Temperature Profile of the Quittapahilla Creek

Fall 2022

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INTRODUCTION

Background

The Quittapahilla Creek (Quittie) is a 3rd order tributary that feeds into the Swatara Creek within the Chesapeake Bay Watershed. The Quittie is surrounded by agricultural, residential, and urban landscapes within Lebanon County. It has four main tributaries: Snitz Creek, Beck Creek, Bachman Run, and Killinger Creek. It also has inputs from four different municipal wastewater treatment plants. There are historic levels of water and sediment pollution in the area that the Quittapahilla Watershed Association (QWA) has worked on in past projects such as stream bank stabilization, removing sediment, increasing stream velocity, and creating riparian buffers.

Understanding measures of water quality is a large part of assessing the Quittie's affinity for biodiversity. Freshwater streams are self-regulating systems, where abiotic and biotic factors work together to create a healthy ecosystem that provides ecological services of economic value for society (Griebler and Avramov 2015). Any natural pollutants or eutrophic disturbances would be filtered through the stream ecosystem through the food web and the natural minerals in rock sediments (Griebler and Avramov 2015). Urbanization and agricultural cultivation practices have increased pollutants in aquatic environments (Wilson *et al.* 2001, Arango *et al.* 2008). Urban cities produce lots of trash and microplastics that make their way into waterways and groundwater (Pal *et al.* 2010). Urban areas increase the amount of runoff, especially of sediment, into waterways (Somers *et al.* 2013). All stressors can alter the different communities in an ecosystem. The effects of these stressors are seen successionally throughout ordered streams due to sediment and nutrient deposition (Solomon *et al.* 2009).

Climate change, urban heat islands, and warm water inputs can cause temperature pollution in waterways as well (Marschall and Crowder 1996, Somers *et al.* 2013). Impermeable surfaces increase the amount of erosion and pollution that flows into waterways (Field and Cibik 1980). These lead to increased warm-water inputs because pavement has a low albedo, so it absorbs heat then deposits the warmer runoff water into the stream system. Increases in water temperature cause decreases in the ability of a water body to hold dissolved oxygen (Gordon 1991). Dissolved oxygen is necessary for many aquatic species, especially trout due to their affinity for cooler water (Irving *et al.* 1941).

The Pennsylvania Fish and Boat Commission stocks the Quittie Creek and tributaries with brown (*Salmo trutta)* and rainbow trout (*Oncorhynchus mykiss*) (PA Fish and Boat Commission 2022). Golden rainbow trout (also *Oncorhynchus mykiss*) are stocked throughout the Quittie; this is a hybrid between the rainbow trout and West Virginia golden rainbow trout. Each species has similar but specific necessities for proper embryo development and survival (**Table 1**).

Table 1. Habitat requirements for optimal fitness in Brook, Brown, and Rainbow trout.

Requirement	Brook trout	Brown trout	Rainbow trout
Water Movement	Moderate flow, require groundwater upwelling	Moderate flow	Low, Moderate, or High flow, Prefer cooler groundwater upwelling
Spawning Sediment Type	Gravel	Gravel	Gravel
Nest Habitat	Shallow headwaters of streams	Alongside rocky, gravel shore	Fine gravel in riffle above a pool
Optimal Temperature Range of Survival	62.6 – 70 °F (17 - 21°C)	62.6 – 75.2 °F (17 - 24°C)	55.4 - 70 °F (13 - 21 °C)
Optimal Temperature Range for Egg Survival	41 - 48 °F (5 - 9°C)	41 - 48 °F (5 - 9°C)	50- 60 °F (10 – 15.5 °C)
Oxygen	High amounts	High amounts	High amounts
Spawning Time	Mid-September through November	After brook trout in the Fall	Early to late spring (January to June)

Sources: Greeley 1932, Hazzard 1932, Hazzard and Madsen 1993, Scott and Crossman 1973, Nevada DEP 2017

Issue

The QWA and Doc Fritchey Trout Unlimited Chapter have noticed stocked trout are not seen later in the summer following stocking in the spring, indicating these fish are not sustaining their populations naturally. The stocked fish are not establishing new generations by successful spawning in the Quittapahilla Creek. One of the driving factors of trout population decline is increasing stream water temperature (Marschall and Crowder 1996, Kemp and Spotila 1997, Somers *et al.* 2013). This could be due to elevated stream temperatures caused by runoff from impermeable and dark surfaces (streets, sidewalks, rooftops, driveways, parking lots) as an effect of urbanization (Somers *et al.* 2013). Wastewater treatment facilities require water temperature to be around 32°C for optimal treatments but can be seen to be as high as 70°C (Alisawi 2020). So, discharge from wastewater treatment facilities can increase water temperatures in receiving waters (Hamdhani *et al.* 2020). Trout species are especially vulnerable due to the specific temperature ranges (Table 1) for survival and egg viability (Scott and Crossman 1973, Bell 2006). Streams and creeks like the Quittapahilla are susceptible to temperature change.

