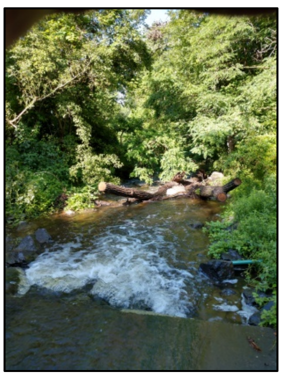
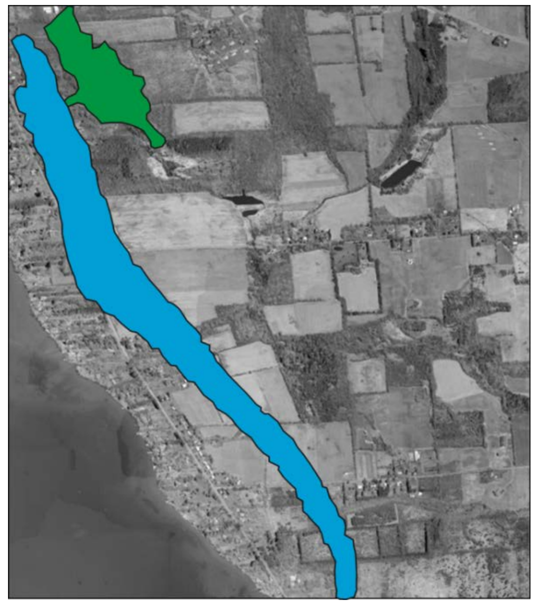
Water quality and flow of Shotwell Brook to Skaneateles Lake, 2019





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Cover images from l-r: (top) May 10, (bottom) July 23, and sub-watershed (image from UFI 2016)

1. Introduction

1.1. Skaneateles Lake: Characteristics, use, and management

Skaneateles Lake is located in central New York within Onondaga, Cortland, and Cayuga counties (Figure 1a); this area is known as the “Finger Lakes” region due to the presence of eleven long, narrow lakes formed by a receding glacier. The lake is the second easternmost Finger Lake (Figure 1b), and approximately 19 km south-southwest of Syracuse, NY and 8 km east of Auburn, NY. The Village of Skaneateles lies at the northern end of the lake, at the outflow; the lake is oriented along a north/northwest and south/southeast axis. Of the eleven Finger Lakes, Skaneateles Lake is the third deepest (maximum = 90.5 m, mean = 43.5 m), has the fourth largest volume ($1{,}563 \times 10^6$ m^3), and has the fifth smallest surface area (35.9 km^2; Schaffner and Oglesby 1978).

Skaneateles Lake is classified by New York State as an AA waterbody; under the highest rating, water from the lake can be used for potable purposes and must meet certain water quality regulations set by the New York State Department of Health (NYSDOH). The City of Syracuse uses the lake as its primary source of water, and maintains an active watershed management program (i.e. Skaneateles Lake Watershed Agricultural Program) in order to protect water quality. Two intakes located in the northern end of the lake, approximately 1.3 and 2 km south of the Village of Skaneateles, withdraw the drinking water. Skaneateles Lake is also used recreationally for swimming, boating, and fishing.

Skaneateles Lake has a relatively small watershed (154 km^2) and is made up of primarily agricultural (36%) and forested (34%) lands with very little residential and commercial development. According to the 2017 Harmful Algal Bloom Action Plan for Skaneateles Lake, an estimated 80% of nonpoint source phosphorus loading, a potential trigger for harmful algal blooms (HABs), was attributed to agricultural land within the watershed (NYSDEC 2017). One way to manage water quality within the lake is to manage the watershed; best management practices are intended to improve the quality and/or lessen the quantity of water entering the lake via the tributaries.

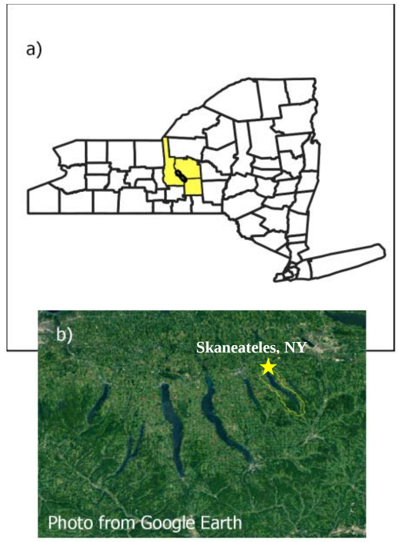


Figure 1. Skaneateles Lake and watershed location in (a) New York and (b) Finger Lakes region.

1.2. Shotwell Brook

Shotwell Brook is a short tributary that enters Skaneateles Lake in the northeast corner of the lake, approximately 3 km south-southeast of the Village of Skaneateles and 1.5 km southeast of the drinking water intakes. The tributary is known to be a source of turbidity to the lake during periods of high flow, including periods after high intensity rainfall events and after snow melt. The watershed of Shotwell Brook accounts for approximately 5.6 % of the Skaneateles Lake watershed (8.6 km^2; Pradhanang 2009), and it is the third largest sub-watershed in the Skaneateles Lake basin. Agricultural lands make up a majority of the tributary's watershed (64 %; Table 1; Figure 2). Due to the predominant land cover and its proximity to the drinking water intakes, the water quality of Shotwell Brook is important to the water quality of Skaneateles Lake.

Water quality and streamflow of Shotwell Brook has been monitored annually since 2016 by Upstate Freshwater Institute (UFI) with funding from the Town of Skaneateles. The sampling design has varied only slightly since 2016. Because of the longevity and consistency of the Shotwell Brook monitoring program, more accurate characterization of the tributary over a range of conditions is possible. The data collected during this multi-year monitoring program will be useful for the future management of Skaneateles Lake.

Table 1. Landcover classes of Shotwell Brook (tributary to Skaneateles Lake) watershed (USGS 2016, NLCD 2018).

Tributary	Drainage area (km^2)	Pasture and hay	Cultivated crops	Forest and grassland	Developed	Wetlands
Shotwell Brook	9.1	21	43	20	7	7

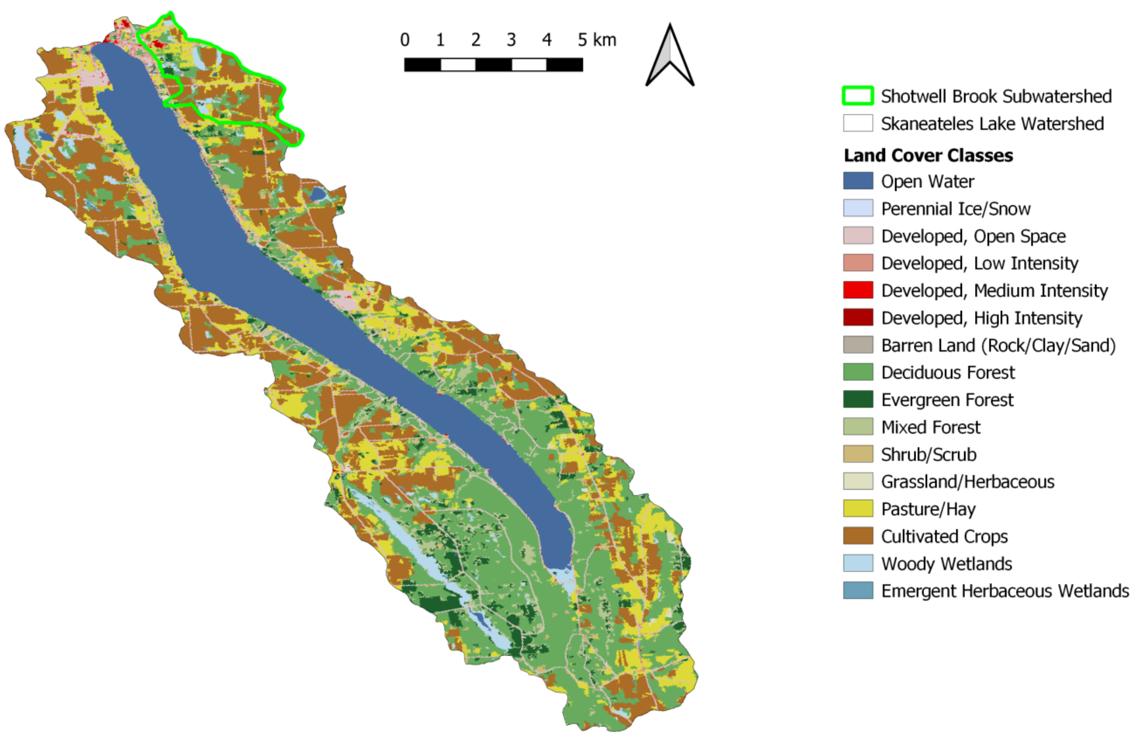


Figure 2. Landcover of Skaneateles Lake watershed with Shotwell Brook subwatershed delineated (green outline). Watersheds delineated with StreamStats (USGS 2016). Land cover from 2016 National Land Cover Dataset (NLCD 2018).

1.3. Objectives

The goal of the 2019 Shotwell Brook monitoring program was to build on the historic record that will be used in the development of a nine element (9E) watershed management plan and simulation models of Skaneateles Lake and its watershed.

Specific objectives of this study include:

1) Develop estimates of streamflow using stream velocity and cross-sectional area measurements over a range of conditions (i.e. high and low flow).
2) Provide near-continuous measurements of select water quality parameters using high frequency measurements from *in-situ* equipment.
3) Describe patterns of constituents affecting water quality (i.e. phosphorus compounds) during baseflow and high flow conditions.

2. Methods

2.1. Study area and sampling period

Shotwell Brook was monitored approximately biweekly from May to late November 2019. Two additional sampling events took place before May. Each monitoring event consisted of both water quality sample collection and field measurements, as conditions allowed.

