

City of Frederick Stream Temperature Study

Prepared for:

The City of Frederick, Maryland
Sustainability Manager
111 Airport Drive East
Frederick, MD 21701



Prepared by:

Center for Coastal and Watershed Studies
Hood College
401 Rosemont Ave.
Frederick, MD 21701

Catherine Gaudlip, CCWS Field Technician
Susan Simonson, CCWS Project Coordinator
Drew Ferrier, Center Director, and Professor of Biology

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Cover Photo: Hood-CCWS student worker deploying temperature loggers at Monocacy Riverwalk Park, May 26, 2022.

Project Summary

In 2022, Hood College Center for Coastal and Watershed Studies (Hood-CCWS) conducted a temperature study of five stream reaches within the City of Frederick for two purposes: 1) to collect a third year of baseline data for stream sections slated for potential restoration projects; and 2) to collect data at additional monitoring sites to further characterize the temperature variation within the streams through the study period.

During the summer months of 2022, from June 1 until September 1, Hood-CCWS collected temperature data following the Maryland Department of the Environment/Department of Natural Resources Temperature Assessment Methodology (MDE, 2019). The resulting temperature data were analyzed and compared to water quality standards for temperature required by the Maryland Department of the Environment Designated Use Class for Surface Waters (MDE, 2019). Previously collected data was also used to compare to this year's stream study data. Three of the streams in the study are categorized as State Stream Use Class III-P (Nontidal Cold Water and Public Water Supply), two are designated as Use Class IV-P (Recreational Trout Waters and Public Water Supply), while one stream, Carroll Creek, has a split designation of both Use Class III-P and IV-P (see MDE Maryland's Designated Uses/Use Class Map - <https://mdewin64.mde.state.md.us/WSA/DesigUse/index.html>).

All stream sites exceeded their Use Class temperature criteria in either one or more categories during summer 2022.

Methods

Hood-CCWS utilized ONSET HOBO MX 2201 loggers for both water and air temperature data collection. All loggers were tested for accurate temperature calibration prior to deployment, following the MDDNR Quality Assurance Document for Temperature Monitoring (MDDNR, 2016). Loggers designated for water sites were enclosed in a protective PVC pipe and weighted with a standard masonry brick (Figure 1). The water loggers were secured to a streamside tree root or metal stake, with coated stainless-steel cabling.

Loggers used for air temperature data were outfitted within a reflective radiation housing and secured with plastic cable-ties on a stream-side tree in each study area (Figure 2). The purpose of the air loggers is to collect ambient air temperatures for comparison to stream temperatures to determine if the water logger became "dewatered" (i.e., exposed to air and out of the water) during the deployment period.



Figure 1: Water logger housing



Figure 2: Air logger housing mounted on a tree

All loggers were programmed to record temperature at 20-minute intervals from June 1st 00:00 to September 1st 00:00. During the month of May, Hood-CCWS deployed a total of 43 loggers along 5 stream reaches. Table 1 displays all loggers deployed, including those that were ultimately dewatered or lost.

Table 1: Summary of Stream Deployment Sites in Frederick City, 2022.

Stream Name	State Designated Use Class	Water Logger Placement in Potential Restoration Sites	Total No. Deployed Loggers
Carroll Creek (CC)	III-P/IV-P	Walnut Ridge/Slagle Property; Renn Farm	13 water (1 duplicate), 1 air
Monocacy Tributary (MT-RW)	IV-P	Riverwalk Park	5 water (1 duplicate), 1 air
Rock Creek (RC)	III-P	Old Camp	7 water (2 duplicates), 1 air
Little Tuscarora Creek (TC-CR)	III-P	Clover Ridge Unnamed Trib; Little Tuscarora Creek	7 water (1 duplicate), 1 air
Tuscarora Creek (TC)	III-P	Willow Brook (WB)	4 water, (1 duplicate), 1 air
Monocacy River (WWTP)	IV-P	Wastewater Treatment Plant	7 water, (3 duplicates), 1 air

Water loggers were placed in pairs at several deployment sites to serve as duplicates. Logger ID and GPS locations for each logger deployment site are provided in Appendix 1.

During the deployment period, 1 Rock Creek, 1 Tuscarora, 4 Carroll Creek, and all Riverwalk loggers were checked on June 9, 2022, immediately following a storm event. No loggers appeared to have been dewatered, disturbed, or misplaced. One Riverwalk logger (MT-RW1) indicated a low battery; therefore, out of caution, another logger was deployed as a duplicate on June 22, 2022.

All loggers were retrieved during the months of September and October, and their data downloaded. A calibration check was conducted on each logger after downloading the data, following the MDDNR QA Guidelines (MDDNR, 2016). Water temperature data were screened against the associated air temperatures for potential errors following US EPA QA\QC Best Practices (EPA, 2014). Raw data files for each data location will be submitted electronically to the City for future reference.

Maryland has established the thermal criteria for each stream Use Class. These are codified in COMAR 26.08.02.03-3 as follows:

- Use Class I and Use Class II waters may not exceed 90°F (32°C).
- Use Class III and III-P waters may not exceed 68°F (20°C) at the 90th percentile for the range of readings collected or 75°F (23.8°C) as an acute maximum temperature throughout the temperature collection period. (Also see MDDNR, 2016)
- Use Class IV and IV-P waters may not exceed 75°F (23.9°C). There is no acute maximum temperature for this Use Class.

Currently, special interest by MDE is focused on Use Class III temperatures regarding TMDL development. (Personal communication, Matt Stover, 6 Jan. 2023)

Exceedances of these metrics are highlighted in yellow in each data summary table for each respective stream.

Loggers that underwent dewatering any time during the summer are noted for each respective stream, as well as in Appendix 2.

Results and Discussion

Carroll Creek:

Carroll Creek headwaters originate on the west side of the City of Frederick in the Catoctin Mountains, flowing easterly towards the city (Figure 3). The land-use in these western headwaters is primarily wooded and residential, changing to agricultural as the stream progresses towards the city. Urban development intensifies to mixed use residential and commercial as Carroll Creek approaches the SR-15 bridge. The Creek flows through Baker Park and is then diverted mostly underground beneath the City Center with an outfall reopening east of the city. Note that logger CC-2mile was placed in the elevated, artificial stream channel in Carroll Creek Park while the natural flow of the stream is diverted to an underground conduit which emerges just upstream of site CC-1.4mile. The stream discharges into the Monocacy River. Carroll Creek has a split State Designated Use Class of III-P for the upper westerly reaches and Use Class IV-P downstream of SR-15. Loggers placed from 4 to 6.6 miles from the mouth

are in the portion of the stream designated with Use Class is III-P (upstream of SR-15); the remaining loggers (mile 3 to the mouth) are within stream with Designated Use Class IV-P. Similar to 2021, the monitored section extended from the farthest upstream site located in a tributary that intersects “Old Receiver Road” (west of the City) to the mouth of the creek near the Monocacy River (Figure 3). This year, 2 new sites were added: Renn Farm, about 1 mile from the mouth, and Baker Park, before the stream is diverted underground, about 2.5 miles from the mouth.