This study proposes to evaluate water temperatures in the Quittapahilla Creek and its major tributaries to see if temperature is a major stressor for trout survival. The study was undertaken as a special student project in the Biology Department of Lebanon Valley College under the guidance of Dr. Rebecca Urban. Using the data we collect, we hope to point out possible management options for enhancing trout survivability in the Quittapahilla Creek.

Study Objectives

1. Establish structured methods of data collection for temperature surveys;
2. Conduct a longitudinal temperature survey of the Quittapahilla Creek and its tributaries;

3. Identify possible sources of warm and cold-water inputs; and

4. Assess water quality characteristics of the Quittapahilla Creek through discrete seasonal sampling of temperature, dissolved oxygen (DO), pH, specific conductance, and depth.

METHODS

Measurements

Water sampling took place on September 19th, September 29th, October 6th, and October 14th of 2022. Sampling occurred about every half mile of the Quittapahilla Creek in Lebanon County, Pa, USA. There were areas where this was not followed and more or fewer samples were taken. Samples were taken upstream and downstream of tributary inputs and at or near the mouth of the tributary itself. Similarly, samples were taken upstream, downstream, and in the effluent of the Lebanon Wastewater Treatment Plant.

Calibrating the Sonde

A YSI 6920 V2-2 Multi-parameter Water Quality Sonde with a YSI handheld display unit was borrowed from the Department of Environmental Protection to take water quality measurements of temperature, dissolved oxygen, specific conductance, and pH. To prepare this sonde for the field, calibration for the specific conductance and pH were prepared indoors, in the laboratory, while the calibration for the dissolved oxygen was done in the field. The calibration for each parameter was performed once a day before the samples were taken, starting with specific conductance. The sonde probes were rinsed 3 times with a 1000 μS/cm specific conductance standard and the specific conductance probe was calibrated using that standard. Subsequently, the sonde was rinsed 3 times with a 100 μS/cm standard and placed in that standard to check to make sure that the specific conductance was calibrated correctly.

To calibrate for pH, we performed a 2-point calibration for pH 7 and pH 10. For each of the two pH values, the probe was rinsed 3 times with the pH buffer, and then calibrated to the correct pH.

The last step was to calibrate the dissolved oxygen (DO). DO is calibrated in an air environment that is 100% saturated. To create this environment, a small amount of deionized water was placed in the calibration cup, just enough to cover the bottom, and the sonde was loosely screwed back onto the cup. The sonde was allowed 5-10 minutes or until it stabilized to the saturated atmosphere created in the calibration cup. Once the sonde was stabilized, it then could be calibrated to 100% dissolved oxygen saturation based on the ambient temperature and barometric pressure.

Taking a Sample

Field data were collected at twenty-six locations. A twenty-seventh location, Quittapahilla Creek at Metro Drive, was dry when we visited on September 19, 2022 so no sample could be taken at this location. Before using the sonde, the right side, left side, and thalweg of the stream were identified, and the depths of those areas were measured using a USGS top setting wading rod. The water-quality measurements were then taken at the right side, left side, and thalweg of the stream. To do this, the probes were submerged at mid-depth in the stream and the sonde allowed to stabilize for each reading. One person recorded the readings while a second person took the measurements. For this paper, we will report results from only 18 sampling locations that provide a longitudinal snapshot of conditions in the Quittapahilla Creek (**Table 2**).

Table 2. Sampling locations in the Quittapahilla Creek Watershed.

Station Number	Location	Latitude	Longitude	Date Sampled	Time Sampled[1]
3	Quittapahilla Creek at Lincoln Avenue	40.3417145	-76.4117571	September 19, 2022	15:20
6	Quittapahilla Creek at S. 22nd Street	40.3374930	-76.4503253	September 19, 2022	16:20
7	Quittapahilla Creek at Chestnut Street	40.3385645	-76.4574010	September 19, 2022	16:30
12	Quittapahilla Creek U/S of WWTP Effluent	40.337589	-76.462351	September 29, 2022	15:55
10	Lebanon WWTP Effluent	40.337563	-76.4623979	September 29, 2022	15:35
9	Snitz Creek at Dairy Road	40.3358474	-76.4629756	September 29, 2022	15:00
14	Quittapahilla Creek at Dairy Road	40.3365453	-76.4657748	October 6, 2022	13:15
15	Quittapahilla Creek at Garfield Street	40.3326805	-76.4698866	October 6, 2022	13:55
17	Quittapahilla Creek U/S of Beck Creek	40.3293669	-76.4823965	October 6, 2022	14:35
18	Beck Creek at Bricker Lane	40.3238302	-76.4833768	October 6, 2022	15:00
19	Quittapahilla Creek at Spruce Street	40.3291297	-76.4998563	October 6, 2022	15:20
20	Quittapahilla Creek at Quittie Park	40.3271559	-76.5071660	October 6, 2022	15:45
21	Quittapahilla Creek at D/S White Oak Street	40.324637	-76.514307	October 14, 2022	15:05
22	Bachman Run at Reigerts Lane	40.320101	-76.519738	October 14, 2022	15:55
23	Quittapahilla Creek at Syner Road	40.331857	-76.550773	October 14, 2022	16:50
24	Quittapahilla Creek U/S of Killinger Creek	40.335005	-76.555725	October 14, 2022	17:30
26	Killinger Creek at the mouth	40.335175	-76.555985	October 14, 2022	17:50
27	Quittapahilla Creek D/S of Killinger Creek	40.335277	-76.556182	October 14, 2022	17:55

[1]Eastern Daylight Time. D/S = downstream. U/S = upstream.

