Angler Science in the Driftless Area, Using the WiseH2O Mobile Application: Pilot Project Report

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Executive Summary

Pilot Project Overview

Over the past year, MobileH2O, LLC has partnered with the Kiap-TU-Wish Chapter of Trout Unlimited (TU) on a pilot project coupling citizen science and innovative water quality monitoring technology. The intent of the project was to engage anglers to better understand the quality of coldwater resources in the Driftless Area of Wisconsin while pilot testing the WiseH2O mobile application (mApp), a customized mobile app technology.

Angler training on the use of the WiseH2O mApp

The pilot project was structured into four phases:

1. Scoping – Determine the desired outcomes, overall approach, participants, and target areas
2. Initiation and Customization – Develop a monitoring plan, customize the mApp based on rapid prototyping and feedback, survey users, and provide training
3. Implementation and Reporting – Launch mApp monitoring, provide technical support to users, and evaluate and report on project results
4. Refinement and Expansion – Make adjustments to the mApp and monitoring process based on report findings, and expand to other chapters within TU, to increase angler awareness and water quality data

Technology: WiseH2O Mobile Application

Kiap-TU-Wish anglers screened water quality and gathered other information on Pierce County, WI streams and rivers, using the WiseH2O mApp (Figure 1). While streamside, anglers used the mApp to:

- Screen water quality measurements of alkalinity, hardness, nitrate, nitrite, ortho-phosphate, and pH,
- Record water temperature,
- Record stream disturbances (e.g. bank erosion, fish barrier, trash, pipe/ditch outfall),
- Record recent weather conditions influencing stream flow and water quality,
- Record stream water level and clarity,
- Take photographs of monitoring site conditions,
- Record additional notes that characterized conditions at the monitoring location.

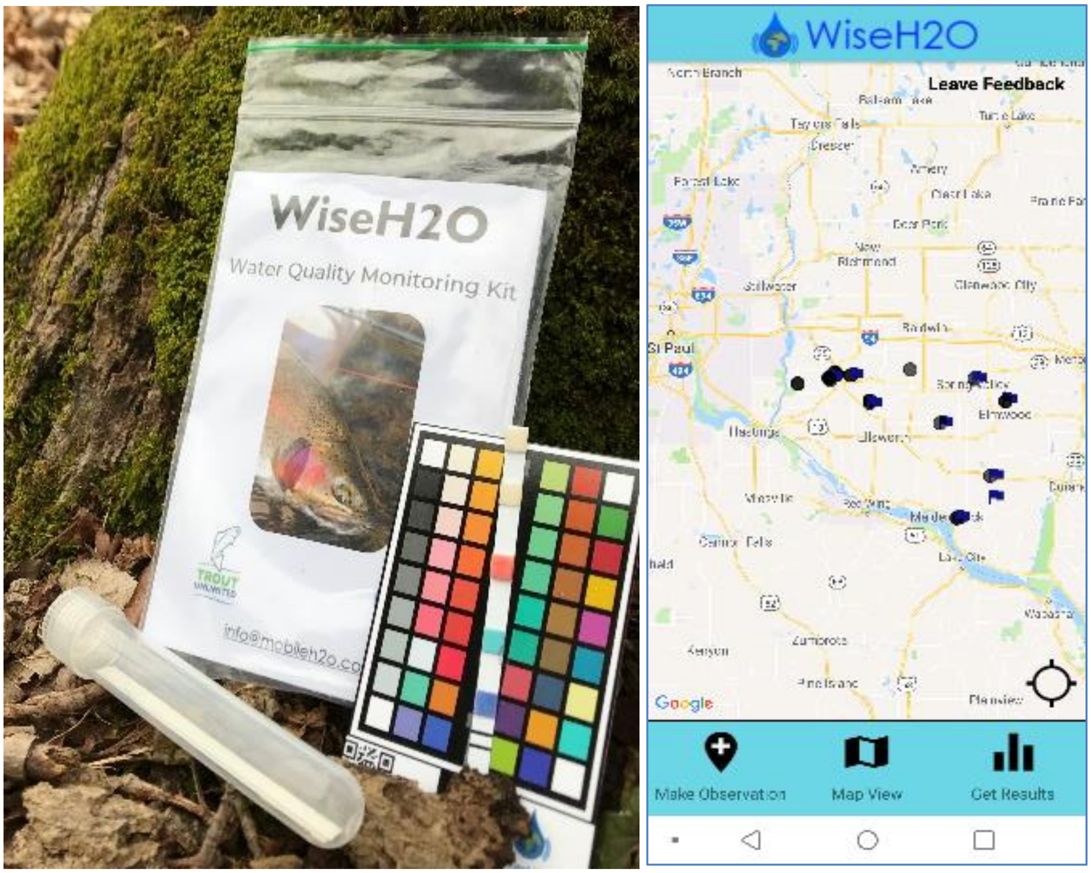

Figure 1 WiseH2O mApp test kit provided to anglers for making water quality observations. On the right, the screen shot illustrates where anglers made observations during the Pilot.

Using the mApp, water quality is screened by photographing a chemical test strip laid on a calibration card, then hitting the "Submit" button to automatically send the photograph for colorimetric analysis[1]. Within seconds, water quality concentrations are returned on a color scale informing the angler of the quality of the water chemistry for habitat conditions[2]. Later, anglers can revisit each observation to review the data or bring up a map view showing the regional water quality and stream disturbances. For resource management agencies, the data is posted to the cloud, allowing for the collection of large data sets across geographies and timespans to support actions, planning, education, emergency response, etc. As the platform is flexible, the mApp can be adapted to many applications, such as conservation, agriculture, and education. Additional information on the WiseH2O mApp is available in Appendix A.

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[1] Exception is the orthophosphate screening method, which requires anglers to visually determine a color change by looking down a tube filled with a water sample and a reagent.

[2] In the next version of the mApp, along with results, messaging will be included that informs the angler of how water chemistry influences the habitat conditions. See Table 1 as an example.

Angler Needs Assessment

As one of the first steps in the Pilot, an angler needs assessment was conducted (additional results can be found in Appendix B). A total of 41 anglers participated in an online survey, which sought to understand the anglers' knowledge of water quality issues, what water quality concerns were most important to them, their familiarity with technology and its use, how they prefer to engage with technology, and current smartphone types in use.

Key Needs Assessment Findings:

- Awareness of water quality problems in local streams: 51% Extremely/Very Aware; 49% Somewhat/Not Very Aware (Figure 2)
- Importance of water quality awareness to angler: 98% Extremely/Very Important; 2% Somewhat Important (Figure 2)
- Top two concerns about physical impacts on local trout streams: 1. Bank Erosion; 2. Pipe/Ditch draining polluted water
- Top optional write-in responses to concerns about physical impacts on local trout streams: Livestock access and agricultural runoff
- Top two concerns about water quality and quantity impacts on local trout streams: 1. Excess Sediment; 2. Nutrients (Nitrates/Phosphorus)
- Awareness of Trout Unlimited initiatives in the area: 56% Extremely/Very Aware; 44% Somewhat/Not Very/Not at All Aware
- Amount of time willing to spend per site using an mApp to monitor water quality: 2% less than 2 minutes; 22% 2-5 minutes; 39% 5-10 minutes; 37% 10-20 minutes

The results of this survey helped to inform how the mApp should be customized and what kind of training would work best.

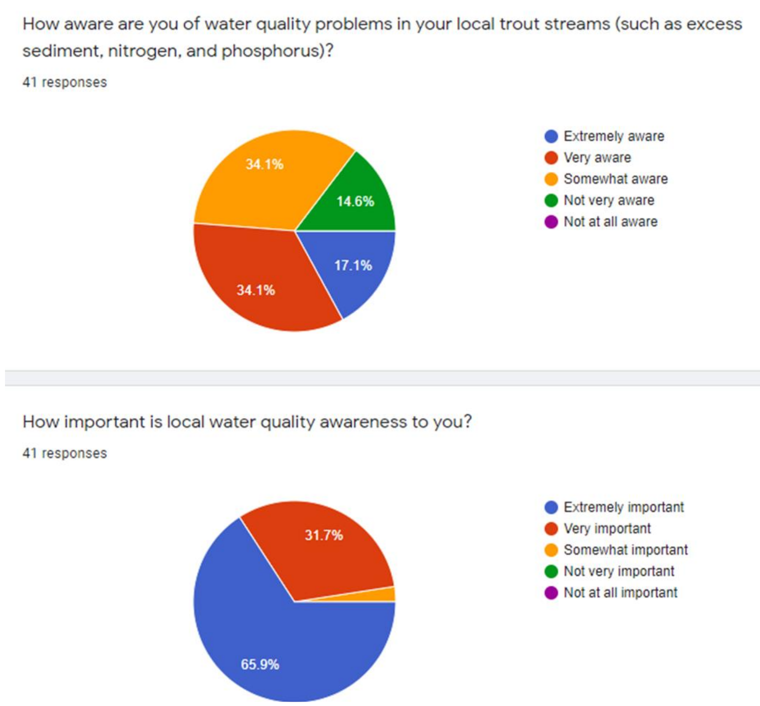


Figure 2: Partial results of angler needs assessment

Angler Monitoring with the WiseH2O mApp

From March 15 - September 14, 2019, members of the Kiap-TU-Wish Chapter of Trout Unlimited (TU) made 83 observations using the WiseH2O™ mApp (mApp) in water bodies within Pierce County, Wisconsin (Figure 4), as participants in the TU Driftless Area Angler Science Pilot (Pilot) Project. These observations included: screening water quality and temperature; reporting weather, water level, and water clarity conditions; and identifying the presence of stream disturbances. Of the 83 observations, 76 were from trout streams, 1 was from a canal/ditch, 1 was from a spring, and 5 were from unknown sources. The Pilot monitoring results provide a good overview of stream conditions in Pierce County throughout the study period. This report presents an analysis of preliminary water quality conditions with respect to fisheries health, as well as a summary of the stream disturbances identified. For individuals seeking detailed information on water quality conditions at the Pilot monitoring sites, including relationships of those conditions with weather, water clarity, and water level, Appendix C includes tables, graphs, and maps for each constituent monitored.

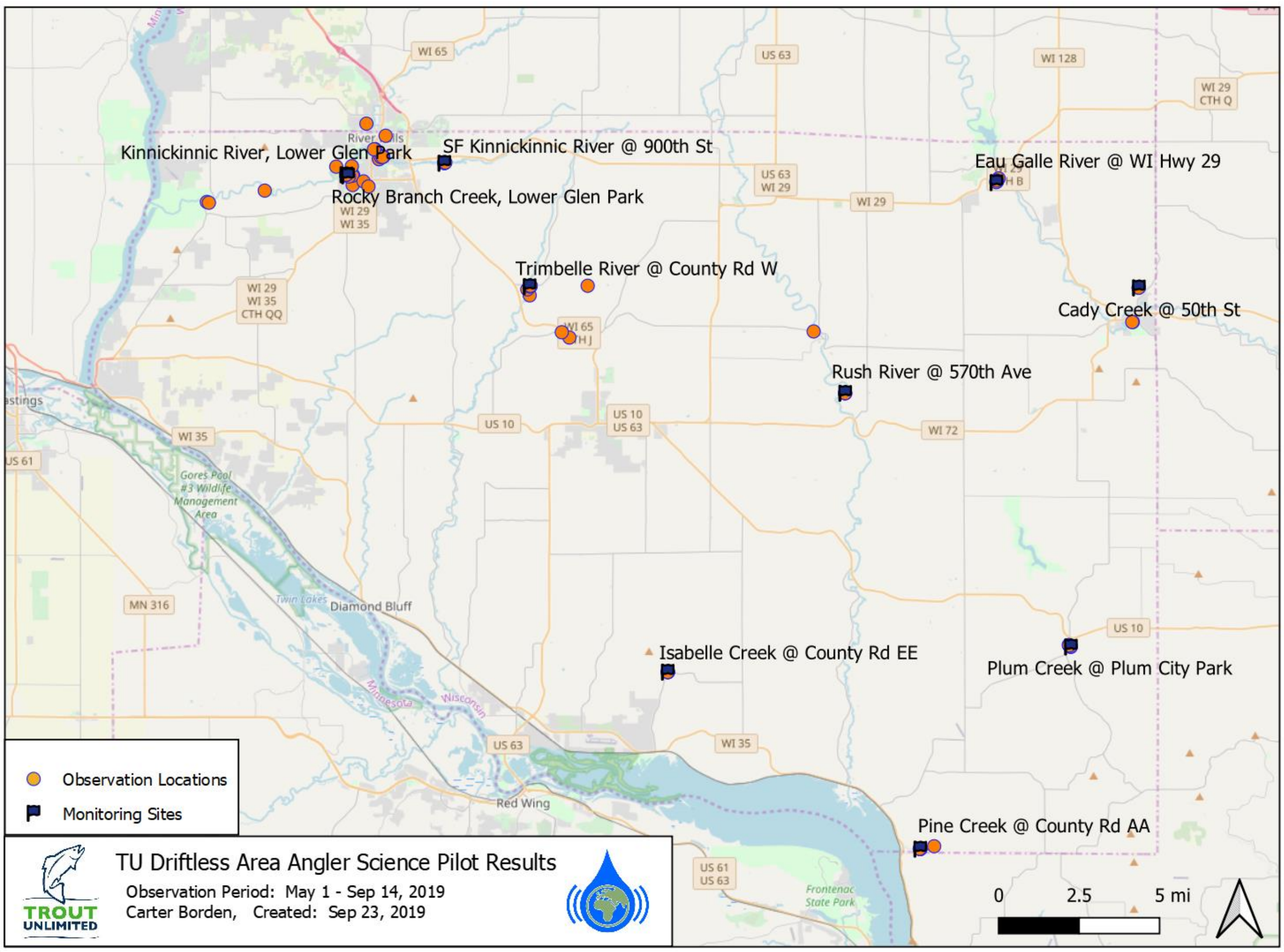


Figure 3. Angler observation locations in Pierce County, WI trout streams.

Water Quality Results Overview

Via the mApp, 72 water quality screenings were made during the Pilot, using the 5-in-1 test strips, with colorimetric analysis. Anglers also made 53 orthophosphate and 57 water temperature measurements. Table 1 summarizes the water quality conditions for each mApp analyte, estimates the fishery condition based on analyte observations, and describes the potential impacts of each analyte on trout and coldwater ecosystems. Overall, water conditions are favorable in the Pierce County trout streams, according to the 2019 mApp observations (Table 1). More information on each analyte, including concentrations at specific monitoring sites and relationships with weather events, water level, and water clarity, are presented in Appendix C.

Table 1. Summary of water quality observations and their impact on trout and coldwater ecosystems.

Analyte	Water Quality Summary^	Fishery Condition	Trout and Coldwater Ecosystem Impacts
Alkalinity [ppm $CaCO_3$]	Min: 0 Median: 80 Max: 240 N: 72		High alkalinity concentrations provide buffering capacity to offset increasing acid levels (decreasing pH) in streams [1]. Pierce County trout streams have higher alkalinity concentrations, so are less likely to become acidic (Table 5).
Hardness [ppm $CaCO_3$]	Min: 0 Median: 60 Max: 180 N: 72		Lower hardness concentrations can increase the toxicity of some metals (e.g. Cd, Hg) in fish [1]. Based on the higher hardness concentrations observed, Pierce County trout streams exhibit moderately hard to hard water conditions (Table 8).
Nitrate-Nitrogen (NO_3) [ppm]	Min: 0 Median: 0 Max: 40[3] N: 72		Nitrate-nitrogen concentrations exceeding 100 ppm have negative impacts on some trout species, such as stunted growth (curved spines), sideways swimming, and increased swimming speeds [2]. In drinking water, nitrate concentrations greater than 10 ppm exceed Wisconsin and federal standards [3,4], and such water is unfit for consumption by infants and pregnant women. Preliminary[3] results of the 72 nitrate observations in Pierce County (Table 11), showed that 55 concentrations (76%) were 0 ppm, while 16 concentrations (22%) were 20-40 ppm. These higher concentrations were much lower than the toxicity level, but above the recommended levels for stream and groundwater health [5]. Common sources of nitrate in groundwater and surface waters include fertilizer, animal waste, and wastewater treatment systems.
Ortho-phosphate [ppb]	Min: 0 Median: 0 Max: 300 N: 53		Excess phosphorus in surface waters, a condition known as eutrophication, can lead to undesirable algae growth and low oxygen levels (hypoxia) that suffocate aquatic life. The Wisconsin water quality standard for total phosphorus in streams is 75 ppb [5,6]. Of the 53 orthophosphate observations in Pierce County (Table 14), 32 concentrations (59%) were 0 ppb and 21 concentrations (39%) ranged from 100-300 ppb, exceeding the

[3] Note, as the colorimetric algorithm analysis of nitrates is being trained, the preliminary reported nitrate concentrations are higher than actual values. Revised values will be used once the algorithm is trained.

