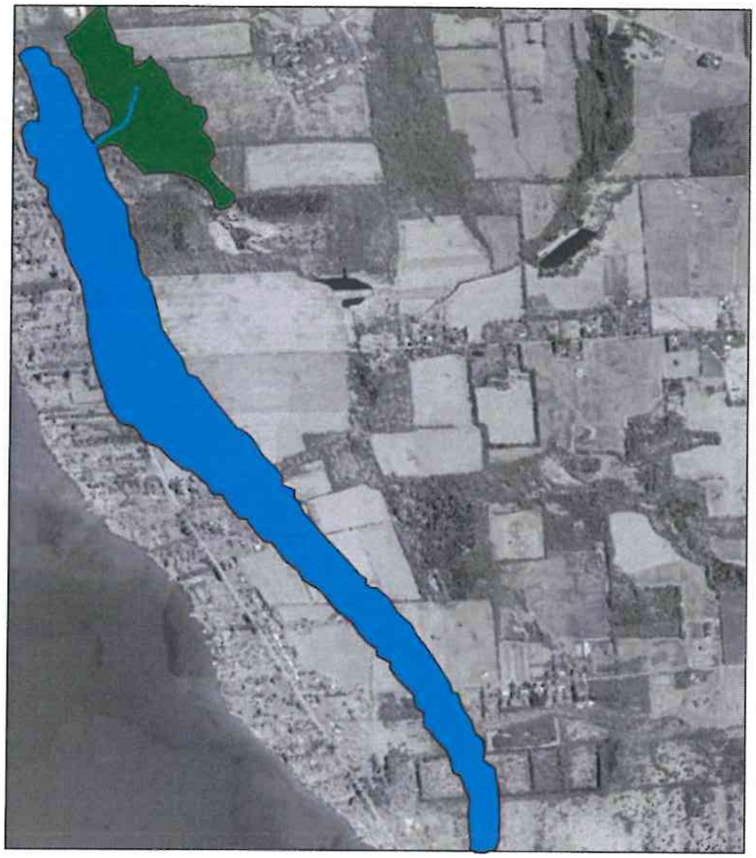
# Monitoring Report for Shotwell Brook, 2018



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**December 2018**

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## Glossary

| Term | Definition |
|---|---|
| Baseflow | the portion of streamflow that is generated from groundwater inputs, not from precipitation or snowmelt |
| Cross-sectional area | the area of a two-dimensional plane that intersects a three-dimensional object |
| Evapotranspiration | the combined loss of water from a watershed from evaporation and transpiration (process by which water is carried through plants from roots to small pores on the underside of leaves and is released to the atmosphere) |
| Ground-truthing | information provided by direct observations to validate another set of measurements |
| Head | the height or depth of a body of water |
| *In-situ* | in an objects original place |
| Interception storage | precipitation that does not reach the soil but is instead intercepted by the leaves and branches of forest and agricultural plants |
| Load (or loading) | the mass quantity of a substance delivered to a water body over a given period of time (for example, pounds per second or kilograms per day) |
| NTU | nephelometric turbidity units (relative units of the turbidity measurement) |
| Oligotrophic | the condition of a lake having low levels of nutrients and primary production (algae) |
| p-value | the probability of obtaining a result equal to or greater than what was actually observed, when the null hypothesis is true (a p-value less than 0.05 is usually the level to determine statistical significance). |
| $R^2$ | also known as the coefficient of determination; proportion of the variability in the dependent variable that is predictable from the independent variable |
| Reach | a specific section of a stream with defined upstream and downstream boundaries used for environmental studies |
| Runoff | the portion of streamflow that results from precipitation or snowmelt that is not infiltrated into the ground and flows over the land surface directly into a stream channel |
| Specific conductance | the measure of how well a water can conduct an electrical current (used as a surrogate of total dissolved solids, salt content, or salinity) |
| Stream stage | height or depth of water above stream bottom |
| Transparent Velocity Head Rod (or TVHR) | a flat Plexiglas® sheet of specific width with meter sticks used to estimate stream velocity |
| Turbidity | cloudiness or haziness of a fluid caused by individual particles that are generally invisible to the naked eye |
| Watershed | the area of land surrounding a water body that contributes water to that body |

# 1. Background

## 1.1. Skaneateles Lake and Shotwell Brook

Skaneateles Lake is located in central New York, approximately 19 kilometers (km) south-southwest of Syracuse and 8 km east of Auburn. It is the second easternmost of the Finger Lakes. The main axis of the lake is oriented approximately along a north/northwest-south/southeast line with the Village of Skaneateles at its northern end. Skaneateles Lake has a surface area of 35.9 $km^2$, a volume of 1,563 x $10^6$ cubic meters ($m^3$), and mean and maximum depths of 43.5 and 90.5 meters (m). Skaneateles Lake is the third deepest of the Finger Lakes; it has the fourth largest volume, but the fifth smallest surface area (Schaffner and Oglesby 1978).

The lake has a small watershed (154 $km^2$) relative to its size; i.e., the smallest watershed to surface area ratio of the Finger Lakes. The lake's good water quality, including its oligotrophic (low primary production) state, has been in part attributed to this feature (Oglesby and Schaffner 1978, Perkins et al. 2009). Residential and commercial development in the watershed is relatively low (< 10% by area). The watershed is 37% forested and agriculture accounts for 36% of land use. Hydrologic inputs are rather diffuse, with many small tributaries rather than a single dominant input. The lake has a single natural outflow at its northern end, Skaneateles Creek, which flows north to the Seneca River and eventually to Lake Ontario. The lake has a long hydraulic retention time. That is, it flushes relatively slowly, about once every 18 years on a completely-mixed basis, the second slowest of the Finger Lakes (Schaffner and Oglesby 1978).

Skaneateles Lake is an extremely valuable aquatic resource that is tremendously important to the economies of the Town of Skaneateles, the surrounding towns and villages, and the eastern Finger Lakes region. The pristine aesthetic quality of the lake attracts tourism and is important for maintaining property values along its shores. The shoreline is largely developed with cottages and year-round homes. Boating and swimming are popular activities, and it is considered a good fishing lake. The lake is also the principal source of water for the City of Syracuse and Village of Skaneateles. The City of Syracuse maintains an active watershed management program for Skaneateles Lake to protect its water quality. Currently, because of very low turbidity levels, the City does not have to filter its drinking water (i.e., filtration avoidance). The drinking water is withdrawn from two different intakes that extend approximately 1.3 and 2.0 km south from the Village of Skaneateles. The lake is classified AA by New York State, which is its highest rating.

The exceptional water quality of Skaneateles Lake is presently threatened by harmful algal blooms (HABs), which occurred during late summer and early fall of 2017 and 2018. Not only do these blooms of cyanobacteria cause aesthetic issues, but they are also capable of producing toxins that potentially limit use of the lake as a water supply. Although toxins (i.e., microcystin) have been detected in the waters of Skaneateles Lake, they have not been detected in public water supplies. Reducing nutrient inputs from tributaries is a primary management approach for controlling HABs, which highlights the need to monitor phosphorus and nitrogen inputs from Skaneateles Lake tributaries, including Shotwell Brook.

Shotwell Brook is a small tributary that enters Skaneateles Lake in the northeast corner of the lake, approximately 3 km south-southeast of the Village of Skaneateles and approximately 1.5 km southeast of the drinking water intakes. Shotwell Brook's watershed (8.6 $km^2$) is approximately 5.6% of the lake's drainage area. Agriculture accounts for 71% of land usage in the Shotwell Brook watershed (Pradhanang 2009). Approximately 28% of the watershed is forested and other land uses comprise less than 1%. Because of its land use make-up, and despite its small size, Shotwell Brook is known to be an important source of turbidity to Skaneateles Lake, especially during periods of high flow, such as during snow melt and high intensity rainfall events. Because of its proximity to the Village of Skaneateles and the drinking water intakes, knowledge of the general water quality of Shotwell Brook and the timing and quantification of high turbidity events is important information for lake managers, property owners, and other stakeholders.

### 1.2. Objectives

The overarching goal of the 2018 monitoring program was to add to the baseline characterization of hydrology and water quality of Shotwell Brook that began in 2016 and continued in 2017, focusing this year on the April through mid-December period. This study provides lake managers with information necessary to evaluate the water quality of Shotwell Brook, assess potential impacts to Skaneateles Lake, and begin to identify possible turbidity remediation strategies for this stream. Specifically, the objectives of the study were to: (1) develop estimates of streamflow (or flow) using stream velocity and cross-sectional area measurements for a range of conditions; (2) characterize the water quality of Shotwell Brook with high frequency (15-minute measurement interval) *in-situ* probes to provide near-continuous measurements of temperature (T; in degrees Celsius or °C), specific conductance (SC; in micro-Siemens per centimeter or μS/cm), and turbidity (Tn; in nephelometric turbidity units or NTU); and (3) describe the patterns of total, dissolved, and particulate forms of phosphorus (P) during baseflow and runoff event conditions.

## 2. Methods

### 2.1. Study Location

The 2018 Shotwell Brook monitoring location was at the Route 41 (East Lake Rd.) bridge between Pork St. and Coon Hill Rd. on the eastern shore of Skaneateles Lake (Figure 1). This location is approximately 690 feet upstream of the brook's mouth (42.924°N, -76.408°W). Monitoring equipment was installed at this location to avoid the influence of lake water and for convenience in sample collection and equipment maintenance. This site is also used by the City of Syracuse for their monitoring purposes and has been used for previous studies (Pradhanang 2009).

## 2.2. Cross-sectional Area, Velocity, and Estimates of Streamflow

Streamflow is a critical variable, necessary for the environmental analysis of streams. Streamflow (Q; in cubic feet per second or cfs) is calculated as the product of a stream's cross-sectional area (A; in square feet or $ft^2$) and velocity (V; feet per second or ft/s). A graphical representation of a stream channel, including the components of streamflow, is provided in Figure 2. Multiple measurements of area and velocity over a wide range of conditions are needed to accurately characterize the flow conditions of a stream. For this study, a statistical relationship, called a rating curve, between stream depth (or stage, S) and streamflow was developed so that near-continuous flow can be estimated from easily measured, near-continuous stage measurements.

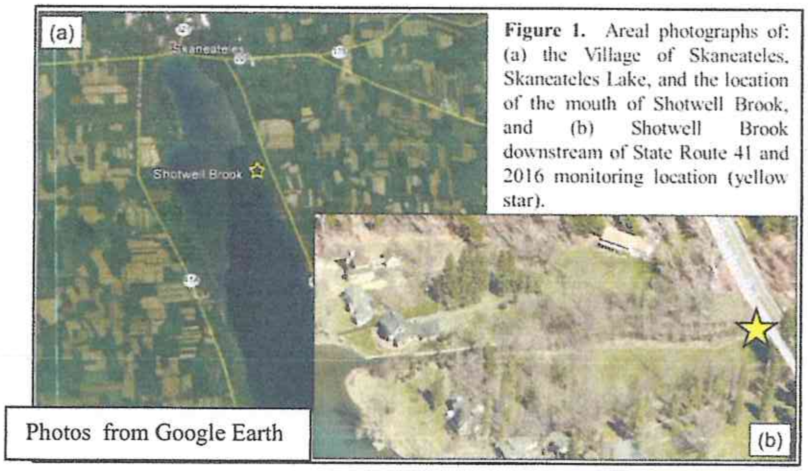


**Figure 1.** Areal photographs of: (a) the Village of Skaneateles, Skaneateles Lake, and the location of the mouth of Shotwell Brook, and (b) Shotwell Brook downstream of State Route 41 and 2016 monitoring location (yellow star).

Stream cross-sectional area measurements were made by making depth measurements at intervals across the width of the stream and using geometric calculations (similar to Figure 2). Velocity measurements were made with three tools or techniques so that results could be compared and verified: (1) the float method, (2) a velocity meter, and (3) a transparent velocity head rod (TVHR; Fonstad et al. 2005). Velocity measurements were made at multiple sites across the width of the stream if possible with the velocity meter and TVHR. For consistency, area and velocity measurements were made at the same locations under the Route 41 bridge. Paired area and velocity measurements and resulting streamflow estimates were then paired with *in-situ* stage measurements to create a representative rating curve for Shotwell Brook.

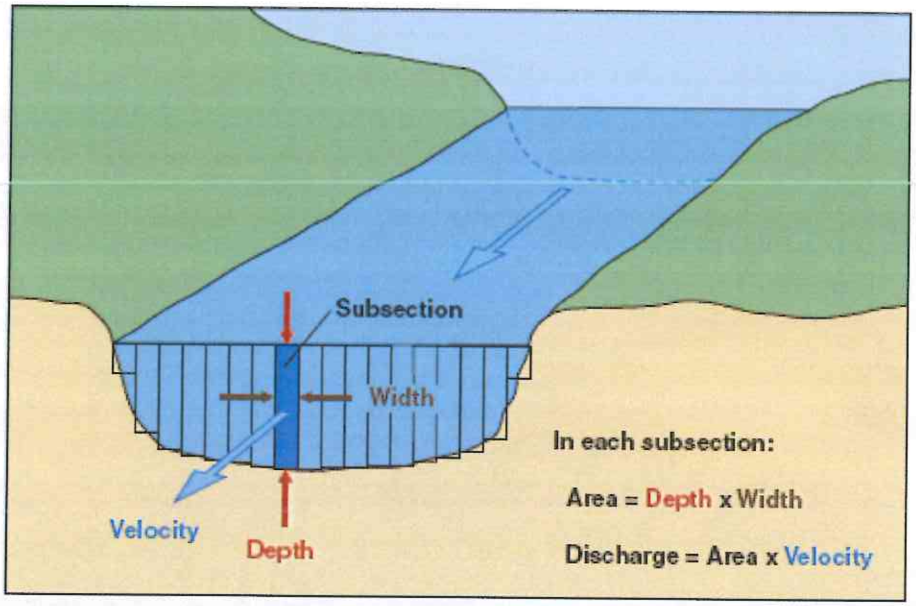


**Figure 2.** A graphical representation of the components of streamflow (also called discharge; courtesy of the USGS).

### 2.2.1. The Float Method

The float method is a common method for estimating stream velocity (Michaud and Wierenga 2005). It involves measuring the travel time (in seconds) of a buoyant float over a reach of known distance (in feet). For this study the reach was the length of the stream underneath the Route 41 Bridge from an upstream gage marker to the overspill of the concrete culvert base (44 ft; see Figure 3). The process is repeated several times per trip over the same reach and the average travel time is divided into the reach length. The result is the average surface velocity. The surface velocity is adjusted to an average flow velocity (the velocity at a mid-point in the flow depth) by multiplying the surface velocity by 0.8 or 0.9 (Michaud and Wierenga 2005). For this study, all surface velocities estimated from the float method were adjusted by a factor of 0.85.