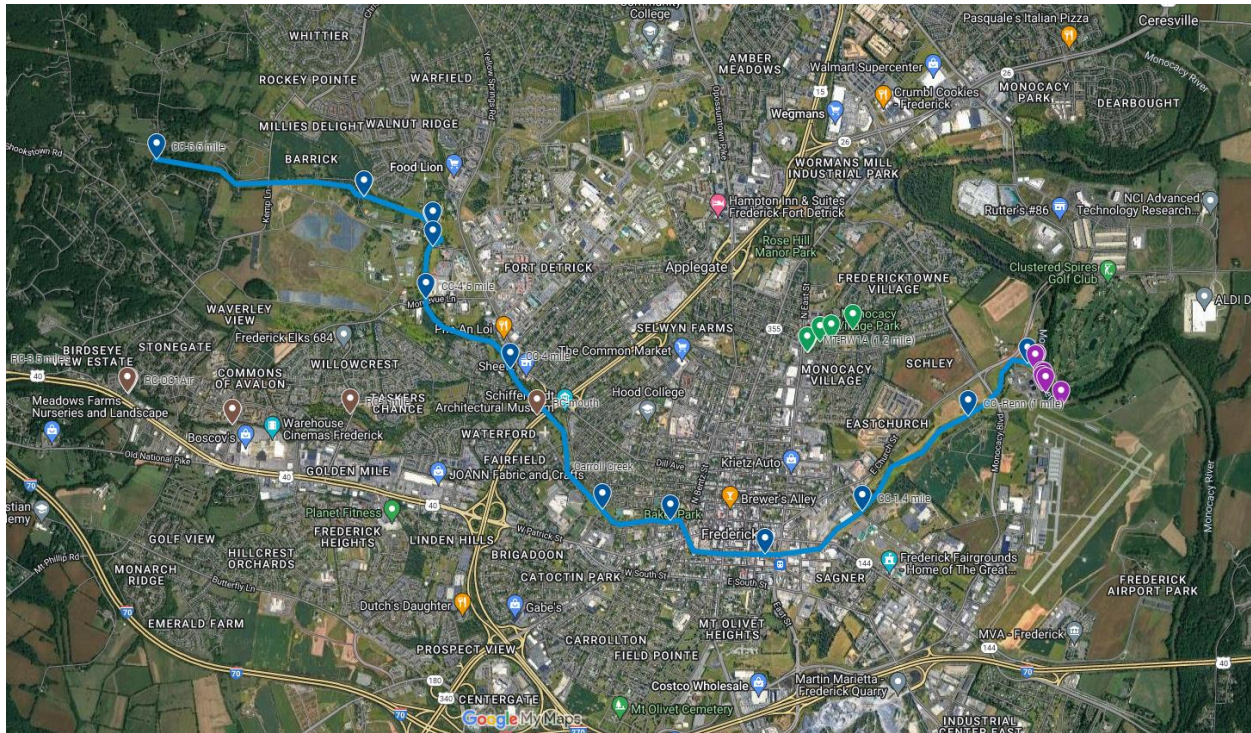


Figure 3. Carroll Creek (solid blue trace) and its logger sites (blue way points).

A section of the Carroll Creek under consideration for restoration called “Walnut Ridge” extends from the western boundary of Walnut Ridge Park at the intersection of Rocky Springs Road to the eastern boundary of the “Slagle Farm”, near Rosemont Avenue (Figure 4). The “upstream” logger and a duplicate were deployed east of Rocky Springs Road bridge, in a mostly wooded area (CC-WR1). The logger downstream of the proposed project area was also deployed with a duplicate within Slagle Farm agricultural fields (CC-WR2). An air logger was deployed for this stream section in the riparian zone at CC-WR2.

A second reach of Carroll Creek is also under consideration for a stream restoration project. This restoration project is generally expected to occur from Highland Avenue (Logger CC-1.4) to the mouth of Carroll Creek (CC-mouth) and designated as Use Class IV. Hence an additional logger was placed at Renn Farm.

Logger Anomalies:

- CC-WR2A -dewatered for the entirety of deployment
- CC-WR2B -not found at the time of retrieval

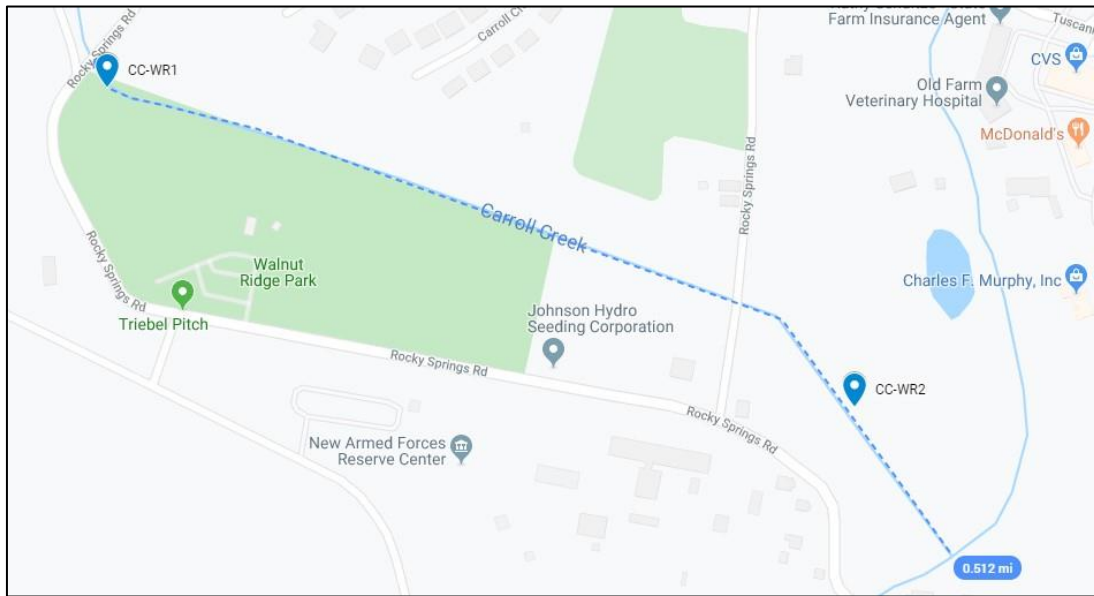


Figure 4. Map of locations at the Carroll Creek-Walnut Ridge (CC-WR) study section.

Table 2 provides a data summary for all Carroll Creek sites, excluding the dewatered logger data and missing logger, which is noted.

- All the loggers within the Use Class III-P designations exceeded the State Standard of 20°C, with 90th percentile temperatures ranging from 20.07-25.39°C, and temperatures exceeding 20°C were recorded from 11 to 81% at various sites during the study period.
- All the loggers within the Use Class IV-P designed reached or exceeded the State Standard of 23.9°C, ranging from 21.62-26.72°C, and temperatures exceeding 24°C were recorded from 1 to 36% of the study period.
- It should be noted that monitoring site CC-1.4 mile is located at the stream outfall exiting the City flood-control conduit. Underground passage through the city center likely shades and cools the stream water in the reach upstream of this site.

Table 2: Data Summary for Carroll Creek 2022 -cells highlighted in yellow indicate temperature criteria were exceeded.

Parameter	CC-6.6 mile	CC-WR1 A&B	CC-WR2A	CC-SKC	CC-4.6 mile	CC-4 mile	CC-3 mile	CC-Baker	CC-2 mile	CC-1.4 mile	CC-RennFarm	CC-mouth	All Loggers combined
No. of loggers	1	2	1	1	1	1	1	1	1	1	1	1	12
Use Class	III	III	III	III	III	III	IV	IV	IV	IV	IV	IV	
Notes	-	-	Dewatered	-	-	-	-	-	Elevated channel	Underground outfall	-	-	Dewatered data omitted
Total No. Readings	6624	13248		6624	6624	6624	6624	6624	6624	6624	6624	6624	79488
Average Temp °C	20.26	22.40		19.04	18.16	18.36	19.85	20.56	23.25	21.24	22.58	23.12	20.94
Median Temp °C	20.12	22.69		18.57	17.89	18.27	19.9	20.59	23.25	21.4	22.52	22.99	20.89
Max Temp °C	27.37	28.23		25.09	24.54	24.79	26.17	24.88	27.54	29.77	29.34	30.5	30.5
Min Temp °C	14.67	15.44		14.07	13.77	14.37	15.61	16.64	18.79	17.2	17.16	16.6	13.77
StDev	2.42	2.48		2.33	1.83	1.40	1.48	1.45	1.59	1.55	2.16	2.60	2.69
90th Percentile °C	23.55	25.39		22.55	20.8	20.07	21.62	22.35	25.44	23.12	25.48	26.72	24.45
No. of rdgs >20°C	3442	10678		2159	1205	738	3091	4521	6524	5148	5769	5819	49094
% rdgs ≥ 20 °C	52%	81%		33%	18%	11%	47%	68%	98%	78%	87%	88%	62%
No. of rdgs ≥ 23.9°C	532	3905		165	3	7	63	87	2268	210	1694	2361	11295
% rdgs ≥ 23.9 °C	8%	29%		2%	0%	0%	1%	1%	34%	3%	26%	36%	14%

The future Walnut Ridge restoration area continues to show elevated upstream 90th percentile temperatures compared to the past 3 years of this monitoring study:

	2019	2020	2021	2022
CC-WR1 (upstream)	24.54°C	26.30°C	24.95 °C	25.39 °C
CC-WR2 (downstream)	26.51°C	23.43°C ¹	No data ²	No data ²

¹only one week of data was useable at the downstream site in 2020 due to site dewatering.