Analyte	Water Quality Summary^	Fishery Condition	Trout and Coldwater Ecosystem Impacts
			water quality standard. The highest orthophosphate concentrations were present in the Kinnickinnic River and Rocky Branch Creek near River Falls. More moderate orthophosphate concentrations were present in Isabelle Creek and the Eau Galle, Rush, and Trimbelle Rivers (Figure 17). Common sources of phosphorus in surface waters include fertilizer, animal waste, wastewater treatment systems, and stormwater runoff.
pH	Min: 6.0 Median: 7.5 Max: 8.5 N: 72	Good	Most fish species prefer pH levels between 6.5 and 9.0 and are negatively impacted when levels fall below 5.0 or rise above 9.6 [1, 7,8]. Of the 72 pH observations in Pierce County (Table 17), 66 values (92%) were within the preferred pH range of 6.5-9.0. 50 values (69%) were 7.5 and 8.0, which is likely due to the limestone or dolomite bedrock that buffers groundwater sources. Six pH values (8%) were 6.0, and further monitoring is needed to determine whether low pH levels persist at these locations.
Water Temperature [°F]	Average Mar 45 Apr 47 May 53 Jun 60 Jul 60 Aug 57 Sep 59	Good	Depending on the species and life stage, desirable stream temperatures vary. For rainbow, brown, and brook trout, the preferred temperature range is 50-61°F and the upper incipient lethal temperature (UILT) is 77°F [1,8,9]. Of the 57 temperature measurements in Pierce County (Table 21), none exceeded the UILT. However, preferred temperatures were exceeded in June and July in Cady, Plum, and Isabelle Creeks, the Eau Galle River, and the South Fork of the Kinnickinnic River (Figure 22).

^ *N* denotes the number of observations and *Min* and *Max* denote minimum and maximum bin concentrations

Fishery condition: Good Fair Poor Lethal

Stream Disturbances Overview

When making a WiseH2O mApp observation, anglers can record the presence of one or more stream disturbances that could impair trout fisheries. The disturbance options in the mApp include *Fish Barriers*, *Bank Erosion*, *Trash*, and *Pipe/Drain Outflow* into a stream. If no disturbances are present, anglers note *None*. Of the 83 total mApp observations made by anglers in Pierce County, 79 observations noted the absence or presence of one or more disturbances (Table 2). Overall, Pierce County trout streams are relatively free of disturbances, with 67 observations reporting *None* and one observation reporting *Trash* in River Falls (Wisconsinites are not litter bugs). *Bank Erosion* was reported in 11 observations, mostly along the Kinnickinnic River and Rocky Branch Creek, with one location along Pine Creek upstream from the monitoring site (Figure 4-6). Note that the Kinnickinnic River locations where bank erosion was present are listed in Figure 5 as "Other Locations", because these observations were not made at a specific monitoring site. Given the number of observations along the Kinnickinnic River and Rocky Branch Creek (Figure 5), bank erosion needs to be further inspected as a source of sediment and channel instability. *Fish Barriers* were reported at two monitoring sites, including 2 observations at Plum Creek @ Plum City Park and 1 observation at the Trimbelle River @ County Rd W (Figure 5).

Table 2. Angler observations of disturbances in Pierce County, WI trout streams

Disturbance Type	Frequency
Fish Barrier	3
Bank Erosion	11
Trash	1
Pipe Drain	0
None	67
Not Reported	4

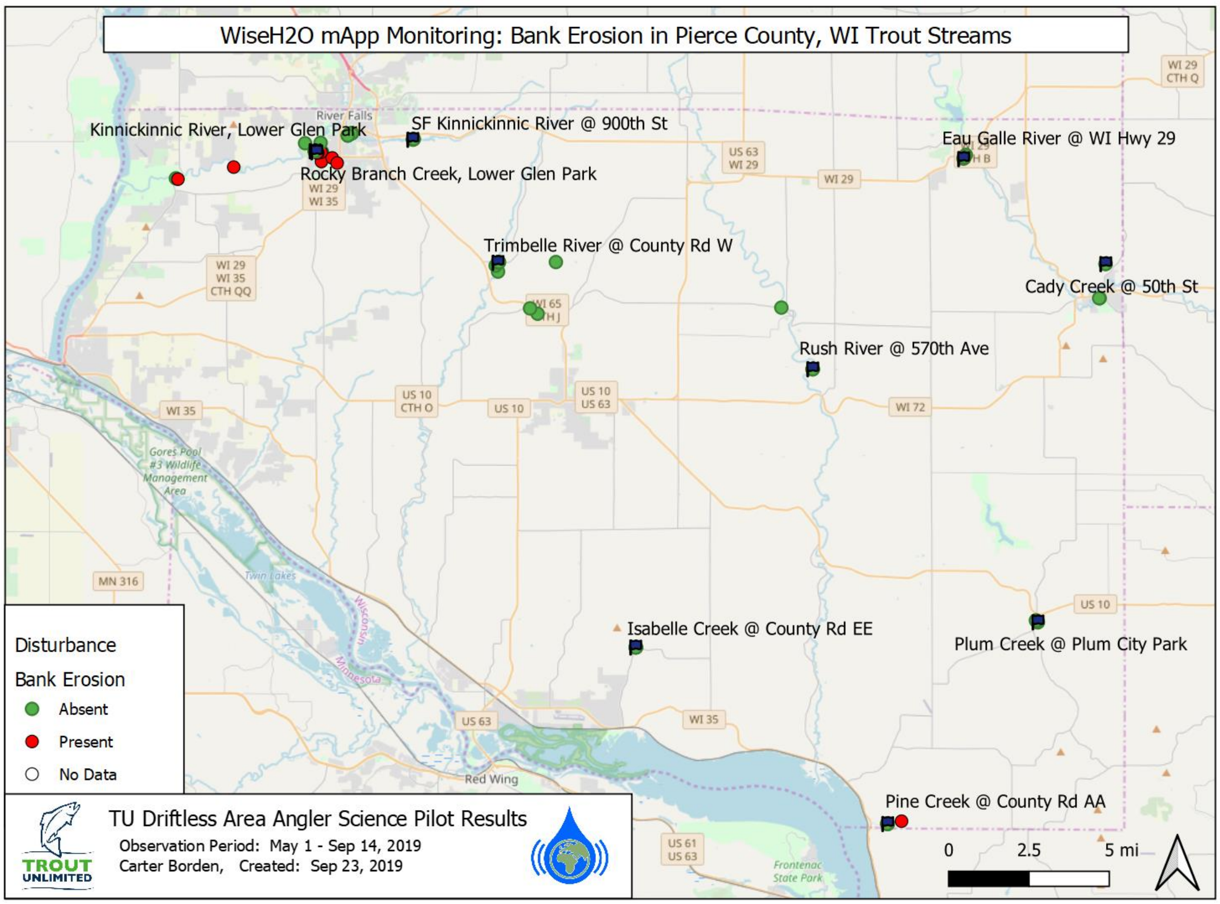


Figure 4. Angler observations of bank erosion in Pierce County trout streams.

Figure 5. Angler observations of disturbances in Pierce County trout streams, by monitoring location.

Figure 6. Streambank erosion at a location along the lower Kinnickinnic River, photo-documented following spring runoff

Next Steps

Building on the information gathered during the Pilot, potential improvements for continued implementation of the mApp include:

- Increasing the number of anglers monitoring in the TU Kiap-TU-Wish Chapter. More anglers using the mApp will provide more data points within the Pilot area, and these data can be used to better characterize stream conditions.
- Expanding to other TU chapters in the region. Other TU chapters work in different areas, so expanding the monitoring program will allow for characterization of new streams. Such information can be used to understand differences in regional stream conditions and identify locations for conservation projects.
- Developing angler incentives to encourage mApp usage along streams not covered by other anglers. While a handful of Pilot observations were made outside of the designated monitoring locations, many were made at the monitoring stations. Incentivizing anglers to venture to undocumented areas will provide a more complete picture of regional stream conditions.
- Incorporating more refined Nitrate/Nitrite test strips (Hach 2-in-1) into the analysis (Table 3). The test strips ranges need to be closer to the nitrate/nitrite concentrations found in Driftless Area streams, so that the mApp provides better resolution for measuring concentrations of these two analytes.
- Increasing the stream disturbances list to include the categories of *Fish Kill* and *Livestock in Stream*. Two fish kill events in Wisconsin have been attributed to manure spills; however, the causes could not be definitively determined as such, since WDNR staff were unaware of these events until stream conditions had returned to normal [10]. Livestock can directly contribute to stream bank erosion and sediment and nutrient loading when they enter water bodies (Figure 7).

Figure 7. Cows escaping the summer heat head into the creek, causing stream bank erosion and contributing to sediment and nutrient loading.

Acknowledgments

Many people contributed to important aspects of this project. Jacob Lemon, Michael Miller, Jeff Hastings, and Matt Barney provided valuable feedback as Advisory Team members, as did participants during a workshop at the 2019 Driftless Area Symposium in La Crosse, Wisconsin (February 2019). We would especially like to thank members of the Kiap-TU-Wish Chapter of Trout Unlimited, who expressed their interest in the project, attended project workshops in River Falls, Wisconsin (March and April 2019), participated in on-site training sessions (April and May 2019), took time to fill out the pilot project survey form, and collected data using the WiseH2O mApp as Target and General Anglers, thereby providing the foundational data for this report. All of these Kiap-TU-Wish project supporters are recognized by name in Appendix D. John Kaplan (Kiap-TU-Wish Stream Monitoring Coordinator) deserves a special thank you for his project support and training. This project was funded by Trout Unlimited's Coldwater Conservation Fund and the Kiap-TU-Wish Chapter of Trout Unlimited.

Appendix A: About the WiseH2O mApp

Overview: The WiseH2O mApp is a flexible platform that allows users to make an observation, examine previous observation data and messaging on what the results mean, and view regional observation results. Information is posted to the cloud, allowing water quality screening data to be crowd-sourced across broad geographies to characterize regional water quality conditions, identify potential problem areas, and educate anglers and other users on water quality. The mApp Base Map page (Figure 8A) shows observation and predefined monitoring locations on a map. At a desired field location, the Observation Entry page (Figure 8B) allows users to log water source, water quality screening concentrations, photographs, stream disturbances impacting fish habitat, current conditions (weather and stream water level and clarity), presence of a monitoring site, and additional notes. Once the observation is saved, the data is posted to the cloud, where at a later time the Observation Data page (Figure 8C) allows the observation data to be reviewed at a location and the Results Map page (Figure 8D) displays observation results from across the landscape. Customized messaging accompanying water quality screening results (not shown) increases user knowledge, drives actions to be taken, and/or supports communication by resource management agencies to effect behavioral changes.

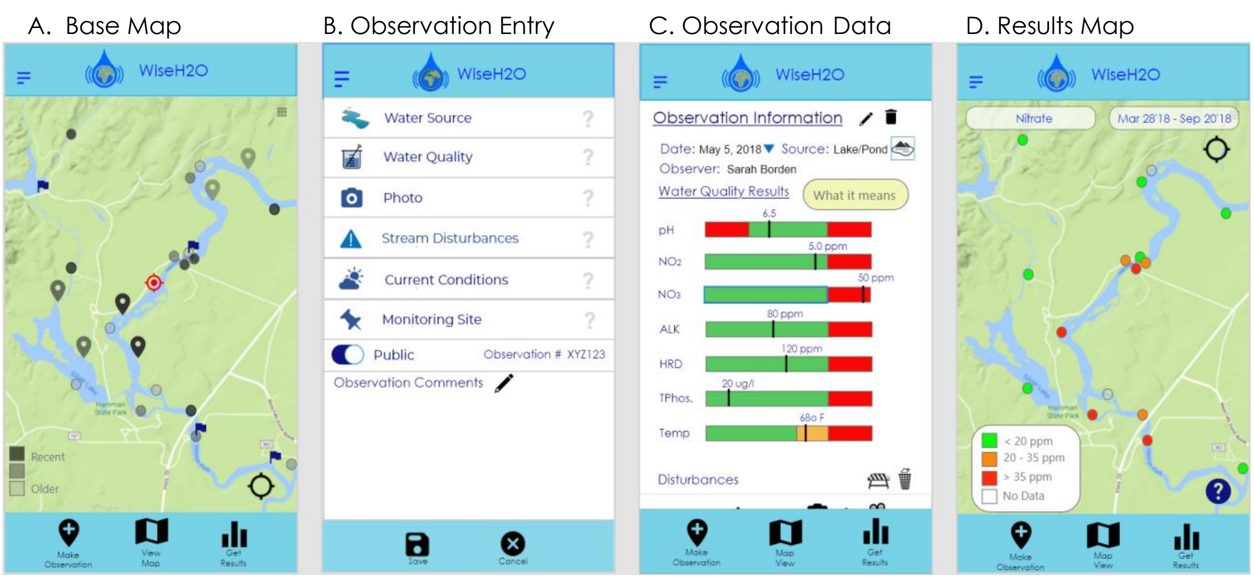


Figure 8. Key interfaces for the WiseH2O mApp.

Projects and applications using the WiseH2O mApp benefit multiple stakeholders, specifically:

mApp Users

- ✓ Real-time results using test strips and WiseH2O mApp
- ✓ Data collected via phone and sent to database; no paper required
- ✓ On demand results and information per observation
- ✓ Regional understanding of water quality conditions
- ✓ Helping to protect/improve stream habitat

Organizations/Agencies

- ✓ Platform for deploying test strip analysis/instrumentation
- ✓ Larger sets of actionable data
- ✓ Customization interfaces/post-processing results for agency personnel
- ✓ Ability to provide targeted messages to users and citizens
- ✓ Automated export of data to third-party databases

Making Observations/Screening Water Quality: The WiseH2O mApp was developed to support colorimetric analysis of chemical test-strip technology. The process begins with a user dipping a test strip into the stream and placing it on a calibration card (Figure 9). After waiting 30 seconds for the test-strip to change color based on the water chemistry, the user photographs the test strip/calibration card and hits the "Submit" button for processing. Within seconds, the user receives the screened water quality values of the test strip's water quality constituents, as well as messaging conveying their significance. For the Kiap-TU-Wish Pilot, the mApp used the LaMotte Insta-Test 5-Way test strip that screens alkalinity, hardness, pH, nitrate, and nitrite (the latter two at coarse resolutions, as shown in Table 3). The mApp is also built around a higher resolution Hach 2-in-1 Nitrate/Nitrite test strip (Table 3), but the models translating the test strip's colors to concentrations are currently under development. While these two test strips were selected for this Pilot, the algorithm can be trained to read other colorimetric test strips, as well.

Figure 9. Procedure for water quality screening using the WiseH2O mApp.

Table 3. Ranges and bins for the test strips used during the Pilot.

Test Strip	LaMotte 5-Way					Hach 2-in-1 Nitrate/Nitrite		LaMotte Ortho-
Analyte	**Alkalinity**	**Hardness**	**Nitrate**	**Nitrite**	**pH**	**Nitrate**	**Nitrite**	**Phosphate**
Range	0-240	0-180	0-200	0-10	6-9	0-50	0-3	0-2500
Unit	ppm	ppm	ppm	ppm	-	ppm	ppm	ppb
Bin 1	0	0	0	0	6.0	0	0.0	0
2	40	30	20	0.5	6.5	1	0.15	100
3	80	60	40	1	7.0	2	0.3	200
4	120	120	80	3	7.5	5	1.0	300
5	180	180	160	5	8.0	10	1.5	500
6	240		200	10	8.5	20	3.0	1000
7					9.0	50		2500

In addition to the test strip measurements for the analytes noted above, the mApp allows users to manually enter orthophosphate concentrations and stream temperatures. Although orthophosphate does not have a test strip option for photography and colorimetric analysis, LaMotte's Phosphate Test Strip Low Range (0-2500 ppb, Table 3) is a reagent-based test that involves a user mixing a reagent strip with the water sample in a test tube, matching the water color against a color chart, and manually selecting the concentration (bin value) in the mApp. For stream temperatures, users manually enter thermometer readings directly into the mApp.

Finally, the mApp allows users to document disturbances and other ancillary information associated with an observation. Currently, the mApp has 5 disturbance categories from which to choose: *Fish Barrier*, *Bank Erosion*, *Trash*, *Pipe/Drain Outflow*, or *None*. To characterize conditions, users can enter the water source (e.g. stream, groundwater, canal, etc.), recent weather events influencing stream conditions, and stream water clarity and level. Finally, users can also take a photograph of the disturbance and enter additional information in a notes section. These data are intended to provide context to water quality screening data using the test strip or can be used as stand-alone data.