RESULTS

Measured Temperatures

Measured temperatures for 18 sampling locations in the Quittapahilla Creek Watershed are presented in **table 3**. Thirteen of the sampling sites were on the mainstem of the Quittapahilla Creek, four stations were on tributaries, and one station was from the outflow of the Lebanon Wastewater Treatment Plant. For our comparisons, we will consider measurements from thalweg samples only. Measurements from the right side and left side samples are available from the authors.

The lowest temperature measured was 13.96 °C from a tributary, Bachman Run **(Table 3, Figure 1**). From Quittie Park downstream, temperatures remained fairly uniform, with measured temperatures ranging between 14.65 and 14.85 °C. (**Table 3, Figure 1**). The highest temperature measured was 22.86 °C from the effluent of the Lebanon Wastewater Treatment Plant (**Table 3, Figure 1**). The second highest temperature measured was in the mainstem of the Quittapahilla Creek, immediately downstream from the City of Lebanon (at S. 22nd Street), with a temperature of 19.22 °C (**Table 3, Figure 1**). Temperatures in the mainstem of the Quittapahilla Creek did not vary greatly and were within a range of 14.5 °C to 15.5 °C. Three of the tributaries, Snitz Creek, Bachman Run, and Killinger Creek provide cooling water for the mainstem Quittie.

Table 3. Measurements of temperature, DO, pH, and specific conductance in the Quittapahilla Creek Watershed.

Station Number	Site Name	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductance (μS/cm)
3	Quittapahilla Creek at Lincoln Avenue	15.48	8.78	7.06	646
6	Quittapahilla Creek at S. 22nd Street	19.22	9.46	7.89	745
7	Quittapahilla Creek at Chestnut Street	18.70	9.25	7.98	761
12	Quittapahilla Creek U/S of WWTP Effluent	---[1]	10.00	8.16	741
10	Lebanon WWTP Effluent	22.86	8.39	8.28	808
9	Snitz Creek at Dairy Road	14.84	11.32	8.06	505
14	Quittapahilla Creek at Dairy Road	15.04	9.83	---[2]	662
15	Quittapahilla Creek at Garfield Street	15.29	9.64	7.21	668
17	Quittapahilla Creek U/S of Beck Creek	15.35	9.80	7.59	672
18	Beck Creek at Bricker Lane	17.05	12.97	7.80	607
19	Quittapahilla Creek at Spruce Street	15.19	9.86	7.61	660
20	Quittapahilla Creek at Quittie Park	14.73	9.75	7.66	658
21	Quittapahilla Creek at D/S White Oak Street	14.82	9.72	7.74	605
22	Bachman Run at Reigerts Lane	13.96	10.33	8.59	589
23	Quittapahilla Creek at Syner Road	14.71	10.04	8.24	604
24	Quittapahilla Creek U/S of Killinger Creek	14.68	10.01	8.42	607
26	Killinger Creek at the mouth	14.65	10.08	8.44	605
27	Quittapahilla Creek D/S of Killinger Creek	14.65	9.99	8.48	613

[1]Measured temperature value of 14.04 was likely erroneous and was discarded.
[2]Measured pH value of 6.45 was likely erroneous and was discarded.