The site selected for this monitoring period has been utilized by UFI for previous monitoring efforts (2016-2018) as well as by the City of Syracuse (Pradhanang 2009). It is located approximately 210 m (690 ft) upstream of the mouth of the brook (42°55'27.70"N, 76°24'18.30"W; Figure 3). Selection of this site was attributed to the proximity to the mouth without the influence of lake water on water quality and convenience in equipment deployment, maintenance, and sample collection.

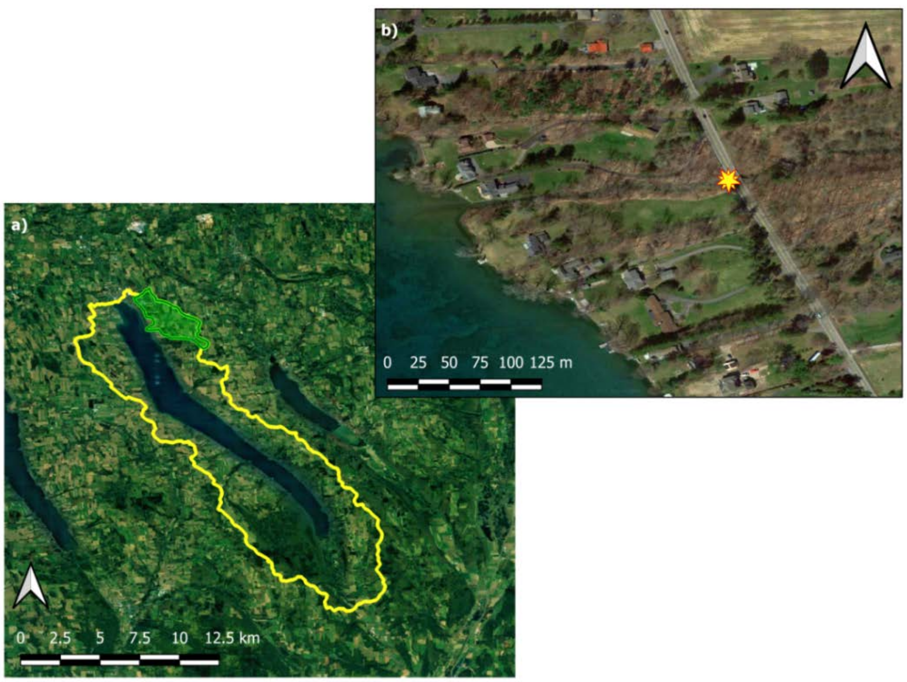


Figure 3. Location of Shotwell Brook and sampling site: (a) Shotwell Brook subwatershed (green) of Skaneateles Lake watershed (yellow), and (b) sampling location for 2019 monitoring program. Watersheds delineated with StreamStats (USGS 2016). Satellite imagery from Google Earth.

2.2. Laboratory measurements

Water quality samples were collected at the overspill of the concrete culvert near the *in-situ* sensors. Samples were analyzed at UFI's ELAP-certified laboratory for the following analytes: total phosphorus (TP), total dissolved phosphorus (TDP) and turbidity (Tn). All analyses were completed using standard methods (Table 2). From these measured parameters, particulate phosphorus (PP) was derived as $= TP - TDP$.

Table 2. Laboratory analytical methods specification. "SM" refers to Standard Methods (Rice et al. 2012).

Analysis	Method No.
Phosphorus, Total, Total Dissolved (as P; TP, TDP) low range	SM 4500-P F-H -2011
Turbidity	SM 2130 B -2011

2.3. Field measurements

2.3.1. Streamflow

Streamflow (Q; measured in cubic feet per second or cfs) is the product of the cross sectional area (A; measured in ft^2) and velocity (V; measured in ft/s). This is visually represented in Figure 4. Measurements of streamflow are needed during both high and low flow conditions in order to best characterize the flow of the stream. A rating curve, or the statistical relationship between stream depth (stage, S) and streamflow, was developed for this monitoring period using measurements made in the field. A near-continuous flow record can be developed using the rating curve relationship and near-continuous stage measurements collected by *in-situ* equipment.

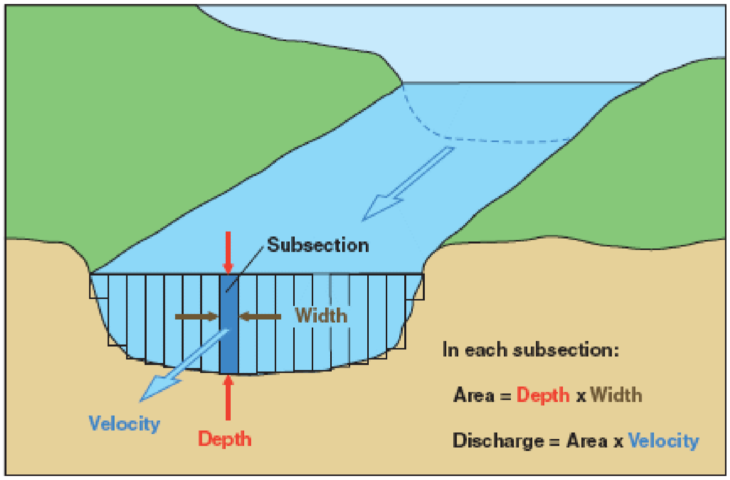


Figure 4. Visual representation of streamflow (discharge) components (Graphic courtesy of USGS).

Cross-sectional area measurements were calculated by measuring the depth of the stream at a regular interval across the width of the stream, then geometrically calculating the area for each interval (see Figure 4).

Velocity measurements were made using a combination of 3 techniques (float method, electronic velocity meter, and transparent velocity head rod). These methods were selected in order to provide the most accurate velocity measurements under various conditions (i.e. low and high flow, shallow and deep portions of the stream). When conditions allowed, all 3 methods of measuring velocity were used in the field. Measurements for each method were attempted at equal intervals across the width of the stream.

2.3.1.a. Float Method

The float method is a simple, common technique used to estimate stream velocity (Michaud and Wierenga 2005). A buoyant object, such as a leaf or orange, was timed (in seconds) travelling down the stream over a known distance (in feet). This process was repeated multiple times (typically 5) to account for any obstructions or unusual flow patterns. The surface velocity was calculated by dividing the travel time by the reach length. The average flow velocity, or the velocity at the midpoint of the depth of the stream, was determined by multiplying the surface velocity by 0.85. This adjustment factor is the midpoint of the accepted values of 0.8 and 0.9 (Michaud and Wierenga 2005). The average flow velocity was used for streamflow calculations.

2.3.1.b. Velocity meter

A Global Water velocity meter is an electronic instrument that calculates the velocity instantaneously (Global Water Instruments Inc. 2009). The instrument was held perpendicularly to the surface of the stream for 15-30 seconds at multiple points across the width of the stream. The average velocity during this time period was recorded for each point in the stream. An average of the average velocities recorded across the width of the stream was used for streamflow calculations.

2.3.1.c. Transparent Velocity Head Rod

A transparent velocity head rod (TVHR) is a flat Plexiglas® sheet with two meter sticks attached. The method and device were based on Fonstad et al. (2005). In order to measure velocity, the TVHR was placed perpendicular to streamflow at multiple points across the width of the stream. At each location, the height of the water (head) was recorded for the upstream, which is visible through the Plexiglas®, and the downstream (Figure 5). The difference between upstream head and downstream head was used in conjunction with TVHR dimensions to calculate the water velocity. An average velocity of the measurements taken across the width of the stream was used for streamflow calculations.

Figure 5. Measuring velocity of flow in Shotwell Brook with transparent velocity head rod (TVHR) requires the device to be held upright in stream (a). The difference in the upstream and downstream head (b) is used to calculate the velocity.

2.3.2. *In-situ* equipment

Measurements were made near-continuously with onsite or *in-situ* monitoring equipment. The equipment was positioned in a pool in order to 1) avoid damage during high flow events, 2) maintain position during high flow events, and 3) gather accurate information (Figure 6). *In-situ* measurements of stage were made with a Campbell Scientific model CS450 pressure sensor (Campbell Scientific 2012). A YSI Series 6600 multi-probe datasonde (YSI 2011) positioned near the pressure sensor was used to collect water quality data including temperature, specific conductivity, and turbidity. These instruments were connected to a battery and data logger that recorded data every 15 minutes; the collected data was sent via cellular modem to UFI for storage and analysis. The data from these sensors were used to create a rating curve and estimate near-continuous flow.

Figure 6. Position of pressure sensor (attached to gray cable) and YSI data sonde (attached to green cable) in Shotwell Brook. Photo taken in April 2019.

2.4. 2019 Environmental conditions

Temperature, rainfall, and snowfall data for Shotwell Brook from January through November 18 were obtained from the National Weather Service station in Auburn, NY. This station is approximately 10 km (6 mi) west of the Village of Skaneateles and 11.9 km (7.4 mi) west of the mouth of Shotwell Brook.

2.4.1. 2019 temperature, precipitation and long-term comparisons

Air temperatures during 2019 were lower than the long-term (1980-2018) average in January, March, April, May, June, and November (Figure 7a). Temperatures were slightly greater than the average in July, September, and October. The air temperatures during 2019 followed the general pattern of the long-term average temperatures.

Monthly precipitation during 2019 was above the monthly long-term averages in January, February, May, June, July, August, and October (Figure 7b). The greatest amount of precipitation fell in July of 2019 (6.3 in), which is greater than the long-term average, but within the expected range for this month. The summer (June – September) of 2019 was wetter than the average long-term summer with a total of 20.5 inches of rain in 2019 compared to the long-term average of 17.7 inches. Cumulative precipitation for January-November in 2019 was 4 inches higher than the long-term average (Figure 7c).