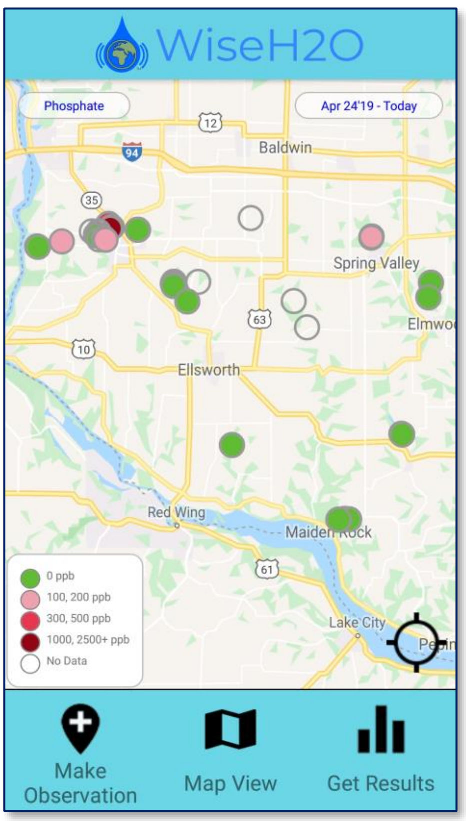


Figure 10. Results map view displaying orthophosphate results from the Pilot

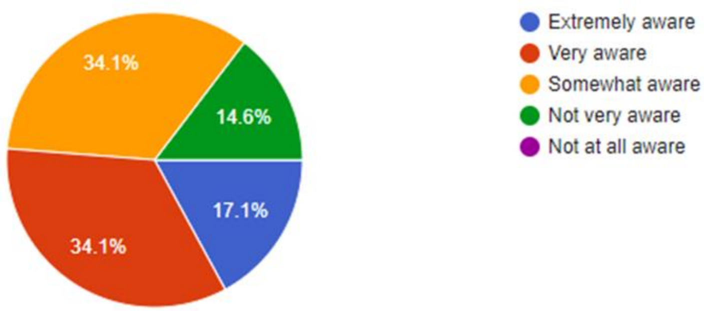
Viewing Results: As stated, results can be viewed by an individual observation (Figure 8C) or the results maps (Figure 8D, Figure 10). When the user taps on an individual observation, a synopsis presents all of the information collected at the location, along with the messaging and the time and date the observation was made. When the user taps on the "Get Results" icon in the lower right of the display, a map displays the element values for all observations on the screen. The results map view allows the user to select the element and time period to be viewed. Elements that can be viewed include chemical analytes, temperature, disturbance presence or absence (by type), and stream level and clarity.

Appendix B: Needs Assessment Results

A total of 41 anglers participated in an online survey intended to understand anglers' knowledge of water quality issues, what water quality concerns were most important to them, their familiarity with technology and its use, how they prefer to engage with technology, and current smartphone types in use. The results of this survey helped inform mApp customization needs, training requirements, and next steps.

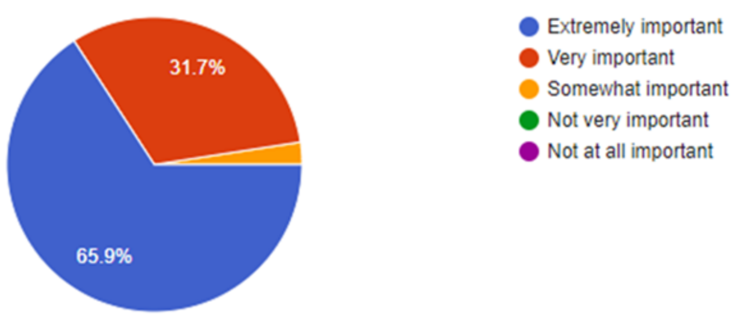
How aware are you of water quality problems in your local trout streams (such as excess sediment, nitrogen, and phosphorus)?

41 responses

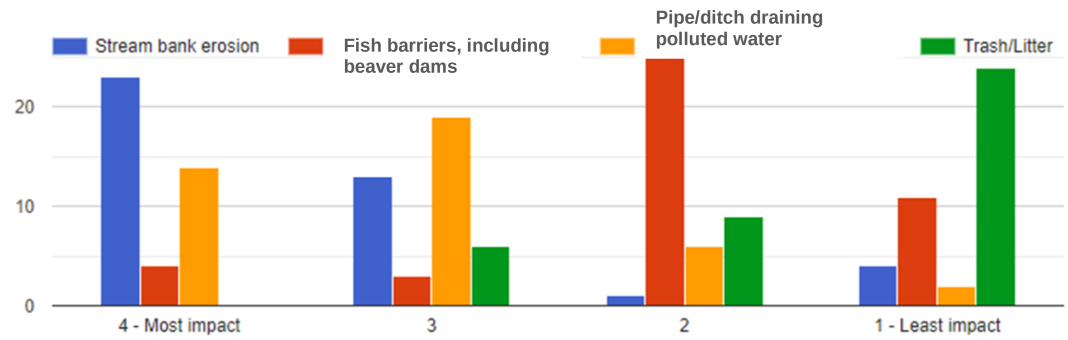


How important is local water quality awareness to you?

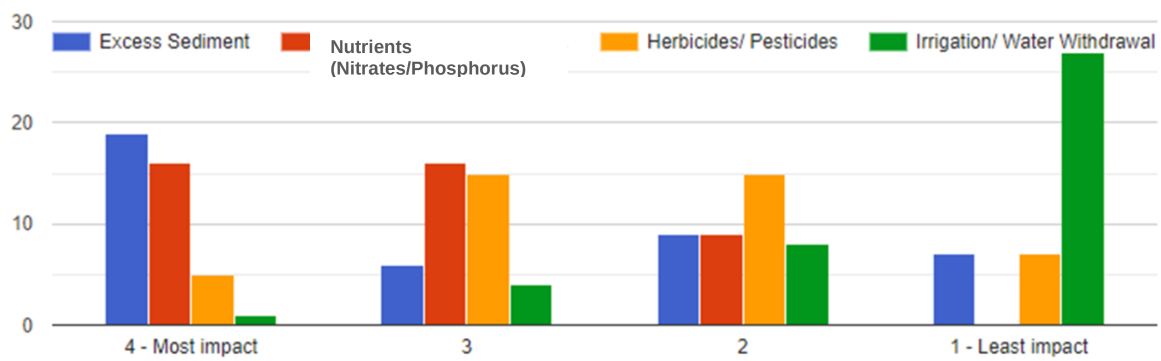
41 responses



Rank order your perception of physical impacts on local trout streams.

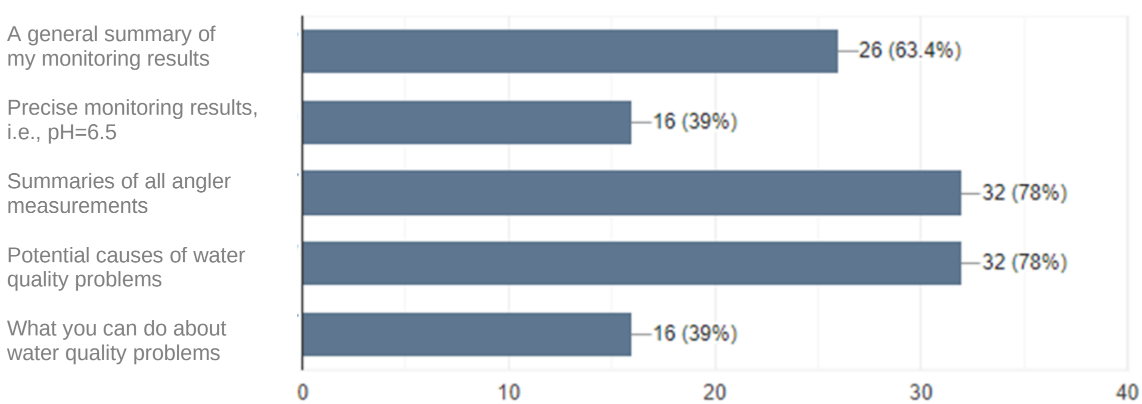


Rank order your perception of the water quality and quantity impacts on local trout streams.



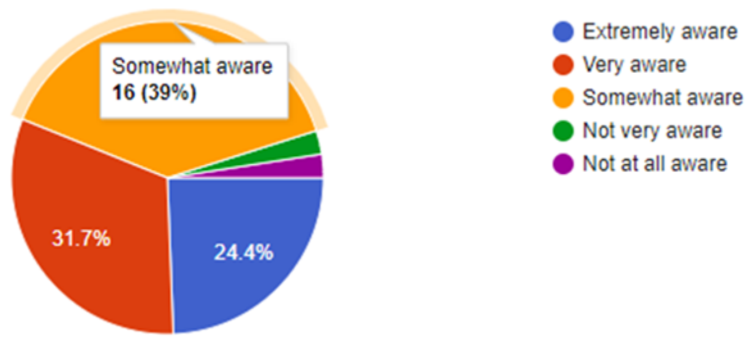
Select the top 3 results you would like to get from the water quality app.

41 responses



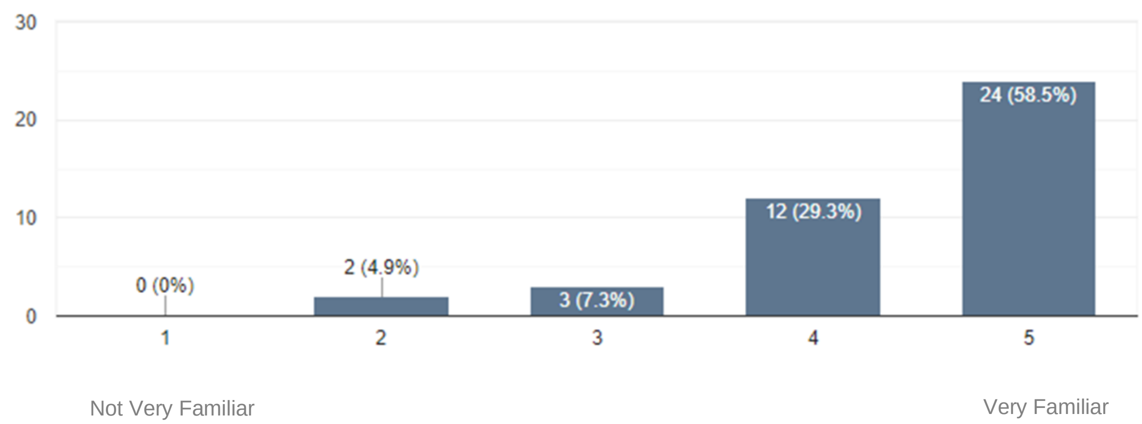
How aware are you of Trout Unlimited initiatives in the area?

41 responses



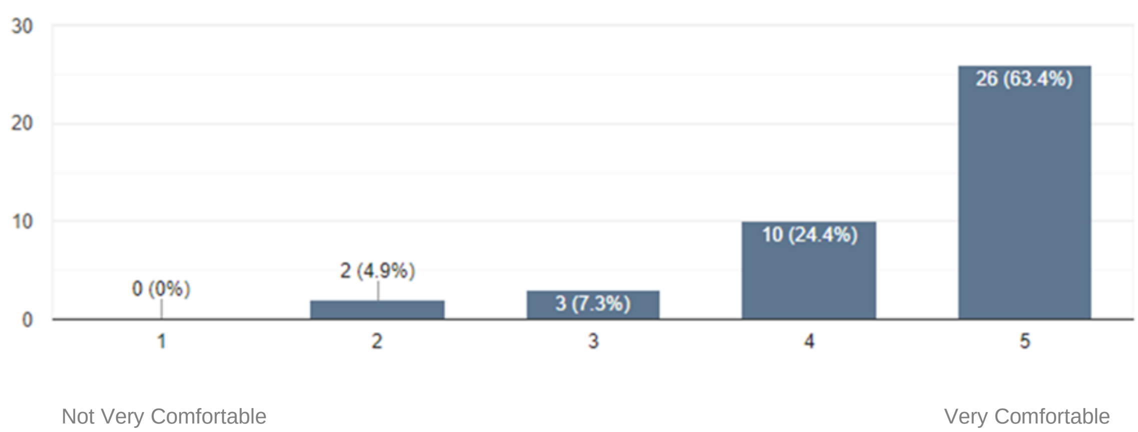
How familiar are you with downloading cell phone apps?

41 responses



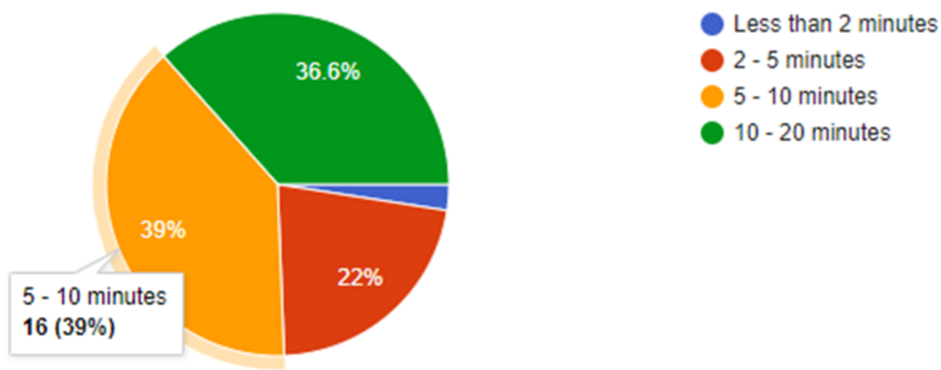
How comfortable are you with using cell phone apps?

41 responses



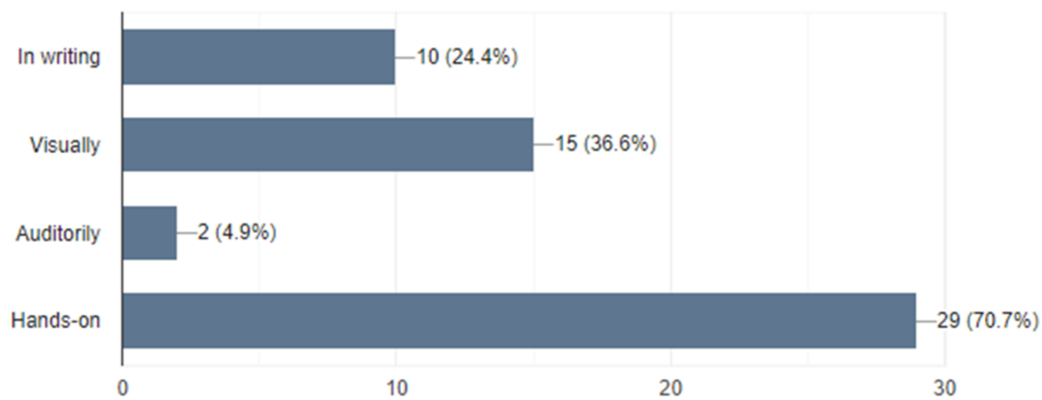
How much time are you willing to spend per site visit using an app to monitor water quality?

41 responses



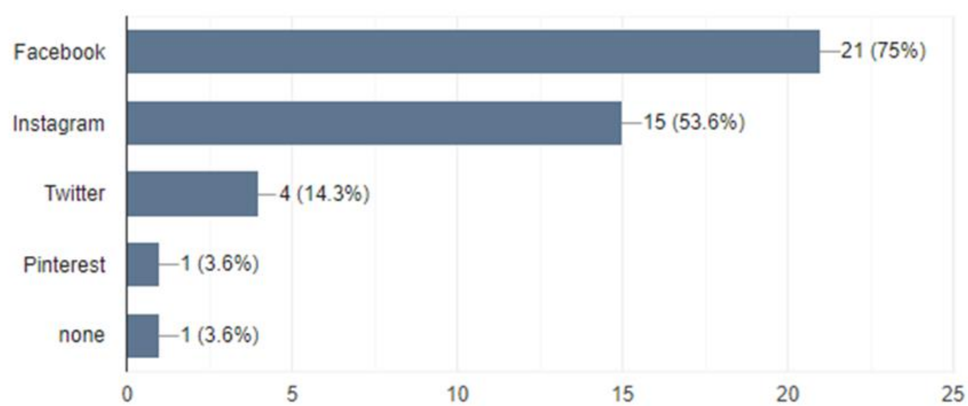
How do you prefer to learn something new?

