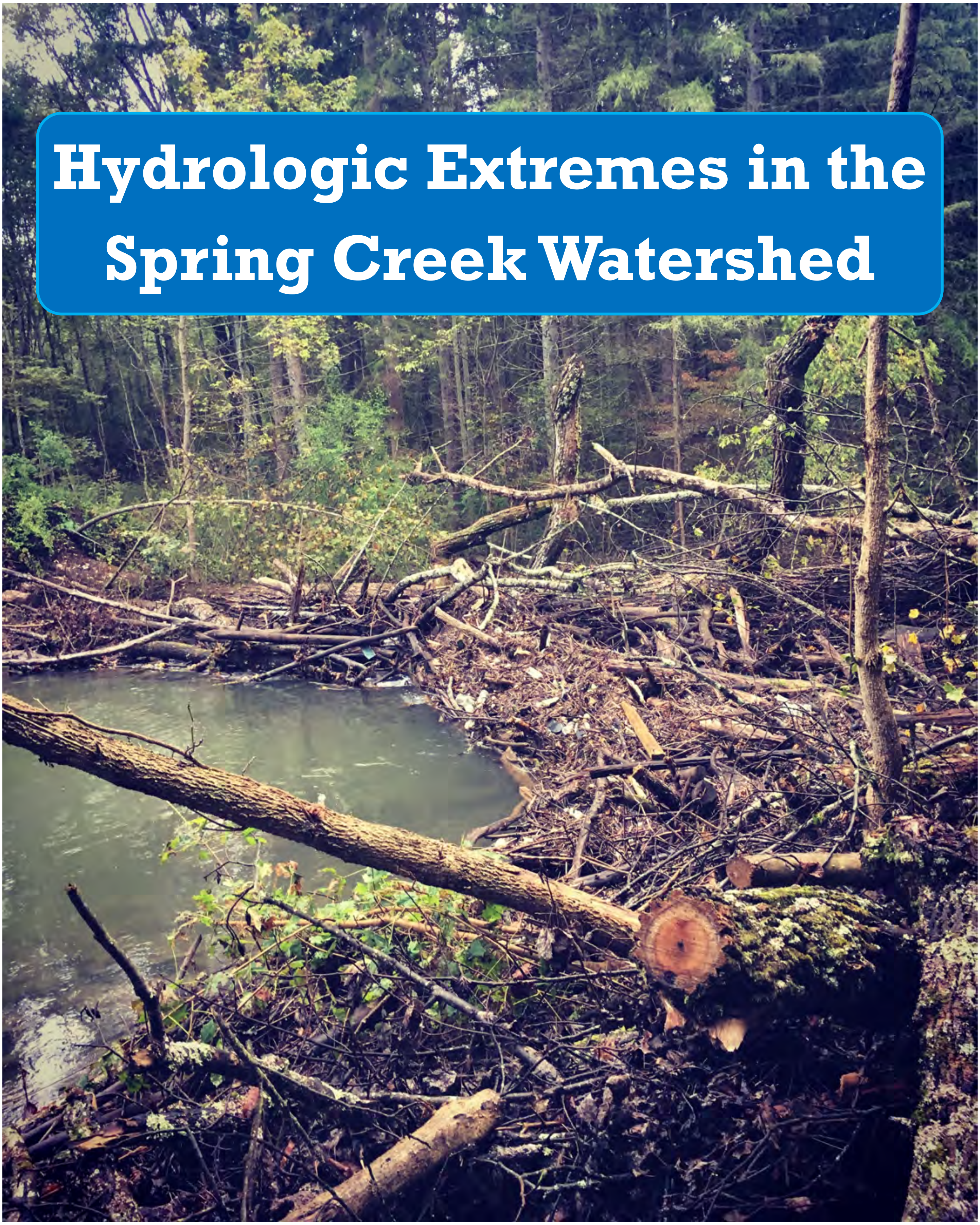
Hydrologic Extremes in the Spring Creek Watershed



KEYSTONE
Water
Resources
CENTER

The Spring Creek Water Resources Monitoring Project (WRMP) is conducted in partnership with the Keystone Water Resources Center, a publicly-funded non-profit organization with the mission of collecting scientifically useful data on the water resources of Pennsylvania and making those data available to the public. The following municipalities and organizations provide financial support for the WRMP to collect the necessary data for establishing long-term water resource data trends within the Spring Creek basin:

Bellefonte Borough

Benner Township

College Township

Ferguson Township

Halfmoon Township

Harris Township

Patton Township

Penn 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

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Introduction

Background

Fig. 1 Spring Creek after a large storm in 2018

Changing weather patterns on local to global scales are now a daily topic in the news and our conversations with family and friends. As seasonal weather patterns change our long-term climate trends will follow suit, which are forecast to have potentially adverse impacts on the environment as we know it, including our water resources. The WRMP has been designed to capture the key water quality and streamflow data in strategic locations around the Spring Creek watershed so that we can track trends at the basin scale, including seasonal to annual to decadal trends. Rainfall amounts during 2017 and 2018 ranged from 42.18 to 64.63, respectively, with 2018 being the wettest year on record, thus providing an opportunity to compare and contrast hydrologic extremes, the topic of this annual report. The significance of extremely wet versus dry years will be explored, and put into the context of the Spring Creek watershed through the WRMP data.

Hydrologic Extremes

Fig. 2 Buffalo Run during an extreme flow event in 2018

Streams and stable hydrologic regimes play an important role in not only providing ecosystem services essential for human well-being but also in maintaining stream physical and ecological stability (Palmer & Richardson, 2009). Ecosystem services provided by running water systems include erosion and sediment control, water supply, flood control, biodiversity, recreation and food production. Because a stable hydrologic regime is a critical supporting factor to these services, hydrologic extremes can reduce and even nullify the benefits of aquatic ecosystem services.

Frequent and high peak flows can erode stream channels and banks and increase sediment and nutrient levels within the stream (Boothe and Jackson, 1997; Paul and Meyer, 2001). Sediment is a critical water quality issue in the United States that can cause both ecological and economic disasters through decreases in stream biodiversity and impacts on flood control measures and water storage areas (Simon et al., 1999; Gauge et al., 2004). Additionally, flow variability and flashiness are strongly associated with benthic macroinvertebrate community structure, an indicator of health and stress levels of aquatic ecosystems (Richards et al. 1997; Petkovskae and Urbanic, 2015; Daoust et al. 2019). Studies have suggested that alterations in peak rather than low flow patterns can have the greatest impact on stream biology (Lynch et al. 2019).

Not only do these peak flows impact aquatic physical and biologic stability, but they also affect above-ground structures and human and wildlife populations. Floods are considered by some to be the most destructive natural disaster in the world (Bates et al., 2008). In 2008, river floods in the Midwest region of the United States caused $15 billion dollars in damage, and economic flood losses continue to rise (Pielke et al., 2002). In 2017, the economic damage caused by floods exceeded $60 billion dollars (NOAA). Despite the risk of flood damage, many urban areas are situated within flood plains of major rivers and pressure to develop in floodplains continues (Pinter, 2005). Land development can lead to increases in impervious surfaces, which, in turn, increases surface runoff and magnifies downstream flooding, which is relevant to understand in the Spring Creek watershed due to significant regional land development (Figure 3).

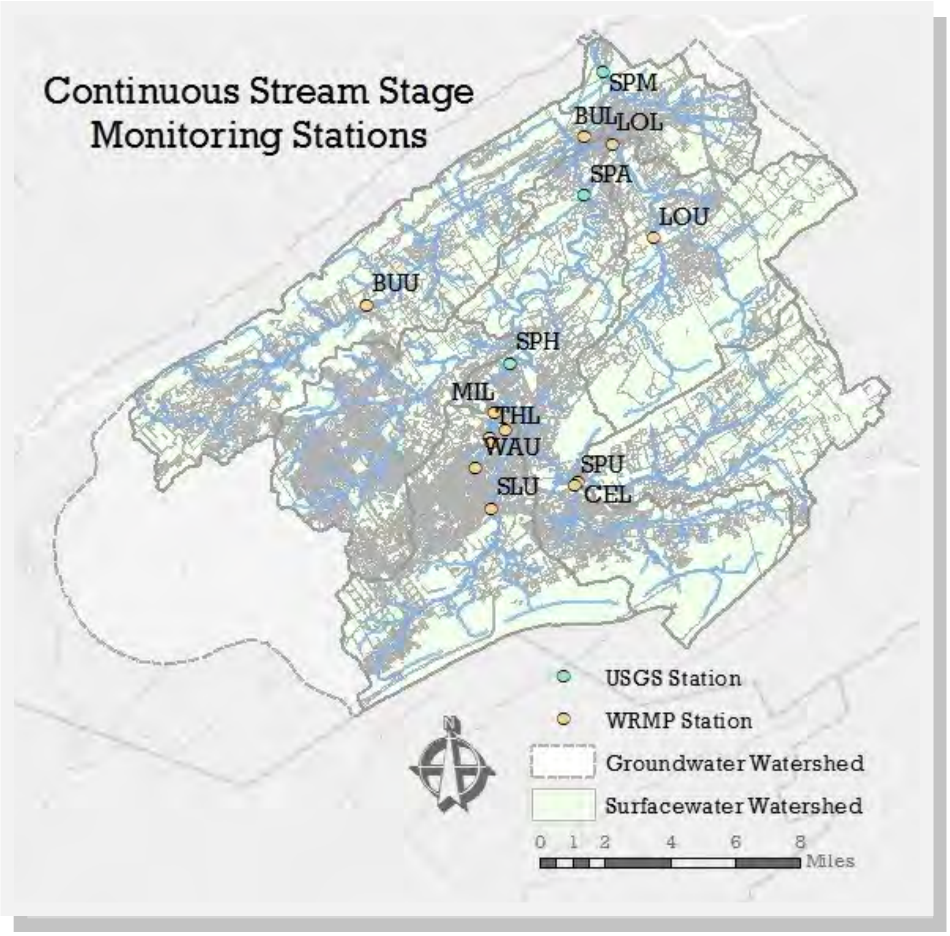


Fig. 3 WRMP and USGS stream level monitoring stations in the Spring Creek Watershed. Gray indicates developed land cover.

Historically, in urban and suburban areas, human population growth and associated land-use and development changes were the major stressors to watershed hydrology (Stendera et al., 2012). Increased impervious surfaces, stormwater drain networks and diminished floodplains can all result in modifications of water pathways that increase runoff rates and volumes (Fletcher et al., 2013). However, the

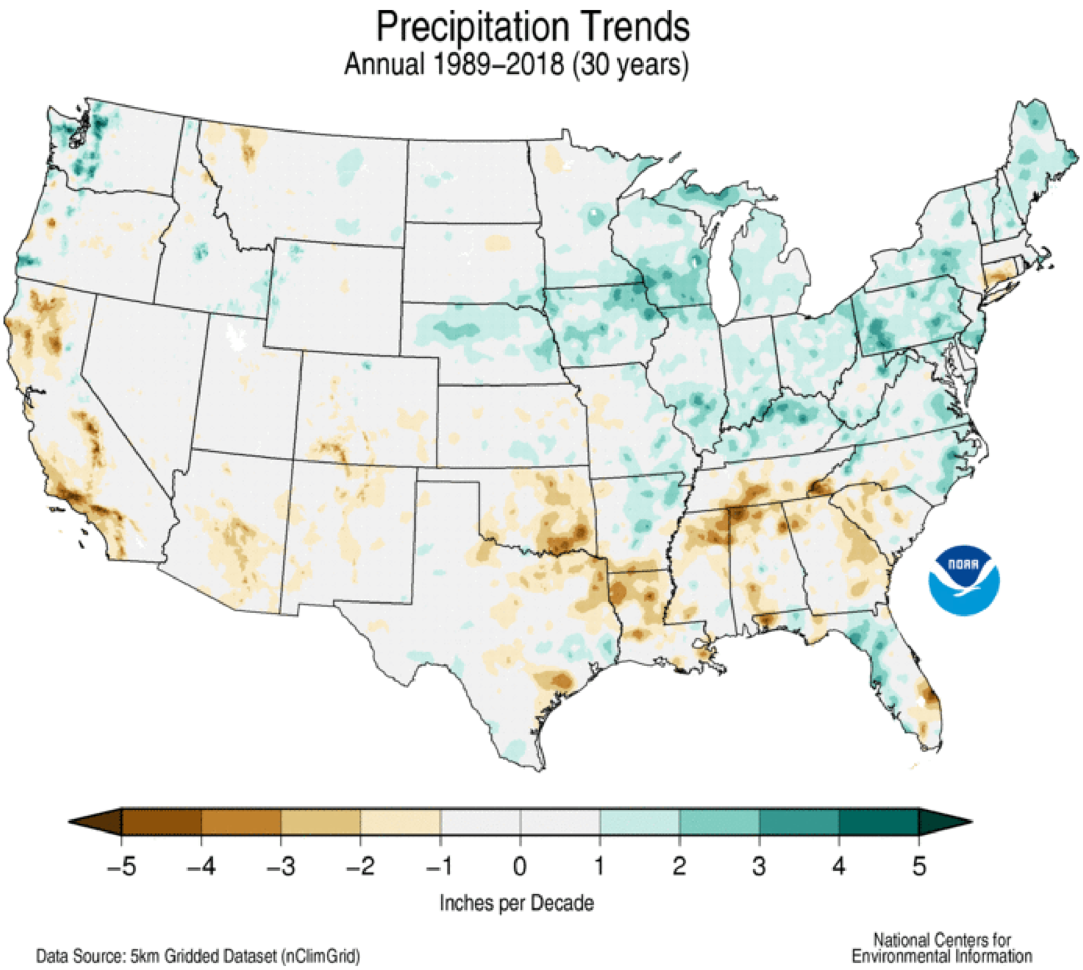
Fig. 4 A storm drain releasing surface runoff directly into Spring Creek

potential impact of climate change may become increasingly important in its hydrologic impact. Impact assessments predict that the mid-latitude in the United States will experience more extreme precipitation events in both frequency and intensity (Stocker et al., 2013). Combined with the impact of urban development, floods may be one of the most important issues to address in regions with rivers and nearby urban development.

Climate Trends in the Spring Creek Watershed

Precipitation

While climate models predict increases in large storm events for the Northeast Region in the coming decades, do the data already show any trends in precipitation patterns over the last 30 to 50 years? Figure 5 shows the national annual precipitation trends based on the last 30 years of precipitation data collected by the National Oceanic and Atmospheric Administration (NOAA). Pennsylvania has shown an overall trend of increased annual precipitation between zero and four inches of increased precipitation per decade, depending on the region. This increase is mostly during summer months with much of the state receiving one to four inches of increased precipitation per decade. Most of the state is within the one to two inch range of annual in-



Data Source: 5km Gridded Dataset (nClimGrid)

National Centers for Environmental Information

Fig. 5 National precipitation trends based on data collected between 1989 and 2018. The color scale indicates increased or decreases in precipitation per decade.

creased precipitation per decade, which would mean if current trends continue, much of the state would experience five to ten more inches of annual precipitation in 50 years.

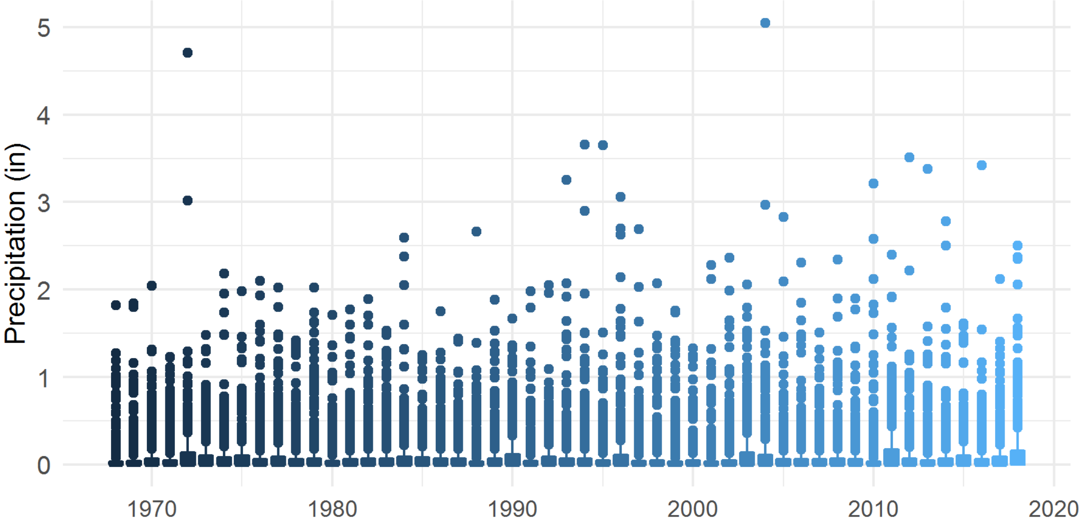


Fig. 6 Distribution of: daily combined precipitation and snowmelt in State College, PA. Data obtained from the PSU Weather Station

State-wide trends, while significant, are also unevenly distributed. Where does the Spring Creek Watershed fall on this spectrum of neutral to increased precipitation? Figure 6 outlines the overall distribution of total daily rain and snowmelt in State College, PA between 1968 and 2018. No clear changes in total distribution can be seen in daily precipitation levels over time. However, when looking strictly at days with a minimum total of one inch of rain, a slight positive trend can be seen (Figure 7). Additionally, 2018 did have the highest number of days with one inch or more of combined precipitation and snowmelt. Days with no precipitation showed no trend over time, which is consistent with trends across the state. Figure 8 compares cumulative precipitation for all between 1968 and 2018. Not only did 2018 have the highest total precipitation, but the top five years of total precipitation have been in the last 15 years. More details on 2018 as a record setting year will be discusses in more detail in later sections.

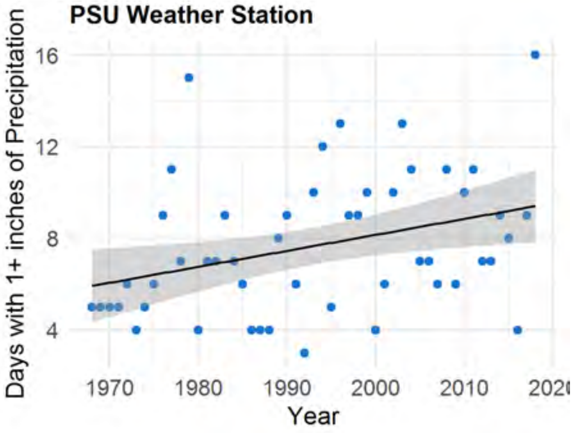


Fig. 7 Days with combined precipitation and snowmelt equal to or exceeding one inch.