**Figure 3.** Reach of Shotwell Brook used for velocity and area measurements. The photograph was taken at the overspill, looking upstream.

### 2.2.2. The Velocity Meter

Stream velocity measurements were also made with a Global Water velocity meter (Global Water Instrumentation Inc. 2009). The Global Water velocity meter was positioned at multiple cross-sectional locations and depths in the brook to provide a depth-width integrated velocity measurement on each trip when there was adequate flow volume. Because it is depth-width integrated, this average velocity was used directly in streamflow estimation. The velocity meter was replaced with a new unit following a number of inaccurate measurements made early in the 2018 monitoring program.

### 2.2.3. The Transparent Velocity Head Rod (TVHR)

For this study, UFI fabricated a TVHR (a flat Plexiglas® sheet of specific width with meter sticks) based on the description provided by Fonstad et al. 2005. Briefly, the method involves placing the TVHR into the streamflow and measuring the difference between the height of the water (called head) on the upstream side of the Plexiglas® and the height of the water on the downstream side (Figure 4a and b). The difference in the upstream and downstream head is proportional to the water velocity, given the TVHR dimensions (Fonstad et al. 2005). This tool was used at multiple locations across the stream width, when possible, to estimate average velocity on each trip. No velocity adjustments are needed for this technique.

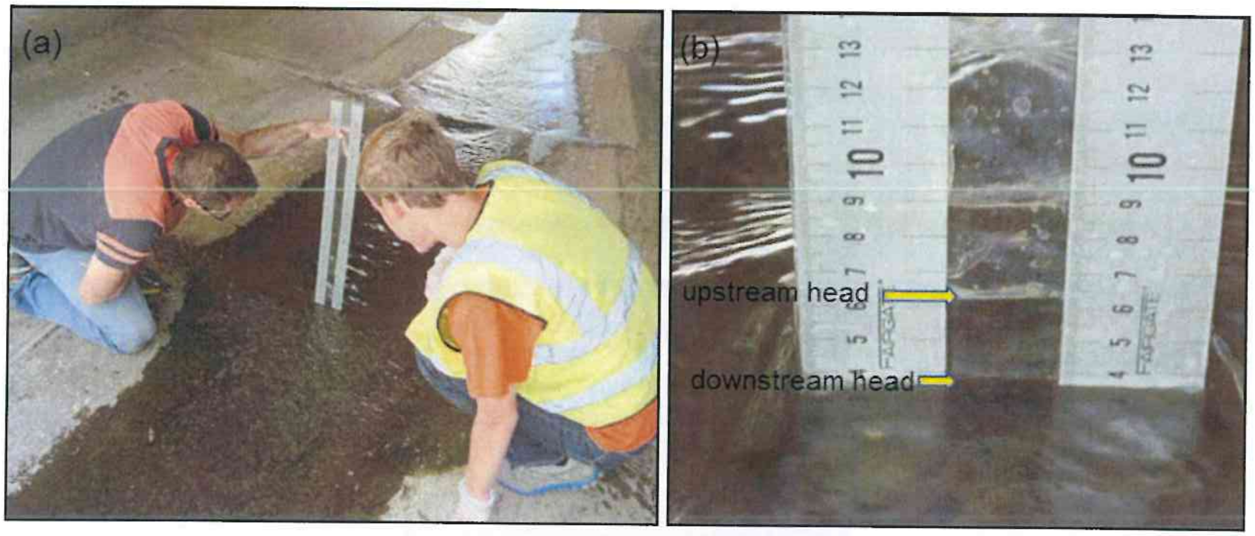


**Figure 4.** The use of the TVHR in Shotwell Brook at low flow: (a) TVHR in stream, and (b) difference in upstream and downstream head.

## 2.3. *In-situ* Equipment

The *in-situ* measurements consisted of stream stage and water quality parameters (T, SC, and Tn). Stage was measured by a Campbell Scientific model CS450 pressure sensor (Campbell Scientific 2012) and water quality measurements were made with a YSI Series 6600 multi-probe datasonde (YSI 2011). The pressure sensor and datasonde were installed in pools approximately 10 feet downstream of the culvert (Figure 5). The pressure sensor and datasonde both moved several times during the study because of high flows. These two sensors were connected to a battery and data logger and the 15-minute data was sent via cellular modem to UFI in Syracuse for storage and analysis. *In-situ* readings were validated with an independent YSI multi-probe datasonde on sampling trips (this process is referred to as ground-truthing).

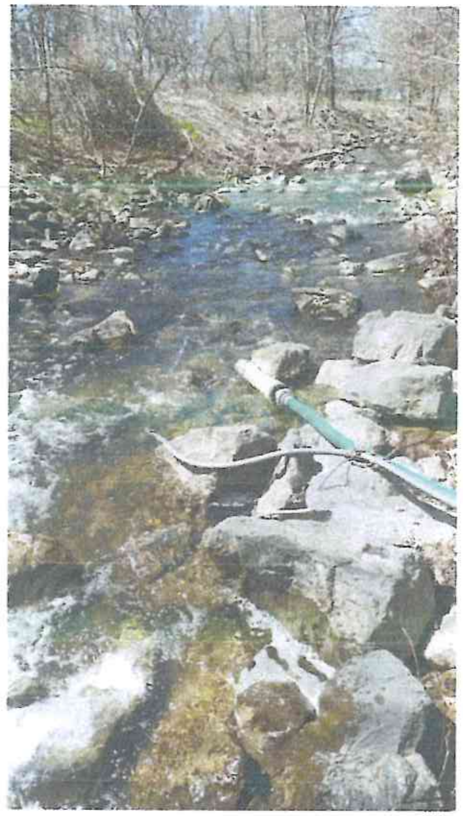

**Figure 5.** Location of *in-situ* monitoring equipment in Shotwell Brook.

### 2.4. Chemistry Samples

Water chemistry samples were collected as grab samples at the overspill from the concrete culvert near the *in-situ* sensors (see Figure 5). Chemistry samples were collected twice per month and during high flow events. Samples were analyzed for total phosphorus (TP), total dissolved phosphorus (TDP), and turbidity (Tn) according to standard methods (Rice et al. 2012). Particulate phosphorus (PP) was calculated as the difference between TP and TDP.

## 3. 2017 Environmental Conditions

Representative snowfall, temperature, and precipitation data for Shotwell Brook for the 2018 monitoring period was obtained from the National Weather Service (NWS) station in Auburn, NY. The NWS Auburn station is located approximately 10 km west of the Village of Skaneateles and 11.9 km west of the mouth of Shotwell Brook.

### 3.1. 2017 Temperature and Precipitation

Air temperatures during 2018 were lower than the long-term (1980-2017) average in January, March, April, and November (Figure 6a). During the months of February, May, August, and September of 2018 air temperatures were above the long-term average.

Temperatures were close to the long-term average in June, July, and October.

Total precipitation was well above average during January–March of 2018, followed by much drier conditions during April–June (Figure 6b). Above average precipitation returned for most of the August–November period, with the highest monthly totals occurring during November (6.1 inches). Cumulative precipitation for the January–November period of 2018 was 9.0 inches higher than the long-term average (Figure 6c). However, precipitation during summer (June–September) was just 0.3 inches higher than average.

### 3.2. Snowfall Winter 2017 - Spring 2018

Snowfall in Auburn was elevated during the winter of 2017–2018 compared with long-term average conditions. Total snowfall during the 2017–2018 winter season was 132.2 inches, substantially higher than the average annual snowfall of 99.7±34.6 inches (± represents ± one standard deviation). The 2017–2018 winter season ranked as the 5$^{th}$ highest annual total over the 1999–2017 period. The highest total was observed in 2003-2004 (153.4 inches) and the lowest was observed in 2011–2012 (43.4 inches).

## 4. Results

### 4.1. Cross-sectional Area, Velocity, and Estimates of Streamflow

The three methods used to estimate water velocity compared well for most of the study interval (Figure 7a). The largest differences were observed with the TVHR, which generally under-predicted compared to the other methods. Having three methods available for velocity estimation was critical because each method had its own specific advantages and short-comings. For example, the TVHR and float methods were the only methods that could be used during the dry part of the summer. We found that the velocity meter usually required a minimum of 2.5 inches of water depth in the culvert; less than 2 inches of depth caused invalid results. When possible, an average of the three methods was used in flow calculations. Over the course of the 2018 study, velocity measurements ranged from 0.5 ft/s to 12.6 ft/s and cross-sectional areas varied from 0.2 ft$^2$ to 4.0 ft$^2$. For each sampling trip the streamflow was calculated as the product of velocity and cross-sectional area measurements. In total, 17 direct streamflow measurements were made from March 21 through November 9. Direct measurements of streamflow ranged from 0.18 cfs to 21.04 cfs. A number of faulty velocity meter results from the early portion of the 2018 monitoring season were omitted from the analyses presented in this report.

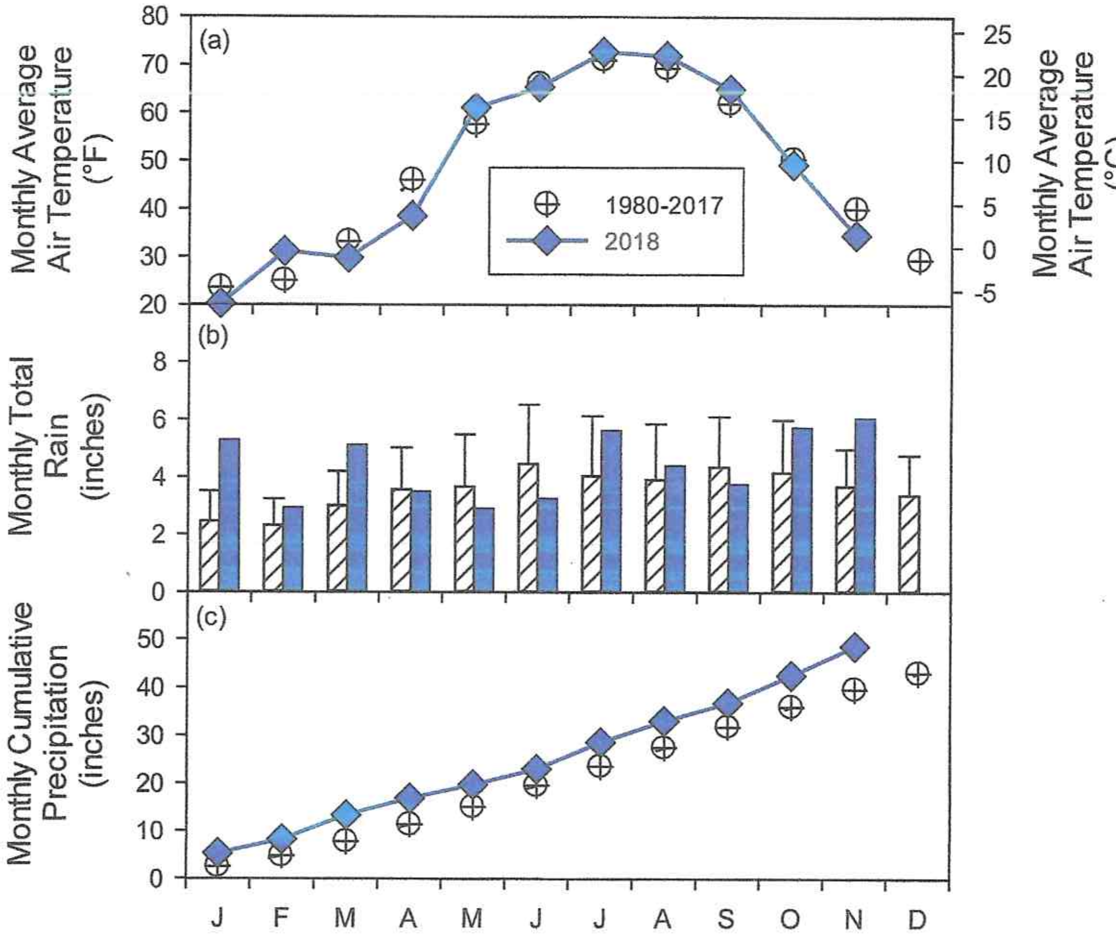


**Figure 6.** Auburn NWS meteorological conditions in 2018 compared with the 1980–2017 average as represented by the: (a) monthly average air temperature in degrees Fahrenheit (b) monthly total rain in inches (error bars are standard deviations on monthly averages), and (c) monthly cumulative rain in inches.

The statistical relationship between stage (S; independent variable) and streamflow (Q; dependent variable), called a rating-curve, is provided in Figure 7b, based on 2016–2018 measurements. The resulting equation was highly statistically significant as indicated by the low *p*-value (<0.0001) and high $R^2$ (0.92). This relationship was applied to the 15-minute measurements of stage from the *in-situ* pressure sensor (adjusted from the pool to an equivalent stage in the culvert) to obtain a (nearly) continuous 15-minute record of streamflow for Shotwell Brook for the study interval.