41 responses



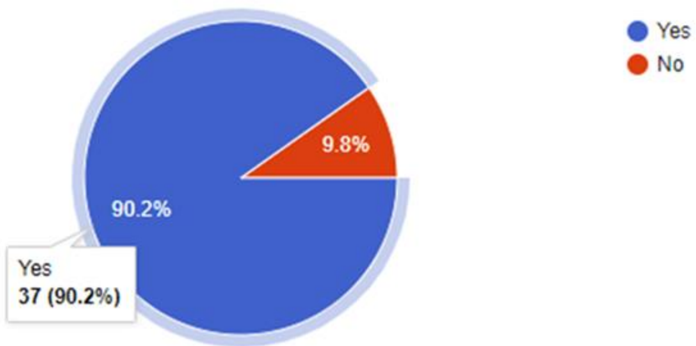
Please select any social media sites you frequent.

28 responses



Would you be interested in learning more about how to become involved in the pilot project to assess the viability of monitoring water quality conditions using cell phones?

41 responses



Appendix C: Water Quality Detailed

Of the 83 observations made during this Pilot, water quality in Pierce County trout streams was characterized by 72 5-Way test strip measurements (each measurement included alkalinity, hardness, nitrate, nitrite, and pH), 53 orthophosphate measurements, and 58 water temperature measurements. This section includes the detailed information for each analyte in the Pilot, except for nitrite-nitrogen. At this stage of mApp development, the colorimetric algorithm analysis of nitrate-nitrogen is close to being fully trained but reported nitrate concentrations are slightly higher than actual values. These results have been marked as preliminary. Revised values will be used once the algorithm is fully trained. Nitrite-nitrogen still has a poor observation correlation between the photographed test strip image and actual concentrations. Future reports will include these results.

For each analyte, a summary of the observation values is presented, along with maps and figures showing the distribution of values by monitoring site, recent weather events, stream water clarity, and water level. Furthermore, each section includes an analysis of the impacts on trout and habitat health, as well as sources that can contribute to changes in water quality conditions.

1. Alkalinity

Background

Alkalinity, measured as the concentration of carbonate and bicarbonate ions, is the capacity of water to resist changes in pH that would make the water more acidic. High alkalinity concentrations provide buffering to prevent increasing acid levels (decreasing pH) in streams, which can affect cellular function and, thus, the physiology of aquatic organisms, including fish. Natural and human-made sources that affect alkalinity concentrations in streams and lakes are presented in Table 4.

Table 4. Common sources that affect alkalinity concentrations.

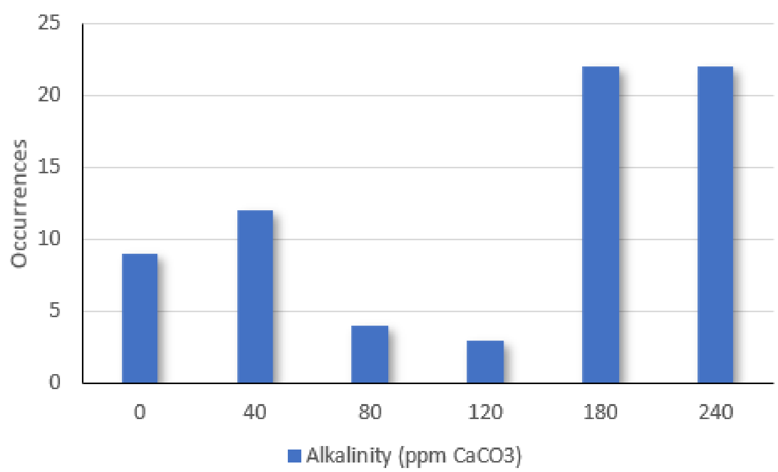
Occurrence	Point Source	Non-Point Source
Natural	• Tributary inflows • Springs	• Precipitation • Watershed runoff (dispersed inflow) • Baseflow (exchange of groundwater-stream flow through the streambed)
Human-Made	• Industrial, commercial, and agricultural drains/pipes • Residential/municipal storm water systems	• Agricultural runoff (non-drain) • Acid rainfall

Alkalinity Concentrations in Pierce County Trout Streams

The distribution of alkalinity concentrations measured by anglers in Pierce County trout streams is presented in Table 5. A map of alkalinity concentrations at all observation locations is presented in Figure 11. Detailed information on alkalinity concentrations at each monitoring site, and as related to weather events, water clarity, and water level, can be found in Figure 12.

Table 5. Distribution of alkalinity concentrations (ppm) in Pierce County trout streams.

Alkalinity (ppm CaCO3)	Observations
0	9
40	12
80	4
120	3
180	22
240	22
Total	72



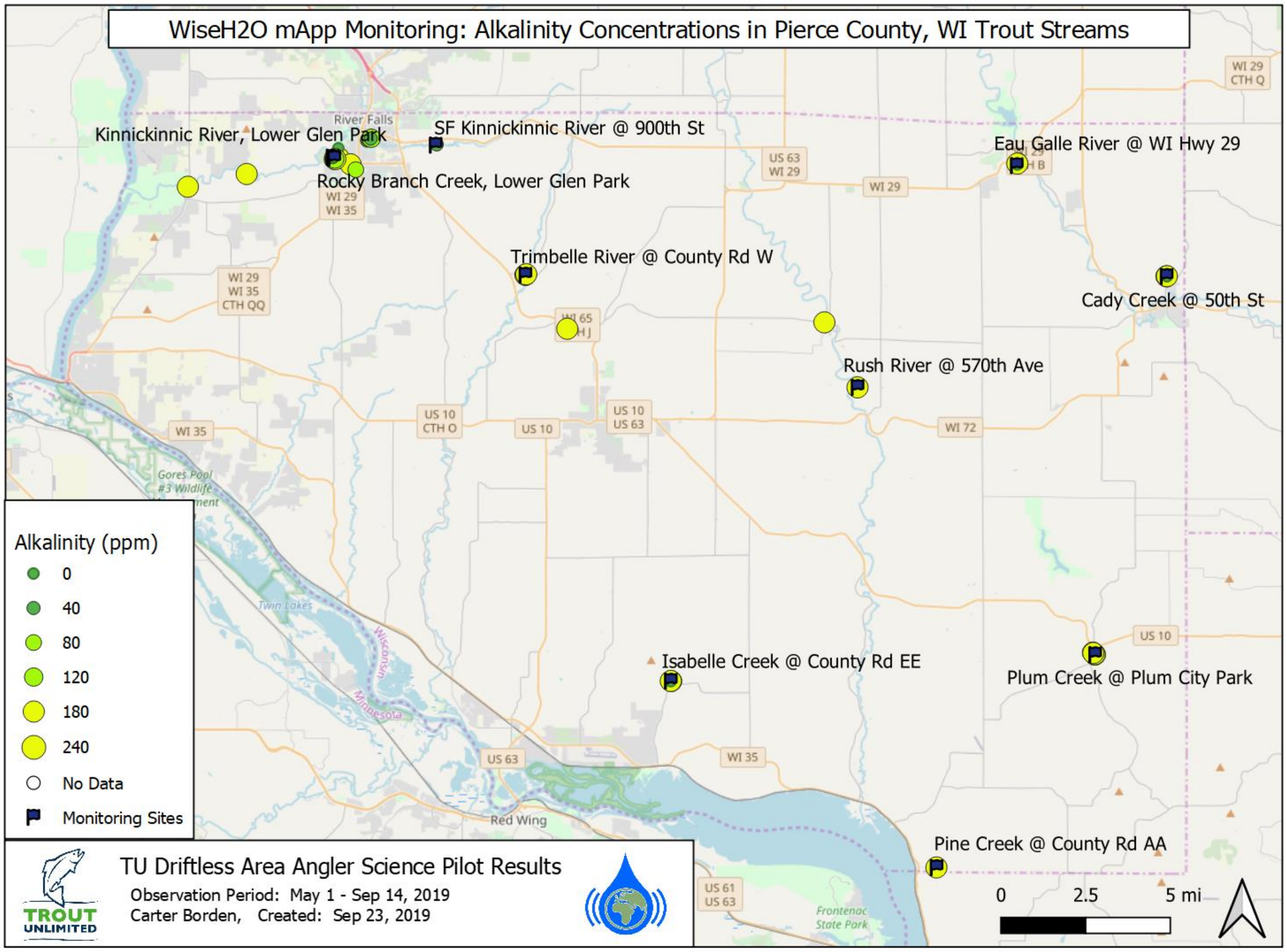


Figure 11. Alkalinity concentrations (ppm) in Pierce County trout streams, by monitoring site.

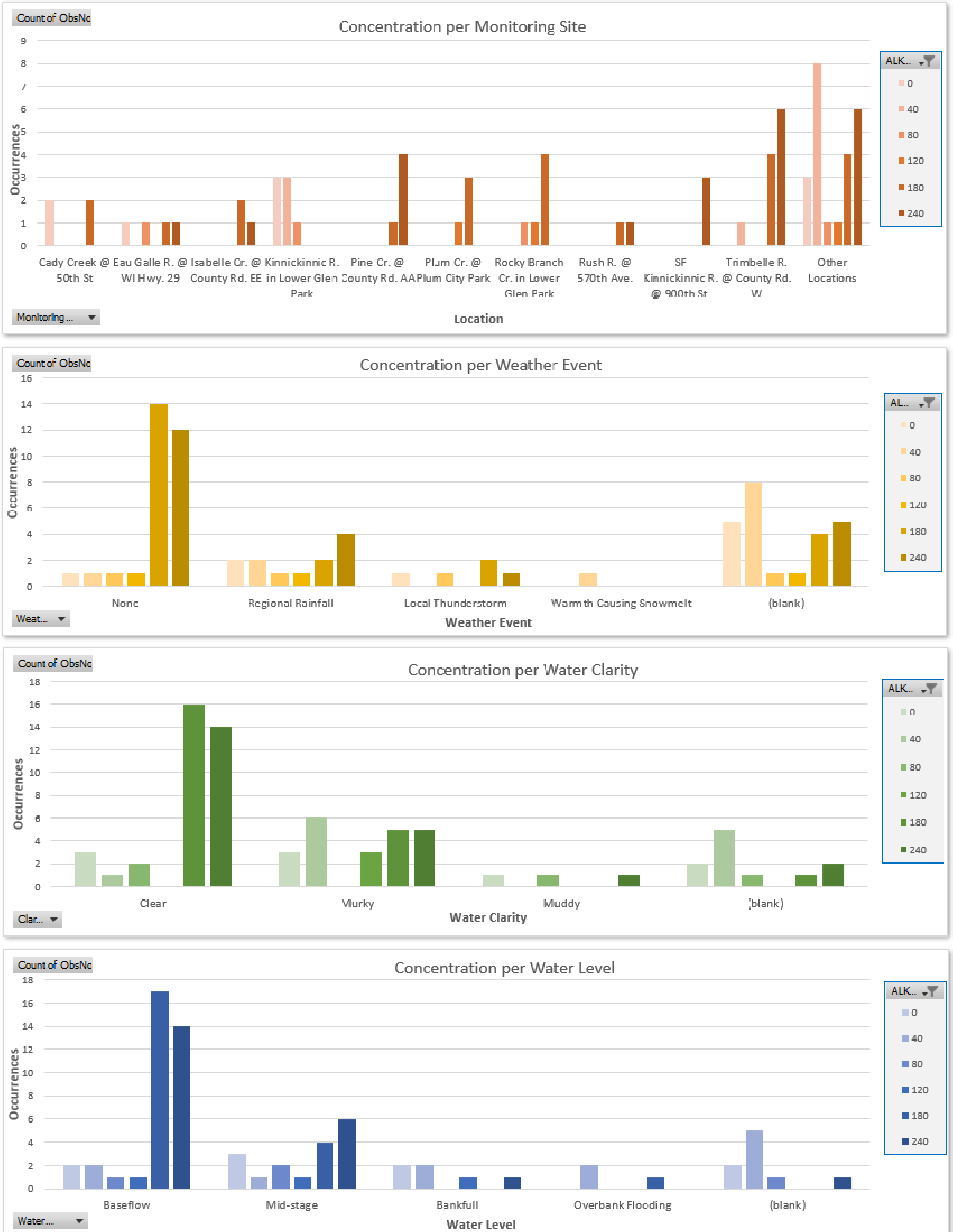


Figure 12. Alkalinity concentrations (ppm) by monitoring site, weather event, water clarity, and water level. The "Blank" category represents observations without reported conditions

Alkalinity Impacts on Trout and Coldwater Ecosystems

Pierce County trout streams have higher alkalinity concentrations, due to precipitation (lower in alkalinity) interacting with underlying calcareous rocks (limestone and dolomite) and soils as it moves into the groundwater sources that feed trout streams (Table 4) [11]. Many of the lower alkalinity concentrations are associated with regional rainfall, runoff events, and higher water levels that dilute solute concentrations, or occur in urban locations, where direct runoff from impervious surfaces limits exposure to calcareous soils and underlying rocks (Figure 12). Also refer to Table 4, which lists natural and human-made sources that can affect alkalinity concentrations.

With respect to fishery condition, higher alkalinity concentrations (80-240 ppm) are beneficial for trout and coldwater ecosystems (Table 6) [1]. As the majority (70%) of the alkalinity concentrations in Pierce County streams ranged from 80-240 ppm, fishery conditions are favorable.

Table 6. Alkalinity impacts on trout and coldwater ecosystems [1].

Bin Value (ppm)	Fishery Condition[a]	Trout and Coldwater Ecosystem Impacts
0 40		*Direct*: Low alkalinity concentrations may increase the uptake of trace metals (e.g. cadmium) in fish. *Habitat/Prey*: Streams with lower alkalinity concentrations are more susceptible to acidic shocks from wastewater discharges, agricultural runoff, and acid rainfall.
80 120 180 240		*Direct*: No direct impact from alkalinity. *Habitat/Prey*: Higher alkalinity concentrations in streams create a greater buffering capacity against acidic stressors, such as wastewater discharges, agricultural runoff, and acid rainfall.

a Fisheries condition: Good Fair Poor Lethal

2. Hardness

Background

Hardness is a measurement of the concentration of dissolved calcium and magnesium in water, usually acquired as rainwater percolates through soil and rock. In most natural waters, calcium and magnesium salts contribute most of the hardness, with only trace contributions from other metals such as iron and zinc. These salts are important to aquatic organisms because they are used to make shells (molluscs) and are important in cellular function, general physiology, and skeletal structure (bones) of fish. General guidelines for classification of water hardness are: 0-60 ppm (as $CaCO_3$) is classified as soft, 61-120 ppm as moderately hard, 121-180 ppm as hard, and more than 180 as very hard. Natural and human-made sources that affect hardness concentrations in streams and lakes are presented in Table 7.

Table 7. Common sources that affect hardness concentrations.

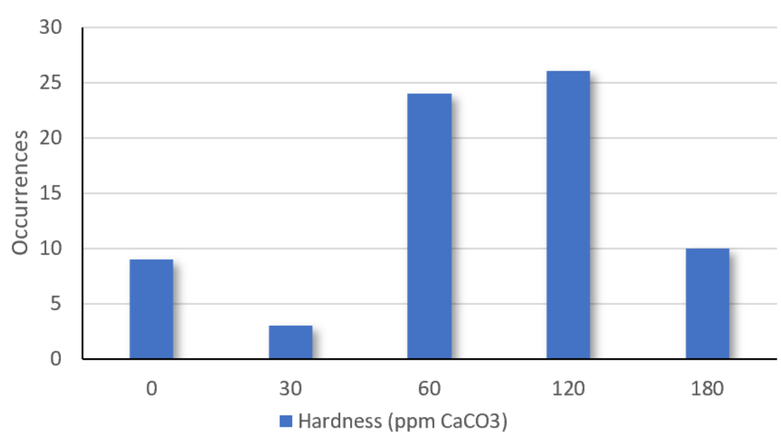
Occurrence	Point Source	Non-Point Source
Natural	• Tributary inflows • Springs	• Precipitation • Watershed runoff (dispersed inflow) • Baseflow (exchange of groundwater-stream flow through the streambed)
Human-Made	• Industrial, commercial, and agricultural drains/pipes • Residential/municipal storm water systems	• Agricultural runoff (non-drain) • Acid rainfall

Hardness Concentrations in Pierce County Trout Streams

The distribution of hardness concentrations measured by anglers in Pierce County trout streams is presented in Table 8, and a map of hardness concentrations all observation locations is presented in Figure 13. Detailed information on hardness concentrations at each monitoring site, and as related to weather events, water clarity, and water level, can be found in Figure 14.