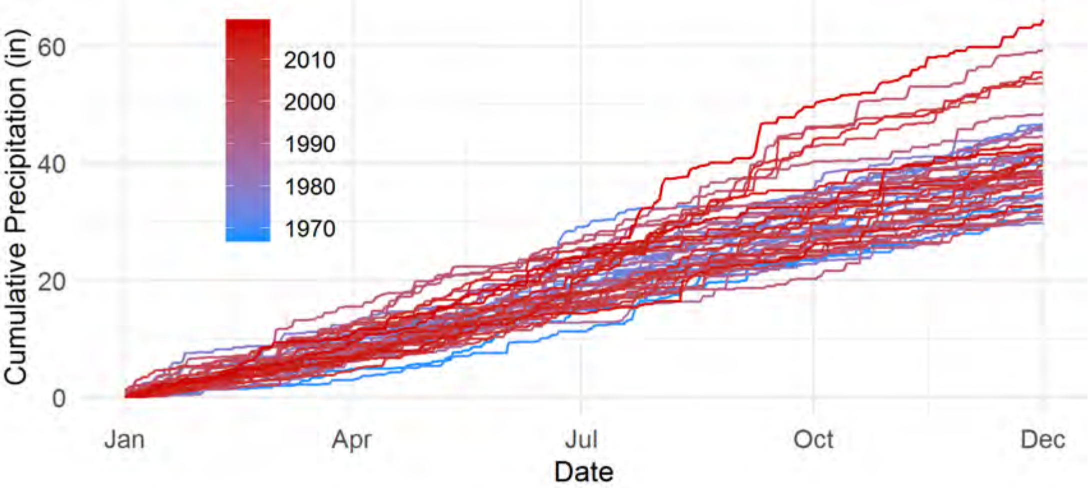


Fig. 8 Cumulative precipitation and snowmelt in State College, PA. Data obtained from the PSU Weather Station

Hydrologic Trends in the Spring Creek Watershed

Stream Discharge and Baseflow Rates

While precipitation trends do seem to be increasing across Pennsylvania and within the Spring Creek Watershed, understanding how this translates into watershed hydrology is critical. The 2015 Update to the Pennsylvania Climate Impacts Assessment of water resources compared recent (2005-2014) and historic (1965-2004) streamflow data at USGS gages across Pennsylvania. The analysis revealed that in much of the state, extreme flow events have increased in size in recent years, while low flow events have remained relatively steady. In contrast, hydrographs of the two USGS gages in the Spring Creek Watershed that have complete periods of record between 1968 and 2018 - Spring Creek at Milesburg (SPM) (Figure 9) and Spring Creek near Axemann (SPA) (Figure 10) - revealed little change in the distribution of both daily discharge and baseflow, which is streamflow unaffected by surface runoff. The increase in both total rates at the end of both the historic and recent periods of record are very similar with peak flows near 500 and 1000 cfs (cubic feet per second) in Axemann and Milesburg, respectively. Baseflow

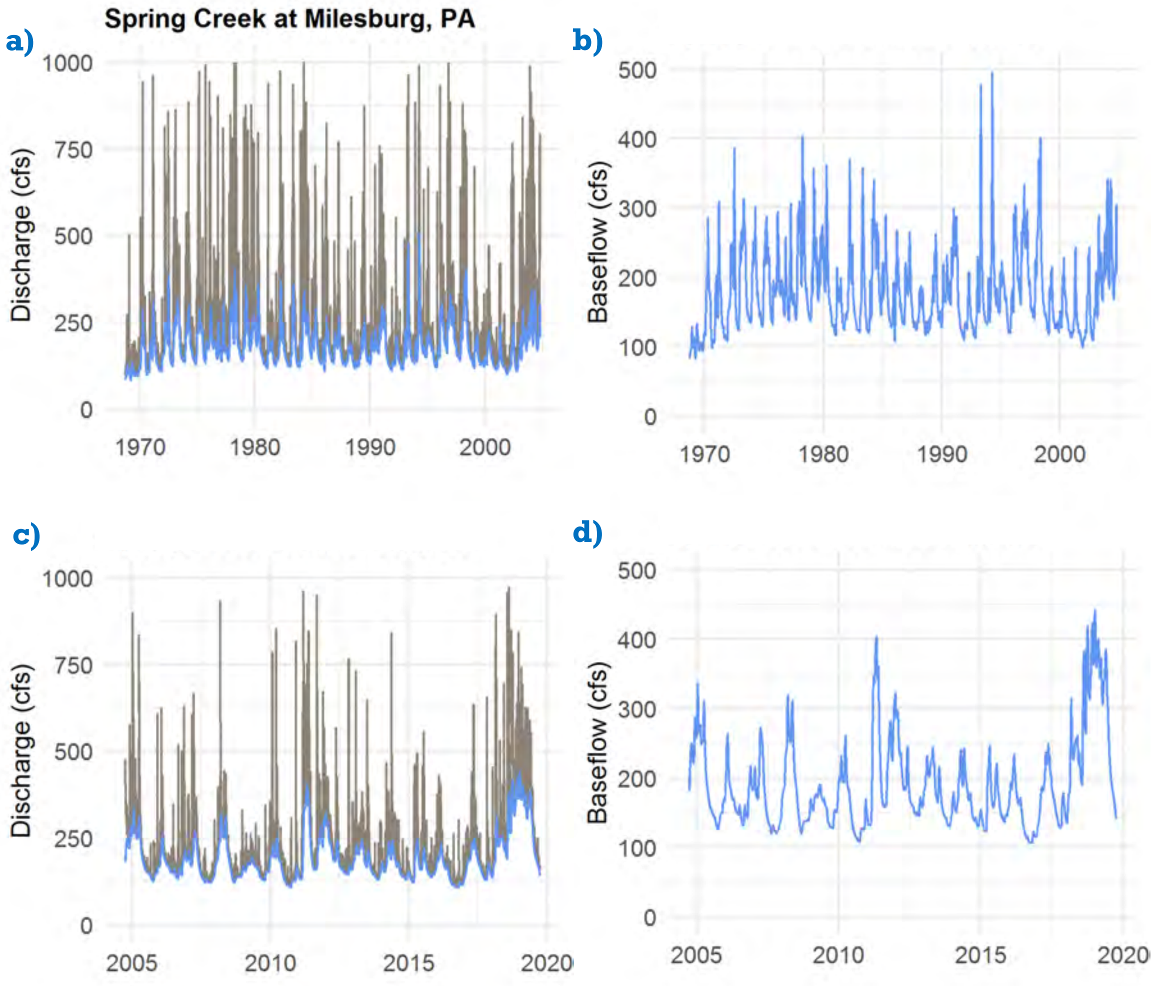


Fig. 9 Discharge and baseflow data at Spring Creek in Milesburg: (a) historic discharge data (b) historic baseflow data (c) recent discharge data (d) recent baseflow data (Data obtained from USGS)

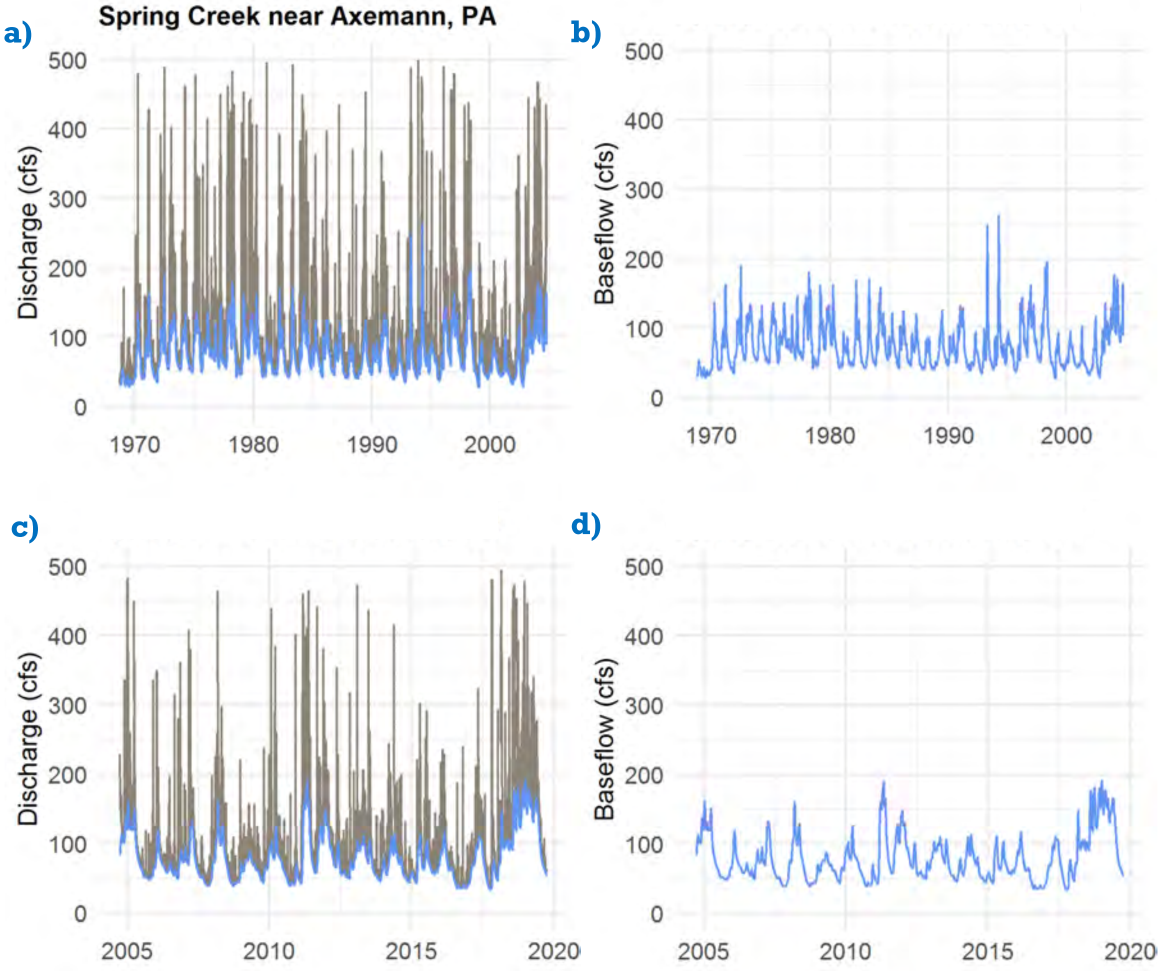


Fig. 10 Discharge and baseflow data at Spring Creek near Axemann: (a) historic discharge data (b) historic baseflow data (c) recent discharge data (d) recent baseflow data (Data obtained from USGS)

rates did reach higher levels in Milesburg in 2018 than 2004 (440 and 340 cfs, respectively), however the highest baseflow rate of over 500 cfs was observed in 1994.

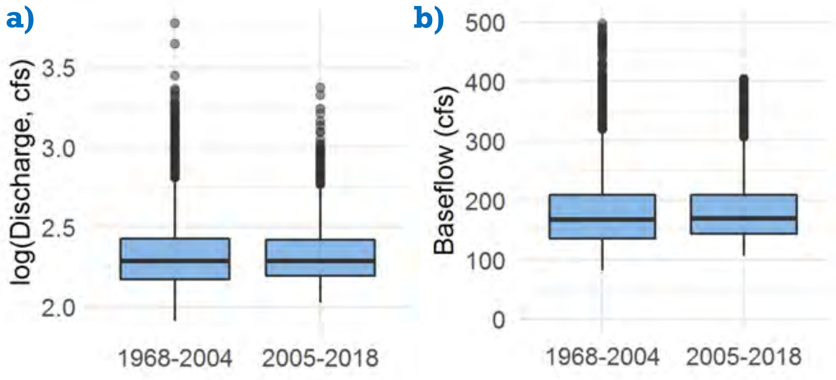


Fig. 11 Boxplots of (a) normalized discharge (natural log of discharge) and (b) baseflow rates for historic and recent time series in Spring Creek at Milesburg, PA..

Overall median discharge and baseflow rates were also similar for both periods. Figure 11 compares box plots of normalized discharge (the natural log of discharge) and baseflow rates. A box plot indicates the median value with the center line, the middle 50 percent range of normal distribution within the box, the outer 25 percent range with the vertical lines above and below the box and all outliers as dots outside of the vertical lines. Both distributions indicated similar median discharge and baseflow rates and peak flows outside of the normal distribution. Since these peak flows are likely to increase, trends in frequency of flow variability or flashiness and number of peak flow events were also analyzed.

Peak Flows , Low Flows and Flashiness

In order to determine if more extreme peak and low flow events occurred at the Milesburg monitoring station in the 2004-2018 time period, days with discharge rates above the 90th percentile and below the 10th percentile were counted for both periods. Figure 12 indicates that neither period of record had a significant difference in days over the 90th percentile or under the 10th percentile. The median value of low flow days was slightly higher in more recent years, while the median value for peak flow days was slightly lower in recent years. However, the overall distributions for both periods were within similar ranges, which indicates no statistically significant difference between either period.

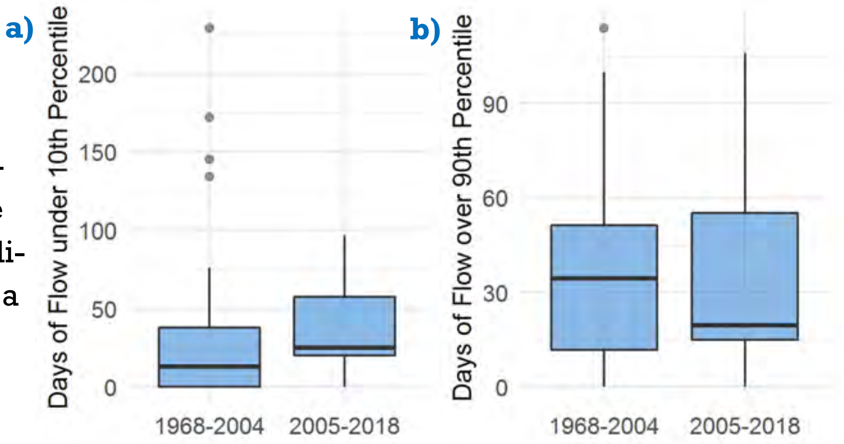


Fig. 12 Boxplots of days (a) under the 10th percentile and (b) over 90th percentile flow rates for historic and recent time series.

$$R-B\ Index = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

Eq. 1 R-B Flashiness Index

Flashiness is another parameter used to determine if a stream is experiencing frequent runoff from storm events. The R-B Flashiness Index identifies how much a stream varies in discharge rates between days (Baker et al., 2004). The index is calculated by dividing the sum of the differences between daily discharge rates by the sum of daily discharge rates. Factors that can influence a streams flashiness include stream size and surrounding urban development. Smaller streams that receive a large amount of surface runoff tend to be the most flashy. Spring Creek in Milesburg did not show any changes in flashiness over the past 50 years (Figure 13). However, Milesburg is near

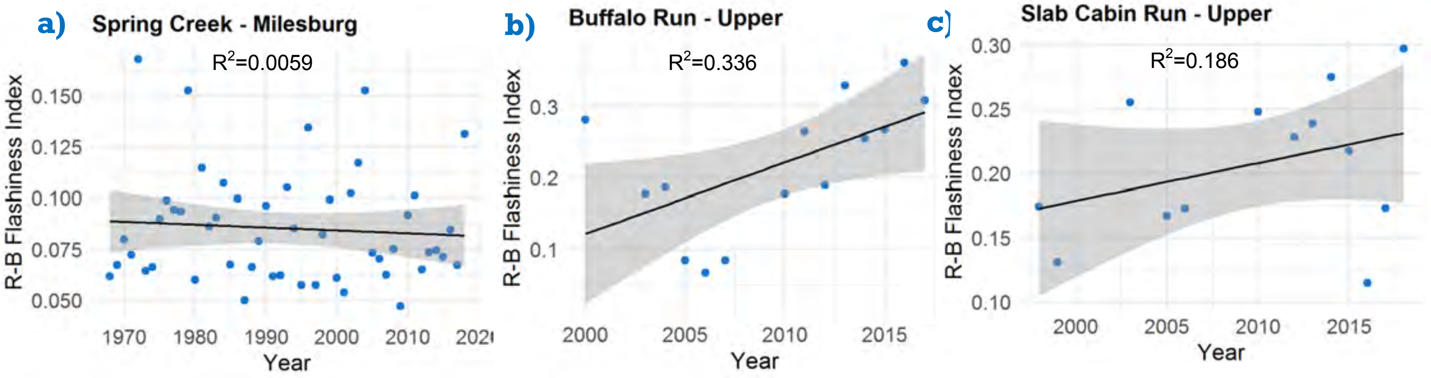


Fig. 13 R-B Flashiness Index for Spring Creek at Milesburg (SPM) , Buffalo Run - Upper (BUU) and Slab Cabin Run—Upper (SLU)

the mouth of Spring Creek, where flows are generally higher and influenced more by groundwater and tributary input than surface runoff. The R-B Flashiness Index of the Upper Buffalo Run (BUU) and Upper Slab Cabin Run (SLU) stations were also calculated for years with complete data between 1999 and 2018. These locations did show generally greater flashiness than Spring Creek at Milesburg with a positive trend in flashiness over the past 17 years. Hydrographs of these stations show many more peak flow events in the past couple years, however no long-term trends in overall discharge rates (Figure 14).

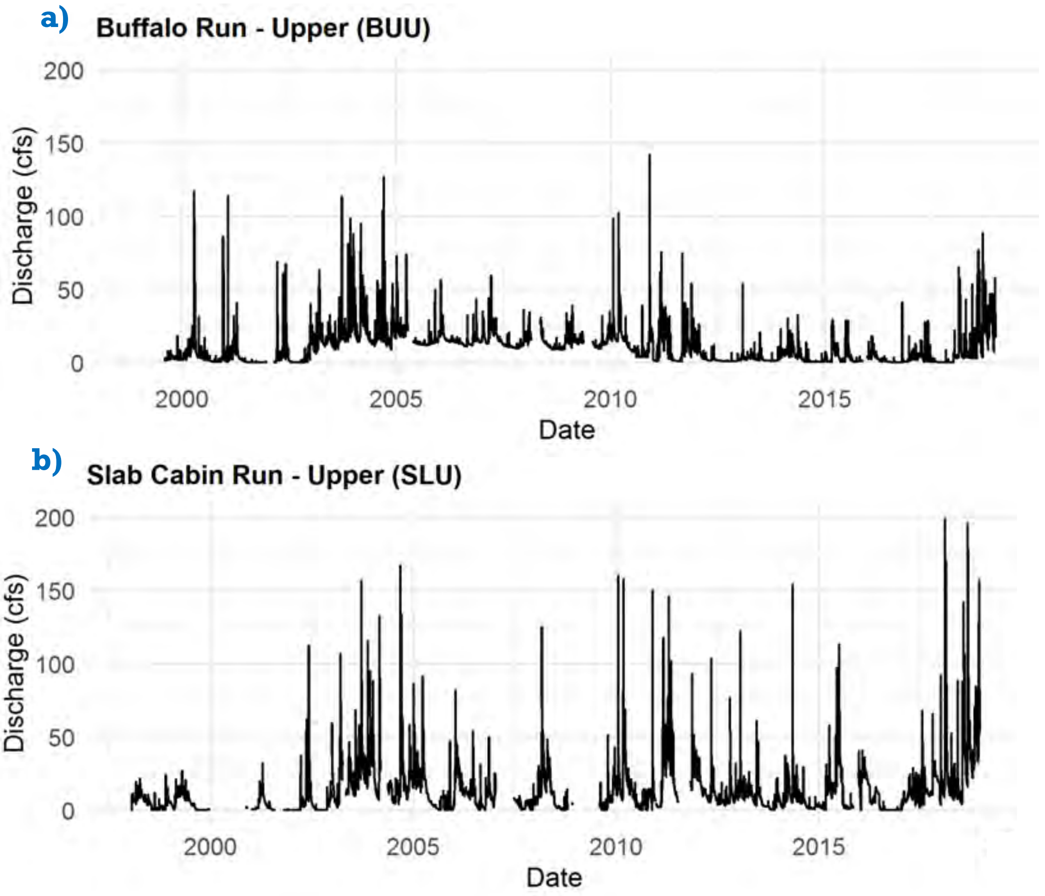


Fig. 14 Discharge of (a) Buffalo Run—Upper and (b) Slab Cabin Run– Upper

Groundwater Levels

Groundwater data has only been collected for the last 20 years, so comparison of historic and recent records could not be completed. Figure 15 depicts groundwater levels for USGS wells CE 686 and CE 118 since 2001 and the WRMP well in Fillmore since 2004. The data indicate no trend in groundwater levels rising or falling over the last 15 to 20 years. Typical seasonal variation can be seen at all three locations, with wetter years causing greater increases in groundwater elevations, especially in the USGS wells that are located farther away from streams and thus

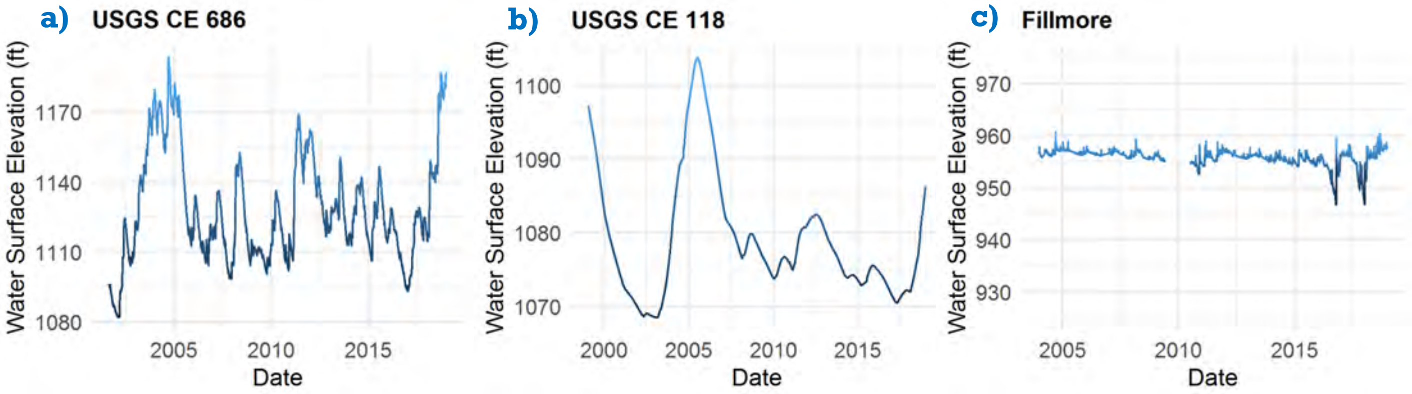


Fig. 15 Groundwater surface elevation for (a) USGS CE 686 (b) USGS CE 118 and (c) the WRMP's Fillmore well.

have greater water level fluctuations. Geologic differences between the locations create variability in how quickly groundwater levels change, with the CE 118 well responding on a more seasonal basis due to a greater depth to water through a thick soil causing longer groundwater recharge infiltration times.