2.4.2. 2018 – 2019 winter snowfall and long-term comparisons

Total snowfall in Auburn from November of 2018 through March of 2019 was 115.5 inches, slightly above the average annual snowfall of 102.53 ± 11.27 inches from 1980 to 2017. The total snowfall during the 2018-2019 winter season was less than the 2017-2018 winter season (132.2 inches; UFI 2017). Snowfall can affect water quality by increasing runoff and loading to the tributary during the spring snowmelt period.

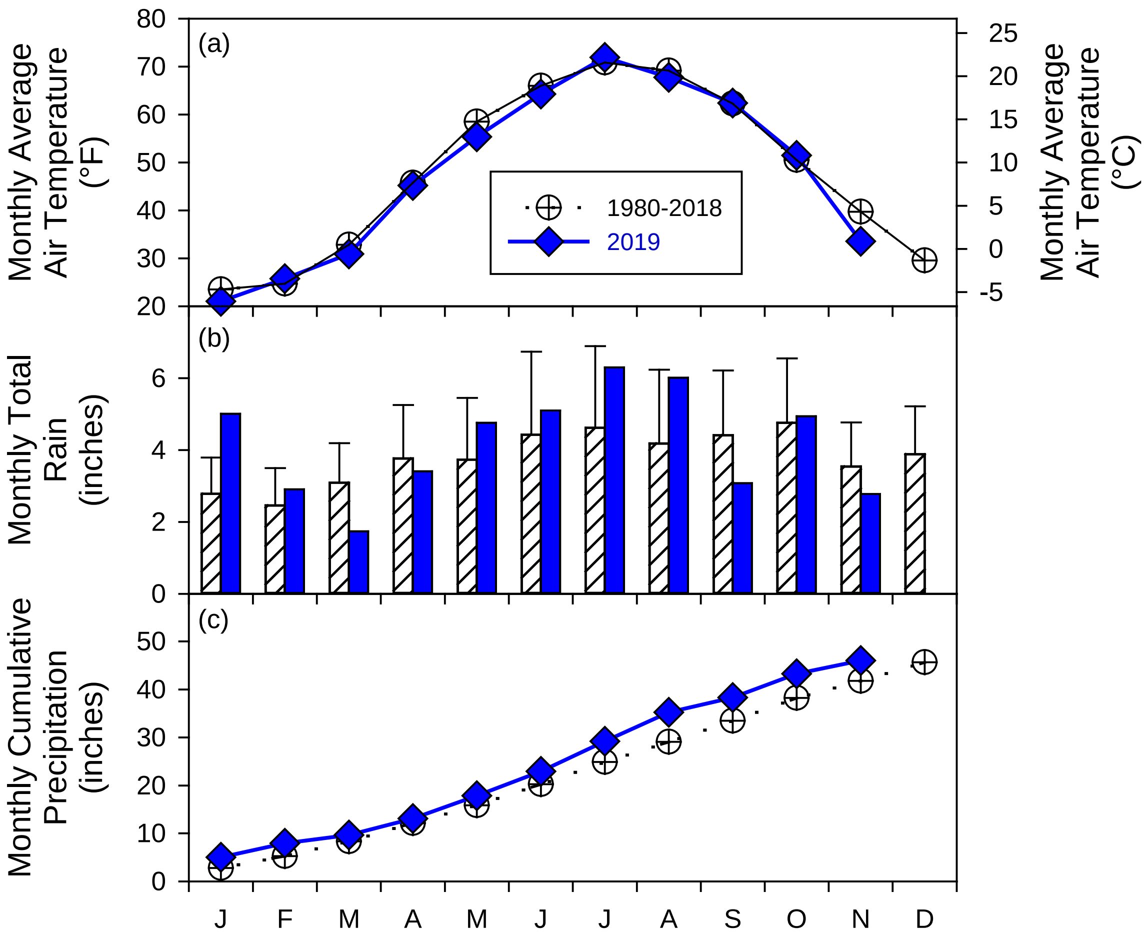


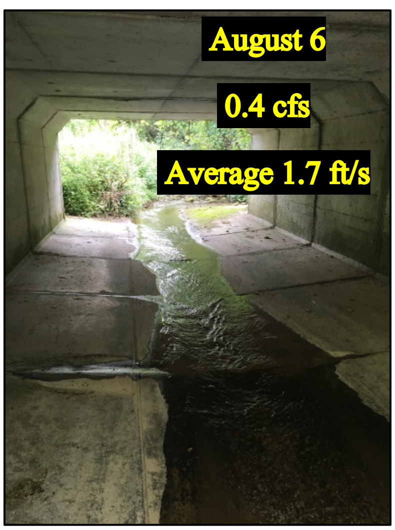
Figure 7. Auburn National Weather Service metrological conditions in 2019 compared with the 1980-2018 average: (a) monthly average air temperature, (b) monthly total rainfall (inches), and (c) monthly cumulative rainfall (inches).

3. Results and Discussion

3.1. Streamflow and continuous data

3.1.1. 2019 results - Streamflow

In order to calculate streamflow, three methods were used to estimate velocity; although variations in velocity were observed between the three methods, they were fairly consistent with one another (Figure 9a). The largest differences between methods were observed with the TVHR, which generally under-predicted the velocity compared to the other methods. This method could only effectively be used during low flow conditions because the device would bend under high flow. On the other hand, the velocity meter was the only method that could be used during 2 high flow events (May 10 and June 20). The average velocity (utilizing velocity measurements of every method used) of Shotwell Brook ranged between 1.7 ft/s to 7.3 ft/s, and the cross sectional area ranged from 0.5 ft^2 to 7.5 ft^2 (Figure 8). The average velocity and cross sectional areas measured during each sampling trip were used to estimate the flow.



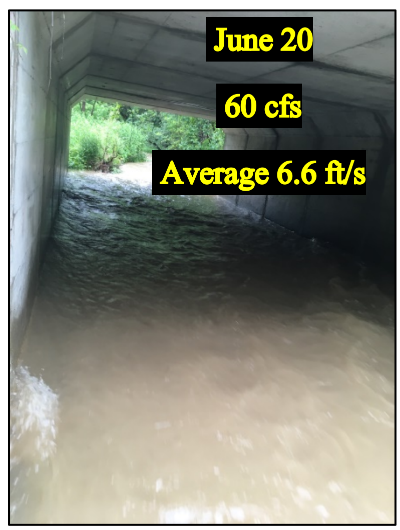


Figure 8. Photographs of Shotwell Brook under the State Route 41 Bridge showing the range of velocity, cross-sectional area, and estimated streamflow observed during the monitoring period. Photos from left to right: August 6 and June 20, 2019.

A cubic polynomial function was fit to the calculated streamflow measurements and average depth of the pressure sensor during the time period streamflow measurements were taken in the field. One streamflow measurement (taken on June 20) was not used to create the rating curve as there were an insufficient number of measurements that could safely be taken during the high flow. The pressure sensor depth was used as the S variable in the equation generated from the rating curve (Figure 9b) to calculate near-continuous flow throughout the monitoring period. A paired t-test was performed to evaluate the difference between measured flows and estimated flows (using the rating curve) at the times that field measurements were taken. Most flow estimations using the curve were similar to those that were measured (difference of 0 to 3 cfs), and there was no detectable significant difference between the two groups ($p = 0.36$).

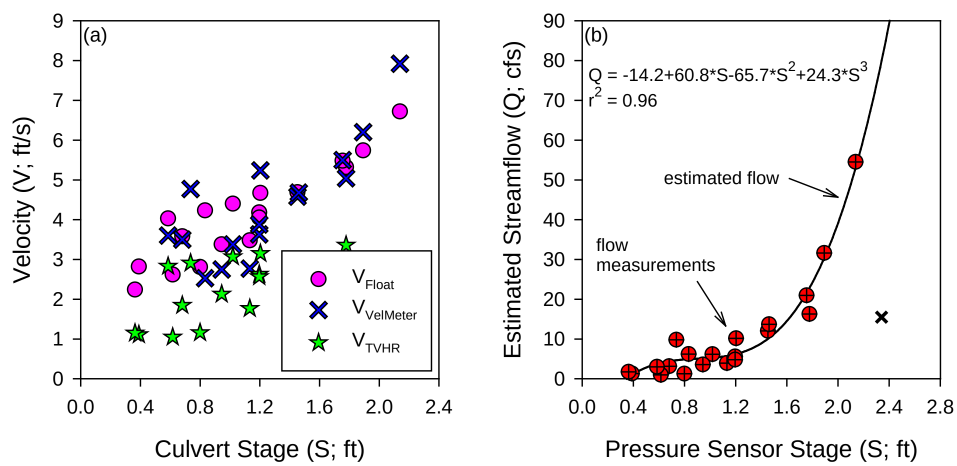


Figure 9. Estimation of streamflow in Shotwell Brook in 2019: (a) bridge/culvert stage-velocity relationships for three velocity estimation methods, and (b) pressure sensor stage-flow relationship (rating curve) with associated equation and statistics. Point marked with “X” was not used to develop the rating curve.

Velocity measurements were made in the culvert, while the pressure sensor was located outside the culvert. The pressure sensor was installed in a pool below the culvert; a downed tree in the brook may have periodically created a deep pool with minor backwater effects on the pressure sensor (Figure 10a). Near the end of the monitoring period, though, there was an apparent high flow event that moved the tree downstream (Figure 10b). The near-continuous estimated streamflow may be slightly elevated due to the position of the sensor during the majority of the monitoring period.