² loggers at this location dewatered or lost and were entirely removed from the study.

The future Renn Farm restoration area shows slightly lower 90th percentile temperatures from previous years, but increasing temperatures from upstream to downstream in 2022:

	2020	2021	2022
CC-1.4 (upstream) ¹	23.28°C	23.38 °C	23.12
CC-RennFarm	-	-	25.48 ²
CC-mouth (downstream)	25.09°C	27.11°C	26.72

¹ Monitoring site Mile 1.4 is located at the stream outfall exiting the City flood-control conduit. Underground passage through the city center likely shades and cools the stream water in the reach upstream of this site

²New monitoring site added this year.

Overall 90th percentile stream temperatures along Rock Creek remained relatively consistent with air temperatures throughout the past 4 years (Fig. 5).

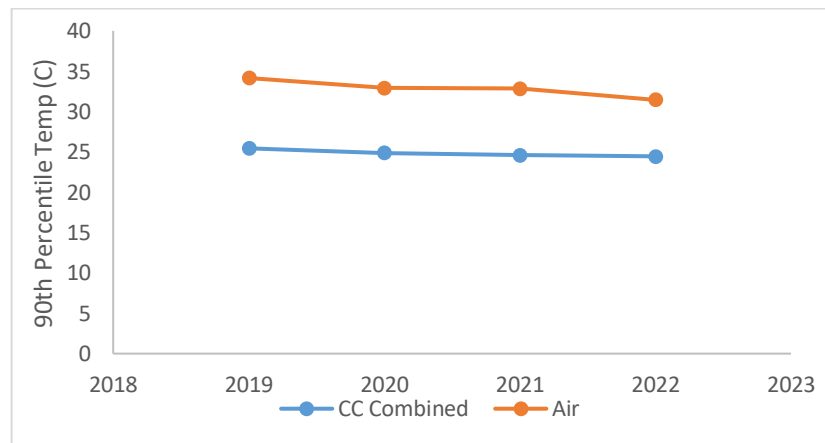


Figure 5. Overall 90th percentile stream temperatures and air temperatures at Carroll Creek.

Monocacy Tributary-Riverwalk (MT-RW):

This project area is an approximately 1-mile long section of an unnamed tributary of the Monocacy River (now known as Abraham Faw Run) on the east side of the City that flows easterly from East Street through Monocacy Village Park and Riverwalk Park (Figure 6). The stream is fed by springs and urban stormwater discharge from the City. The study section contains sinkholes which disrupt the stream channel and flow of water. The proposed restoration project area ends at the eastern boundary of Riverwalk Park where the tributary flows onto a private agricultural property. The stream's designated Use Class is IV-P, with a water temperature standard of 23.9°C.

A logger was placed upstream at the stormwater discharge culvert at East Street (MT-RW1), where it is primarily wooded with vegetated banks. Additional loggers were placed downstream within the proposed stream restoration area in Riverwalk Park behind the pavilion. No loggers were placed downstream of Dogwood Drive because of past years' data and observations showing the stream drying up. The air logger was deployed in woods along the streambank with the MT-RW4 downstream logger.



Figure 6. Map of logger locations at the Monocacy Tributary -Riverwalk (MT-RW) site.

Two loggers occupied the upstream site by the culvert after June 24, when a duplicate was placed in the event that the original logger, which had a low battery during an early June logger check, died.

Each logger displayed signs of being dewatered during sporadic periods throughout all three months. Periods of likely dewatering are provided below:

MT-RW2	7/3 to 8/10
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MT-RW3	6/1 to 6/30, 7/5 to 7/16, 8/20 to 8/22
MT-RW4	6/17 to 7/2, 7/18 to 8/19

The data summary (Table 3) below is representative of only the periods the loggers were presumed to not have been dewatered.

Table 3: Data Summary for Monocacy Tributary – Riverwalk Park in Frederick City, 2022.

Parameter	Upstream (MT-RW1, MT-RW1dup)	Downstream (MT-RW2, MT-RW3, MT-RW4)	All Water Loggers combined
No. of loggers	2	3	5
Use Class	IV	IV	
Notes	Partially dewatered, periods missing	Partially dewatered, periods missing	Partially dewatered, periods missing
Total No. Readings	11520	10296	21816
Average Temp °C	19.16	22.22	20.60
Median Temp °C	18.92	22.39	20.03
Max Temp °C	31.4	31.01	31.4
Min Temp °C	15.66	15.53	15.53
StDev	1.97	2.50	2.71
90th Percentile °C	21.7	25.35	24.49
No. of rdgs > 20 °C	2661	8316	10977
% rdgs ≥ 20 °C	23%	81%	50%
No. of rdgs ≥ 23.9 °C	352	2680	3032
% rdgs ≥ 23.9 °C	3%	26%	14%

At the downstream sites, temperatures exceeded the standard temperature of 23.9 °C about 26% of the time. Temperatures for the upstream site exceeded the State Use Class IV-P temperature standard of

23.9°C only 3% of the time. Despite being in an urban drainage area, lower temperatures are most likely due to the presence of spring inputs in the region.

Annual water temperatures (expressed as 90th percentile) recorded for the Monocacy Tributary – Riverwalk Park site since the inception of this project in 2019 have increased from 18.1 to 24.5°C. This trend is illustrated in Figure 7.

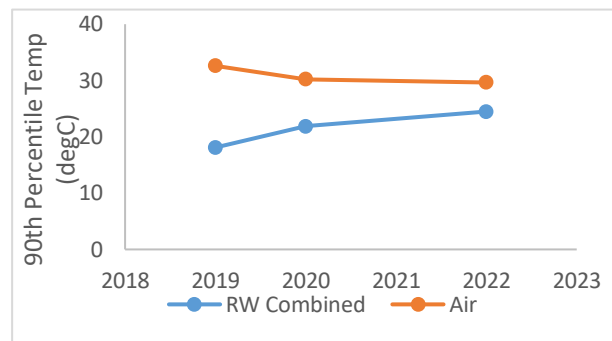


Figure 7. Overall 90th percentile stream temperatures and air temperatures at Riverwalk Park.

As shown in Figure 7, air temperature decreased between 2019 and 2020 while stream temperature increased during that interval. They appear to be more stable from 2020 to 2022.

It is worth noting that, as in previous years, the 2022 data for this location exhibited high temperature “spikes” corresponding to rain events, with maximum temperatures exceeding 20 °C (Refer to Figure 8). The temperature spikes may be indications of heated stormwater runoff from the catchment’s impervious surfaces being discharged to the stream.

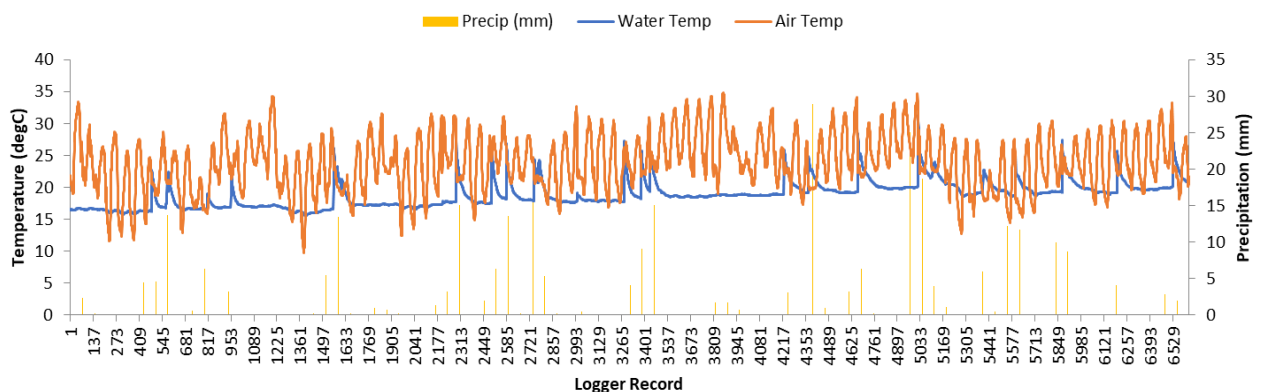


Figure 8: Water and Air Temperature Data at MT-RW1 compared to rainfall events in Frederick, MD. Note numerous water temperature spikes that generally correspond closely with precipitation events and elevated air temperatures.