Why Precipitation Trends may not Match Hydrologic Trends

While days with precipitation at or above one inch may be increasing in the Spring Creek Watershed, particularly in the last 15 to 20 years, average stream discharge and baseflow rates, peak flow events, low flow events and flashiness of the main stem of Spring Creek remain similar compared to historic data and do not indicate any significant increasing trend. Groundwater levels also have remained relatively stable. Some of the smaller tributaries in the watershed do indicate potential increases in flashiness, but again no major trends in average discharge or baseflow rates. There are a number of factors other than precipitation that impact a watershed's hydrology. In fact, one study found that across 390 watersheds in the United States, 99th percentile precipitation only resulted in 99th percentile flow 36 percent of the time (Ivancic & Shaw, 2015).

The major factors that determine how a stream will respond to a precipitation event include basin size, time of year, snowpack and antecedent soil moisture, urban development and stormwater infrastructure. Small basins are much more susceptible to the influence of surface runoff than larger basins. A study looking at over 1000 large watersheds across the United States and Europe found no increases in major flood occurrences over the last 80 years, which is consistent with the trends of the Spring Creek watershed (Hodgkins et al. 2017). Besides basin size, certain times of year are more likely to produce floods than others. Typically, during the driest, warmest months of the year, floods are less likely to occur (Hodgkins & Dudley, 2013). During dry conditions in the growing season, evapotranspiration rates are highest and soil moisture is lowest, so more water will be taken up by plants, evaporated into the atmosphere or adsorbed to the soil than during cooler months of the year. When snowpack is present and soil moisture levels are highest, flooding is much more likely to occur after a precipitation event as the ground may be frozen and does not infiltrate significant volumes of water. Floods do occur during summer months, however sequences of precipitation events rather than singular events are much more likely to produce larger floods. Sequences of precipitation events builds up soil moisture to the point of saturation, which will increase surface runoff rather than infiltration. As previously discussed, urban infrastructure can greatly increase the risk of flooding. However, stormwater infrastructure


Fig. 16 Flooding during winter months is more common after rain events (USGS)

in urban and suburban areas can retain water, control flow rates and paths, and increase infiltration rates, in turn, influencing the way surface runoff impacts streams.

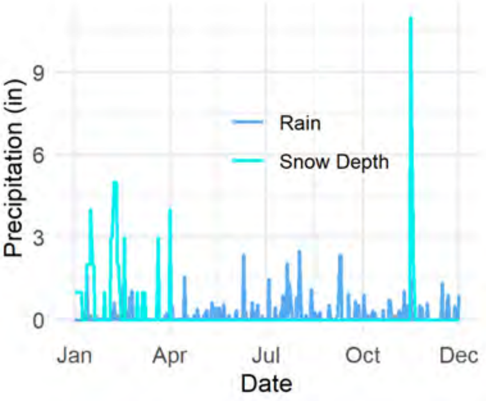


Fig. 17 Precipitation and snow depth for 2018 (source: PSU Weather Station)

2018: A Hydrologic Extreme

Precipitation

2018 was the wettest year on record for State College, PA and many location across the United States. The Weather Station at the Pennsylvania State University in State College recorded 63.75 inches of combined precipitation and snowmelt over the course of the year. In addition to multiple storm events and steady rain throughout the entire year, the watershed also received a large snow event in November that quickly melted into runoff. This heavy amount of precipitation and runoff kept stream and groundwater levels well above average levels. The National Weather service map of deviation from normal precipitation indicates that 2018 in much of Pennsylvania received 20+ inches of precipitation above average.

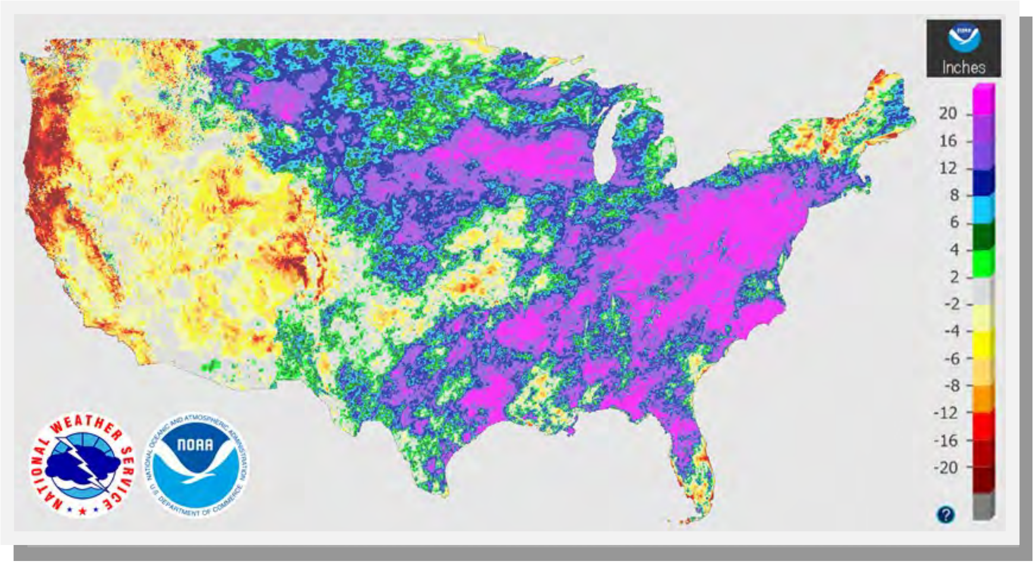


Fig. 18 Departure from normal precipitation in 2018 (Source: NWS)

Eight states had their wettest year on record and as a nation, 2018 was the third wettest year on record. Hurricane Florence contributed to this nationwide total in September when it pushed many locations in North Carolina and southern Appalachia to over 100 inches of annual precipitation for the first time.

Table 1 outlines precipitation for each month in 2018 for Pennsylvania. The state had record setting months in both February and July as well as a record setting summer with 18.78 inches of precipitation, one inch greater than the previous record in 1928.

Table 1 Monthly precipitation totals for Pennsylvania in 2018 (Source: NOAA)

Month	Statewide Precipitation (inches)	Rank (Wettest between 1895-2018)
January	3.28	50
February	5.4	1
March	3.12	73
April	4.17	37
May	5.48	23
June	5.32	20
July	7.53	1
August	6.26	9
September	8.88	2
October	4.28	36
November	6.06	4
December	4.26	22
Annual	64.04	1

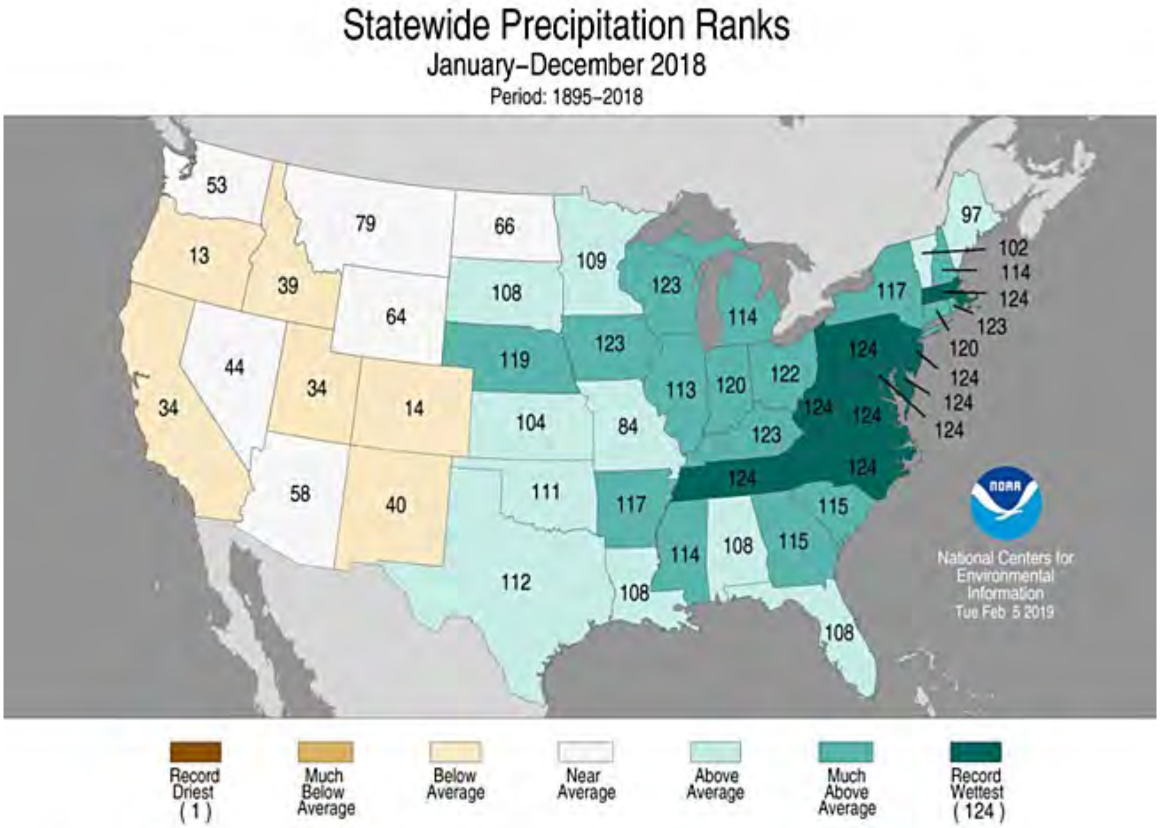


Fig. 19 Precipitation ranks for all states in 2018. TN, NC, VA, WV, PA, MD, DE, NJ all had their wettest years on record.

The Northeast region as a whole had its 8th wettest summer on record. Figure 19 indicates the ranks of each state across the nation in 2018.

In order to understand how extremes in precipitation can compare in hydrologic expression, the seventh driest year on record for Pennsylvania (2001), was compared to 2018. Figure 20 shows the differences between cumulative annual precipitation of those years in State College, PA. In 2018, the location received over 30 more inches of precipitation than 2001.

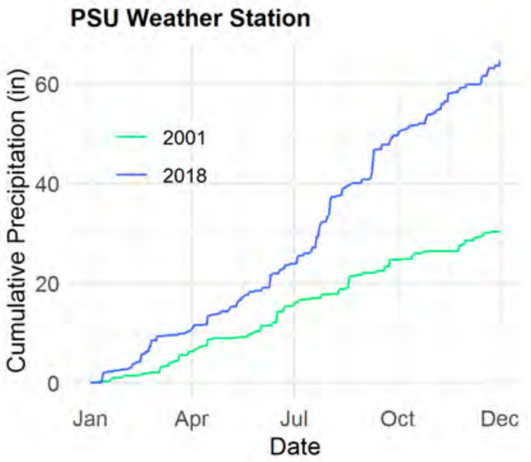


Fig. 20 Cumulative annual precipitation for 2001 and 2018 in State College, PA.

Stream Discharge Rates

The high levels of precipitation during 2018 were reflected in stream discharge rates well above median and 2001 levels throughout most of the year. Figure 21 compares these rates for the main stem of Spring Creek and two of its tributaries, Slab Cabin Run and Cedar Run. During peak flows, 2018 discharge rates were close to 10x the discharge rates of 2001. The flows were also substantially more flashy than 2001, with many more peak flow events in the main steam of Spring Creek and its tributaries.

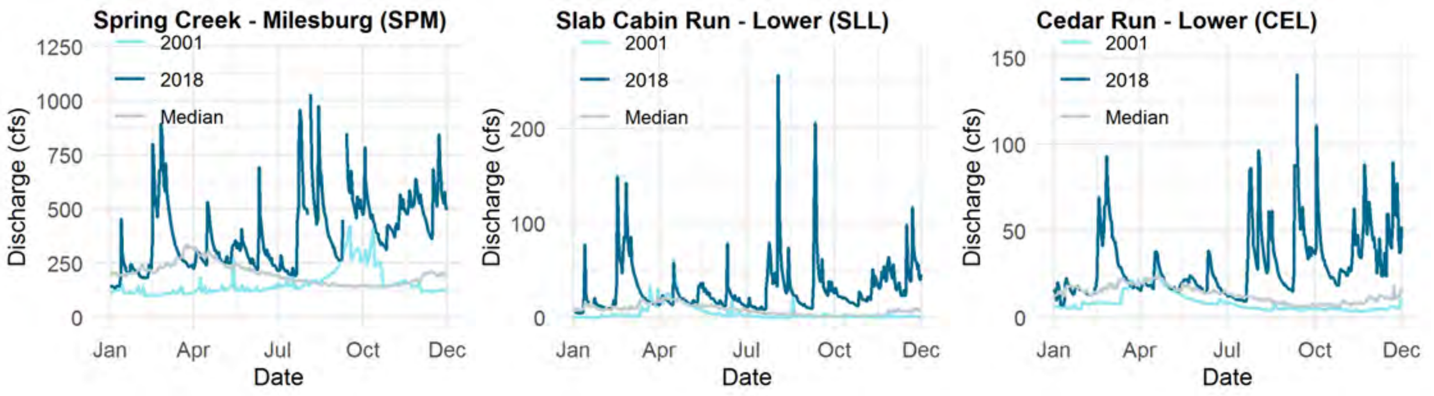


Fig. 21 2018, 2001 and median stream discharge rates for (a) Spring Creek at Milesburg (b) Lower Slab Cabin Run and (c) Lower Cedar Run

Groundwater Levels and Groundwater Ridging

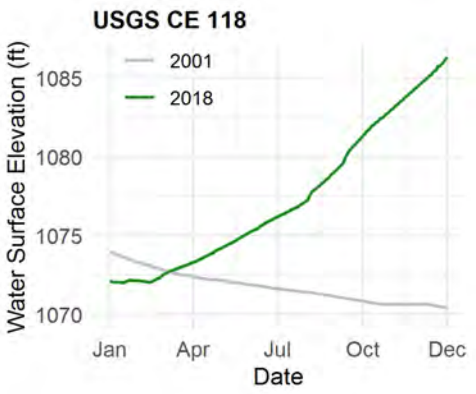


Fig. 22 Water surface elevation at the USGS CE 118 groundwater well in 2001 and 2018

Similar to stream discharge rates, groundwater levels were much higher than historic and 2001 levels. The groundwater surface elevation at the USGS CE 118 well was almost 20 feet higher than levels in 2001 by the end of the year (Figure 22). Groundwater levels were so high in 2018 that certain areas within the Big Hollow sub-basin within the Spring Creek Watershed exhibited groundwater ridging, a phenomenon when groundwater reaches the ground surface, forms pools and contributes to runoff (Figure 24). The Big Hollow Basin is an underdrained stream with no perennial flow and the most common source of surface flow in the basin results from surface runoff that drains from upslope regions, thus groundwater-derived surface flow is extremely rare. Data from a Pennsylvania State University Gage in the basin indicated that of the total duration of flow measured by that gage over a 12 year period, 44% of that flow time was recorded in 2018. Figure 23 shows provisional data for water surface elevation at the area that ridging occurred. (OPP-WRP-SR-BHGR-2019)

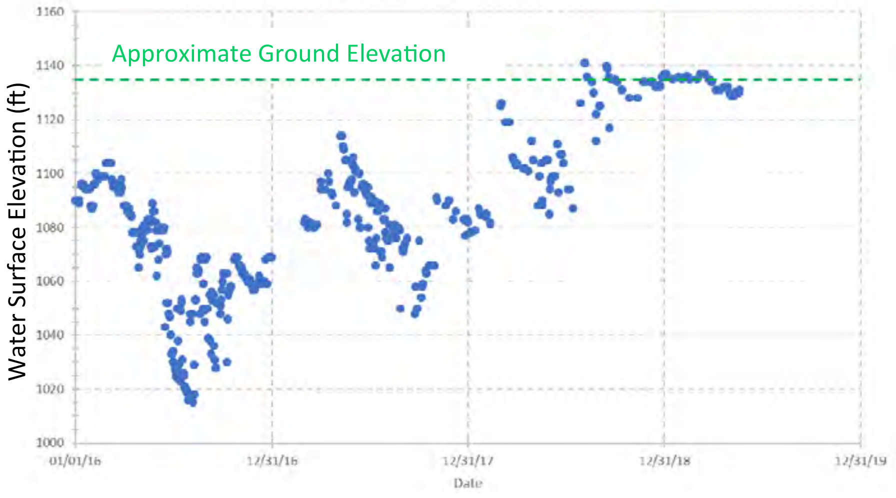


Fig. 23 Provisional 2018 water surface elevation in the Big Hollow basin (Source: PSU OPP)

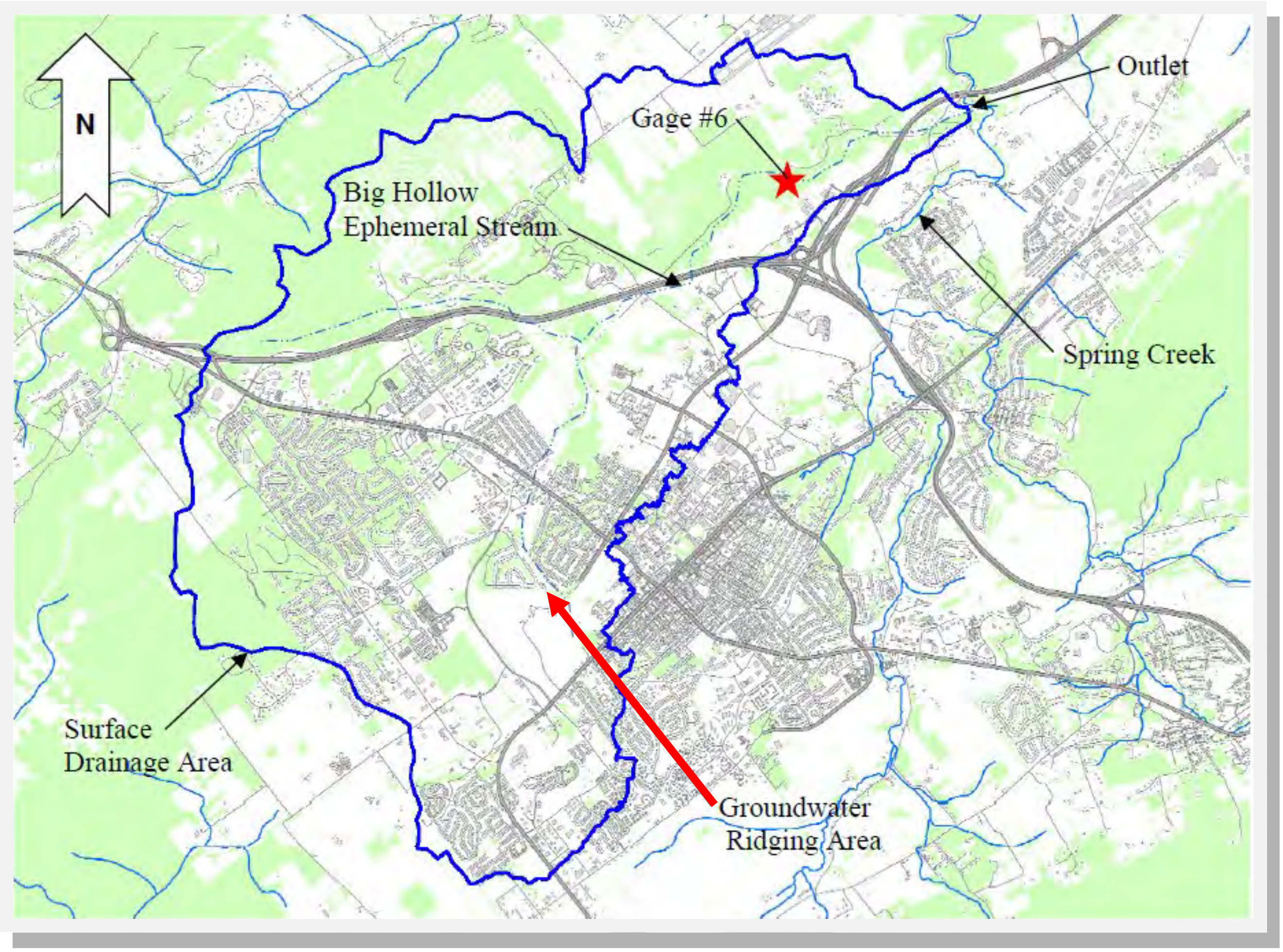


Fig. 24 The Big Hollow surface drainage area and area where groundwater ridging occurred in 2018 (OPP-WRP-SR-BHGR-2019)

Mitigating Impacts of Hydrologic Extremes

Stormwater Control Measures

Methods that create resilience to storm events and hydrologic extremes such as green infrastructure, reduced impervious surfaces and other types of stormwater infrastructure are a suggested adaption tool for water resources in Pennsylvania (Shortle etl al, 2015). These types of infrastructure help to reduce surface runoff and increase infiltration in areas where stormwater can be filtered or retained, thus reducing the overall impacts of storm events by lowering the overall risk of flooding through management of the stormwater flow paths and decreasing water quality impacts.