Table 8. Distribution of hardness concentrations (ppm) in Pierce County trout streams.

Hardness (ppm CaCO3)	Observations
0	9
30	3
60	24
120	26
180	10
Total	72



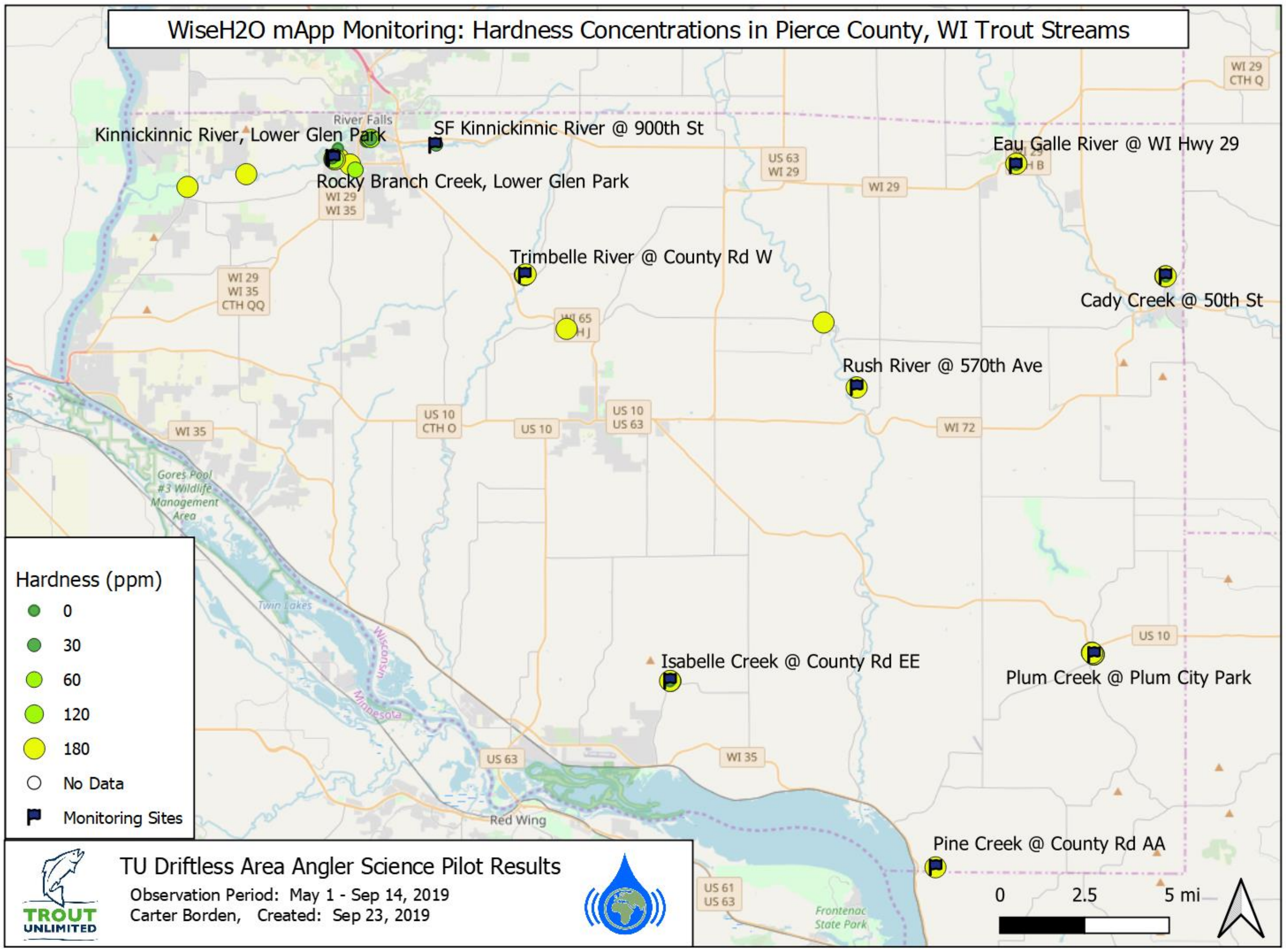


Figure 13. Hardness concentrations (ppm) in Pierce County trout streams, by monitoring site.

Figure 14. Hardness concentrations (ppm) by monitoring site, weather event, water clarity, and water level. The "Blank" category represents observations without reported conditions.

Hardness Impacts on Trout and Coldwater Ecosystems

Pierce County trout streams have higher hardness concentrations, with 60 of 72 observations (83%) ranging from 60-180 ppm (Table 8, Figure 13). These higher hardness concentrations are due to precipitation interacting with underlying calcareous soils and rocks as it moves into the groundwater sources that feed trout streams [11]. Many of the lower hardness concentrations are associated with regional rainfall, runoff events, and higher water levels, or occur in urban locations, where direct runoff from impervious surfaces limits exposure to calcareous soils and underlying rocks (Figure 14). Also refer to Table 7, which lists natural and human-made sources that can affect hardness concentrations.

With respect to fishery condition, higher hardness concentrations (60-180 ppm) are beneficial for trout and coldwater ecosystems (Table 9). As the majority (83%) of the hardness concentrations in Pierce County streams ranged from 60-180 ppm, fishery conditions are favorable.

Table 9. Hardness impacts on trout and coldwater ecosystems [1].

Bin Value (ppm)	Fishery Condition[a]	Trout and Coldwater Ecosystem Impacts
0		*Direct*: Low hardness concentrations may increase the uptake of metals (e.g. cadmium) in fish
30		*Habitat/Prey*: Streams with lower hardness concentrations are more susceptible to acidic shocks from wastewater discharges, agricultural runoff, and acid rainfall
60		*Direct*: No direct impact from hardness
120		*Habitat/Prey*: Good range for trout and other coldwater species. Higher hardness concentrations generally indicate the presence of strong groundwater sources to the stream.
180		

a Fishery condition: Good Fair Poor Lethal

3. Nitrate-Nitrogen (NO_3)

Background

Nutrients, such as nitrogen and phosphorus, are necessary for plant and animal nourishment and growth, but too much in surface waters and groundwater can cause several undesirable health and ecological effects [13]. Nitrate-nitrogen is a necessary nutrient for the growth of aquatic plants, but excessive amounts (nutrient pollution, or eutrophication) can lead to problems like algae blooms, decreased oxygen levels (hypoxia) from the decay of organic matter, and fish kills. In drinking water, nitrate concentrations greater than 10 ppm exceed Wisconsin and federal standards and can lead to methemoglobinemia ("blue baby syndrome"), a blood condition in infants that is caused by nitrate molecules interfering with the ability of red blood cells to efficiently transport oxygen. High nitrate concentrations in drinking water have also been linked to birth defects and miscarriages in pregnant women and livestock.

Common sources of nitrate-nitrogen include lawn and agricultural fertilizers, manure, decomposing plant material, septic systems, and municipal wastewater treatment plants. Nitrate is soluble in water and highly leachable, readily moving through the soil if it is not used by plants. With excessive rainfall or over-irrigation, nitrate can be leached below the plant's root zone and may eventually reach groundwater. The karst geology of the Driftless Area greatly facilitates the transfer of nitrate-nitrogen to groundwater, and subsequently to coldwater streams. Natural and human-made sources that affect nitrate-nitrogen concentrations in streams and lakes are summarized in Table 10.

Table 10. Common sources that affect nitrate-nitrogen concentrations.

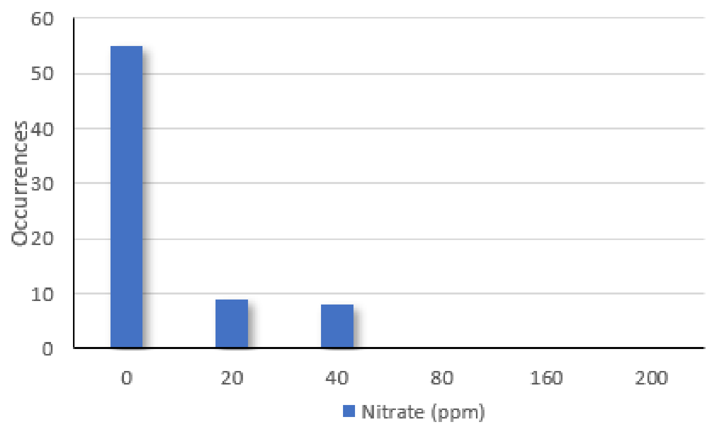
Occurrence	Point Source	Non-Point Source
Natural	• Tributary inflows • Springs	• Precipitation • Watershed runoff (dispersed inflow) • Baseflow (exchange of groundwater-stream flow through the streambed)
Human-Made	• Industrial, commercial, and agricultural drains/pipes • Municipal wastewater treatment plants • Residential/municipal storm water systems	• Agricultural runoff (non-drain) and infiltration, from fertilizer use • Agricultural manure • Septic systems

Nitrate-Nitrogen Concentrations in Pierce County Trout Streams

Table 11 shows the distribution of preliminary nitrate-nitrogen concentrations measured by anglers in Pierce County trout streams. Nitrate concentrations at all monitoring sites are presented in Figure 15. Detailed information on nitrate concentrations at each monitoring site, and as related to weather events, water clarity, and water level, can be found in Figure 16. Note, the colorimetric algorithm analysis of nitrate is still being trained, so the preliminary reported nitrate concentrations are higher than actual values. Revised values will be used once the algorithm is trained.

Table 11. Distribution of preliminary[4] nitrate-nitrogen (NO_3) concentrations (ppm) in Pierce County trout streams.

NO3 (ppm)	Observations
0	55
20	9
40	8
80	0
160	0
200	0
Total	72



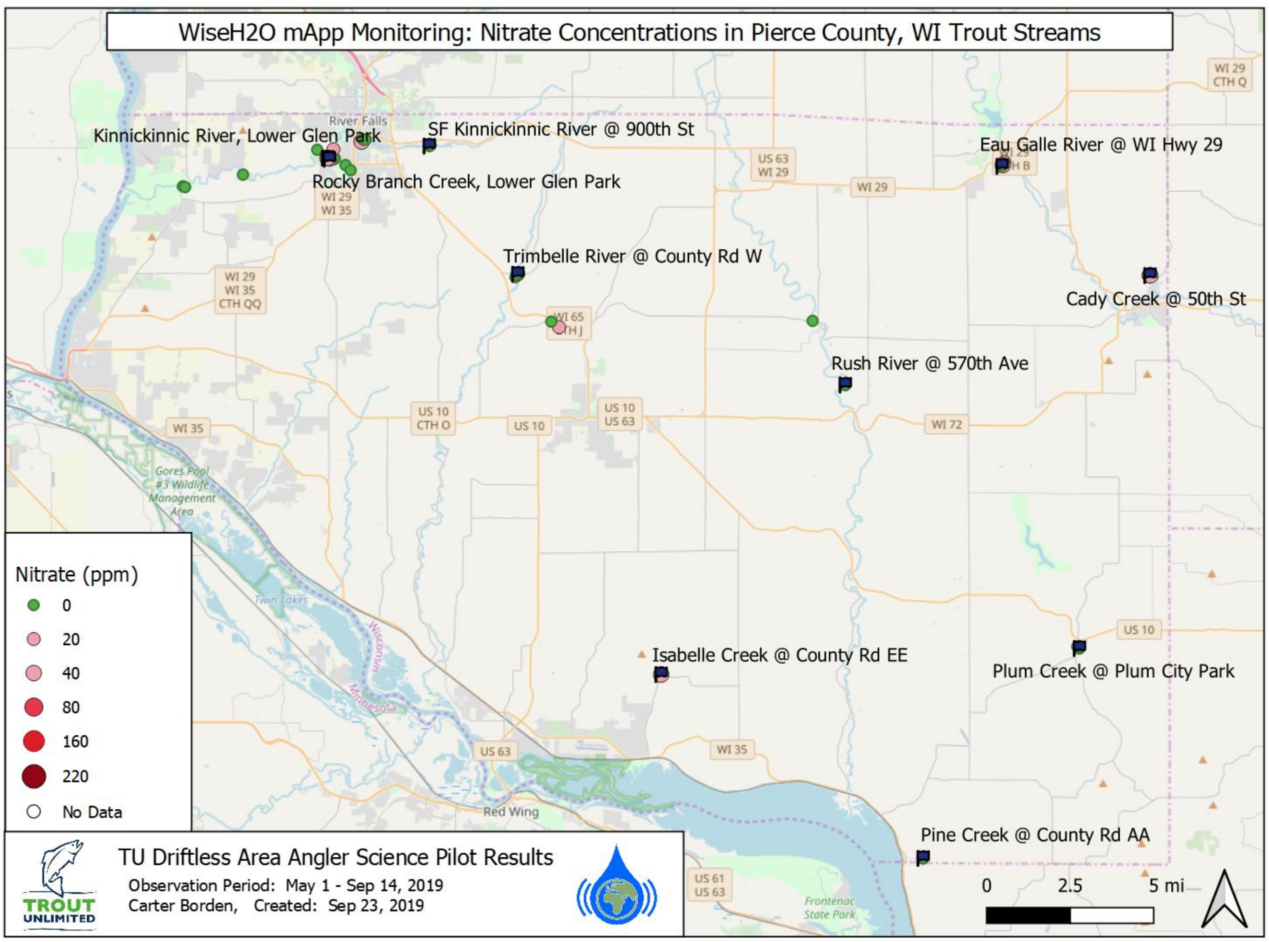


Figure 15. Preliminary[4] nitrate-nitrogen concentrations (ppm) in Pierce County trout streams, by monitoring site.

[4] Note, the colorimetric algorithm analysis of nitrate concentrations is being trained, so the preliminary reported nitrate concentrations are higher than actual values. Revised values will be used once the algorithm is trained.

Figure 16. Preliminary nitrate-nitrogen (NO3) concentrations (ppm), by monitoring site, weather event, water clarity, and water level. The "Blank" category represents observations without reported conditions.

Nitrate-Nitrogen Impacts on Trout and Coldwater Ecosystems

Of the 72 observations of preliminary[5] nitrate-nitrogen concentrations in Pierce County trout streams, 55 reported a concentration of 0 ppm, 9 reported a concentration of 20 ppm, and 8 reported a concentration of 40 ppm (Table 11). Based on the current colorimetric algorithm that generated these preliminary concentrations, 17 nitrate-nitrogen concentrations exceeded the drinking water standard of 10 ppm [3,4]. There was no discernable relationship between nitrate-nitrogen concentrations and weather events, water clarity, and water level (Figure 16). Also refer to Table 10, which lists natural and human-made sources that can affect nitrate-nitrogen concentrations.

Nitrate-nitrogen concentrations exceeding 100 ppm have negative impacts on some trout species, such as stunted growth (curved spines), sideways swimming, and increased swimming speeds (Table 12) [2]. Nitrate shock can also occur in trout when they are suddenly exposed to a much different concentration, often by as much as several hundred ppm [ibid]. The probability of such an event occurring in natural conditions is extremely low. Indirectly, higher nitrate concentrations may impact trout habitat via eutrophication (see "**Background**", above). All nitrate-nitrogen concentrations were $\leq$40 ppm suggesting no direct impacts on trout health, but posing an increased risk for eutrophication of trout habitat.

Table 12. Nitrate-nitrogen impacts on trout and coldwater ecosystems.

Bin Value (ppm)	Fishery Condition[a]	Trout and Coldwater Ecosystem Impacts
0		*Direct*: No impact on trout health. *Habitat/Prey*: No impact.
20, 40, 80		*Direct*: No impact on trout health. *Habitat/Prey*: Increased nitrate-nitrogen concentrations pose a higher risk of eutrophication.
160, 200		*Direct*: Nitrate-nitrogen concentrations exceeding 100 ppm have negative impacts on some trout species, such as stunted growth (curved spines), sideways swimming, and increased swimming speeds. *Habitat/Prey*: Increased nitrate-nitrogen concentrations pose a higher risk of eutrophication.

a Fishery condition: Good Fair Poor Lethal

[5] Note, the colorimetric algorithm analysis of nitrate is still being trained, so the preliminary reported nitrate concentrations are higher than actual values. Revised values will be used once the algorithm is trained.