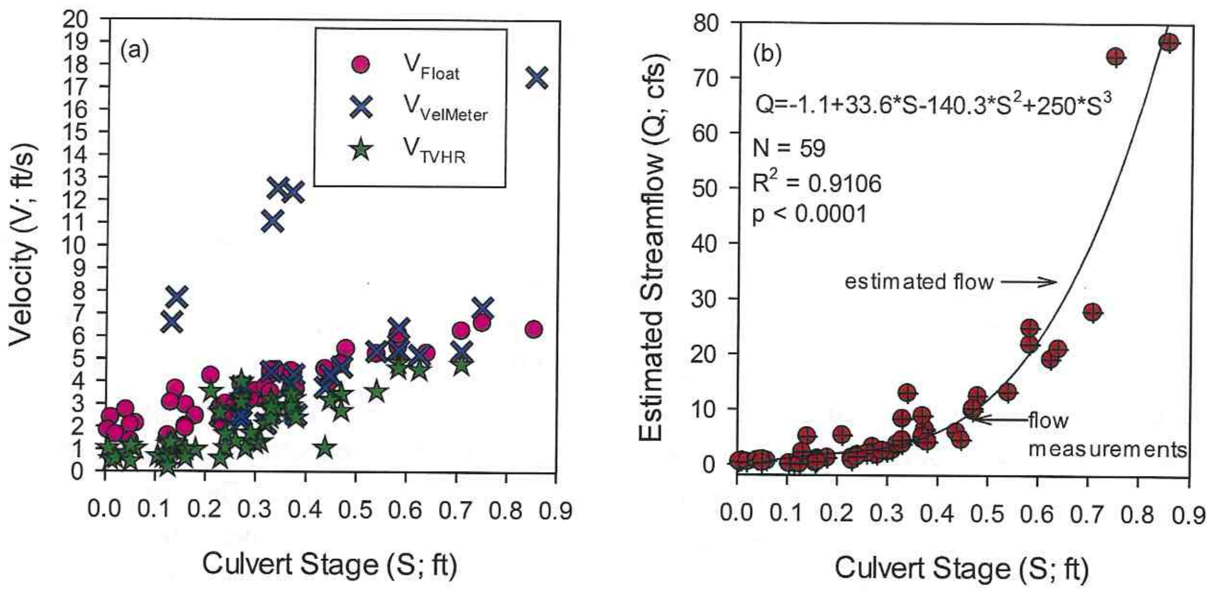


**Figure 7.** Estimating water velocity and streamflow in Shotwell Brook for 2016 through 2018: (a) stage-velocity relationships for the three velocity estimation methods, and (b) Shotwell Brook stage-flow relationship (rating curve) with equation and statistics.

## 4.2. Observations of Streamflow and Water Quality in 2018

### 4.2.1. 15-minute Streamflow Observations

Over 22,000 observations of stage, streamflow (from stage and the rating-curve in Figure 7b), temperature, specific conductance, and turbidity were collected in 2018 (Table 1). The duration of the study was 250 days, with data recorded at 15-minute time intervals. There were brief periods when data could not be collected, sometimes after large runoff events that dislodged the monitoring equipment from the stream and deposited it on the stream bank. UFI took steps to anchor the equipment in pools, but at times the flow was too strong to prevent displacement.

**Table 1.** Description of water quality in Shotwell Brook in 2018.

| Water Quality Parameter | Number of Observations | Mean (Standard Deviation) | Median | 25%-75% Inter-Quartile Range |
|---|---|---|---|---|
| Stage, S (ft) | 22,802 | 0.24 (0.18) | 0.21 | 0.12-0.35 |
| Streamflow, Q (cfs) | 22,802 | 5.7 (21.9) | 2.1 | 1.4-4.3 |
| Temperature, T (°C) | 23,974 | 13.4 (6.7) | 15.4 | 7.2-19.0 |
| Specific Conductance, SC (μS/cm) | 23,969 | 610 (94) | 643 | 588-672 |
| Turbidity, Tn (NTU) | 22,329 | 5.4 (13.5) | 2.4 | 1.4-4.0 |

Shotwell Brook is a small stream with a small watershed and, as expected, streamflow is generally low. Mean and median flows in 2018 were 5.7 and 2.1 cfs, respectively, with 75% of observations less than 4.3 cfs (the inter-quartile range is the range between the 25$^{th}$ and 75$^{th}$ quartiles; Figure 8). In 2017, the median flow was slightly lower (1.9 cfs) but the mean flow was significantly higher (10.0 cfs) due to more intense rainfall events. As a point of comparison, the median streamflow in Skaneateles Creek near Chatfield Rd. (approximately 6 miles north the Village of Skaneateles) was 21 cfs over the same time interval in 2018. The maximum 15-minute flow recorded in Shotwell Brook during 2018 was 646 cfs on December 2 and associated with a rainfall/snowmelt event. The highest flow event during summer was 43 cfs on August, 29. Summer high flow events of this magnitude were rare but are extremely important because they account for a disproportionate share of nutrient and material loading to the lake. Additionally, these events cause high levels of turbidity, degrading the water quality of both the brook and the lake. The contrast between low and high flow conditions is illustrated in Figure 9.

### 4.2.2. General Patterns of Streamflow

Average daily streamflow in 2018 was generally lower and less variable than in 2017 (Figure 10). Although a number of rainfall events during 2018 exceeded one inch of rain in a day, they did not result in particularly large flows in Shotwell Brook. This is in stark contrast to the wetter conditions of 2017 that resulted in saturated soil conditions and a more responsive hydrograph (Figure 10a). It is also possible that upstream beaver activity affected the relationship between rainfall and runoff during 2018 (personal communication with Rich Abbott). Prior to a high runoff event in late October of 2018, streamflow remained below 25 cfs. On October 28 daily average flow peaked for the first time at 36.8 cfs. November had several significant runoff events, with a peak flow for the month occurring on November 27 at 71 cfs. Daily average flow peaked for 2018 on December 2 at 264 cfs.

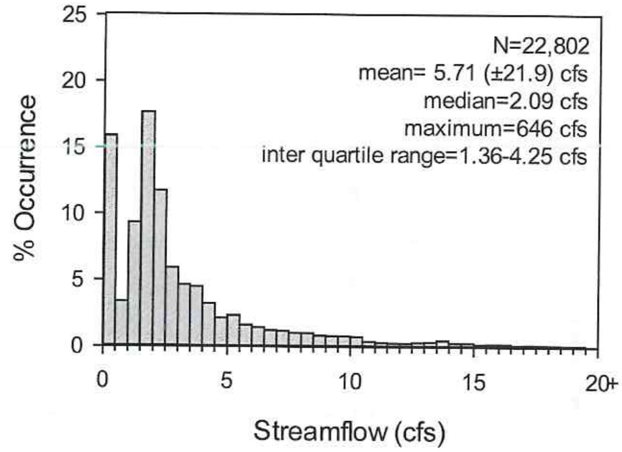


**Figure 8.** 15-minute flow observations in Shotwell Brook in 2018 as a frequency distribution with associated statistics.


**Figure 9.** Photographs of Shotwell Brook under the State Route 41 bridge: (a) low streamflow on July 6, 2018 and (b) high streamflow on November 27, 2018.

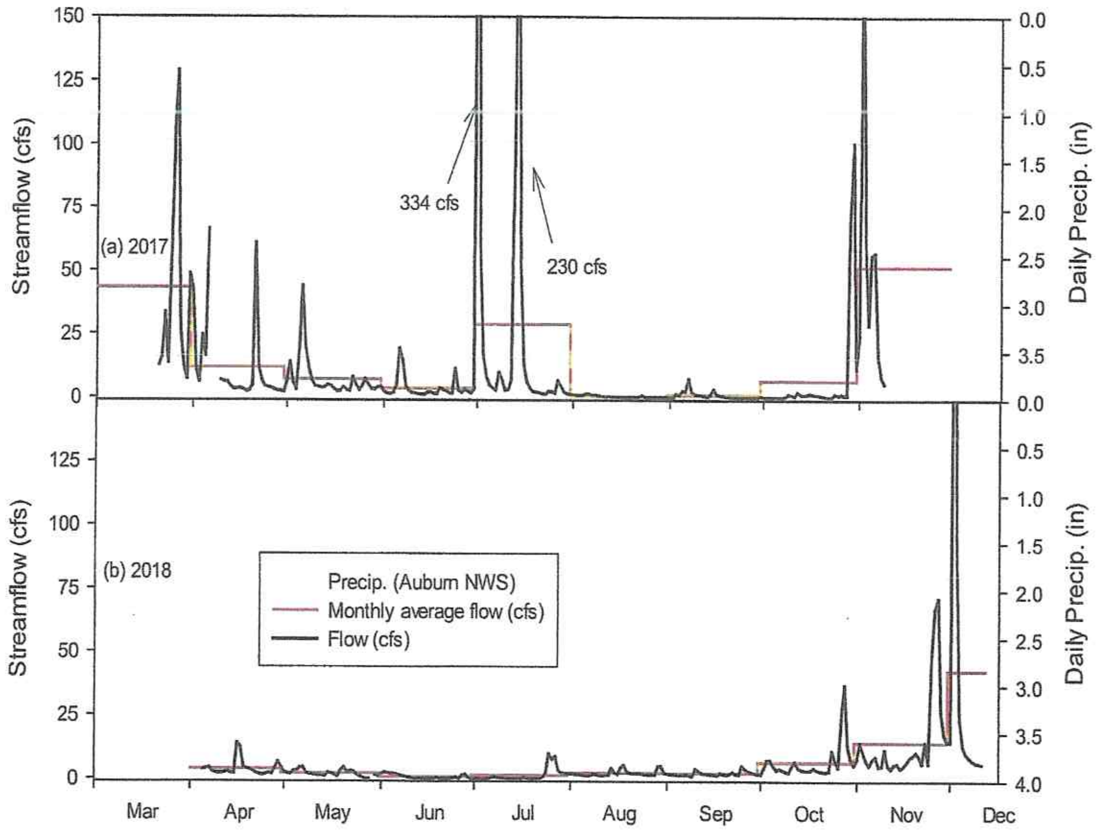


**Figure 10.** Time series of daily averaged streamflow, monthly averaged streamflow, and total daily precipitation for Shotwell Brook during March-December of 2017 and 2018.

When streamflow was observed directly in Shotwell Brook, it was not correlated to 48-hour precipitation totals in the spring and fall, but was correlated during the summer. In early spring and during the fall of 2018 (April, May, and October–December), the correlation between precipitation and streamflow was 0.32 ($p$=0.09; Figure 11a). During the summer (June-September), the correlation was 0.82 and was statistically significant ($p$=0.002). In 2017 (Figure 11b), the spring and fall rainfall was also not correlated with streamflow. These results suggest that streamflow is affected by conditions other than recent precipitation during the spring and fall, but 48-hour rainfall totals can influence streamflow in the summer.

The total flow volume for Shotwell Brook between April and December 11 was estimated to be 117.1 million cubic feet. This flow volume is relatively small compared to the volume of Skaneateles Lake (only 0.2% of lake's total volume). The flow volume for a given period is expected to be proportional to precipitation over the same interval, assuming stable groundwater inputs. Total precipitation during the April–December 2018 (36.3 inches) multiplied by Shotwell's watershed area (3.3 $mi^2$) yields a total precipitation volume of 278.5 million cubic feet. For the 2018 study period, 42% of the precipitation volume was converted to streamflow. A higher percentage (60%) of the precipitation volume was converted to streamflow in 2017 due to wetter conditions.

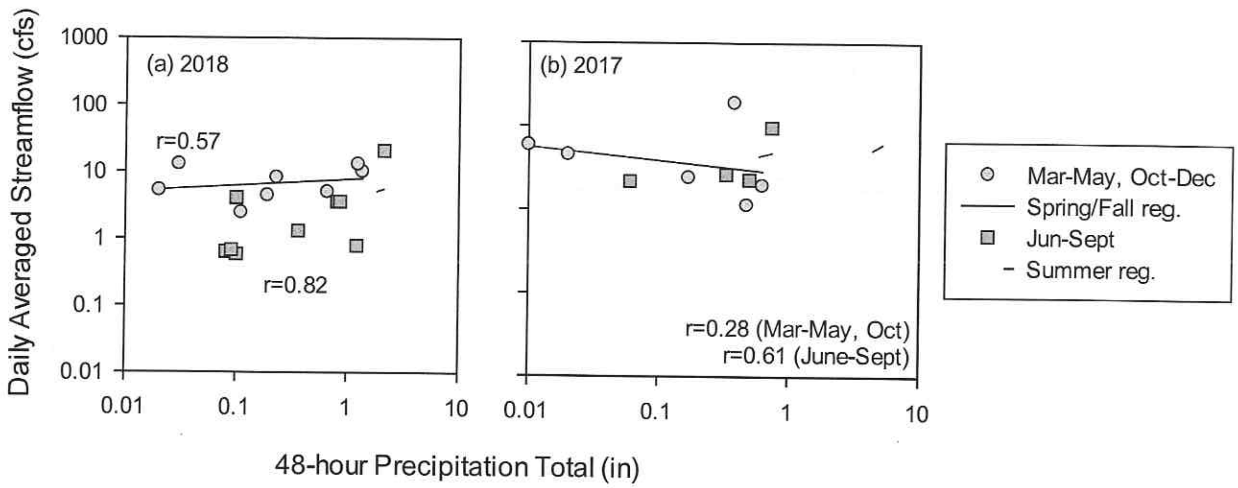


**Figure 11.** Relationship between 48-hour precipitation totals and direct streamflow measurements in Shotwell Brook (presented on log-log scale).