A great deal of stormwater infrastructure already exists within the Spring Creek Watershed and will continue to develop over the next decades. College, Harris, Ferguson and Patton Townships, the Borough of State College and Penn State University are all designated by the Pennsylvania Department of Environmental Protection (DEP) to implement stormwater management programs. These municipalities and the university form the MS4 Partnership (ms4partners.org). An MS4 is a municipal separate storm sewer system, which means that the stormwater system can be managed separately from sewer systems. All MS4s must meet specific goals to reduce the amount of sediment and nutrients that directly flow into streams. Permits and plans outline specific projects that will be implemented in their governing area. Some examples of stormwater control measures in the watershed include retention ponds, underground storage facilities, rain gardens and constructed wetlands.

Fig. 25 Examples of stormwater control measures and green infrastructure : (a) infiltration basin in Fox Hollow (PSU OPP), (b) rain gardens in State College (State College Borough), (c) green roof at PSU (PSU OPP)

Monitoring, Assessing and Restoring Streambanks

Another suggested adaption for Pennsylvana water resources is the monitoring, assessment and restoration of streams. Stream restoration can stabilize streambanks and channels, in turn creating habitat for wildlife and reducing erosion and its impact on water quality. In-stream and streambank infrastructure stabilize stream banks and reduce channelized flow. Riparian buffer restoration can also help to stabilize stream banks, slow the flow of surface runoff into streams as well as provide shade, food and habitat for many species of wildlife. A number of other government and NGO partners work together to implement stream and riparian buffer restoration projects in the Spring Creek Watershed.

Fig. 26 Examples of stream restoration projects in the Spring Creek Watershed (a) in-stream restoration project in Spring Creek (Spring Creek Chapter of TU) ,(b) riparian buffer restoration on Slab Cabin Run (ClearWater Conservancy)

Conclusions

Hydrologic extremes can cause biological, physical and economic damage to a watershed and its inhabitants. While data at the USGS gages in the Spring Creek Watershed do not indicate any major changes in hydrology over the last 50 years, trends in precipitation may be on the rise. Many factors, including time of year, soil moisture levels, urban development and basin size all affect how a stream responds to precipitation, which was observed in increased flashiness in some smaller tributaries but not the main stem of Spring Creek. 2018 was an example year of a hydrologic extreme in the Spring Creek Watershed, Pennsylvania and across the Northeast. Record precipitation resulted in large increases in baseflow, peak flows and groundwater levels. Stream discharge rates were at times 10x higher than the previous driest year in WRMP records. Groundwater levels in certain areas increased upwards of 15 feet throughout the year and resulted in groundwater ridging in Big Hollow, which is rarely observed. Continued monitoring efforts will help determine trends in the coming years for stream and groundwater levels and will be critical to long-term water resource management planning including stream restoration and stormwater engineering.

WRMP Monitoring Methods & 2018 Data

Fig. 27 (a) The WRMP gaging station at Logan Branch - Lower (b) Downloading temperature data from Linden Hall spring

Continuous Water Temperature Monitoring

Water temperature is measured continuously at 18 stream stations (Figure 16) and 8 spring stations (Figure 17) with submersible Onset Computer Corporation Optic Stowaway Tid-Bitv2 data loggers. Eleven of these stream temperature monitoring stations are co-located with WRMP gaging stations and three are co-located with existing USGS gaging stations on Spring Creek. Temperature is recorded hourly at all stations except for the Thompson Run and Middle Walnut Run station. Temperature is recorded every five minutes at these stations because past data have shown that temperatures can fluctuate rapidly at these locations during storm events.

Temperature loggers are installed based on the EPA's Best Practices for Continuous Monitoring of Temperature and Flow in Wadeable Streams. Loggers are housed in PVC units and anchored to the stream bed or other large object such as a rock, tree root or cement wall. Data is downloaded from the loggers every four weeks. Loggers are additionally checked during low flow periods to ensure they are fully submersed in the stream or spring.

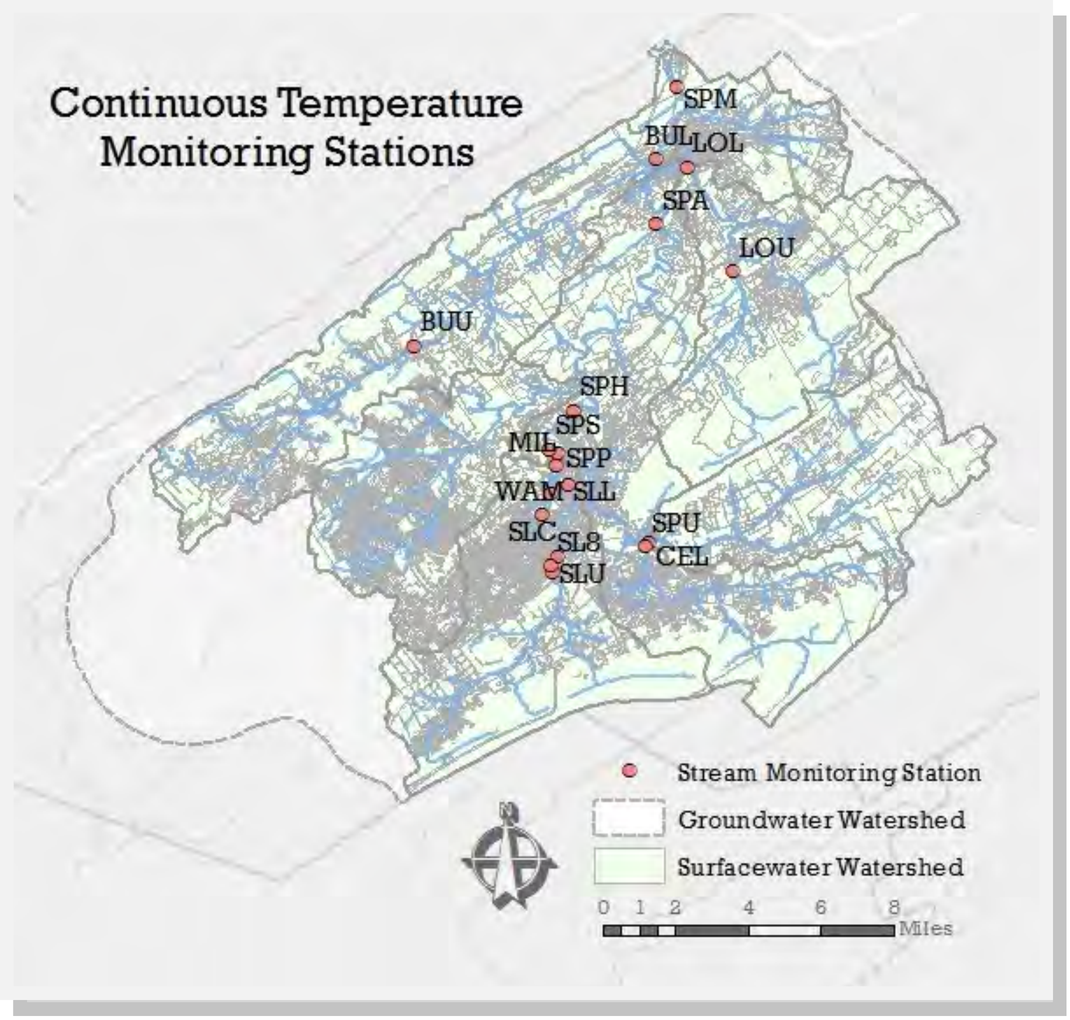
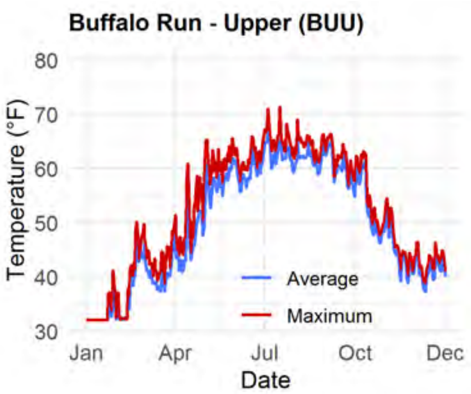
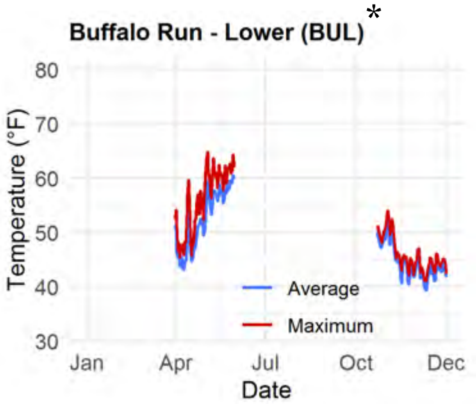
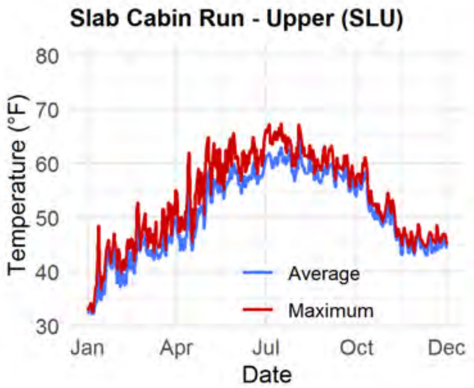


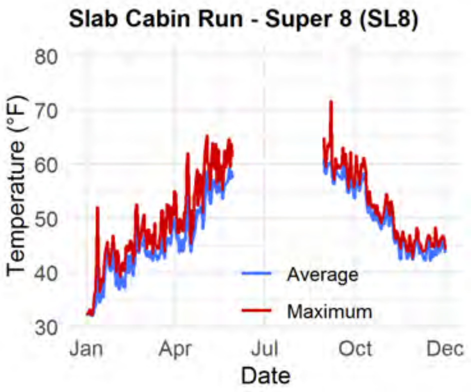
Fig. 28 Continuous stream temperature monitoring stations managed by the WRMP

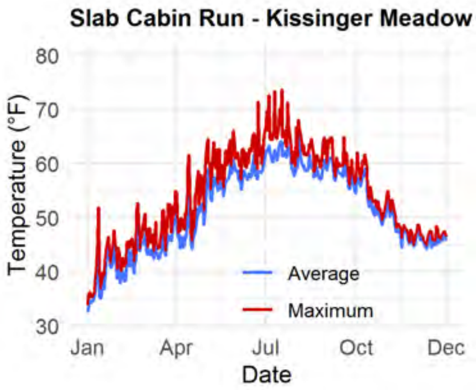
2018 Stream Temperature Data

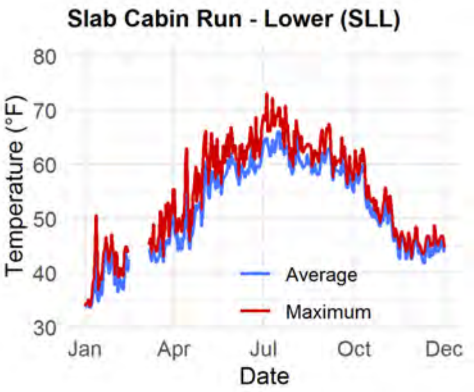

Buffalo Run - Upper (BUU)

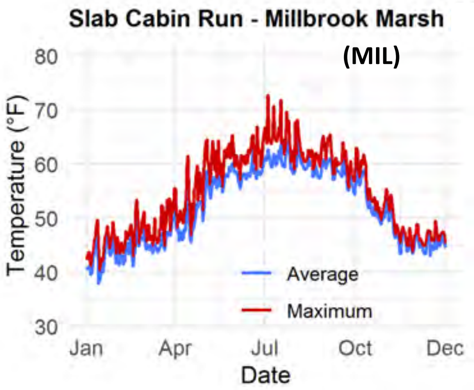

Buffalo Run - Lower (BUL)*

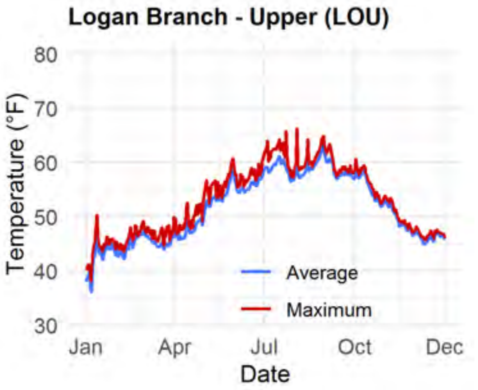

Slab Cabin Run - Upper (SLU)

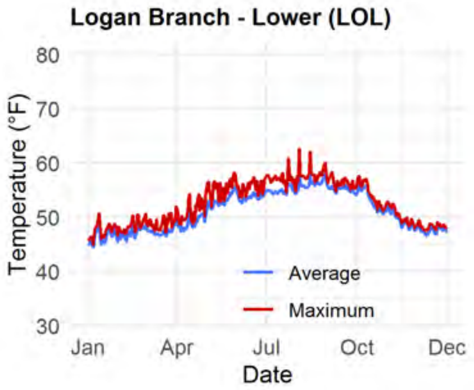

Slab Cabin Run - Super 8 (SL8)

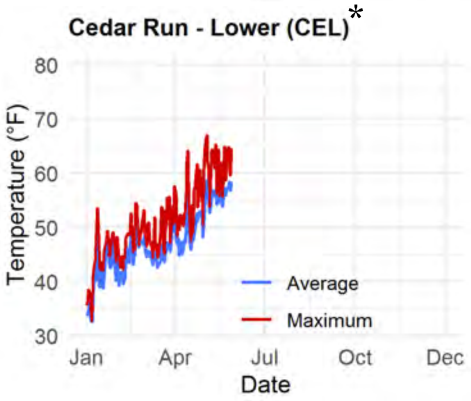

Slab Cabin Run - Kissinger Meadow

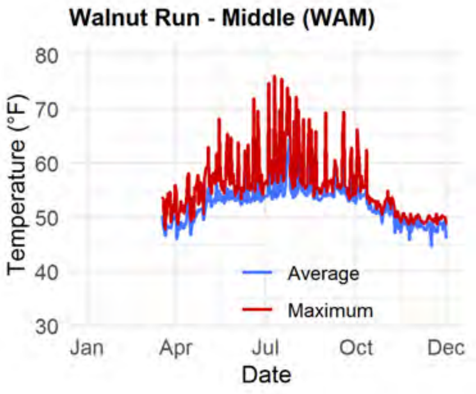

Slab Cabin Run - Lower (SLL)

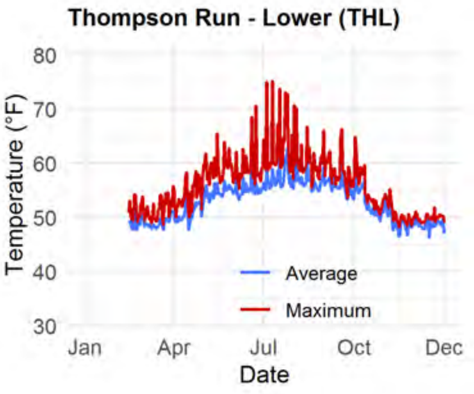

Slab Cabin Run - Millbrook Marsh (MIL)


Logan Branch - Upper (LOU)

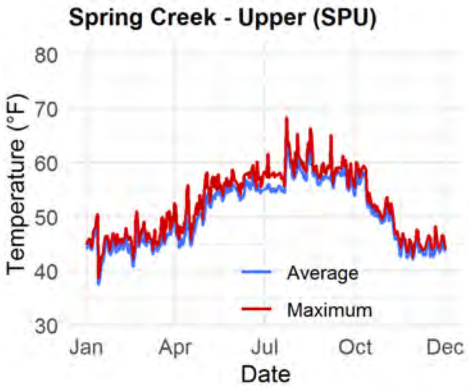

Logan Branch - Lower (LOL)

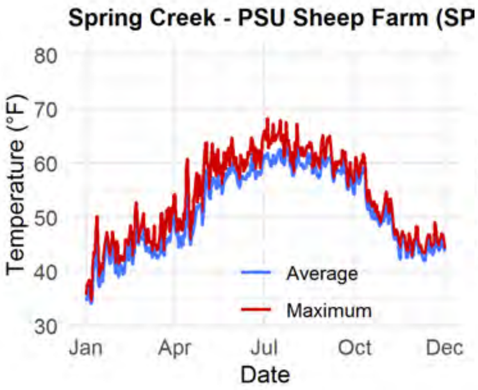

Cedar Run - Lower (CEL)*

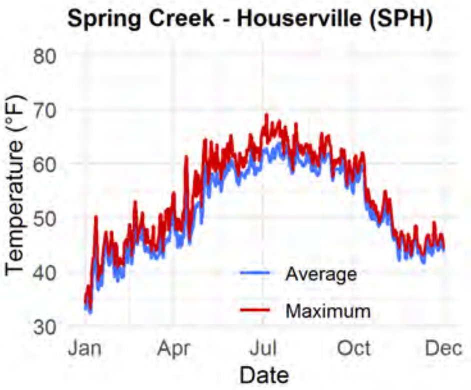

Walnut Run - Middle (WAM)

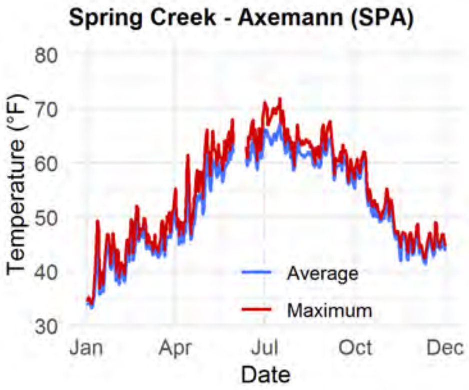

Thompson Run - Lower (THL)

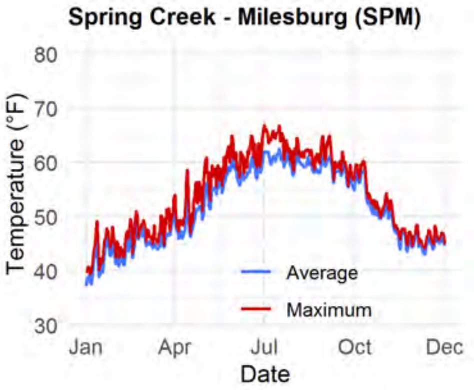
* Large flood events removed multiple loggers at these monitoring stations in 2018





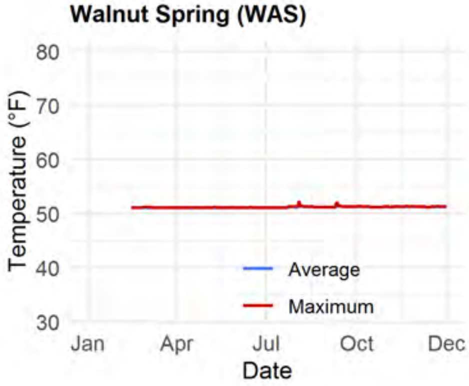


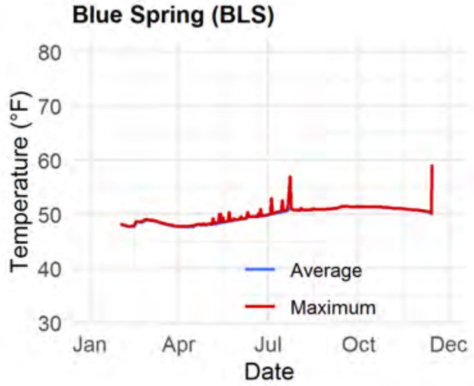


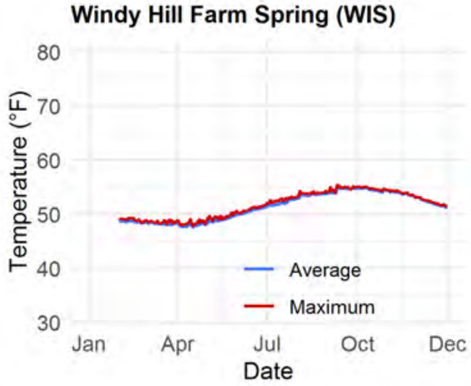


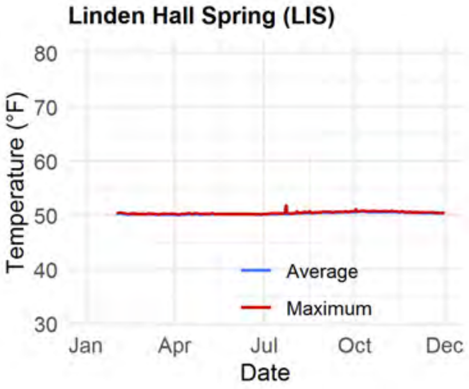
Stream temperatures generally remained well below the lethal threshold for brown trout (75.2°F) except for very rapid increases in the middle Walnut Run (WAM) and lower Thompson Run (THL) stream reaches. These stations are surrounded by a great deal of urban development and experience many rapid peaks in summer stream temperatures due to large amounts of stormwater runoff.