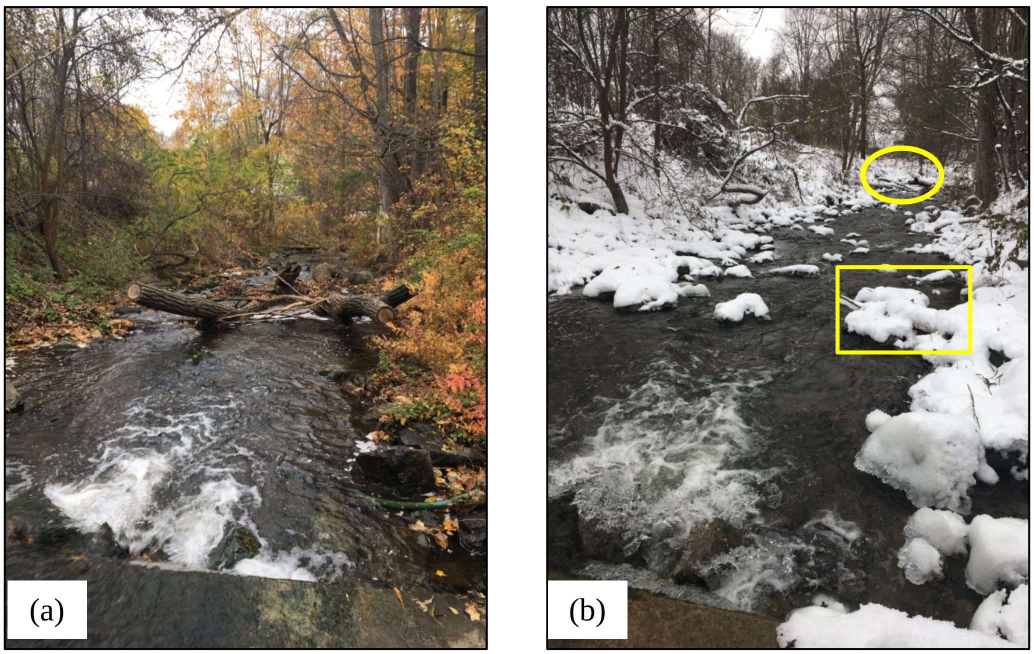


Figure 10. View of the tree downstream of the monitoring location in Shotwell Brook: (a) October 30 and (b) November 14, with new location circled. It is believed that the tree acted as a weir throughout a majority of the monitoring period, and may have affected *in-situ* data collection. Note the YSI datasonde out of water and under snow in (b), outlined in yellow box.

From April 4 to November 25, over 22,000 measurements of the stage (depth of the pressure sensor) were recorded. The stage in Shotwell Brook was consistent with depths observed in previous monitoring periods (UFI 2016, 2017, 2018), and was most often 0.38 ft in 2019 (Figure 11a). The median flow rate was 4.98 cfs, with 75% of the observations less than 6.01 cfs (Figure

11b). The upper limit of the inter-quartile range (6.01 cfs) is greater than what has been estimated in previous years (Table 3), probably due to the wet conditions in 2019. The highest flow event accurately measured in the field was October 7 with a calculated streamflow of 55 cfs (53 cfs using rating curve and pressure sensor depth). More than 0.8 inches of rain fell on this day. The streamflow on June 20 was grossly underestimated using field measurements (16 cfs), but was the highest streamflow observed by UFI over the monitoring period (60 cfs using the rating curve and pressure sensor depth). Although there was no rainfall on this day, approximately 0.7 inches of rain fell over a period of two days prior to this high flow event. The maximum 15-minute average flow recorded in the tributary during 2019, though, was 158 cfs on October 31 at 8:00 PM. During this event, which spanned over 24 hours, about 2 total inches of precipitation was recorded at Auburn.

Although there is not a strong statistical relationship between daily average streamflow and daily precipitation ($r^2 = 0.21$), stage depth, and therefore streamflow, is generally related to rainfall (Figure 12). Between April and November, an estimated 175.6 million ft^3 of total flow volume entered Skaneateles Lake, about 0.3% of the total volume of Skaneateles Lake. Despite the small contribution to the lake, the water quality of the stream under low and high flow conditions and the timing of high flow events are important to lake water quality.

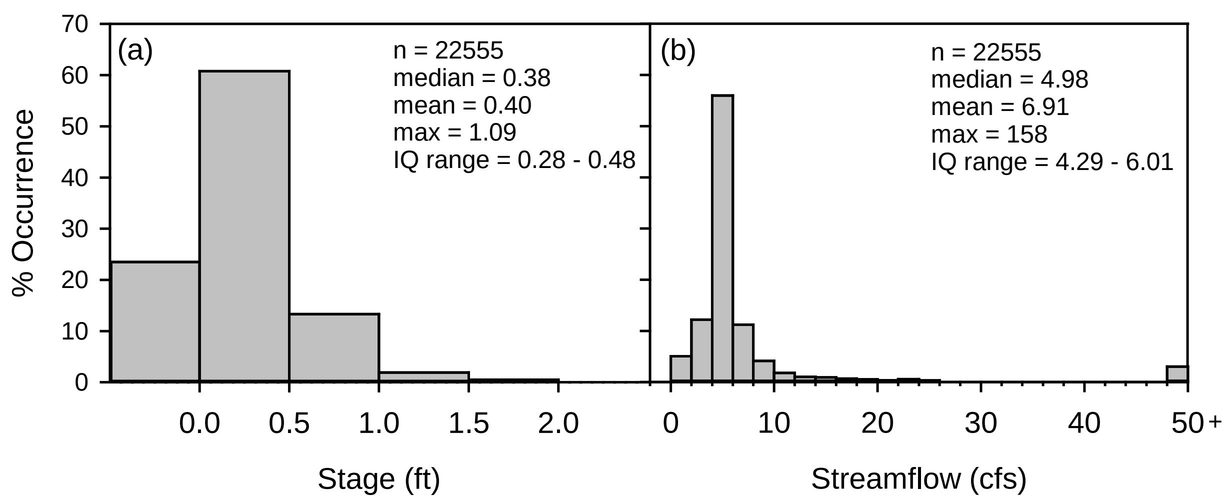


Figure 11. Observation frequency of (a) stage (ft) and (b) streamflow (cfs) at 15-minute intervals in Shotwell Brook in 2019. Associated descriptive statistics shown; IQ range represents the 25 – 75 % interquartile range.

Table 3. Mean and median flows (cfs) of contemporary monitoring (2016-present) in Shotwell Brook. Standard deviation shown in parentheses.

Year	Mean	Median	25 – 75 % Interquartile range
2016	3.70 (8.3)	0.63	0.13 – 4.4
2017	9.99 (47.58)	1.88	0.63 – 4.46
2018	5.70 (21.9)	2.10	1.40 – 4.30
2019	6.91 (8.84)	4.98	4.29 – 6.01

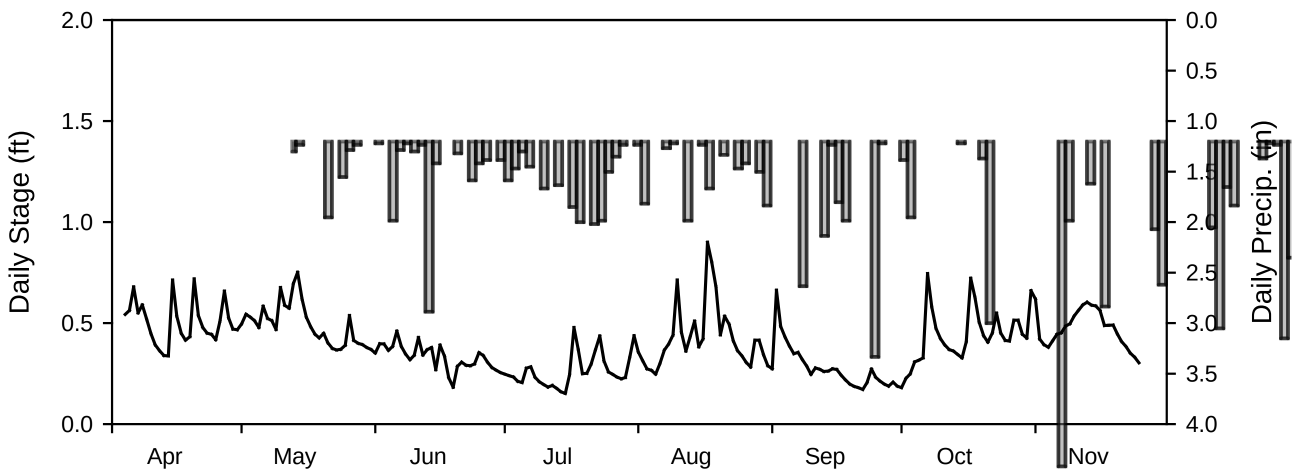


Figure 12. Time series of daily averaged stage (ft) in Shotwell Brook and precipitation (in) in 2019. Precipitation data from Auburn National Weather Service station located in Auburn, NY.

3.1.2. 2019 results – *In-situ* YSI data and relations to streamflow

From April 4 to November 25, over 22,000 measurements of temperature, specific conductance, and turbidity were made (Figure 13). Data that fell outside the standard YSI performance ranges (Table A.1.) were removed for calculating daily averages and subsequent analyses. For example, the YSI sonde was found out of the stream and under snow on November 14 (Figure 10b), and temperatures below -5 °C that were observed before the YSI was relocated were most likely air temperatures. Daily average observations are shown in Figure 14. On November 14 UFI used a second YSI handheld data sonde to ground truth, or validate measurements made by *in-situ* equipment.