Though the temperature spikes are likely due to storm runoff from precipitation as is evident in Figure 8, a closer look at the drastic spikes in temperature shows other possible temporal trends as well that may correspond to commercial or domestic activities in the watershed. For example, sump pump or laundry outputs may be improperly emptying into the stormwater system. The date, day, and time of temperature spikes are given below (Table 4).

Table 4: Temperature spikes at MT-RW1 in Frederick City, 2022.

Date	Day	Time
6/7	Tuesday	4:40PM
6/8	Wednesday	11:00PM
6/12	Sunday	6:40AM
6/14	Tuesday	5:20AM
6/22	Wednesday	3:40PM
7/2	Saturday	5:40PM
7/5	Tuesday	3:40PM
7/6	Wednesday	8:40PM
7/9	Saturday	3:20AM
7/9	Saturday	11:40AM
7/12	Tuesday	4:40PM
7/16	Saturday	1:40PM
7/17	Sunday	11:00PM
7/18	Monday	3:40PM
7/29	Friday	4:40PM
7/31	Sunday	4:20PM
8/4	Thursday	6:00PM
8/9	Tuesday	4:40PM
8/17	Wednesday	5:20PM
8/21	Sunday	1:40PM
8/26	Friday	1:20PM
8/30	Tuesday	4:00PM

Rock Creek:

The headwaters of Rock Creek originate in Gambrill State Park on the west side of the City, flowing generally southeasterly towards its confluence with Carroll Creek near SR-15 and Rosemont Avenue. The stream reach assessed during the 2022 study is approximately 3.5 miles in length beginning near the I-70/SR-40 on-ramp and ending at the confluence of Rock and Carroll Creeks (Figure 9). Rock Creek runs through mixed land-use of residential, retail, and three small parks: Stonegate Park, Willowdale Park, and Waterford Park.

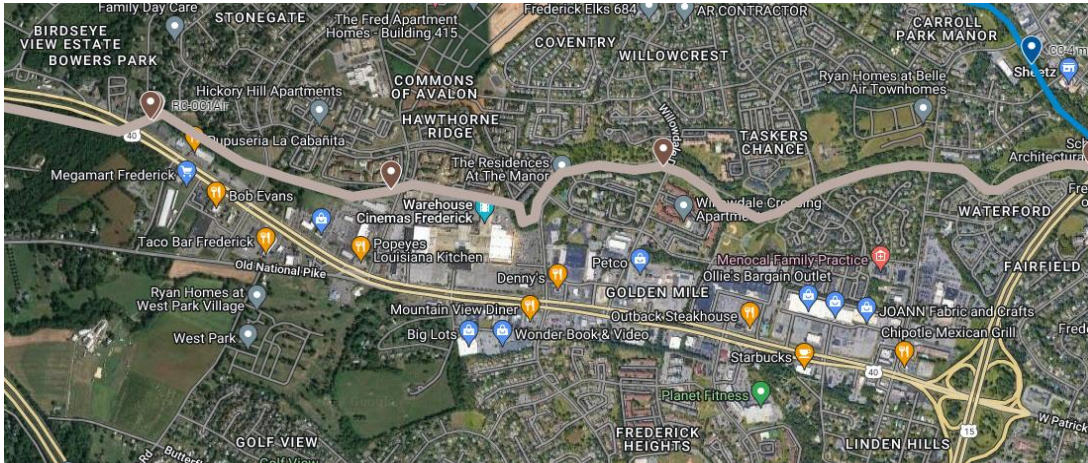


Figure 9: Rock Creek (beige solid trace) with logger sites shown as brown way points.

A section of Rock Creek, known as “Old Camp” is under consideration for restoration. This approximately 1-mile stream reach begins at the SR-40 intersection, running behind Westpoint Plaza (Figure 10). The creek runs through mixed land use, with approximately 650 feet crossing Stonegate Park. Two temperature loggers were placed at an upstream location near Rock Creek Drive with a rocky and partially wooded streamside (RC-OC1A&B). Two loggers were also deployed downstream just west of the Waverly Drive road bridge in a location with vegetated streambanks in a mixed residential/commercial land use (RC-OC2A&B). The air logger was deployed along the streambank with the upstream loggers at site RC-OC1; however, it was not found upon retrieval in September, due to deforestation of surrounding trees in that zone. Therefore, to compare air temperatures with stream temperatures for evidence of dewatering, the Carroll Creek air logger data was used.

The stream’s State Designated Use Class is III-P, with a standard temperature requirement of 20°C (90th percentile) and maximum limit of 23.8°C.



Figure 10: Rock Creek temperature study section- Old Camp Park (RC-OC).

RC-OC1B logger was dewatered between 7/3 and 8/21, and again from 8/28 through 9/1. Those data were taken out of the summary analysis. RC-3.5mile logger was dewatered during the whole summer and thus was not used in the data analysis.

Results indicate that the Old Camp upstream temperatures exceeded the State Water Quality temperature standard for Stream Use Class III (20°C) 44% of the time, with an overall 90th percentile temperature of 22.18 °C; whereas, Old Camp downstream temperatures exceeded the Standard 71% of the time, with an overall 90th percentile temperature of 23.76 °C (Table 5). The average downstream temperature was higher than the upstream location by 1.58 °C, which is greater than last year's difference in the temperatures of 1.45 °C.

Table 5: Data Summary for Rock Creek and the Old Camp potential restoration site in Frederick, 2022.

Parameter	RC-3.5 mile	Upstream (RC-OC1&B)	Downstream (RC-OC2A&B)	RC-1 mile	RC-Mouth	All Water Loggers combined
No. of loggers	1	2	2	1	1	7
Use Class	III	III	III	III	III	
Notes	Dewatered	1B Partially dewatered periods omitted	-	-	-	Dewatered data omitted
Total No. Readings	-	9360	13248	6624	6624	35856
Average Temp °C	-	19.66	21.11	18.99	20.75	20.27
Median Temp °C	-	19.73	21.23	18.83	20.8	20.25
Max Temp °C	-	27.07	30.07	26.47	25.95	30.07
Min Temp °C	-	13.38	15.36	15.06	15.57	13.38
StDev	-	1.99	2.14	1.56	1.72	2.1
90th Percentile °C	-	22.18	23.76	21.02	22.91	22.99
No. of rdgs >20 °C	-	4127	9342	1408	4524	19401

% rdgs \geq 20 °C	-	44%	71%	21%	68%	54%
No. of rdgs \geq 23.9 °C	-	142	1160	52	198	1552
% rdgs \geq 23.9 °C	-	2%	9%	1%	3%	4%

Combined, loggers exceeded the State Water Quality temperature standard for Stream Use Class III (20°C) 21-71% of the time, with an average temperature of 20.27°C and maximum temperatures ranging from 25.95 °C to 30.07 °C. The overall 90th percentile temperature was 22.99°C, which is similar to the previous 3 years of this monitoring shown here:

	2019	2020	2021	2022
90th Percentile (°C)	23.2°C	23.6 °C	23.3 °C	22.99
% time \geq 20 °C	62%	64%	56%	54%

Figure 11 shows not much change in stream temperature in relation to air temperature over the last 4 years.