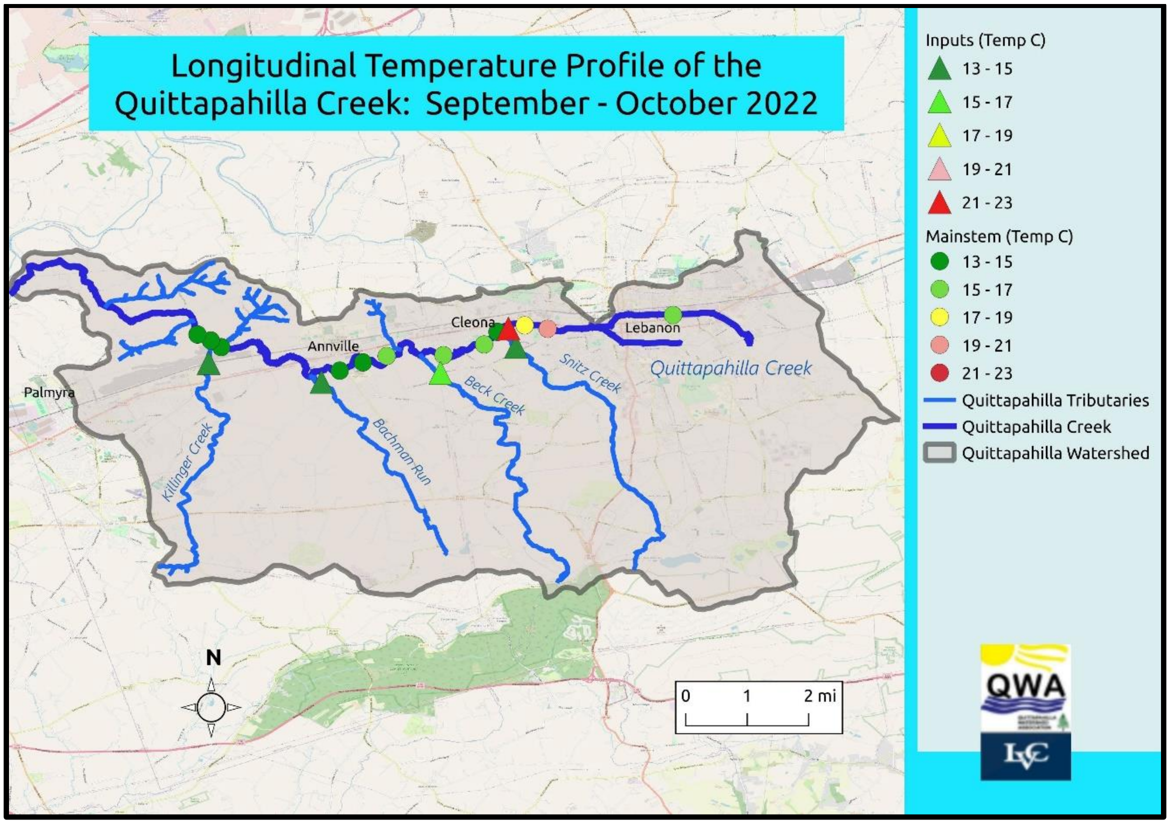

Figure 1. Map of the Quittapahilla Creek Watershed showing water temperatures (in ^{o}C) measured at sampling sites.

Measured Dissolved-Oxygen Concentrations

Dissolved oxygen concentrations were also measured at 18 locations in the Quittapahilla Watershed (**Table 3**). The lowest dissolved oxygen concentration was 8.39 mg/L from the Lebanon Wastewater Treatment Plant (**Table 3, Figure 2**). The second lowest dissolved oxygen concentration was 8.78 mg/L from the upstream-most collection site on the mainstem of the Quittapahilla Creek (Quittapahilla Creek at Lincoln Avenue) (**Table 3, Figure 2**). The highest dissolved oxygen concentration was 12.97 mg/L from a tributary, Beck Creek (**Table 3, Figure 2**). The second highest dissolved oxygen concentration was 11.32 mg/L from Snitz Creek at

Dairy Road (**Table 3, Figure 2**). Each of the four highest dissolved-oxygen concentrations were from tributary streams.

<u>Measured pH and Specific Conductance Values</u>

Specific conductance and pH are also reported for the same 18 locations as our temperature and dissolved oxygen measurements. The lowest pH value was 7.06 from the upstream-most mainstem sampling location, Quittapahilla Creek at Lincoln Avenue. The second lowest pH value was 7.21 from the Quittapahilla Creek at Garfield Street (**Figure 3**). The highest pH value was 8.59 from Bachman Run. From Bachman Run downstream, pH values in the mainstem Quittie remained slightly lower than 8.5 pH units (**Figure 3**).

The lowest specific conductance values were 505 and 589 µS/cm from two tributaries, Snitz Creek and Bachman Run (**Figure 4**). The highest specific conductance value was 808 µS/cm from the Lebanon Wastewater Treatment Plant effluent (**Figure 4**).