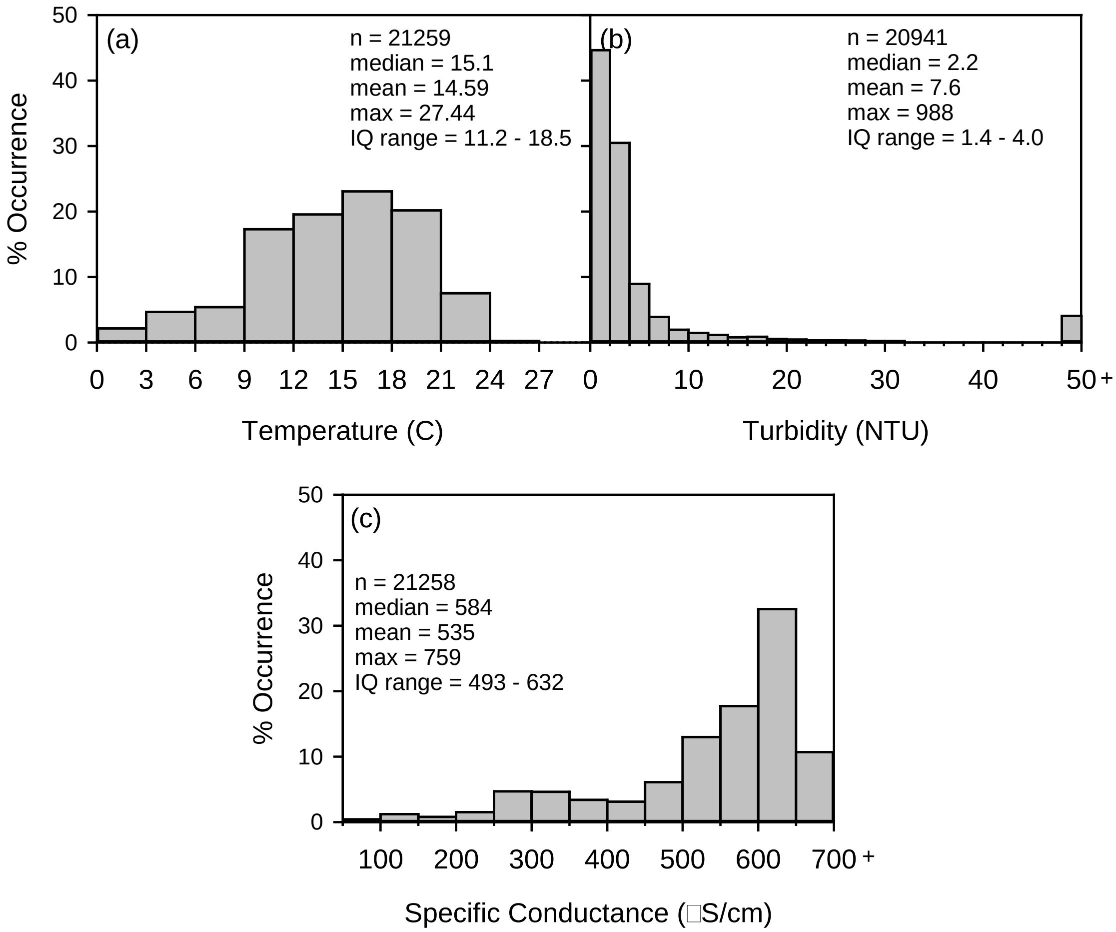


Figure 13. Observation frequency of (a) temperature (°C), (b) turbidity (NTU), and (c) specific conductance (µS/cm) at 15-minute intervals in Shotwell Brook in 2019. Associated descriptive statistics shown; IQ range represents the 25 – 75% interquartile range.

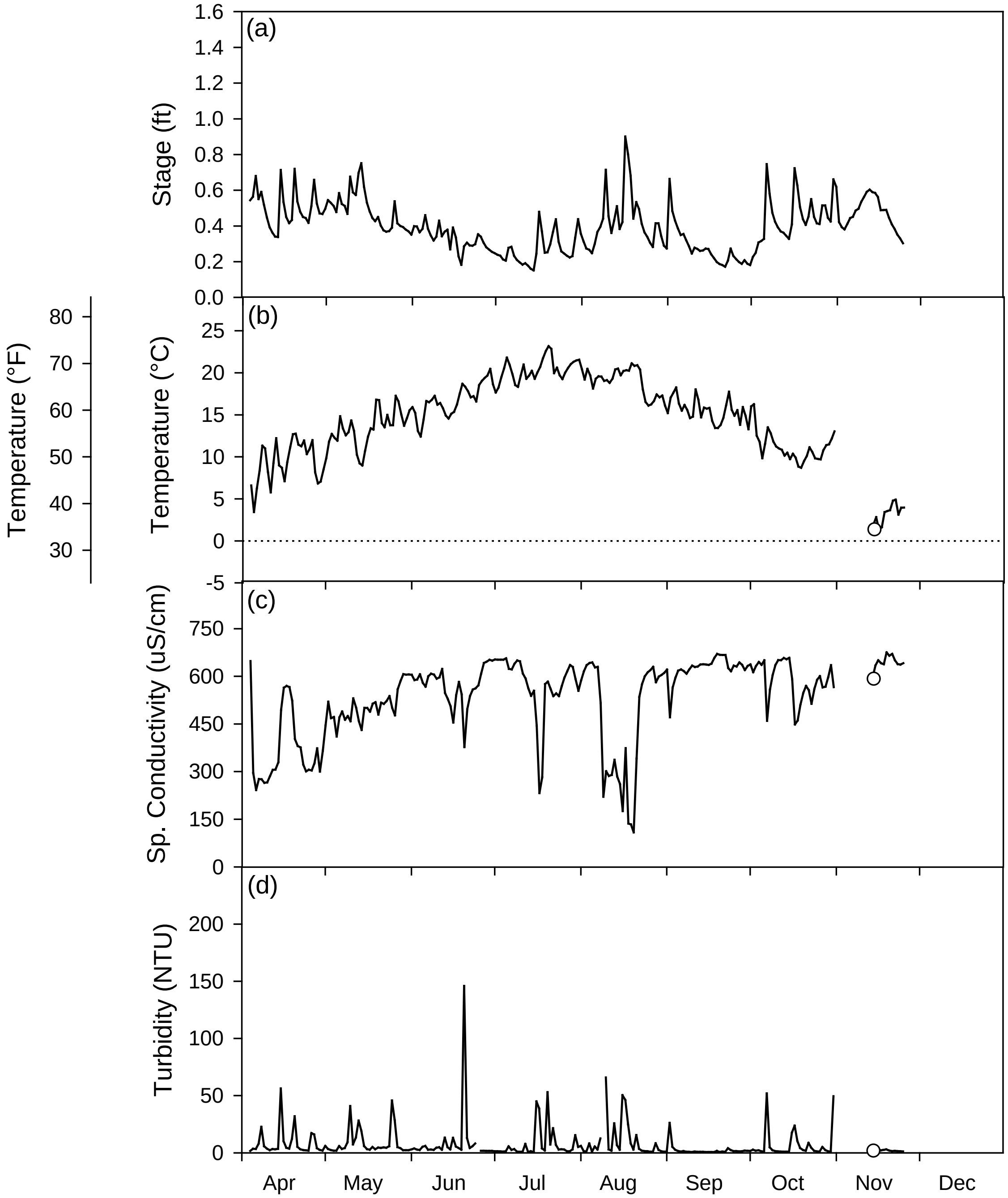


Figure 14. Time series of daily averaged parameters measured at high frequency in Shotwell Brook in 2019: (a) stage (ft), (b) temperature (°C; additional (°F) axis shown for reference), (c) specific conductance (µS/cm), and (d) turbidity (NTU). Points represent data collected with handheld YSI to ground truth the *in-situ* equipment. Gaps within the time series indicate suspect data.

Daily average stream temperatures in Shotwell Brook were typical of streams in temperate zones (Figure 14b). During the spring, stream temperatures were variable from day-to-day. As the summer began, temperatures experienced less daily variation and generally increased. The maximum temperature 22.5 °C (72.5 °F) was recorded on July 10. Temperatures gradually decreased between August and October. The YSI datasonde was exposed to the air during early November so stream temperatures were not recorded. As with many small streams, water temperature is closely related to air temperature (Figure 15). Between October 31 and November 14, average air temperatures dropped from 14 °C (57 °F) to -6 °C (20 °F). Stream temperatures most likely gradually decreased from about 13 °C (daily average stream temperature on October 31) to below 5 °C until the sonde was replaced on November 14 (2 °C daily average stream temperature). Shotwell Brook temperatures did not fluctuate as widely as air temperatures throughout the monitoring period. This is attributed to the buffering effect of thermally stable (not affected by air temperature) groundwater inputs to streamflow and the shading from trees along the stream.

Temperature is an important regulator of water density, and the relationship observed between air temperature and Shotwell Brook temperature may be important to future water quality modeling of Skaneateles Lake. By monitoring the temperature of the stream, an estimate of the depth of entry to Skaneateles Lake can be made; this would allow for estimates of depths/locations of the lake that may be impacted by the stream during high flow events. For example, if the stream temperature is substantially cooler than the surface of the lake, the water from the stream is denser than the upper lake waters and would enter below the surface of the lake. On the other hand, if the stream temperature is warmer than the surface of the lake, the water from the stream would be less dense and directly impact the upper waters of the lake.

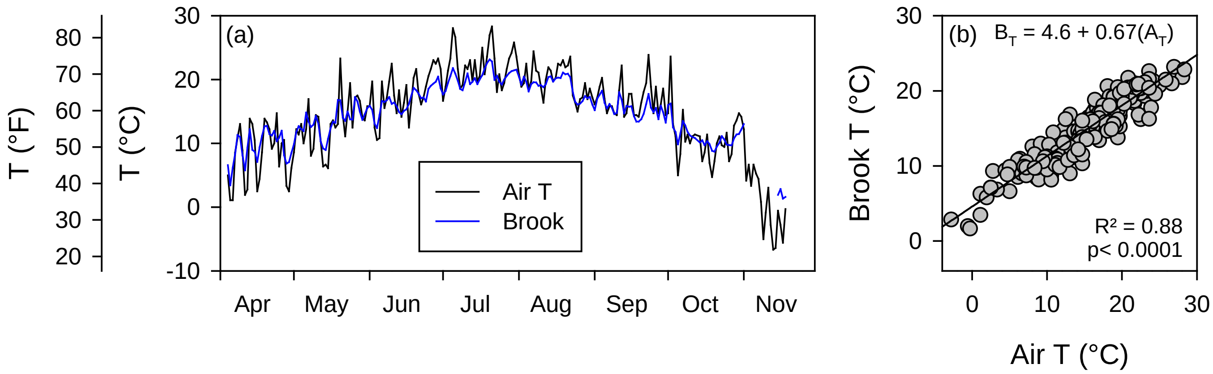


Figure 15. Relationship between air temperatures (Air T or A_T) and Shotwell Brook temperatures (Brook T or B_T) in 2019: (a) time series of daily average air and brook temperatures (°C), and (b) regression of daily brook and air temperatures. Fahrenheit (°F) scale included in (a) for reference.