### 4.2.3. 15-minute Turbidity Observations

Over the April 5 to December 11, 2018 interval, 22,329 turbidity measurements were recorded in Shotwell Brook. The distribution of turbidity measurements in 2018 is depicted in Figure 12. The distribution was right-skewed due to the dominance of low turbidity observations and infrequent high turbidity events. The average turbidity was 5.4 NTU with a standard deviation of 14 NTU. Median turbidity was low (2.4 NTU) and the inter-quartile range of turbidity observations was 1.4 to 4.0 NTU. Turbidity was low in Shotwell Brook during low flow periods. Turbidity was observed to increase rapidly in response to rain events, but high Tn conditions generally were short-lived. The maximum turbidity was 376 NTU, measured on July 25. The number of observations at various turbidity levels is provided in Table 2. A relative turbidity scale is provided in Figure 13. A turbidity value of between 100 and 500 NTU (water would be colored like chocolate milk) was exceeded for 89 observations or ~0.93 d (~22 hours) over the course of the study period. In contrast, turbidity values between 10 and 25 (water would appear slightly cloudy and opaque) was exceeded for 1,436 observations or ~15 d of the study. As is confirmed in Figure 12 and Table 2, the vast majority of turbidity readings were below 5 NTU (80% of observations).

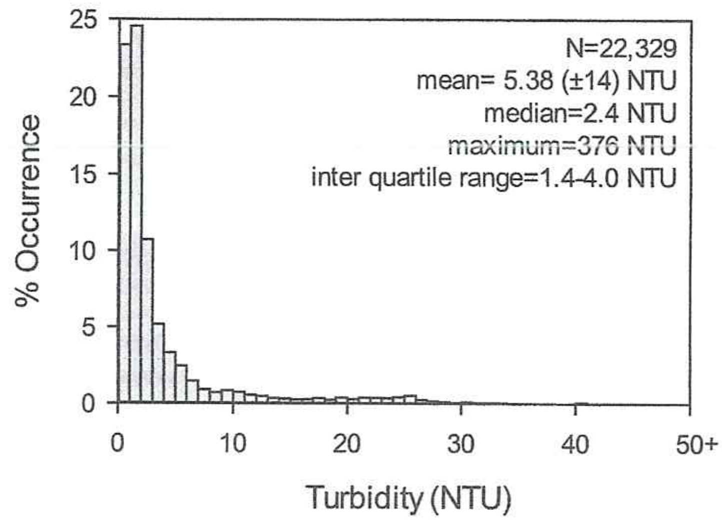


**Figure 12.** 15-minute Tn observations in Shotwell Brook in 2018 as a frequency distribution with associated statistics.

**Table 2.** Percent occurrence of 15-minute turbidity observations in Shotwell Brook, 2018.

| Turbidity level | Number of Observations | Percent of Observations | Approximate Number of Days |
|---|---|---|---|
| 100 ≤ NTU< 500 | 89 | 0.4 % | 0.9 d |
| 50 ≤ NTU < 100 | 160 | 0.7 % | 1.7 d |
| 25 ≤ NTU < 50 | 606 | 2.7 % | 6.3 d |
| 10 ≤ NTU < 25 | 1,436 | 6.4 % | 15.0 d |
| 5 ≤ NTU < 10 | 2,091 | 9.4 % | 21.8 d |
| < 5 NTU | 17,940 | 80.3% | 186.9 d |


**Figure 13.** A relative turbidity scale (image courtesy of www.learnnc.org).

### 4.2.4. General Patterns of Water Quality

Daily average temperature patterns in Shotwell Brook in 2018 (Figure 14d) were typical of streams in the New York State. Temperatures were colder in the early spring and fall (< 10°C) and fluctuated diurnally in response to solar heating. These daily fluctuations can be seen more clearly in the 15-minute temperature time series in the Appendix (Section 8). A Fahrenheit temperature scale is provided on Figure 14a and 14d for reference. Temperatures warmed to between 15°C and 25°C during the summer, and sometimes dropped below 1°C in December. Note that 2017 values are included in panels 10a, 10b, and 10c for reference.

Daily average specific conductance (SC), a surrogate of total dissolved solids or salinity, is regulated by the geology of the watershed. These ionic inputs to a stream are, to a large extent, transported by groundwater, so SC values tend to be high when groundwater dominates streamflow. Specific conductance in Shotwell Brook was indeed inversely related to flow; i.e., the highest values occurred during low flow and low values occurred during wetter periods and in the summer during runoff events (Figure 14e). During high flow conditions, specific conductance values were often less than 450 μS/cm. Conversely, during dry-weather baseflow conditions, specific conductance values often ranged between 600 and 700 μS/cm. These values are typical of other streams in the area. For example, common SC values for tributaries to Cayuga Lake range from 200 to 700 μS/cm (UFI, unpublished data).

Daily average turbidity values were usually low during baseflow and increased abruptly during runoff events (Figure 14f). Turbidity was less than 5 NTU for ~80% of the 2018 study period. During major runoff events, turbidity values were often above 40 NTU. Daily average turbidity values greater than 40 NTU were observed on five days (April 16, July 25, October 2, October 27, and December 2), all in response to rain events. The largest daily averaged turbidity was 56 NTU observed on October 2. Approximately one and a half days had turbidity values between 50 and 100 NTU and values between 25 and 50 NTU occurred for approximately 6 days. A gap in the turbidity record occurred between May 6 and May 17 because of a faulty turbidity sensor.

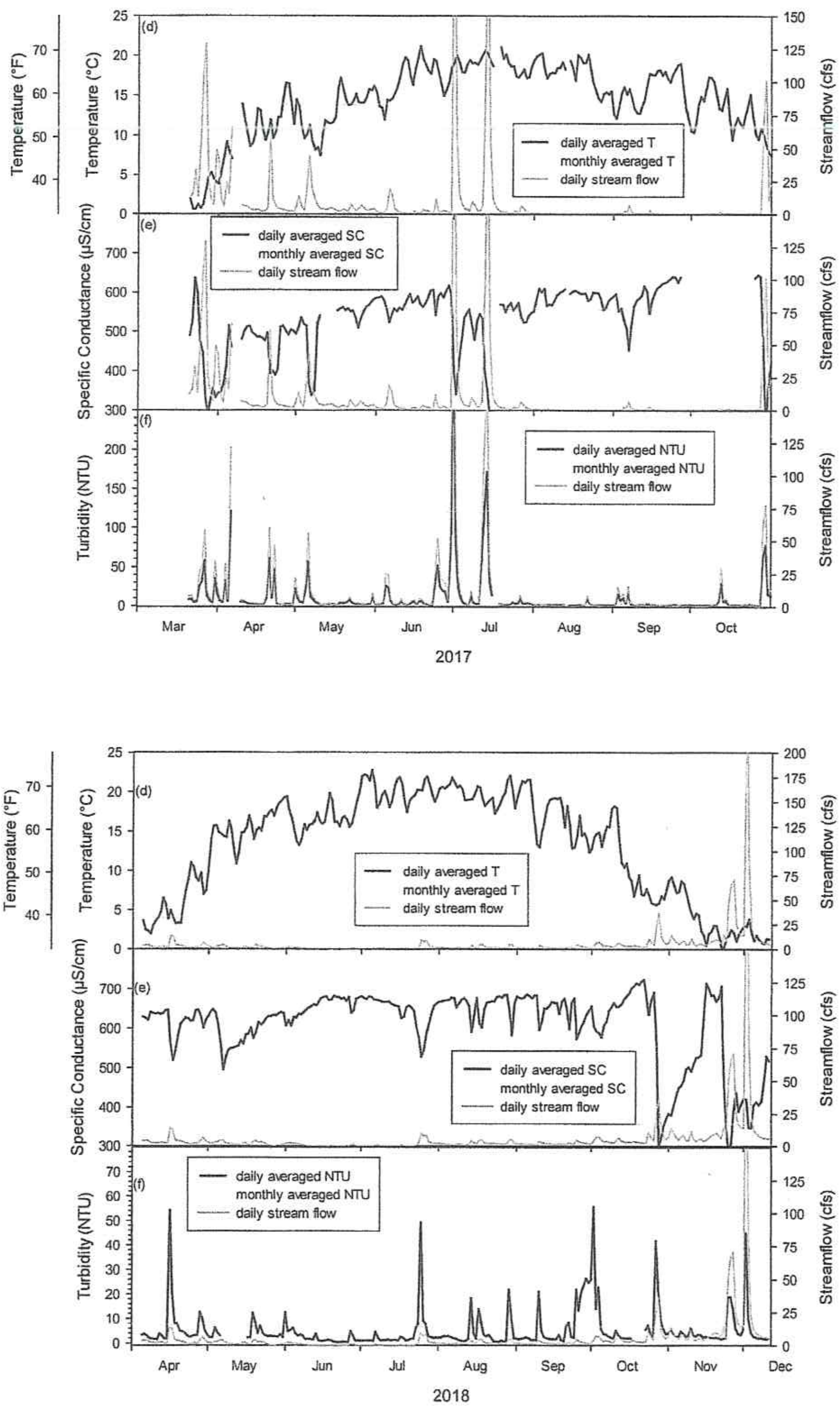


**Figure 14.** Time series of daily averaged stream temperature (a/d), specific conductance (a/d), and turbidity (c/f) for Shotwell Brook in 2017 and 2018.

#### 4.2.5. High Turbidity Events

Eleven high turbidity events, defined as an event with a maximum Tn of greater than 100 NTU (and corresponding flow above 4.25 cfs), were observed in 2018 (Table 3). The highest turbidity value of 2018 was 376 NTU, corresponding to a flow of 26.2 cfs on July 25. These types of events were more common in 2017 (n=21), occurring in every month during the study interval except August. It is expected that such turbidity events would be more common in wetter years with more frequent and/or more intense rainfall events.

**Table 3.** Description of major runoff events with event peak turbidity greater than 100 NTU.

| Event Date | Flow (cfs) | Peak *In-situ* Turbidity (NTU) |
|---|---|---|
| April 16 | 17.9 | 296 |
| July 25 | 26.2 | 376 |
| August 29 | 37.4 | 265 |
| September 10 | 15.8 | 165 |
| September 25 | 14.7 | 110 |
| October 2 | 13.4 | 164 |
| October 4 | 16.7 | 140 |
| October 27 | 48.4 | 198 |
| December 1 | 24.3 | 240 |
| December 2 | 297 | 122 |

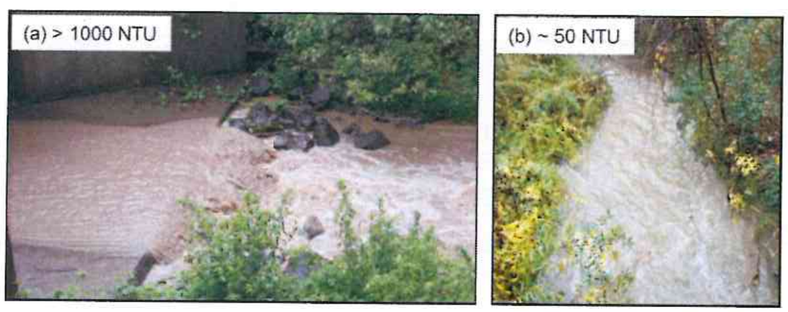


**Figure 15.** Photographs of two high turbidity events in Shotwell Brook from 2016: (a) on June 11, and (b) October 24.

### 4.3. Phosphorus

During the 2018 study interval 22 samples were collected for phosphorus analysis at UFI's laboratory. Nineteen of these samples were collected during the routine monitoring program and three were collected during special sampling targeting high flow conditions during rain events. Additionally four samples were collected as part of the bi-weekly routine schedule that happened to coincide with rain events. Sixteen samples were collected at low flow (less than 4.25 cfs, the 75[th] percentile of flow) and six were collected at high flow. In 2017, the high-flow designation was somewhat higher (4.5 cfs) due to wetter conditions. Low flow average TP was

31 μg/L (Table 4). At low flow 77% of TP was as TDP (24 μg/L) and 23% was PP (7 μg/L). Conversely, at high flows TP averaged 81 μg/L and was dominated by PP (57% or 46 μg/L). This is due to the increased transport of sediment particles during high flow events. TDP comprised 43% of TP at high flow. These results are consistent with other streams in this region (Prestigiacomo et al. 2016). Note that PP decreased in 2018 compared to 2016 and 2017 due to generally drier conditions.

**Table 4.** Comparison of 2016 and 2017 average phosphorus concentrations at low and high streamflow in Shotwell Brook.

| | | | 2016 Phosphorus Concentrations | | | |
|---|---|---|---|---|---|---|
| Streamflow Regime | Count | TP (μg/L) | TDP (μg/L) | TDP Fraction of TP (%) | PP (μg/L) | PP Fraction of TP (%) |
| Low | 11 | 29 (9)[a] | 20 (7) | 69% | 9 (7) | 31% |
| High | 10 | 424 (886) | 29 (26) | 7% | 395 (885) | 93% |
| Overall | 21 | 236 (658) | 25 (19) | 11% | 211 (656) | 89% |

| | | | 2017 Phosphorus Concentrations | | | |
|---|---|---|---|---|---|---|
| Streamflow Regime | Count | TP (μg/L) | TDP (μg/L) | TDP Fraction of TP (%) | PP (μg/L) | PP Fraction of TP (%) |
| Low | 12 | 21 (7) | 16 (7) | 76% | 5 (4) | 24% |
| High | 9 | 80 (68) | 26 (24) | 32% | 54 (53) | 68% |
| Overall | 21 | 46 (53) | 20 (17) | 43% | 26 (42) | 57% |

| | | | 2018 Phosphorus Concentrations | | | |
|---|---|---|---|---|---|---|
| Streamflow Regime | Count | TP (μg/L) | TDP (μg/L) | TDP Fraction of TP (%) | PP (μg/L) | PP Fraction of TP (%) |
| Low | 16 | 31 (16) | 24 (11) | 77% | 7 (6) | 23% |
| High | 6 | 81 (83) | 35 (24) | 43% | 46 (59) | 57% |
| Overall | 22 | 45 (48) | 27 (16) | 60% | 18 (34) | 40% |

[a] values in parentheses are ± 1 standard deviation

## 4.4. Flow-Concentration Relationships

Each of the water quality metrics influenced by particulates (Tn, TP, and PP) was positively dependent on streamflow (log-log format; Figure 16a-c). Concentration-flow relationships were statistically significant ($p < 0.05$) for turbidity ($p = 0.002$) and moderately significant for PP ($p = 0.051$). The Q-Tn relationship was the stronger ($R^2$=0.40) than that of TP and PP. The Q-TP relationship (Figure 16b) was the weakest of these water quality parameters because a portion of TP is composed of dissolved fractions of P that are not substantially regulated by streamflow. Similar patterns are observed in other streams in central New York. These relationships were much weaker in 2018 compared to 2017 due to drier conditions and may also have been influenced by upstream beaver activity.