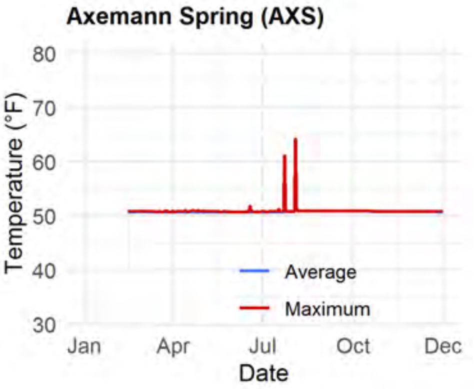
2018 Spring Temperature Data

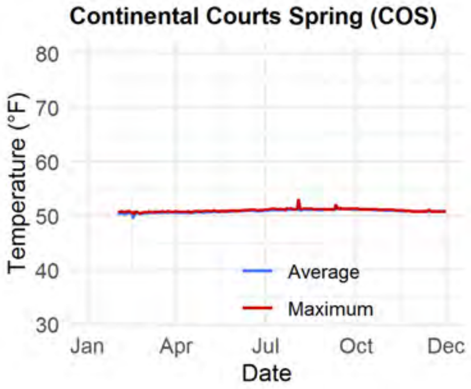


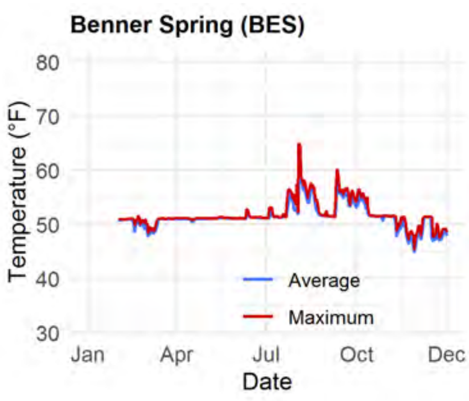


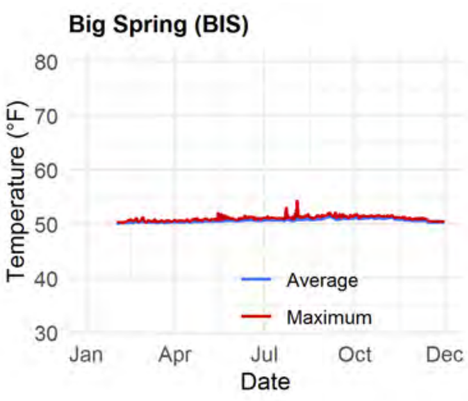












The WRMP began monitoring spring temperature in 2018. The data reveal that most springs maintained steady temperatures around the average temperature of groundwater (approximately 50°F). Some springs did experience peaks or drops in temperature when surface runoff mixed with the spring water around the temperature logger. Additionally, the Windy Hill Spring (WIS) data indicate that temperature at that location follows a seasonal pattern, which could mean that the location is a seep that is impacted by seasonal fluctuations in air temperatures.

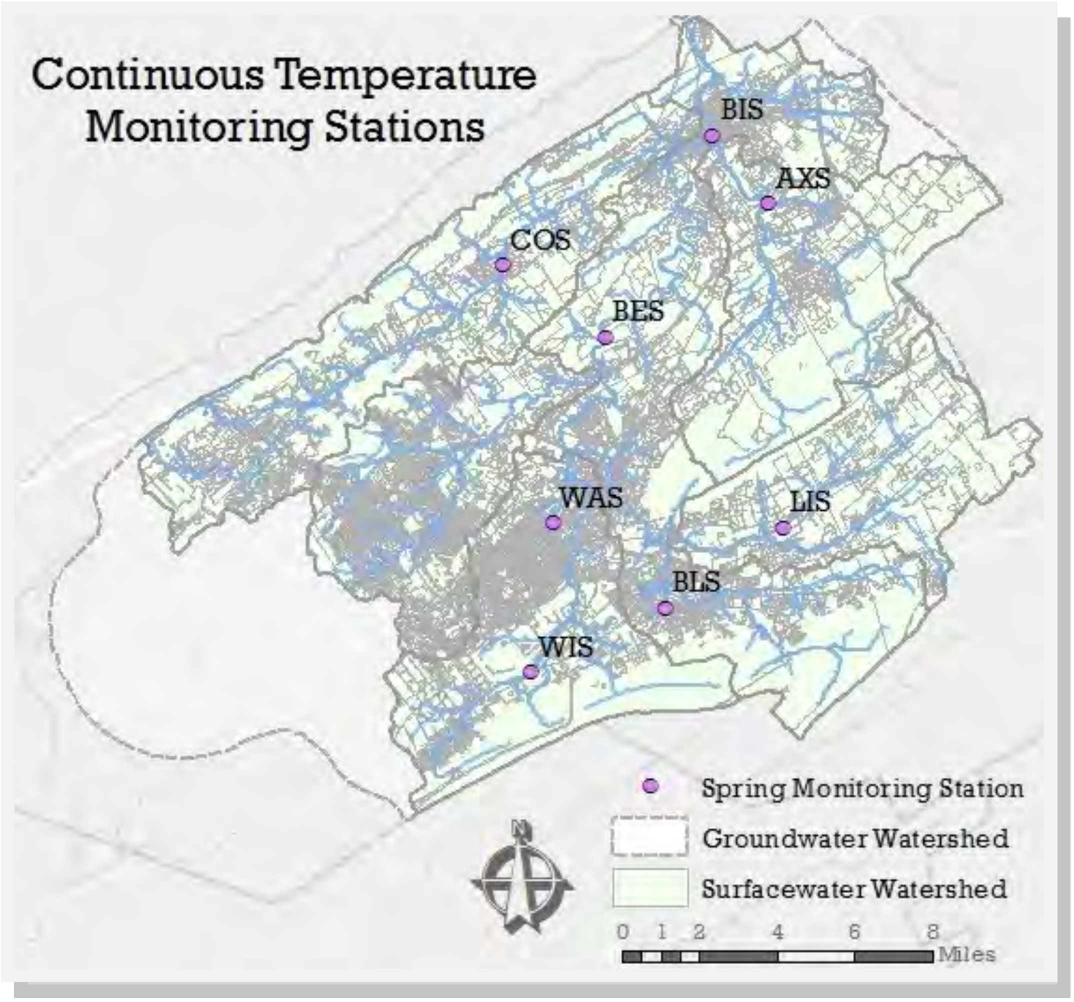


Fig. 29 Continuous spring temperature monitoring stations managed by the WRMP

Continuous Stream Stage and Discharge Monitoring

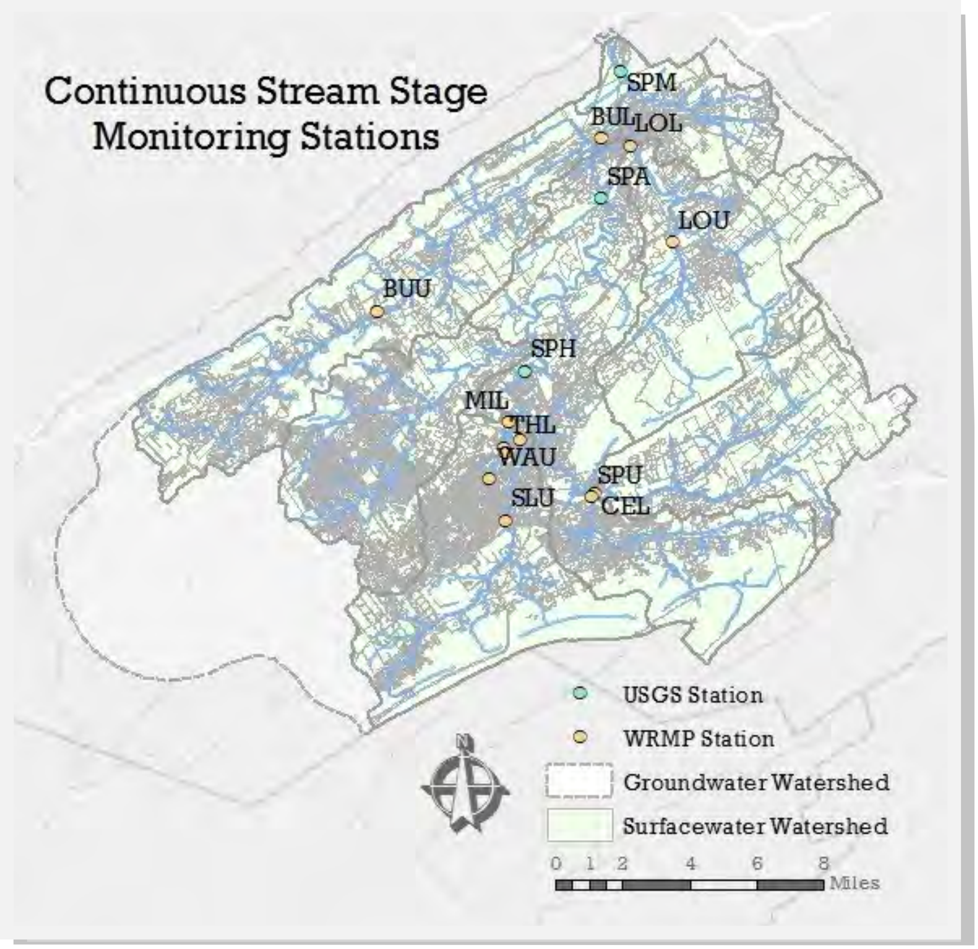


Fig. 30 USGS and WRMP stream stage monitoring stations

The WRMP operates 12 stream monitoring stations with one site on the main stem of Spring Creek and 11 tributary sites located throughout the stream's five major sub-basins. The sites are representative of land use practices across the watershed. There are three USGS-operated stream gages on the main stem of Spring Creek. Stations are equipped with continuously water level, or stage, loggers.

Stream stage is digitally recorded every 30 minutes for all gaging stations except Lower Thompson Run and two stations on Walnut Run, where stream stage is recorded every 5 minutes due to rapid fluctuations in stage level during storm events. Rating curves are developed and maintained at each of these sites to convert stream stage into discharge rates.

2018 discharge rates began close to median rates then steadily increased throughout the year due to high precipitation levels. Many storms resulted in peak flows at all sites. However sites in more urban areas (THL, WAU) experienced pronounced peak events and falls rather than steady increases in baseflow.

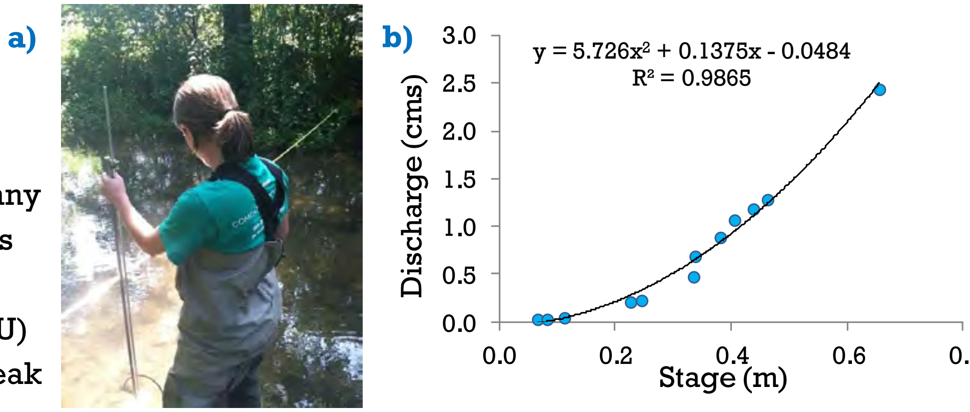
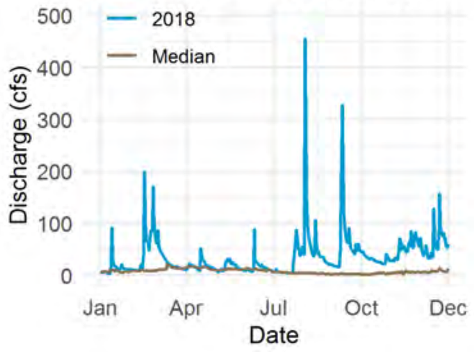


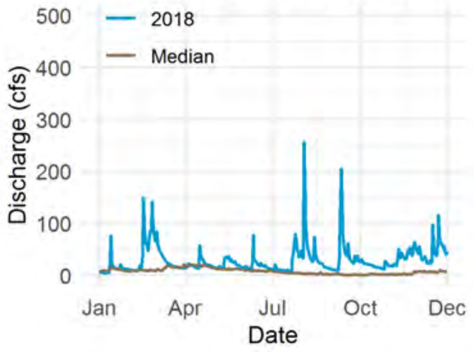
Fig. 31 (a) Manual discharge measurement being taken to develop a (b) rating curve at Slab Cabin Run - Upper (SLU)

2018 Discharge Data

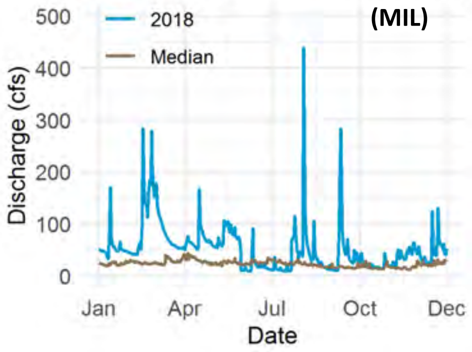
Slab Cabin Run - Upper (SLU)



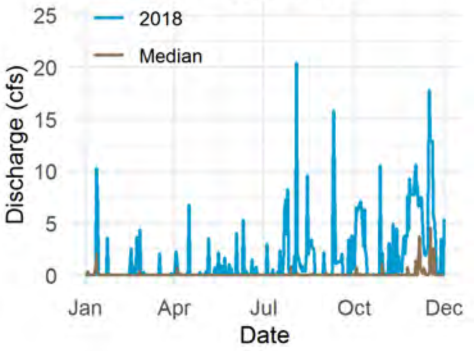
Slab Cabin Run - Lower (SLL)



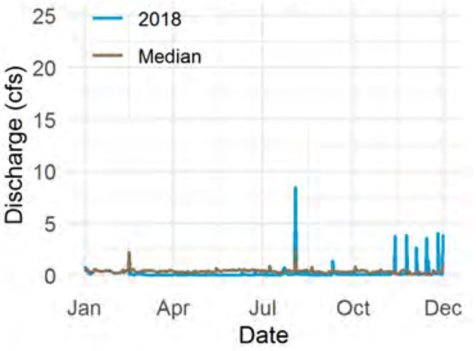
Slab Cabin Run - Millbrook Marsh (MIL)



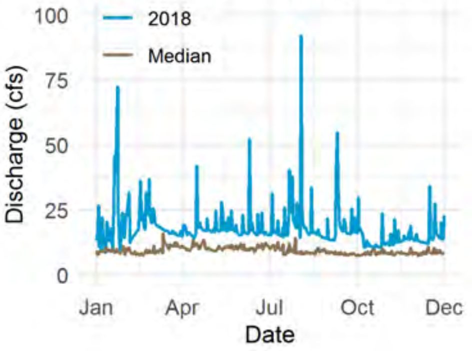
Walnut Run - Upper (WAU)



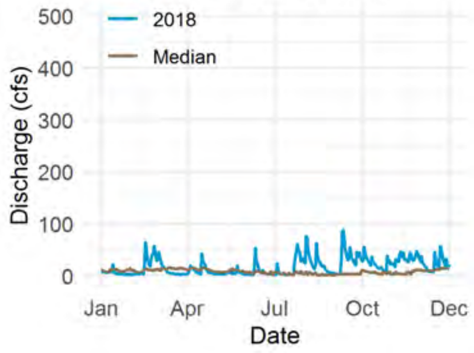
Walnut Run - Lower (WAL)



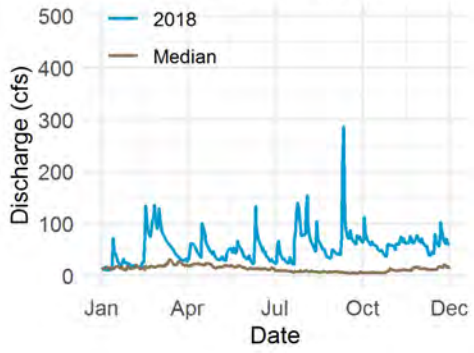
Thompson Run - Lower (THL)



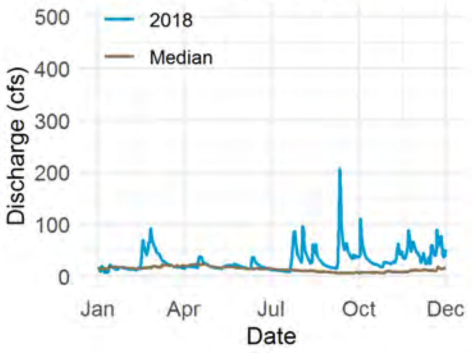
Buffalo Run - Upper (BUU)



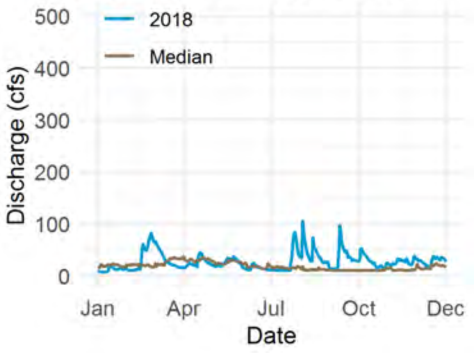
Buffalo Run - Lower (BUL)



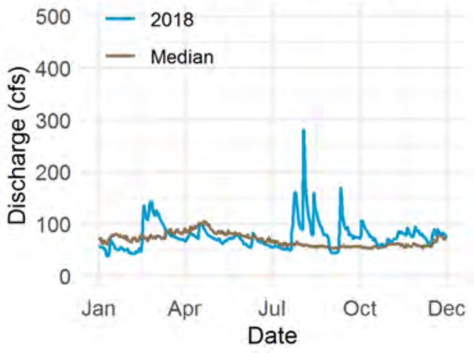
Cedar Run - Lower (CEL)



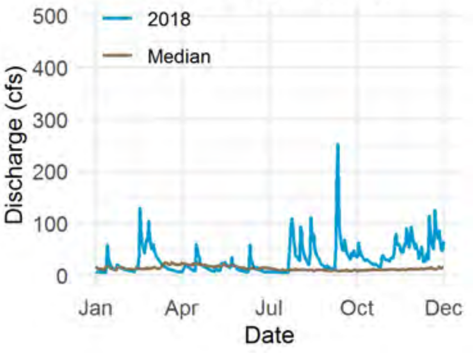
Logan Branch - Upper (LOU)



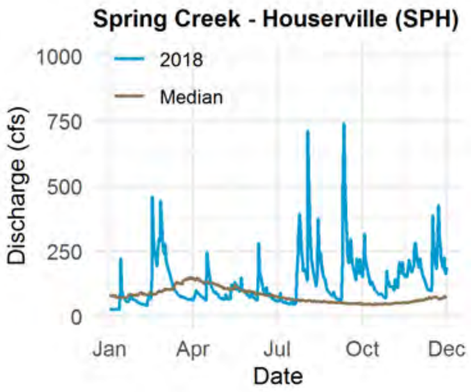
Logan Branch - Lower (LOL)

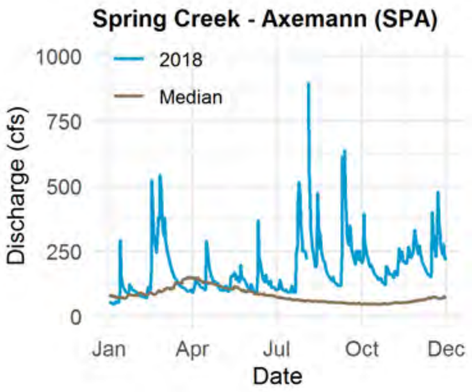


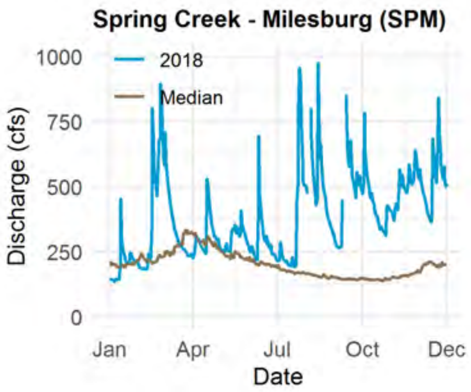
Spring Creek - Upper (SPU)



2018 USGS Discharge Data







Quarterly Water Quality Sampling

WRMP staff and volunteers collect water samples from 15 stream sites and 8 springs on a quarterly basis (spring, summer, fall and winter) during baseflow conditions. The water samples are analyzed for chemical and nutrient content by the Pennsylvania Department of Environmental Protection Analytical Laboratories. Coliform analysis is conducted for spring samples by the University Area Joint Authority laboratory.

