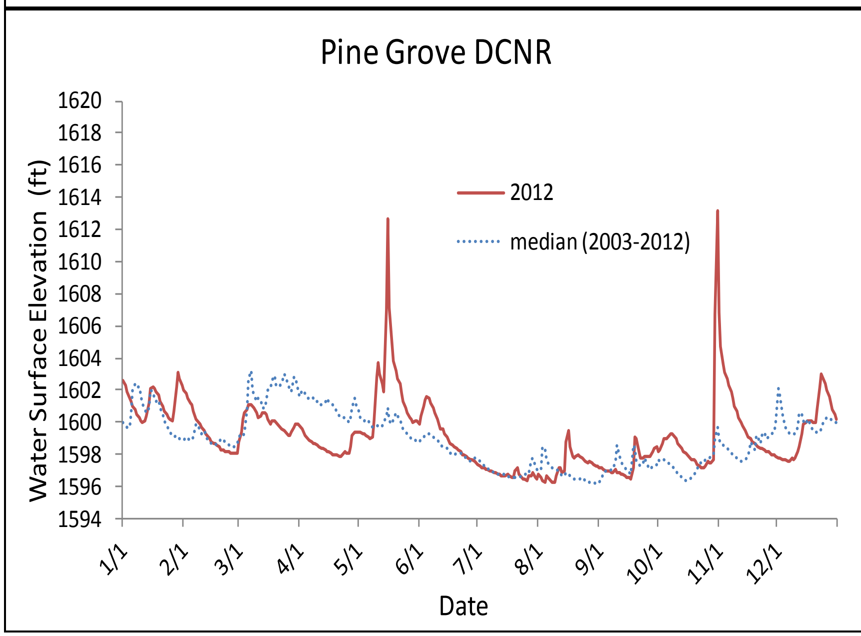


Appendix 9: Daily Groundwater Elevations for 2012

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







Appendix 9: Daily Groundwater Elevations for 2012 (*continued*)

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