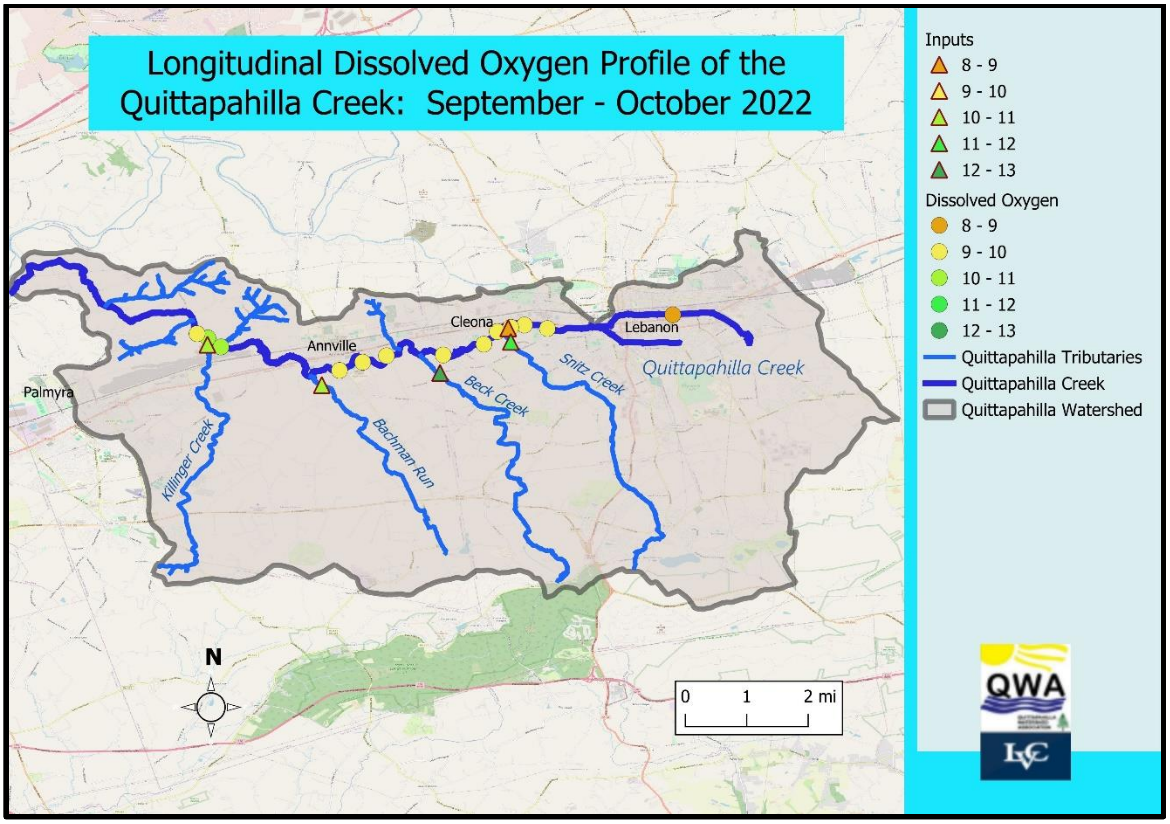

Figure 2. Map of the Quittapahilla Creek Watershed with dissolved oxygen concentrations (in mg/L) measured at sampling sites.