Specific conductance (SC) is an aggregate measure of ionic content that can indicate relative concentrations of primary ionic species (i.e. Ca^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}). Ionic content within an aquatic system is often regulated by the geology of a watershed. A majority of the ionic compounds in a stream are inputted via groundwater; SC values are usually high when groundwater dominates streamflow. The median SC observed in Shotwell Brook was 584 µS/cm with 75 % of the observations less than 632 µS/cm and greater than 493 µS/cm (Figure 13c). In Shotwell Brook, SC is inversely related to streamflow, with high SC measurements during periods of low flow and the low SC observed during periods of high flow (Figure 14c, Figure 16).

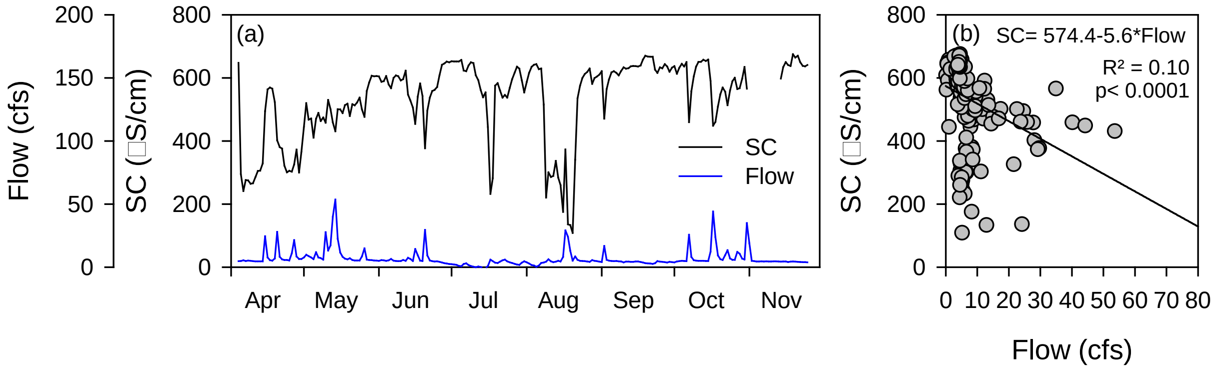


Figure 16. Relationship between the specific conductance (SC; µS/cm) and streamflow (cfs) of Shotwell Brook in 2019: (a) time series of daily average SC and streamflow, and (b) regression of daily SC and streamflow. Daily average of 15-minute high frequency SC observations and streamflow estimations.

Daily average turbidity over the monitoring period was 7.6 NTU, but the median was 2.2 NTU (Figure 13b; range visible in Figure 17). About 75 % of the observations made throughout the monitoring period were less than 4.0 NTU, with increased turbidity often seen during high flow events (Figure 18). There were instances when *in-situ* turbidity was very high (> 100 NTU) during low flow, which may be the result of bioturbation, fouling, or excessive buildup of sediments in the YSI field cup after a storm event (Figure A.1.). One hundred twenty-two observations were greater than the performance range of the probe (1000 NTU), and were commonly observed after periods of high flow or large amounts of rainfall. These values and unusually high turbidity values (likely due to the reasons previously mentioned) were removed from analyses. Turbidity is a measurement of optical properties (Kirk 2011) that is related to the amount and size of particles suspended in water (Figure 19 for relative scale; Gelda et al. 2009, 2012). Increases in turbidity (and typically sediment loading) are often observed during periods of high flow, and a majority of annual loading to a lake or reservoir can be attributed to these intermittent runoff events (O’Donnell and Effler 2006).

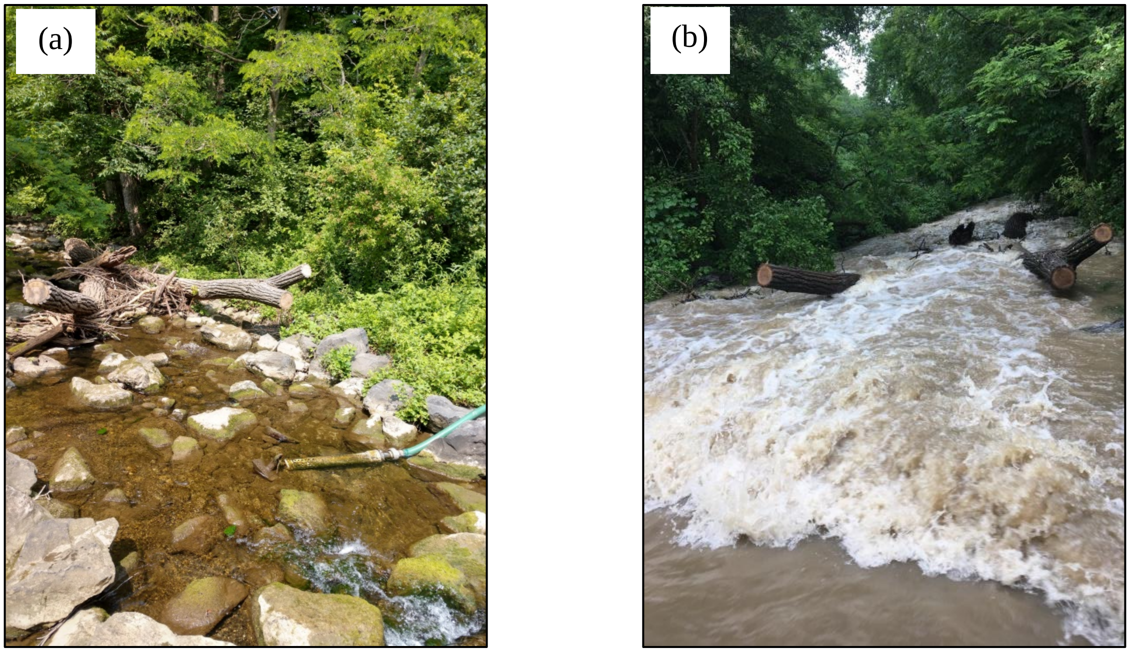


Figure 17. Photographs showcasing the range of turbidity in Shotwell Brook in 2019: (a) July 10 (~1 NTU) and (b) June 20 (> 300 NTU).

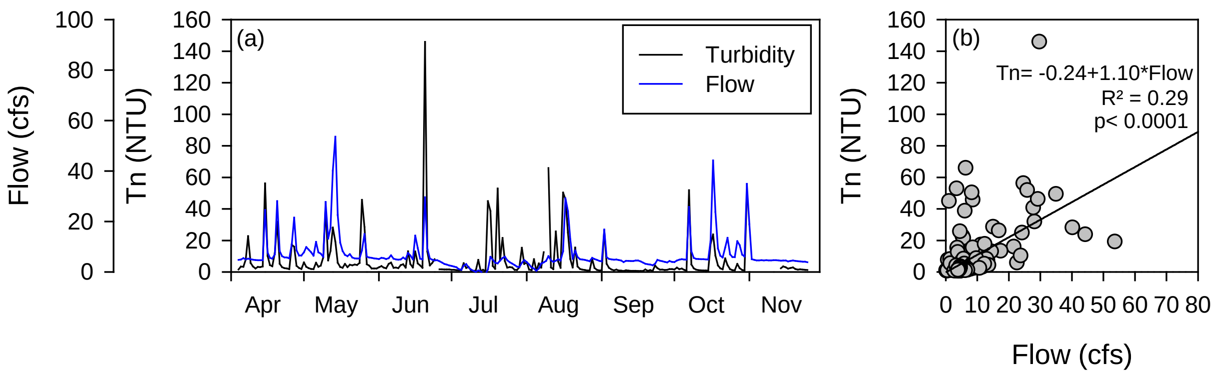


Figure 18. Relationship between the turbidity (Tn; NTU) and streamflow (cfs) of Shotwell Brook in 2019: (a) time series of daily average turbidity and streamflow, and (b) regression of daily turbidity and streamflow. Daily average of 15-minute high frequency turbidity observations and streamflow estimations.

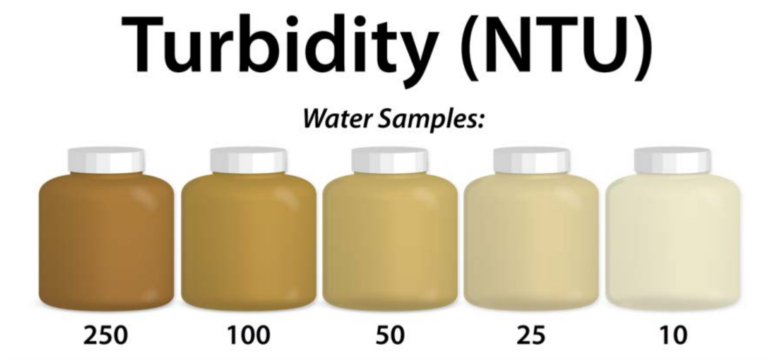


Figure 19. A relative turbidity scale (image courtesy of www.learnnc.org).