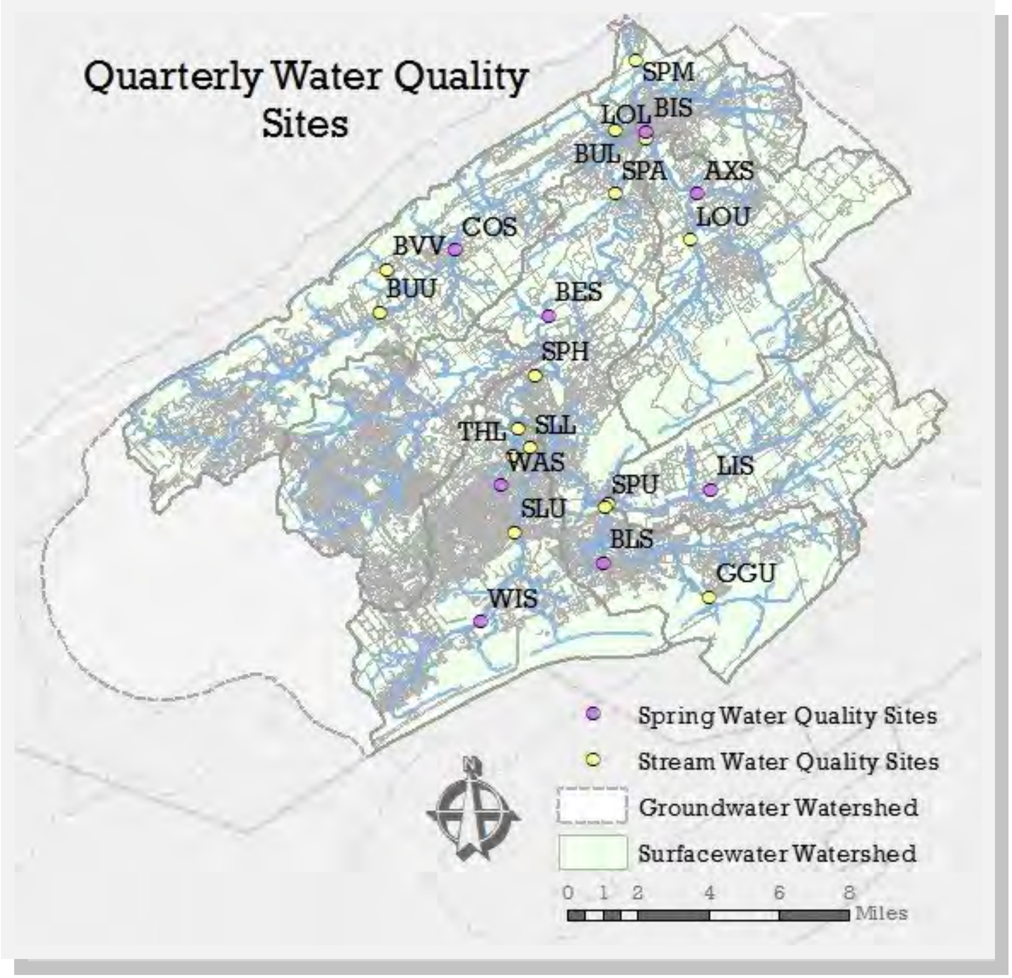
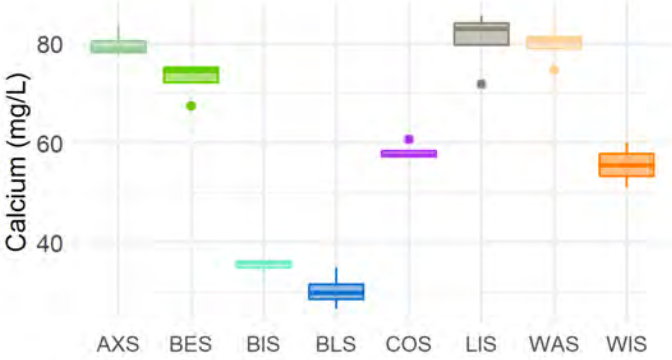


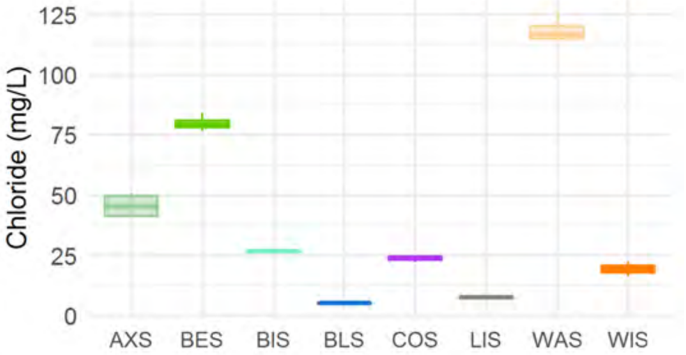
Fig. 32 Stream and spring water quality sampling locations

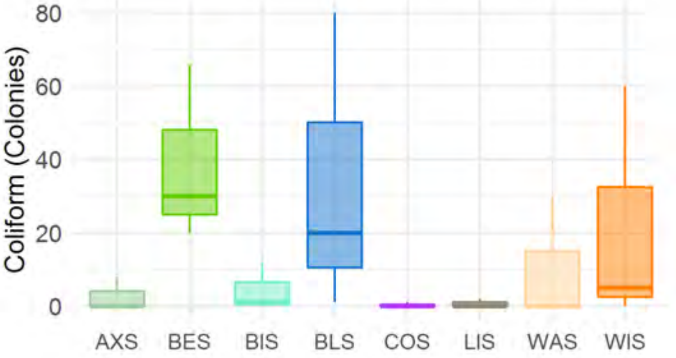
2018 data showed similar quality levels as most years except for increased chloride, sodium and conductivity levels at Thompson Run: 93.25 mg/L, 817.25 μS/cm, and 37.135 mg/L compared to 72.55 mg/L, 638 μS/cm, and 30.05 mg/L in 2016/2017. This increase is likely to due to urban runoff.

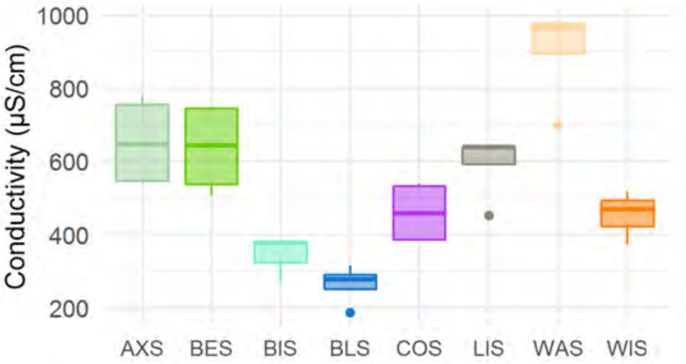
2018 Spring Water Quality Data

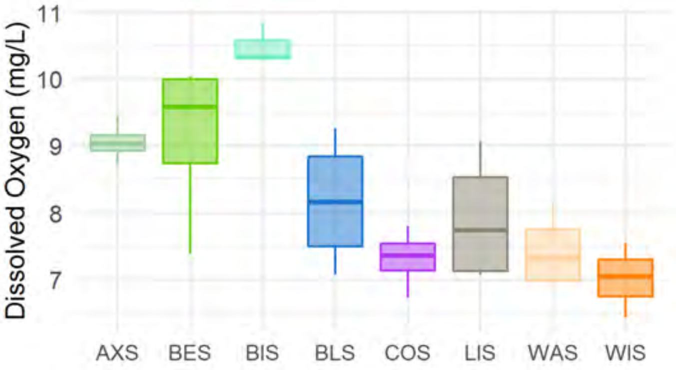
Physiochemical Parameters

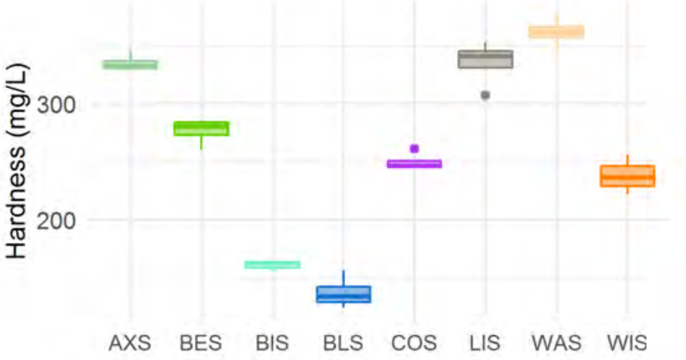


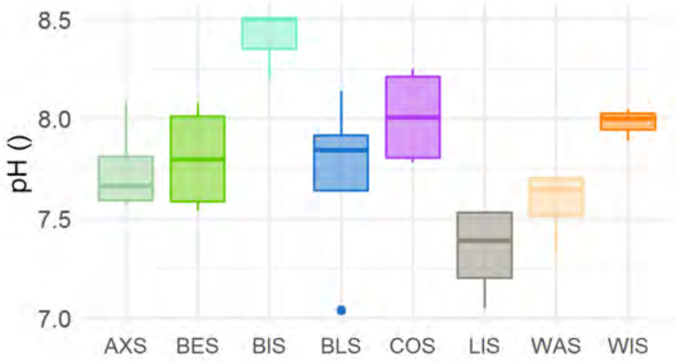


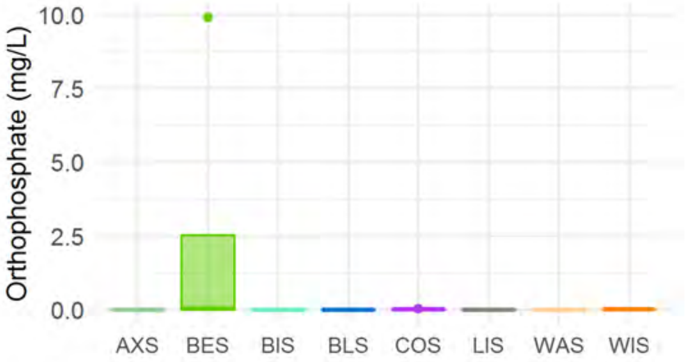


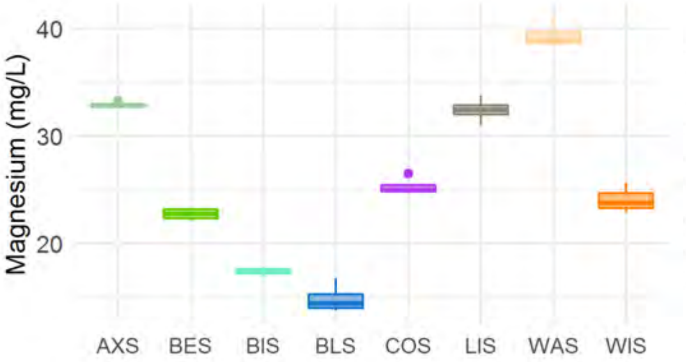


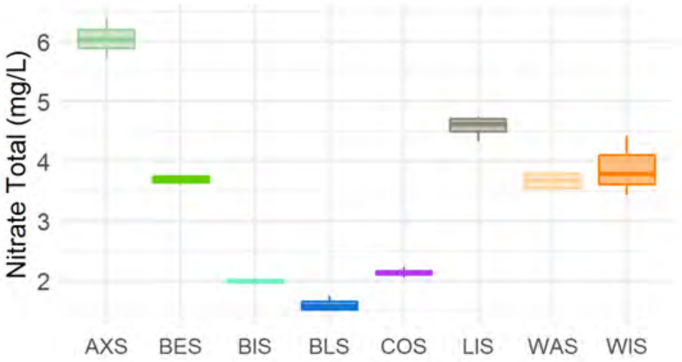


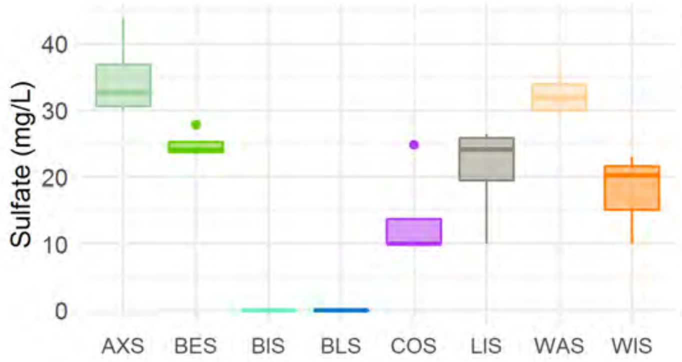


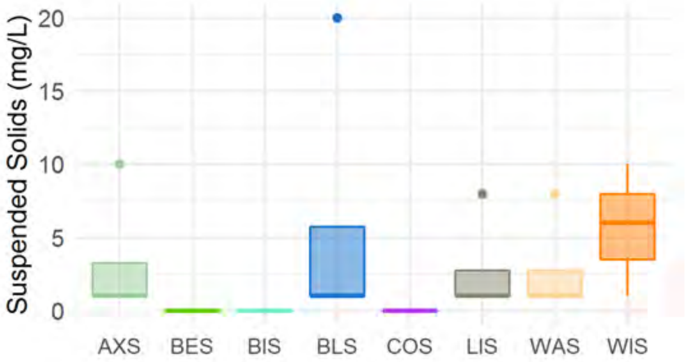


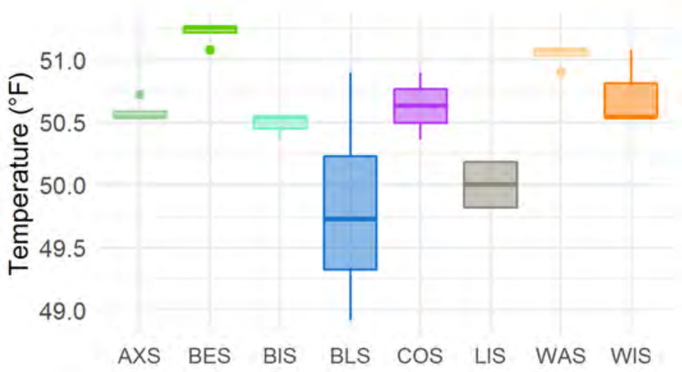


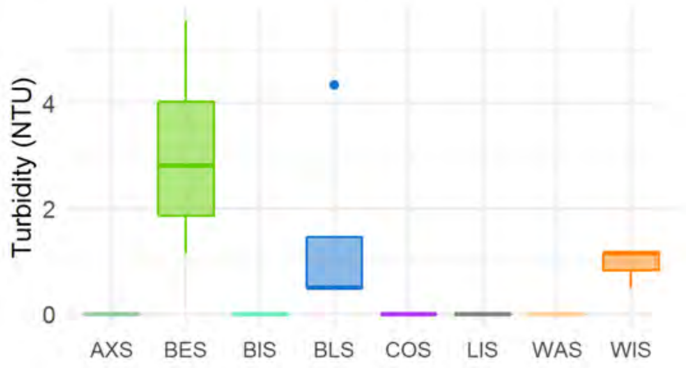








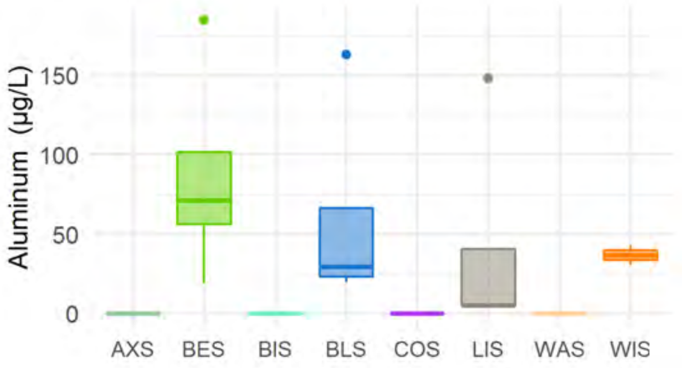


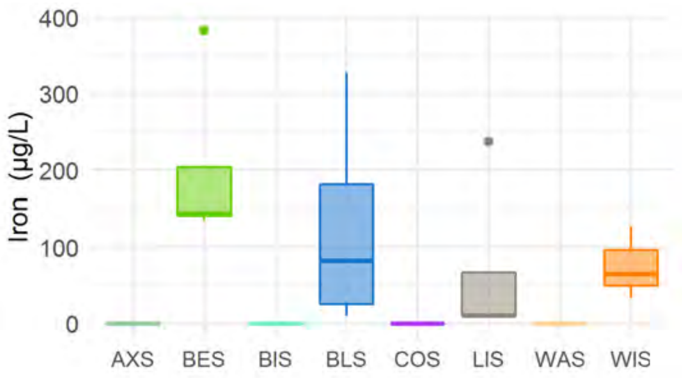


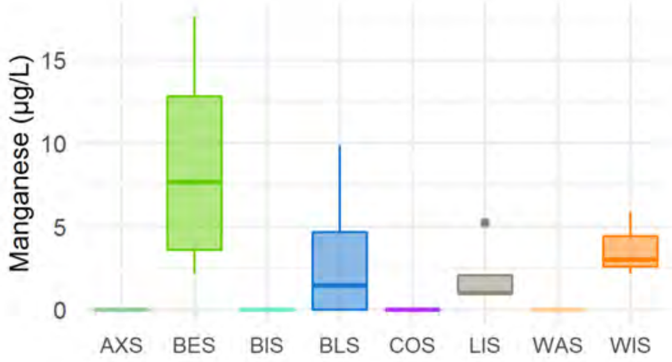
2018 Spring Water Quality Data

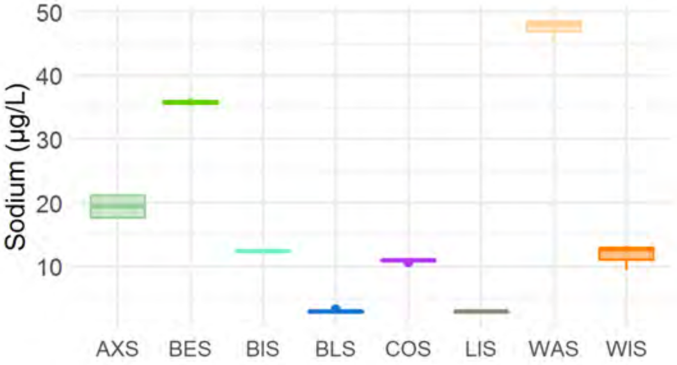
Metals—Total

Concentrations of nickel, lead, copper, chromium, cadmium and zinc were all non-detectable, so plots of these parameters are not included.