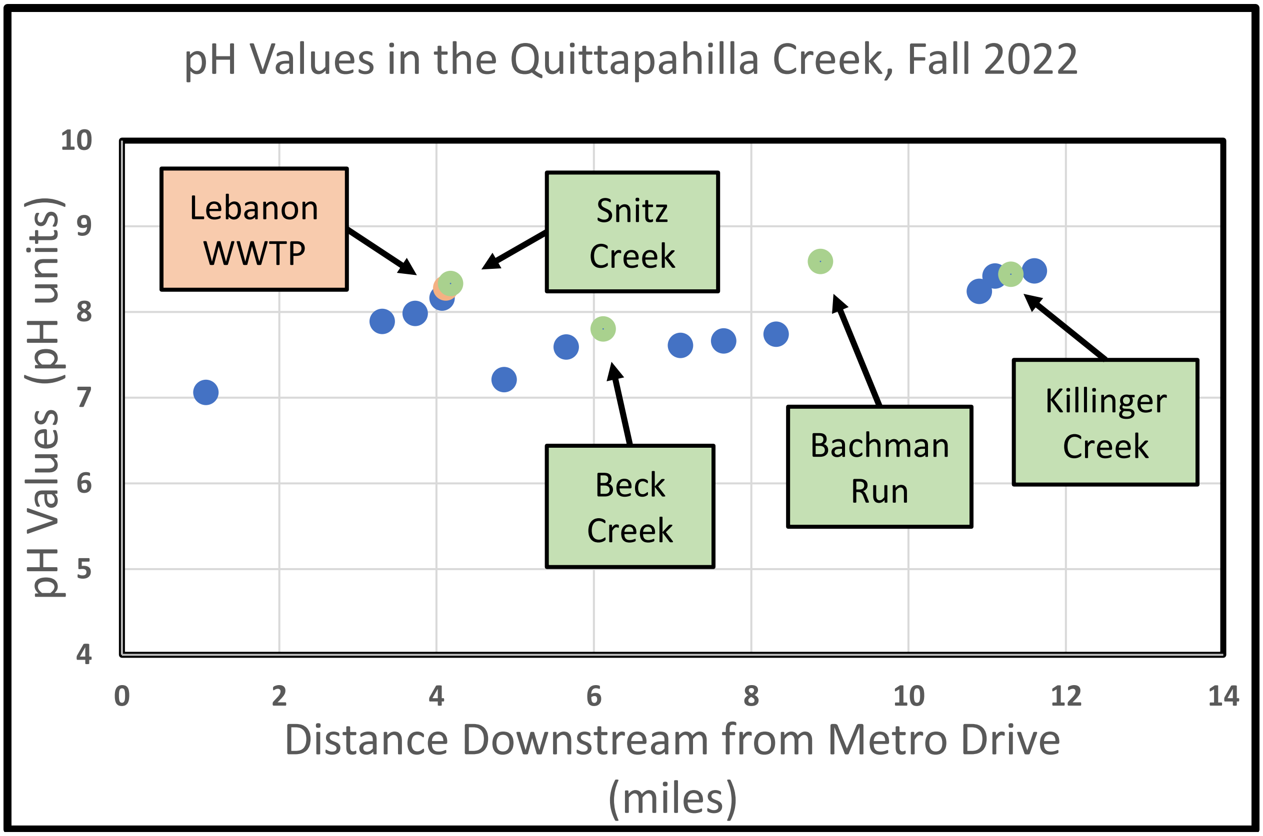

Figure 3. Graph showing pH values measured in the Quittapahilla Creek Watershed.

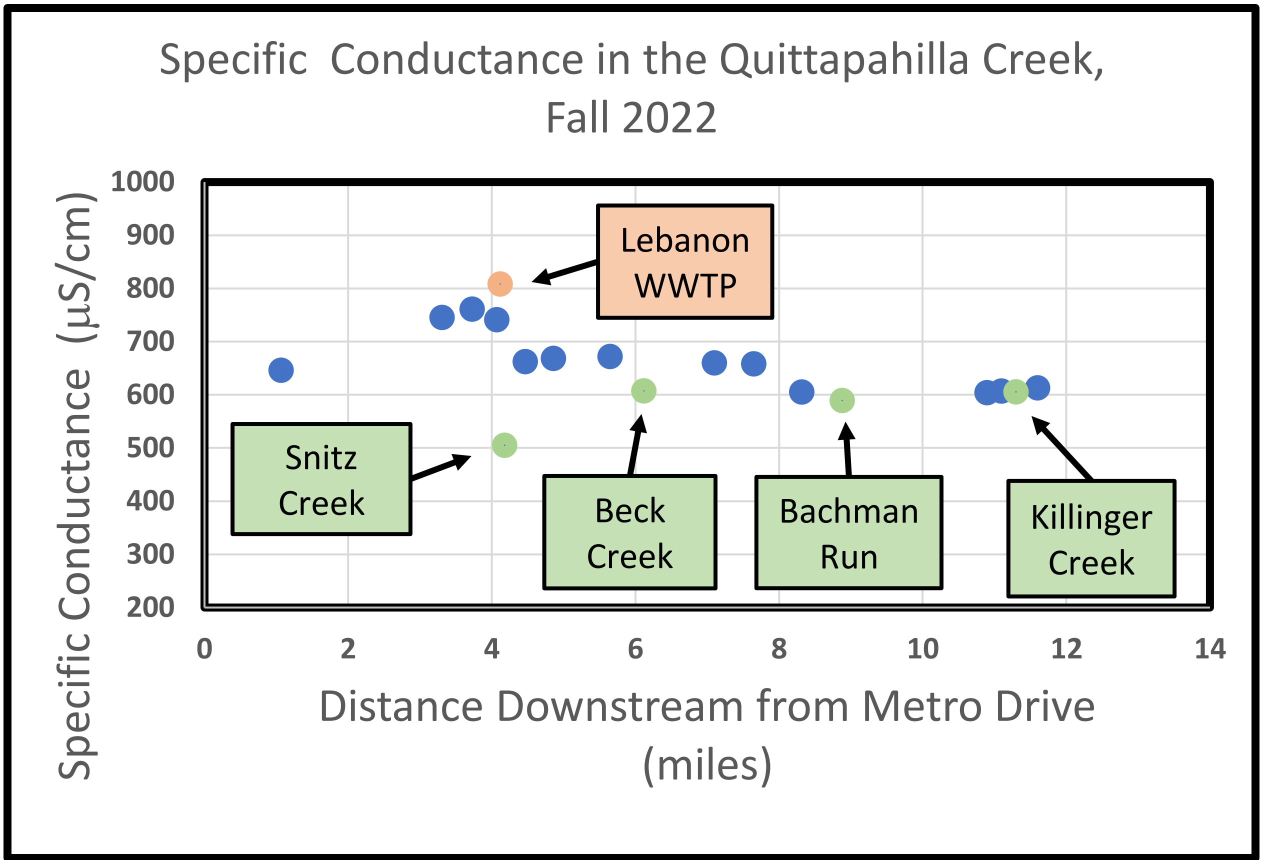

Figure 4. Graph showing specific conductance measured in the Quittapahilla Creek Watershed.