3.1.2.a. Rain and runoff events

In 2019, 18 high turbidity events (periods of time with multiple 15-minute observations that were greater than 100 NTU) were observed, and 3 dates within the monitoring period had high daily average turbidity (Table 4). Typically periods of high turbidity were observed shortly after stream depth (stage), and therefore streamflow, increased. Turbidity values were initially high during periods of elevated flow, and quickly subsided before stream stage had returned to baseline levels. The peak *in-situ* turbidity measurements were often observed prior to the estimated peak flow of the rain event. Daily average turbidity was high (greater than 100 NTU) on June 20. In comparison to previous monitoring periods, 2019 had the second greatest number of high turbidity events (highest in 2017 with 21 events; UFI 2016, 2017, 2018)

Rain events were also characterized by elevated stream stage and lowered SC. Stream stage would typically return to baseline levels within 18 - 48 hours after the stage initially increased. Under high flow/stage conditions SC was markedly lower than SC during low-flow conditions. Specific conductance typically increased gradually to baseline values, whereas turbidity peaked and recovered quickly. The amount of rain and number of consecutive days with precipitation appeared to influence 1) the amount of time it took for SC to return to baseline values, and 2) the number and timing of high *in-situ* turbidity measurements.

Table 4. Description of major runoff events identified by multiple 15-minute observations of turbidity greater than 100 NTU. [a] indicates the date that had > 100 NTU daily average

Event #	Event Start Date	Flow during peak turbidity (cfs)	Peak *in-situ* turbidity (NTU)	Peak flow of event (cfs)
1	April 15	37.3	251.3	60.1
2	April 20	52.7	123	54.8
3	May 10	10.3	230.6	47.5
4	May 13	46.9	124.9	50.4
5	May 25	32.9	792.7	42.2
6[a]	June 20	6.5	970.5	6.5
7	July 16	14.1	755.3	21.8
8	July 17	15.8	343.1	31.1
9	July 20	5.3	987.9	8.1
10	July 30	10.3	191.7	12.2
11	August 10	10.0	975.4	peak
12	August 13	17.2	358.5	33.9
13	August 16	37.6	725	104.5
14	August 18	88.5	110	peak
15	September 2	26.1	134.3	38.7
16	October 7	25.9	268.3	75
17	October 16	27.1	152.3	39.6
18	October 31	24.7	863.6	109.9

3.2. Water quality

During the 2019 study period, 18 samples were collected for phosphorus analysis. These samples were collected in March, April, and biweekly between May 1 and November 25. Seven samples were collected during low flow conditions (less than 6.01 cfs, the 75% interquartile of flow), and 11 were collected at high flow. The “low” flow was higher in 2019 than in previous years due to increased precipitation (Figure 7). The TDP fraction of TP and derived PP values calculated on September 18 were not used to calculate the average TDP fraction, PP, or PP fraction due to TDP values greater than TP.

Turbidity, TP, and PP (and thus the PP fraction of TP) values were greater in high flow conditions than low flow (Table 5). Conversely, TDP was lower during high flow and higher during low flow conditions. Total dissolved phosphorus made up more of the TP than PP at low flows. During high flows, TDP and PP each made up half of the TP.

In comparison to previous studies, the average TP (37 µg/L) was lower than the overall averages observed in previous years (Table 6). The average TP during high flows (46.6 µg/L) was almost twice as lower than values observed under the same streamflow regime in previous monitoring years (Table 6). Additionally, the PP concentration and PP fraction of TP during high flows (25.5 µg/L, 50%) were lower in 2019 than values observed in other years. Total dissolved phosphorus averages were similar to those observed in previous years and under the two flow regimes.

Table 5. Average turbidity and phosphorus concentrations in Shotwell Brook at low (≤ 6.01 cfs) and high (> 6.01 cfs) streamflow during 2019 study period. Standard deviation shown in parentheses.

Streamflow regime	Count	Tn (NTU)	TP (µg/L)	TDP (µg/L)	TDP fraction of TP (%)	PP (µg/L)	PP fraction of TP (%)
Low	7	1.8 (1)	29.2 (23)	23.6 (21)	76	6.7 (5)	24
High	11	10.2 (11)	46.6 (31)	21.1 (16)	50	25.5 (20)	50
2019 Overall	18	5.5 (8)	37.0 (27)	22.5 (18)	64	15.6 (17)	36

Table 6. Comparison of annual average phosphorus concentrations and at low and high streamflow regimes in Shotwell Brook 2016-2019.

Year and Streamflow Regime	Count	TP (µg/L)	TDP (µg/L)	PP (µg/L)	TDP fraction of TP (%)	PP fraction of TP (%)
2016	21	236	25	211	11	89
Low (≤ 4.4 cfs)	11	29	20	9	69	31
High (> 4.4 cfs)	10	424	29	395	7	93
2017	21	46	20	26	43	57
Low (≤ 4.5cfs)	12	21	16	5	76	24
High (> 4.5 cfs)	9	80	26	54	32	68
2018	22	45	27	18	60	40
Low (≤ 4.25 cfs)	16	31	24	7	77	23
High (> 4.25 cfs)	6	81	35	46	43	57
2019	18	37	23	16	64	36
Low (≤ 6.01 cfs)	7	29	24	7	76	24
High (> 6.01 cfs)	11	47	21	26	50	50

3.2.1. Flow – Concentration Relationships

Daily flow estimates made using the rating curve were used to evaluate the relationships between streamflow and water quality. Each of the water quality metrics containing particulates (i.e., Tn, TP, and PP) was positively related to streamflow (log-log format; Figure 20). Total phosphorus was not as strongly related to flow as Tn and PP, which is most likely due to the large fraction of TP that is TDP. Dissolved phosphorus was not strongly related to streamflow (Figure 20c), suggesting that TDP in Shotwell Brook is not preferentially mobilized during runoff events.

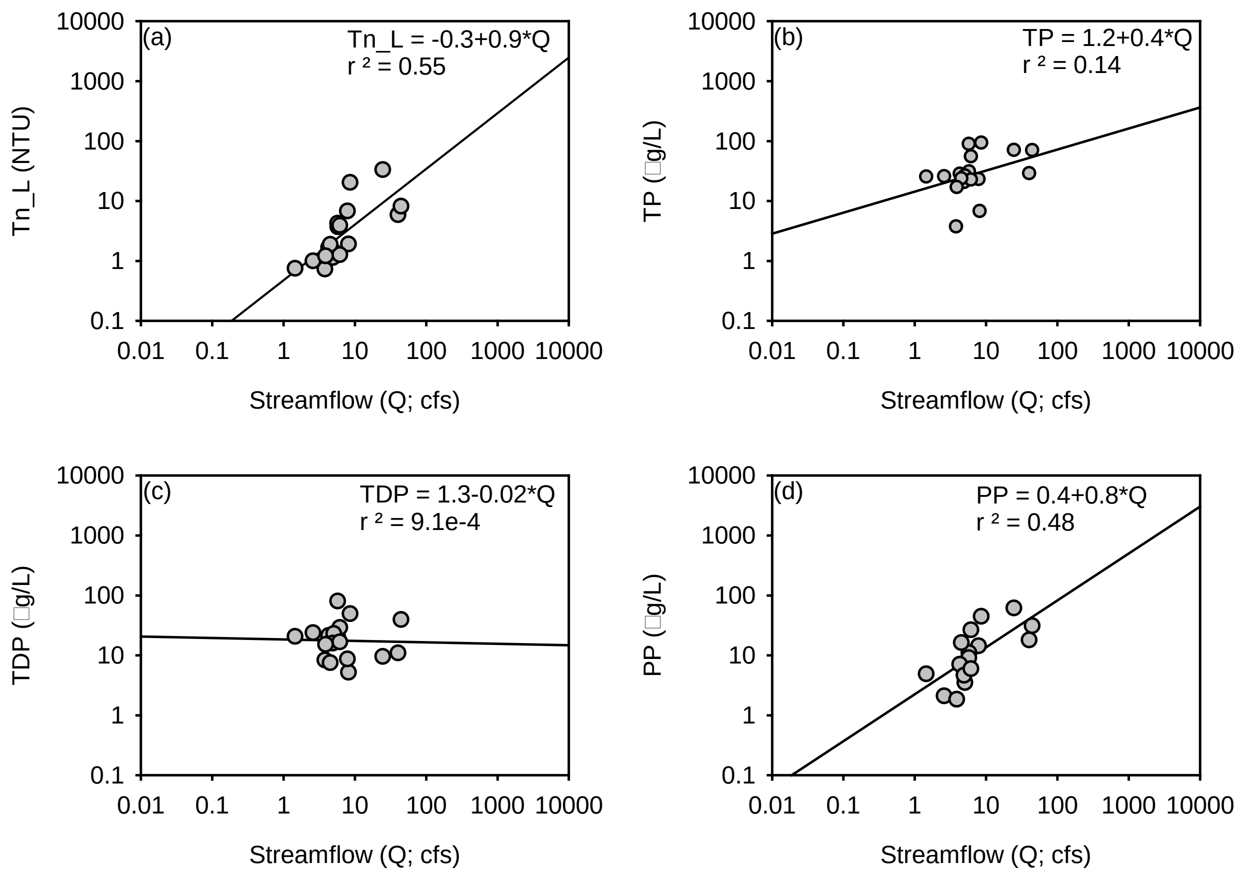


Figure 20. Relationship of daily average streamflow and water quality constituents: (a) turbidity (Tn_L), (b) total phosphorus (TP), (c) total dissolved phosphorus (TDP), and (d) particulate phosphorus (PP). Measurements shown on a log-log scale.

3.2.2. Turbidity – Concentration Relationships

Daily average turbidity measurements made *in-situ* were used to evaluate the relationships between turbidity and the phosphorus fractions measured in Shotwell Brook. As with the relationships observed with streamflow, phosphorus fractions containing particulates (TP and PP) were positively related to turbidity (Figure 21a,c). Total dissolved phosphorus did not have a strong relationship with turbidity ($r^2 = 0.04$). This relationship and the elevated TDP observed during low flows (Table 5) suggests groundwater may be an important source of TDP to Shotwell Brook.