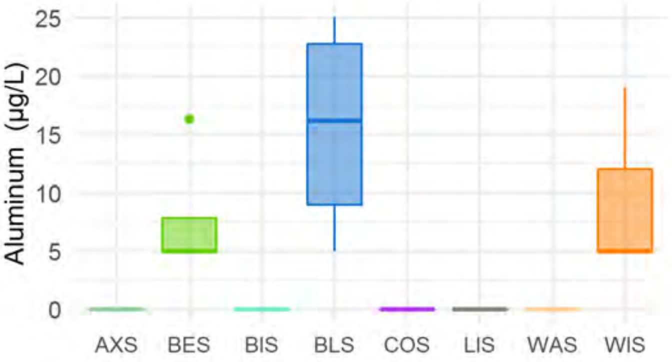


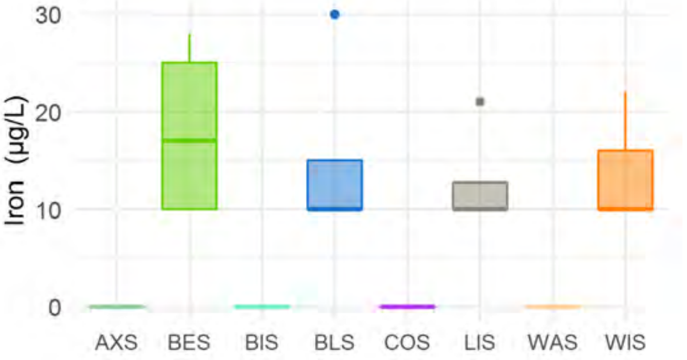


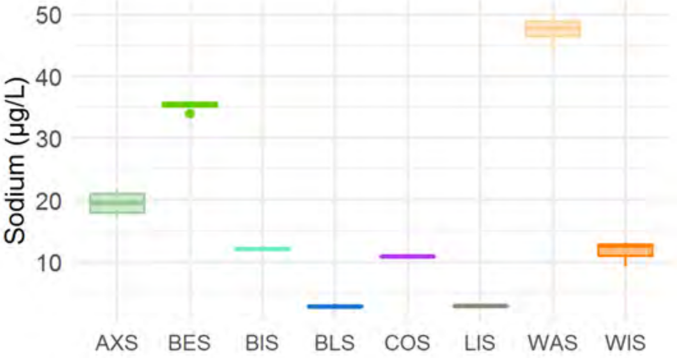


2018 Spring Water Quality Data

Metals—Dissolved

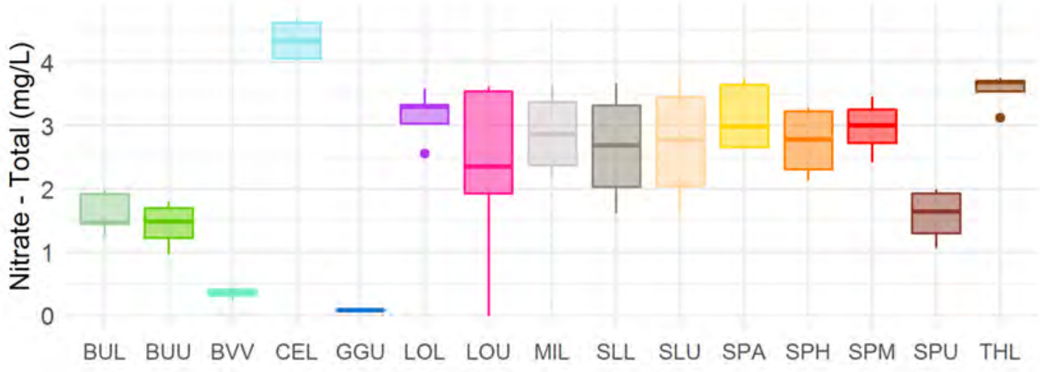


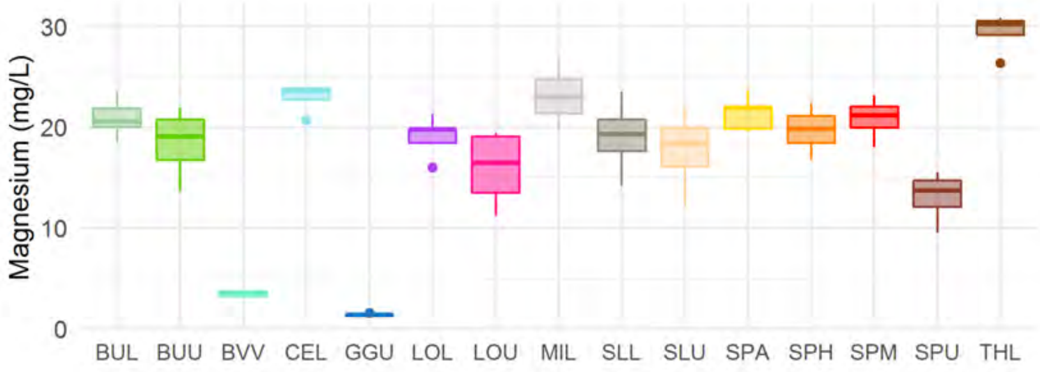


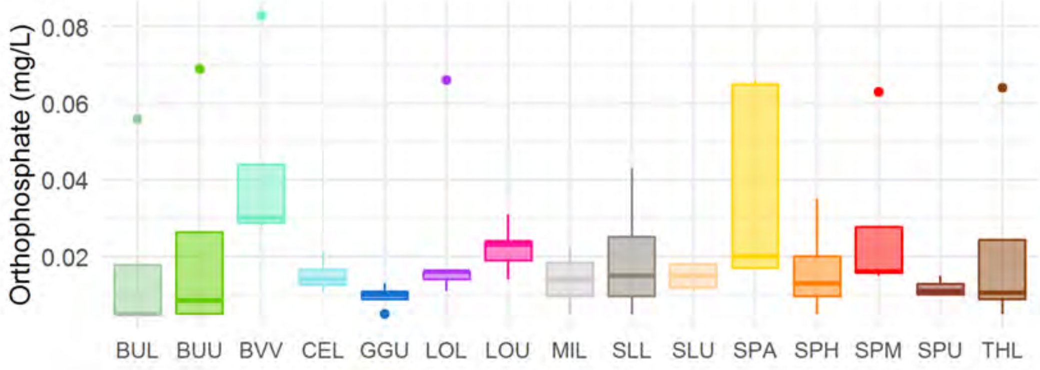


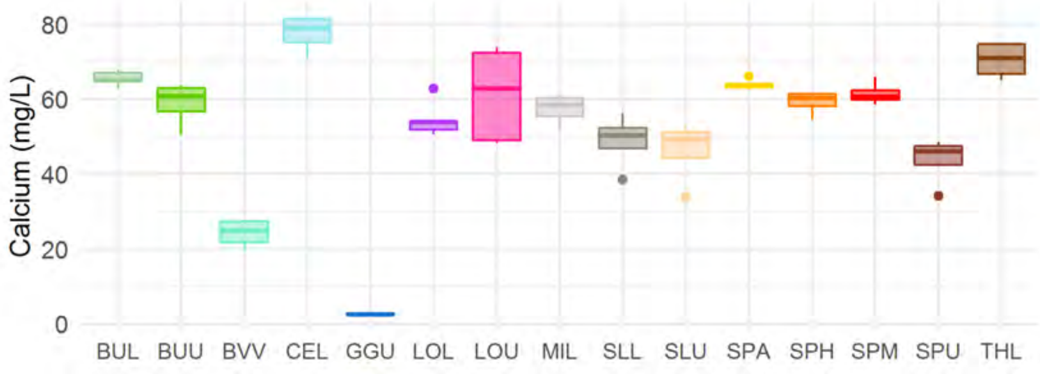
2018 Stream Water Quality Data

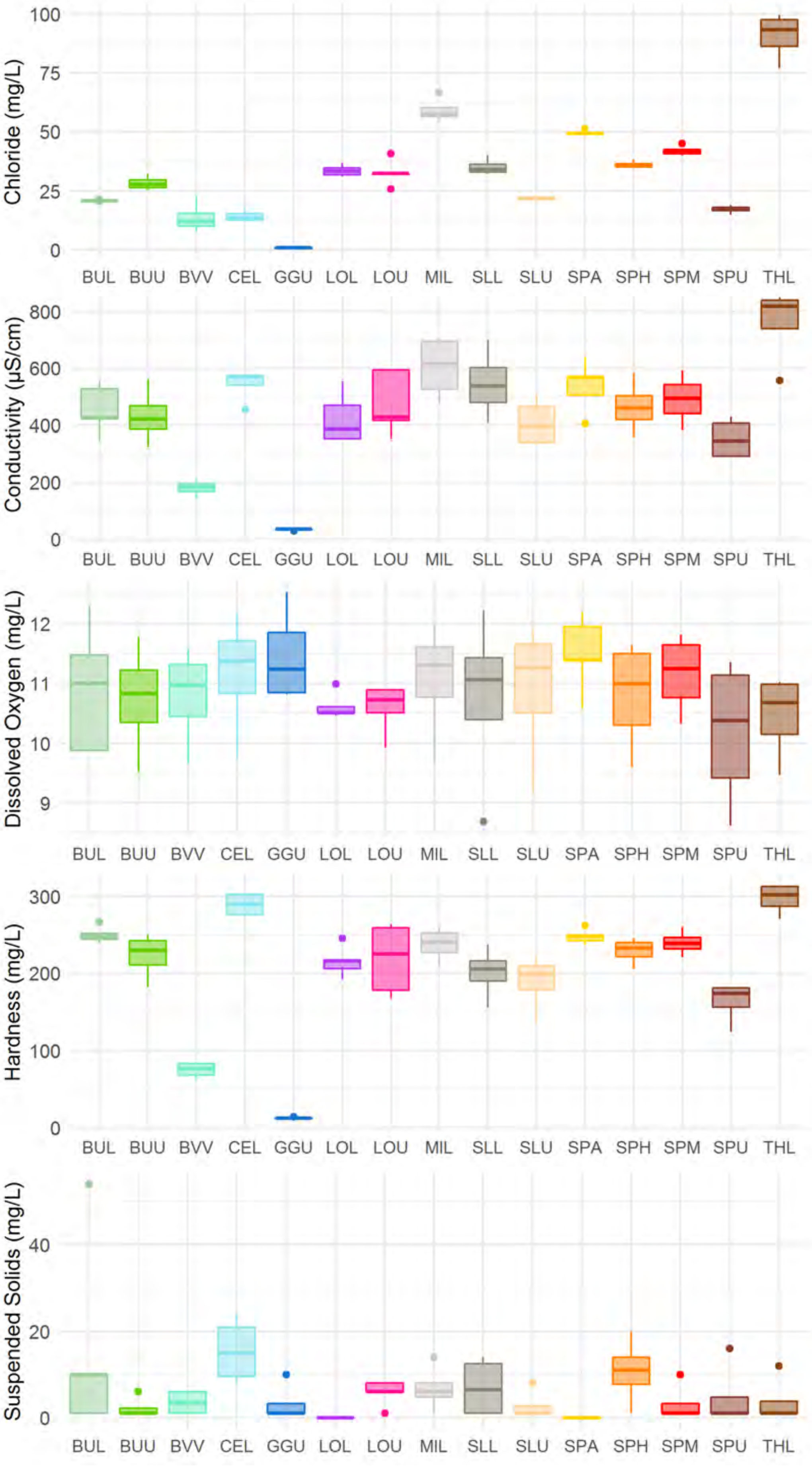
Physiochemical Parameters

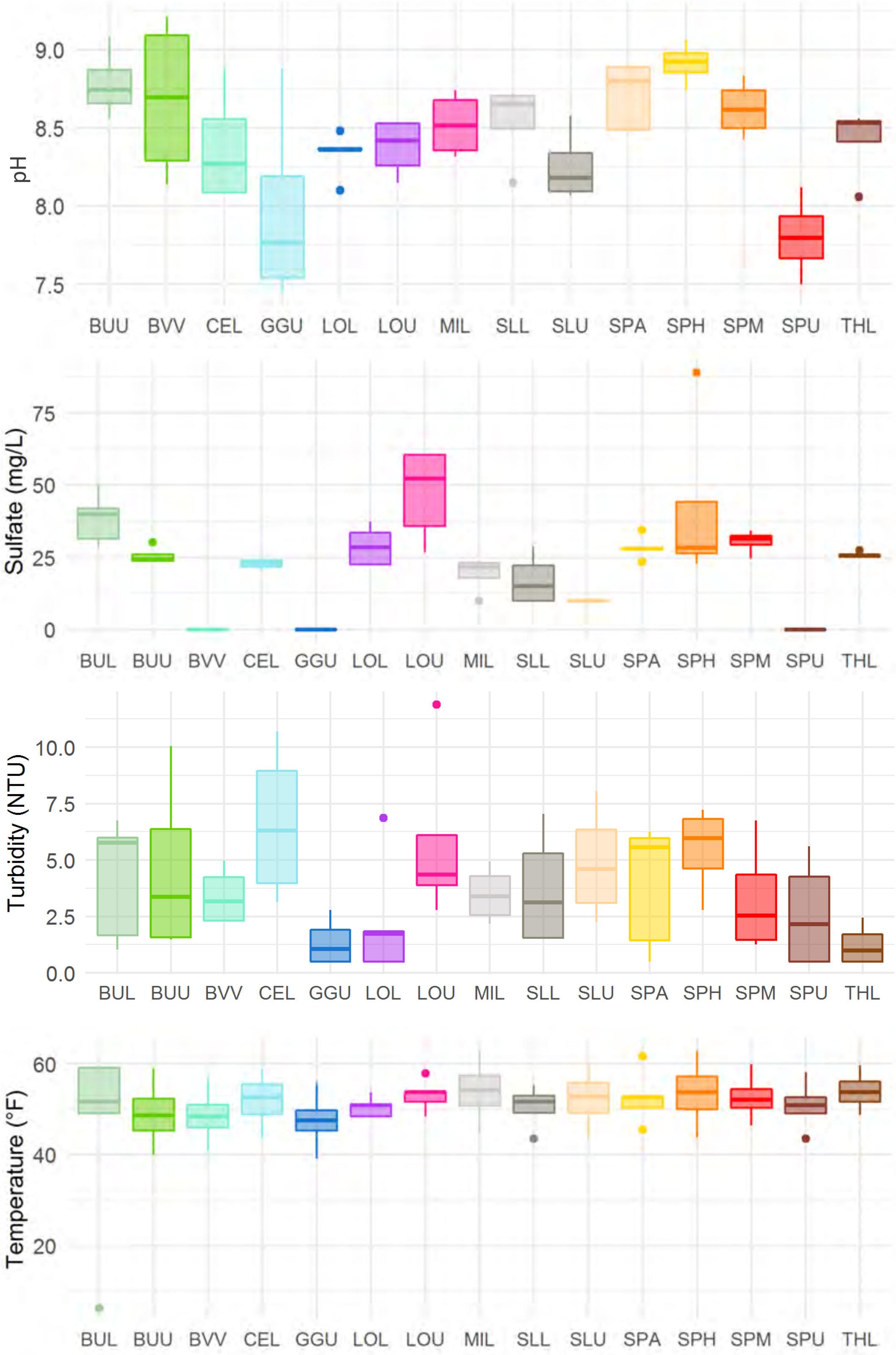






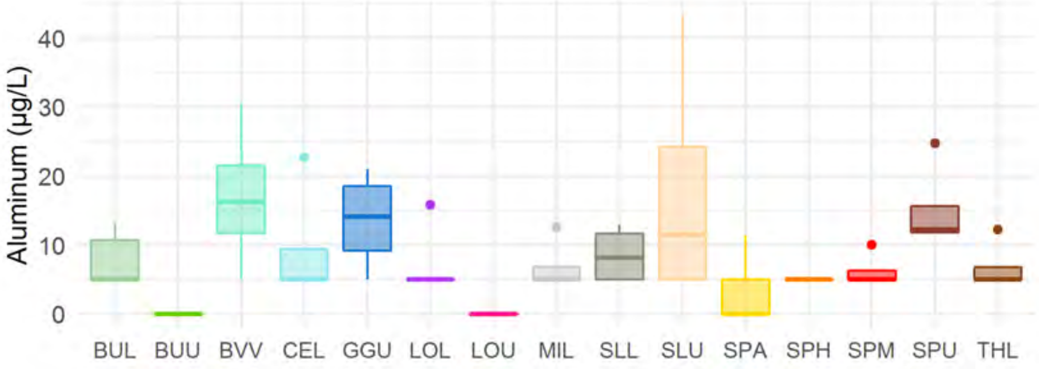


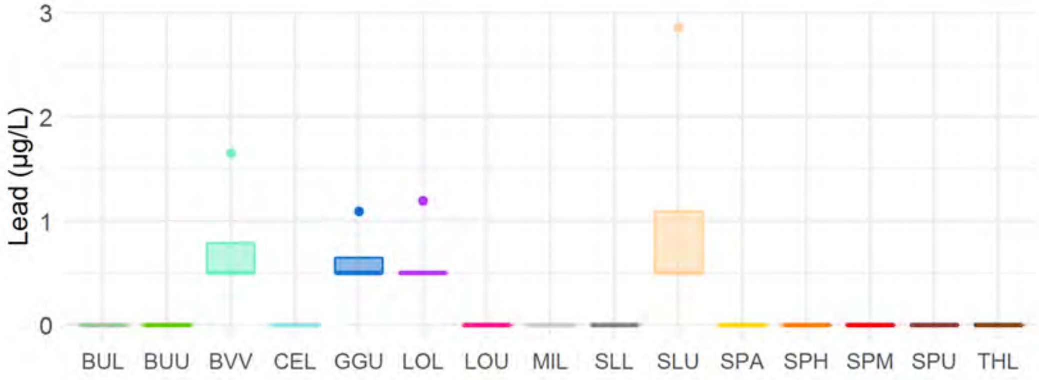

Chloride (mg/L)
100
75
50
25
0
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Conductivity (µS/cm)
800
600
400
200
0
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Dissolved Oxygen (mg/L)
12
11
10
9
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Hardness (mg/L)
300
200
100
0
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Suspended Solids (mg/L)
40
20
0
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL

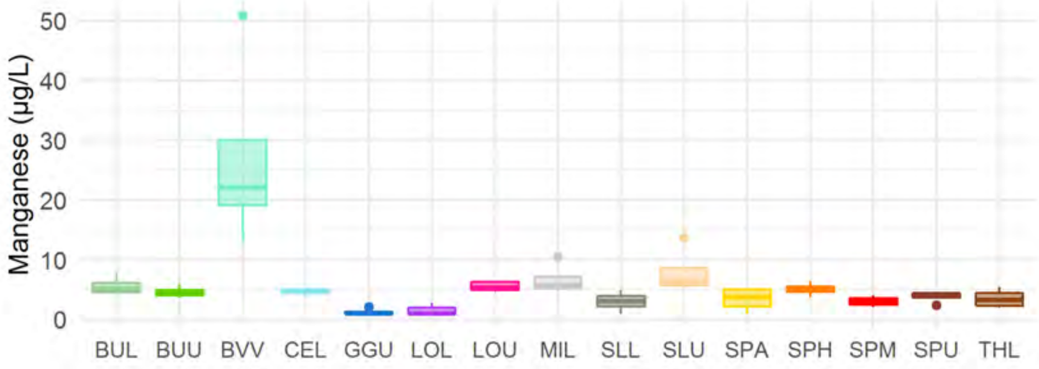

pH
9.0
8.5
8.0
7.5
BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Sulfate (mg/L)
75
50
25
0
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Turbidity (NTU)
10.0
7.5
5.0
2.5
0.0
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL
Temperature (°F)
60
40
20
BUL BUU BVV CEL GGU LOL LOU MIL SLL SLU SPA SPH SPM SPU THL