DISCUSSION AND CONCLUSIONS

Temperatures measured in the Quittapahilla Creek and tributaries during a survey in the fall of 2022 would not pose issues for the survival or reproduction of trout. But remember that our survey was conducted in early fall past the time for maximum summertime temperatures. The highest measured temperature in our study was 22.86 °C which is outside the optimal temperature range of survival for brook trout and rainbow trout. But, this temperature came from the outflow of the Lebanon Wastewater Treatment Plant. The temperature of this effluent is quickly attenuated as the effluent mixes with the receiving water in the Quittapahilla Creek.

In general, temperatures in tributaries entering the Quittapahilla Creek are lower than temperatures of the mainstem of the Creek. This finding suggests management options for trout survival. That is, providing temperature protection (for example, additional shading, narrowing the stream, or providing additional infiltration) for the tributaries may offer remediation for the higher temperatures of the mainstem Quittie.

Quittapahilla Creek water temperatures increase as the stream flows through the City of Lebanon. This finding is predictable because the stream flows through an open flood-control channel for approximately 3 miles through the City. This channel is essentially a cement trough, completely open to the sun, with no shading. At some locations, during low flows, the stream depth within the channel is shallow, allowing sunlight to penetrate the entire water column and warm the water. This finding suggests that temperature control within the City would provide lower temperatures downstream in the Creek.

We also measured dissolved oxygen, pH, and specific conductance to see if these water quality parameters were higher or lower than critical values. Dissolved oxygen can be affected by the temperature of the water. As temperature increases, dissolved oxygen levels will decrease, and we see this trend occurring in the Quittapahilla Creek. For the growth of trout and their general wellbeing, the dissolved oxygen concentration of the water they are living in should not go below 6 mg/L (Commonwealth of PA 2013) and in the Quittapahilla Creek in the fall of 2022, we see that it does not.

The water in the Quittapahilla Creek has alkaline characteristics, staying in a pH range from 7 to 8.5. The watershed is surrounded by bedrock of Lower Paleozoic shale, limestone, and dolomite formations which can cause the pH to rise in the water and give more basic levels (Clear Creeks Consulting, LLC 2006) (Boyd 2015). Most aquatic life typical of Pennsylvania streams should be fine to live in the pH range measured in the Quittapahilla Creek considering the optimal pH range for most aquatic organisms ranges from 6.5 to 8.5 (Boyd 2015).

Specific conductance is the ability of water to conduct an electric current. The concentration of total dissolved solids (TDS) can affect the specific conductance. Changes in TDS levels and ions can be caused by a variety of anthropogenic sources such as industry, mining, and gas well development and also by the underlying geology. Discharges from industries and wastewater treatment facilities can cause high levels of TDS, which in turn cause higher levels of specific conductance (Kimmel and Argent 2010). We observed this trend for the effluent of the Lebanon Wastewater Treatment Plant where we measured the highest specific conductance of any of our samples, 808 µS/cm. The lowest specific conductance measured in our study was in Snitz Creek which has slightly lower percentage of carbonate rock than the Quittie watershed as a whole. Most lake and stream waters with healthy fish populations are in a range of 150 to 800 µS/cm, so the highest reading of 808 µS/cm, is just slightly over the healthy limit (Huron River Watershed Council, 2013).

Our focus here was to see if the temperature levels in the Quittapahilla Creek were affecting trout survival, but our data suggest that temperature is not a limiting factor for trout at the time of our data collections. The dissolved oxygen, pH, and specific conductance do not seem to be limiting factors either. However, our data-collection period occurred during the fall, when the highest stream temperatures of summer had passed. All our objectives were accomplished, but we suggest that this study be replicated during the hottest time of the year, in July or August, when stream temperatures are at their peak. Also, it is critical to condense the sampling to a very short time period with all the samples collected in the same day if possible. This will require multiple sampling crews working simultaneously at different locations throughout the watershed. We also noted that the highest temperature in the entire watershed came from the Lebanon Wastewater Treatment Plant (WWTP). Any follow-up study should be sure to capture the impact of warm waters from the WWTPs in the watershed.

We believe that warm water temperatures in the summer are prohibiting trout survival in the Quittapahilla Creek. If so, then it is encouraging to know that with the slightly cooler temperatures in early fall (September and October), stream temperatures are in a suitable range for trout survival. So, it seems that if temperature-control management practices (shading, deeper water, faster water velocities) could be implemented, the Quittapahilla Creek could become a year-round trout fishery.

References

Alisawi HAO. 2020. Performance of wastewater treatment during variable temperature. Applied Water Science. 10(4). doi:10.1007/s13201-020-1171-x. [accessed 2022 Dec 9]. 14. 85 .

Arango CP, Tank JL, Johnson LT, Hamilton SK. 2008. Assimilatory uptake rather than nitrification and denitrification determines nitrogen removal patterns in streams of varying land use. Limnology and Oceanography. 53(6):2558–2572.

Bell JM. 2006. The assessment of thermal impacts on the mortality of brown trout (Salmo trutta): A Review of the Literature. Vermillion River Watershed. Retrieved December 8, 2022, from: https://www.vermillionriverwatershed.org/attachments/056_VRW-6%20Trout%20Thermal%20Impacts%20Literature%20Review.pdf.