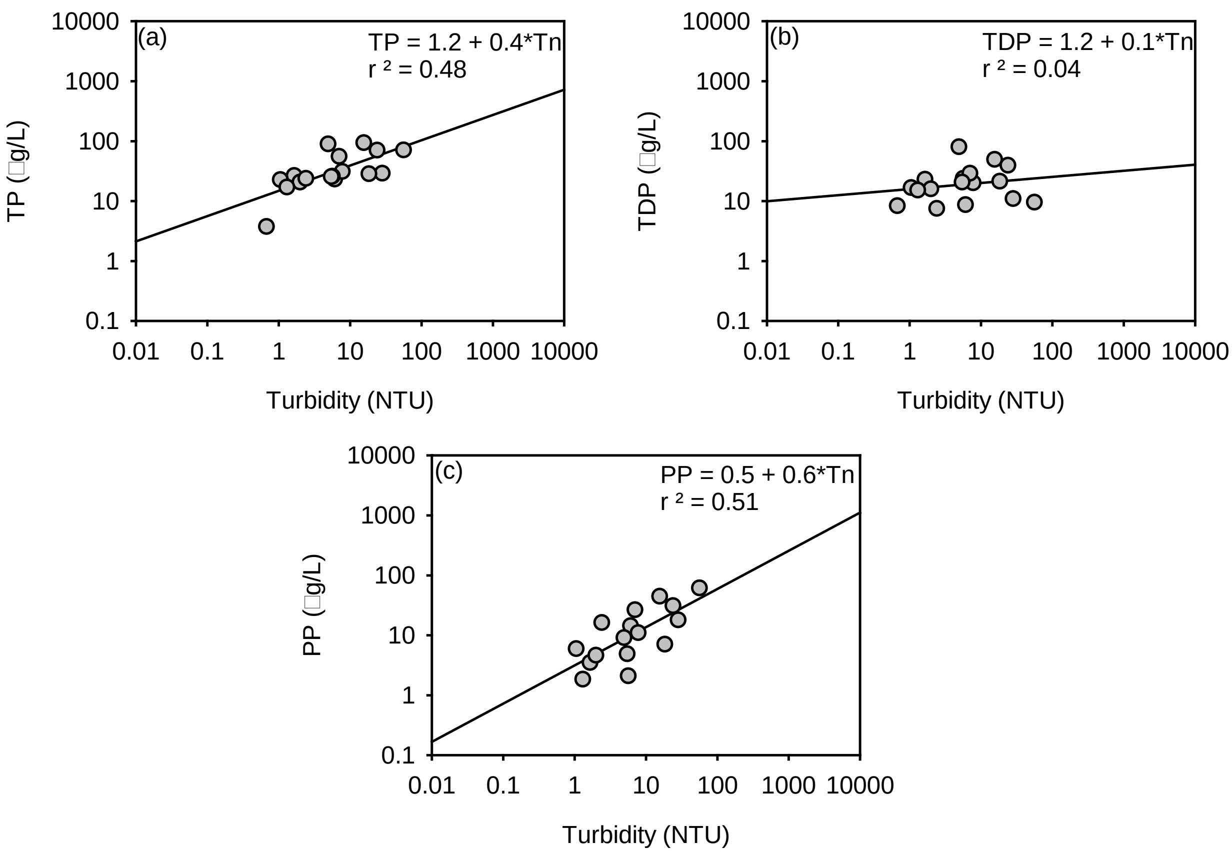


Figure 21. Relationship of daily average in-situ turbidity and water quality constituents: (a) total phosphorus (TP), (b) total dissolved phosphorus (TDP), and (c) particulate phosphorus (PP). Measurements shown on a log-log scale.

4. Conclusions

Shotwell Brook is a small yet important tributary to Skaneateles Lake because of its proximity to the drinking water intakes for the Village of Skaneateles and City of Syracuse. The objectives of the 2019 study were met: 1) estimates of streamflow were developed using stream velocity and cross-sectional area measurements over a range of conditions (i.e. high and low flow), 2) near-continuous measurements of select water quality parameters were made using high frequency in-situ equipment, and 3) patterns of constituents affecting water quality (i.e. phosphorus compounds) during baseflow and high flow conditions were documented.

Because Shotwell Brook is a relatively small stream, it is expected to have generally low streamflow. In 2019 the median flow was 4.98 cfs and average flow was 6.91 cfs. The median flow during 2019 was higher than those observed in previous years. The year 2019 was wetter than the long term average, which most likely contributed to the overall higher flow. There were a greater number of high turbidity/flow events in 2019 than 2018. Despite the relative infrequency of high flow events, a considerable portion of the total annual loading of nutrients and sediments to the lake occurs during these periods of high flow. Rain/runoff events also cause high levels of turbidity within Shotwell Brook and in areas near the mouths of the brook, degrading the aesthetic quality of both the tributary and lake.

Turbidity was below 4 NTU during much of the monitoring period; however, turbidity values did exceed 1000 NTU on days that experienced high flow and large amounts of rainfall. Eighteen high turbidity events were observed in Shotwell Brook, and one date had a daily average turbidity value greater than 100 NTU. The median turbidity observed in 2019 (2.2 NTU) was the same as the median turbidity measured in 2018 and 2017.

The overall average TP was 37 µg/L. At low flow TP was dominated by TDP (76%), and at high flows PP became a more important fraction of TP (50%). Average TP and PP during high flows were lower than values reported for high flows in previous works. Although the average TP and PP were less than values observed in previous studies, the average TDP (under all streamflow regimes) was similar to the observed TDP in years prior. Total dissolved phosphorus appeared to be weakly related to streamflow and turbidity, whereas TP and PP were more strongly related to these stream conditions.

The Upstate Freshwater Institute has several recommendations related to future monitoring of Shotwell Brook. These recommendations were guided by the findings of this report, previous monitoring results, and the data needs for the development of a nine element watershed plan and lake water quality model. Potential future monitoring could include:

1. Continued monitoring and sample collection following implementation of best management practices or other perturbations.
2. Addition of upstream sampling locations to provide water quality information and identify locations that would benefit from best management practices.
3. Paired observations of turbidity and temperature from Shotwell Brook and Skaneateles Lake in order to assess impacts from high turbidity events.
4. Monitoring should be extended to cover the winter-spring period, particularly thaw periods and rain on snow events.

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6. 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
ELAP	Environmental Laboratory Approval Program
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-truth	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 object's 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/loading	the mass quantity of a substance delivered to a water body over a given period of time (e.g., pounds per second, kilograms per day, etc.)
NTU	nephelometric turbidity units (relative units of turbidity)
oligotrophic	waterbody with low levels of primary production and nutrients
p-value	probability of obtaining a result equal to or greater than what was actually observed, when the null hypothesis is true; typically a p-value < 0.05 is used to determine statistical significance
r^2	the coefficient of determination; proportion of the variability in the dependent variable that is predictable from the independent variable
reach	a section of the stream with well-defined upstream and downstream boundaries used for scientific studies
runoff	the portion of streamflow that is the result of precipitation or snowmelt that does not infiltrate the ground and runs over land surfaces directly into a stream channel
specific conductance	the measure of how well a water can conduct an electrical current; used as a surrogate metric of total dissolved solids, salt content, or salinity
stream stage	height or depth of water above bottom of stream
Transparent Velocity Head Rod (TVHR)	a flat Plexiglas® sheet of specific dimensions with attached meter sticks used to estimate stream velocity
turbidity	cloudiness of a fluid caused by an accumulation of individual particles
watershed	the area of land surrounding a water body that contributes water to that system

7. Appendix

Table A.1. Performance ranges for the YSI datasonde probes used for the *in-situ* measurements.

Probe	Range of Detection	Resolution	Accuracy
Turbidity	0 – 1000 NTU	.1 NTU	2 NTU or +/- 5 % of reading, whichever is greater
Temperature	-5 – 45 °C	0.01 °C	+- 0.15
Conductivity	0 – 100 mS/cm	0.001 to 0.1 mS/cm (range dependent)	+- 0.5 % of reading + 0.001 mS/cm

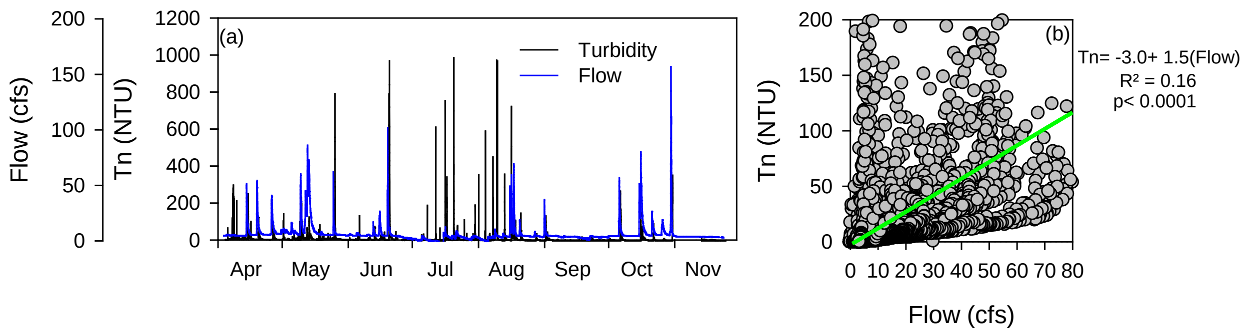

Figure A.1. Relationship between the turbidity (Tn; NTU) and streamflow (cfs) of Shotwell Brook in 2019: (a) time series of 15-minute average turbidity and streamflow observations, and (b) regression of 15-minute turbidity and streamflow observations.