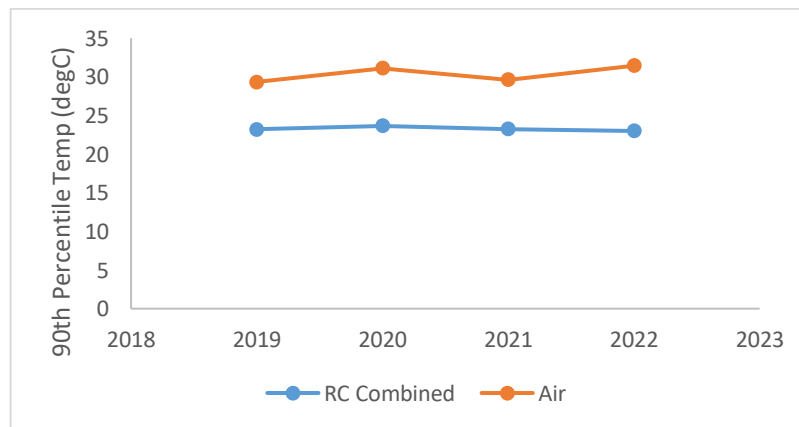


Figure 11. Overall 90th percentile stream temperatures and air temperatures at Rock Creek.

Tuscarora Creek-Clover Ridge (TC-CR):

Little Tuscarora Creek lies within the northwestern limits of Frederick City. The creek's headwaters originate in the Catoctin Mountains, generally flowing easterly to its confluence with Tuscarora Creek near Willowbrook Road. The land use surrounding this creek section is primarily developed or under

construction with multiple residential communities. The study area, Clover Ridge, is a 1.5-mile long stretch of tributary that flows through the Clover Ridge residential community into Little Tuscarora Creek, just west of Willowbrook Road (Figure 12). Portions of the study area have undergone riparian buffer plantings and/or small-scale stream restorations, with additional restoration work being considered. The stream's designated Use Class is III-P, with a water temperature standard of 20 °C.

Four water loggers were deployed along the Clover Ridge study area: two loggers upstream in Clover Hill Park (TC-CR1), one logger approximately mid-section just north of the Poole Jones Road (TC-CR2), and one logger (TC-CR3) in a downstream location just upstream from the Opossumtown Pike. An air logger was deployed streamside at the TC-CR2 midpoint site but was not found upon retrieval. Therefore, an air logger at LTC-5.7 miles that was previously deployed and already collecting temperature data was used for this area.

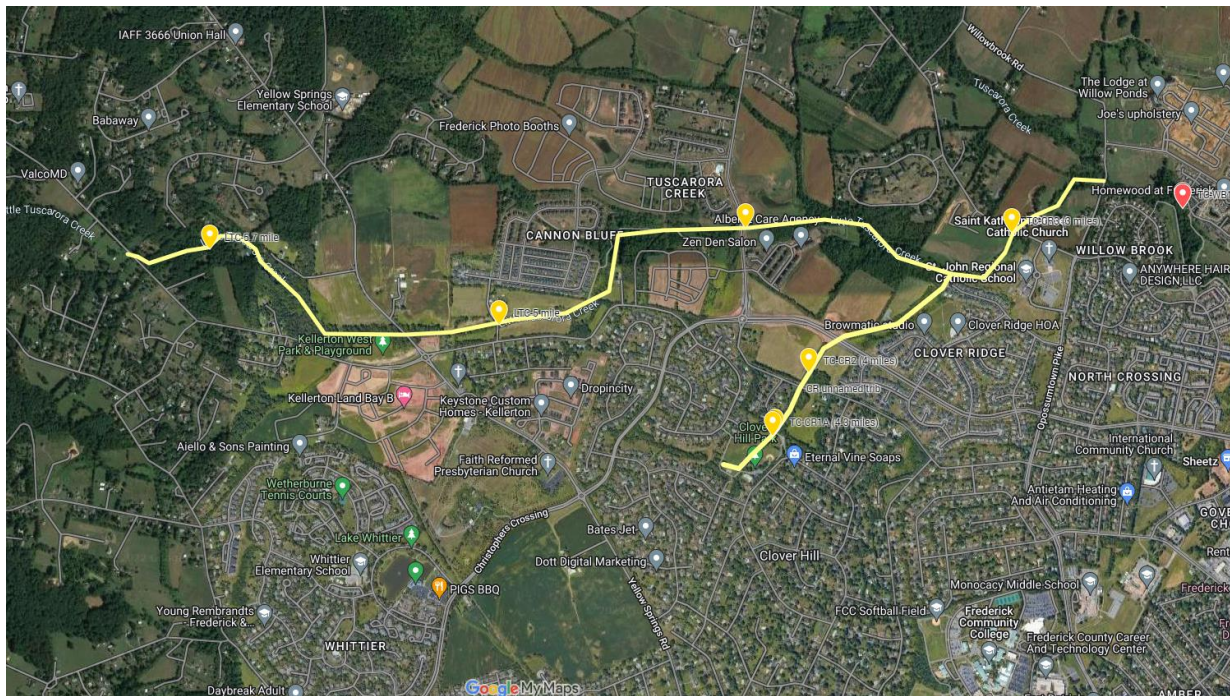


Figure 12. Map of logger locations for Tuscarora Creek - Clover Ridge (TC-CR) and Little Tuscarora Creek (LTC).

Three loggers were deployed upstream of the study area, near the headwaters, which is considered Little Tuscarora Creek. One logger placed at 5.7 miles away from the mouth, one at 5 miles, and one at 4 miles from the mouth of Tuscarora Creek into the Monocacy River.

Two loggers displayed dewatering during these periods:

LTC-4mile	6/21 to 6/24; 7/10 to 7/16, 8/20 to 8/22
LTC-5mile	8/18 to 8/26

Table 6 displays the summary data, without dewatered periods, from the Clover Ridge study area and the Little Tuscarora Creek sites.

Table 6: Data Summary for Tuscarora Creek - Clover Ridge in Frederick City, 2022.

Parameter	LTC-5.7mile	LTC-5mile	LTC-4mile	Upstream (TC-CR1 A&B)	Midpoint (TC-CR2)	Downstream (TC-CR3)	All Water Loggers combined
No. of loggers	1	1	1	2	1	1	7
Use Class	III	III	III	III	III	III	
Notes	-	Partially dewatered	Partially dewatered	-	-	-	Dewatered data omitted
Total No. Readings	6624	5976	5616	13248	6624	6624	44712
Average Temp °C	18.56	20.59	21.30	21.23	20.94	20.46	20.60
Median Temp °C	18.74	20.68	21.45	21.45	21.19	20.55	20.76
Max Temp °C	22.61	26.3	29.17	26.34	26.42	25.65	29.17
Min Temp °C	14.2	14.93	14.97	15.57	15.1	15.18	14.2
StDev	1.66	2.25	2.28	1.97	2.09	1.80	2.20
90th Percentile °C	20.63	23.42	24.06	23.68	23.46	22.69	23.42
No. of rdgs >20 °C	1341	3638	4092	9620	4547	4094	27332
% rdgs ≥ 20 °C	20%	61%	73%	73%	69%	62%	61%
No. of rdgs ≥ 23.9 °C	0	401	646	174	366	966	2553
% rdgs ≥ 23.9 °C	0%	7%	12%	3%	6%	7%	6%

All monitoring sites exceed the State Water Quality temperature standard for Stream Use Class III-P (20 °C) more than 20% of the time. With the exception of site LTC-5.7mile, acute temperature maxima of 23.8°C were exceeded at all sites hundreds of times. An overall 90th percentile temperature of 23.4°C was observed for the Tuscarora Creek - Clover Ridge location. This is a little lower than the previous years which are shown as follows:

	2019	2020	2021	2022
90th Percentile (°C)	25.4 °C	24.88 °C	24.6 °C	23.42 °C

Clover Ridge upstream, midpoint, and downstream 90th percentile temperatures exceeded the State Water Quality temperature standard for Stream Use Class III (20 °C) more than 62% of the time, but with slightly decreasing 90th percentile temperatures downstream. The 90th percentile temperatures for this study area slightly decreased from previous years:

	2019	2020	2021	2022
CR-1 Park (upstream)	22.6 °C	24.4 °C	24.11 °C	23.68°C
CR-2 (downstream)	23.2 °C	22.6 °C	23.98 °C	23.46°C

Stream temperatures appear to follow air temperature trends in 2019 and 2020; however, there is not much drop in stream temperature in 2022 where there is a drop in air temperature (Figure 13).