4. Orthophosphate (P)

Background

Nutrients, such as nitrogen and phosphorus, are necessary for plant and animal nourishment and growth, but too much in surface waters and groundwater can cause several undesirable health and ecological effects [13]. Phosphorus in water exists in two main forms: dissolved (soluble) and particulate (attached to soil particles or organic matter). Orthophosphate is the primary dissolved form of phosphorus, and it is readily available to algae and aquatic plants. Under natural conditions, phosphorus (P) is typically scarce in water. However, human activities can result in excessive "loading" of phosphorus into many freshwater ecosystems [15]. These excessive amounts of phosphorus can lead to eutrophication, a water quality condition that typically includes algae blooms, decreased oxygen levels (hypoxia), and fish kills. Lakes that appear relatively clear in spring can resemble "green soup" in late summer, due to algae blooms fueled by phosphorus. Similarly, excessive phosphorus in streams and rivers may lead to the development of algae (periphyton) attached to in-stream habitat (e.g., rocks), thereby diminishing benefits for invertebrates and fish [ibid].

Common sources of phosphorus include lawn and agricultural fertilizers, manure, stream bank erosion, decomposing plant material, septic systems, and municipal wastewater treatment plants. The karst geology of the Driftless Area greatly facilitates the transfer of orthophosphate to groundwater, and subsequently to coldwater streams. Natural and human-made sources that affect orthophosphate concentrations in streams and lakes are summarized in Table 13.

Table 13. Common sources that affect orthophosphate concentrations

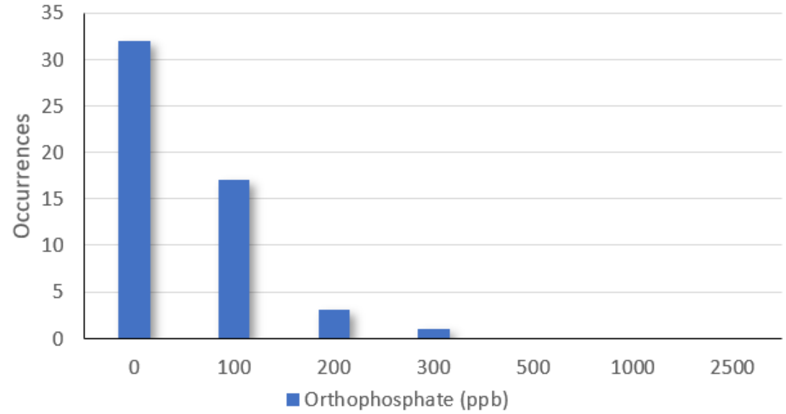
Occurrence	Point Source	Non-Point Source
Natural	• Tributary inflows • Springs	• Precipitation • Watershed runoff (dispersed inflow) • Baseflow (exchange of groundwater-stream flow through the streambed)
Human-Made	• Industrial, commercial, and agricultural drains/pipes • Municipal wastewater treatment plants • Residential/municipal storm water systems	• Agricultural runoff (non-drain) and infiltration, from fertilizer use • Agricultural manure • Stream bank erosion • Septic systems

Orthophosphate Concentrations in Pierce County Trout Streams

Table 14 shows the distribution of orthophosphate concentrations measured by anglers in Pierce County trout streams. Orthophosphate concentrations at all monitoring sites are presented in Figure 17. Detailed information on orthophosphate concentrations at each monitoring site, and as related to weather events, water clarity, and water level, can be found in Figure 18.

Table 14. Distribution of orthophosphate concentrations (ppb) in Pierce County trout streams.

Orthophosphate (ppb)	Observations
0	32
100	17
200	3
300	1
500	0
1000	0
2500	0
Total	53



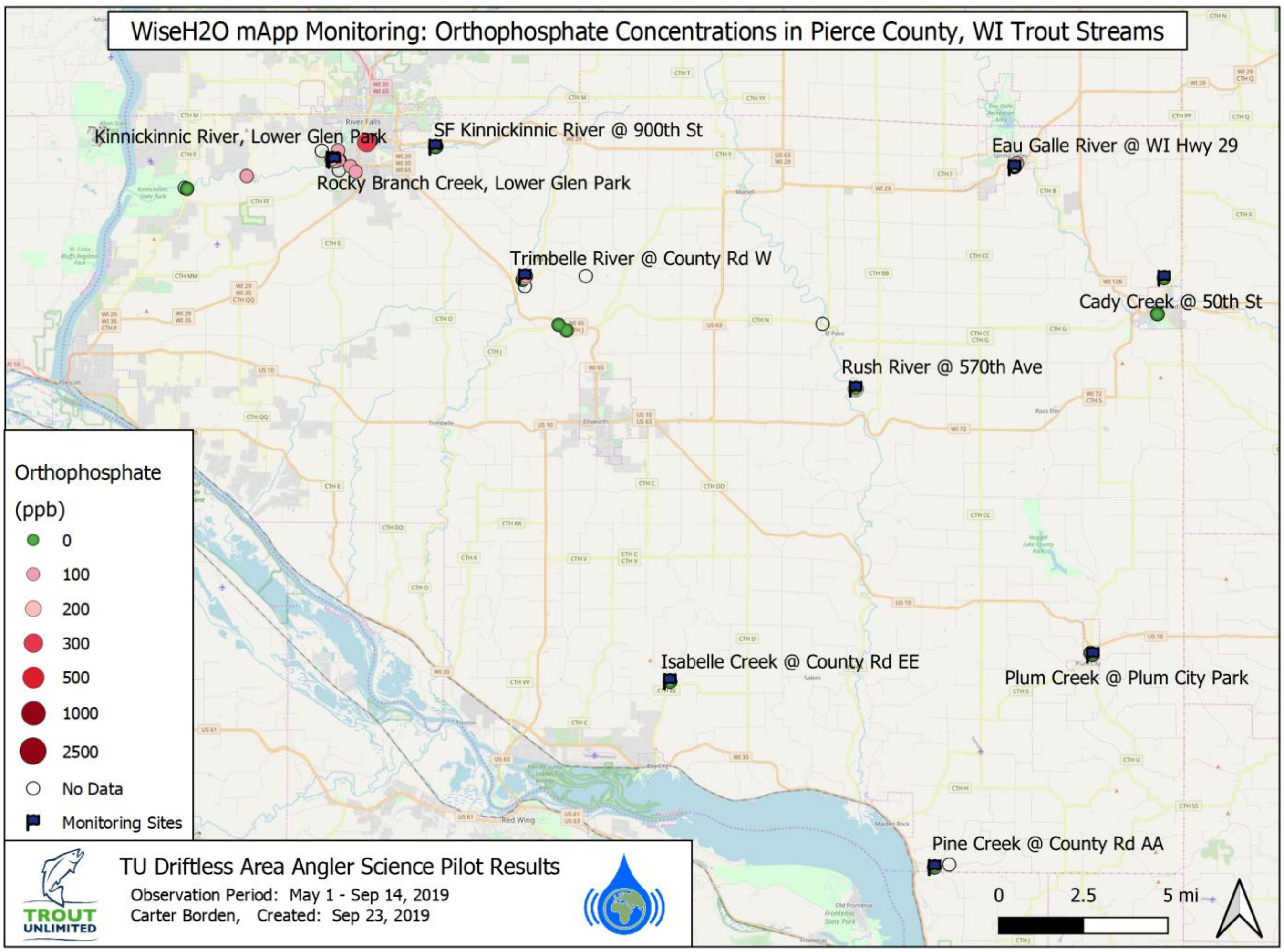


Figure 17. Orthophosphate concentrations (ppb) in Pierce County trout streams, by monitoring site.

Figure 18. Orthophosphate concentrations (ppb), by monitoring site, weather event, water clarity, and water level. The "Blank" category represents observations without reported conditions.

Orthophosphate Impacts on Trout and Coldwater Ecosystems

In Wisconsin, the water quality standard for total phosphorus in rivers and streams, which was set to protect aquatic life, is 75 ppb [4]. Of the 53 observations of orthophosphate concentrations in Pierce County trout streams, 32 reported a concentration of 0 ppb, 17 reported a concentration of 100 ppb, 3 reported a concentration of 200 ppb, and 1 reported a concentration of 300 ppb (Table 14). Thus, 21 orthophosphate concentrations exceeded the water quality standard of 75 ppb. The highest orthophosphate concentrations were observed in the Kinnickinnic River and Rocky Branch Creek near River Falls. Orthophosphate concentrations in the Trimbelle, Rush, and Eau Galle Rivers and Isabelle Creek were more moderate (Figure 17, Figure 18). Higher orthophosphate concentrations were often associated with rainfall events, when water clarity decreased (murky and muddy conditions) and water levels increased (mid-stage, bankfull, and over-bank flooding) (Figure 18). This suggests that orthophosphate primarily enters streams via watershed runoff, rather than by groundwater contributions during baseflow conditions. Phosphorus also binds to inorganic sediments (e.g., soils), and is often stored in streambank material. As a result, phosphorus can be released during high flows that cause streambank erosion, when phosphorus re-dissolves after entering the stream.

While there is no direct physiological impact of orthophosphate on trout, concentrations ≥100 ppb can create eutrophic conditions in coldwater ecosystems (Table 15). Some Pierce County trout streams are susceptible to eutrophication, as 40% of the observed orthophosphate concentrations exceed the Wisconsin water quality standard for total phosphorus (75 ppb).

Table 15. Orthophosphate impacts on trout and coldwater ecosystems.

Bin Value (ppb)	Fishery Condition[a]	Trout and Coldwater Ecosystem Impacts
0		*Direct*: None Habitat/Prey: Good range for trout and other coldwater species.
100, 200, 300, 500, 1000, 2400		*Direct*: None *Habitat/Prey*: With higher orthophosphate concentrations, coldwater ecosystems are more likely to become eutrophic.

[a] Fishery condition: Good Fair Poor Lethal

5. pH

Background

pH is a measure of the acidity or basicity of water. The range for pH in water extends from 0 to 14, with 7 being neutral. pH values less than 7 indicate acidity, whereas pH values greater than 7 indicate basicity. Water that has more free hydrogen ions (H+) is acidic, whereas water that has more free hydroxyl ions (OH-) is basic. pH is reported in logarithmic units, with each pH value representing a 10-fold change in the acidity/basicity of the water. For example, water with a pH value of five is ten times more acidic than water having a pH value of six. Examples of typical environmental pH values are shown in Figure 19.

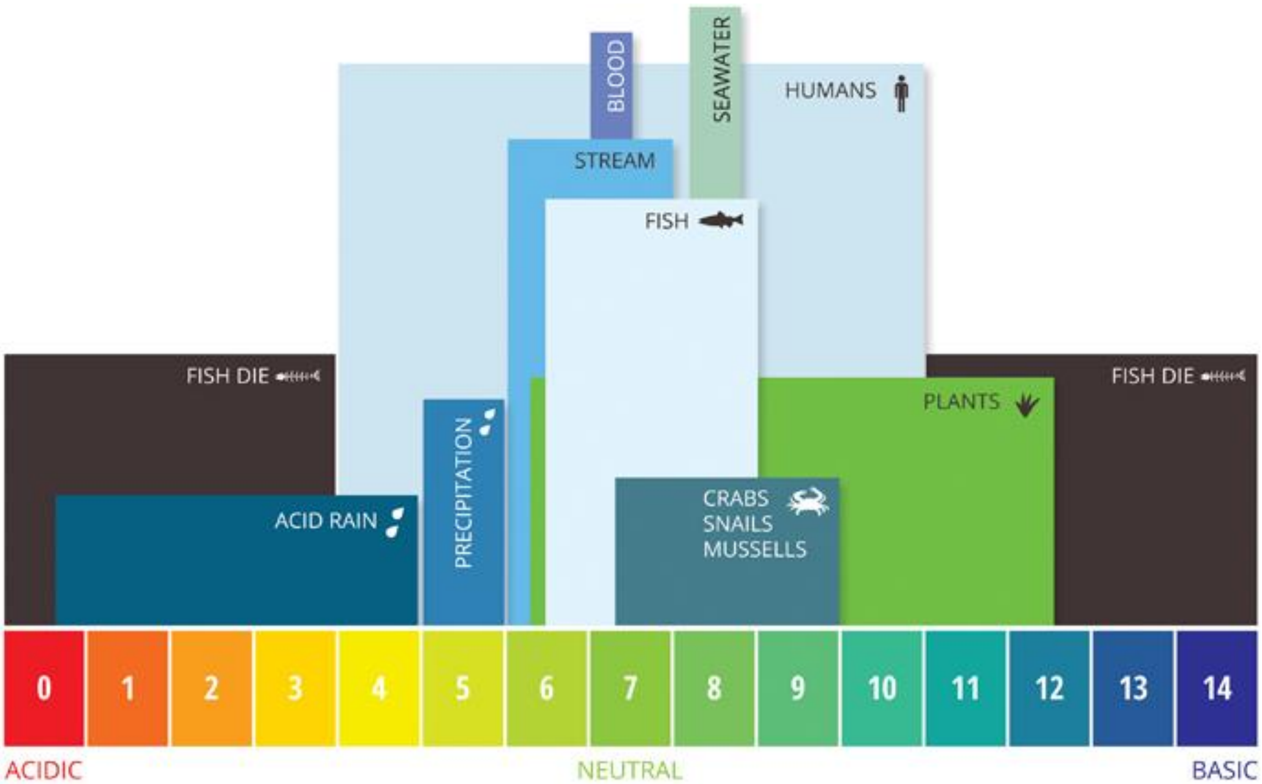


Figure 19. Typical environmental pH values [Figure source: 7]

pH determines the solubility and biological availability of other chemicals in water, such as nutrients (phosphorus and nitrogen) and heavy metals (cadmium, chromium, copper, lead, mercury, nickel, zinc) [14]. It also plays an important role in the physiology of aquatic organisms. Hence, pH is a significant factor determining the suitability of water for aquatic life [ibid].

pH is Influenced by geology, soils, precipitation, and human activities (Table 16). Precipitation is slightly acidic (average pH=5.6), due to its interaction with atmospheric CO_2. However, as this acidic precipitation percolates through underlying soils and rocks, it dissolved minerals and becomes more basic. This is particularly true in the Driftless Area, where precipitation interacts with calcareous soils and rock with higher alkalinity and hardness concentrations, thereby creating groundwater with higher pH values.

Table 16. Common sources that affect pH values.

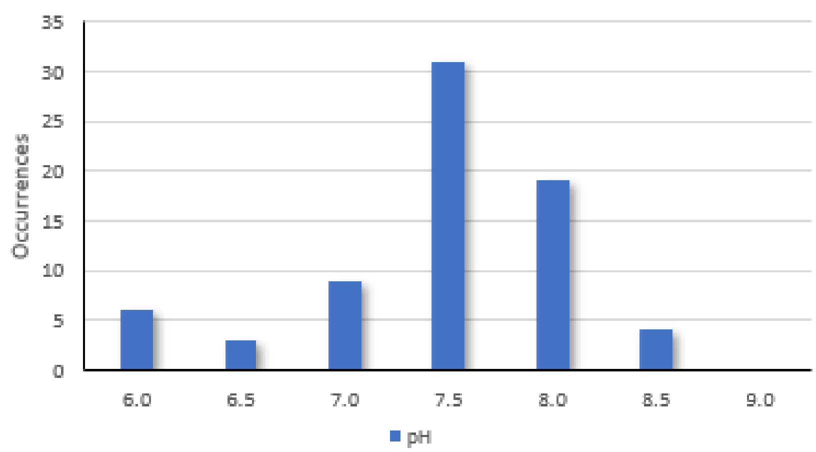
Occurrence	**Point Source**	**Non-Point Source**
Natural	• Tributary inflows • Springs	• Precipitation • Watershed runoff (dispersed inflow) • Baseflow (exchange of groundwater-stream flow through the streambed)
Human-Made	• Mine drainage • Industrial, commercial, and agricultural drains/pipes • Residential/municipal storm water systems	• Agricultural runoff (non-drain) • Acid rainfall

pH Values in Pierce County Trout Streams

Table 17 shows the distribution of the pH values measured by anglers in Pierce County trout streams. pH values at all monitoring sites are presented in Figure 20. Detailed information on pH values at each monitoring site, and as related to weather events, water clarity, and water level, can be found in Figure 21.