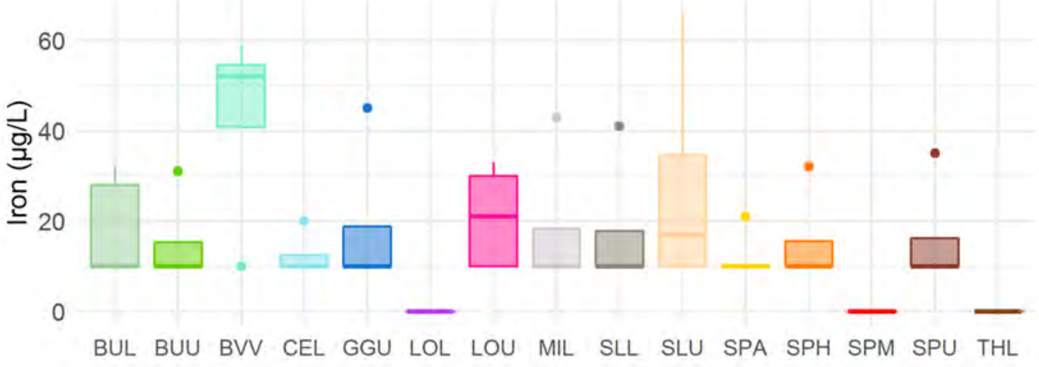
2018 Stream Water Quality Data

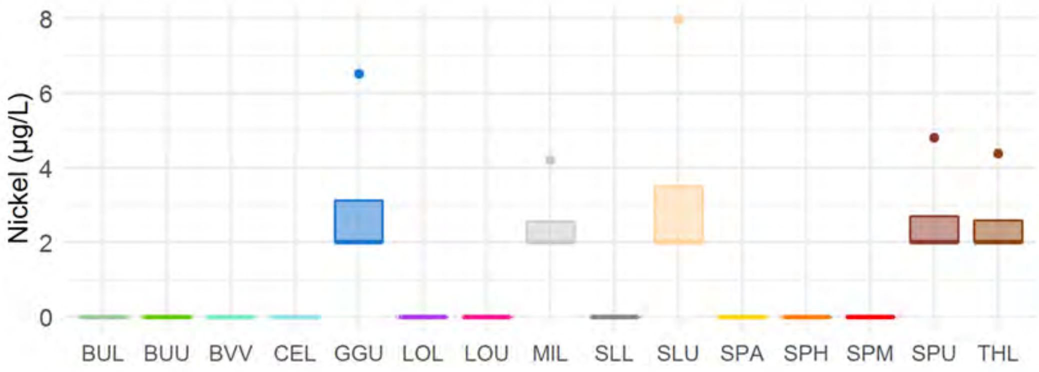
Metals—Dissolved

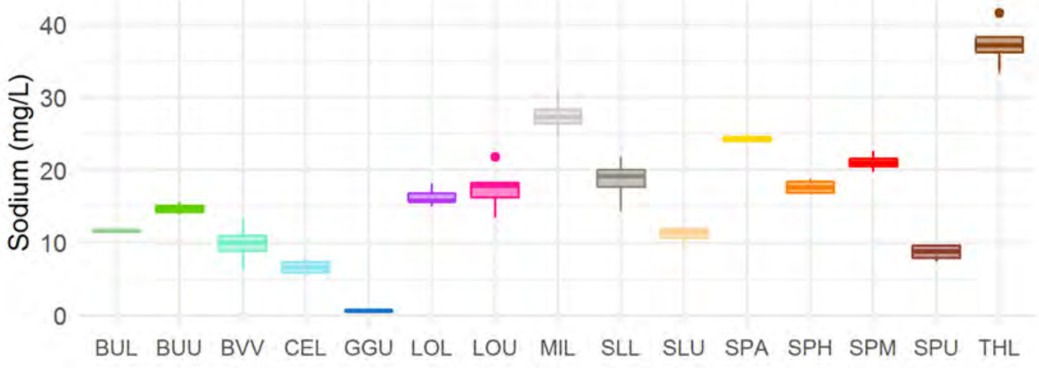


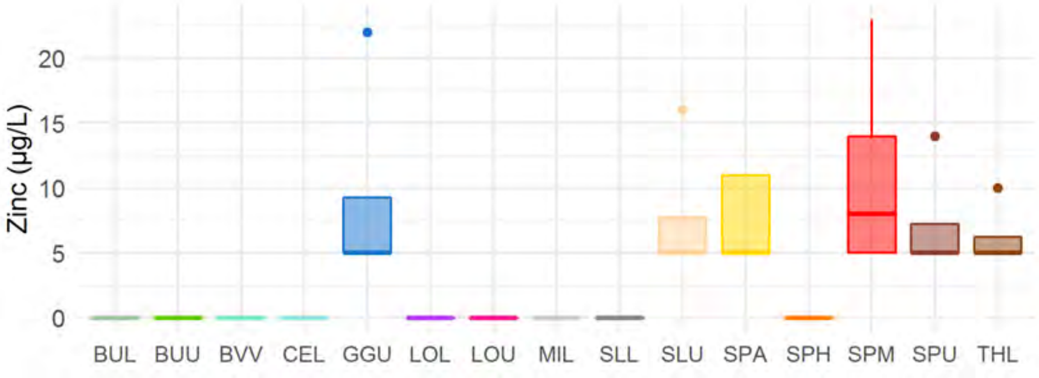






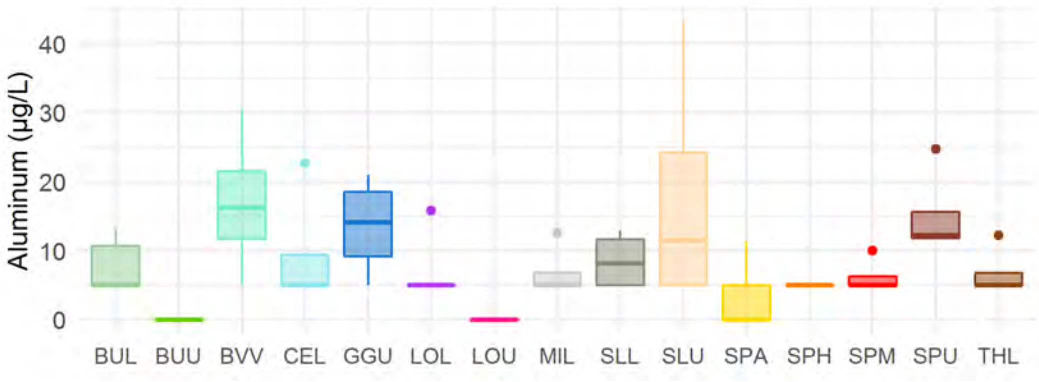


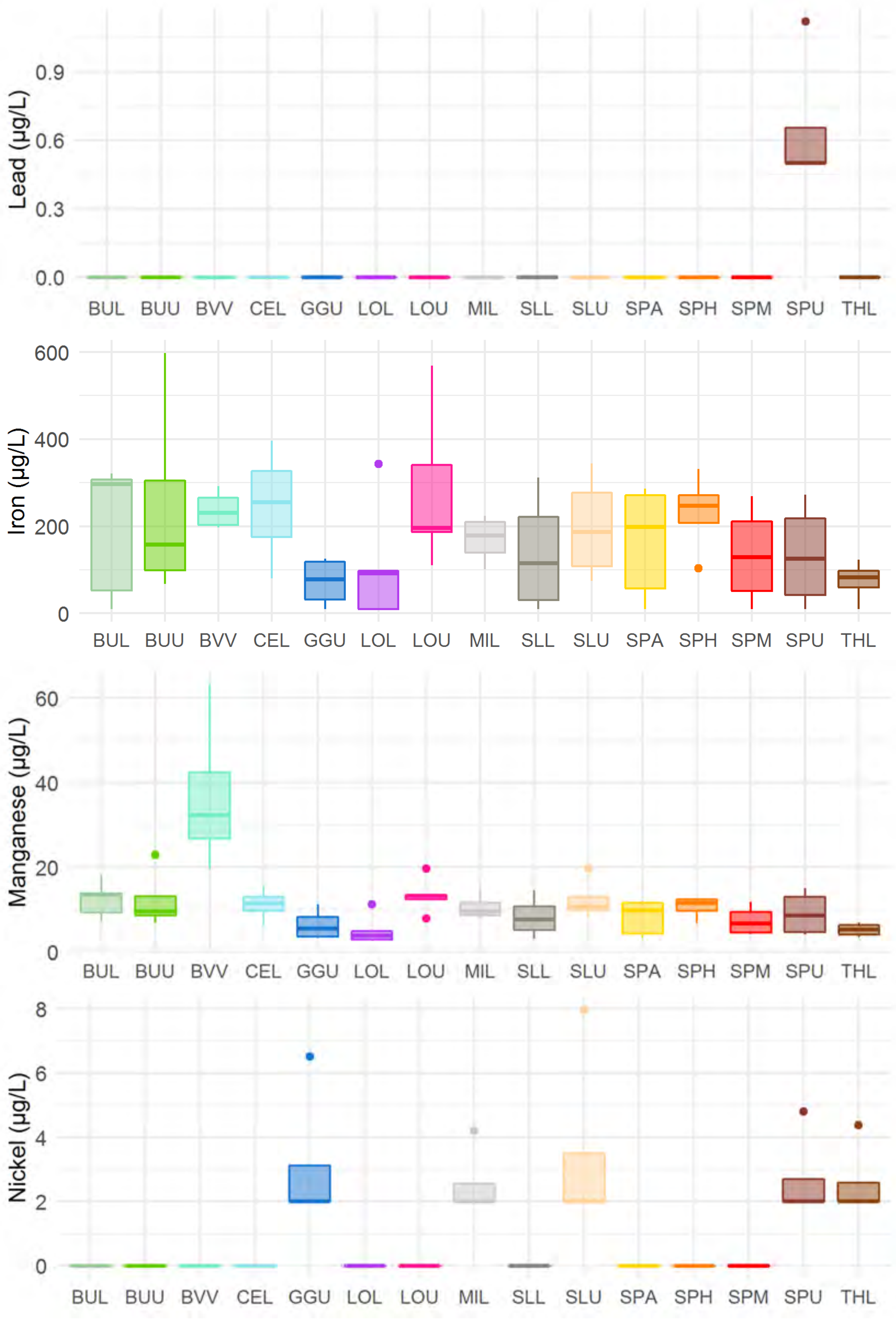


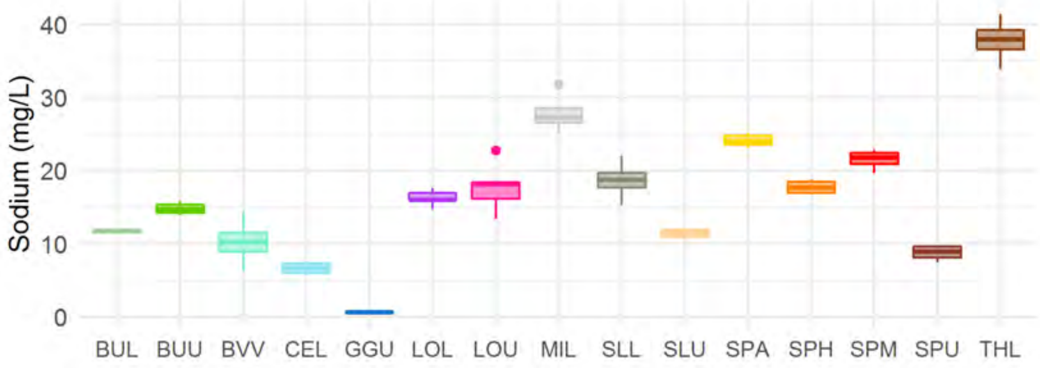


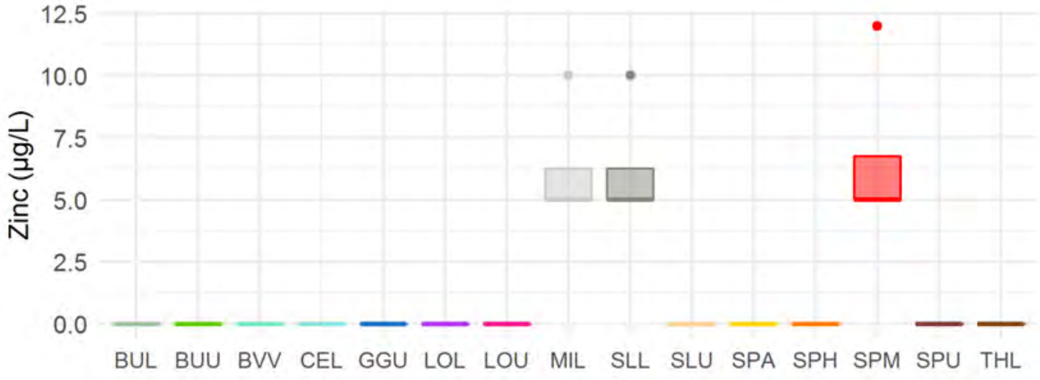
2018 Stream Water Quality Data

Metals—Total



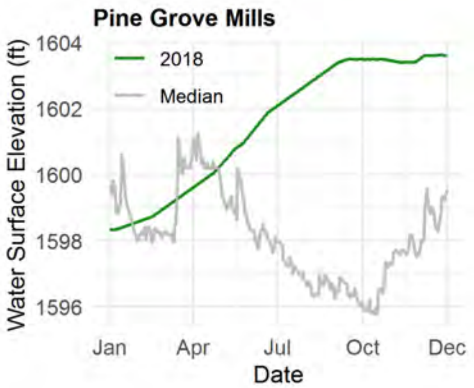

Lead (µg/L)
0.0
0.3
0.6
0.9
Iron (µg/L)
0
200
400
600
Manganese (µg/L)
0
20
40
60
Nickel (µg/L)
0
2
4
6
8
BUL
BUU
BVV
CEL
GGU
LOL
LOU
MIL
SLL
SLU
SPA
SPH
SPM
SPU
THL

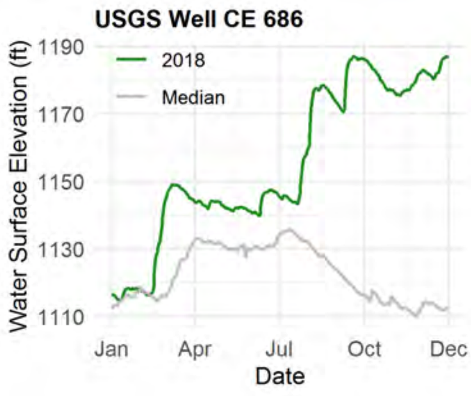


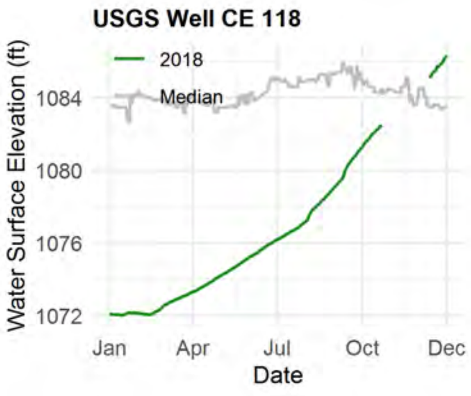


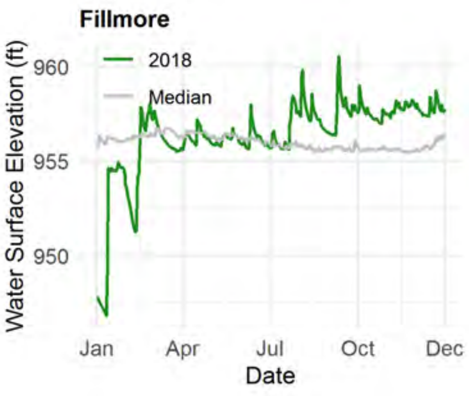
Groundwater Elevation Monitoring

At the three wells comprising the WRMP groundwater monitoring network, water surface elevation is recorded every 3 hours with digitally-recording pressure transducers. Two USGS groundwater wells are also located in the watershed (Figure). In 2018, all groundwater levels steadily rose and/or were much higher than median levels, a reflection of the large amount of precipitation received that year.









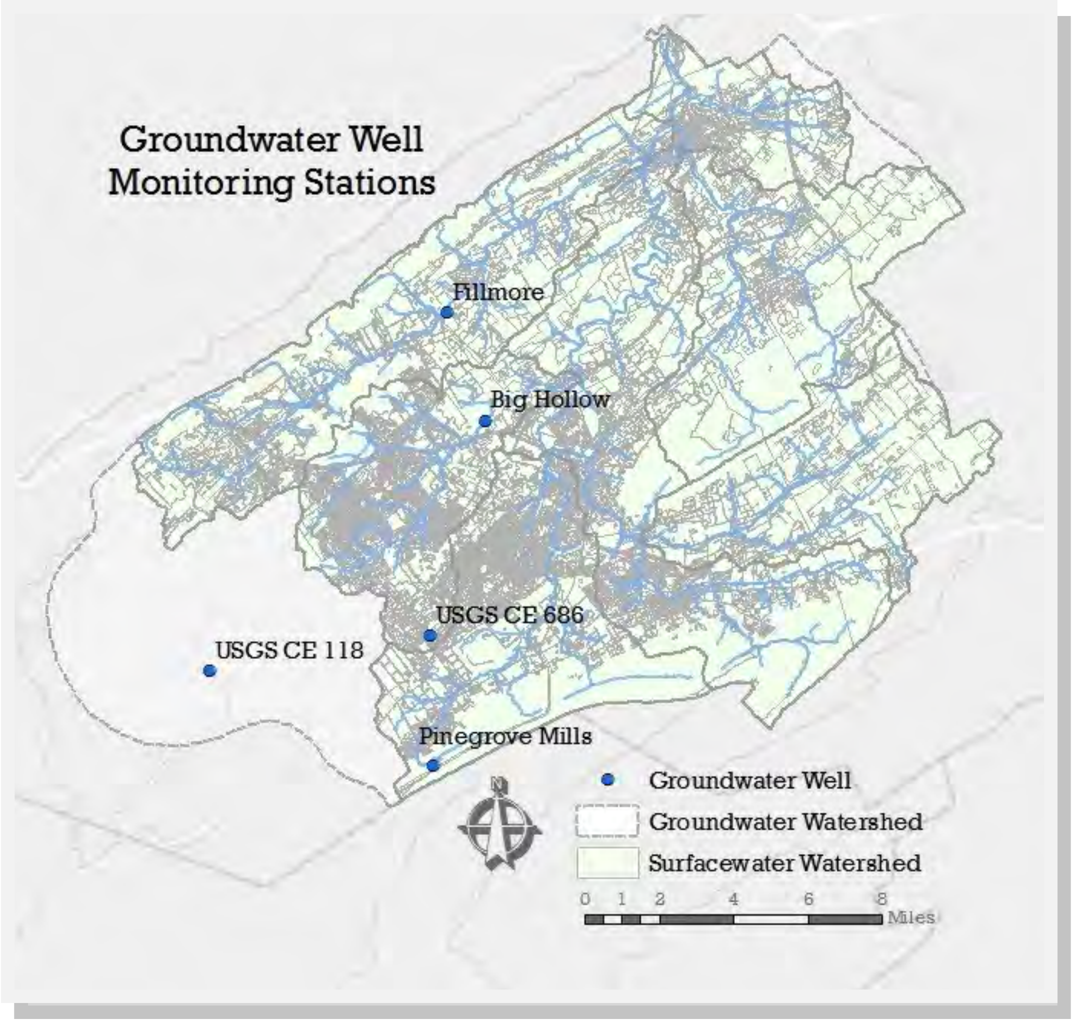


Fig. 33 Groundwater well locations maintained by the WRMP and the USGS

Data Quality and Requests

To assure the consistency and quality of data collected as part of the WRMP, the Keystone Water Resources Center Board of Directors and the Pennsylvania State University developed a set of standardized procedures for data collection, sample processing and database maintenance. The WRMP has been working directly with the Department of Environmental Protection to update this protocol and become quality assured by their Bureau of Clean Water. A detailed description of these methods may be found in the WRMP's protocol. To review this document, please contact the Water Resources Specialist at lexie@keystonewaterresources.org.

All data requests can be made through the Keystone Water Resources Center Website (www.keystonewaterresources.org) or by directly contacting Lexie Orr, the Water Resources Specialist at lexie@keystonewaterresources.org.

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