Boyd CE. 2015. pH, carbon dioxide, and alkalinity. In: Water Quality: An Introduction. Springer, 153-178. https://doi.org/10.1007/978-3-319-17446-4_8

Clear Creeks Consulting, LLC. 2006. Principal subwatersheds of the Quittapahilla watershed. Adapted from: Quittapahilla Creek Watershed Assessment Volume 1 – Findings Report, vol. 1 (2006), Plate 2. http://www.quittiecreek.org/documents/Design%20Report%20May%202012.pdf.

Commonwealth of Pennsylvania. 2013. Rationale for the development of ambient water quality criteria for dissolved oxygen. Department of Environmental Protection, 1-13. https://files.dep.state.pa.us/publicparticipation/Public%20Participation%20Center/PubPartCenterPortalFiles/Environmental%20Quality%20Board/2013/April%2016%20EQB/TRIENNIAL/finalTR13_Rationale-Dissolved_Oxygen_Criteria-020113-072013.pdf.

Field R and Cibik C. 1980. Urban runoff and combined sewer overflow. Journal Water Pollution Control Federation. 52(6):1290–1307.

Gordon JA. 1991. Dissolved oxygen in streams and reservoirs. Research Journal of the Water Pollution Control Federation. 63(4):550–552.

Greeley JR. 1932. The spawning habits of the brook, brown, and rainbow trout and the problem of egg predators. Trans. Amer. Fish. Soc. 62(1932):239-248.

Griebler C and Avramov M. 2015. Groundwater ecosystem services: a review. Freshwater Science. 34(1):355–367. doi:10.1086/679903.

Hamdhani H, Eppehimer DE, Bogan MT. 2020. Release of treated effluent into streams: A global review of ecological impacts with a consideration of its potential use for environmental flows. Freshwater Biology. 65(9):1657–1670. doi:10.1111/fwb.13519.

Hazzard AS. 1932. Some phases of the life history of the eastern brook trout, *Salvelinus fontinalis* Mitchell. Trans. Amer. Fish. Soc. (62)1: 344-350.

Hazzard HS and Madsen MJ. 1933. Studies of the food of the cutthroat trout. Trans. Amer. Fish. Soc. 63 (1933):198-203.

Huron River Watershed Council. 2013. Conductivity. https://www.hrwc.org/wp-content/uploads/2013/09/Conductivity.pdf.

Irving L, Black EC, Safford V. 1941. The influence of temperature upon the combination of oxygen with the blood of trout. Biological Bulletin. 80(1):1–17. doi:10.2307/1537702.

Kemp SJ and Spotila JR. 1997. Effects of urbanization on brown trout *Salmo trutta*, other fishes, and macroinvertebrates in Valley Creek, Valley Forge, Pennsylvania. The American Midland Naturalist. 138(1):55–68. doi:10.2307/2426654.

Kimmel WG and Argent DG. 2010. Stream fish community responses to a gradient of specific conductance. Water, Air, and Soil Pollution, 206, 49-56.

Marschall EA and Crowder LB. 1996. Assessing Population Responses to Multiple Anthropogenic Effects: A Case Study with Brook Trout. Ecological Applications. 6(1):152–167. https://doi.org/10.2307/2269561.

Nevada Department of Environmental Protection. 2017. Brown trout (*Salmo trutta*) thermal tolerance analyses – juvenile and adult, summer. Available at: https://ndep.nv.gov/uploads/water-wqs-docs/BrownTTA.pdf. (Accessed: December 8, 2022).

PA Fish and Boat Commission. 2022. Trout Stocking Schedule. Retrieved December 8, 2022, from https://fbweb.pa.gov/stocking/TroutStockingDetails_GIS.aspx.

Pal A, Gin KY-H, Lin AY-C, Reinhard M. 2010. Impacts of emerging organic contaminants on freshwater resources: Review of recent occurrences, sources, fate and effects. Science of The Total Environment. 408(24):6062–6069. doi:10.1016/j.scitotenv.2010.09.026.

Scott WB and Crossman ES. 1973. Frshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, 966 pp.

Solomon CT, Hotchkiss ER, Moslemi JM, Ulseth AJ, Stanley EH, Hall RO, Flecker AS. 2009. Sediment size and nutrients regulate denitrification in a tropical stream. Journal of the North American Benthological Society. 28(2):480–490. doi:10.1899/07-157.1.

Somers KA, Bernhardt ES, Grace JB, Hassett BA, Sudduth EB, Wang S, Urban DL. 2013. Streams in the urban heat island: spatial and temporal variability in temperature. Freshwater Science. 32(1):309–326. doi:10.1899/12-046.1.

Wilson S, Griffiths M, Anielski M. 2001. Agricultural impacts on surface water quality. Pembina Institute the Alberta GPI Accounts. 24.