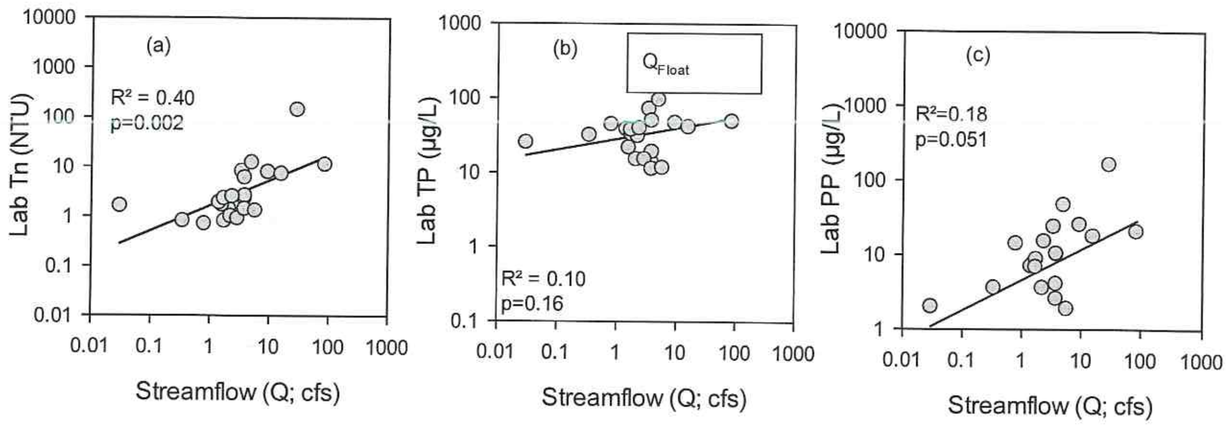


**Figure 16.** Flow-concentration scatterplots and regression statistics for particulate metrics of water quality for: (a) Q-Tn, (b) Q-TP, and (c) Q-PP.

The flow-concentration relationships for the two dissolved metrics of water quality showed low correlation. SC was inversely related to streamflow, with higher values observed during periods of lower flow (Figure 17a); however, this relationship was neither significant nor strong ($p$=0.35, $R^2$=0.04). The Q-TDP relationship was also weak and not statistically significant ($p$=0.66, $R^2$=0.01; Figure 17b), suggesting that streamflow was not an important regulator of dissolved P in Shotwell Brook.

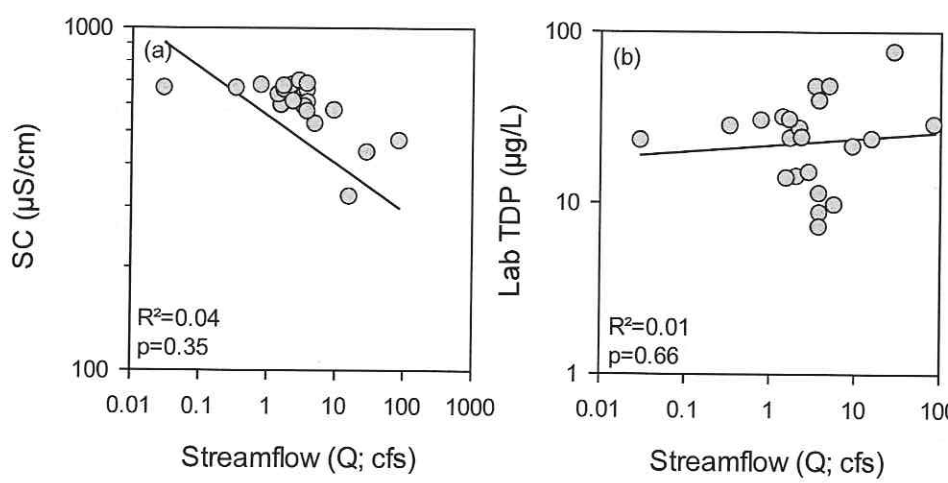


**Figure 17.** Flow-concentration scatterplots and regression statistics for dissolved metrics of water quality for: (a) Q-SC and (b) Q-TDP.

## 4.5. Relationships Between Tn and P

Relationships between turbidity and TP, PP, and TDP were all statistically significant ($p$ < 0.05) (Figure 18). Increases in turbidity were relatively strong predictors of increases in particulate forms of phosphorus for the data collected in 2018. The strongest relationship was between turbidity and TP ($R^2 = 0.52$, $p = 0.0002$; Figure 18a).

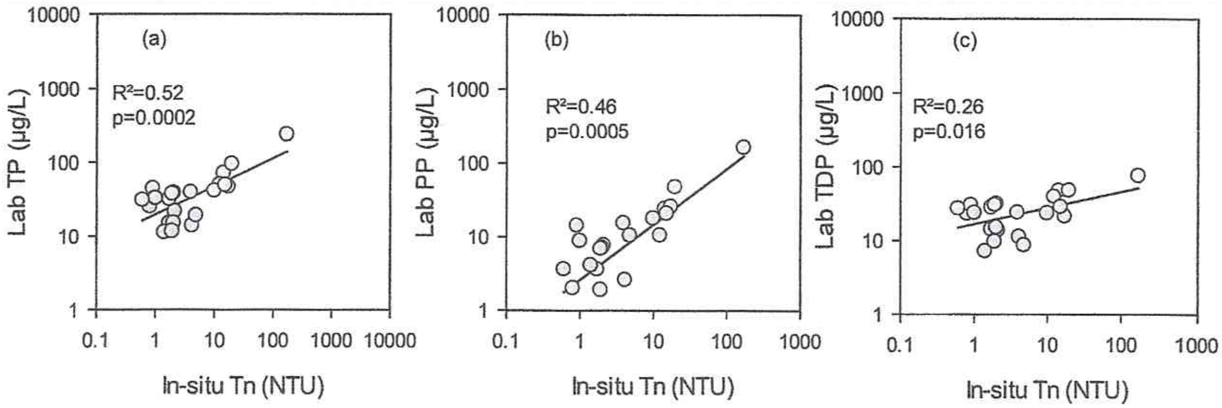


**Figure 18.** Flow-concentration scatterplots and regression statistics for particulate metrics of water quality for: (a) Tn-TP, (b) Tn-PP, and (c) Tn-TDP.

## 4.7. Relationship between Air and Stream Temperature

The paired time series of stream and air T (Figure 20a) show that stream T fluctuated daily and seasonally in response to air T, although the daily fluctuations in the stream T were less dramatic than air T. Also, stream T was noticeably cooler than the air T in the summer as was observed in 2017. This is characteristic of streams in temperate climates and attributed here to the: (1) shading from trees and (2) buffering effect of (more) thermally stable groundwater inputs to streamflow. A Fahrenheit temperature scale is provided on Figure 20a for reference.

The temperature of Shotwell Brook was highly correlated with air temperature ($R^2$=0.94; Figure 20b). This observation is not unexpected, but the high correlation between air T and stream T is useful because T is an important regulator of water density. Estimates of the stream's density would allow for estimating its entry depth relative to the surface of Skaneateles Lake. If temperature profile data was available in the lake, estimates of stream T would allow for first-order estimates of the depths impacted by the stream, (i.e., during a high turbidity runoff event), which would provide an early warning if intake water quality was at risk. For example, if stream T was warmer (i.e., less dense) than the surface of the lake, the stream would be expected to impact the upper waters of the lake. If, however, the stream T was substantially cooler than the surface of the lake (i.e., more dense), the stream would enter the depths of the lake with similar temperature and density.

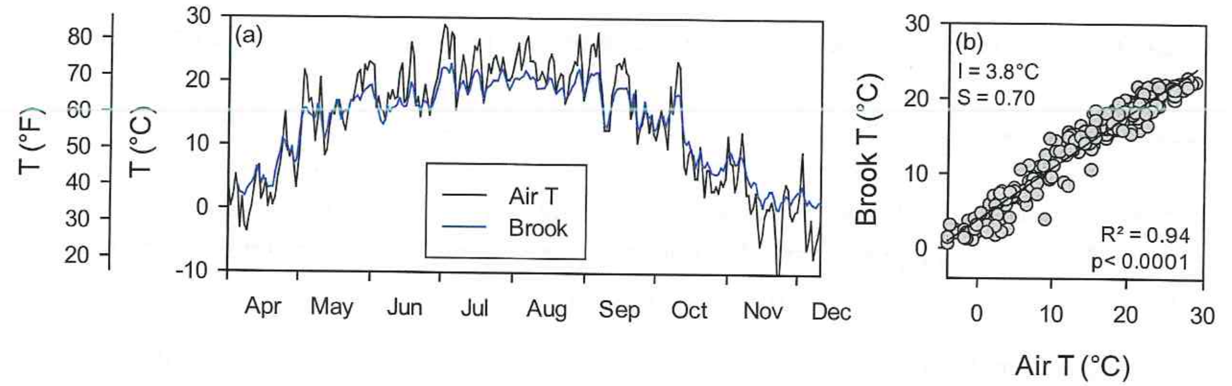


**Figure 20.** Analysis of temperature patterns in Shotwell Brook: (a) time series of temperature (in °C) in Shotwell Brook and air temperature and (b) regression plot of air temperature versus brook temperature. °F scale for (a) included as reference.

## 5. Conclusions

Shotwell Brook is a small but important tributary to Skaneateles Lake because of its proximity to the Village of Skaneateles and drinking water intakes for the Village of Skaneateles and City of Syracuse. The 2018 study of Shotwell Brook met all stated objectives: (1) estimates of streamflow were made using stream velocity and cross-sectional area measurements for a range of conditions, (2) a (nearly) continuous record of flow was generated from *in-situ* stage measurements and a developed rating curve, (3) the water quality of Shotwell Brook was characterized with *in-situ* probes and laboratory analyses, and (4) the patterns of phosphorus were described during baseflow and runoff event conditions.

Environmental conditions in 2018 consisted of a high precipitation winter with a slightly warmer than normal later summer (July-September) compared with the 1980-2017 average. July, August, October and November were also much wetter than 1980-2017 average rainfall, leading to higher flows in Shotwell Brook.

Shotwell Brook is a small stream with a small watershed, resulting in generally low streamflow. Mean flow in 2017, a very wet year, was 10 cfs compared to 5.7 cfs in 2018. However, the median flow in 2018 (2.1 cfs) was somewhat higher than the 2017 median flow of 1.9 cfs. While relatively rare, high flow events are extremely important because they contribute most of the nutrients and materials loaded to the lake and they cause high levels of turbidity which degrades the aesthetic quality in the brook and lake.

15-minute turbidity values were less than 5 NTU for 80% of the study period but increased abruptly during runoff events. Median turbidity was 2.4 NTU and 75% of Tn observations were less than 4.0 NTU. Eleven high Tn events of greater than 100 NTU with flows above 4.25 cfs were observed in 2018. Daily average Tn values greater than 40 NTU were observed on 5 days, all in response to rainfall events of varying magnitude. The highest daily averaged turbidity was 55.8 NTU observed on October 2. Mean turbidity in 2018 was 5.4 NTU, compared to 11.3 NTU in 2017. Median turbidity in 2018 was 2.4 NTU compared to 2.2 NTU in 2017.

At low flow TP was dominated by TDP (77%), but at high flows TP was comprised mostly of PP (57%). The contribution of PP to TP was slightly higher during high flows (68%) in 2017.

## 6. Recommendations for Future Monitoring

The Upstate Freshwater Institute has several recommendations related to future monitoring of Shotwell Brook. These recommendations were guided by the findings of the monitoring conducted in 2018. They are:

1. Continued monitoring and sampling in additional years to provide a more comprehensive assessment of the brook's hydrological and water quality conditions under different snowfall and precipitation driving conditions. For example, additional years of phosphorus data would contribute to more accurate loading estimates.
2. Hydrograph separation would allow for the quantification of seasonal or event-specific runoff volumes, which could be used to plan for and assess the success of turbidity remediation strategies (e.g., retention ponds, constructed wetlands),
3. Paired observations from Shotwell Brook and Skaneateles Lake should be made to assess impacts from high turbidity events.
4. Pairing of Shotwell Brook and Skaneateles temperatures and turbidity would allow for the assessment of the in-stream conditions that contribute to deteriorations in drinking water quality.
5. The monitoring program should also be extended to include measurements of nitrogen (i.e., total nitrogen, total dissolved nitrogen, nitrate, and ammonia).