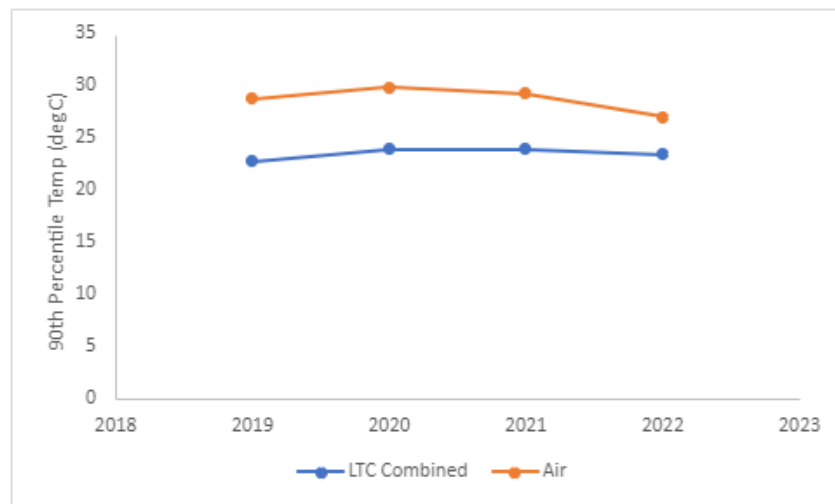


Fig. 13. Overall 90th percentile stream temperatures and air temperatures at Tuscarora Creek - Clover Ridge location.

Tuscarora Creek-Willow Brook (TC-WB):

This study section is approximately 2 miles of Tuscarora Creek, which runs southeasterly from the Catoctin Mountains through Willow Brook Park in the northwestern Frederick City limits, under SR-15, through Worman's Mill where it empties into the Monocacy River (Figure 14). A potential restoration project is under consideration within the Willow Brook Park which is characterized as mostly wooded riparian area within residential communities. The entirety of the project area is within a wooded park area with mixed residential use beyond the parkland. The study area streams are designated Use Class III-P, with a water temperature standard of 20 °C (90th percentile) and an acute maximum of 23.8 °C.

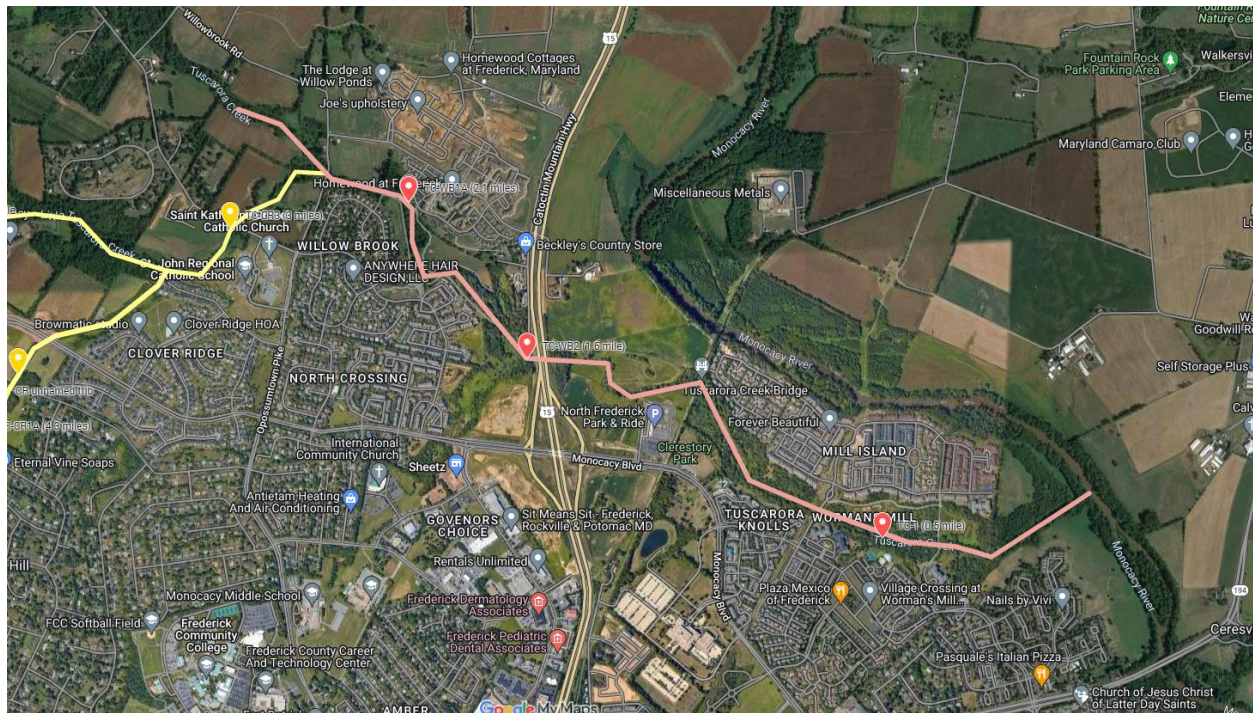


Figure 14: Map of logger sites at Tuscarora Creek in Willow Brook (TC-WB). Stream is a solid red trace; logger location are designated as red way points.

Two loggers were deployed upstream at 2.1 miles from the mouth to the Monocacy River (TC-WB1A&B). These upstream loggers were placed downstream of a small unnamed tributary confluence. This unnamed tributary drains stormwater from Willow Road and runoff from a new residential development. One downstream logger was placed approximately 150' upstream from the SR-15 highway bridge (TC-WB2). Lastly, the furthest downstream logger was placed 0.6 miles from the mouth of the Creek (TC-1). The air logger was deployed along the streambank with the upstream loggers.

No anomalies or dewatering were noted during the deployment period for these loggers.

Table 7 displays summary results from the Willow Brook study area with the downstream mouth data logger results as well.

Table 7: Data Summary for Tuscarora Creek - Willow Brook in Frederick City, 2022.

Parameter	Upstream (TC-WB1A&B)	Downstream (TC-WB2)	Mouth (TC-1)	All Water Loggers combined
No. of loggers	2	1	1	4
Use Class	III	III	III	
Notes	-	-	-	-
Total No. Readings	13248	6624	6624	26496
Average Temp °C	21.46	21.39	21.91	21.55
Median Temp °C	21.45	21.53	22.01	21.62
Max Temp °C	27.02	25.95	27.02	27.02
Min Temp °C	15.78	16.08	16.51	15.78
StDev	2.10	1.87	1.99	2.03
90th Percentile °C	24.11	23.68	24.36	24.11
No. of rdgs >20 °C	10087	5096	5418	20601
% rdgs ≥ 20 °C	76%	77%	82%	78%
No. of rdgs ≥ 23.9 °C	1580	515	1031	3126
% rdgs ≥ 23.9 °C	12%	8%	16%	12%

Results (Table 7) indicate that downstream temperatures in the Willow Brook study area (TC-WB2) are slightly lower than the upstream temperatures. However, the water temperature increases again before it reaches the mouth, which could be due to runoff from SR-15.

Combined 90th percentile temperatures exceeded the Use Class III-P State Water Quality temperature standard 78% of the time, with an overall 90th percentile temperature of 24.11°C. This overall exceedance follows similar exceedances in previous study years:

	2019	2020	2021	2022
Tuscarora Creek- Miles 0.6 -2.5 Combined	23.6 °C	24.7 °C	24.2 °C	24.11°C

Overall, air and stream temperatures at the Tuscarora Creek - Willow Brook location do not appear to vary from year to year since the inception of the project in 2019 (Figure 15).