Table 17. Distribution of pH values in Pierce County trout streams.

pH	Observations
6.0	6
6.5	3
7.0	9
7.5	31
8.0	19
8.5	4
9.0	0
Total	72



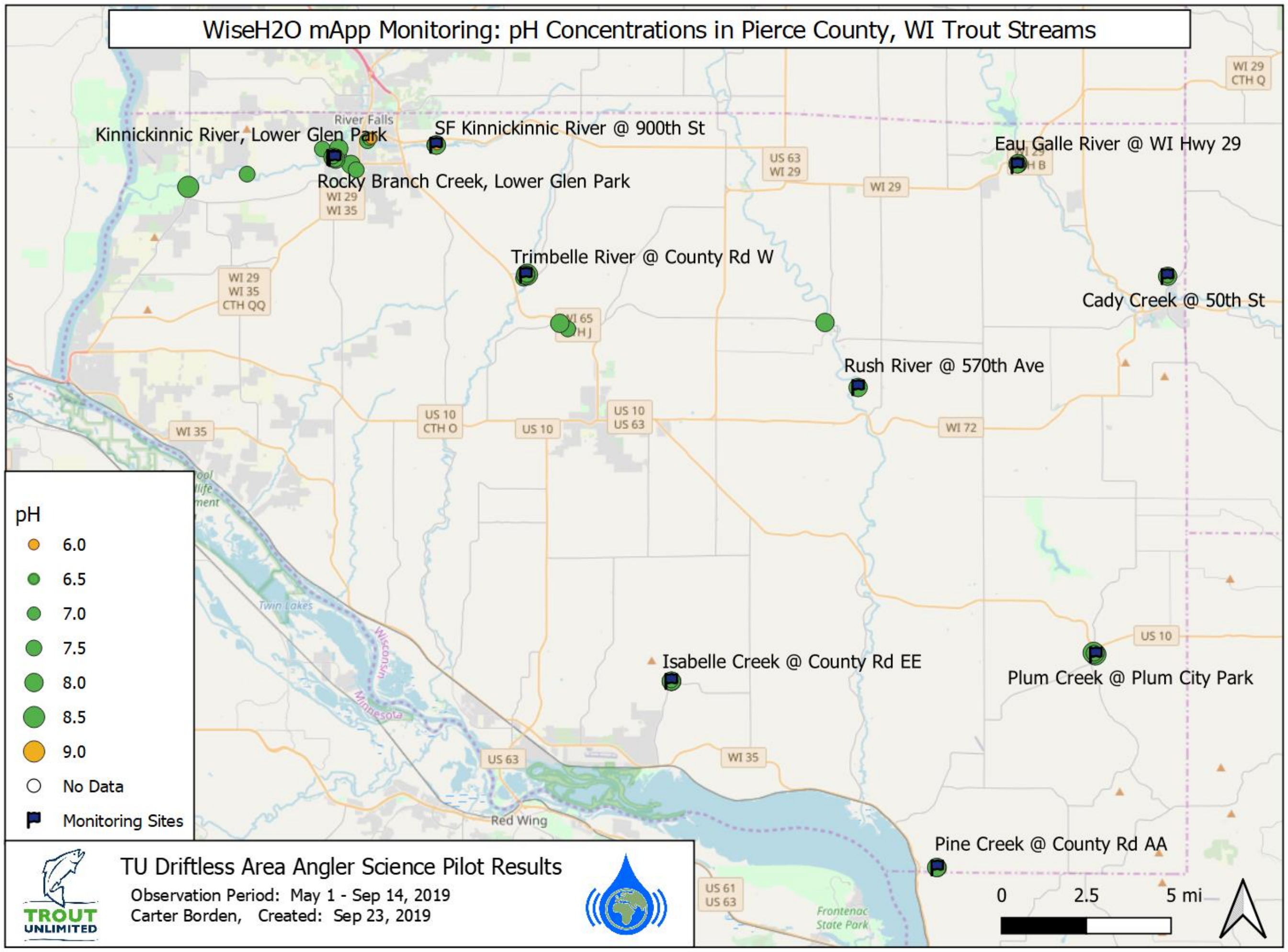


Figure 20. pH values in Pierce County trout streams, by monitoring site.

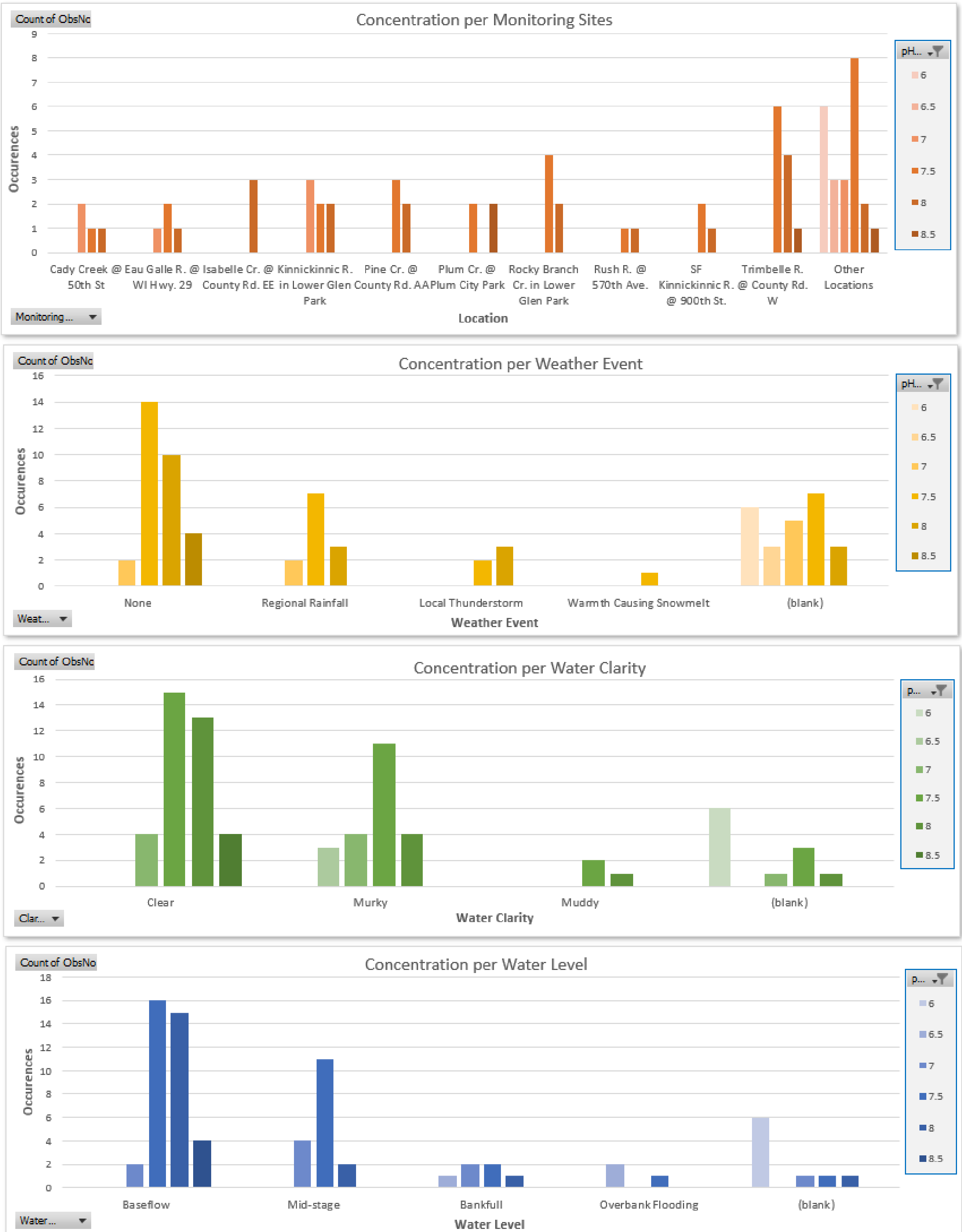


Figure 21. pH values, by monitoring site, weather event, water clarity, and water level. The "Blank" category represents observations without reported conditions.

pH Impacts on Trout and Coldwater Ecosystems

Of the 72 observations of pH values in Pierce County trout streams, 50 pH values (69%) were reported as 7.5 or 8.0, which is likely due to the high buffering capacity of the calcareous soils and rocks (limestone and dolomite) underlying the Driftless Area (Table 17, Figure 20, Figure 21). Sixty-six pH values (92%) were reported in a range from 6.5-8.5. Based on the observation dates, the six lowest pH values (6.0) occurred during the spring runoff season, when snowmelt and rainfall had minimal contact with underlying soils before entering the streams.

While Wisconsin has no water quality standard for pH, most fish species prefer pH values between 6.5 and 9.0 [4], and are negatively impacted when values are less than 5.0 or greater than 9.6 (Table 18) [7]. When pH values are less than 6.0, fish become vulnerable to fungal infections and toxicity from heavy metals and ammonia. pH values less than 4.0 are typically lethal to fish [8]. Even within the preferred pH range of 6.5-9.0, rapid pH fluctuations (±1.4 units) can negatively impact trout [ibid].

pH values in Pierce County trout streams were indicative of good water quality, with 92% of the values falling within the preferred range for trout (6.5-8.5). The six lowest pH values (6.0) occurred during high flows associated with snowmelt and rainfall, when risk from acidic shocks was minimal.

Table 18. pH impacts on trout and coldwater ecosystems.

pH	Fishery Condition[a]	Trout and Coldwater Ecosystem Impacts
≤ 6.0		*Direct*: Trout become vulnerable to fungal infections and toxicity from heavy metals and ammonia Habitat/Prey: Ecosystems are susceptible to acidic shocks
6.5 – 8.5		*Direct*: None *Habitat/Prey*: Good range for trout and other coldwater species
≥9.0		*Direct*: pH levels above 9.6 are lethal to trout *Habitat/Prey*: Ecosystems have more capacity to buffer acidic shocks

[a] Fishery condition: Good Fair Poor Lethal

6. Water Temperature

Background

Water temperature is a critical factor for determining the health of trout, invertebrates, and other aquatic life in coldwater ecosystems. All aquatic species have a preferred temperature range, outside of which their ability to survive, grow, and reproduce is diminished. Even within preferred temperature ranges, rapid changes in water temperature (thermal shock) can be detrimental to aquatic life.

The thermal environment in which trout live can be defined by lower and upper lethal limits, and within these bounds are suitable and preferred temperatures for survival, growth, and reproduction. The suitable and preferred temperature ranges and upper incipient lethal temperature for brook, brown, and rainbow trout are presented in Table 19. A temperature range of 39-72°F is suitable for trout survival, although 72°F is only tolerable as an average temperature for as long as 3 weeks [11]. Further, temperatures less than 39°F can be stressful to trout, particularly if winter habitat is lacking. Although trout can feed and grow at temperatures within the 39-72°F range, feeding and growth are compromised as temperatures move farther away from the preferred temperature range (50-61°F).

Table 19. Suitable and preferred temperature ranges and upper incipient lethal temperature for trout [12].

Species	Suitable Temperature Range for Survival (ºF)	Preferred Temperature Range for Feeding and Growth (ºF)	Upper Incipient Lethal Temperature (ºF)
Brook, Brown, Rainbow Trout	39-72	50-61	77[1]

[1] Upper Incipient Lethal Temperature (UILT) is a daily average temperature

In addition to directly determining where trout and other aquatic organisms can live in streams, water temperature has an important influence on pH, density, specific conductance, the rate of chemical reactions, and solubility of constituents in water. Changes in water temperature affect nutrient availability, oxygen solubility, and decomposition rates. Warmer water holds less dissolved oxygen than colder water, and also triggers higher plant growth and respiration rates. The lower oxygen levels in warmer waters are further reduced when plants and animals die and decay. Natural and human-made sources that affect water temperature in streams and lakes are summarized in Table 20.

Table 20. Common sources that affect water temperature.

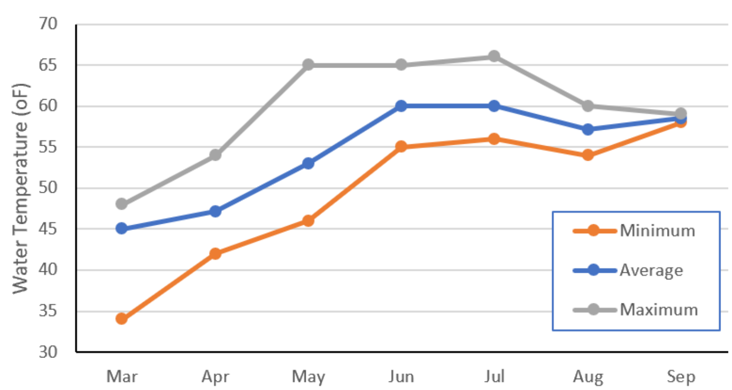
Occurrence	Point Source	Non-Point Source
Natural	• Lake and pond outflows • Tributary inflows • Springs	• Climate conditions (air temperature,) • Sunlight (exposure) and shading • Watershed runoff (dispersed inflow) • Baseflow (exchange of groundwater-stream flow through the streambed)
Human-Made	• Industrial, commercial, and agricultural drains/pipes • Municipal wastewater treatment plants • Power plants • Dams and reservoirs	• Agricultural runoff (non-drain) • Urban storm water runoff (direct drainage from impervious surfaces) • Climate change

Water Temperatures in Pierce County Trout Streams

Table 21 shows the monthly minimum, average, and maximum water temperatures in Pierce County trout streams, based on 57 angler measurements made during the March-September period. Water temperatures at all monitoring sites are presented in Figure 22. Detailed information on water temperatures, as related to weather events, water clarity, and water level, can be found in Figure 23, Figure 24, and Figure 25, respectively.

Table 21. Monthly minimum, average, and maximum water temperatures (°F) in Pierce County trout streams.

Month	Minimum	Average	Maximum	Observations
Mar	34	45	48	6
Apr	42	47	54	7
May	46	53	65	14
Jun	55	60	65	10
Jul	56	60	66	8
Aug	54	57	60	8
Sep	58	59	59	4
			Total	57



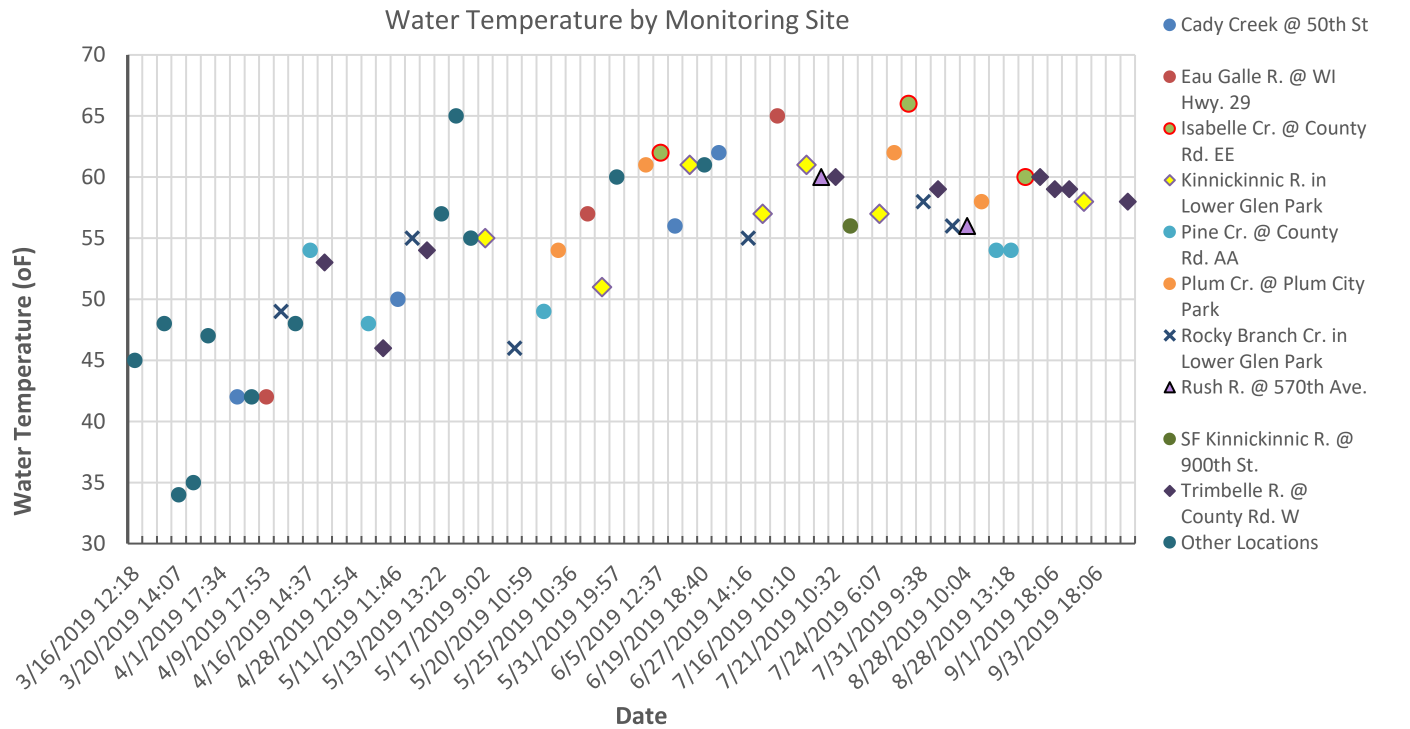


Figure 22. Water temperatures (°F) in Pierce County trout streams, by monitoring site.