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# 8. Appendix

## 8.1. Monthly Time Series of Measurements

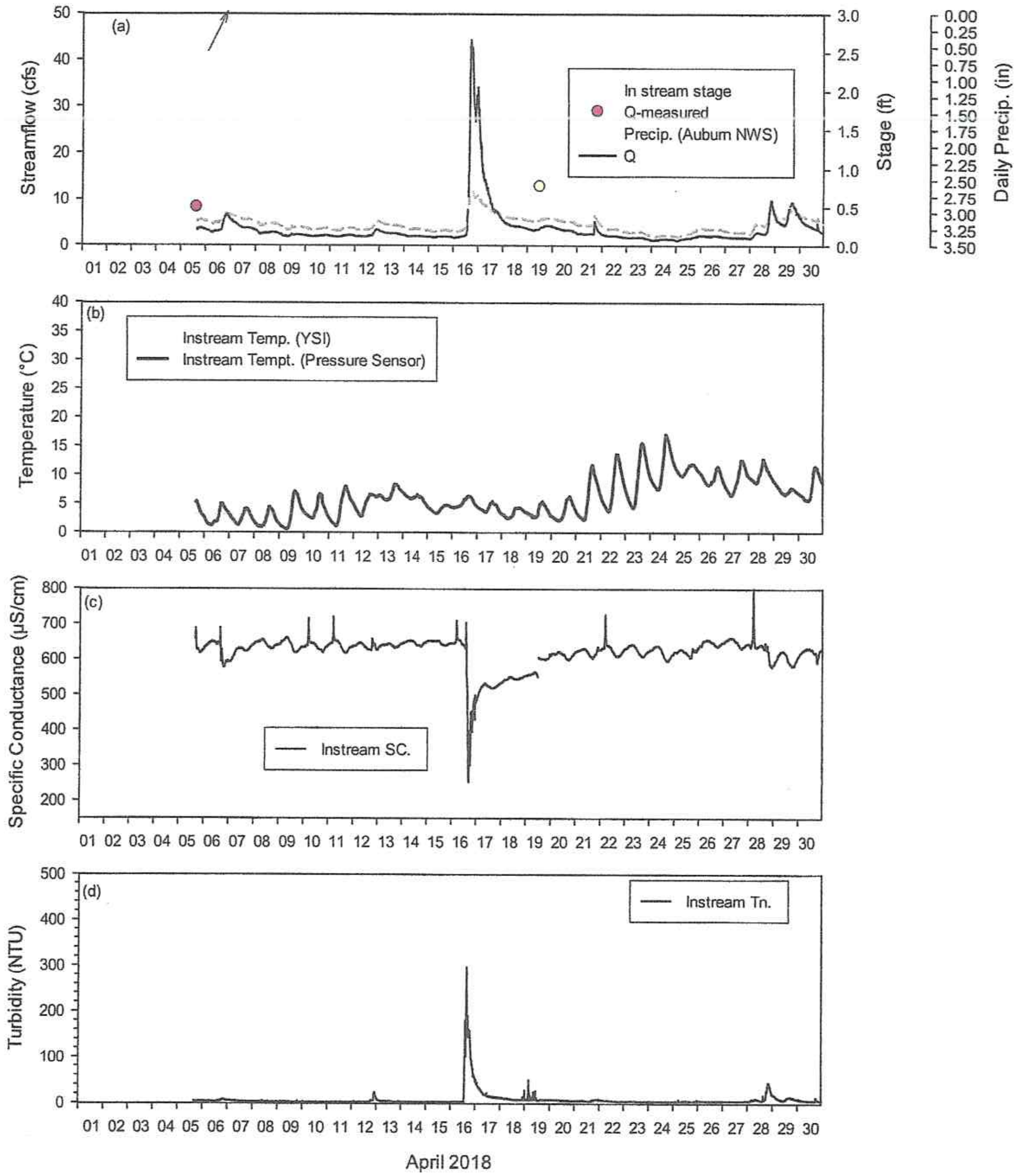


**Figure A1.** Shotwell Brook April 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

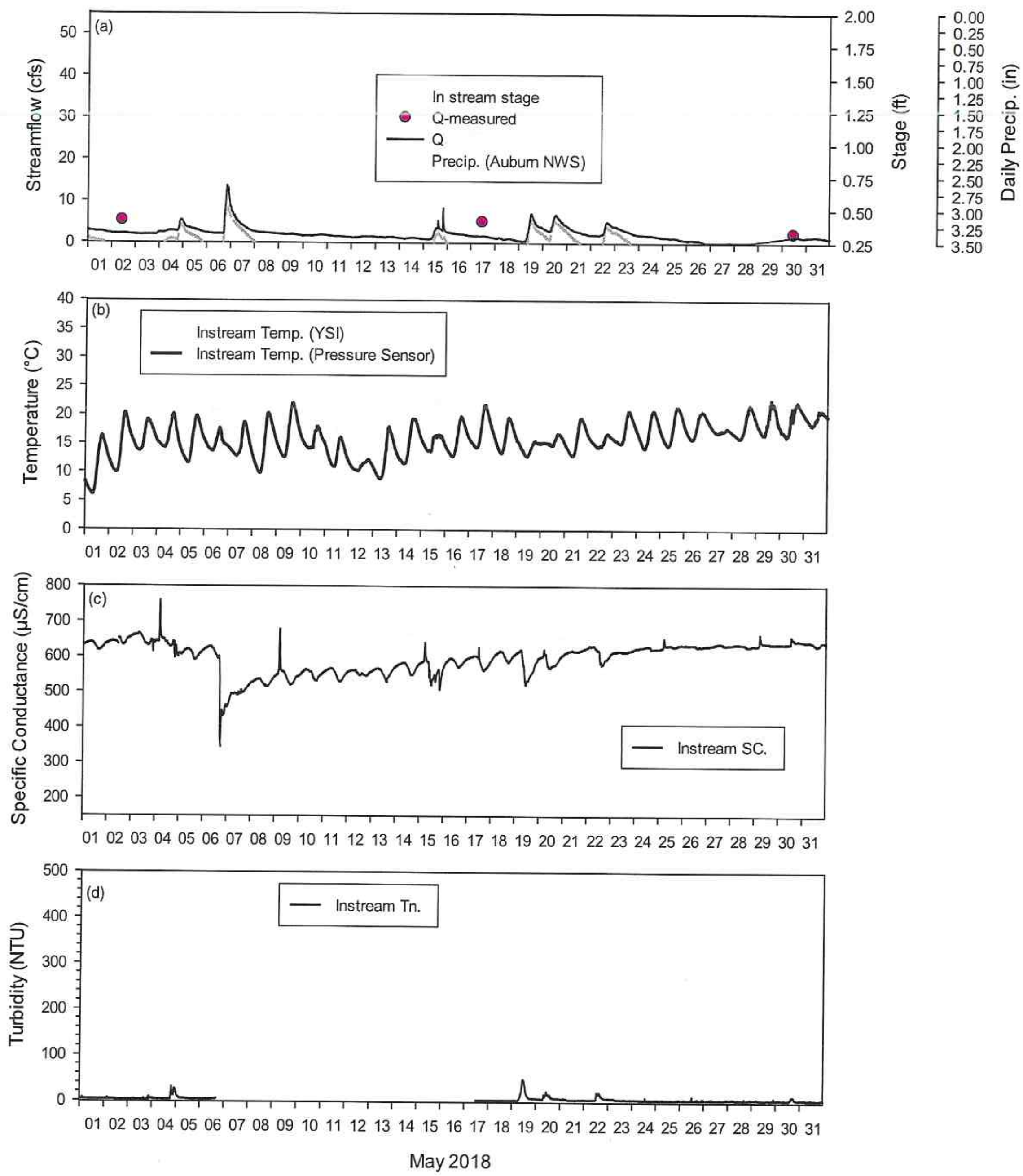


**Figure A2.** Shotwell Brook May 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

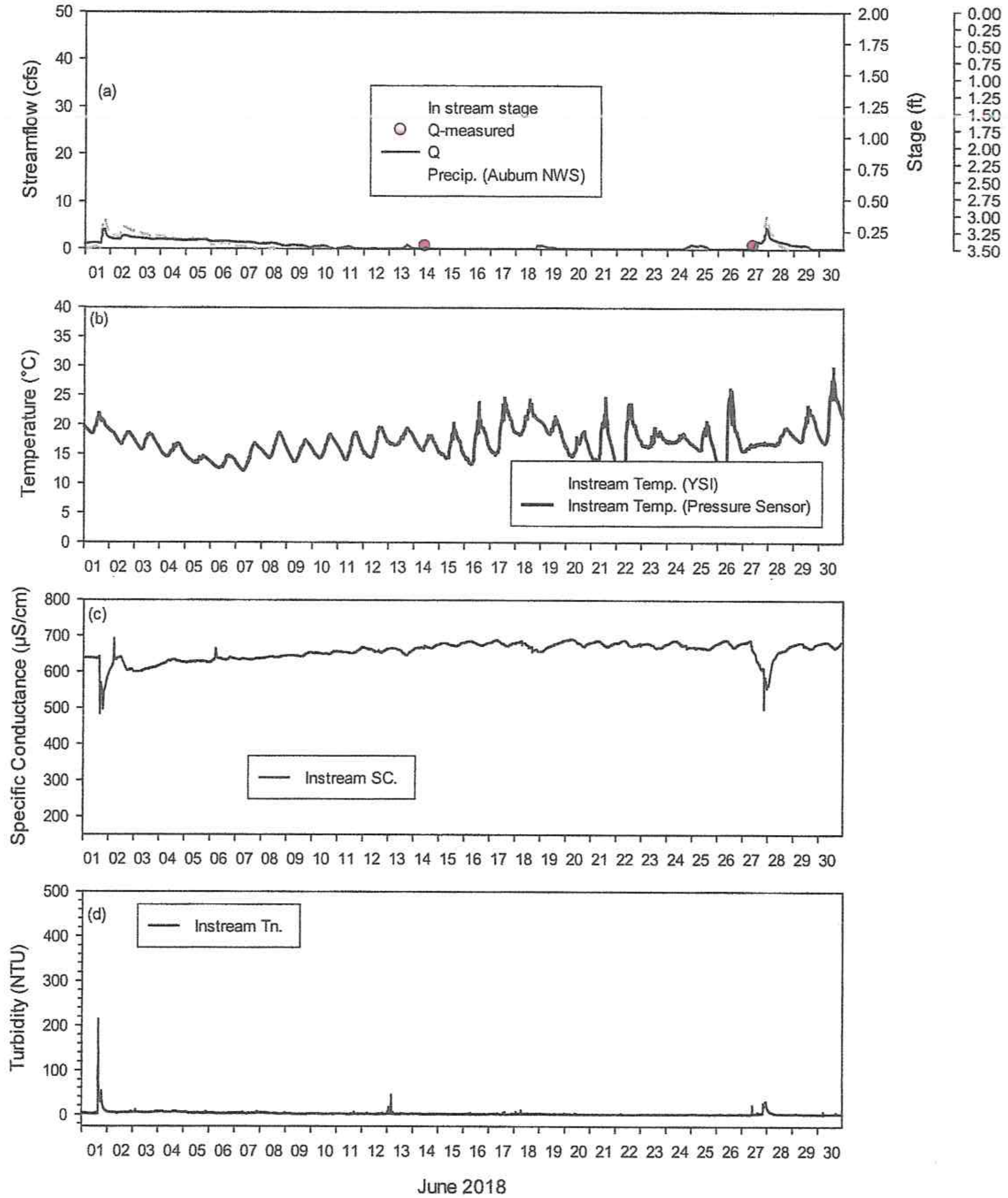


**Figure A3.** Shotwell Brook June 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

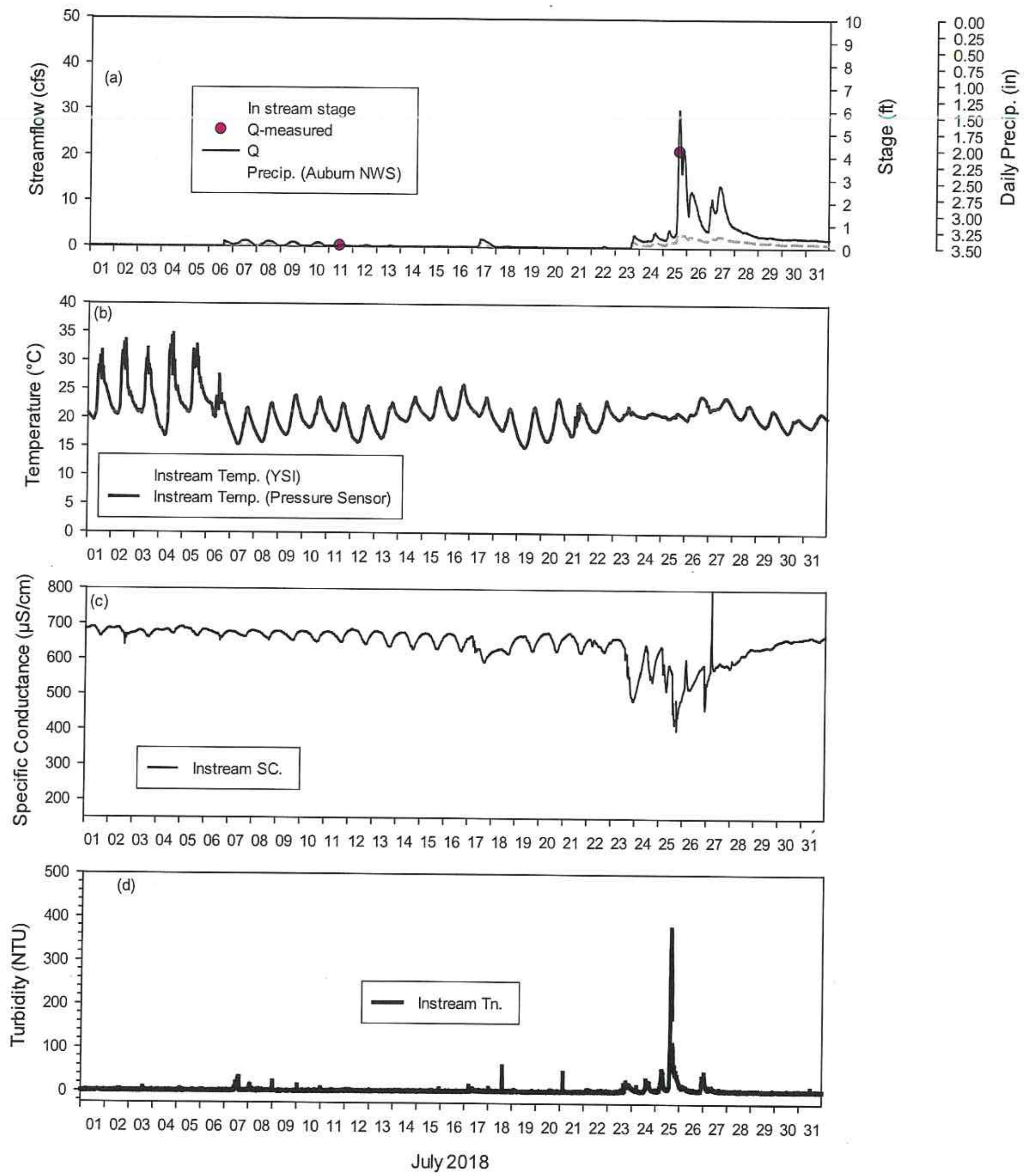


**Figure A4.** Shotwell Brook July 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

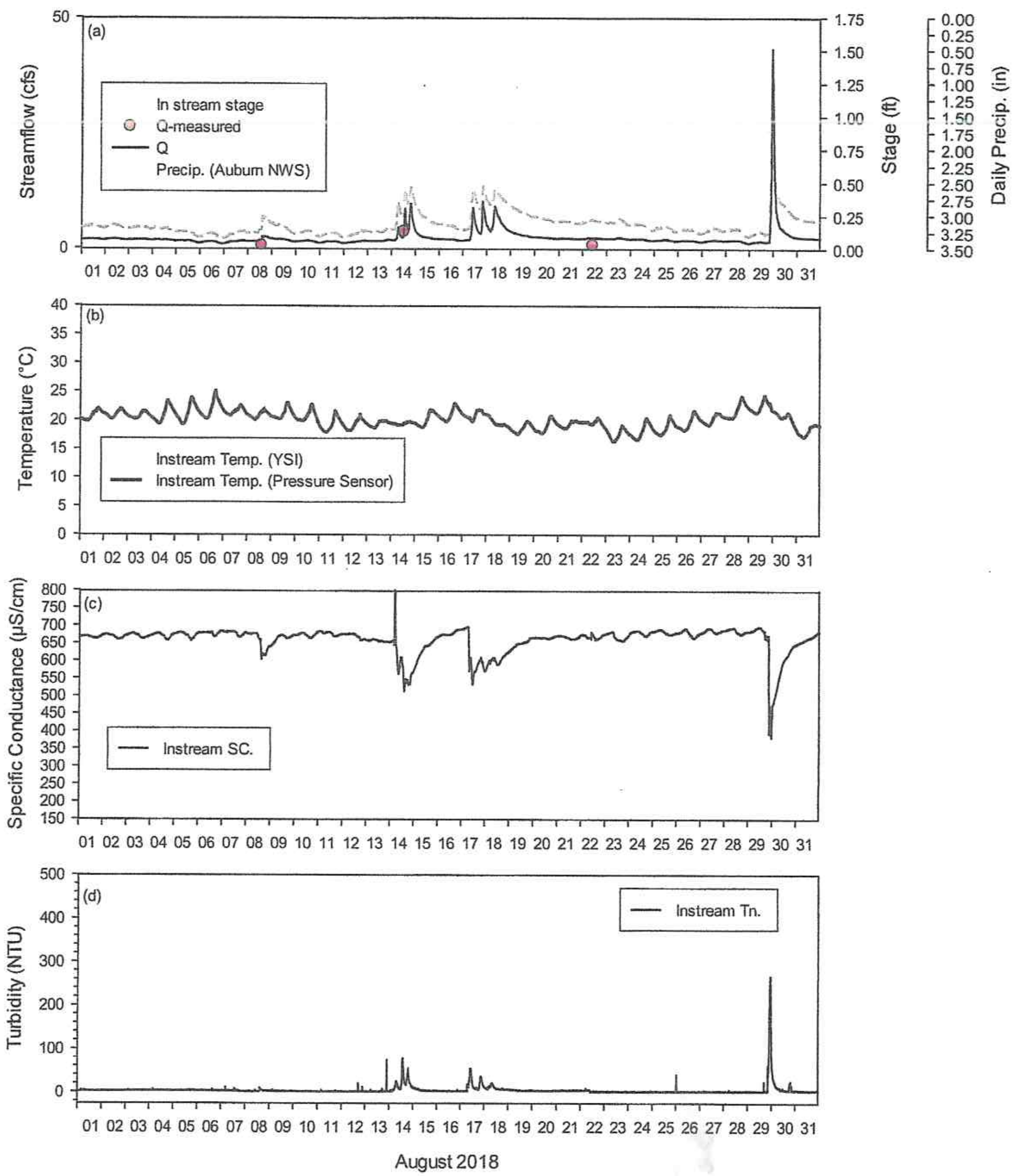


**Figure A5.** Shotwell Brook August 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

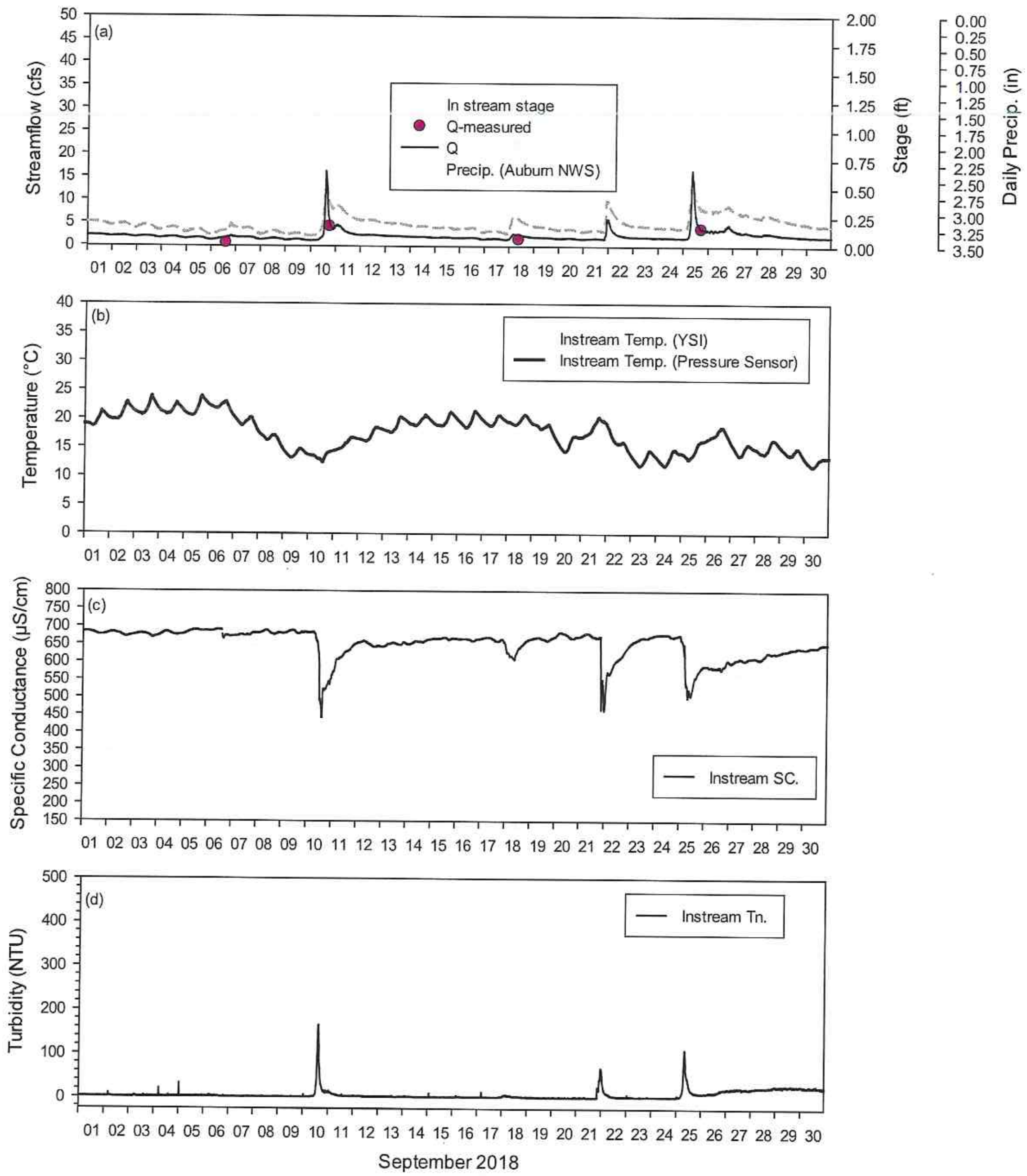


**Figure A6.** Shotwell Brook September 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

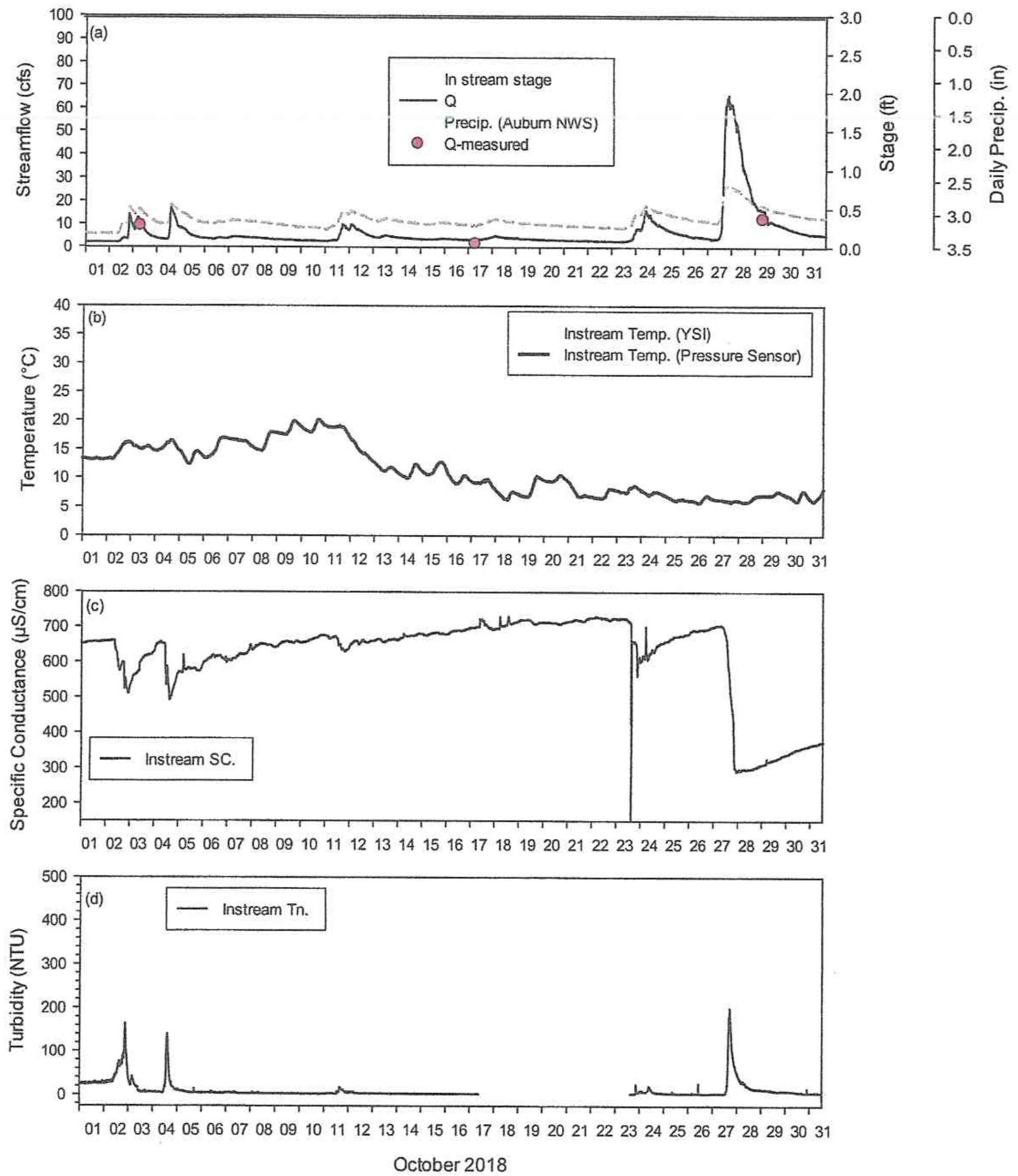


**Figure A7.** Shotwell Brook October 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

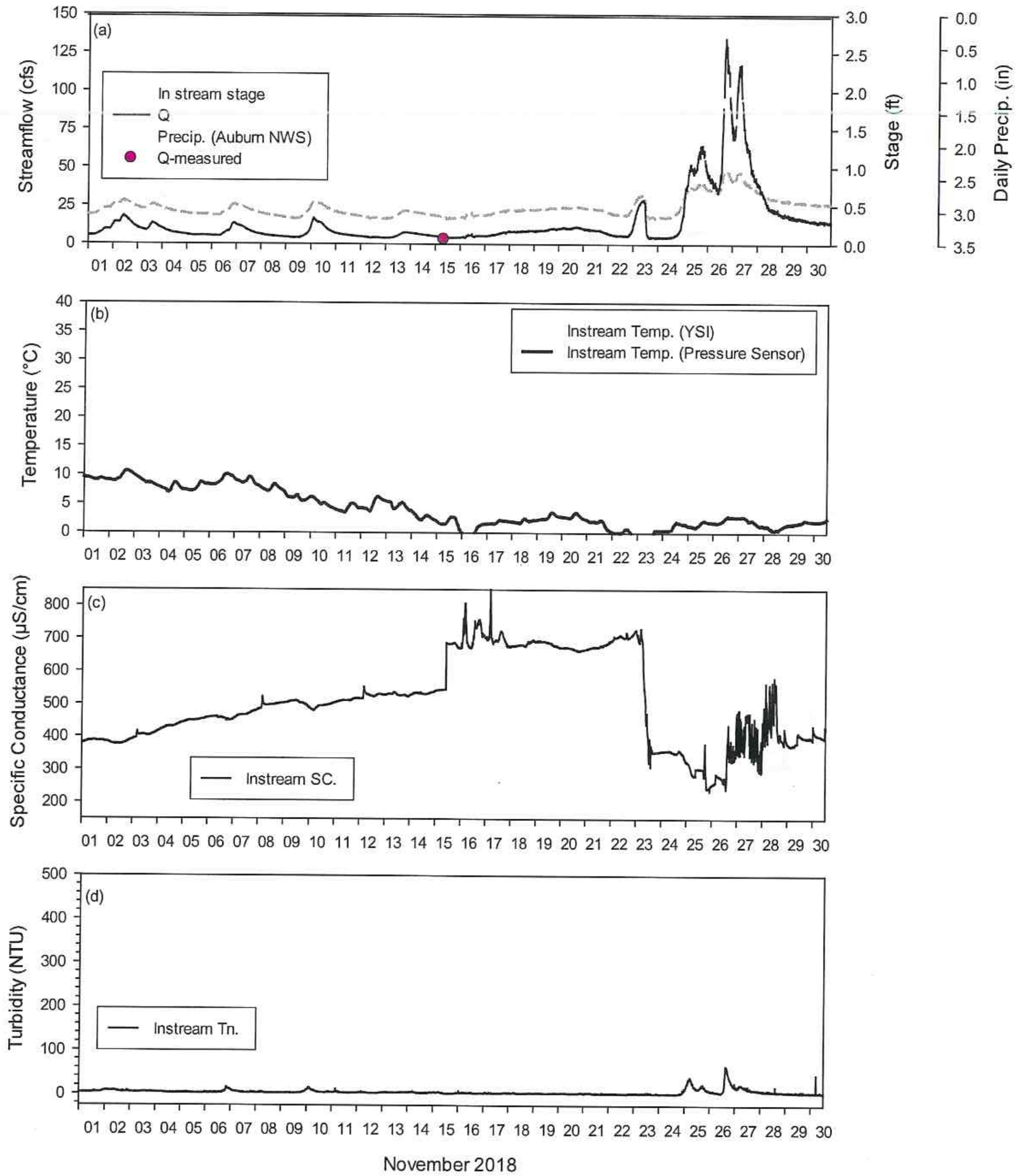


**Figure A8.** Shotwell Brook November 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

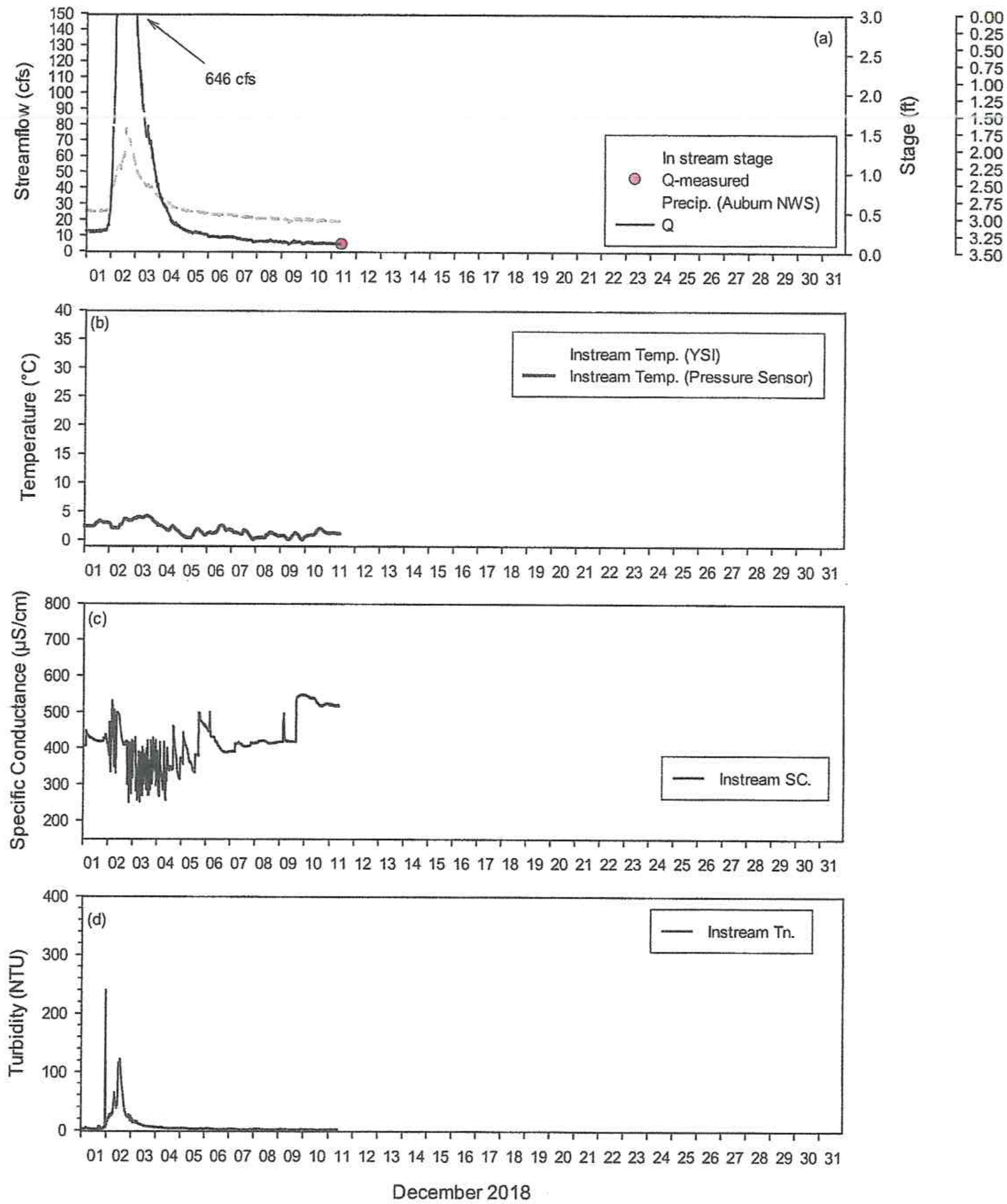


**Figure A9.** Shotwell Brook December 2018 time series of: (a) streamflow, stage, and precipitation, (b) stream temperature, (c) specific conductance, and (d) turbidity.

**Table A1.** Summary of stream cross-sectional area, velocity, and flow measurements.

| Date/Time | Bridge Stage (ft) | Cross-Sectional Area ($ft^2$) | Float Velocity (ft/s) | Velocity Meter (ft/s) | TVHR Velocity (ft/s) | Average velocity (ft/s) | Estimated streamflow (cfs) |
|---|---|---|---|---|---|---|---|
| 4/05/18 15:01 | .33 | 1.33 | 4.27 | 11.08 | 3.20 | 6.18 | 8.24 |
| 4/19/18 11:28 | .34 | 1.94 | 4.48 | 12.55 | 2.87 | 6.63 | 12.90 |
| 5/02/18 10:37:00 | .21 | 1.35 | 4.21 | - | 3.54 | 3.88 | 5.22 |