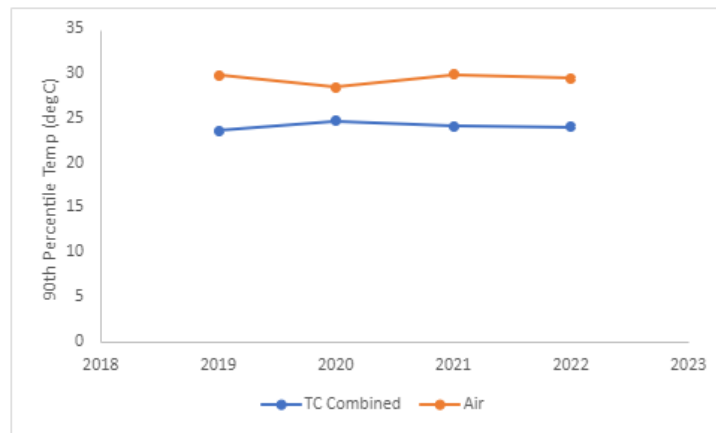


Fig. 15. Overall 90th percentile stream temperatures and air temperatures at the Tuscarora Creek - Willow Brook location.

Monocacy River at Wastewater Treatment Plant (WWTP):

This study area along the Monocacy River was focused at the City of Frederick Wastewater Treatment Plant (WWTP) located at 100 Treatment Plant Road (Figure 16). The stream's designated Use Class is IV-P, with a water temperature standard of 23.9 °C.

A total of seven water loggers were deployed in the vicinity of the plant. Duplicate loggers were situated at three sites along the Monocacy River, with one site upstream of the WWTP (WWTP-1), just below the confluence of Carroll Creek. Two sites were situated immediately above the WWTP discharge (WWTP-2) and two sites below the WWTP outfall (WWTP-3). Lastly, one logger was deployed at a site approximately 750' downstream of the outfall, just above the input of stormwater from agricultural fields (WWTP-4). An air logger was deployed in the newly wooded area near site WWTP-2.



Figure 16: Map of logger locations at the City of Frederick Wastewater Treatment Plant (WWTP) study site. Solid purple trace is the Monocacy River; purple way points indicate logger locations.

One logger at the furthest upstream site (WWTP-1B) appeared dewatered between 6/26 and 7/10. A logger at WWTP-2 (WWTP-2A) was dewatered for the last 3 days of deployment: 8/28-9/1. Lastly, WWTP-3B logger was dewatered from 8/11 through the end of deployment. The temperature data recorded by dewatered loggers were removed from the overall temperature analysis.

Table 8 displays the summary of results for the WWTP location below.

Table 8: Data Summary for Frederick City's Wastewater Treatment Plant, 2022.

Parameter	Upstream WWTP-1	Upstream of Outfall WWTP-2	Downstream of Outfall WWTP-3	Downstream WWTP-4	All Water Loggers combined
No. of loggers	2	2	2	1	7
Use Class	IV	IV	IV	IV	
Notes	1B dewatered 6/26-7/10	2A dewatered 8/28-9/1	3B dewatered 8/11-9/1	-	Dewatered data omitted
Total No. Readings	12168	12960	11736	6624	43488

Average Temp °C	24.95	25.22	24.41	24.97	24.89
Median Temp °C	24.79	25.22	24.45	24.92	24.84
Max Temp °C	39.81	30.8	31.06	30.28	39.81
Min Temp °C	13.9	19.95	19.99	20.46	13.9
StDev	3.13	2.00	1.65	1.81	2.29
90th Percentile °C	28.53	27.75	26.47	27.24	27.54
No. of rdgs > 20 °C	11679	12958	11735	6624	42996
% rdgs ≥ 20 °C	96%	100%	100%	100%	99%
No. of rdgs ≥ 23.9 °C	7739	9642	7282	4810	29473
% rdgs ≥ 23.9 °C	64%	74%	62%	73%	68%

Results indicate that all four sites along the Monocacy River exceeded the State Water Quality temperature standard for Stream Use Class IV (23.9 °C) more than 60% of the time. The 90th percentile temperature for sites above the outfall was 27.8-28.5 °C versus 26.4 °C downstream, but with maximum temperatures exceeding 30°C.

These exceedances are similar to previous years' data:

	2019	2020	2021	2022
90th Percentile (°C)	26.7 °C	28.18 °C	27.5 °C	27.5°C
% time ≥ 23.9 °C	54%	66%	73%	68%

Stream temperature follows air temperature trends as shown in Figure 17.

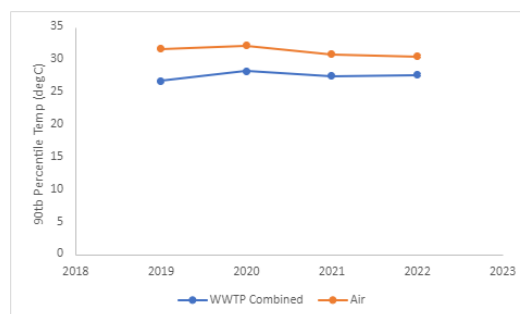


Fig. 17. Overall 90th percentile stream temperatures and air temperatures at Wastewater Treatment Plant.

Summary

Overall, the majority of the stream study areas exceeded their respective State Use Class Water Quality standards for temperature at greater than 40% of the time, with the exception of Monocacy Riverwalk Park.

Carroll Creek experienced higher average temperatures and 90th percentile temperatures as we observe further downstream. Walnut Ridge shows lower upstream temperatures this year compared to 2020, but higher temperatures than 2019 and 2021. The downstream site for Walnut Ridge did not provide data this year, but the next site downstream indicates a much lower average temperature and 90th percentile temperature. The future restoration area at Renn Farm exhibited a large increase in temperature ($> 3^{\circ}\text{C}$) from upstream to downstream of the site, which indicates a substantial need for restoration efforts.

Monocacy Riverwalk Tributary, a Use Class IV reach, had relatively low average temperatures, with low percentages of temperatures exceeding the State Use Class Water Quality standard temperature of 23.9°C . However, maximum temperatures were high, with rapid spikes in temperature correlating with precipitation events and thus storm runoff. There was a large difference in average temperatures between upstream and downstream sites in the Park, signifying a potential need for greater canopy cover for shading. Heated stormwater runoff and lack of vegetated buffers is likely the cause for these temperature differences. Overall, 90th percentile temperatures increased somewhat over the past four years.

Rock Creek temperatures still exceed the State Use Class Water Quality standard temperature throughout the reach. This year, there is a slight decline in overall 90th percentile temperature from last year, which, in turn, is lower than 2020. The Old Camp study area shows that temperatures increase downstream, again reinforcing the reach for potential restoration work.

Tuscarora Creek Clover Ridge restoration site exhibited 90th percentile temperatures and average temperatures decreasing from upstream to downstream, signifying some improvement. Overall, the 90th percentile temperature decreased approximately 2°C in the past four years; yet, the location still exceeds the State Use Class Water Quality standard temperatures for both the 90th percentile and the acute maximum.

Tuscarora Creek Willow Brook restoration site shows a slight decrease in 90th percentile temperature from upstream to downstream, but still exceeds the State Use Class Water Quality standard temperature. Overall, the 90th percentile temperature has decreased in the past three years, signifying a small improvement.

The Waste Water Treatment Plant site downstream of the outfall (WWTP3) experienced a lower 90th percentile temperature than the site upstream of the outfall (WWTP2). Maximum temperatures were greater than 30°C and still exceed the State Use Class Water Quality standard temperature. The overall temperatures have been similar to the past three years, which were all higher than 2019.

Two loggers were completely omitted due to being dewatered the entire summer, and ten loggers had some data omitted due to partial dewatering during periods of the summer. For future monitoring,

loggers will be deployed in as deep water as possible in the smaller of headwater streams. We will also perform more frequent logger checks throughout the summer.

Stream restorations to improve canopy cover and installation/adoption of stormwater best management practices specific to each watershed land use should be considered in order to improve stream habitat and to meet State water quality standards.

One aspect of restoration efforts should be to preserve and enhance the thermal mitigation provided by in-stream groundwater seeps of cooler water. In future years, it may be beneficial to perform high-resolution water temperature monitoring along entire stream reaches targeted for restoration. This could take place manually or by using a drone with thermal sensor technology.

Follow-up temperature studies should be conducted post-implementation of these corrective actions to evaluate stream temperature mitigation efforts.

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Additionally, this project would not have been possible without the dedicated fieldwork completed by Hood-CCWS staff: Catherine Gaudlip, Kate Maltby, and Matt Hardesty.