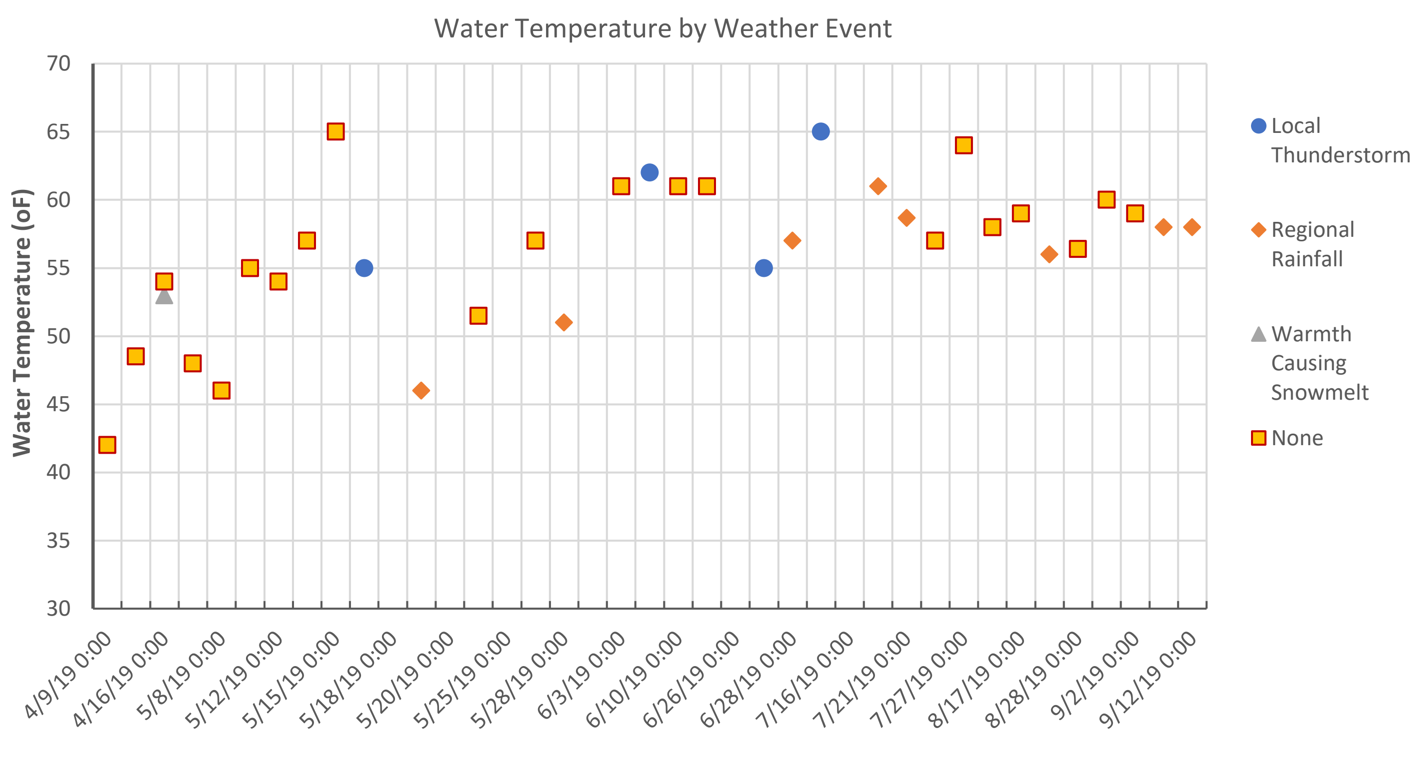


Figure 23. Water temperatures (°F) in Pierce County trout streams, by weather event.

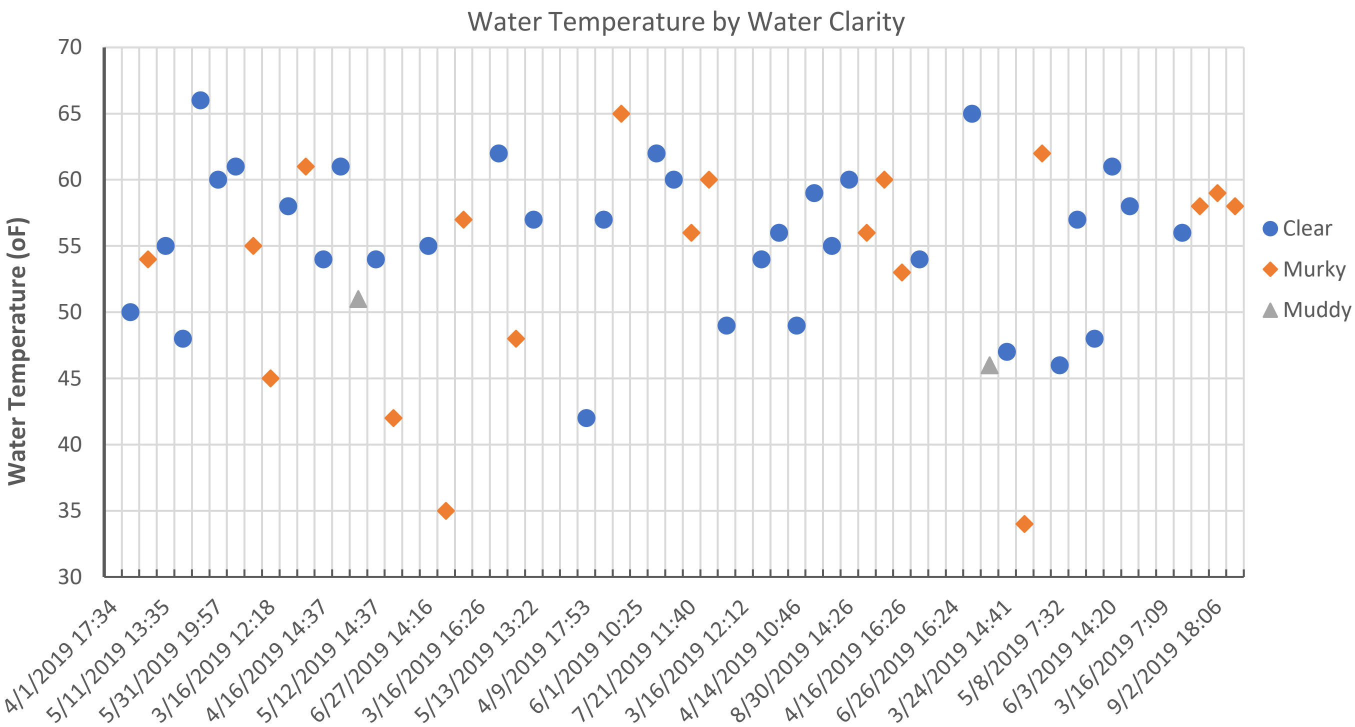


Figure 24. Water temperatures (°F) in Pierce County trout streams, by water clarity.

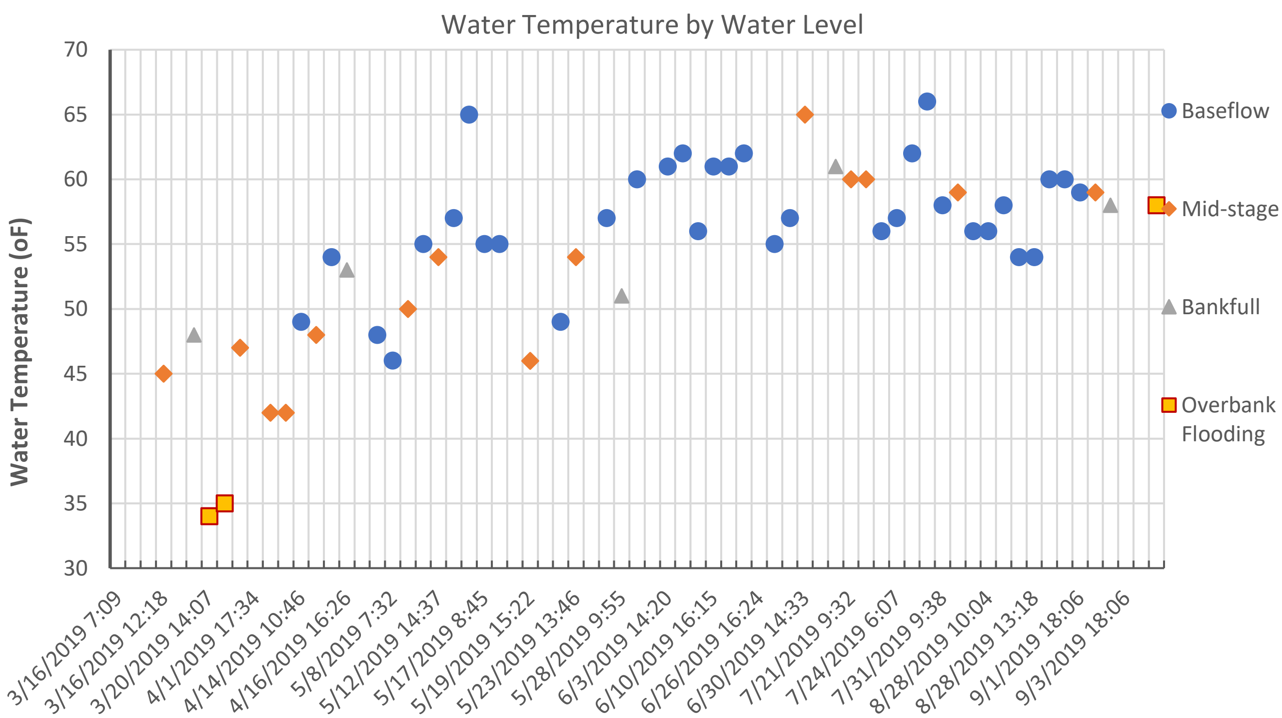


Figure 25. Water temperatures (°F) in Pierce County trout streams, by water level.

Water Temperature Impacts on Trout and Coldwater Ecosystems

In Wisconsin, water quality criteria have been established for water temperature, to protect fish and aquatic life in coldwater ecosystems (NR 102.25) [4]. These criteria are presented in Table 22. Table 23 also characterizes water temperature impacts on trout and coldwater ecosystems [12].

Table 22. Wisconsin water quality criteria for water temperatures (°F), to protect coldwater ecosystems [12]

	Coldwater Ecosystems[1]		
Month	**Ta[2]**	**SL[3]**	**A[4]**
JAN	35	47	68
FEB	36	47	68
MAR	39	51	69
APR	47	57	70
MAY	56	63	72
JUN	62	67	72
JUL	64	67	73
AUG	63	65	73
SEP	57	60	72
OCT	49	53	70
NOV	41	48	69
DEC	37	47	69

[1] **Cold** = Waters with a fish and aquatic life use designation of "cold water community"
[2] **Ta** = Ambient water temperature
[3] **SL** = Sub–lethal criterion (maximum weekly average temperature)
[4] **A** = Acute criterion (daily maximum temperature)

Table 23. Water temperature impacts on trout and coldwater ecosystems.

Temperature (°F)	Fishery Condition[a]	Trout and Coldwater Ecosystem Impacts
39 - 66		*Direct*: None *Habitat/Prey*: Good range for trout and other coldwater species
67 - 76		*Direct*: Increasing stress on trout and other coldwater species, as temperatures extend beyond suitable ranges and less dissolved oxygen is available for respiration *Habitat/Prey*: Increasing competition from warm water species
≥77		*Direct*: Lethal to trout and other coldwater species (depending on acclimation and duration of exposure)

[a] Fisheries condition: Good Fair Poor Lethal

The 57 angler measurements of water temperature suggest that temperature conditions are favorable in Pierce County trout streams. Water temperatures were very susceptible to air temperatures, with minimum, average, and maximum water temperatures notably changing from month to month as seasons transitioned (Table 21, Figure 22). The lowest water temperatures occurred in March, while the highest temperatures were evident in May, June, and July. All monthly maximum water temperatures measured in Pierce County trout streams (Table 21) were less than the corresponding monthly acute water temperature criteria for Wisconsin coldwater ecosystems (Table 22).

With the exception of two colder water temperatures in March (34-35 °F), when snowmelt and runoff were occurring (Figure 23, Figure 24, Figure 25), all 57 water temperature measurements were within a range from 41-66 °F (Table 21 and Figure 23). Ninety-six percent (96%) of all angler-measured water temperatures were within the suitable temperature range for trout survival (Table 19 and Table 23), while 60% were within the preferred temperature range for trout feeding and growth (Table 19). No temperatures approached the upper incipient lethal temperature of 77 °F (Table 19 and Table 23).

Appendix D: Kiap-TU-Wish Chapter Pilot Project Participants

Pilot Project Participants	
Rainbow Barry [T]	Maria Manion
Don Blegen	Bethany Olson
Peter Borden	Chris Olson [T]
Tim Christensen [T]	Greg Olson
Ed Constantini [T]	Jon Olson
Dave Drewiske	Bruce Orensteen
Dan Duncan	Mark Peerenboom
Joseph Duncan	Bob Peterfeso
Cole Eckelman	Aaron Przybylski
David Feifarek	Tony Randazzo
Dave Gregg	Gary Richardson
Trish Hannah	Sarah Sanford
Cline Hickok	Nate Scheibe [T]
Jeffrey Jackson	Charlie Schlatter [T]
Matt Janquart [T]	Mike Stary [T]
Eric Johnson	Scott Wagner [T]
Kent Johnson*	Larry Walbrun
Joe Kaplan	Dan Wilcox
John Kaplan**	Warren Wolfe [T]
Tyler Linton	MacKenzie Zajec

[T] = Target Angler

*Project Coordinator

**Monitoring Coordinator

References

1. Wurts, William & Durborow, Robert, 1992. Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds. Southern Regional Aquaculture Center Publication. 464.
2. Davidson, J., C. Good, C. Welsh, and S.T. Summerfelt. 2016. Comparing the effects of high vs. low nitrate on the health, performance, and welfare of juvenile rainbow trout *Oncorhynchus mykiss* with water recirculating aquaculture systems. Aquaculture Engineering 59 (2014) 30-40.
3. EPA Ground Water and Drinking Water Standards. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations Accessed September 2019.
4. State of Wisconsin, 2010. Chapter NR 102, Water Quality Standards for Wisconsin Surface Waters. November 2010. https://docs.legis.wisconsin.gov/code/admin_code/nr/100/102/
5. Chislock, M. F., Doster, E., Zitomer, R. A. & Wilson, A. E. (2013) Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems. *Nature Education Knowledge* 4(4):1 https://www.nature.com/scitable/knowledge/library/eutrophication-causes-consequences-and-controls-in-aquatic-102364466/
6. Stackpoole, S. M., E. G. Stets, and L. A. Sprague. 2019. Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality. Proceedings of the National Academy of Sciences: 201903226.
7. Fondriest Environmental, Inc. "pH of Water." Fundamentals of Environmental Measurements. 19 Nov. 2013. https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/ https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/
8. Bozeman, Bryan (2016). An Anglers Guide to Water Quality Monitoring. Trout Unlimited Water Quality Monitoring Handbook. 35 p.
9. Wehrly, K. E., L. Wang, and M. Mitro. 2007. Field-based estimates of thermal tolerance limits for trout: incorporating exposure time and temperature fluctuation. Transactions of the American Fisheries Society 136:365-374.
10. Gillian Pomplun, 2019. "DNR staff review recent manure spills and fish kills". News article, SWNEWS4U.com, October 19, 2019. https://www.swnews4u.com/local/dnr-staff-review-recent-manure-spills-and-fish-kills/.
11. Dieterman, D. J., and M. G. Mitro. 2019. Stream habitat needs for brook trout and brown trout in the Driftless Area. Pages 29-44 in D. C. Dauwalter, editor. A look back at Driftless Area science to plan for resiliency in an uncertain future. Special Publication of the 11th Annual Driftless Symposium, La Crosse, Wisconsin.
12. Matthew Mitro, WDNR Coldwater Fisheries Research Scientist, by Personal Communication, November 1, 2019.
13. USGS Water Science School (2019). Nitrogen and Water. https://www.usgs.gov/special-topic/water-science-school/science/nitrogen-and-water?qt-science_center_objects=0#qt-science_center_objects
14. USGS Water Science School (2019). pH and Water. https://www.usgs.gov/special-topic/water-science-school/science/ph-and-water?qt-science_center_objects=0#qt-science_center_objects
15. USGS Water Science School (2019). Phosphorous and Water. https://www.usgs.gov/special-topic/water-science-school/science/phosphorus-and-water?qt-science_center_objects=0#qt-science_center_objects