| 5/17/18 11:13 | .14 | 1.2 | 3.63 | 7.70 | 1.20 | 4.18 | 5.01 |
| 5/30/18 11:17 | .13 | .60 | 3.03 | 6.60 | 1.30 | 3.64 | 2.19 |
| 6/14/18 09:40 | .04 | .36 | 2.71 | - | .82 | 1.76 | .64 |
| 6/27/18 09:20 | .05 | .50 | 2.04 | - | 1.14 | 1.59 | .80 |
| 7/11/18 11:10 | .05 | .20 | 1.34 | - | .45 | .90 | .18 |
| 7/25/18 16:30:00 | .64 | 4.00 | 5.26 | - | - | 5.26 | 21.04 |
| 8/08/18 13:40 | .16 | .40 | 1.99 | - | .94 | 1.48 | .59 |
| 8/14/18 12:15 | .32 | 1.37 | 3.74 | 2.13 | 2.11 | 2.66 | 3.65 |
| 8/22/18 09:51 | .23 | .49 | 2.20 | - | .59 | 1.39 | .68 |
| 9/06/18 14:15 | .16 | .35 | 1.89 | - | .60 | 1.25 | .44 |
| 9/10/18 18:00 | .38 | 1.44 | 3.63 | 2.53 | 2.39 | 2.85 | 4.10 |
| 9/18/18 09:00 | .24 | .63 | 2.50 | - | 1.66 | 2.08 | 1.32 |
| 9/25/18 17:10 | .33 | 1.29 | 3.50 | 2.60 | 2.37 | 2.82 | 3.65 |
| 10/03/18 09:15 | .47 | 2.38 | 4.76 | 4.65 | 3.45 | 4.29 | 10.18 |
| 10/17/18 08:55 | .29 | 1.00 | 3.17 | - | 1.71 | 2.44 | 2.44 |
| 10/29/18 09:20 | .54 | 2.79 | 5.22 | 5.35 | 3.57 | 4.71 | 13.16 |
| 11/15/18 09:45 | .33 | 1.13 | 4.47 | 4.43 | 2.85 | 3.92 | 4.42 |
| 12/11/18 09:45 | .45 | 1.18 | 3.95 | 4.30 | 3.18 | 3.81 | 4.49 |

- results were invalid due to interference or inadequate flow volume

**Table A2.** Monthly average of water quality parameters in Shotwell Brook in 2018.

| Month | Q (cfs) | T (°C) | SC (µS/cm) | Tn (NTU) |
|---|---|---|---|---|
| April | 3.80±4.49 | 5.67±3.25 | 618±42.2 | 6.78±17.82 |
| May | 2.06±1.52 | 15.48±3.01 | 596±44.6 | 4.14±4.47 |
| June | 0.65±0.85 | 16.58±2.10 | 656±26.5 | 2.33±5.57 |
| July | 1.34±3.13 | 20.19±2.14 | 644±44.5 | 3.91±16.46 |
| August | 2.25±2.35 | 19.81±1.51 | 659±36.6 | 3.97±12.62 |
| September | 2.12±1.29 | 17.11±2.99 | 651±38.9 | 6.98±12.18 |
| October | 6.42±8.80 | 10.68±4.14 | 616±121.0 | 10.26±19.97 |
| November | 14.13±18.77 | 3.95±2.87 | 502±129.4 | 4.64±5.85 |
| December* | 42.41±91.05 | 1.84±1.07 | 421±64.4 | 7.53±17.33 |