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**Appendix 1: Temperature Logger QC
and Field Notes**

Client: City of Frederick
Deployment Season: June 1-August 31, 2022

Site Name	Site ID	Dup?	Logger Serial Number	Logger location (Latitude and Longitude)	Housing Type	Pre-deploy QC Check	Deployment Comments	Post-deploy QC Check	Retrieval Notes
Carroll Creek	CC-4 mile		6427	39.426995, -77.432506	Water Housing	Pass	Behind Truist Bank, by fallen tree	Pass	
Carroll Creek	CC-2 mile		9898	39.41274, -77.40713	Water Housing	Pass	Near Arts Center	Pass	
Carroll Creek	CC-6.6 mile		6436	39.443111, -77.467789	Water Housing	Pass	7627 Old Receiver Road	Pass	
Carroll Creek	CC-Mouth		6433	39.427393, -77.380900	Water Housing	Pass		Pass	
Carroll Creek	CC-1.4 mile		9907	39.41602, -77.39737	Water Housing	Pass	Discharge at Highland St.	Pass	
Carroll Creek	CC-4.6 mile		9917	39.432363, -77.440885	Water Housing	Pass	Montevue Lane	Pass	
Carroll Creek	CC-3 mile		6422	39.41615, -77.42335	Water Housing	Pass	By Culler Lake	Pass	
Carroll Creek - Renn Farm	CC -Renn		6409	39.42332, -77.38687	Water Housing	Pass	Farm Lane at Renn Farm	Pass	
Carroll Creek - Baker Park	CC-baker		6444	39.415324, -77.416514	Water Housing	Pass	Before it goes underground	Pass	
Carroll Creek - Walnut Ridge	CC-WR1A (5.5 miles)	Yes	6410	39.440248, -77.447098	Water Housing	Pass	Rocky Springs Rd	Pass	
Carroll Creek - Walnut Ridge	CC-WR1B (5.5 miles)	Yes	9895	39.440248, -77.447098	Water Housing	Pass	Rocky Springs Rd	Pass	
Carroll Creek - Walnut Ridge	CC-WR2A (5.1 miles)	Yes	6426	39.437793, -77.440299	Water Housing	Pass	Slagle Farm	Pass	

Carroll Creek - Walnut Ridge	CC-WR2B (5.1 miles)	Yes	6417	39.437793, -77.440299	Water Housing	Pass	Slagle Farm	Missing	Not found.
Carroll Creek - Walnut Ridge	CC-WR2 Air		9931	39.437877, -77.440260	Air Housing	Pass	Slagle Farm	Pass	
Carroll Creek - Scott Key Center	CC -SKC		6434	39.436368, -77.440261	Water Housing	Pass		Pass	
Little Tuscarora	LTC-5		6420	39.46553, -77.44410	Water Housing	Pass	Walter Martz Farm	Pass	
Little Tuscarora	LTC-5.7 mile		6446	39.468578, -77.459173	Water Housing	Pass	White Flint Dr.	Pass	
Little Tuscarora	LTC-4 mile		9939	39.46944, -77.43122	Water Housing	Pass	Under Walter Martz Bridge, big tree	Pass	
Monocacy - WWTP	WWTP-1A	Yes	9904	39.426892, -77.379959	Water Housing	Pass		Pass	
Monocacy - WWTP	WWTP-1B	Yes	6424	39.426892, -77.379960	Water Housing	Pass		Pass	
Monocacy - WWTP	WWTP-air		9923	39.426842, -77.380118	Air Housing	Pass		Pass	
Monocacy - WWTP	WWTP2A	Yes	6445	39.42561, -77.37944	Water Housing	Pass		Pass	
Monocacy - WWTP	WWTP-2B	Yes	6419	39.42549, -77.37929	Water Housing	Pass		Pass	
Monocacy - WWTP	WWTP-3A	Yes	6415	39.42525, -77.379414	Water Housing	Pass		Pass	
Monocacy - WWTP	WWTP-3B	Yes	9897	39.42514, -77.37914	Water Housing	Pass		Pass	
Monocacy - WWTP	WWTP-4A		6431	39.42408, -77.37760	Water Housing	Pass		Pass	
Monocacy Trib- Riverwalk Park	MT-RW1A	Yes	9920	39.42824, -77.40284	Water Housing	Pass		Pass	
Monocacy Trib- Riverwalk Park	MT-RW1dup	Yes	6438	39.42824, -77.40284	Water Housing	Pass		Pass	

Monocacy Trib- Riverwalk Park	MT- RW1Air		6430	39.42823, -77.40288	Air Housing	Pass		Pass	
Monocacy Trib- Riverwalk Park	MT-RW2		9903	39.42904, -77.40156	Water Housing	Pass		Pass	
Monocacy Trib- Riverwalk Park	MT-RW3		9901	39.42914, -77.40045	Water Housing	Pass		Pass	
Monocacy Trib- Riverwalk Park	MT-RW4		9894	39.42997, -77.39833	Water Housing	Pass		Pass	
Rock Creek	RC 1 mile	No	6413	39.42348, -77.44847	Water Housing	Pass		Pass	
Rock Creek	RC-mouth		9908	39.42337, -77.42983	Water Housing	Pass		Pass	
Rock Creek	RC-3.5 miles		7474	39.42681, -77.48385	Water Housing	Pass		Pass	
Rock Creek - Old Camp Park	RC-OC2A	Yes	6437	39.42268, -77.46025	Water Housing	Pass		Pass	
Rock Creek - Old Camp Park	RC-OC2B	Yes	6439	39.42268, -77.46025	Water Housing	Pass		Pass	
Rock Creek - Old Camp Park	RC-OC1Air		9922	39.42509, -77.47054	Air Housing	Pass		Missing	Not found. Trees cut down.
Rock Creek - Old Camp Park	RC-OC1A	Yes	6441	39.42504, -77.47057	Water Housing	Pass		Pass	
Rock Creek - Old Camp Park	RC-OC1B	Yes	6440	39.42510, -77.47071	Water Housing	Pass		Pass	
Tuscarora Creek (Near mouth)	TC-1		6421	39.45728, -77.38471	Water Housing	Pass		Pass	
Tuscarora - Willow Brook Park	TC-WB1A	Yes	9925	39.47028, -77.40837	Water Housing	Pass		Pass	
Tuscarora - Willow Brook Park	TC-WB1B	Yes	6432	39.47022, -77.40839	Water Housing	Pass		Pass	

Tuscarora - Willow Brook Park	TC-WB air		9924	39.47021, -77.40836	Air Housing	Pass		Pass	
Tuscarora - Willow Brook Park	TC-WB2		9915	39.46421, -77.40247	Water Housing	Pass	Route 15	Pass	
Little Tuscarora Creek- Clover Hill	TC-CR1A	Yes	6423	39.46113, -77.42966	Water Housing	Pass		Pass	
Little Tuscarora Creek- Clover Hill	TC-CR1B	Yes	6408	39.46116, -77.42966	Water Housing	Pass		Pass	
Little Tuscarora Creek- Clover Hill	TC-CR1 Air		6418	39.46105, -77.42981	Air Housing	Pass		Missing	Not found
Little Tuscarora Creek- Clover Hill	TC-CR2		9921	39.46360, -77.42790	Water Housing	Pass	Poole Jones Rd.	Pass	
Little Tuscarora Creek- Clover Hill	TC-CR3		6416	39.46923, -77.41731	Water Housing	Pass	Past St. Katherine Drexel	Pass	

Appendix 2: Dewatered Loggers

Logger	Dewatered Period
Carroll Creek	
CC WR-2	All
Monocacy WWTP	
WWTP-1B	6/26 – 7/10
WWTP-2A	8/28 - end
WWTP-3B	8/11 - end
Rock Creek	
RC-OC1B	7/3 – 8/21, 8/28 - end
RC-3.5mile	All
Little Tuscarora Creek	
LTC-4mile	6/21-6/24, 7/10-7/16, 8/20-8/22
LTC-5mile	8/18-8/26
Monocacy Riverwalk	
MT-RW1 dup (placed on 6/22)	6/1-6/24
MT-RW2	7/3-8/10
MT-RW3	6/1-6/30, 7/5-7/16, 8/20-8/22
MT-RW4	6/17-7/2, 7/18-8/19