± 1 standard deviation, *through December 11

**Table A3.** Summary of laboratory results for phosphorus and turbidity.

| UFI Lab ID | Date and Time | Flow (cfs) | TP (μgP/L) | TDP (μgP/L) | PP (μgP/L) | Tn (NTU) |
|---|---|---|---|---|---|---|
| 2018095001 | 4/05/18 15:01:00 | 3.79 | 13.9 | 11.3 | 2.6 | 2.3 |
| 2018109029 | 4/19/18 11:28:00 | 3.84 | 19.1 | 8.7 | 10.4 | 2.6 |
| 2018122005 | 5/02/18 10:37:00 | 2.07 | 15.0 | 14.2 | 0.8 | 1.4 |
| 2018137020 | 5/17/18 11:13:00 | 1.57 | 21.6 | 13.9 | 7.7 | 1.7 |
| 2018150029 | 5/30/18 11:17:00 | 1.42 | 38.7 | 31.6 | 7.1 | 1.9 |
| 2018165028 | 6/14/18 09:40:00 | 0.03 | 25.1 | 23.1 | 2.0 | 1.6 |
| 2018180010 | 6/29/18 09:20:00 | 0.79 | 44.4 | 30.2 | 14.2 | 0.7 |
| 2018192081 | 7/11/18 11:10:00 | 0.34 | 31.7 | 28.1 | 3.6 | 0.8 |
| 2018206082 | 7/25/18 16:30:00 | 28.54 | 240.0 | 76.2 | 163.8 | 142.0 |
| 2018220082 | 8/08/18 13:40:00 | 1.73 | 32.6 | 23.8 | 8.8 | 0.8 |
| 2018226064 | 8/14/18 12:15:00 | 3.42 | 71.6 | 47.6 | 24.0 | 8.1 |
| 2018234084 | 8/22/18 09:51:00 | 2.22 | 30.8 | 27.2 | 3.6 | 1.0 |
| 2018250001 | 9/06/18 14:15:00 | 1.70 | 37.5 | 30.6 | 6.9 | 2.3 |
| 2018254013 | 9/10/18 18:00:00 | 4.98 | 95.3 | 47.9 | 47.4 | 12.1 |
| 2018261127 | 9/18/18 09:00:00 | 2.36 | 39.3 | 24.0 | 15.3 | 2.5 |
| 2018268060 | 9/25/18 17:10:00 | 3.79 | 50.0 | 39.5 | 10.5 | 6.0 |
| 2018276032 | 10/03/18 09:15:00 | 9.38 | 46.9 | 21.3 | 25.6 | 7.8 |
| 2018290005 | 10/17/18 08:55:00 | 2.89 | 15.1 | 15.0 | 0.1 | 0.9 |
| 2018303001 | 10/29/18 09:20:00 | 15.70 | 41.3 | 23.5 | 17.8 | 7.2 |
| 2018319001 | 11/15/18 09:45:00 | 3.79 | 11.3 | 7.2 | 4.1 | 1.4 |
| 2018331005 | 11/27/18 09:50:00 | 85.06 | 49.3 | 28.6 | 20.7 | 11.2 |
| 2018346001 | 12/11/18 09:45:00 | 5.75 | 11.6 | 9.7 | 1.9 | 1.3 |

Note: highlighted data were ran out of hold time to check for TP-TDP ratio discrepancies

## 8.2. Data Files

Please see the attached CD for the data files